

GA22-7000-7
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Systems

**IBM System/370
Principles of Operation**

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This major revision obsoletes GA22-7000-6. Considerable material has been added to Chapters 5 and 10, and a number of changes have been made to Chapters 3, 6, and 12 and to Appendix D. Except for Chapter 12, the majority of these additions and changes were made to incorporate information about architectural facilities of the 3033 extension feature, principally the dual-address-space (DAS) facility. This facility, together with the cross-memory services of the MVS/System Product, helps to satisfy user virtual-storage requirements and to improve data isolation.

In addition to DAS, which introduces 12 new instructions, two other new instructions (BRANCH AND SAVE and TEST BLOCK) are described, and an external-interruption condition called "service signal" is defined.

Chapter 12, "Input/Output Operations," has been revised for clarity and to reflect the current definition of the recently updated IBM System/360 and System/370 I/O Interface Channel to Control Unit OEMI, GA22-6974-5. A new command, sense ID, has been defined, and a new definition of the ready-to-not-ready transition status has been included.

Except for minor style alterations, changes are identified by a vertical bar in the left margin.

Changes are periodically made to the information herein; before using this publication in connection with the operation of IBM equipment, refer to the latest IBM System/370 and 4300 Processors Bibliography, GC20-0001, for the editions that are applicable and current.

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This publication provides, for reference purposes, a detailed definition of the machine functions performed by System/370.

The publication describes each function to the level of detail that must be understood in order to prepare an assembler-language program that relies on that function. It does not, however, describe the notation and conventions that must be employed in preparing such a program, for which the user must instead refer to the appropriate assembler-language publication, such as the OS/VS-DQS/VSE-VM/370 Assembler Language, GC33-4010.

The information in this publication is provided principally for use by assembler-language programmers, although anyone concerned with the functional details of System/370 will find it useful.

Note that this publication is written as a reference document and should not be considered an introduction or a textbook for System/370. It assumes the user has a basic knowledge of data processing systems and, specifically, the System/370, such as can be derived from the Introduction to IBM Data Processing Systems, GC20-1684, and the IBM System/370 System Summary: Processors, GA22-7001. All publications relating to System/370 are listed and described in the IBM System/370 and 4300 Processors Bibliography, GC20-0001.

All facilities discussed in this publication are not necessarily available on every model of System/370. Furthermore, in some instances the definitions have been structured to allow for some degree of extensibility, and therefore certain capabilities may be described or implied that are not offered on any model. Examples of such capabilities are the provisions for the number of channel-mask bits in the control register, for the size of the CPU address, and for the number of CPUs sharing main storage. The allowance for this type of extensibility should not be construed as implying any intention by IBM to provide such capabilities. For information about the characteristics and availability of features on a specific System/370 model, use the functional characteristics publication for that model. The availability of features on System/370 models is summarized in the IBM System/370 System Summary: Processors, GA22-7001.

Largely because the publication is arranged for reference purposes, certain words and phrases appear, of necessity, earlier in

the publication than the principal discussions explaining them. The reader who encounters a problem of this sort should refer to the index, which indicates the location of the key description.

The information presented in this publication is grouped in 13 chapters and several appendixes:

Introduction highlights some of the major features of System/370.

Organization describes the major groupings within the system--the central processing unit (CPU), storage, and input/output--with some attention given to the composition and characteristics of those groupings.

Storage explains the information formats, the types of addresses used to access storage, and the facilities for storage protection. It also deals with dynamic address translation (DAT), which, coupled with special programming support, makes the use of a virtual storage possible in System/370. DAT eliminates the need to assign a program to a fixed location in real storage and thus reduces the addressing constraints on system and problem programs.

Control describes in depth the facilities for the switching of system status, for special externally initiated operations, and for debugging and timing the system. It deals specifically with CPU states, control modes, the program-status word (PSW), control registers, program-event recording, timing facilities, resets, store status, and initial program loading.

Program Execution explains the role of instructions in program execution, looks in detail at instruction formats, and describes briefly the use of the program status word (PSW), of branching, and of interruptions. It contains the principal description of the dual-address-space (DAS) facility. It also details the aspects of program execution on one CPU as observed by channels or another CPU.

Interruptions details the System/370 mechanism that permits the CPU to change its state as a result of conditions external to the system, within the system, or within the CPU itself. Six classes of interruptions are identified and described: machine-check interruptions, program interruptions, supervisor-call interruptions, external interruptions, input/output interruptions, and restart interruptions.

General Instructions contains detailed descriptions of all unprivileged instructions, except for the decimal and floating-point instructions.

Decimal Instructions describes in detail the decimal instructions, which, together with the general instructions, make up the commercial instruction set.

Floating-Point Instructions contains detailed descriptions of the instructions provided by the floating-point feature and by the extended-precision floating-point feature.

Control Instructions contains detailed descriptions of all of the semiprivileged and privileged instructions, except for the I/O instructions.

Machine-Check Handling describes the System/370 mechanism for detecting, correcting, and reporting machine malfunctions.

Input/Output Operations explains the programmed control of I/O devices by the channel and by the CPU. It includes detailed descriptions of the I/O instructions, channel-command words, and other I/O-control formats.

Operator Facilities describes the basic manual functions and controls available for operating and controlling the system.

The Appendixes include:

- Information about number representation
- Instruction-use examples
- Lists of the instructions arranged in several sequences
- Summary of condition-code settings

- A list of the System/370 facilities and an indication of their availability as features on models that implement the System/370 architecture.
- A table of the powers of 2
- Tabular information helpful in dealing with hexadecimal numbers
- An EBCDIC chart
- A discussion of changes affecting compatibility between System/360 and System/370
- A discussion of changes affecting compatibility within System/370

SIZE NOTATION

The letters K and M denote the multipliers 2^{10} and 2^{20} , respectively. Although the letters are borrowed from the decimal system and stand for kilo (10^3) and mega (10^6), they do not have the decimal meaning but instead represent the power of 2 closest to the corresponding power of 10. Their meaning in this publication is as follows:

| Symbol | Value |
|----------|----------------------|
| K (kilo) | $1,024 = 2^{10}$ |
| M (mega) | $1,048,576 = 2^{20}$ |

The following are some examples of the use of K and M:

2,048 is expressed as 2K.
4,096 is expressed as 4K.
65,536 is expressed as 64K (not 65K).
 2^{24} is expressed as 16M.

When the words "thousand" and "million" are used, no special power-of-2 meaning is assigned to them.

ABBREVIATIONS

The abbreviations used often in this publication and their meanings are given in the following list. Instruction mnemonics are listed in Appendix C under "Instructions Arranged by Mnemonic."

| | | | |
|------|--|-------|---|
| AFT | ASN first table | hex | hexadecimal |
| AFTO | ASN-first-table origin | ID | identifier; identification |
| AFX | ASN-first-table index | IDAW | indirect-data-address word |
| AKM | authorization key mask | ILC | instruction-length code |
| ASN | address-space number | IML | initial microprogram loading |
| AST | ASN second table | I/O | input/output |
| ASTE | AST entry | IOEL | I/O extended logout |
| ASTO | AST origin | IPL | initial program load |
| ASX | ASN-second-table index | K | 1,024 (bytes) |
| AT | authority table | LT | linkage table |
| ATL | authority-table length | LTD | linkage-table designation |
| ATO | authority-table origin | LTL | linkage-table length |
| AX | authority index | LTO | linkage-table origin |
| BC | basic control (a mode bit in the PSW) | LX | linkage index |
| CAI | channel-available interruption | M | 1,048,576 (bytes) |
| CAW | channel-address word | PASN | primary ASN |
| CBC | checking-block code | PC | program call |
| CCW | channel-command word | PC-cp | program call to current primary |
| CPU | central processing unit | PC-ss | program call with space switching |
| CSW | channel-status word | PCI | program-controlled interruption (flag in CCW or function) |
| DAS | dual address space (facility) | PER | program-event recording |
| DAT | dynamic address translation | PFRA | page-frame real address |
| EC | extended control (a mode bit in the PSW) | PKM | PSW-key mask |
| EKM | entry key mask | PSTD | primary segment-table designation |
| ET | entry table | PSTL | primary segment-table length |
| ETL | entry-table length | PSTO | primary segment-table origin |
| ETO | entry-table origin | PSW | program-status word |
| EX | entry index or execute | PT | program transfer |
| | | PT-cp | program transfer to current primary |
| | | PT-ss | program transfer with space switching |

| | | | |
|------|--|---------|--|
| PTL | page-table length | SS | storage-and-storage instruction format (or operation) |
| PTO | page-table origin | SSAR | set secondary ASN |
| PX | page index | SSAR-cp | set secondary ASN to current primary |
| RR | register-and-register instruction format (or operation) | SSAR-ss | set secondary ASN with space switching |
| RRE | register-and-register instruction format (or operation) using an extended operation code | SSE | storage-and-storage instruction format (or operation) using an extended operation code |
| RS | register-and-storage instruction format (or operation) | SSTD | secondary segment-table designation |
| RX | register-and-indexed-storage instruction format (or operation) | SSTL | secondary segment-table length |
| S | implied-operand-and-storage instruction format (or operation) | SSTO | secondary segment-table origin |
| SASN | secondary ASN | STD | segment-table designation |
| SI | storage-and-immediate-operand instruction format (or operation) | STL | segment-table length |
| SLI | suppress length indication (flag in CCW) | STO | segment-table origin |
| | | TLB | translation-lookaside buffer |
| | | TOD | time of day |

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This publication describes the IBM System/370 architecture. The architecture of a machine defines its attributes as seen by the programmer, that is, the conceptual structure and functional behavior of the machine, as distinct from the organization of the data flow, the logical design, the physical design, and the performance of any particular implementation. Several dissimilar machine implementations may conform to a single architecture. When programs running on different machine implementations produce the results that are defined by a single architecture, the implementations are considered to be compatible.

IBM System/370 is a product of the experience gained in developing and using a few generations of compatible general-purpose systems. Starting with System/360 as a base, it incorporates a number of new facilities, which are described below.

- Dynamic address translation (DAT) is a facility that eliminates the need to assign a program to fixed locations in real main storage and thus reduces the addressing constraints on both system and problem programs, provides greater freedom in program design. DAT permits a more efficient and effective utilization of main storage. When one of the operating systems for virtual storage is used, dynamic address translation allows the use of up to 16,777,216 bytes of virtual storage. Two page sizes (2K and 4K bytes) and two segment sizes (64K and 1M bytes) are provided, although some models offer only the 64K-byte-segment size. Extensions to this facility include the common-segment bit, the use of which increases the effective size of the translation-lookaside buffer and thus improves CPU performance, and the instruction INVALIDATE PAGE TABLE ENTRY, which improves CPU performance in a demand-paging environment.
- Channel indirect data addressing, a companion facility to dynamic address

translation, provides assistance in translating data addresses for I/O operations. It permits a single channel-command word to control the transmission of data that spans noncontiguous areas of real main storage.

- Multiprocessing provides for the interconnection of CPUs to enhance system availability and share data and resources. It includes facilities for shared main storage, for programmed and special machine signaling between CPUs, and for the programmed reassignment of the first 4,096 bytes of real storage for each CPU.
- Channel-set switching permits the collection of channels in a channel set to be connected to any CPU in a multiprocessing configuration.
- Timing facilities include a TOD clock, a clock comparator, and a CPU timer, along with an interval timer that is also available in System/360. The TOD clock provides a measure of elapsed time suitable for the indication of date and time; it has a cycle of approximately 143 years and a resolution such that the incrementing rate is comparable to the instruction-execution rate of the model. The clock comparator provides for an interruption when the TOD clock reaches a program-specified value. The CPU timer is a high-resolution timer that initiates an interruption upon being decremented past zero.
- Extended-precision floating point includes the facilities for addition, subtraction, and multiplication of floating-point numbers with a fraction of 28 hexadecimal digits. Included in the feature are instructions for rounding from extended to long and from long to short formats.
- Program-event recording provides program interruptions on a selective

basis as an aid in program debugging.

- The instruction MONITOR CALL provides for passing control to a monitoring program when selected indicators are reached in the monitored program. It can be used, for example, in analyzing which programs get executed, how often, and in what length of time.
- Recovery extensions include (1) the CLEAR CHANNEL instruction, for performing an I/O-system reset on a channel and on the associated I/O interface, (2) provisions for a detailed indication of the cause of external damage, and (3) logout indications of whether the I/O interface is operative and the logout valid.
- Protection extensions include (1) low-address protection, the use of which increases the protection of storage locations 0 through 511, which are vital to the system control program, and (2) the TEST PROTECTION instruction, which can be used to perform tests for potential protection violations without causing program interruptions for protection exceptions.
- The dual-address-space (DAS) facility provides for the support of semiprivileged programs, which are executed in the problem state but which, when allowed by authorization controls, are also permitted to use additional capabilities previously available only through the assistance of supervisor-state programs. The capabilities include (1) a PSW-key mask that controls the PSW keys which can be set by the program, (2) a second address space, called the secondary address space, together with an address-space-control bit in the PSW that permits the program to switch between the primary and secondary address spaces, and (3) a table-based linkage mechanism which permits a program with one authority to call a program with greater authority.
- The service-signal external interruption provides the program with a signal that the service processor has completed a function that was requested by means of the DIAGNOSE instruction.
- The instruction TEST BLOCK permits the program to test the usability of a block of storage.
- The instruction BRANCH AND SAVE may be used in place of BRANCH AND LINK when it is desirable to obtain the

instruction address without the instruction-length code, program mask, and condition code.

- The block-multiplexer channel, which permits concurrent processing of multiple channel programs, provides an efficient means of handling I/O devices that transfer data on the I/O interface at a high data rate but have relatively long periods of channel inactivity between transfers.

GENERAL-PURPOSE DESIGN

System/370 is a general-purpose system that can readily be tailored for a variety of applications. A commercial instruction set provides the basic processing capabilities of the system. If the floating-point feature is installed with the commercial instruction set, a universal instruction set is obtained. Adding other features, such as the extended-precision floating-point feature or the conditional-swapping feature, extends the processing capabilities of the system still further.

System/370 has the capability of addressing a main storage of 16,777,216 bytes, and the System/370 translation feature, used with appropriate programming support, can provide a user this maximum address space even when a lesser amount of real storage is attached. This feature and this support permit a System/370 model with limited real storage to be used for a much wider set of applications, and they make many applications with requirements for extensive storage practical and convenient. Additionally, for many System/370 models, the speed of accessing storage is improved by the use of a cache. The cache is a buffer--not apparent to the user--that often provides information requested from storage without the delay associated with accessing storage itself.

Another major aspect of the general-purpose design of System/370 is the capability provided to attach a wide variety of I/O devices through a selector channel and two types of multiplexing channels. System/370 has a byte-multiplexer channel for the attachment of unbuffered devices and of a large number of communications devices. Additionally, it offers a block-multiplexer channel, which is particularly well-suited for the attachment of buffered devices and high-speed cyclic devices.

An individual System/370 installation is obtained by selecting the system components best suited to the applications from a wide variety of alternatives in internal performance, functional ability, and

input/output.

compatibility among System/370 models. These changes are described in Appendix I.

COMPATIBILITY

COMPATIBILITY BETWEEN SYSTEM/360 AND SYSTEM/370

COMPATIBILITY AMONG SYSTEM/370 MODELS

Although models of System/370 differ in implementation and physical capabilities, logically they are upward and downward compatible. Compatibility provides for simplicity in education, availability of system backup, and ease in system growth. Specifically, any program gives identical results on any model, provided that it:

1. Is not time-dependent.
2. Does not depend on system facilities (such as storage capacity, I/O equipment, or optional features) being present when the facilities are not included in the configuration.
3. Does not depend on system facilities being absent when the facilities are included in the configuration. For example, the program should not depend on interruptions caused by the use of operation codes or command codes that in some models are not assigned or not installed. Also, it must not use or depend on fields associated with uninstalled facilities. For example, data should not be placed in an area used by another model for logout. Similarly, the program must not use or depend on unassigned fields in machine formats (control registers, instruction formats, etc.) that are not explicitly made available for program use.
4. Does not depend on results or functions that are defined in this publication to be unpredictable or model-dependent, or on special-purpose functions (such as emulators) that are not described in this publication. This includes the requirement that the program should not depend on the assignment of I/O addresses and CPU addresses.
5. Does not depend on results or functions that are defined in the functional-characteristics publication for a particular model to be deviations from this publication.
6. Takes into account those changes made to the original System/370 architectural definition that affect

System/370 is forward-compatible from System/360. A program written for the System/360 will run on the System/370, provided that it:

1. Observes the limitations described in the preceding section.
2. Does not use PSW bit 12 as an ASCII bit (a special case of the second rule in the preceding section).
3. Does not use or depend on main-storage locations assigned specifically for System/370, such as the interruption-code areas, the machine-check save areas, and the extended-logout area (a special case of the third rule in the preceding section).
4. Takes into account other changes made to the System/360 architectural definition that affect compatibility between System/360 and System/370. These changes are described in Appendix H.

Programming Note

This publication assigns meanings to various operation codes, to bit positions in instructions, channel-command words, registers, and table entries, and to fixed locations in the low 512 bytes of storage (addresses 0-511). Other operation codes, bit positions, and low-storage locations are specifically noted as being available for programming use. The remaining ones are unassigned and reserved for future assignment to new facilities and other extensions of the architecture.

To ensure that existing programs run if and when such new facilities are installed, programs should not depend on an indication of an exception as a result of invalid values that are currently defined as being checked. If a value must be placed in unassigned positions that are not checked, the program should enter zeros. When the machine provides a code or field, the program should take into account that new codes and bits may be assigned in the future. The program should not use unassigned low-storage locations for keeping information since these locations

may be assigned in the future in such a way that the machine causes this location to be changed.

SYSTEM PROGRAM

The system is designed to operate with a supervisory program that coordinates the use of system resources and executes all I/O instructions, handles exceptional conditions, and supervises scheduling and execution of multiple programs.

AVAILABILITY

Availability is the capability of a system to accept and successfully process an individual job. System/370 permits substantial availability by (1) allowing a large number and broad range of jobs to be processed concurrently, thus making the system readily accessible to any particular job, and (2) limiting the effect of an error and identifying more precisely its cause, with the result that the number of jobs affected by errors is minimized and the correction of the errors facilitated.

Several design aspects make this possible.

- A program is checked for the correctness of instructions and data as the program is executed, and program errors are indicated separate from equipment errors. Such checking and reporting assists in locating failures and isolating effects.
- The protection facilities, in conjunction with dynamic address translation, permit the protection of the contents of storage from destruction or misuse caused by erroneous or unauthorized storing or fetching by a program. This provides increased security for the user, thus permitting applications with different security requirements to be processed concurrently with other applications.
- Dynamic address translation allows isolation of one application from another, still permitting them to share common resources. Also, it

permits the implementation of virtual machines, which may be used in the design and testing of new versions of operating systems along with the concurrent processing of application programs. Additionally, it provides for the concurrent operation of incompatible operating systems.

- Multiprocessing and channel-set switching permit better use of storage and processing capabilities, more direct communication between CPUs, and duplication of resources, thus aiding in the continuation of system operation in the event of machine failures.
- MONITOR CALL, program-event recording, and the timing facilities permit the testing and debugging of programs without manual intervention and with little effect on the concurrent processing of other programs.
- Emulation is performed under supervisory program control, thus making it possible to perform emulation concurrently with other applications.
- On most models, error checking and correction (ECC) in main storage, instruction retry, and command retry provide for circumventing intermittent equipment malfunctions, thus reducing the number of equipment failures.
- An enhanced machine-check handling mechanism provides model-independent fault isolation, which reduces the number of programs impacted by uncorrected errors. Additionally, it provides model-independent recording of machine-status information. This leads to greater machine-check handling compatibility between models and improves the capability for loading and running a program on a different model when a system failure occurs.
- A small number of manual controls are required for basic system operation, permitting most operator-system interaction to take place via a unit operating as an I/O device and thus reducing the possibility of accidental operator errors.

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Logically, System/370 consists of main storage, one or more central processing units (CPUs), operator facilities, channels, and input/output devices. Input/output devices are usually attached to channels through control units. The physical identity of these functions may vary among implementations, called "models." The figure "Logical Structure" depicts the logical structure for a single-CPU system and for a two-CPU multiprocessing system.

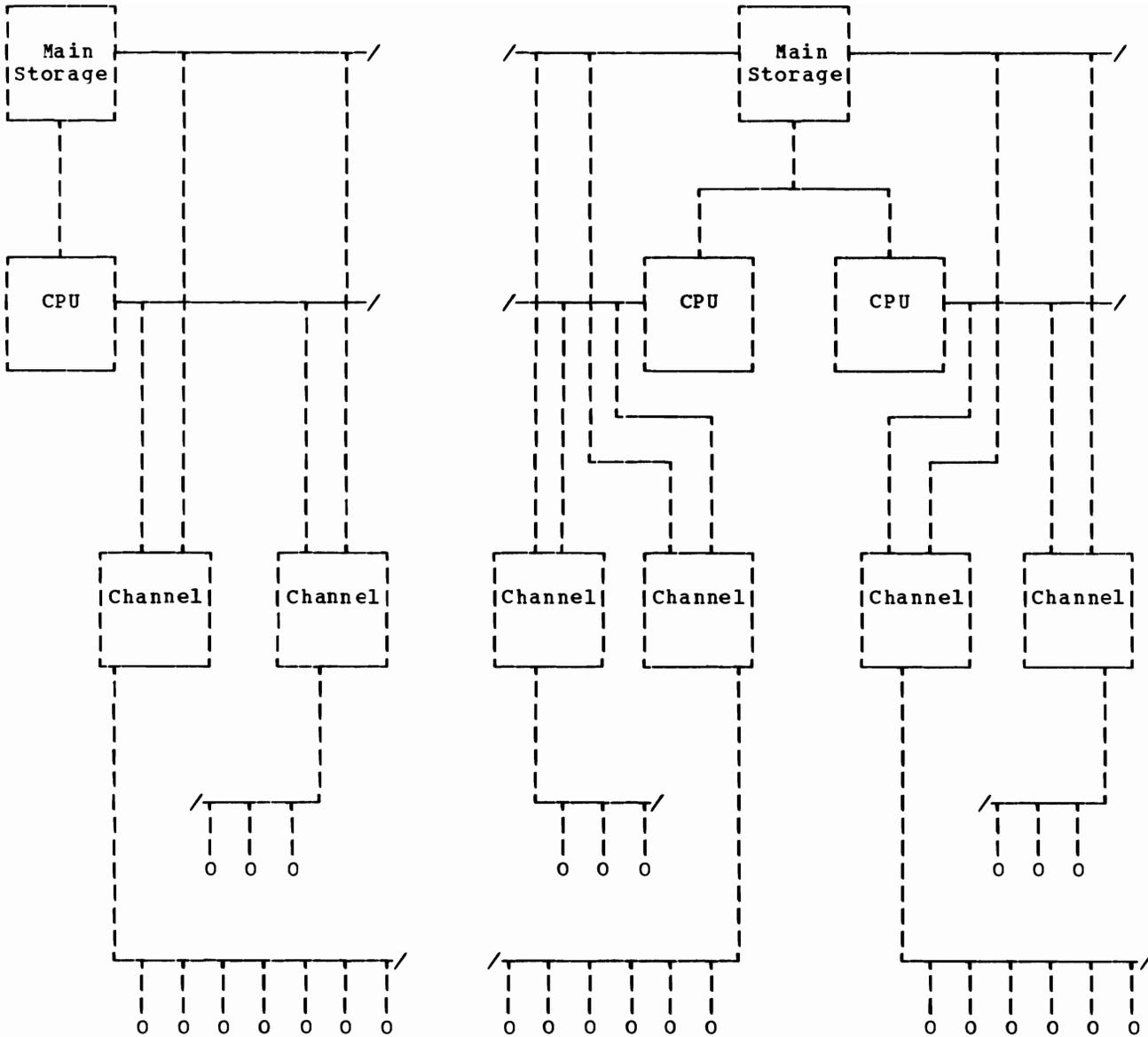
Specific processors may differ in their internal characteristics, the number and types of channels, the size of main storage, and the representation of the operator facilities. The differences in internal characteristics are apparent to the observer only as differences in machine performance.

Model-dependent configuration controls may be provided to change the amount of main storage and the number of CPUs. In some instances, the configuration controls may be used to partition a single system into multiple systems. Each of the systems so configured has the same structure, that is, main storage, one or more CPUs, and channels. Each system is isolated from the other in that the main storage in one system is not directly addressable by the CPUs and channels in the other. It is, however, possible for one system to communicate with another by means of shared I/O devices or a channel-to-channel adapter. At any one time, the storage, CPUs, and channels connected together in a system are referred to as being in the configuration. Each CPU and storage location can be in only one configuration at a time.

MAIN STORAGE

Main storage provides the system with directly addressable fast-access storage. Both data and programs must be loaded into main storage from input devices before they can be processed. The amount of main storage available on the system depends on the model, and, depending on the model, the amount in the configuration may be under control of model-dependent configuration controls. The storage is available in multiples of 2,048-byte blocks. At any one time, each block of storage in the configuration is addressed with the same absolute addresses by all CPUs and channels in the configuration. Each block of storage is accessible to all CPUs and channels in the configuration.

Main storage may be either physically integrated with a CPU or constructed as standalone units. Additionally, main storage may be composed of large-volume storage and a faster-access buffer storage, sometimes called a cache. Each CPU may have an associated cache. The effects, except on performance, of the physical construction and the use of distinct storage media are not observable by the program.



Logical Structure

CENTRAL PROCESSING UNIT

The central processing unit (CPU) is the controlling center of the system. It contains the sequencing and processing facilities for instruction execution, interruption action, timing functions, initial program loading, and other machine-related functions.

The physical makeup of the CPU may differ among models, but the logical function remains the same. The result of executing a valid instruction is the same for each model.

The CPU, in executing instructions, can

process binary integers and floating-point numbers of fixed length, decimal integers of variable length, and logical information of either fixed or variable length. Processing may be in parallel or in series; the width of the processing elements, the multiplicity of the shifting paths, and the degree of simultaneity in performing the different types of arithmetic differ from one CPU to another without affecting the logical results.

Instructions which the CPU executes fall into five classes: general, decimal, floating-point, control, and input/output instructions. The general instructions are used in performing fixed-point arithmetic operations and logical, branching, and

other nonarithmetic operations. The decimal instructions operate on data in the decimal format, and the floating-point instructions on data in the floating-point format. The control instructions and the input/output instructions are privileged instructions that can be executed only when the CPU is in the supervisor state.

To perform its functions, the CPU may use a certain amount of internal storage. Although this internal storage may use the same physical storage medium as main storage, it is not considered part of main storage and is not addressable by programs.

The CPU provides registers which are available to programs but do not have addressable representations in main storage. They include the current program-status word (PSW), the general registers, the floating-point registers, the control registers, the prefix register, and the registers for the TOD clock, the clock comparator, and the CPU timer. The instruction operation code determines which type of register is to be used in an operation. See the figure "General, Floating-Point, and Control Registers" later in this chapter for the format of those registers.

PROGRAM-STATUS WORD

The program-status word (PSW) includes the instruction address, condition code, and other information used to control instruction sequencing and to determine the state of the CPU. The active or controlling PSW is called the current PSW. It governs the program currently being executed.

The CPU has an interruption capability, which permits the CPU to switch rapidly to another program in response to exceptional conditions and external stimuli. When an interruption occurs, the CPU places the current PSW in an assigned storage location, called the old-PSW location, for the particular class of interruption. The CPU fetches a new PSW from a second assigned storage location. This new PSW determines the next program to be executed. When it has finished processing the interruption, the interrupting program reloads the old PSW, making it again the current PSW, so that the interrupted program can continue.

There are six classes of interruption: external, I/O, machine check, program, restart, and supervisor call. Each class has a distinct pair of old-PSW and new-PSW locations permanently assigned in storage.

GENERAL REGISTERS

Instructions may designate information in one or more of 16 general registers. The general registers may be used as base-address registers and index registers in address arithmetic and as accumulators in general arithmetic and logical operations. Each register contains 32 bits. The general registers are identified by the numbers 0-15 and are designated by a four-bit R field in an instruction. Some instructions provide for addressing multiple general registers by having several R fields. For some instructions, the use of a specific general register is implied rather than explicitly designated by an R field of the instruction.

For some operations, two adjacent general registers are coupled, providing a 64-bit format. In these operations, the program must designate an even-numbered register, which contains the leftmost (high-order) 32 bits. The next higher-numbered register contains the rightmost (low-order) 32 bits.

In addition to their use as accumulators in general arithmetic and logical operations, 15 of the 16 general registers are also used as base-address and index registers in address generation. In these cases, the registers are designated by a four-bit B field or X field in an instruction. A value of zero in the B or X field specifies that no base or index is to be applied, and, thus, general register 0 cannot be designated as containing a base address or index.

FLOATING-POINT REGISTERS

Four floating-point registers are available for floating-point operations. They are identified by the numbers 0, 2, 4, and 6. Each floating-point register is 64 bits long and can contain either a short (32-bit) or a long (64-bit) floating-point operand. A short operand occupies the leftmost bit positions of a floating-point register. The rightmost portion of the register is ignored and remains unchanged in arithmetic operations that call for short operands. Two pairs of adjacent floating-point registers can be used for extended operands: registers 0 and 2, and registers 4 and 6. Each of these pairs provides for a 128-bit format.

CONTROL REGISTERS

The CPU has provisions for 16 control registers, each having 32 bit positions. The bit positions in the registers are assigned to particular facilities in the system, such as program-event recording, and are used either to specify that an operation can take place or to furnish special information required by the facility.

The control registers are identified by the numbers 0-15 and are designated by four-bit

R fields in the instructions LOAD CONTROL and STORE CONTROL. Multiple control registers can be addressed by these instructions.

INPUT AND OUTPUT

Input/output (I/O) operations involve the transfer of information between main storage and an I/O device. I/O devices and their control units attach to channels, which control this data transfer.

| R Field | Register Number | Control Registers <—32 bits—> | General Registers <—32 bits—> | Floating-Point Registers <—64 bits—> |
|---------|-----------------|-----------------------------------|-----------------------------------|--|
| 0000 | 0 | [] | [] | [] |
| 0001 | 1 | [] | [] | [] |
| 0010 | 2 | [] | [] | [] |
| 0011 | 3 | [] | [] | [] |
| 0100 | 4 | [] | [] | [] |
| 0101 | 5 | [] | [] | [] |
| 0110 | 6 | [] | [] | [] |
| 0111 | 7 | [] | [] | [] |
| 1000 | 8 | [] | [] | [] |
| 1001 | 9 | [] | [] | [] |
| 1010 | 10 | [] | [] | [] |
| 1011 | 11 | [] | [] | [] |
| 1100 | 12 | [] | [] | [] |
| 1101 | 13 | [] | [] | [] |
| 1110 | 14 | [] | [] | [] |
| 1111 | 15 | [] | [] | [] |

Note: The brackets indicate that the two registers may be coupled as a double-register pair, designated by specifying the lower-numbered register in the R field. For example, the general-register pair 0 and 1 is designated in the R field by the number 0.

CHANNEL SETS

The group of channels which connects to a particular CPU is called a channel set. When channel-set switching is installed in a multiprocessing system, the program can control which CPU is connected to a particular channel set. A CPU can be connected to only one channel set at a time, and a channel set can be connected to only one CPU at a time.

CHANNELS

A channel relieves the CPU of the burden of communicating directly with I/O devices and permits data processing to proceed concurrently with I/O operations. A channel is connected with main storage, with control units, and with a CPU.

A channel may be an independent unit, complete with the necessary logical and internal-storage capabilities, or it may time-share CPU facilities and be physically integrated with the CPU. In either case, the functions performed by a channel are identical. The maximum data-transfer rate may differ, however, depending on the implementation.

There are three types of channels: byte-multiplexer, block-multiplexer, and selector channels.

INPUT/OUTPUT DEVICES AND CONTROL UNITS

Input/output devices include such equipment as card readers and punches, magnetic-tape units, direct-access storage, displays, keyboards, printers, teleprocessing devices, communications controllers, and sensor-based equipment. Many I/O devices function with an external medium, such as punched cards or magnetic tape. Some I/O devices handle only electrical signals, such as those found in sensor-based networks. In either case, I/O-device operation is regulated by a control unit. In all cases, the control-unit function provides the logical and buffering capabilities necessary to operate the associated I/O device. From the programming point of view, most control-unit functions merge with I/O-device functions. The control-unit function may be housed with the I/O device or in the CPU, or a separate control unit may be used.

OPERATOR FACILITIES

The operator facilities provide the functions necessary for operator control of the machine. Associated with the operator facilities may be an operator-console device, which may also be used as an I/O device for communicating with the program.

The main functions provided by the operator facilities include resetting, clearing, initial program loading, start, stop, alter, and display.

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This chapter discusses the representation of information in storage, how information is addressed, address transformations, and protection. The chapter also contains a list of permanently assigned storage locations.

The aspects of addressing which are covered include describing the format of addresses, introducing the concept of address spaces, defining the various types of addresses,

and specifying the manner in which one type of address is translated to another type of address. Also presented are the mechanisms for selectively protecting portions of storage, the operation of change and reference recording, and lists of storage locations having permanently assigned uses.

The term "main storage" (or "absolute storage") is used to describe that storage which is addressable by means of an

absolute address. This distinguishes fast-access storage from auxiliary storage, such as direct-access storage devices. Because most references to main storage apply to virtual storage, the abbreviated term "storage" is used in place of "virtual storage," and it is also used in place of "absolute storage" when the meaning is clear.

Main storage provides the system with directly addressable fast-access storage of data. Both data and programs must be loaded into main storage (from input devices) before they can be processed.

Main storage may consist of standalone units or be integrated with a CPU. Additionally, main storage may be composed of large-volume storage and a faster access buffer storage, sometimes called a cache. Each CPU may have an associated cache. The effects, except on performance, of the physical construction and the use of distinct storage media are not observable by the program.

Fetching and storing of data by the CPU are not affected by any concurrent I/O data transfer or by concurrent reference to the same storage location by another CPU. When concurrent requests to a main-storage location occur, access normally is granted in a sequence that assigns highest priority to references by channels and that alternates priority between CPUs. If a reference changes the contents of the location, any subsequent storage fetches obtain the new contents.

Main storage may be volatile or nonvolatile. If it is volatile, the contents of main storage are not preserved when power is turned off. If it is nonvolatile, turning power off and then back on does not affect the contents of main storage, provided the CPU is in the stopped state and no references are made to main storage by channels when power is turned off. In both types of main storage, the contents of the keys in storage are not necessarily preserved when the power for main storage is turned off.

STORAGE ADDRESSING

Storage is viewed as a long horizontal string of bits. For most operations, accesses to storage proceed in a left-to-right sequence. The string of bits is subdivided into units of eight bits. An eight-bit unit is called a byte, which is the basic building block of all information formats.

Each byte location in storage is identified

by a unique nonnegative integer, which is the address of that byte location or, simply, the byte address. Adjacent byte locations have consecutive addresses, starting with 0 on the left and proceeding in a left-to-right sequence. Addresses are 24-bit unsigned binary integers, which provide 16,777,216 (2^{24} or 16M) byte addresses.

The CPU performs address generation when it forms an operand or instruction address, or when it generates the address of a table entry from the appropriate table origin and index. It also performs address generation when it increments an address to access successive bytes of a field. Similarly, the channel generates an address when it increments an address to fetch a channel-command word (CCW) from a CCW list, to fetch an indirect-data-address word (IDAW) from an IDAW list, or to transfer data.

When, during address generation, an address is obtained that exceeds $2^{24} - 1$, the carry out of the high-order bit position of the address is ignored. This handling of an address of excessive size is called wraparound.

The effect of wraparound is to make the sequence of addresses appear circular; that is, address 0 appears to follow the maximum byte address, 16,777,215. Address arithmetic and wraparound occur before transformation, if any, of the address by DAT or prefixing. In 16M-byte storage, information may be located partially in the last and partially in the first locations of storage and is processed without any special indication of crossing the maximum-address boundary.

INFORMATION FORMATS

Information is transmitted between storage and the CPU or a channel one byte, or a group of bytes, at a time. Unless otherwise specified, a group of bytes in storage is addressed by the leftmost byte of the group. The number of bytes in the group is either implied or explicitly specified by the operation to be performed. When used in a CPU operation, a group of bytes is called a field.

Within each group of bytes, bits are numbered in a left-to-right sequence. The leftmost bits are sometimes referred to as the "high-order" bits and the rightmost bits as the "low-order" bits. Bit numbers are not storage addresses, however. Only bytes can be addressed. To operate on individual bits of a byte in storage, it is necessary to access the entire byte.

The bits in a byte are numbered 0 through 7, from left to right.

The bits in an address are numbered 8 through 31. Within any other fixed-length format of multiple bytes, the bits making up the format are consecutively numbered starting from 0.

For purposes of error detection, and in some models for correction, one or more check bits may be transmitted with each byte or with a group of bytes. Such check bits are generated automatically by the machine and cannot be directly controlled by the program. References in this publication to the length of data fields and registers exclude mention of the associated check bits. All storage capacities are expressed in number of bytes.

When the length of an operand field is implied by the operation code of an instruction, the field is said to have a fixed length, which can be one, two, four, or eight bytes. Larger fields may be implied for control blocks associated with some instructions.

When the length of an operand field is not implied but is stated explicitly, the field is said to have variable length. Variable-length operands can vary in length by increments of one byte.

When information is placed in storage, the contents of only those byte locations are replaced that are included in the designated field, even though the width of

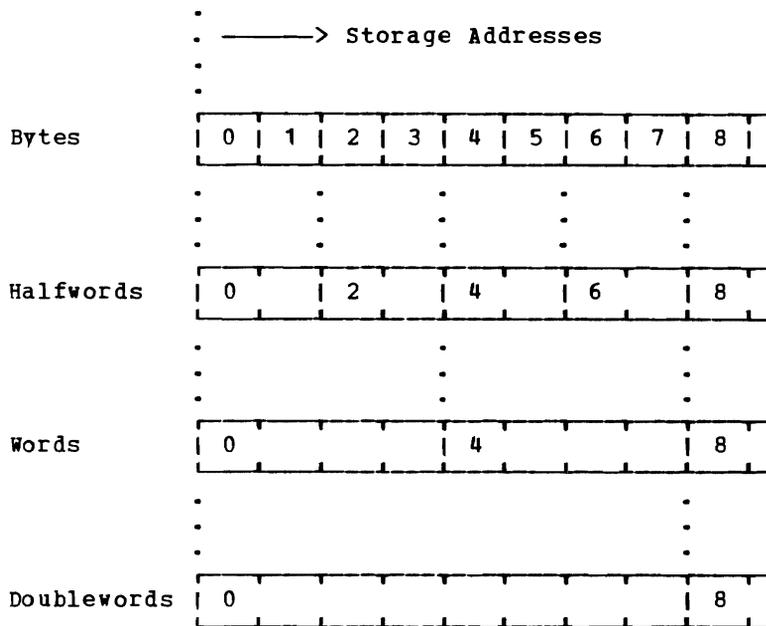
the physical path to storage may be greater than the length of the field being stored.

INTEGRAL BOUNDARIES

Certain units of information must be located in storage on an integral boundary. A boundary is called integral for a unit of information when its storage address is a multiple of the length of the unit in bytes. Special names are given to fields of two, four, and eight bytes when they are located on an integral boundary. A halfword is a group of two consecutive bytes on a two-byte boundary and is the basic building block of instructions. A word is a group of four consecutive bytes on a four-byte boundary. A doubleword is a group of eight consecutive bytes on an eight-byte boundary. (See the figure "Integral Boundaries with Storage Addresses.")

When storage addresses designate halfwords, words, and doublewords on integral boundaries, the binary representation of the address contains one, two, or three rightmost zero bits, respectively.

Instructions must appear on two-byte integral boundaries, and channel-command words and the storage operands of certain instructions must appear on other integral boundaries. The storage operands of most instructions do not have boundary-alignment requirements.



Integral Boundaries with Storage Addresses

BYTE-ORIENTED-OPERAND FEATURE

The byte-oriented-operand feature is standard on System/370. This feature permits storage operands of most unprivileged instructions to appear on any byte boundary.

The feature does not pertain to instruction addresses or to the operands for COMPARE AND SWAP (CS) and COMPARE DOUBLE AND SWAP (CDS). Instructions must appear on two-byte integral boundaries. The low-order bit of a branch address must be zero, and the instruction EXECUTE must designate the target instruction at an even byte address. COMPARE AND SWAP must designate a four-byte integral boundary, and COMPARE DOUBLE AND SWAP must designate an eight-byte integral boundary.

Programming Note

For fixed-field-length operations with field lengths that are a power of 2, significant performance degradation is possible when storage operands are not positioned at addresses that are integral multiples of the operand length. To improve performance, frequently used storage operands should be aligned on integral boundaries.

ADDRESS TYPES

For purposes of addressing main storage, three basic types of addresses are recognized: absolute, real, and virtual. The addresses are distinguished on the basis of the transformations that are applied to the address during a storage access. In addition to the three basic types, additional types are defined which are treated as one or another of the three basic types, depending on the instruction and the current mode.

Absolute Address

An absolute address is the address assigned to a main-storage location. An absolute address is used for a storage access without any transformations performed on it.

All CPUs and channels refer to a shared main-storage location by using the same absolute address. Available main storage is usually assigned contiguous absolute addresses starting at 0, and the addresses are always assigned in complete 2K-byte blocks. An exception is recognized when an attempt is made to use an absolute address in a 2K-byte block which has not been assigned to physical locations. On some models, storage-configuration controls may be provided which permit the operator to change the correspondence between absolute addresses and physical locations. However,

at any one time, a physical location is not associated with more than one absolute address.

Main storage consisting of byte locations sequenced according to their absolute addresses is referred to as absolute storage.

| Real Address

A real address identifies a location in real storage. When a real address is used for an access to main storage, it is converted, by means of prefixing, to an absolute address.

At any instant there is one real-address to absolute-address mapping for each CPU in the system. When a real address is used by a CPU to access main storage, it is converted to an absolute address by prefixing. The particular transformation is defined by the value in the prefix register for the CPU.

Main storage consisting of byte locations sequenced according to their real addresses is referred to as real storage.

| Effective Address

In some situations, it is convenient to use the term "effective address." An effective address is the address which results from address arithmetic, before address translation, if any, is performed. Address arithmetic is the addition of the base and displacement or of the base, index, and displacement. Address translation converts virtual to real, and prefixing converts real to absolute.

| Virtual Address

A virtual address identifies a location in virtual storage. When a virtual address is used for an access to main storage, it is translated by means of dynamic address translation to a real address, which is then further converted to an absolute address.

| Primary Virtual Address

A primary virtual address is a virtual address which is to be translated by means

of the primary segment-table designation. Without DAS, all logical addresses are treated as primary virtual when DAT is on. With DAS, logical addresses and instruction addresses are treated as primary virtual when in primary-space mode. The first-operand address of MOVE TO PRIMARY and the second-operand address of MOVE TO SECONDARY are always treated as primary virtual.

| Secondary Virtual Address

A secondary virtual address is a virtual address which is to be translated by means of the secondary segment-table designation. Without DAS, secondary virtual addresses do not occur. With DAS, logical addresses are treated as secondary virtual when in secondary-space mode. The second-operand address of MOVE TO PRIMARY and the first-operand address of MOVE TO SECONDARY are always treated as secondary virtual.

| Logical Address

Most addresses specified by the program are logical addresses. Without DAS, logical addresses are treated as real addresses when DAT is off and as virtual addresses when DAT is on. With DAS, a logical address is treated as real in real mode, treated as primary virtual in primary-space mode, and treated as secondary virtual in secondary-space mode. The storage-operand addresses for most instructions are logical addresses. However, some instructions have storage-operand addresses or storage accesses associated with the instruction which do not follow the rules for logical addresses. In all such cases, the instruction definition contains a definition of the type of address.

| Instruction Address

Without DAS, instruction addresses are the same as logical addresses. With DAS, an instruction address is treated as real in real mode, treated as primary virtual in primary-space mode, and treated as either primary virtual or secondary virtual in secondary-space mode. The branch address for all branch instructions and the target of EXECUTE are instruction addresses.

When the CPU is in the secondary-space mode, it is unpredictable whether instructions, and the target of EXECUTE, are fetched from the primary address space

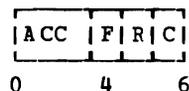
or the secondary address space. However, when the CPU is in secondary-space mode, all copies of an instruction used in a single execution are fetched from a single address space, and the machine can change to or from interpreting instruction addresses as primary virtual or secondary virtual only between instructions and only by issuing a checkpoint-synchronizing function.

Programming Notes

1. Predictable program operation is ensured in secondary-space mode only when the instructions are fetched from virtual-address locations which translate to the same real address by means of both the primary and secondary segment tables. Thus, a program should not enter secondary-space mode if it is not aware of the virtual-to-real address mapping in both the primary and secondary address spaces.
2. The requirement limiting when the CPU can change from fetching instructions to or from the primary address space or secondary address space avoids problems with CPU retry, DAT pretesting, and trial execution of instructions for the purposes of determining PER events.

STORAGE KEY

A storage key is associated with each 2,048-byte block of storage that is provided.



The bit positions in the storage key are allocated as follows:

Access-Control Bits (ACC): The four access-control bits, bits 0-3, are matched with the four-bit access key whenever information is stored, or whenever information is fetched from a location that is protected against fetching.

Fetch-Protection Bit (F): The fetch-protection bit, bit 4, controls whether key-controlled protection applies to fetch-type references: a zero indicates that only store-type references are monitored and that fetching with any access key is permitted; a one indicates that

protection applies both to fetching and storing. No distinction is made between the fetching of instructions and of operands.

Reference Bit (R): The reference bit, bit 5, normally is set to one each time a location in the corresponding storage block is referred to either for storing or for fetching of information.

Change Bit (C): The change bit, bit 6, is set to one each time information is stored at a location in the corresponding storage block.

Storage keys are not part of addressable storage. The entire storage key is set by SET STORAGE KEY and inspected by INSERT STORAGE KEY. Additionally, the instruction RESET REFERENCE BIT provides a means of inspecting the reference and change bits and of setting the reference bit to zero.

PROTECTION

Two protection facilities are provided to protect the contents of main storage from destruction or misuse by erroneous or unauthorized programs: key-controlled protection and low-address protection. The protection facilities are applied independently; access to main storage is only permitted when none of the facilities prohibit the access.

Key-controlled protection affords protection against improper storing or against both improper storing and fetching, but not against improper fetching alone.

KEY-CONTROLLED PROTECTION

When key-controlled protection applies to a storage access, a store is permitted only when the storage key matches the access key associated with the request for storage access; a fetch is permitted when the keys match or when the fetch-protection bit of the storage key is zero.

The keys are said to match when the four access-control bits of the storage key are equal to the access key, or when the access key is zero.

The protection action is summarized in the figure "Summary of Protection Action."

| Conditions | | Is Access to Storage Permitted? | |
|-------------------------------------|--------------|---------------------------------|-------|
| Fetch-Protection Bit of Storage Key | Key Relation | Fetch | Store |
| 0 | Match | Yes | Yes |
| 0 | Mismatch | Yes | No |
| 1 | Match | Yes | Yes |
| 1 | Mismatch | No | No |

Explanation:

Match The four access-control bits of the storage key are equal to the access key, or the access key is zero.

Yes Access is permitted.

No Access is not permitted. On fetching, the information is not made available to the program; on storing, the contents of the storage location are not changed.

Summary of Protection Action

When the access to storage is initiated by the CPU, and key-controlled protection applies, the PSW key is the access key which is used as the compare value. The PSW key occupies bit positions 8-11 of the current PSW.

When the reference is made by a channel, and key-controlled protection applies, the subchannel key associated with the I/O operation is the access key which is used as the compare value. The subchannel key is specified for an I/O operation in bit positions 0-3 of the channel-address word (CAW); the subchannel key is later placed in bit positions 0-3 of the channel-status word (CSW) that is stored as a result of the I/O operation.

When a CPU access is prohibited because of protection, the operation is suppressed or terminated, and a program interruption for a protection exception takes place. When a channel access is prohibited, protection check is indicated in the CSW stored as a result of the operation.

When a store access is prohibited because of key-controlled protection, the contents of the protected location remain unchanged. When a fetch access is prohibited, the protected information is not loaded into a register, moved to another storage location, or provided to an I/O device. For a prohibited instruction fetch, the instruction is suppressed and an arbitrary instruction-length code is indicated.

Key-controlled protection is always active,

regardless of whether the CPU is in the problem or supervisor state, and regardless of the type of CPU instruction or channel-command word being executed.

All accesses to storage locations that are explicitly designated by the program and that are used by the CPU to store or fetch information are subject to key-controlled protection.

All storage accesses by a channel to fetch a CCW or to access a data area designated during the execution of a CCW are subject to key-controlled protection. However, if a CCW or output data is prefetched, a protection check is not indicated until the CCW is due to be executed or the data is due to be written.

Key-controlled protection is not applied to accesses that are implicitly made by the CPU or channel for any of such sequences as:

- An interruption
- Updating the interval timer
- Logout
- Dynamic-address translation
- A store-status function
- Fetching the CAW during the execution of an I/O instruction
- Storing of the CSW by an I/O

instruction or interruption

- Storing channel identification during the execution of STORE CHANNEL ID
- Limited channel logout
- Initial program loading

Similarly, protection does not apply to accesses initiated via the operator facilities for altering or displaying information. However, when the program explicitly designates these locations, they are subject to protection.

LOW-ADDRESS PROTECTION

The low-address-protection facility provides protection against the destruction of main-storage information used by the CPU during interruption processing, by prohibiting instructions from storing using addresses in the range 0 through 511. The range criterion is applied before dynamic translation, if any, and before prefixing.

Low-address protection is under control of bit 3 of control register 0, the low-address-protection-control bit. When the bit is zero, low-address protection is off; when the bit is one, low-address protection is on.

If an access is prohibited because of low-address protection, the contents of the protected location remain unchanged, a program interruption for a protection exception takes place, and the operation is suppressed or terminated.

Any attempt by the program to store using effective addresses in the range 0 through 511 are subject to low-address protection. Low-address protection is applied to the store accesses of instructions whose operand addresses are logical, virtual, or real. Thus it applies to the operands of IPTE, READ DIRECT, TEST BLOCK, MOVE TO PRIMARY, and MOVE TO SECONDARY and to the store-type operands of instructions with logical addresses. Low-address protection is also applied to the trace table.

Low-address protection is not applied to accesses made by the CPU or channel for such sequences as interruptions, logout, and the initial-program-loading and store-status functions, nor is it applied to data stores during I/O data transfer. However, explicit stores by a program at any of these locations are subject to protection.

Programming Note

Low-address protection and key-controlled protection apply to the same store accesses, except that:

- Low-address protection does not apply to storing performed by a channel, whereas key-controlled protection does.
- Key-controlled protection does not apply to the operands of TEST BLOCK, whereas low-address protection does.

REFERENCE RECORDING

Reference recording provides information for use in selecting pages for replacement. Reference recording uses the reference bit, bit 5 of the storage key. A reference bit is provided in each storage key when dynamic address translation is installed. The reference bit is set to one each time a location in the corresponding storage block is referred to either for fetching or storing information, regardless of whether the CPU is in the EC mode or BC mode or whether DAT is on or off.

Reference recording is always active and takes place for all storage accesses, including those made by any CPU, I/O, or operator facility. It takes place for implicit accesses made by the machine, such as those which are part of interruptions and I/O-instruction execution.

Reference recording does not occur for operand accesses of the following instructions since they directly refer to a storage key without accessing a storage location:

```
INSERT STORAGE KEY
INSERT VIRTUAL STORAGE KEY
RESET REFERENCE BIT (reference bit is
set to zero)
SET STORAGE KEY (reference bit is set
to a specified value)
```

The record provided by the reference bit is substantially accurate. The reference bit may be set to one by fetching data or instructions that are neither designated nor used by the program, and, under certain conditions, a reference may be made without the reference bit being set to one. Under certain unusual circumstances, a reference bit may be set to zero by other than explicit program action.

CHANGE RECORDING

Change recording provides information as to which pages have to be saved in auxiliary storage when they are replaced in main storage. Change recording uses the change bit, bit 6 of the storage key. A change bit is provided in each storage key when dynamic address translation is installed.

The change bit is set to one each time a store access causes the contents in the corresponding storage block to be changed. A store access that does not change the contents of storage may or may not set the change bit to one.

The change bit is not set to one for an attempt to store if the access is prohibited. In particular:

1. For the CPU, a store access is prohibited whenever an access exception exists for that access, or whenever an exception exists which is of higher priority than the priority of an access exception for that access.
2. For I/O, a store access is prohibited whenever a key-controlled-protection condition exists for that access.

Change recording is always active and takes place for all store accesses to storage, including those made by any CPU, I/O, or operator facility. It takes place for implicit references made by the machine, such as those which are part of interruptions.

Change recording does not take place for the operands of the following instructions since they directly modify a storage key without modifying a storage location:

```
RESET REFERENCE BIT
SET STORAGE KEY (change bit is set to
a specified value)
```

Change bits are not necessarily restored on CPU retry (see the section "CPU Retry" in Chapter 11, "Machine-Check Handling"). See the section "Exceptions to Nullification and Suppression" in Chapter 5, "Program Execution," for a description of the handling of the change bit in certain unusual situations.

PREFIXING

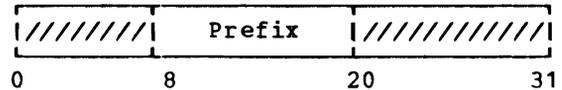
Prefixing provides the ability to assign the range of real addresses 0-4095 (the prefix area) to a different block in absolute main storage for each CPU, thus

permitting more than one CPU sharing main storage to operate concurrently with a minimum of interference, especially in the processing of interruptions.

Prefixing causes real addresses in the range 0-4095 to correspond to the block of 4K absolute addresses identified by the prefix register for the CPU, and the block of real addresses starting with the prefix value to correspond to absolute addresses 0-4095. The remaining real addresses are the same as the corresponding absolute addresses. This transformation allows each CPU to access all of absolute main storage, including the first 4K bytes and the locations designated by the prefix registers of the other CPUs.

The relationship between real and absolute addresses is graphically depicted in the figure "Relationship between Real and Absolute Addresses."

The prefix is a 12-bit quantity located in the prefix register. The register has the following format:



The contents of the register can be set and inspected by the privileged instructions SET PREFIX and STORE PREFIX, respectively. On setting, bits corresponding to bit positions 0-7 and 20-31 of the prefix register are ignored. On storing, zeros are provided for these bit positions. When the contents of the prefix register are changed, the change is effective for the next sequential instruction.

When prefixing is applied, the real address is transformed into an absolute address using one of the following rules, depending on bits 8-19 of the real address:

1. Bits 8-19 of the address, if all zeros, are replaced with bits 8-19 of the prefix.
2. Bits 8-19 of the address, if equal to bits 8-19 of the prefix, are replaced with zeros.
3. Bits 8-19 of the address, if not all zeros and not equal to bits 8-19 of the prefix, remain unchanged.

In all cases, bits 20-31 of the address remain unchanged.

Only the address presented to storage is translated by prefixing. The contents of the source of the address remain unchanged.

The distinction between real and absolute

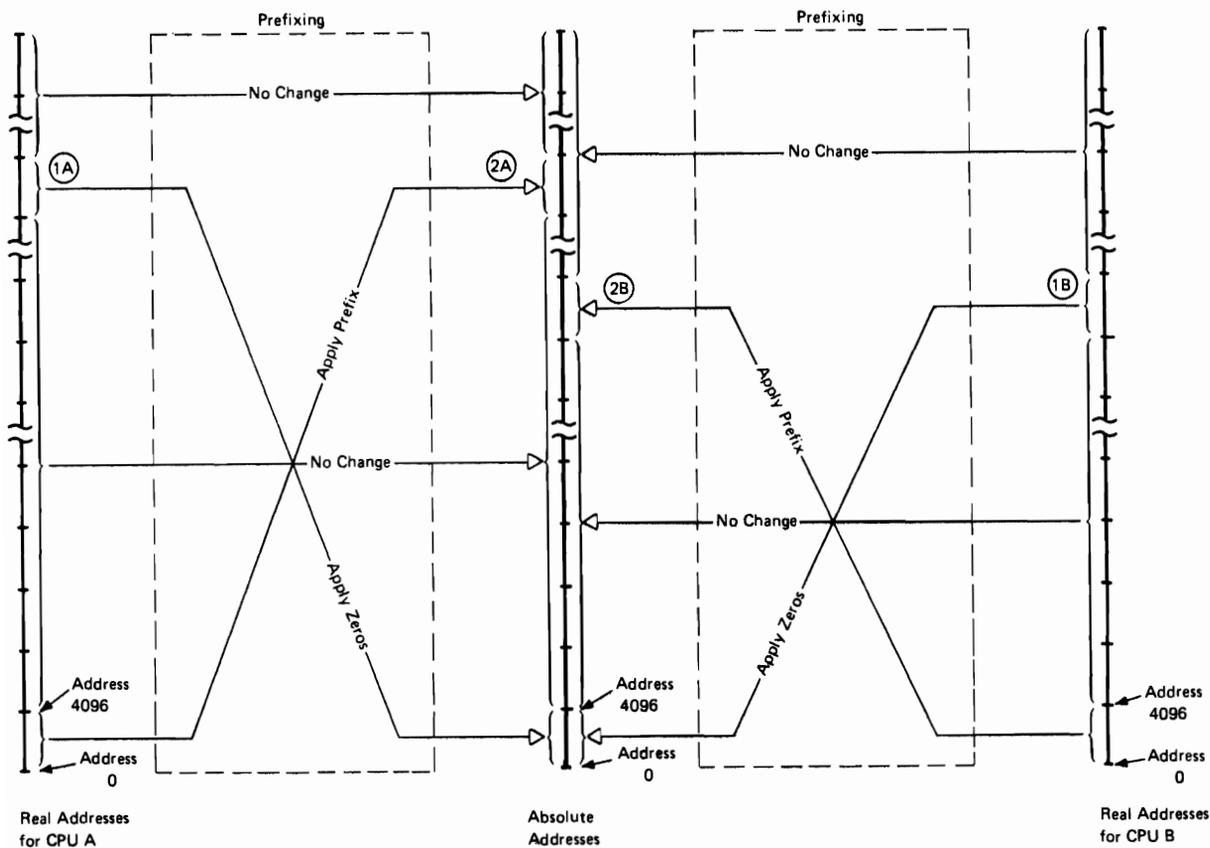
addresses is made even when the prefix register contains all zeros, in which case a real address and its corresponding absolute address are identical.

ADDRESS SPACES

An address space is a consecutive sequence of integer numbers (or virtual addresses), together with the specific transformation parameters which allow each number to be

associated with a byte location in storage. The sequence starts at zero and proceeds left to right.

When a virtual address is used by a CPU to access main storage, it is first converted, by means of dynamic address translation (DAT), into a real address, and then into an absolute address. DAT uses two levels of tables (a segment table and page tables) as transformation parameters. The address of the segment table is found in a control register.



- ① Real addresses in which the high-order 12 bits are equal to the prefix for this CPU (A or B).
- ② Absolute addresses of the block that contains, for this CPU (A or B), the assigned locations in real storage.

Relationship between Real and Absolute Addresses

| With DAS, each address space is assigned an
| address-space number (ASN). An
| ASN-translation mechanism is provided with
| DAS, which, given an ASN, can locate (by
| using a two-level table lookup) the segment
| table which defines the address space and
| load its address into the appropriate
| control register.

| Without DAS, the CPU can translate virtual
| addresses for one address space--the
| primary address space. With DAS, at any
| instant a CPU can translate virtual
| addresses from two address spaces--the
| primary address space and the secondary
| address space. The segment table defining
| the primary address translation is
| specified by control register 1 and that
| defining the secondary by control register
| 7.

| By using the ASN-translation mechanism, any
| one of up to 64K address spaces can be
| selected to become the primary or secondary
| address space.

Virtual storage comprising byte locations
ordered according to their virtual
addresses in an address space is usually
referred to as storage.

DYNAMIC ADDRESS TRANSLATION

Dynamic address translation (DAT) provides
the ability to interrupt the execution of a
program at an arbitrary moment, record it
and its data in auxiliary storage, such as
a direct-access storage device, and at a
later time return the program and the data
to different main-storage locations for
resumption of execution. The transfer of
the program and its data between main and
auxiliary storage may be performed
piecemeal, and the return of the
information to main storage may take place
in response to an attempt by the CPU to
access it at the time it is needed for
execution. These functions may be
performed without change or inspection of
the program and its data, do not require
any explicit programming convention for the
relocated program, and do not disturb the
execution of the program except for the
time delay involved.

With appropriate support by an operating
system, the dynamic-address-translation
facility may be used to provide to a user a
system wherein main storage appears to be
larger than the installed main storage.
This apparent main storage is referred to
as virtual storage, and the addresses used
to designate locations in the virtual
storage are referred to as virtual
addresses. The virtual storage of a user
may far exceed the size of the physical

main storage of the installation and
normally is maintained in auxiliary
storage. The translation occurs in blocks
of addresses, called pages. Only the most
recently referred-to pages of the virtual
storage are assigned to occupy blocks of
physical main storage. As the user refers
to pages of virtual storage that do not
appear in main storage, they are brought in
to replace pages in main storage that are
less likely to be needed. The swapping of
pages of storage may be performed by the
operating system without the user's
knowledge.

| The sequence of virtual addresses
| associated with a virtual storage is called
| an address space. With appropriate support
| by an operating system, the dynamic-
| address-translation facility may be used to
| provide a number of address spaces. These
| address spaces may be used to provide
| degrees of isolation between users. Such
| support can consist of a completely
| different address space for each user, thus
| providing complete isolation, or a shared
| area may be provided by mapping a portion
| of each address space to a single common
| storage area. Also, with DAS, instructions
| are provided which permit the
| semiprivileged program to access more than
| one such address space. Dynamic address
| translation with DAS provides for the
| translation of virtual addresses from two
| different address spaces without requiring
| that the translation parameters in the
| control registers be changed. These two
| address spaces are called the primary
| address space and the secondary address
| space.

In the process of replacing blocks of main
storage by new information from an external
medium, it must be determined which block
to replace and whether the block being
replaced should be recorded and preserved
in auxiliary storage. To aid in this
decision process, a reference bit and a
change bit are associated with the storage
key.

Dynamic address translation may be
specified for instruction and data
addresses generated by the CPU but is not
available for the addressing of data and of
control words in I/O operations. The
channel-indirect-data-addressing feature is
provided to aid I/O operations in a
virtual-storage environment.

The dynamic-address-translation facility
includes the instructions LOAD REAL
ADDRESS, RESET REFERENCE BIT, and PURGE
TLB. It makes use of control register 1
and bits 8-12 in control register 0.

| The dynamic-address-translation facility
| includes the handling of 2K-byte and
| 4K-byte pages and 64K-byte and 1M-byte

segments. On some models, the 1M-byte-segment size may not be offered.

Dynamic address translation is enhanced by that part of the extended facility that includes the instruction INVALIDATE PAGE TABLE ENTRY and the common-segment facility. On some models, the common-segment facility permits improvement of TLB utilization by means of a common-segment bit in the segment-table entry. On other models, this bit is ignored, with no performance improvement.

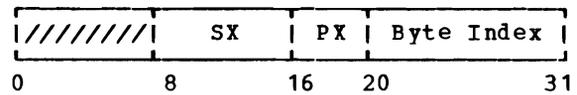
Dynamic address translation is the process of translating a virtual address during a storage reference into the corresponding real address. Without DAS, when DAT is on, a logical address is treated as a virtual address and is translated during a storage reference into the corresponding real address. When DAT is off, the logical address is treated as a real address. With DAS, the virtual address may be either a primary virtual address or a secondary virtual address. Primary virtual addresses are translated by means of the primary segment-table designation and secondary virtual addresses by means of the secondary segment-table designation. After selection of the appropriate segment-table designation, the translation process is the same for both types of virtual addresses.

In the process of translation, two types of units of information are recognized: segments and pages. A segment is a block of sequential addresses spanning 65,536 (64K) or 1,048,576 (1M) bytes and beginning at an address that is a multiple of its size. A page is a block of sequential addresses spanning 2,048 (2K) or 4,096 (4K) bytes and beginning at an address that is a multiple of its size. The size of the segment and page is controlled by bits 8-12 in control register 0.

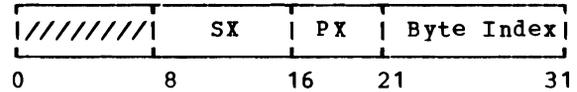
The virtual address, accordingly, is divided into a segment-index (SX) field, a page-index (PX) field, and a byte-index field. The size of these fields depends on the segment and page size.

The segment index starts with bit 8 of the virtual address and extends through bit 15 for a 64K-byte segment size and through bit 11 for a 1M-byte segment size. The page index starts with the bit following the segment index and extends through bit 19 for a 4K-byte page size and through bit 20 for a 2K-byte page size. The byte index consists of the remaining 11 or 12 low-order bits of the virtual address. The formats of the virtual address are as follows:

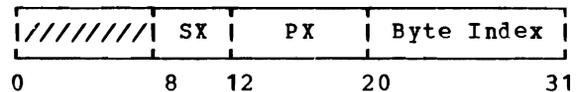
For 64K-byte segments and 4K-byte pages:



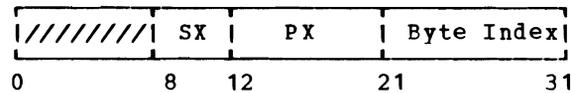
For 64K-byte segments and 2K-byte pages:



For 1M-byte segments and 4K-byte pages:



For 1M-byte segments and 2K-byte pages:



Virtual addresses are translated into real addresses by means of two translation tables, a segment table and a page table, which reflect the current assignment of real storage. The assignment of real storage occurs in units of pages, the real locations being assigned contiguously within a page. The pages need not be adjacent in real storage even though assigned to a set of sequential virtual addresses.

TRANSLATION CONTROL

Without DAS, address translation is controlled by the DAT-mode bit in the PSW and by a set of bits, referred to as the translation parameters, in control registers 0 and 1. With DAS, an additional bit in the PSW is included, and control register 7 is included as part of the translation parameters. Additional controls are located in the translation tables.

PSW

When the dynamic-address-translation facility is installed without DAS, the CPU can operate with DAT either on or off. The mode of operation is controlled by bit 5 of the EC-mode PSW, the DAT-mode bit. When

this bit is one, DAT is on, and logical addresses are treated as virtual addresses; when this bit is zero or the BC mode is specified, DAT is off, and logical addresses are used as real addresses.

mode, and instruction and logical addresses are treated as real. When, in an EC-mode PSW, the DAT-mode bit is one (DAT is on) and the address-space-control bit is zero, the CPU is said to be in primary-space mode, and instruction and logical addresses are treated as primary virtual. When, in an EC-mode PSW, DAT is on and the address-space-control bit is one, the CPU is said to be in secondary-space mode, and logical addresses are treated as secondary virtual. The various modes are shown in the following table:

When DAS is installed, two bits in the EC-mode PSW control dynamic address translation: bit 5, the DAT-mode bit, and bit 16, the address-space-control bit. When a BC-mode PSW is specified, or, when in an EC-mode PSW the DAT-mode bit is zero, DAT is off, the CPU is said to be in real

| PSW Bit | | | DAT | Mode | Handling of Addresses | |
|---------|----|--|-----|---------------------|-----------------------|-----------------------|
| 5 | 12 | | | | Logical Addresses | Instruction Addresses |
| - | 0 | | Off | Real mode (BC mode) | Real | Real |
| 0 | 1 | | Off | Real mode | Real | Real |
| 1 | 1 | | On | Primary-space mode | Primary virtual | Primary virtual |

Translation Modes Without DAS

| PSW Bit | | | DAT | Mode | Handling of Addresses | |
|---------|----|----|-----|----------------------|-----------------------|-----------------------|
| 5 | 12 | 16 | | | Logical Addresses | Instruction Addresses |
| - | 0 | - | Off | Real mode (BC mode) | Real | Real |
| 0 | 1 | - | Off | Real mode | Real | Real |
| 1 | 1 | 0 | On | Primary-space mode | Primary virtual | Primary virtual |
| 1 | 1 | 1 | On | Secondary-space mode | Secondary virtual | See note |

Translation Modes With DAS

Note

When the CPU is in secondary-space mode, it is unpredictable whether instruction addresses are treated as primary virtual or secondary virtual. However, when the CPU is in secondary-space mode, all copies of an instruction used in a single execution are fetched from a single space, and the machine can change the interpretation of instruction addresses as primary virtual or secondary virtual only between instructions and only by issuing a checkpoint-synchronizing function.

Control Register 0

Without DAS, five bits are provided in control register 0 which are used in controlling dynamic address translation. With DAS, a sixth bit is provided. The bits are assigned as follows:

| | |
|---|------|
| D | TF |
| 5 | 8 13 |

Bit 5 of control register 0 is the secondary-space-control bit (D). This bit is provided as part of DAS. When this bit is zero and the instructions SET ADDRESS SPACE CONTROL, MOVE TO PRIMARY, and MOVE TO SECONDARY are executed, a special-operation exception is recognized. This bit also controls whether the secondary segment table is attached while operating in primary-space mode.

Bits 8-12 of control register 0 are called the translation format, which controls the page size and segment size. On models which implement the 1M-byte-segment size, four combinations of the five control bits are valid; all other combinations are invalid. On models which do not implement the 1M-byte-segment size, two combinations are valid. The encoding of the control bits is defined in the following table.

| Bits of Control Register 0 | | | | | Page Size (Bytes) | Segment Size (Bytes) |
|----------------------------|---|----|----|----|-------------------|----------------------|
| 8 | 9 | 10 | 11 | 12 | | |
| 0 | 1 | 0 | 0 | 0 | 2,048 (2K) | 65,536 (64K) |
| 0 | 1 | 0 | 1 | 0 | 2,048 (2K) | 1,048,576 (1M)* |
| 1 | 0 | 0 | 0 | 0 | 4,096 (4K) | 65,536 (64K) |
| 1 | 0 | 0 | 1 | 0 | 4,096 (4K) | 1,048,576 (1M)* |
| All others | | | | | Invalid | Invalid |

*On those models which do not implement the 1M-byte-segment size, the codes 01010 and 10010 are invalid.

When an invalid bit combination is detected in bit positions 8-12, a translation-specification exception is recognized as part of the execution of an instruction using address translation, and the operation is suppressed.

Control Register 1

Control register 1 contains the primary segment-table designation (PSTD). The register has the following format:

| | | |
|------|------------------------------|-------|
| PSTL | Primary Segment-Table Origin | X |
| 0 | 8 | 26 31 |

Primary Segment-Table Length (PSTL): Bits 0-7 of control register 1 designate the length of the primary segment table in units of 64 bytes, thus making the length of the segment table variable in multiples of 16 entries. The length of the primary segment table, in units of 64 bytes, is equal to one more than the value in bit positions 0-7. The contents of the length field are used to establish whether the entry designated by the segment-index portion of the primary virtual address falls within the primary segment table. Without DAS, this field is sometimes referred to as the segment-table length.

Primary Segment-Table Origin: Bits 8-25 of control register 1, with six low-order zeros appended, form a 24-bit real address that designates the beginning of the primary segment table. Without DAS, this field is sometimes referred to as the segment-table origin.

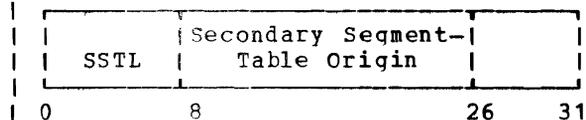
Space-Switch-Event Mask (X): With DAS, bit 31 controls whether a space-switch-event program interruption occurs when a PROGRAM CALL with space switching (PC-ss) or a

| PROGRAM TRANSFER with space switching
 | (PT-ss) is issued. Without DAS, this bit
 | is ignored.

| Bits 26-30 of control register 1 are not
 | assigned and are ignored.

| Control Register 7

| When DAS is installed, control register 7
 | contains the secondary segment-table
 | designation (SSTD). The register has the
 | following format:



| Secondary Segment-Table Length (SSTL):
 | Bits 0-7 of control register 7 designate
 | the length of the secondary segment table
 | in units of 64 bytes, thus making the
 | length of the segment table variable in
 | multiples of 16 entries. The length of the
 | segment table, in units of 64 bytes, is
 | equal to one more than the value in bit
 | positions 0-7. The contents of the length
 | field are used to establish whether the
 | entry designated by the segment-index
 | portion of the secondary virtual address
 | falls within the secondary segment table.

| Secondary Segment-Table Origin: Bits 8-25
 | of control register 7, with six zeros
 | appended on the right, form a 24-bit real
 | address that designates the beginning of
 | the secondary segment table.

| Bits 26-31 of control register 7 are not
 | assigned and are ignored.

Programming Notes

1. The validity of the information loaded into a control register, including that pertaining to dynamic address translation, is not checked at the time the register is loaded. This information is checked and the program exception, if any, is indicated at the time the information is used.
2. The information pertaining to dynamic address translation is considered to be used when an instruction is executed with DAT on or when LOAD REAL ADDRESS is executed. The information is not considered to be used when the PSW specifies translation, but an I/O, external, restart, or machine-check

interruption occurs before an instruction is executed, including the case when the PSW specifies the wait state.

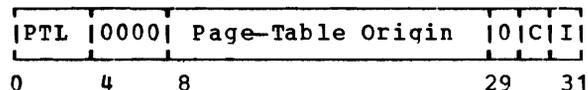
TRANSLATION TABLES

The translation process consists in a two-level lookup using two tables: a segment table and a page table. These tables reside in storage.

Segment-Table Entries

The entry fetched from the segment table designates the length, availability, and origin of the corresponding page table.

An entry in the segment table has the following format:



The fields in the segment-table entry are allocated as follows:

Page-Table Length (PTL): Bits 0-3 designate the length of the page table in increments that are equal to 1/16 of the maximum size of the table, the maximum size depending on the size of segments and pages. The length of the page table, in units 1/16 of the maximum size, is equal to one more than the value in bit positions 0-3. The length field is compared against the high-order four bits of the page-index portion of the logical address to determine whether the page index designates an entry within the page table.

Page-Table Origin: Bits 8-28, with three low-order zeros appended, form a 24-bit real address that designates the beginning of the page table.

Common-Segment Bit (C): Bit 30, with the common-segment facility installed, controls the use of translation-lookaside-buffer copies of the segment-table entry and of the page table which it designates. A zero identifies a private segment; in this case, the segment-table entry and the page table that the entry designates may be used only in association with the segment-table origin which designates the segment table in which the segment-table entry resides. A one identifies a common segment; in this case, the segment-table entry and the page table that the entry designates may continue to be used for translating

addresses corresponding to the segment index, even though a different segment table is selected by changing the segment-table origin in control register 1. In some models, bit 30 in the segment-table entry is ignored, and all segments are treated as private.

The common-segment bit is used only for controlling the loading and use of translation-lookaside-buffer copies. When the common-segment facility is installed, the common-segment bit is ignored for explicit translation and for implicit translation not using the translation lookaside buffer.

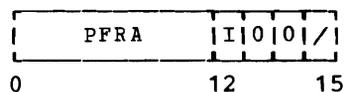
Segment-Invalid Bit (I): Bit 31 controls whether the segment associated with the segment-table entry is available. When bit position 31 contains a zero, address translation proceeds using the designated page table. When the bit is a one, a segment-translation exception is recognized, and the unit of operation is nullified.

The handling of bit positions 4-7 and 29-30 of the segment-table entry depends on the model. Normally a translation-specification exception is recognized and the unit of operation is suppressed when these bits are not zeros; however, on some models the contents of these bit positions may be ignored. On machines with the common-segment facility installed, bit 30 is interpreted as defined or is ignored.

Page-Table Entries

The entry fetched from the page table indicates the availability of the page and contains the high-order bits of the real address. The format of the page-table entry depends on page size, as follows:

Page-table entry with 4K-byte pages:



Page-table entry with 2K-byte pages:



The fields in the page-table entry are allocated as follows:

Page-Frame Real Address (PFRA): Bits 0-11 or bits 0-12, depending on the page size, provide the leftmost 12 or 13 bits of a 24-bit real storage address. When these bits are concatenated with the contents of the byte-index field of the virtual address on the right, the real storage address is obtained.

Page-Invalid Bit (I): Bit 12 or 13, depending on the page size, controls whether the page associated with the page-table entry is available. When the bit is zero, address translation proceeds using the table entry. When the bit is one, a page-translation exception is recognized, and the unit of operation is nullified.

Except for the rightmost bit position of the entry, the bit positions to the right of the page-invalid bit must contain zeros; otherwise, a translation-specification exception is recognized as part of the execution of an instruction using that entry for address translation, and the unit of operation is suppressed.

SUMMARY OF DYNAMIC ADDRESS TRANSLATION FORMATS

The first table summarizes the possible combinations of the page-address and byte-index fields in the formation of a real storage address.

The eight-bit length field in control register 1 provides for a maximum length code of 255 and permits designating a segment table of 16,384 bytes, or 4,096 entries, which is more than can be referred to for translation purposes by the virtual address. With 1M-byte segments, only 16 segments can be addressed, requiring a segment table of 64 bytes. A table of 64 bytes is specified by a length code of 0 and is the smallest table that can be specified. With 64K-byte segments, up to 256 segments can be addressed, requiring at the most a segment table of 1,024 bytes and a length code of 15. These relations are summarized in the second table.

The third table lists the maximum sizes of the page table and the increments in which the size of the page table can be controlled.

| Size of Page (Bytes) | Real Storage Address | | | |
|----------------------|-----------------------------------|-------------|----------------------------------|-------------|
| | Page Address | | Byte Index | |
| | Bit Positions in Page-Table Entry | No. of Bits | Bit Positions in Virtual Address | No. of Bits |
| 2K | 0-12 | 13 | 21-31 | 11 |
| 4K | 0-11 | 12 | 20-31 | 12 |

| Size of Segment (Bytes) | Segment Index Field Size (Bits) | Number of Addressable Segments | Max Segm Tbl | | Segment-Table Increment (Bytes) |
|-------------------------|---------------------------------|--------------------------------|--------------|--------------------|---------------------------------|
| | | | Size (Bytes) | Usable Length Code | |
| 64K | 8 | 256 | 1,024 | 15 | 64 |
| 1M | 4 | 16 | 64 | 0 | 64 |

| Size of Segment (Bytes) | Page Size (Bytes) | Page Index Field Size (Bits) | Number of Pages in Segment | Max Page Tbl | | Page-Table Increment (Bytes) |
|-------------------------|-------------------|------------------------------|----------------------------|--------------|--------------------|------------------------------|
| | | | | Size (Bytes) | Usable Length Code | |
| 64K | 2K | 5 | 32 | 64 | 15 | 4 |
| 64K | 4K | 4 | 16 | 32 | 15 | 2 |
| 1M | 2K | 9 | 512 | 1,024 | 15 | 64 |
| 1M | 4K | 8 | 256 | 512 | 15 | 32 |

Programming Note

The low-order bit position of a page-table entry is unassigned and is not checked for zero; thus, it is available for programming use.

both of which reside in main storage. It is controlled by the DAT-mode bit in the PSW and by the translation parameters in control registers 0 and 1. With DAS, translation is also controlled by the address-space-control bit in the PSW, and the translation parameters also include control register 7.

TRANSLATION PROCESS

This section describes the translation process as it is performed implicitly before a virtual address is used to access main storage. The process of translating the operand address of LOAD REAL ADDRESS and TEST PROTECTION is the same, except that segment-translation and page-translation exceptions do not cause a program interruption but instead are indicated in the condition code. Translation of the operand address of LOAD REAL ADDRESS also differs in that the translation-lookaside buffer is not used.

Translation of an address is performed by means of a segment table and a page table,

Effective Segment-Table Designation

The segment-table designation used for a particular address translation is called the effective segment-table designation. Accordingly, when a primary virtual address is translated, control register 1 is used as the effective segment-table designation, and when a secondary virtual address is translated, control register 7 is used as the effective segment-table designation. Without DAS, the term "effective segment-table designation" is synonymous with "primary segment-table designation."

The segment-index portion of the virtual address is used to select an entry from the

segment table, the starting address and length of which are specified by the effective segment-table designation. This entry designates the page table to be used.

The page-index portion of the virtual address is used to select an entry from the page table. This entry contains the high-order bits of the real address that represents the translation of the virtual address.

The byte-index field of the virtual address is used unchanged for the rightmost bit positions of the real address.

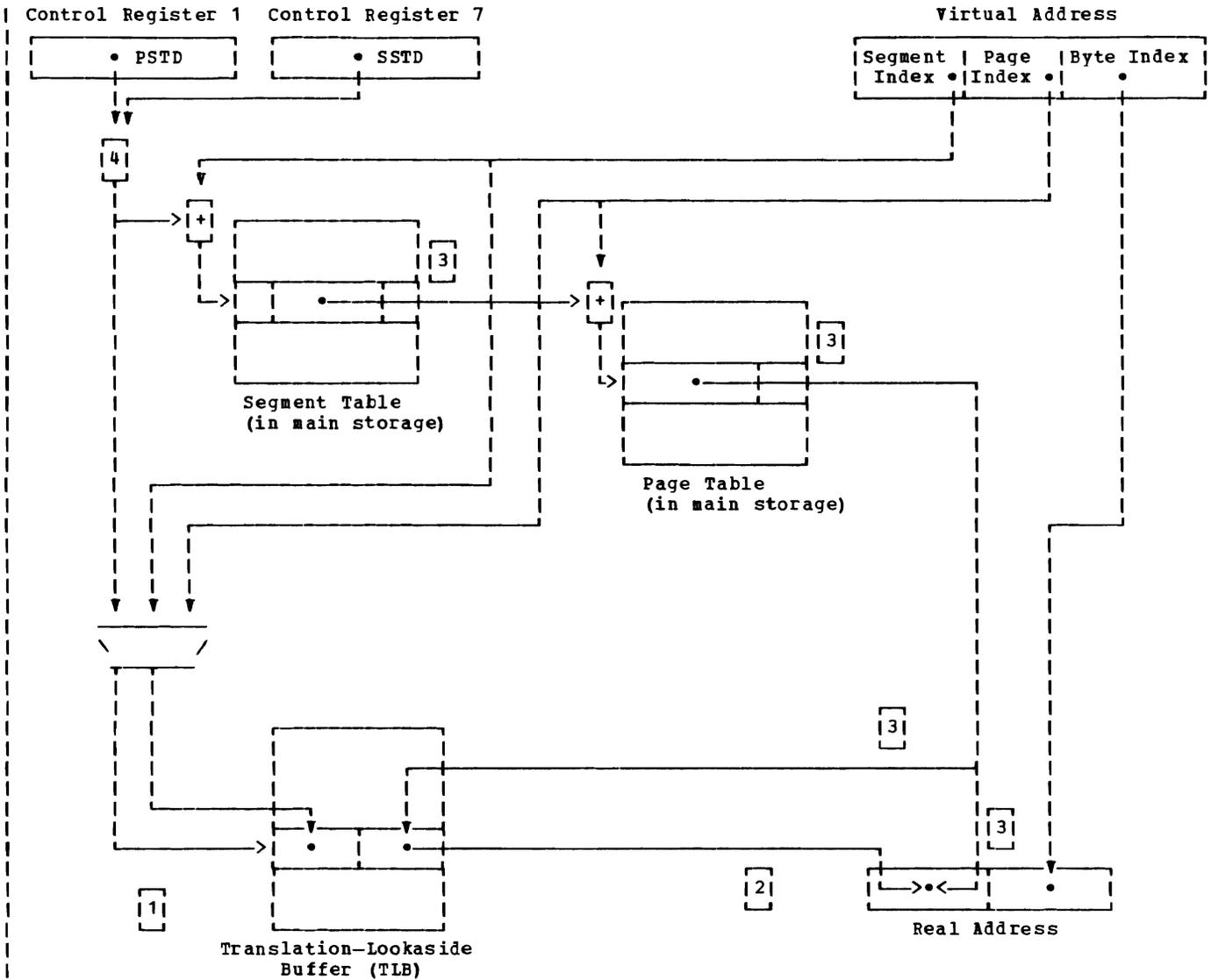
If the I bit is one in either the segment-table entry or the page-table entry, the entry is invalid, and the translation process cannot be completed for this virtual address. A segment-translation or a page-translation exception is recognized, and the unit of operation is

nullified.

In order to avoid the delay associated with references to translation tables in main storage, the information fetched from the tables normally is placed also in a special buffer, the translation-lookaside buffer (TLB), and subsequent translations involving the same table entries may be performed using the information recorded in the TLB. The operation of the TLB is described in the section "Translation-Lookaside Buffer" in this chapter.

Whenever access to main storage is made during the address-translation process for the purpose of fetching an entry from a segment table or page table, key-controlled protection does not apply.

The translation process, including the effect of the TLB, is shown graphically in the figure "Translation Process."



[1] Information, which may include portions of the virtual address and the effective segment-table origin, is used to search the TLB.

[2] If match exists, the address from the TLB is used in forming the real address.

[3] If no match exists, table entries in main storage are fetched to translate the address. The resulting value, in conjunction with the search information, may be used to form an entry in the TLB.

[4] Control register 1 provides the primary segment-table designation for translation of a primary virtual address, and, when DAS is installed, control register 7 provides the secondary segment-table designation for translation of a secondary virtual address.

Translation Process

Inspection of Control Register 0

The interpretation of the virtual address for translation purposes is controlled by the translation format, bits 8-12 of control register 0. If bits 8-12 contain an invalid code, a translation-specification exception is recognized, and the operation is suppressed.

Segment-Table Lookup

The segment-index portion of the virtual address is used to select a segment-table entry that designates the page table to be used in arriving at the real address. The address of the segment-table entry is obtained by appending six zeros to the right of bits 8-25 of the effective segment-table designation and adding the segment index to this value, with the rightmost bit position of the segment index aligned with bit position 29 of the address.

As part of the segment-table-lookup process, the segment index is compared against the segment-table length, bits 0-7 of the effective segment-table designation to establish whether the addressed entry is within the table. With 1M-byte segments, entries for all addressable segments are contained in a table of minimum length (length code of 0). With 64K-byte segments, four zeros are appended to the left of bits 8-11 of the virtual address, and this extended value is compared against the eight-bit segment-table length. If the value in the segment-table-length field is less than the value in the corresponding bit positions of the virtual address, a segment-translation exception is recognized, and the unit of operation is nullified.

All four bytes of the segment-table entry are fetched concurrently. The fetch access is not subject to protection. When the storage address generated for fetching the segment-table entry refers to a location which is not provided, an addressing exception is recognized, and the unit of operation is suppressed.

Bit 31 of the entry fetched from the segment table specifies whether the corresponding segment is available. This bit is inspected, and, if it is one, a segment-translation exception is recognized, with the unit of operation nullified. Handling of bit positions 4-7 and 29-30 of the segment-table entry depends on the model: normally a translation-specification exception is indicated and the unit of operation

suppressed when they do not contain zeros; however, on some models they may be ignored.

On machines with the common-segment facility, a one in bit position 30 does not cause an exception. Bit 30 may be retained with the entry in the TLB, or it may be ignored.

When no exceptions are recognized in the process of segment-table lookup, the entry fetched from the segment table designates the length and beginning of the corresponding page table.

Page-Table Lookup

The page-index portion of the virtual address, in conjunction with the page-table address derived from the segment-table entry, is used to select an entry from the page table. The address of the page-table entry is obtained by appending three zeros to the right of bits 8-28 of the segment-table entry and adding the page index to this value. The addition is performed with the rightmost bit of the page index aligned with bit 30 of the address.

As part of the page-table-lookup process, the four leftmost bits of the page index are compared against the page-table length, bits 0-3 of the segment-table entry, to establish whether the addressed entry is within the table. If the value in the page-table-length field is less than the value in the four leftmost bit positions of the page-index field, a page-translation exception is recognized, and the unit of operation is nullified.

The two bytes of the page-table entry are fetched concurrently. The fetch access is not subject to protection. When the storage address generated for fetching the page-table entry refers to a location which is not provided, an addressing exception is recognized, and the unit of operation is suppressed.

The entry fetched from the page table indicates the availability of the page and contains the leftmost bits of the page-frame real address. The page-invalid bit is inspected to establish whether the corresponding page is available. If this bit is one, a page-translation exception is recognized, and the unit of operation is nullified. If bit positions 13-14 for 4K-byte pages or bit position 14 for 2K-byte pages contains a one, a translation-specification exception is recognized, and the unit of operation is suppressed.

Formation of the Real Address

When no exceptions in the translation process are encountered, the page-frame real address obtained from the page-table entry and the byte-index portion of the virtual address are concatenated, with the page-frame real address forming the leftmost part. The result is the real storage address.

Recognition of Exceptions During Translation

Invalid addresses and invalid formats can cause exceptions to be recognized during the translation process. Exceptions are recognized when information contained in control registers or table entries is used for translation and is found to be incorrect.

The information pertaining to DAT is considered to be used when an instruction is executed with DAT on or when LOAD REAL ADDRESS is executed. The information is not considered to be used when the PSW specifies DAT on but an I/O, external, restart, or machine-check interruption occurs before an instruction is executed, including the case when the PSW specifies the wait state. Only that information required to translate a virtual address is considered to be in use during the translation of that address, and, in particular, addressing exceptions that would be caused by the use of the PSTD or the SSTD are not recognized when the translation of an address uses only the SSTD or only the PSTD, respectively.

A list of translation exceptions, with the action taken for each exception and the priority in which the exceptions are recognized when more than one is applicable, is provided in the section "Recognition of Access Exceptions" in Chapter 6, "Interruptions."

TRANSLATION-LOOKASIDE BUFFER

To enhance performance, the dynamic-address-translation mechanism normally is implemented such that some of the information specified in the segment and page tables is maintained in a special buffer, referred to as the translation-lookaside buffer (TLB). The CPU necessarily refers to a DAT-table entry in main storage only for the initial access to that entry. This information subsequently may be maintained in the TLB, and

subsequent translations may be performed using the information recorded in the TLB. The presence of the TLB affects the translation process to the extent that a modification of the contents of a table entry in main storage does not necessarily have an immediate, if any, effect on the translation.

The size and the structure of the TLB depend on the model. For instance, the TLB may be implemented such as to contain only a few entries pertaining to the currently designated segment table, each entry consisting of the high-order portions of a virtual address and its corresponding real address; or it may contain arrays of values where the real page address is selected on the basis of the current segment-table origin, the translation format, and the high-order bits of the virtual address. Entries within the TLB are not explicitly addressable by the program.

The description of the logical structure of the TLB covers all implementations by System/370 models. The TLB entries are considered as being of two types: TLB segment-table entries and TLB page-table entries. A TLB entry is considered as containing within it both the information obtained from the table entry in storage and the attributes used to fetch the entry from storage. Thus, a TLB segment-table entry would contain the following fields:

| | | | | | |
|----|-----|----|-----|-----|---|
| TF | STO | SX | PTO | PTL | C |
|----|-----|----|-----|-----|---|

- TF The translation format in effect when the entry was formed
- STO The segment-table origin in effect when the entry was formed
- SX The segment index used to select the entry
- PTO The page-table origin fetched from the segment-table entry in storage
- PTL The page-table length fetched from the segment-table entry in storage
- C The common bit fetched from the segment-table entry in storage; when the common-segment facility is not installed, this field is not included in the TLB

A TLB page-table entry would contain the following fields:

| | | | |
|----|-----|----|------|
| TF | PTO | PX | PFRA |
|----|-----|----|------|

- TF The translation format in effect when

the entry was formed

PTO The page-table origin in effect when the entry was formed

PX The page index used to select the entry

PFRA The page-frame real address fetched from the entry in storage

Depending on the implementation, not all of the above items are required in the TLB. For example, if the implementation combines into a single TLB entry (1) the information obtained from a page-table entry and (2) the attributes of both the page-table entry and the segment-table entry, then the page-table-origin and page-table-length fields are not required. If the implementation purges the TLB when the translation parameters are changed, then the segment-table origin and translation format are not required.

Note: The following sections describe the conditions under which information may be placed in the TLB and information from the TLB may be used for address translation, and they describe how changes to the translation tables affect the translation process. Information is not necessarily retained in the TLB under all conditions for which such retention is permissible. Furthermore, information in the TLB may be purged under conditions additional to those for which purging is mandatory.

Use of the Translation-Lookaside Buffer

The formation of TLB entries and the effect of any manipulation of the contents of a table entry by the program depend on whether the entry is valid, on whether the entry is attached, on whether a copy of the entry can be placed in the TLB, and on whether a copy in the TLB of the entry is usable.

The valid state of a table entry denotes that the segment or page associated with the table entry is available. An entry is valid when the segment-invalid bit or page-invalid bit in the entry is zero. The attached state of a table entry denotes that the CPU can attempt to use the table entry for implicit address translation. The usable state of a TLB entry denotes that the CPU can attempt to use the TLB entry for implicit address translation.

A segment-table entry or a page-table entry may be placed in the TLB only when the entry is attached and valid and would not cause a translation-specification exception if used for translation. Except for these restrictions, the entry may be placed in

the TLB at any time.

A segment-table entry is attached to a CPU by means of the primary segment-table designation when all of the following conditions are met:

1. The current PSW specifies DAT on.
2. The current PSW contains no errors which would cause an early exception to be recognized.
3. The current translation format, bits 8-12 in control register 0, is valid.
4. The entry is within the segment table specified by the primary segment-table designation in control register 1.
5. The entry can be selected by the segment-index portion of a virtual address.

Condition 2 does not necessarily apply on models without DAS.

A segment-table entry is attached to a CPU by means of the secondary segment-table designation when all of the following conditions are met:

1. The current PSW specifies DAT on.
2. The current PSW contains no errors which would cause an early exception to be recognized.
3. The current translation format, bits 8-12 in control register 0, is valid.
4. The entry is within the segment table specified by the secondary segment-table designation in control register 7 and either of the following requirements are met:
 - The CPU is in secondary-space mode.
 - The secondary-space control, bit 5 of control register 0, is one.

A page-table entry is attached to a CPU when it is within the page table designated by either a usable TLB segment-table entry or by an attached and valid segment-table entry which would not cause a translation-specification exception if used for translation.

A TLB segment-table entry is in the usable state when all of the following conditions are met:

1. The current PSW specifies DAT on.
2. The current PSW contains no errors which would cause an early exception

to be recognized.

3. The translation-format field in the TLB segment-table entry is the same as the current translation format.
4. The current translation format, bits 8-12 in control register 0, is valid.
5. The TLB-segment-table entry meets at least one of the following requirements:
 - The common bit is one in the TLB entry, or
 - The segment-table-origin field in the TLB entry is the same as the current PSTO, or
 - The segment-table-origin field in the TLB entry is the same as the current SSTO and either PSW bit 16 is one or bit 5 of control register 0 is one.

Condition 2 does not apply on models without DAS.

A TLB segment-table entry may be used for implicit address translation only when the entry is in the usable state and the segment index of the entry matches the segment index of the virtual address to be translated.

A TLB page-table entry is in the usable state when all of the following conditions are met:

1. The TLB page-table entry is selected by a usable TLB segment-table entry or by an attached and valid segment-table entry which would not cause a translation-specification exception if used for translation.
2. The page-table-origin field in the TLB page-table entry matches the page-table-origin field in the segment-table entry which selects it.
3. The page-index field in the TLB page-table entry is within the range permitted by the segment-table-length field in the TLB segment-table entry which selects it.
4. The translation-format field in the TLB page-table entry is the same as the current translation format.

A TLB page-table entry may be used for implicit address translation only when the TLB entry is in the usable state as selected by the TLB segment-table entry being used and only when the page index of the TLB page-table entry matches the page index of the virtual address being

translated.

The operand address of LOAD REAL ADDRESS is translated without the use of the TLB contents. Translation in this case is performed by the use of the designated tables in main storage.

Selected page-table entries are purged from the TLB by means of the INVALIDATE PAGE TABLE ENTRY instruction. All information in the TLB is necessarily cleared only by execution of PURGE TLB, SET PREFIX, or CPU reset.

Programming Notes

1. Although a copy of a table entry may be placed in the TLB only when the entry is both valid and attached, the copy may remain in the TLB even when the entry itself is no longer valid or attached.
2. No entries can be placed in the TLB when DAT is off because the table entries at this time are not attached. In particular, translation of the operand address of LOAD REAL ADDRESS, with DAT off, does not cause entries to be placed in the TLB.

Conversely, when DAT is on, information may be loaded into the TLB from all translation-table entries that could be used for address translation, given the current translation parameters. The loading of the TLB does not depend on whether the entry is used for translation as part of the execution of the current instruction, and such loading can occur when the wait state is specified. Similarly, information from a segment-table or page-table entry having a format error may be recorded in the TLB.

3. More than one copy of a table entry may exist in the TLB. For example, some implementations may cause a copy of a valid table entry to be placed in the TLB for each segment-table origin by which the entry becomes attached.
4. The segment size controls how many segment-table entries can be referred to for translation. Both the page size and segment size control the selection of page-table entries and hence may affect whether or not an entry is attached.
5. The states and use of the DAT entries in both storage and in the TLB are summarized in the figure "Summary of DAT Entries."

| State or Function | Conditions To Be Met |
|--|---|
| STE is attached by means of PSTD (applies only to STE in storage) | <ul style="list-style-type: none"> • DAT on • No early PSW exception* • TF valid • STE in segment table defined by PSTD in CR1 • STE selectable by a 24-bit address |
| STE is attached by means of SSTD (applies only to STE in storage) | <ul style="list-style-type: none"> • DAT on • No early PSW exceptions • TF valid • STE in segment table defined by SSTD in CR7 • STE selectable by a 24-bit address • PSW bit 16 one or bit 5 of CRO one |
| STE in storage is usable for a particular instance of implicit translation | <ul style="list-style-type: none"> • STE in segment table defined and attached by STD being used for the translation • STE selected by SX |
| STE can be placed in TLB | <ul style="list-style-type: none"> • STE attached • STE I bit zero • No TS |
| STE in TLB is usable | <ul style="list-style-type: none"> • DAT on • No early PSW exceptions* • TF matches • STE can be selected by an STD <ul style="list-style-type: none"> - C bit one, or - STO matches PSTO, or - STO matches SSTO and PSW bit 16 one or bit 5 of CRO one |
| STE in TLB is usable for a particular instance of implicit translation | <ul style="list-style-type: none"> • DAT on • No early PSW exceptions* • TF matches • STE selected by STD being used for the translation, that is, <ul style="list-style-type: none"> - STO matches, or - C bit one • SX matches |
| PTE is attached (applies only to PTE in storage) | <ul style="list-style-type: none"> • PTE in page table defined by usable STE in the TLB or defined by an STE that can be placed in the TLB |
| PTE in storage is usable for a particular instance of implicit translation | <ul style="list-style-type: none"> • PTE in page table defined by STE being used for the translation • PTE selected by PX |

| Summary of DAT Entries (Part 1 of 2)

| State or Function | Conditions To Be Met |
|--|--|
| PTE can be placed in TLB | <ul style="list-style-type: none"> • PTE attached • PTE I bit zero • No TS |
| PTE in TLB is usable | <ul style="list-style-type: none"> • PTE selected by a usable STE in the TLB or by an STE that can be placed in the TLB <ul style="list-style-type: none"> - PTO matches, and - PX within PTL, and - TF matches |
| PTE in TLB is usable for a particular instance of implicit translation | <ul style="list-style-type: none"> • PTE selected by STE being used for the translation <ul style="list-style-type: none"> - PTO matches, and - PX within PTL, and - TF matches • PX matches |

Explanation:

- * Condition does not necessarily apply on models which do not have DAS installed
- C bit Common-segment bit in STE
- I bit Invalid bit in table entry
- PSTD Primary segment-table designation
- PSTO Primary segment-table origin
- PTE Page-table entry
- PTL Page-table length
- PTO Page-table origin
- PX Page index
- SSTD Secondary segment-table designation
- SSTO Secondary segment-table origin
- STD Segment-table designation
- STE Segment-table entry
- STO Segment-table origin
- SX Segment index
- TF Translation format (control register 0, bits 8-12)
- TS Translation-specification exception

| Summary of DAT Entries (Part 2 of 2)

Modification of Translation Tables

When an attached and invalid table entry is made valid and no usable entry for the associated virtual address is in the TLB, the change takes effect no later than the end of the current unit of operation. Similarly, when an unattached and valid table entry is made attached and no usable entry for the associated virtual address is in the TLB, the change takes effect no later than the end of the current unit of operation.

When a valid and attached table entry is changed, and when, before the TLB is purged, an attempt is made to refer to storage using a virtual address requiring that entry for translation, unpredictable results may occur, to the following extent. The use of the new value may begin between

instructions or during the execution of an instruction, including the instruction that caused the change. Moreover, until the TLB is purged, the TLB may contain both the old and the new values, and it is unpredictable whether the old or new value is selected for a particular access. If both old and new values of a segment-table entry are present in the TLB, a page-table entry may be fetched using one value and placed in the TLB associated with the other value. If the new value of the entry is a value which would cause an exception, the exception may or may not cause an interruption to occur. If an interruption does occur, the result fields of the instruction may be changed even though the exception would normally cause suppression or nullification.

When LOAD CONTROL changes the translation format, segment-table origin, or

segment-table length, the values of these fields at the start of the operation are in effect for the duration of the operation.

Entries are deleted from the TLB in accordance with the following rules:

1. All entries are deleted from the TLB by PURGE TLB, SET PREFIX, and CPU reset.
2. Selected entries are deleted from the TLB by the execution of INVALIDATE PAGE TABLE ENTRY or by receipt of an INVALIDATE PAGE TABLE ENTRY broadcast from another CPU.
3. Some or all TLB entries may be purged at times other than those required by PURGE TLB and INVALIDATE PAGE TABLE ENTRY.

Programming Notes

1. Entries in the TLB may continue to be used for translation after the table entries from which they have been formed have become unattached or invalid. These TLB entries are not necessarily removed unless explicitly purged from the TLB.

A change made to an attached and valid entry or a change made to a table entry that causes the entry to become attached and valid is reflected in the translation process for the next instruction, or earlier than the next instruction, unless a TLB entry qualifies for substitution of that table entry. However, a change made to a table entry that causes the entry to become unattached or invalid is not necessarily reflected in the translation process until the TLB is purged of entries which qualify for substitution for that table entry.

2. Exceptions associated with dynamic address translation may be established by a pretest for operand accessibility that is performed as part of the initiation of the execution of the instruction. Consequently, a segment-translation or page-translation exception may be indicated when a table entry is invalid at the start of execution even if the instruction would have validated the table entry it uses and the table entry would have appeared valid if the instruction was considered to process the operands one byte at a time.
3. A change made to an attached table entry, except to set the I bit to one

or zero, may produce unpredictable results if that entry is used for translation before the TLB is purged. The use of the new value may begin between instructions or during the execution of an instruction, including the instruction that caused the change. When an instruction, such as MOVE (MVC), makes a change to an attached table entry, including a change that makes the entry invalid, and subsequently uses the entry for translation, a changed entry is being used without a prior purging of the TLB, and the associated unpredictability of result values and of exception recognition applies.

Manipulation of attached table entries may cause spurious table-entry values to be recorded in a TLB. For example, if changes are made piecemeal, modification of a valid attached entry may cause a partially updated entry to be recorded, or, if an intermediate value is introduced in the process of the change, a supposedly invalid entry may temporarily appear valid and may be recorded in the TLB. Such an intermediate value may be introduced if the change is made by an I/O operation that is retried, or if an intermediate value is introduced during the execution of a single instruction.

As another example, if a segment-table entry is changed to designate a different page table and used without purging the TLB, then the new page-table entries may be fetched and associated with the old page-table origin. In such a case, the instruction INVALIDATE PAGE TABLE ENTRY (IPTE) designating the page-table origin will not necessarily purge the page-table entries fetched from the new page table.

4. To facilitate the manipulation of translation tables, IPTE is provided, which sets the I bit in a page-table entry to one and purges all system TLBs of entries formed from that table entry.

IPTE is useful for setting the I bit to one in a page-table entry and causing TLB copies of the entry to be purged from the TLB of each CPU in the configuration. The following aspects of the TLB operation should be considered when using IPTE. (See also the programming notes following IPTE.)

- a. IPTE should be issued before making any change to a page-table entry other than changing the low-order bit; otherwise, the

selective purging portion of IPTE may not purge the TLB copies of the entry.

- b. Invalidation of all the page-table entries within a page table by means of IPTE does not necessarily purge the TLB of the copies, if any, of the segment-table entry designating the page table. When it is desired to invalidate and purge a segment-table entry, the rules in note 5 below must be followed.
- c. When a large number of page-table entries are to be invalidated at a single time, the overhead involved in using PTLB and in following the rules in note 5 below may be less than in issuing an IPTE for each page-table entry.

5. For cases other than the use of IPTE for invalidating a page-table entry, manipulation of table entries should be in accordance with the following rules. If these rules are observed, translation is performed as if the table entries from main storage were always used in the translation process.

- a. An entry must not be changed while it is being used by a CPU except either to invalidate the entry, using PURGE TLB (PTLB) or IPTE, or to alter bit 15 of a page-table entry.
- b. When any change is made to a table entry other than a change to the low-order bit of a page-table entry, each CPU which may have a TLB entry formed from that entry must issue PTLB after the change occurs and prior to the use of that entry for translation by that CPU, except that the purge is unnecessary if the change was made using IPTE or was made to bit 15 of a page-table entry.
- c. When any change is made to an invalid entry in such a way as to cause intermediate valid values to appear in the entry, each CPU to which the entry is attached must issue PTLB after the change occurs and prior to the use of the entry for implicit address translation by that CPU.
- d. When any change is made to a segment-table or page-table length, each CPU to which that table has been attached must issue PTLB after the length has been changed but before that table

becomes attached again to the CPU.

Note that when an invalid page-table entry is made valid without introducing intermediate valid values, the TLB need not be purged in a CPU which does not have any usable TLB copies for that entry. Similarly, when an invalid segment-table entry is made valid without introducing intermediate valid values, the TLB need not be purged in a CPU which does not have any usable TLB copies for that segment-table entry and which does not have any usable TLB copies for the page-table entries attached by it.

Execution of PTLB may have an adverse effect on the performance of some models. Use of this instruction should, therefore, be minimized in conformity with the above rules.

ADDRESS SUMMARY

ADDRESSES TRANSLATED

Most addresses that are explicitly specified by the program and are used by the CPU to refer to storage for an instruction or an operand are logical addresses and are subject to translation when DAT is on. Analogously, the corresponding addresses indicated to the program on an interruption or as the result of executing an instruction are logical.

Translation is not applied to quantities that are formed as storage addresses from the values designated in the B and D fields of an instruction but that are not used to address storage. This includes operand addresses in LOAD ADDRESS, MONITOR CALL, and the shifting and I/O instruction. This also includes the addresses in control registers 10 and 11 designating the starting and ending locations for PER.

With the exception of INSERT VIRTUAL STORAGE KEY, the addresses explicitly designating storage keys (operand addresses in SET STORAGE KEY, INSERT STORAGE KEY, and RESET REFERENCE BIT) are real addresses. Similarly, the addresses implicitly used by the CPU or channel for such sequences as interruptions, updating the interval timer at location 80, DAT-table references, and logout, including the machine-check-extended-logout address in control register 15, are real addresses.

The addresses used by channels to transfer

data, channel-command words, or indirect-data-address words are absolute addresses. Similarly, the I/O-extended-logout address at location 172 is an absolute address.

The handling of storage addresses associated with DIAGNOSE is model-dependent.

The processing of addresses, including dynamic address translation and prefixing, is discussed in the section "Address Types" in this chapter. Prefixing, when provided, is applied after the address has been translated by means of the dynamic-address-

translation facility. For a description of prefixing, see the section "Prefixing" in this chapter.

HANDLING OF ADDRESSES

The handling of addresses is summarized in the figure "Handling of Addresses." This figure lists all addresses that are encountered by the program and specifies the address type.

Virtual Addresses

- Operand address in LOAD REAL ADDRESS
- Operand address in INSERT VIRTUAL STORAGE KEY
- Operand addresses in MOVE TO PRIMARY and MOVE TO SECONDARY.
- Address stored in the word at real location 144 on a program interruption for page-translation or segment-translation exception

Instruction Addresses

- Instruction address in PSW
- Branch addresses
- Target of EXECUTE
- Address stored in the word at real location 152 on a program interruption for PER
- Address placed in general register by BRANCH AND LINK, and PROGRAM CALL

Logical Addresses

- Addresses of storage operands for instructions not otherwise specified
- Address placed in general register 1 by TRANSLATE AND TEST and EDIT AND MARK
- Addresses in general registers updated by MOVE LONG and COMPARE LOGICAL LONG

Real Addresses

- Operand addresses in SET STORAGE KEY, INSERT STORAGE KEY, TEST BLOCK, and RESET REFERENCE BIT
- Operand addresses in READ DIRECT and WRITE DIRECT when INVALIDATE PAGE TABLE ENTRY is installed
- Page-table origin in INVALIDATE PAGE TABLE ENTRY
- Segment-table origins in control registers 1 and 7
- Page-table origin in segment-table entry
- Page-frame real address in page-table entry
- MCEL address in control register 15
- The translated address generated by LOAD REAL ADDRESS
- Address of segment-table entry or page-table entry provided by LOAD REAL ADDRESS
- ASN-first-table origin in control register 14
- ASN-second-table origin in ASN-first-table entry
- Authority-table origin in ASN-second-table entry
- Linkage-table origin in control register 5
- Entry-table origin in linkage-table entry

Handling of Addresses (Part 1 of 2)

Permanently Assigned Real Addresses

- Addresses of PSWs, interruption codes, and associated information used during interruption
- Address used by CPU to update interval timer at real location 80
- Address of CAW, CSW, and other locations used during an I/O interruption or during execution of an I/O instruction, including STORE CHANNEL ID

Absolute Addresses

- Prefix value
- CCW address in CAW
- Data address in CCW
- Address of the indirect-data-address list in a CCW specifying indirect-data addressing
- CCW address in a CCW specifying transfer in channel
- Data address in indirect-data-address words
- IOEL address at real location 172
- Failing-storage address stored in the word at real location 248
- CCW address in CSW

Permanently Assigned Absolute Addresses

- Addresses of PSW and first two CCWs used for initial program loading
- Addresses used for the store-status function

Addresses Not Used to Reference Storage

- PER starting address in control register 10
- PER ending address in control register 11
- The address stored in the word at real location 156 for a monitoring event
- Address in shift instructions and other instructions specified not to use the address to reference storage
- Parameter stored in the word at real location 128 for a service-signal external interruption

Handling of Addresses (Part 2 of 2)

ASSIGNED STORAGE LOCATIONS

8-15 Restart Old PSW: The current PSW is stored as the old PSW at locations 8-15 during a restart interruption.

ASSIGNED REAL-STORAGE LOCATIONS

24-31 External Old PSW: The current PSW is stored as the old PSW at locations 24-31 during an external interruption.

The figure "Assigned Locations in Real Storage" shows the format and extent of the assigned locations in real storage. In a multiprocessing system, real storage addresses are transformed to absolute addresses by means of prefixing. The locations are used as follows. Unless specifically noted, the usage applies to both the BC and EC modes.

32-39 Supervisor-Call Old PSW: The current PSW is stored as the old PSW at locations 32-39 during a supervisor-call interruption.

40-47 Program Old PSW: The current PSW is stored as the old PSW at locations 40-47 during a program interruption.

0-7 Restart New PSW: The new PSW is fetched from locations 0-7 during a restart interruption.

48-55 Machine-Check Old PSW: The current PSW is stored as the old PSW at locations 48-55 during a

machine-check interruption.

56-63 Input/Output Old PSW: The current PSW is stored as the old PSW at locations 56-63 during an I/O interruption.

64-71 CSW: The channel-status word (CSW) is stored at locations 64-71 during an I/O interruption. Part or all of it may be stored during the execution of START I/O, START I/O FAST RELEASE, TEST I/O, CLEAR I/O, HALT I/O, or HALT DEVICE, in which case condition code 1 is set.

72-75 CAW: The channel-address word (CAW) is fetched from locations 72-75 during the execution of START I/O and START I/O FAST RELEASE.

80-83 Interval Timer: Locations 80-83 contain the interval timer. The interval timer is updated whenever the CPU is in the operating state and the manual interval-timer control is set to enable.

84-87 Address of Trace-Table Header: The address of the control block which defines the trace table used by DAS tracing and by the System/370 extended facility is provided in this location.

88-95 External New PSW: The new PSW is fetched from locations 88-95 during an external interruption.

96-103 Supervisor-Call New PSW: The new PSW is fetched from locations 96-103 during a supervisor-call interruption.

104-111 Program New PSW: The new PSW is fetched from locations 104-111 during a program interruption.

112-119 Machine-Check New PSW: The new PSW is fetched from locations 112-119 during a machine-check interruption.

120-127 Input/Output New PSW: The new PSW is fetched from locations 120-127 during an I/O interruption.

128-131 External-Interruption Parameter: During an external interruption due to service signal, the parameter associated with the interruption is stored at locations 128-131.

132-133 CPU Address: During an external interruption due to malfunction alert, emergency signal, or external call, the CPU address associated with the source of the interruption is stored at locations

132-133. For all other external-interruption conditions, zeros are stored at locations 132-133 when the old PSW specified the EC mode, and the field remains unchanged when the old PSW specified the BC mode.

134-135 External-Interruption Code: During an external interruption in the EC mode, the interruption code is stored at locations 134-135.

136-139 Supervisor-Call-Interruption Identification: During a supervisor-call interruption in the EC mode, the instruction-length code is stored in bit positions 5 and 6 of location 137, and the interruption code is stored at locations 138-139. Zeros are stored at location 136 and in the remaining bit positions of 137.

140-143 Program-Interruption Identification: During a program interruption in the EC mode, the instruction-length code is stored in bit positions 5 and 6 of location 141, and the interruption code is stored at locations 142-143. Zeros are stored at location 140 and in the remaining bit positions of 141.

144-147 Translation-Exception Identification: During a program interruption due to a segment-translation exception or a page-translation exception, the virtual address being translated is stored at locations 144-147. This address is sometimes referred to as the translation-exception address. Bits 1-7 of location 144 are set to zeros. With DAS, bit 0 of location 144 is set to zero if the translation was relative to the primary segment table designated by control register 1, and set to one if the translation was relative to the secondary segment table designated by control register 7. Without DAS, bit 0 of location 144 is set to zero.

During a program interruption due to an AFX-translation, ASX-translation, primary-authority, or secondary-authority exception, the ASN being translated is stored at locations 146-147. Locations 144-145 are set to zeros.

During a program interruption for a space-switching event, the old PASN, which appears in the right half of control register 4 before the execution of a space-switching

- PC or PT instruction, is stored at locations 146-147. Locations 144-145 are set to zeros.
- During a program interruption due to an LX-translation or EX-translation exception, the PC number is stored in bit positions 12-31 of the word at location 144. Bits 0-11 are set to zeros.
- 148-149 Monitor-Class Number: During a program interruption due to a monitor event, the monitor-class number is stored at location 149, and zeros are stored at 148.
- 150-151 PER Code: During a program interruption due to a PER event, the PER code is stored in bit positions 0-3 of location 150, and zeros are stored in bit positions 4-7 and at location 151. This field can be stored only when the instruction causing the PER condition was executed under the control of a PSW specifying the EC mode.
- 152-155 PER Address: During a program interruption due to a program event, the PER address is stored at locations 153-155, and zeros are stored at location 152. This field can be stored only when the instruction causing the PER condition was executed under the control of a PSW specifying the EC mode.
- 156-159 Monitor Code: During a program interruption due to a monitor event, the monitor code is stored at locations 157-159, and zeros are stored at location 156.
- 161-163 MABL: Address of a control block used by the System/370 extended facility.
- 168-171 Channel ID: The four-byte channel-identification information is stored at locations 168-171 during the execution of STORE CHANNEL ID.
- 172-175 IOEL Address: The I/O-extended-logout address is fetched from locations 172-175 during the I/O-extended-logout operation.
- 176-179 Limited Channel Logout: The limited-channel-logout information is stored at locations 176-179. This field may be stored only when the CSW or a portion of the CSW is stored.
- 185-187 I/O Address: During an I/O interruption in the EC mode, the two-byte I/O address is stored at locations 186-187, and zeros are stored at location 185.
- 216-223 Machine-Check CPU-Timer Save Area: During a machine-check interruption, the contents of the CPU timer, if installed, are stored at locations 216-223.
- 224-231 Machine-Check Clock-Comparator Save Area: During a machine-check interruption, the contents of the clock comparator, if installed, are stored at location 224-231.
- 232-239 Machine-Check-Interruption Code: During a machine-check interruption the machine-check-interruption code is stored at locations 232-239.
- 244-247 External-Damage Code: During a machine-check interruption due to certain external-damage conditions, depending on the model, an external-damage code may be stored in these locations.
- 248-251 Failing-Storage Address: During a machine-check interruption, a failing-storage address, if any, is stored at locations 249-251, and zeros are stored at location 248.
- 252-255 Region Code: During a machine-check interruption, model-dependent information may be stored at locations 252-255.
- 256-351 Fixed-Logout Area: Depending on the model, logout information may be placed in this area during a machine-check interruption. Additionally, the contents of locations 256-351 may be changed at any time, subject to the asynchronous-fixed-logout-control bit in control register 14.
- 352-383 Machine-Check Floating-Point-Register Save Area: During a machine-check interruption, the contents of the floating-point registers are stored at locations 352-383.
- 384-447 Machine-Check General-Register Save Area: During a machine-check interruption, the contents of the general registers are stored at locations 384-447.
- 448-511 Machine-Check Control-Register Save Area: During a machine-check interruption, the contents of the control registers are stored at locations 448-511.

ASSIGNED ABSOLUTE STORAGE LOCATIONS

The figure "Assigned Locations in Absolute Storage" shows the format and extent of the assigned locations in absolute storage. The locations are as follows, and the usage applies to both the BC and EC modes.

0-7 IPL PSW: The first eight bytes read during the IPL initial read operation are stored at locations 0-7. The contents of these locations are used as the new PSW at the completion of the IPL operation. These locations may also be used for temporary storage at the initiation of the IPL operation.

8-15 IPL CCW1: Bytes 8-15 read during the IPL initial read operation are stored at locations 8-15. The contents of these locations are ordinarily used as the next CCW in an IPL CCW chain after completion of the IPL initial-read operation.

16-23 IPL CCW2: Bytes 16-23 read during the IPL initial read operation are stored at locations 16-23. The contents of these locations may be used as another CCW in the IPL CCW chain to follow IPL CCW1.

216-223 Store-Status CPU-Timer Save Area: During the execution of the store-status operation, the contents of the CPU timer, if installed, are stored at locations 216-223.

224-231 Store-Status Clock-Comparator Save

Area: During the execution of the store-status operation, the contents of the clock comparator, if installed, are stored at location 224-231.

256-263 Store-Status PSW Save Area: During the execution of the store-status operation, the contents of the current PSW are stored at location 256-263.

264-267 Store-Status Prefix Save Area: During the execution of the store-status operation, the contents of the prefix register, if installed, are stored at location 264-267.

268-271 Store-Status Model-Dependent Save Area: During the execution of the store-status operation, model-dependent information may be stored at locations 268-271.

352-383 Store-Status Floating-Point-Register Save Area: During the execution of the store-status operation, the contents of the floating-point registers are stored at locations 352-383.

384-447 Store-Status General-Register Save Area: During the execution of the store-status operation, the contents of the general registers are stored at locations 384-447.

448-511 Store-Status Control-Register Save Area: During the execution of the store-status operation, the contents of the control registers are stored at locations 448-511.

| Hex | Dec | |
|-----|-----|---|
| 0 | 0 | Restart New PSW |
| 4 | 4 | |
| 8 | 8 | Restart Old PSW |
| C | 12 | |
| 10 | 16 | |
| 14 | 20 | |
| 18 | 24 | External Old PSW |
| 1C | 28 | |
| 20 | 32 | Supervisor Call Old PSW |
| 24 | 36 | |
| 28 | 40 | Program Old PSW |
| 2C | 44 | |
| 30 | 48 | Machine-Check Old PSW |
| 34 | 52 | |
| 38 | 56 | Input/Output Old PSW |
| 3C | 60 | |
| 40 | 64 | Channel Status Word |
| 44 | 68 | |
| 48 | 72 | Channel Address Word |
| 4C | 76 | |
| 50 | 80 | Interval Timer |
| 54 | 84 | Address of Trace Table Header |
| 58 | 88 | External New PSW |
| 5C | 92 | |
| 60 | 96 | Supervisor Call New PSW |
| 64 | 100 | |
| 68 | 104 | Program New PSW |
| 6C | 108 | |
| 70 | 112 | Machine-Check New PSW |
| 74 | 116 | |
| 78 | 120 | Input/Output New PSW |
| 7C | 124 | |
| 80 | 128 | External-Interrupt Parameter |
| 84 | 132 | CPU Address External-Interrupt Code |
| 88 | 136 | 000000000000 ILC0 Superv -Call-Irptn Code |
| 8C | 140 | 000000000000 ILC0 Program-Interrupt Code |
| 90 | 144 | Translation-Exception Identification |
| 94 | 148 | 00000000 Monitor CI # PER C 000000000000 |
| 98 | 152 | 00000000 PER Address |
| 9C | 156 | 00000000 Monitor Code |
| A0 | 160 | MAPL Address |
| A4 | 164 | |
| A8 | 168 | Channel ID |
| AC | 172 | IOEL Address |
| B0 | 176 | Limited Channel Logout |
| B4 | 180 | |
| B8 | 184 | 00000000 I/O Address |

Assigned Locations in Real Storage

| Hex | Dec | |
|-------|-----|---|
| BC | 188 | |
| C0 | 192 | |
| C4 | 196 | |
| C8 | 200 | |
| CC | 204 | |
| D0 | 208 | |
| D4 | 212 | |
| D8 | 216 | Machine-Check CPU-Timer Save Area |
| DC | 220 | |
| E0 | 224 | Machine-Check Clock-Comparator Save Area |
| E4 | 228 | |
| E8 | 232 | Machine-Check Interruption Code |
| EC | 236 | |
| F0 | 240 | |
| F4 | 244 | External-Damage Code |
| F8 | 248 | 00000000 Failing-Storage Address |
| FC | 252 | Region Code |
| 100 | 256 | Fixed Logout Area |
| 104 | 260 | |
| 108 | 264 | |
| 10C | 268 | |
| ~ ~ ~ | | |
| 154 | 340 | |
| 158 | 344 | |
| 15C | 348 | |
| 160 | 352 | Machine-Check Floating-Point Register Save Area |
| 164 | 356 | |
| 168 | 360 | |
| 16C | 364 | |
| 170 | 368 | |
| 174 | 372 | |
| 178 | 376 | |
| 17C | 380 | |
| 180 | 384 | Machine-Check General-Register Save Area |
| 184 | 388 | |
| 188 | 392 | |
| 18C | 396 | |
| ~ ~ ~ | | |
| 1B4 | 436 | |
| 1B8 | 440 | |
| 1BC | 444 | |
| 1C0 | 448 | Machine-Check Control-Register Save Area |
| 1C4 | 452 | |
| 1C8 | 456 | |
| 1CC | 460 | |
| ~ ~ ~ | | |
| 1F4 | 500 | |
| 1F8 | 504 | |
| 1FC | 508 | |

| Hex | Dec | |
|-----|-----|------------------------------|
| 0 | 0 | Initial Program Loading PSW |
| 4 | 4 | |
| 8 | 8 | |
| C | 12 | Initial Program Loading CCW1 |
| 10 | 16 | |
| 14 | 20 | Initial Program Loading CCW2 |
| 18 | 24 | |
| 1C | 28 | |
| 20 | 32 | |
| 24 | 36 | |
| 28 | 40 | |
| 2C | 44 | |
| 30 | 48 | |
| 34 | 52 | |
| 38 | 56 | |
| 3C | 60 | |
| 40 | 64 | |
| 44 | 68 | |
| 48 | 72 | |
| 4C | 76 | |
| 50 | 80 | |
| 54 | 84 | |
| 58 | 88 | |
| 5C | 92 | |
| 60 | 96 | |
| 64 | 100 | |
| 68 | 104 | |
| 6C | 108 | |
| 70 | 112 | |
| 74 | 116 | |
| 78 | 120 | |
| 7C | 124 | |
| 80 | 128 | |
| 84 | 132 | |
| 88 | 136 | |
| 8C | 140 | |
| 90 | 144 | |
| 94 | 148 | |
| 98 | 152 | |
| 9C | 156 | |
| A0 | 160 | |
| A4 | 164 | |
| A8 | 168 | |
| AC | 172 | |
| B0 | 176 | |
| B4 | 180 | |
| B8 | 184 | |
| BC | 188 | |

| Hex | Dec | | |
|-----|-----|---|--|
| C0 | 192 | | |
| C4 | 196 | | |
| C8 | 200 | | |
| CC | 204 | | |
| D0 | 208 | | |
| D4 | 212 | | |
| D8 | 216 | | Store-Status CPU Timer Save Area |
| DC | 220 | | |
| E0 | 224 | Store-Status Clock-Comparator Save Area | |
| E4 | 228 | | |
| E8 | 232 | | |
| EC | 236 | | |
| F0 | 240 | | |
| F4 | 244 | | |
| F8 | 248 | | |
| FC | 252 | | |
| 100 | 256 | | Store-Status PSW Save Area |
| 104 | 260 | | |
| 108 | 264 | | Store-Status Prefix Save Area |
| 10C | 268 | Store-Status Model-Dependent Save Area | |
| 110 | 272 | | |
| 158 | 344 | | |
| 15C | 348 | | |
| 160 | 352 | | Store-Status Floating-Point Register Save Area |
| 164 | 356 | | |
| 168 | 360 | | |
| 16C | 364 | | |
| 170 | 368 | | |
| 174 | 372 | | |
| 178 | 376 | | |
| 17C | 380 | | |
| 180 | 384 | Store-Status General-Register Save Area | |
| 184 | 388 | | |
| 188 | 392 | | |
| 18C | 396 | | |
| 1B4 | 436 | | |
| 1B8 | 440 | | |
| 1BC | 444 | | |
| 1C0 | 448 | | Store-Status Control-Register Save Area |
| 1C4 | 452 | | |
| 1C8 | 456 | | |
| 1CC | 460 | | |
| 1F4 | 500 | | |
| 1F8 | 504 | | |
| 1FC | 508 | | |

Assigned Locations in Absolute Storage

| | |
|---|------|
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This chapter describes in detail the facilities for controlling, measuring, and recording the operation of one or more CPUs.

STOPPED, OPERATING, LOAD, AND CHECK-STOP STATES

The stopped, operating, load, and check-stop states are four mutually exclusive states of the CPU. When the CPU is in the stopped state, instructions and interruptions, other than the restart interruption, are not executed. In the operating state, the CPU executes instructions and takes interruptions, subject to the control of the program-status word (PSW) and control registers, and in the manner specified by the setting of the operator-facility rate control. The CPU is in the load state during the initial-program-loading operation. The CPU enters the check-stop state only as the result of machine malfunctions.

A change between these four CPU states can be effected by use of the operator facilities or by acceptance of certain SIGNAL PROCESSOR orders addressed to that CPU. The states are not controlled or identified by bits in the PSW. The stopped, load, and check-stop states are indicated to the operator by means of the manual indicator, load indicator, and check-stop indicator respectively. These three indicators are off when the CPU is in the operating state.

The CPU timer is updated when the CPU is in the operating state or the load state. The TOD clock is updated whenever power is on. The interval timer is updated only when the CPU is in the operating state.

STOPPED STATE

The state of the CPU is changed from operating to stopped by the stop function. The stop function is performed when:

- The stop key is activated while the CPU is in the operating state.
- The CPU accepts a stop or stop-and-store-status order specified by a SIGNAL PROCESSOR instruction addressed to this CPU while it is in the operating state.
- The CPU has finished the execution of a unit of operation initiated by performing the start function with the

rate control set to instruction step.

When the stop function is performed, the transition from the operating to the stopped state occurs at the end of the current unit of operation. When the wait-state bit of the PSW is one, the transition takes place immediately, provided no interruptions are pending for which the CPU is enabled. In the case of interruptible instructions, the amount of data processed in a unit of operation depends on the particular instruction and may depend on the model.

Before entering the stopped state, all pending allowed interruptions are taken while the CPU is still in the operating state. They cause the old PSW to be stored and the new PSW to be fetched before the stopped state is entered. When the CPU is in the stopped state, interruption conditions remain pending.

The CPU is also placed in the stopped state:

- When a reset is completed, except when the reset operation is performed as part of initial program loading, and
- When an address comparison indicates equality and stopping on the match is specified

The execution of resets is described in the section "Resets" in this chapter, and address comparison is described in the section "Address-Compare Controls" in Chapter 13, "Operator Facilities."

If the CPU is in the stopped state when an INVALIDATE PAGE TABLE ENTRY instruction is executed on another CPU in the configuration, the invalidation may be performed immediately or may be delayed until the CPU leaves the stopped state.

OPERATING STATE

The state of the CPU is changed from stopped to operating when the start function is performed or when a restart interruption (see Chapter 6) occurs.

The start function is performed if the CPU is in the stopped state and (1) the start key associated with that CPU is activated or (2) that CPU accepts the start order specified by a SIGNAL PROCESSOR instruction addressed to that CPU. The effect of performing the start function is unpredictable when the stopped state was entered by means of a reset.

When the wait-state bit is one and the rate

control is set to instruction step, the start function causes no instruction to be executed, but all pending allowed interruptions are taken before the CPU returns to the stopped state.

completion after the CPU enters the stopped state. The interruption conditions due to completion of I/O operations remain pending when the CPU is in the stopped state.

LOAD STATE

The CPU enters the load state when the load-normal or load-clear key is activated (see the section "Initial Program Loading" in this chapter). When the initial-program-loading operation is completed successfully, the CPU state changes from load to operating, provided the rate control is set to process; if the rate control is set to instruction step, the CPU state changes from load to stopped.

CHECK-STOP STATE

The check-stop state, which the CPU enters on certain types of machine malfunction, is described in Chapter 11, "Machine-Check Handling."

Programming Notes

1. Except for the relationship between execution time and real time, the execution of a program is not affected by stopping the CPU.
2. When, because of a machine malfunction, the CPU is unable to end the execution of an instruction, the stop function is ineffective, and a reset function has to be invoked instead. A similar situation occurs when an unending string of interruptions results from a PSW with a PSW-format error of the type that is recognized early, or from a persistent interruption condition, such as one due to the CPU timer.
3. Input/output operations continue to

PROGRAM-STATUS WORD

The current program-status word (PSW) contains information required for the execution of the currently active program. The PSW is 64 bits in length and includes the instruction address, condition code, and other control fields. In general, the PSW is used to control instruction sequencing and to hold and indicate much of the status of the CPU in relation to the program currently being executed. Additional control and status information is contained in control registers and permanently assigned storage locations.

Control is switched during an interruption of the CPU by storing the current PSW, so as to preserve the status of the CPU, and then loading a new PSW.

The status of the CPU can be changed by loading a new PSW or part of a PSW.

The instruction LOAD PSW introduces a new PSW. The instruction address is updated by sequential instruction execution and replaced by successful branches. Other instructions are provided which operate on a portion of the PSW. The figure "Operations on System Mask, PSW Key, and Program Mask" summarizes these instructions.

A new or modified PSW becomes active (that is, the information introduced into the current PSW assumes control over the CPU) when the interruption or the execution of an instruction that changes the PSW is completed. The interruption for PER associated with an instruction that changes the PSW occurs under control of the PER mask that is effective at the beginning of the operation.

Bits 0-7 of the PSW are collectively referred to as the system mask.

| Instruction | System Mask (PSW Bits 0-7) | | PSW Key (PSW Bits 8-11) | | Condition Code and Program Mask* | |
|----------------------------|----------------------------------|------|-------------------------------|-----|---|-----|
| | Saved | Set | Saved | Set | Saved | Set |
| BRANCH AND LINK | No | No | No | No | Yes | No |
| INSERT PSW KEY | No | No | Yes | No | No | No |
| SET PROGRAM MASK | No | No | No | No | No | Yes |
| SET PSW KEY FROM ADDRESS | No | No | No | Yes | No | No |
| SET SYSTEM MASK | No | Yes | No | No | No | No |
| STORE THEN AND SYSTEM MASK | Yes | ANDs | No | No | No | No |
| STORE THEN OR SYSTEM MASK | Yes | ORs | No | No | No | No |

Explanation:

* PSW bits 18-23 in EC mode; PSW bits 34-40 in BC mode.

ANDs The logical AND of the immediate field in the instruction and the current system mask replaces the current system mask.

ORs The logical OR of the immediate field in the instruction and the current system mask replaces the current system mask.

Operations on System Mask, PSW Key, and Program Mask

EC AND BC MODES

Two control modes are provided for the formatting and use of control and status information: the extended-control (EC) mode and the basic-control (BC) mode. Certain functions available in the EC mode, such as PER, are not available in the BC mode. The mode currently in effect is specified by PSW bit 12. Bit 12 is one for the EC mode and zero for the BC mode.

Bit 6 of the PSW, in both the BC and EC modes, is the summary-mask bit for controlling I/O interruptions. In addition, I/O interruptions can be controlled individually for up to 32 channels. In the EC mode, the individual control is provided by the 32 mask bits in control register 2, and the summary-mask bit in the PSW applies to all 32 channels. In the BC mode, channels 6 and up are individually controlled by the corresponding bits of control register 2, as well as the summary-mask bit, bit 6 of the PSW. In the BC mode, channels 0-5 are controlled separately by bits 0-5 of the PSW and are not subject to the summary mask or to mask bits in control register 2.

When interruptions occur in the EC mode, the interruption code and

instruction-length code are stored at various permanently assigned storage locations according to the class of interruptions. In the BC mode, the interruption code and instruction-length code are placed in the PSW for all except machine-check interruptions.

The program-mask and condition-code fields in the PSW are allocated to different bit positions in the two control modes.

The instruction INSERT STORAGE KEY provides the reference and change bits when in the EC mode but produces zeros in the corresponding bit positions when in the BC mode.

Programming Notes

1. The BC mode provides a PSW format that is compatible with the PSW of System/360.
2. The choice between the EC and BC modes affects only those aspects of operation that are specifically defined to be different for the two modes. It does not affect the operation of any functions that are not associated with the PSW control bits provided only in the EC mode, and

it does not affect the validity of any instructions. The instructions SET SYSTEM MASK, STORE THEN AND SYSTEM MASK, and STORE THEN OR SYSTEM MASK perform the specified function on the leftmost byte of the PSW regardless of

the mode specified by the current PSW. On the other hand, the instruction SET PROGRAM MASK introduces a new program mask regardless of the PSW bit positions occupied by the mask.

| specific authority tests are met;
| otherwise, a privileged-operation exception
| is recognized, and a program interruption
| takes place.

| Address-Space Control (S): Bit 16, in
| conjunction with PSW bit 5, controls the
| address-space mode. This bit is provided
| with DAS. See the discussion of the PSW
| under "Translation Control" in Chapter 3,
| "Storage."

Condition Code (CC): Bits 18 and 19 are
the two bits of the condition code. The
condition code is set to 0, 1, 2, or 3,
depending on the result obtained in
executing certain instructions. Most
arithmetic and logical operations, as well
as some other operations, set the condition
code. The instruction BRANCH ON CONDITION
can specify any selection of the
condition-code values as a criterion for
branching. A table in Appendix C
summarizes the condition-code values that
may be set for all instructions which set
the condition code of the PSW.

Program Mask: Bits 20-23 are the four
program-mask bits. Each bit is associated
with a program exception, as follows:

| Program- Mask Bit | Program Exception |
|----------------------|----------------------|
| 20 | Fixed-point overflow |
| 21 | Decimal overflow |
| 22 | Exponent underflow |
| 23 | Significance |

When the mask bit is one, the exception
results in an interruption. When the mask
bit is zero, no interruption occurs. The
setting of the exponent-underflow-mask bit
or the significance-mask bit also
determines the manner in which the
operation is completed when the
corresponding exception occurs.

Instruction Address: Bits 40-63 form the
instruction address. This address
designates the location of the leftmost
byte of the next instruction.

Bit positions 0, 2-4, 16, 17, and 24-39 are
unassigned and must contain zeros. A
specification exception is recognized when
these bit positions do not contain zeros.

operation is completed when the corresponding exception occurs.

Instruction Address: Bits 40-63 form the instruction address. This address designates the location of the leftmost byte of the next instruction.

CONTROL REGISTERS

The control registers provide a means for maintaining and manipulating control information that resides outside the PSW. There may be up to sixteen 32-bit control registers.

One or more specific bit positions in control registers are assigned to each facility requiring such register space. When the facility is installed, the bits perform the defined control function.

The LOAD CONTROL instruction loads control information from storage into control registers, whereas the STORE CONTROL instruction transfers information from control registers to storage.

The instruction LOAD CONTROL causes all register positions, within those registers designated by the instruction, to be loaded. Information loaded into the control registers becomes active (that is, assumes control over the system) at the completion of the instruction causing the information to be loaded.

At the time the registers are loaded, the information is not checked for exceptions, such as invalid translation-format code or an address designating an unavailable or a protected location. The validity of the information is checked and the exceptions, if any, are indicated at the time the information is used.

When STORE CONTROL is executed, it returns the current value in each register position. Values corresponding to unassigned or uninstalled register positions are unpredictable.

Only the general structure of control registers is described here; a definition of the register positions appears with the description of the facility with which the register position is associated. The figure "Assignment of Control-Register Fields" shows the control-register positions which are assigned and the initial value of the field upon execution of reset.

Programming Note

To ensure that existing programs run if and when new facilities using additional control-register positions are installed, the program should load zeros in unassigned control-register positions. Although STORE CONTROL may provide zeros in the bit positions corresponding to unassigned register positions, the program should not depend on such zeros. It is permissible, however, for the program to load into the control registers, by LOAD CONTROL, any information previously stored by means of STORE CONTROL.

| Ctrl Reg | Bits | Name of Field | Associated with | Initial Value |
|---|-------|---------------------------------|-----------------------------|------------------|
| 0 | 0 | Block-multiplexing control | Block-multiplexing channels | 0 |
| 0 | 1 | SSM-suppression control | SET SYSTEM MASK | 0 |
| 0 | 2 | TOD-clock-sync control | Multiprocessing | 0 |
| 0 | 3 | Low-address-protection control | Low-address protection | 0 |
| 0 | 4 | Extraction-authority control | Dual-address-space control | 0 |
| 0 | 5 | Secondary-space control | Dual-address-space control | 0 |
| 0 | 8-12 | Translation format | Dynamic address translation | 0 |
| 0 | 16 | Malfunction-alert mask | Multiprocessing | 0 |
| 0 | 17 | Emergency-signal mask | Multiprocessing | 0 |
| 0 | 18 | External-call mask | Multiprocessing | 0 |
| 0 | 19 | TOD-clock-sync-check mask | Multiprocessing | 0 |
| 0 | 20 | Clock-comparator mask | Clock comparator | 0 |
| 0 | 21 | CPU-timer mask | CPU timer | 0 |
| 0 | 22 | Service-signal mask | Service signal | 0 |
| 0 | 24 | Interval-timer mask | Interval timer | 1 |
| 0 | 25 | Interrupt-key mask | Interrupt key | 1 |
| 0 | 26 | External-signal mask | External signal | 1 |
| 1 | 0-7 | Primary-segment-table length | Dynamic address translation | 0 |
| 1 | 8-25 | Primary-segment-table origin | Dynamic address translation | 0 |
| 1 | 31 | Space-switch-event bit | Dual-address-space control | 0 |
| 2 | 0-31 | Channel masks | Channels | 1 |
| 3 | 0-15 | PSW-key mask | Dual-address-space control | 0 |
| 3 | 16-31 | Secondary ASN | Dual-address-space control | 0 |
| 4 | 0-15 | Authorization index | Dual-address-space control | 0 |
| 4 | 16-31 | Primary ASN | Dual-address-space control | 0 |
| 5 | 0 | Subsystem-linkage control | Dual-address-space control | 0 |
| 5 | 8-24 | Linkage-table origin | Dual-address-space control | 0 |
| 5 | 25-31 | Linkage-table length | Dual-address-space control | 0 |
| 7 | 0-7 | Secondary-segment-table length | Dual-address-space control | 0 |
| 7 | 8-25 | Secondary-segment-table origin | Dual-address-space control | 0 |
| 8 | 16-31 | Monitor Masks | MONITOR CALL | 0 |
| 9 | 0 | Successful-branching-event mask | Program-event recording | 0 |
| 9 | 1 | Instruction-fetching-event mask | Program-event recording | 0 |
| 9 | 2 | Storage-alteration-event mask | Program-event recording | 0 |
| 9 | 3 | GR-alteration-event mask | Program-event recording | 0 |
| 9 | 16-31 | PER general-register masks | Program-event recording | 0 |
| 10 | 8-31 | PER starting address | Program-event recording | 0 |
| 11 | 8-31 | PER ending address | Program-event recording | 0 |
| 14 | 0 | Check-stop control | Machine-check handling | 1 |
| 14 | 1 | Synchronous-MCEL control | Machine-check handling | 1 |
| 14 | 2 | I/O-extended-logcut control | I/O extended logout | 0 |
| 14 | 4 | Recovery-report mask | Machine-check handling | 0 |
| 14 | 5 | Degradation-report mask | Machine-check handling | 0 |
| 14 | 6 | External-damage-report mask | Machine-check handling | 1 |
| 14 | 7 | Warning mask | Machine-check handling | 0 |
| 14 | 8 | Asynchronous-MCEL control | Machine-check handling | 0 |
| 14 | 9 | Asynchronous-fixed-log control | Machine-check handling | 0 |
| 14 | 12 | ASN-translation control | Dual-address-space control | 0 |
| 14 | 20-31 | ASN-first-table origin | Dual-address-space control | 0 |
| 15 | 8-28 | MCEL address | Machine-check handling | 512 ¹ |
| Explanation: | | | | |
| The fields not listed are unassigned. | | | | |
| ¹ Bit 22 is set to one, with all other bits set to zeros, thus yielding a decimal byte address of 512. | | | | |

Assignment of Control-Register Fields

DAS TRACING

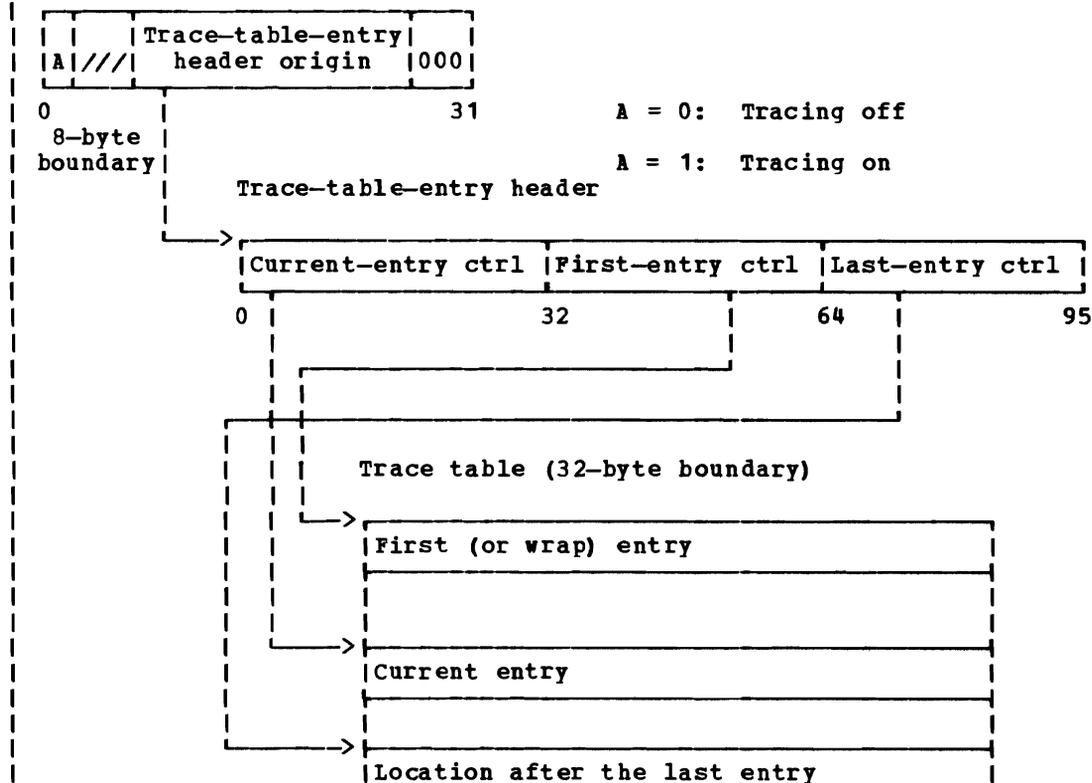
Three DAS instructions optionally store 32 bytes of information about the circumstances under which the instructions are executed. This action is called DAS tracing and is performed by placing information in a 32-byte block, called a trace entry, in an area called a trace table. DAS tracing assists in problem determination for system and semiprivileged problems by providing an on-going record in storage of significant events. The trace table and the location of the last-used entry are described by a control block called the trace-table-entry header. The origin of the header is specified in the word at location 84 (hex 54). These relationships are illustrated in the figure "DAS Tracing."

DAS tracing is controlled by bit 0 of location 84, called the DAS-trace-control bit. When the bit is one, a trace entry is made each time PROGRAM CALL (PC), PROGRAM TRANSFER (PT), and SET SECONDARY ASN (SSAR) are executed.

All locations associated with DAS tracing are treated as logical addresses whose handling depends on the DAT-mode and address-space-control bits of the PSW. For PROGRAM CALL and PROGRAM TRANSFER, the addresses are translated by using the old primary segment-table designation. For SET SECONDARY ASN, the addresses are translated by using either the old primary segment-table designation or the old secondary segment-table designation depending on whether PSW bit 16 specifies primary or secondary mode.

Bits 8-27 of location 84 provide the origin of the three-word trace-table-entry header. Conceptually, the header defines a table of 32-byte elements, called trace entries. The second and third words of the header designate, respectively, the beginning and end of this table. When DAS tracing is on, the first word of the header, called the current-entry control, is updated in conjunction with the execution of the instruction to be traced. The trace entry designated by the updated contents of the current-entry control is used to contain the trace information about the instruction being traced. Updating is interlocked to ensure that distinct entries are produced when a common table is used for tracing by two CPUs.

Location 84 (hex 54)



DAS Tracing

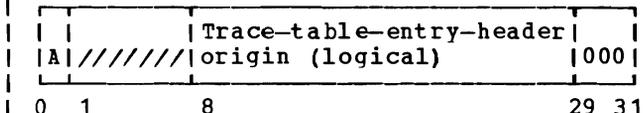
Updating the current-entry-control word of the header normally consists in advancing the contents of the current-entry-control word by 32. However, if the advanced value equals or exceeds the value in the last-entry-control word of the header, the contents of the first-entry-control word replaces the contents of the current-entry-control word. Thus, the dynamic filling of successive entries wraps from the last entry to the first entry, with no special recognition accorded this event.

The references to location 84, to the trace-table-entry header, and to a trace entry for the purpose of DAS tracing are not subject to key-controlled protection. Low-address protection does apply, however, to the store into the current-entry-control word of the header and into a trace entry.

The details of the trace-table-header origin, trace-table-entry header, and the trace entry are contained in the following section.

TRACE-TABLE-ENTRY-HEADER ORIGIN

The origin of the trace-table-entry header is contained in the word at location 84 (hex 54). Location 84 is considered to be a logical address. Access to location 84 for DAS tracing is not subject to key-controlled protection. The format of this word is:



Bit 0 (DAS-trace control) controls whether implicit tracing is performed for PC, PT, and SSAR. When this bit is zero, no tracing is performed during execution of these instructions. When the bit is one, a trace entry is made each time one of these instructions is executed.

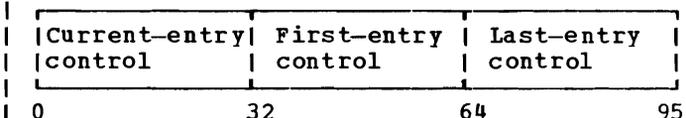
Bits 1-7 are reserved and should be zeros. They are ignored during implicit tracing.

Bits 8-28 (trace-table-entry-header origin), with three low-order zeros appended, constitute the logical address of a control block called the trace-table-entry header. When the address designates a location in the range 0-511 and both low-address protection and tracing are activated, a protection exception is recognized.

Bits 29-31 must be zeros; otherwise, a specification exception is recognized, and instruction execution is suppressed.

TRACE-TABLE-ENTRY HEADER

The trace-table-entry header defines a table of 32-byte entries. One entry is filled with information for each traced instruction. After updating, the first word of the header designates the entry into which information is placed about the current instruction. The second and third words of the header designate the beginning and end of the table. The format of the header is:

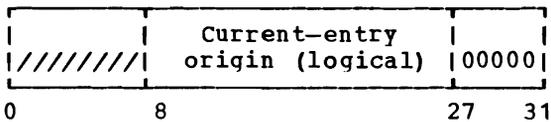


Bits 0-31 (current-entry control) are updated to contain the origin of the trace-table entry used for the current instruction.

To update the field, a 32-bit intermediate quantity called the next-entry designator is formed by the logical addition of 32 to the contents of bit positions 0-31, with overflow out of bit 0 ignored and lost. The next-entry designator is then logically compared with the contents of bits 64-95. The designator replaces the contents of bits 0-31 if the designator is less than the contents of the last-entry-control field. If the designator is equal to or greater than the contents of the last-entry-control field, then the contents of bits 32-63 replace the contents of bit positions 0-31. Instruction execution is suppressed and a specification exception is recognized if the new value of bits 27-31 would not be zero.

Bits 0-31 are replaced under an interlocked-for-update control. The field is not updated until it is determined that no exceptions will be encountered before the filling of the current trace entry is completed or before the current instruction is completed.

The new contents of bits 8-26 (called the current-entry origin), with five zero bits appended on the right, constitute the logical address of the trace entry for the current instruction. For the purpose of determining the address of the current entry, the first word of the header has this format:



The second and third words of the header are used as follows:

Bits 32-63 (first-entry control) replace the contents of bit positions 0-31 when the last-entry control disallows tracing in the location following the last-used trace entry.

Bits 64-95 (last-entry control) are compared with a derived 32-bit quantity called the next-entry designator. Depending on whether the designator is (1) less than, or (2) equal to or greater than bits 64-95, bits 0-31 are replaced under an interlocked-for-update control either by (1) the designator or (2) the contents of bit positions 32-63.

Applicable Controls

Key-controlled protection does not apply to references to the fields of the header. Low-address protection does apply, however, to the store reference to update the first word of the header. The store reference is also monitored for a PER storage-alteration event. Change and reference recording are performed as usual. A serialization and checkpoint-synchronization function is performed before and after updating the first word of the header.

The current-entry-control word is changed under a word-concurrent interlocked-for-update control. The fetches of the first-entry-control and last-entry words are word-concurrent and are made without regard to when the interlock on the current-entry-control word is established.

During tracing, the fetches of the first-entry-control word and of the last-entry-control word that are performed in conjunction with updating the current entry-control word are not necessarily interlocked to prevent subsequent storing into these words by I/O or other CPUs.

Programming Notes

1. The last-entry-control word should be thought of as designating the location beyond the last entry in the table. This is because an equal comparison with the last-entry-control value results in wrapping to the first

entry.

2. The high-order byte of each word of the header should be set to zero; otherwise, unexpected results can occur. This is because 32 bits participate in the comparison and replacement actions but only 24 bits are used to address the trace entry. Thus, a trace table may wrap from high storage locations to low storage locations, and, depending on high-order bit values, not wrap to the intended beginning of the table.
3. Because current trace information is placed in the location designated by the updated contents of current-entry-control word, the entry designated before updating occurs is not used initially, although it may subsequently be used if it is in the range of the table after wrapping.

TRACE ENTRY

A trace entry consists of 32 bytes beginning on a 32-byte boundary. The trace-entry address for the current instruction is formed from bits 8-26 of the updated current-entry-control word of the trace-table-entry-header table. It is treated as a logical address. Access to an entry is subject to low-address protection but is not subject to key-controlled protection. Store accesses are monitored for PER storage-alteration events, and change and reference recording is performed as usual.

The store-type reference to a trace entry is not necessarily a single-access reference. During the execution of an implicitly traced instruction, it may appear to another CPU or to I/O that an entry, or portions of an entry, are stored more than once. The intermediate results observed may or may not correspond to the final results. All accesses are byte-concurrent.

The format of an entry for the instructions PROGRAM CALL (PC), PROGRAM TRANSFER (PT), and SET SECONDARY ASN (SSAR) is shown in the figure "Trace-Entry Formats."

| Decimal (Hex) Offsets within Trace Entry | Contents of Trace Entry | | |
|--|-------------------------------|------------------------------|------------------------------|
| | For PC | For PT | For SSAR |
| Bytes 0-1 | New PSW, bytes 0-1 | New PSW, bytes 0-1 | New PSW, bytes 0-1 |
| Byte 2 | Hex 90 ¹ | Hex A0 ¹ | Hex B0 ¹ |
| Bytes 3-7 | New PSW, bytes 3-7 | New PSW, bytes 3-7 | New PSW, bytes 3-7 |
| Bytes 8-9 | New PASN | New PASN | PASN |
| Bytes 10-11 (A-B) | New SASN | 0 | New SASN |
| Bytes 12-13 (C-D) | GR14 | Old PASN | 0 |
| Bytes 14-15 (E-F) | After | 0 | Old SASN |
| Bytes 16-19 (10-13) | 0 | 0 | 0 |
| Byte 20 (14) | ILC ² CC PM | ILC ² CC PM | ILC ² CC PM |
| Byte 21 (15) | CPU Address ³ | CPU Address ³ | CPU Address ³ |
| Bytes 22-23 (16-17) | 0 | 0 | 0 |
| Bytes 24-27 (18-1B) | Operand 2 (PC #) ⁴ | 0 | 0 |
| Bytes 28-31 (1C-1F) | TOD clock, bytes 3-6 | TOD clock, bytes 3-6 | TOD clock, bytes 3-6 |

Explanation:

- ¹ Byte 2 contains the entry-type identifier value. This position is used to uniquely identify the type of event for which the entry is made.
- ² Byte 20 (hex 14) contains the instruction-length count (ILC), condition code (CC), and program mask (PM) of the old PSW. The ILC is always binary 10, including when the traced instruction is the target of an EXECUTE instruction.
- ³ Byte 21, "CPU Address," is interpreted as the CPU address of the CPU which executed the instruction for which the trace entry is made. This quantity is obtained from logical location 795 (hex 31B).
- ⁴ Bytes 24-27 for the PC instruction, "Operand 2 (PC #)," contain 32 bits, consisting of eight high-order zero bits appended to the 24-bit effective address specified by the PROGRAM CALL instruction. The low-order 20 bits constitute the PC number.

Trace-Entry Formats

PROGRAM-EVENT RECORDING

The purpose of the program-event-recording (PER) facility is to assist in debugging programs. It permits the program to be alerted to the following types of PER events:

- Execution of a successful branch instruction.
- Fetching of an instruction from the

designated storage area.

- Alteration of the contents of the designated storage area.
- Alteration of the contents of designated general registers.

The program can selectively specify one or more of the above types of events to be monitored. The information concerning a PER event is provided to the program by means of a program interruption, with the

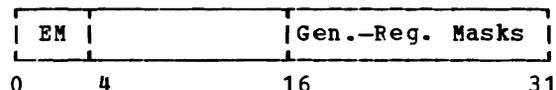
cause of the interruption being identified in the interruption code. PER is only available in the EC mode.

PER Ending Address: Bits 8-31 of control register 11 are the address of the end of the monitored storage area.

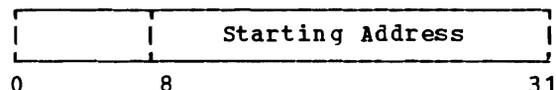
CONTROL-REGISTER ALLOCATION

The information for controlling PER resides in control registers 9, 10, and 11 and consists of the following fields:

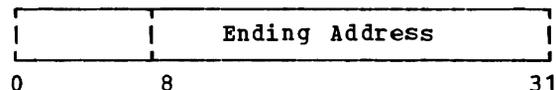
Control Register 9:



Control Register 10:



Control Register 11:



PER-Event Masks (EM): Bits 0-3 of control register 9 specify which types of events are monitored. The bits are assigned as follows:

- Bit 0: Successful-branching event
- Bit 1: Instruction-fetching event
- Bit 2: Storage-alteration event
- Bit 3: General-register-alteration event

Bits 0-3, when ones, specify that the corresponding types of events are monitored. When a bit is zero, the corresponding type of event is not monitored.

PER General-Register Masks: Bits 16-31 of control register 9 specify which general registers are monitored for replacement of their contents. The 16 bits, in the sequence of ascending bit numbers, correspond one for one with the 16 registers, in the sequence of ascending register numbers. When a bit is one, the associated register is monitored for replacement; if zero, the register is not monitored.

PER Starting Address: Bits 8-31 of control register 10 are the address of the beginning of the monitored storage area.

Programming Note

Models may operate at reduced performance while the CPU is enabled for PER events. To ensure that CPU performance is not degraded because of the operation of the PER facility, programs that do not use it should disable the facility by setting the PER mask in the EC-mode PSW to zero. No degradation due to PER occurs in the BC mode or when the PER mask in the EC-mode PSW is zero. Disabling of PER in the EC mode by means of the masks in control register 9 does not necessarily prevent performance degradation due to the facility.

OPERATION

PER is under control of bit 1 of the EC-mode PSW, the PER mask. When the mask is zero, no PER event can cause an interruption. When the mask is one, a monitored event, as specified by the contents of control registers 9, 10, and 11, causes a program interruption. In BC mode, PER is disabled.

An interruption due to a PER event is taken after the execution of the instruction responsible for the event. The occurrence of the event does not affect the execution of the instruction, which may be either completed, terminated, suppressed, or nullified.

When the CPU is disabled for a particular PER event at the time it occurs, either by the mask in the PSW or by the masks in control register 9, the event is not recognized.

A change to the PER mask in the PSW or to the PER control fields in control registers 9, 10, and 11 affects PER starting with the execution of the very next instruction. If the CPU is enabled for some PER event but an instruction causes the CPU to be disabled for that particular event, the event causes a PER condition to be recognized if it occurs during the execution of the instruction.

When LOAD PSW or SUPERVISOR CALL causes a PER condition and at the same time changes CPU operation from the EC mode to the BC mode, the PER interruption is taken with the old PSW specifying the BC mode and with the interruption code stored in the old

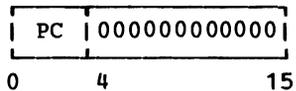
PSW. The additional information identifying the PER condition is stored in its regular format at locations 150-155.

PER applies to emulation instructions in the following way. Emulation instructions indicate all events that have occurred and may additionally indicate events that did not occur and were not called for in the instruction, provided monitoring was enabled for the type of event by the PER mask in the PSW and the PER-event masks, bits 0-3 in control register 9. In such cases, the contents of the remaining positions in control registers 9, 10, and 11 may be ignored. Thus, for example, an emulation instruction may cause general-register alteration to be indicated even though no general registers are altered and even though bits 16-31 of control register 9 are all zeros.

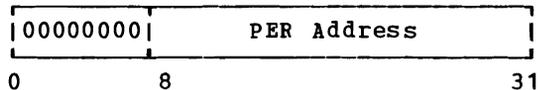
Identification of Cause

A program interruption for PER sets bit 8 of the interruption code to one and places identifying information in storage locations 150-155. The format of the information stored at locations 150-155 is as follows:

Locations 150-151:



Locations 152-155:



The event causing a PER interruption is identified by a one in one of bit positions 0-3 of location 150, the PER code (PC), with the rest of the bits in the code set to zeros. The bit position in the PER code for a particular event is the same as the bit position for that event in the PER event-mask field in control register 9.

The PER address at locations 153-155 is the address of the instruction causing the event. When the instruction is executed by means of EXECUTE, the address of the location containing the EXECUTE instruction is placed in the PER-address field. In either case, the address of the instruction to be executed next is placed in the PSW. Zeros are stored in bit positions 4-7 of location 150 and at locations 151 and 152.

Priority of Indication

When a PER interruption occurs and more than one designated PER event has been recognized, all recognized PER events are concurrently indicated in the PER code. Additionally, if another program interruption condition concurrently exists, the interruption code for a program interruption indicates both the PER condition and the other condition.

Except as listed below, a PER event does not cause premature interruption of the interruptible instruction, and the PER condition is held pending until the completion of the instruction.

- When the execution of an interruptible instruction is due to be interrupted by an I/O, external, or repressible machine-check condition, an interruption for a pending PER condition occurs first, and the I/O, external, or machine-check interruption is subsequently subject to the control of mask bits in the new PSW.
- Similarly, when the CPU is placed in the stopped state during the execution of an interruptible instruction, an interruption for a pending PER condition occurs before the stopped state is entered.
- When any program exception is encountered, the pending PER condition is indicated concurrently.
- Depending on the model, in certain situations, a PER condition may cause the execution of an interruptible instruction to be interrupted without an associated asynchronous condition or program exception.

In the case of an instruction-fetching event for SUPERVISOR CALL, the PER interruption occurs immediately after the supervisor-call interruption.

Programming Notes

1. In the following cases, an instruction can both cause a program interruption for a PER event and change the value of masks controlling an interruption for PER events. The original mask values determine whether a program interruption takes place for the PER event.
 - a. The instructions LOAD PSW, SET SYSTEM MASK, STORE THEN AND SYSTEM

MASK, and SUPERVISOR CALL can cause an instruction-fetching event and disable the CPU for PER interruptions. Additionally, STORE THEN AND SYSTEM MASK can cause a storage-alteration event to be indicated. In all these cases, the program old PSW associated with the program interruption for the PER event may indicate that the CPU was disabled for that type of PER event.

b. An instruction-fetching event may be recognized during execution of a LOAD CONTROL instruction which also changed the value of the PER-event masks in control register 9 or the addresses in control registers 10 and 11 controlling indication of instruction-fetching events.

2. No instructions can both change the values of general-register-alteration masks and cause a general-register-alteration event to be recognized.

3. When a PER interruption occurs during the execution of an interruptible instruction, the ILC indicates the length of that instruction or EXECUTE, as appropriate. When a PER interruption occurs as a result of LOAD PSW or SUPERVISOR CALL, the ILC indicates the length of these instructions or EXECUTE, as appropriate, unless a concurrent specification exception on LOAD PSW calls for an ILC of 0.

4. When a PER interruption is caused by branching, the PER address identifies the branch instruction (or EXECUTE, as appropriate), whereas the old PSW points to the next instruction to be executed. When the interruption occurs during the execution of an interruptible instruction, the PER address and the instruction address in the old PSW are the same.

STORAGE-AREA DESIGNATION

Two of the PER events--instruction fetching and storage alteration--involve the designation of an area in storage. The storage area monitored for the references starts at the location designated by the starting address in control register 10 and extends up to and including the location designated by the ending address in control register 11. The area extends to the right of the starting address.

An instruction-fetching event occurs

whenever the first byte of an instruction or the first byte of the target of an EXECUTE instruction is fetched from the designated area. A storage-alteration event occurs when a store access is made to the designated area by using an operand address that is defined to be a logical or a virtual address. A storage-alteration event does not occur for a store access made with an operand address defined to be a real address.

The set of addresses monitored for instruction-fetching and storage-alteration events wraps around at address 16,777,215; that is, address 0 is considered to follow address 16,777,215. When the starting address is less than the ending address, the area is contiguous. When the starting address is greater than the ending address, the set of locations monitored includes the area from the starting address to address 16,777,215 and the area from address 0 to, and including, the ending address. When the starting address is equal to the ending address, only the location designated by that address is monitored.

The monitoring of storage alteration and instruction fetching is performed by comparing all 24 bits of the monitored address with the starting and ending addresses.

PER EVENTS

Successful Branching

Execution of a successful branch operation causes a program-event interruption if bit 0 of the PER-event-mask field is one and the PER mask in the PSW is one.

A successful branch occurs whenever one of the following instructions causes control to be passed to the instruction designated by the branch address:

BRANCH AND LINK
 BRANCH AND SAVE
 BRANCH ON CONDITION
 BRANCH ON COUNT
 BRANCH ON INDEX HIGH
 BRANCH ON INDEX LOW OR EQUAL
 PROGRAM CALL
 PROGRAM TRANSFER

The branch event is also indicated by an emulation instruction when the emulation instruction itself causes a branch. That is, the branch event is indicated when the location of the next instruction executed

by the CPU after leaving emulation mode does not immediately follow the location of the emulation instruction.

The event is indicated by setting bit 0 of the PER code to one.

Instruction Fetching

Fetching the first byte of an instruction from the storage area designated by the contents of control registers 10 and 11 causes a program-event interruption if bit 1 of the PER-event-mask field is one and the PER mask in the PSW is one.

A PER event for instruction fetching is recognized whenever the CPU executes an instruction whose initial byte is located within the monitored area. When the instruction is executed by means of EXECUTE, a PER event is recognized when the first byte of the EXECUTE instruction or the target instruction or both is located in the monitored area.

The event is indicated by setting bit 1 of the PER code to one.

Storage Alteration

Storing of data by the CPU in the storage area designated by the contents of control registers 10 and 11 causes a program-event interruption if bit 2 of the PER-event-mask field is one and the PER mask in the PSW is one.

The contents of storage are considered to have been altered whenever the CPU executes an instruction that causes all or part of an operand to be stored within the monitored area of storage. Alteration is considered to take place whenever storing is considered to take place for purposes of indicating protection exceptions. (See the section "Recognition of Access Exceptions" in Chapter 6, "Interruptions.") Storing constitutes alteration for PER purposes even if the value stored is the same as the original value.

Implied locations that are referred to by the CPU in the process of (1) interval-timer updating, (2) interruptions, and (3) execution of I/O instructions are not monitored. Such locations include the interval-timer, PSW, and CSW locations. These locations, however, are monitored when information is stored there explicitly by an instruction. Similarly, monitoring does not apply to storing of data by a channel.

Storage alteration does not apply to instructions whose operands are specified to be real addresses. Thus, storage alteration does not apply to SET STORAGE KEY, RESET REFERENCE BIT, TEST BLOCK, and INVALIDATE PAGE TABLE ENTRY. When INVALIDATE PAGE TABLE ENTRY is installed, the operand address of READ DIRECT is a real address and storage alteration does not apply. When INVALIDATE PAGE TABLE ENTRY is not installed, the operand address of READ DIRECT is a logical address, and storage alteration does apply.

The instructions COMPARE AND SWAP and COMPARE DOUBLE AND SWAP are considered to alter the second-operand location only when storing actually occurs.

The instruction STORE CHARACTERS UNDER MASK is not considered to alter the storage location when the mask is zero.

The event is indicated by setting bit 2 of the PER code to one.

General-Register Alteration

Alteration of the contents of a general register causes a PER interruption if bit 3 of the PER-event-mask field is one, the alteration mask corresponding to that general register is one, and the PER mask in the PSW is one.

The contents of a general register are considered to have been altered whenever a new value is placed in the register. Recognition of the event is not contingent on the new value being different from the previous one. The execution of an RR-format arithmetic or movement instruction is considered to fetch the contents of the register, perform the indicated operation, if any, and then replace the value in the register. The register can be designated implicitly, such as in TRANSLATE AND TEST and EDIT AND MARK, or explicitly by an RR, RX, or RS instruction, including BRANCH AND LINK, BRANCH ON COUNT, BRANCH ON INDEX HIGH, and BRANCH ON INDEX LOW OR EQUAL.

The instructions EDIT AND MARK and TRANSLATE AND TEST are considered to have altered the contents of general register 1 only when these instructions have caused information to be placed in the register.

The instructions MOVE LONG and COMPARE LOGICAL LONG are always considered to alter the contents of the four registers specifying the two operands, including the cases where the padding byte is used, when both operands have zero length, or when condition code 3 is set for MOVE LONG.

The instruction INSERT CHARACTERS UNDER MASK is not considered to alter the general register when the mask is zero.

The instructions COMPARE AND SWAP and COMPARE DOUBLE AND SWAP are considered to alter the general register, or general-register pair, designated by R_1 , only when the contents are actually replaced, that is, when the first and second operands are not equal.

The event is indicated by setting bit 3 of the PER code to one.

Programming Note

The following are some examples of general-register alteration:

1. Register-to-register load instructions are considered to alter the register contents even when both operand addresses designate the same register.
2. Addition or subtraction of zero and multiplication or division by one are considered to constitute alteration.
3. Logical and fixed-point shift operations are considered to alter the register contents even for shift amounts of zero.
4. The branching instructions BRANCH ON INDEX HIGH and BRANCH ON INDEX LOW OR EQUAL are considered to alter the first operand even when zero is added to its value.

INDICATION OF EVENTS CONCURRENTLY WITH OTHER INTERRUPTION CONDITIONS

The following rules govern the indication of PER events caused by an instruction that also causes a program exception, a monitor event, or a supervisor-call interruption.

1. The indication of an instruction-fetching event does not depend on whether the execution of the instruction was completed, terminated, suppressed, or nullified. The event, however, is not indicated when an access exception prohibits access to the first byte of the instruction. When the first halfword of the instruction is accessible but an access exception applies to the second or third halfword of the instruction, it is unpredictable whether the instruction-fetching event is indicated.
2. When the operation is completed, the event is indicated regardless of whether any program exception or the monitoring event is recognized.
3. Successful branching, storage alteration, and general-register alteration are not indicated for an operation or, in case the instruction is interruptible, for a unit of operation that is suppressed or nullified.
4. When the execution of the instruction is terminated, general-register or storage alteration is indicated whenever the event has occurred, and a model may indicate the event if the event would have occurred had the execution of the instruction been completed, even if altering the contents of the result field is contingent on operand values.
5. When LOAD PSW or SUPERVISOR CALL causes a PER condition and at the same time introduces a new PSW with the type of PSW-format error that is recognized immediately after the PSW becomes active, the interruption code identifies both the PER condition and the specification exception. When these instructions introduce a PSW-format error of the type that is recognized as part of the execution of the following instruction, the PSW is stored as the old PSW without the specification exception being recognized.

The indication of PER events concurrently with other program-interruption conditions is summarized in the figure "Indication of PER Events."

| Exception | Type of Ending | PER Event | | | |
|-----------------------------------|----------------|-----------|----------------|--------------------|----------------|
| | | Branch | Instr Fetch | Storage Alteration | GR Alteration |
| Operation | S | - | X ¹ | - | - |
| Privileged operation | S | - | X ¹ | - | - |
| Execute | S | - | X ¹ | - | - |
| Protection | | | | | |
| Instruction | S | - | - ¹ | - | - |
| Operand | S or T | - | X | X+ | X+ |
| Addressing | | | | | |
| DAT entry for instruction address | S | - | - ¹ | - | - |
| Instruction | S | - | - ¹ | - | - |
| DAT entry for operand address | S | - | X | X ² | X ² |
| Operand | S or T | - | X | X+ | X+ |
| Specification | | | | | |
| Odd instruction address | S | - | - | - | - |
| Invalid PSW format | C | - | X | - | - |
| Other | S | - | X | - | - |
| Data | | | | | |
| Invalid sign | S | - | X | - | - |
| Other | T | - | X | X+ | X+ |
| Fixed-point overflow | C | - | X | - | X |
| Fixed-point divide | | | | | |
| Division | S | - | X | - | - |
| Conversion | C | - | X | - | X |
| Decimal overflow | C | - | X | X | - |
| Decimal divide | S | - | X | - | - |
| Exponent overflow | C | - | X | - | - |
| Exponent underflow | C | - | X | - | - |
| Significance | C | - | X | - | - |
| Floating-point divide | S | - | X | - | - |
| Segment translation | | | | | |
| Instruction-address translation | N | - | - ¹ | - | - |
| Page translation | | | | | |
| Instruction-address translation | N | - | - ¹ | - | - |
| Operand-address translation | N | - | X | X ² | X ² |
| Translation specification | | | | | |
| Instruction-address translation | S | - | - ¹ | - | - |
| Operand-address translation | S | - | X | X ² | X ² |
| Special operation | S | - | X | - | - |
| Monitor event | C | - | X | - | - |

Indication of PER Events (Part 1 of 2)

Explanation:

- C The operation or, in the case of the interruptible instructions, the unit of operation is completed.
- N The operation or, in the case of the interruptible instructions, the unit of operation is nullified. The instruction address in the old PSW has not been updated.
- S The operation or, in the case of the interruptible instructions, the unit of operation is suppressed.
- T The execution of the instruction is terminated.
- X The event is indicated with the exception if the event has occurred; that is, the contents of the monitored storage location or general register were altered, or an attempt was made to execute an instruction whose first byte is located in the monitored area.
- + A model is permitted, but not required, to indicate the event if the event would have occurred had the operation been completed but did not take place because the execution of the instruction was terminated.
- The event is not indicated.
- ¹ When an access exception applies to the second or third halfword of the instruction but the first halfword is accessible, it is unpredictable whether the instruction-fetching event is indicated.
- ² This condition may occur in the case of the interruptible instructions when the event is recognized in the unit of operation that is completed and when the exception causes the next unit of operation to be suppressed or nullified.

Indication of PER Events (Part 2 of 2)

Programming Notes

1. The execution of the interruptible instructions MOVE LONG (MVCL) and COMPARE LOGICAL LONG (CLCL) can cause events for general-register alteration and instruction fetching. Additionally, MVCL can cause the storage-alteration event.

Since the execution of MVCL and CLCL can be interrupted, a program event may be indicated more than once. It may be necessary, therefore, for a program to remove the redundant event indications from the PER data. The following rules govern the indication of the applicable events during execution of these two instructions:

- a. The instruction-fetching event is indicated whenever the instruction is fetched for execution, regardless of whether it is the

initial execution or a resumption.

- b. The general-register-alteration event is indicated on the initial execution and on each resumption and does not depend on whether or not the register actually is changed.
- c. The storage-alteration event is indicated only when data has been stored in the monitored area by the portion of the operation starting with the last initiation and ending with the last byte transferred before the interruption. No special indication is provided on premature interruptions as to whether the event will occur again upon the resumption of the operation. When the storage area designates a single byte location, a storage-alteration event can be recognized only once in the

execution of MOVE LONG.

2. The following is an outline of the general action a program must take to delete the redundant entries in the PER data for MOVE LONG and COMPARE LOGICAL LONG so that only one entry for each complete execution of the instruction is obtained:
 - a. Check to see if the PER address is equal to the instruction address in the old PSW and if the last instruction executed was MVCL or CLCL.
 - b. If both conditions are met, delete instruction-fetching and register-alteration events.
 - c. If both conditions are met and the event is storage alteration, delete the event if some part of the remaining destination operand is within the monitored area.

DIRECT CONTROL

The direct-control feature provides (1) a read-write-direct facility, consisting of the two instructions READ DIRECT and WRITE DIRECT and an associated 27-line interface, and (2) an external-signal facility with six signal-in lines. These facilities operate independent of the facilities that perform I/O operations.

READ-WRITE-DIRECT FACILITY

The READ DIRECT and WRITE DIRECT instructions use the 27-line interface to provide timing signals and to transfer a single byte of information, normally for controlling and synchronizing purposes, between CPUs or between a CPU and an external device. The 27 lines are:

| <u>Name</u> | <u>Number of Lines</u> | <u>Direction</u> |
|-------------|----------------------------|------------------|
| Write out | 1 | Output |
| Read out | 1 | Output |
| Hold | 1 | Input |
| Signal out | 8 | Output |
| Direct out | 8 | Output |
| Direct in | 8 | Input |

EXTERNAL-SIGNAL FACILITY

The external-signal facility consists of six signal-in lines and an external-signal mask, which is bit 26 of control register 0. Each of the six signal-in lines, when pulsed, sets up the condition for one of six distinct interruptions (see the section "External Signal" in Chapter 6, "Interruptions").

Note: Some models provide the external-signal facility as a separate feature (without the READ DIRECT and WRITE DIRECT instructions).

For a detailed description, see the System/360 and System/370 Direct Control and External Interruption Features--Original Equipment Manufacturers' Information, GA22-6845.

TIMING

The timing facilities include four facilities for measuring time: the TOD clock, the clock comparator, the CPU timer, and the interval timer.

In a multiprocessing system, a single TOD clock may be shared by more than one CPU, or each CPU may have a separate TOD clock. However, each CPU has a separate clock comparator, CPU timer, and interval timer.

TIME-OF-DAY CLOCK

The time-of-day (TOD) clock provides a high-resolution measure of real time suitable for the indication of date and time of day. The cycle of the clock is approximately 143 years.

In a configuration with more than one CPU, each CPU may have a separate TOD clock, or more than one CPU may share a clock, depending on the model. In all cases, each CPU has access to a single clock.

Format

The TOD clock is a binary counter with the format shown in the following illustration. The bit positions of the clock are numbered 0 to 63, corresponding to the bit positions of a 64-bit unsigned binary integer.

Not-Operational State: The clock is in the not-operational state when its power is off or when it is disabled for maintenance. It depends on the model if the clock can be placed in this state. Whenever the clock enters the not-operational state, a timing-facility-damage machine check is generated on each CPU that has access to that clock.

When the clock is in the not-operational state, execution of STORE CLOCK causes condition code 3 to be set, and zero is stored.

Changes in Clock State

When the TOD clock accessed by a CPU changes value or changes state, interruption conditions pending for the TOD-clock sync check, clock comparator, and CPU timer may or may not be recognized for a period of time up to 1.048576 seconds (2^{20} microseconds) after the change.

Setting and Inspecting the Clock

The clock can be set to a specific value by execution of SET CLOCK if the manual TOD-clock control of any configured CPU is set to the enable-set position. Setting the clock replaces the values in all bit positions from bit position 0 through the rightmost position that is incremented when the clock is running. However, on some models, the low-order bits starting at or to the right of bit 52 of the specified value are ignored, and zeros are placed in the corresponding positions of the clock.

The TOD clock can be inspected by executing STORE CLOCK, which causes a 64-bit value to be stored. Two executions of STORE CLOCK, possibly on different CPUs in the same configuration, always store different values if the clock is running, or, if separate clocks are accessed, both clocks are running and are synchronized.

The values stored for a running clock always correctly imply the sequence of execution of STORE CLOCK on one or more CPUs for all cases where the sequence can be established by means of the program. Zeros are stored in positions to the right of the bit position that is incremented. In a configuration with more than one CPU, however, when the value of a running clock is stored, nonzero values may be stored in positions to the right of the rightmost position that is incremented. This ensures that a unique value is stored.

In a system where more than one CPU accesses the same clock, SET CLOCK is interlocked such that the entire contents appear to be updated at once; that is, if SET CLOCK instructions are issued simultaneously by two CPUs, the final result is either one or the other value. If SET CLOCK is issued on one CPU and STORE CLOCK on the other, the result obtained by STORE CLOCK is either the entire old value or the entire new value. When SET CLOCK is issued by one CPU, a STORE CLOCK issued on another CPU may find the clock in the stopped state even when the TOD-clock-sync-control bit is zero. The TOD-clock-sync-control bit is bit 2 of control register 0. Since the clock enters the set state before incrementing, the first STORE CLOCK issued after the clock enters the set state may still find the original value introduced by SET CLOCK.

Programming Notes

1. Bit position 31 of the clock is incremented every 1.048576 seconds; for some applications, reference to the leftmost 32 bits of the clock may provide sufficient resolution.
2. Communication between systems is facilitated by establishing a standard time origin, or standard epoch, which is the calendar date and time to which a clock value of zero corresponds. January 1, 1900, 0 AM Greenwich Mean Time (GMT) is recommended as the standard epoch for the clock.
3. A program using the clock value as a time-of-day and calendar indication must be consistent with the programming support under which the program is to run. If the programming support uses the standard epoch, bit 0 of the clock remains one through the years 1972-2041. Ordinarily, testing the high-order bit for a one is sufficient to determine if the clock value is in the standard epoch.

In converting to or from the current date or time, the programming support assumes each day to be 86,400 seconds. It does not take into account "leap seconds" inserted or deleted because of time-correction standards.
4. Because of the limited accuracy of manually setting the clock value, the rightmost bit positions of the clock, expressing fractions of a second, are normally not valid as indications of the time of day. However, they permit elapsed-time measurements of high resolution.

5. The following chart shows the time interval between instants at which various bit positions of the TOD clock are stepped. This time value may also be considered as the weighted time value that the bit, when one, represents.

| TOD-Clock Bit | Stepping Interval | | | |
|---------------|-------------------|-------|---------|------------|
| | Days | Hours | Minutes | Seconds |
| 51 | | | | 0.000 001 |
| 47 | | | | 0.000 016 |
| 43 | | | | 0.000 256 |
| 39 | | | | 0.004 096 |
| 35 | | | | 0.065 536 |
| 31 | | | | 1.048 576 |
| 27 | | | | 16.777 216 |
| 23 | | | 4 | 28.435 456 |
| 19 | | 1 | 11 | 34.967 296 |
| 15 | | 19 | 5 | 19.476 736 |
| 11 | | 12 | 17 | 11.627 776 |
| 7 | | 203 | 14 | 6.044 416 |
| 3 | | 3257 | 19 | 36.710 656 |

6. The following chart shows the clock setting at the start of various years. The clock settings, expressed in hexadecimal notation, correspond to 0 AM Greenwich Mean Time on January 1 of each year.

| Year | 0000 | 0000 | 0000 | 0000 |
|------|------|------|------|------|
| 1900 | 0000 | 0000 | 0000 | 0000 |
| 1976 | 8853 | BAF0 | B400 | 0000 |
| 1980 | 8F80 | 9FD3 | 2200 | 0000 |
| 1984 | 96AD | 84B5 | 9000 | 0000 |
| 1988 | 9DDA | 6997 | FE00 | 0000 |
| 1992 | A507 | 4E7A | 6C00 | 0000 |
| 1996 | AC34 | 335C | DA00 | 0000 |
| 2000 | B361 | 183F | 4800 | 0000 |

7. The stepping value of TOD-clock bit position 63, if implemented, is 2^{-12} microseconds, or approximately 244 picoseconds. This value is called a clock unit.

The following chart shows various time intervals in clock units expressed in hexadecimal notation.

| Interval | Clock Units (Hex) |
|-------------------------|--------------------|
| 1 microsecond | 1000 |
| 1 millisecond | 3E 8000 |
| 1 second | F424 0000 |
| 1 minute | 39 3870 0000 |
| 1 hour | D69 3A40 0000 |
| 1 day | 1 41DD 7600 0000 |
| 365 days | 1CA E8C1 3E00 0000 |
| 366 days | 1CC 2A9E B400 0000 |
| 1,461 days ¹ | 72C E4E2 6E00 0000 |

¹ Number of days in four years, including a leap year.

8. On a multiprocessing system, after the TOD clock is set and begins running, the program should delay activity for 2^{20} microseconds (1.048576 seconds) to ensure that the CPU-timer, clock-comparator, and TOD-clock-sync-check interruption conditions are recognized by the CPU.

TOD-CLOCK SYNCHRONIZATION

In a configuration with more than one CPU, each CPU may have a separate TOD clock, or more than one CPU may share a TOD clock, depending on the model. In all cases, each CPU has access to a single clock.

The TOD-clock-synchronization facility provides the functions that make it possible to provide, in conjunction with a supervisor clock-synchronization program, only one TOD clock, in effect, in a multiprocessing system. The result is such that, to all programs storing the clock value, it appears that all CPUs read the same clock. The TOD-clock-synchronization facility provides these functions in such a way that even though the number of clocks in a multiprocessing system is model-dependent, a single model-independent clock-synchronization routine can be written. The following functions are provided:

- Synchronizing the stepping rates for all TOD clocks in the configuration. Thus, if all clocks are set to the same value, they stay in synchronism.
- Comparing the rightmost 32 bits of each clock in the configuration. An unequal condition is signaled by an external interruption indicating the TOD-clock-sync-check condition.
- Setting a TOD clock in the stopped state.
- Causing a stopped clock to start

incrementing in response to a signal from a running clock.

- Causing a stopped clock, with the TOD-clock-sync-control bit set to one, to start incrementing when bits 32-63 of any running clock in the configuration are incremented to zero. This permits the program to synchronize all clocks to any particular clock without requiring special operator action to select a "master clock" as the source of the clock-synchronization pulses.

Programming Notes

1. TOD-clock synchronization provides for checking and synchronizing only the rightmost bits of the TOD clock. The program must check for synchronization of the leftmost bits and must communicate the leftmost-bit values from one CPU to another in order to correctly set the TOD-clock contents.
2. The TOD-clock-sync-check external interruption can be used to determine the number of TOD clocks in the configuration.

CLOCK COMPARATOR

The clock comparator provides a means of causing an interruption when the TOD-clock value exceeds a value specified by the program.

In a multiprocessing system, each CPU has a separate clock comparator.

The clock comparator has the same format as the TOD clock. In the basic form, the clock comparator consists of bits 0-47, which are compared with the corresponding bits of the TOD clock. In some models, higher resolution is obtained by providing more than 48 bits. The bits in positions provided in the clock comparator are compared with the corresponding bits of the clock. When the resolution of the clock is less than that of the clock comparator, the contents of the clock comparator are compared with the clock value as this value would be stored by executing STORE CLOCK.

The clock comparator causes an external interruption with the interruption code 1004 (hex). A request for a clock-comparator interruption exists whenever either of the following conditions exists:

1. The TOD clock is running and the value of the clock comparator is less than the value in the compared portion of the clock, both values being considered unsigned binary integers. Comparison follows the rules of unsigned binary arithmetic.
2. The TOD clock is in the error state or the not-operational state.

A request for a clock-comparator interruption does not remain pending when the value of the clock comparator is made equal to or greater than that of the TOD clock or when the value of the TOD clock is made less than the clock-comparator value. The latter may occur as a result of the TOD clock either being set or wrapping to zero.

The clock comparator can be inspected by executing the instruction STORE CLOCK COMPARATOR and can be set to a specific value by executing the SET CLOCK COMPARATOR instruction.

The contents of the clock comparator are initialized to zero by initial CPU reset.

Programming Notes

1. An interruption request for the clock comparator persists as long as the clock-comparator value is less than that of the TOD clock or as long as the TOD clock is in the error or not-operational state. Therefore, one of the following actions must be taken after an external interruption for the clock comparator has occurred and before the CPU is again enabled for external interruptions: the value of the clock comparator has to be replaced, the TOD clock has to be set, or the clock-comparator-subclass mask has to be set to zero. Otherwise, loops of external interruptions are formed.
2. The instruction STORE CLOCK may store a value which is greater than that in the clock comparator, even though the CPU is enabled for the clock-comparator interruption. This is because the TOD clock may be incremented one or more times between when instruction execution is begun and when the clock value is accessed. In this situation, the interruption occurs when the execution of STORE CLOCK is completed.

CPU TIMER

The CPU timer provides a means for measuring elapsed CPU time and for causing an interruption when a prespecified amount of time has elapsed.

In a multiprocessing system, each CPU has a separate CPU timer.

The CPU timer is a binary counter with a format which is the same as that of the TOD clock, except that bit 0 is considered a sign. In the basic form, the CPU timer is decremented by subtracting a one in bit position 51 every microsecond. In models having a higher or lower resolution, a different bit position is decremented at such a frequency that the rate of decrementing the CPU timer is the same as if a one were subtracted in bit position 51 every microsecond. The resolution of the CPU timer is such that the stepping rate is comparable to the instruction-execution rate of the model.

The CPU timer requests an external interruption with the interruption code 1005 (hex) whenever the CPU-timer value is negative (bit 0 of the CPU timer is one). The request does not remain pending when the CPU-timer value is changed to a nonnegative value.

When both the CPU timer and the TOD clock are running, the stepping rates are synchronized such that both are stepped at the same rate. Normally, decrementing the CPU timer is not affected by concurrent I/O activity. However, in some models the CPU timer may stop during extreme I/O activity and other similar interference situations. In these cases, the time recorded by the CPU timer provides a more accurate measure of the CPU time used by the program than would have been recorded had the CPU timer continued to step.

The CPU timer is decremented when the CPU is in the operating state or the load state. When the manual rate control is set to instruction step, the CPU timer is decremented only during the time in which the CPU is actually performing a unit of operation. However, depending on the model, the CPU timer may or may not be decremented when the TOD clock is in the error, stopped, or not-operational state.

Depending on the model, the CPU timer may or may not be decremented when the CPU is in the check-stop state.

The CPU timer can be inspected by executing the instruction STORE CPU TIMER and can be set to a specific value by executing the SET CPU TIMER instruction.

The CPU timer is set to zero by initial CPU reset.

Programming Notes

1. The CPU timer in association with a program may be used both to measure CPU-execution time and to signal the end of a time interval on the CPU.
2. The time measured for the execution of a sequence of instructions may depend on the effects of such things as I/O interference, page faults, and instruction retry. Hence, repeated measurements of the same sequence on the same installation may differ.
3. The fact that a CPU-timer interruption does not remain pending when the CPU timer is set to a positive value eliminates the problem of an undesired interruption. This would occur if, between the time when the old value is stored and a new value is set, the CPU is disabled for CPU-timer interruptions and the CPU timer value goes from positive to negative.
4. The fact that CPU-timer interruptions are requested whenever the CPU timer is negative (rather than just when the CPU timer goes from positive to negative) eliminates the requirement for testing a value to ensure that it is positive before setting the CPU timer to that value.

As an example, a program being timed by the CPU timer is interrupted for a cause other than the CPU timer, external interruptions are disallowed by the new PSW, and the CPU-timer value is then saved by STORE CPU TIMER. This value could be negative if the CPU timer went from positive to negative since the interruption. Subsequently, when the program being timed is to continue, the CPU timer may be set to the saved value by SET CPU TIMER. A CPU-timer interruption occurs immediately after external interruptions are again enabled if the saved value was negative.

The persistence of the CPU-timer-interruption request means, however, that after an external interruption for the CPU timer has occurred, either the value of the CPU timer has to be replaced or the CPU-timer-subclass mask has to be set to zero before the CPU is again enabled for external interruptions. Otherwise, loops of external interruptions are formed.

available at location 76.

If any means other than the instruction MOVE (MVC) are used to interrogate and then replace the value of the interval timer, including MOVE LONG or two separate instructions, the program may lose a time increment when an updating cycle occurs between fetching and storing.

Location 84 is used as the trace-table-entry-header origin by DAS tracing. If the above means for updating the interval timer are used in a system which also uses the DAS tracing, then the program must restore the contents of the word at location 84 after updating the interval timer.

3. When the value of the interval timer is to be recorded on an I/O device, the program should first store the interval-timer value in a temporary storage location to which the I/O operation subsequently refers. When the channel fetches the interval-timer value directly from location 80, the value obtained is unpredictable.

EXTERNALLY INITIATED FUNCTIONS

SERVICE SIGNAL

The service-signal facility permits the service processor to communicate with the CPU. Communications to the service processor are model-dependent and are accomplished by means of the DIAGNOSE instruction. When the service processor has completed all or part of a function requested by means of the DIAGNOSE instruction, a service-signal external interruption is generated. The service-signal external interruption is a floating interruption condition and can be accepted by any CPU in the configuration. The service-signal request causes an external interruption with the interruption code 2401 (hex). A 32-bit parameter is also stored at location 128. The subclass mask for service signal is bit 22 of control register 0.

RESETS

Seven reset functions are provided:

- CPU reset
- Initial CPU reset

- Subsystem reset
- Program reset
- Initial program reset
- Clear reset
- Power-on reset

CPU reset provides a means of clearing equipment-check indications and any resultant unpredictability in the CPU state with the least amount of information destroyed. In particular, it is used to clear check conditions when the CPU state is to be preserved for analysis or resumption of the operation.

Initial CPU reset provides the functions of CPU reset together with initialization of the current PSW, CPU timer, clock comparator, prefix, and control registers.

Subsystem reset provides a means for clearing floating interruption conditions and for resetting channel-set connections as well as for invoking I/O-system reset.

Program reset and initial program reset cause CPU reset and initial CPU reset, respectively, to be performed and cause I/O-system reset to be performed (see the section "I/O-System Reset" in Chapter 12, "Input/Output Operations").

Clear reset causes initial CPU reset and subsystem reset to be performed and, additionally, clears or initializes all storage locations and registers in all CPUs in the configuration, with the exception of the TOD clock. Such clearing is useful in debugging programs and in ensuring user privacy. Clearing does not affect external storage, such as direct-access storage devices used by the control program to hold the contents of unaddressable pages.

The power-on-reset sequences for the TOD clock, main storage, and channels may be included as part of the CPU power-on sequence, or the power-on sequence for these units may be initiated separately.

CPU reset, subsystem reset, and clear reset are initiated manually by using the operator facilities (see Chapter 13, "Operator Facilities"). Initial CPU reset is part of the initial-program-loading function. The figure "Manual Initiation of Resets" summarizes how these four resets are manually initiated. Power-on reset is performed as part of turning power on. The reset actions are tabulated in the figure "Summary of Reset Actions." For information concerning what resets can be performed by the SIGNAL PROCESSOR instruction, see the section "Signal-Processor Orders" in this chapter.

| Key Activated | Function Performed on ¹ | | |
|---|--|--------------------------|----------------------------|
| | CPU on which Key was Activated | Other CPUs in Config | Remainder of Configuration |
| System-reset-normal key | | | |
| • without store-status facility | Initial CPU reset | * | Subsystem reset |
| • with store-status facility | CPU reset | CPU reset | Subsystem reset |
| System-reset-clear key | Clear reset ² | Clear reset ² | Clear reset ³ |
| Load-normal key | Initial-CPU reset, followed by IPL | CPU reset | Subsystem reset |
| Load-clear key | Clear reset ² , followed by IPL | Clear reset ² | Clear reset ³ |
| <u>Explanation:</u> | | | |
| * This situation cannot occur, since the store-status facility is provided in a CPU equipped for multiprocessing. | | | |
| ¹ Activation of a system-reset or load key may change the configuration, including the connection with I/O, storage units, and other CPUs. | | | |
| ² Only the CPU elements of this reset apply. | | | |
| ³ Only the non-CPU elements of this reset apply. | | | |

Manual Initiation of Resets

| Area Affected | Reset Function | | | | | | |
|----------------------------------|------------------|----------------|----------------|-------------------|-----------------------|-----------------|------------------|
| | Sub-system Reset | CPU Reset | Program Reset | Initial CPU Reset | Initial Program Reset | Clear Reset | Power-on Reset |
| CPU | U | S | S | S ¹ | S | S ¹ | S |
| PSW ² | U | U/V | U/V | C* ¹ | C* | C* ¹ | C* |
| Prefix | U | U/V | U/V | C | C | C | C |
| CPU timer | U | U/V | U/V | C | C | C | C |
| Clock comparator | U | U/V | U/V | C | C | C | C |
| Control registers | U | U/V | U/V | I | I | I | I |
| General registers | U | U/V | U/V | U/V | U/V | C/V | C/X |
| Floating-point registers | U | U/V | U/V | U/V | U/V | C/V | C/X |
| Storage keys | U | U | U | U | U | C | C/X ⁴ |
| Volatile main storage | U | U | U | U | U | C | C/X ⁴ |
| Nonvolatile main storage | U | U | U | U | U | C | U |
| TOD clock | U ³ | U ³ | U ³ | U ³ | U ³ | U ³ | T ⁴ |
| Channel-set connection | I | U | U | U | U | I | I ⁵ |
| Floating interruption conditions | C | U | U | U | U | C | C ⁴ |
| Configured channels | RA | U | RC | U | RC | RA | RA ⁴ |

Explanation:

- S The CPU is reset; current operations, if any, are terminated; interruption conditions in the CPU are cleared; and the CPU is placed in the stopped state.
- RA I/O-system reset is performed in all the channels in the configuration and pending I/O-interruption conditions are cleared. As part of this reset, system reset is signaled to the I/O control units and devices configured to the channels being reset.
- RC I/O-system reset is performed in those channels connected to the CPU performing the program reset or initial-program reset. As part of this reset, system reset is signaled to the I/O control units and devices configured to the channels being reset.
- U The state, condition, or contents of the field remain unchanged. However, the resulting value is unpredictable if an operation is in progress that changes the state, condition, or contents of the field at the time of reset.
- U/V The contents remain unchanged, provided the field is not being accessed at the time the reset function is performed. However, on some models the checking-block code of the contents may be made valid. The subsequent contents of a field are unpredictable if it is accessed at the time of the reset.
- C The condition or contents are cleared. If the area affected is a field, the contents are cleared to zero with valid checking-block code.
- C/V The checking-block code of the contents is made valid. The contents normally are cleared to zeros but in some models may be left unchanged.
- C/X The checking-block code of the contents is made valid. The contents normally are cleared to zeros but in some models may be left unpredictable.
- I The state or contents are initialized. If the area affected is a field, the contents are set to their initial values with valid checking-block code.
- T The TOD clock is initialized to zero and validated; it enters the not-set state.

Summary of Reset Actions (Part 1 of 2)

Explanation (Continued):

- * Clearing the contents of the PSW to zero causes the CPU to assume the BC-mode format.
- 1 When the IPL sequence follows the reset function on that CPU, the CPU does not enter the stopped state, and the PSW is not necessarily cleared to zeros.
- 2 For a BC-mode PSW, the ILC and interruption-code fields are unpredictable in the current PSW.
- 3 Access to the TOD clock by means of STORE CLOCK at the time a reset function is performed does not cause the value of the TOD clock to be affected.
- 4 When these units are separately powered, the action is performed only when the power for the unit is turned on.
- 5 When these units are separately powered, the action is model-dependent.

Summary of Reset Actions (Part 2 of 2)

CPU Reset

CPU reset causes the following actions:

1. The execution of the current instruction or other processing sequence, such as an interruption, is terminated, and all program-interruption and supervisor-call-interruption conditions are cleared.
2. Any pending external-interruption conditions which are local to the CPU are cleared. Floating external-interruption conditions are not cleared.
3. Any pending machine-check-interruption conditions and error indications which are local to the CPU and any check-stop states are cleared. Floating machine-check-interruption conditions are not cleared. A broadcast machine check which has been made pending to a CPU is said to be local to the CPU.
4. All copies of prefetched instructions or operands are cleared. Additionally, any results to be stored because of the execution of instructions in the current checkpoint interval are cleared.
5. The translation-lookaside buffer is cleared of entries.
6. The CPU is placed in the stopped state after actions 1-5 have been completed.

Registers, storage contents, and the state of conditions external to the CPU remain unchanged by CPU reset. However, the subsequent contents of the register,

location, or state are unpredictable if an operation is in progress that changes the contents at the time of the reset.

When the reset function in the CPU is initiated at the time the CPU is executing an I/O instruction or is in the process of taking an I/O interruption, the current operation between the CPU and the channel may or may not be completed, and the resultant state of the associated channel may be unpredictable.

Programming Note

Most operations which would change a state, a condition, or the contents of a field cannot occur when the CPU is in the stopped state. However, some signal-processor functions and some operator functions may change these fields. To eliminate the possibility of losing a field when CPU reset is issued, the CPU should be stopped, and no operator functions should be in progress.

Initial CPU Reset

Initial CPU reset combines the CPU reset functions with the following clearing and initializing functions:

1. The contents of the current PSW, prefix, CPU timer, and clock comparator are set to zero.
2. All assigned control-register positions are set to their initial values.

These clearing and initializing functions include validation.

Setting the current PSW to zero causes the PSW to assume the BC-mode format. The instruction-length code and interruption code are unpredictable, because these values are not retained when a new PSW is introduced.

Subsystem Reset

Subsystem reset operates only on those elements of the configuration which are not CPUs. It performs the following actions for the remainder of the configuration.

1. I/O-system reset is performed in each channel in the configuration.
2. All floating interruption conditions in the configuration are cleared.
3. Channel-set connections are initialized to connect each channel set to its home CPU if one exists, or to make the channel set disconnected if no home CPU exists.

As part of the I/O-system reset performed in each channel, pending I/O-interruption conditions are cleared, and system reset is signaled to all control units and devices configured to the channel (see the section "I/O-System Reset" in Chapter 12, "Input/Output Operations"). The effect of system reset on I/O control units and devices and the resultant control-unit and device state are described in the appropriate publication on the control unit or device. A system reset, in general, resets only those functions in a shared control unit or device that are associated with the particular channel signaling the reset.

Program Reset

For program reset, CPU reset is performed, and I/O-system reset is performed in each channel connected to this CPU.

As part of the I/O-system reset performed (see the section "I/O-System Reset" in Chapter 12, "Input/Output Operations"), pending I/O-interruption conditions are cleared, and system reset is signaled to all control units and devices configured to the channel. The effect of system reset on I/O control units and devices and the resultant control-unit and device state are described in the appropriate publication on the control unit or device. A system

reset, in general, resets only those functions in a shared control unit or device that are associated with the particular channel signaling the reset.

Initial Program Reset

Initial program reset combines the program-reset functions with the clearing and initializing functions of initial CPU reset.

Clear Reset

Clear reset combines the initial-CPU-reset function with an initializing function which causes the following actions:

1. In most models, the contents of the general and floating-point registers are set to zero, but in some models the contents may be left unchanged except that the checking-block code is made valid.
2. The contents of the main storage and the storage keys in the configuration are set to zero with valid checking-block code.
3. A subsystem reset is performed.

Validation is included in setting registers and in clearing storage.

Programming Notes

1. For the CPU-reset or program-reset operation not to affect the contents of fields that are to be left unchanged, the CPU must not be executing instructions and must be disabled for all interruptions at the time of the reset. Except for the operation of the TOD clock, interval timer, and CPU timer and for the possibility of taking a machine-check interruption, all CPU activity can be quiesced by placing the CPU in the wait state and by disabling it for I/O and external interruptions. To avoid the possibility of causing a reset at the time the timing facilities are being updated or a machine-check interruption occurs, the CPU must be in the stopped state.
2. CPU reset, initial CPU reset, program reset, initial program reset, and clear reset do not affect the value

and state of the TOD clock.

3. The conditions under which the CPU enters the check-stop state are model-dependent and include malfunctions that preclude the completion of the current operation. Hence, if CPU reset, initial CPU reset, program reset, or initial program reset is executed while the CPU is in the check-stop state, the contents of the PSW, registers, and storage locations, including the storage keys and the storage location accessed at the time of the error, may have unpredictable values, and, in some cases, the contents may still be in error after the check-stop state is cleared by these resets. In such a case, a clear reset is required to clear the error.
4. Clear reset causes all bit positions of the interval timer to be cleared to zeros.

Power-On Reset

The power-on-reset function for a component of the system is performed as part of the power-on sequence for that component.

The power-on sequences for the TOD clock, main storage, and channels may be included as part of the CPU power-on sequence, or the power-on sequence for these units may be initiated separately. The following sections describe the power-on resets for the CPU, TOD clock, main storage, and I/O. See also Chapter 12, "I/O Operations," and the appropriate System Library (SL) publication for channels, control units, and I/O devices.

CPU Power-On Reset: The power-on reset causes initial CPU reset to be performed and may or may not cause I/O-system reset to be performed in the channel. The contents of general registers and floating-point registers normally are cleared to zeros, but in some models may be left unpredictable, with valid checking-block code.

TOD-Clock Power-On Reset: The power-on reset causes the value of the TOD clock to be set to zero and causes the clock to enter the not-set state.

Main-Storage Power-On Reset: For volatile main storage (one that does not preserve its contents when power is down) and for storage keys, power-on reset causes valid checking-block code to be placed in these fields. In most models, the contents are cleared to zeros, but, in some models, the

contents may be left unpredictable except for the checking-block code. The contents of nonvolatile main storage, including the checking-block code, remain unchanged.

I/O Power-On Reset: The I/O power-on reset causes I/O-system reset to be performed (see the section "I/O-System Reset" in Chapter 12, "Input/Output Operations").

INITIAL PROGRAM LOADING

Initial program loading (IPL) is provided to initiate processing when the contents of storage or of the PSW are not suitable for processing.

Initial program loading is initiated manually by designating an input device with the load-unit-address controls and subsequently activating the load-normal or load-clear key. The load-normal key causes an initial-program-reset operation to be performed, and the load-clear key causes a clear-reset operation to be performed. The CPU enters the load state. Subsequently, a read operation is initiated from the selected input device. The CPU does not necessarily enter the stopped state during the execution of the reset operation. The load indicator is on while the CPU is in the load state.

The read operation is performed as if a START I/O instruction were executed that specified the channel, subchannel, and I/O device designated by the load-unit-address controls. The operation uses an implied channel-address word (CAW) containing a subchannel key of zero, and a channel-command-word (CCW) address of 0, but the CAW location in storage, location 72, is not accessed. The load-unit-address controls provide the 12 rightmost bits of the I/O address; zeros are implied for the leftmost bits.

Although the location of the first CCW to be executed is specified by the CCW address as 0, the first CCW actually executed is an implied CCW, containing, in effect, a read command with the modifier bits set to zeros, a data address of 0, a byte count of 24, the chain-command flag set to one, the SLI flag set to one, the chain-data flag set to zero, the skip flag set to zero, and the PCI flag set to zero. The CCW fetched, as a result of command chaining, from storage location 8 or 16, as well as any subsequent CCW in the IPL sequence, is interpreted the same as a CCW in any I/O operation, except that any PCI flags that are specified in CCWs used for the IPL sequence are ignored.

When the I/O device provides channel-end

status for the last operation of the IPL chain and no exceptional conditions are detected in the operation, a new PSW is obtained from storage locations 0-7. When this PSW specifies the EC mode, the I/O address that was used for the IPL operation is stored at locations 186-187, and zeros are stored at location 185; when the BC mode is specified, the I/O address is stored at locations 2-3. The CPU leaves the load state and enters the operating state, with CPU operation proceeding under the control of the new PSW, provided the rate control is set to process; if the rate control is set to instruction step, the CPU enters the stopped state after the new PSW has been obtained.

When channel-end status for the IPL operation is presented, either separate from or along with device-end status, no I/O-interruption condition is generated. Similarly, any PCI flags specified by the program in the CCWs used for the IPL sequence are ignored. If the device-end status for the IPL operation is provided separately after channel-end status, it causes an I/O interruption condition to be generated.

If the IPL I/O operation or the PSW loading is not completed satisfactorily, the CPU remains in the load state, and the load indicator remains on. This occurs when the device designated by the load-unit-address controls is not operational, when the device or channel signals any condition other than channel end, device end, or status modifier during or at the completion of the IPL I/O operation, or when the PSW loaded from location 0 has a PSW-format error that is recognized during the loading procedure. The address of the I/O device used in the IPL operation is not stored. The contents of storage locations 0-7 are unpredictable. The contents of other storage locations remain unchanged, except possibly for those locations due to be changed by the read operations.

When fewer than eight bytes are read into locations 0-7, the PSW fetched from location 0 at the conclusion of the IPL operation is unpredictable.

Programming Notes

1. The information read and placed at locations 8-15 and 16-23 may be used as CCWs for reading additional information during the IPL sequence: the CCW at location 8 may specify reading additional CCWs elsewhere in storage, and the CCW at location 16 may specify the transfer-in-channel command, causing transfer to these

CCWs.

The status-modifier bit has its normal effect during the IPL operation, causing the channel to fetch and chain to the CCW whose address is 16 higher than that of the current CCW. This applies also to the initial chaining that occurs after completion of the read operation specified by the implicit CCW.

The PSW that is loaded at the completion of the IPL procedure may be provided by the first eight bytes of the IPL I/O operation or may be placed at locations 0-7 by a subsequent CCW.

2. When the PSW in location 0 has bit 14 set to one, the CPU is placed in the wait state after the IPL procedure is completed; at that point, the load and manual indicators are off, and the wait indicator is on.
3. Activating the load-normal key permits an IPL program to be loaded with a minimum disturbance of storage contents. This function may be useful in debugging. When the power is turned on or the load-clear key is activated, the IPL program starts with a cleared machine in a known state, except that information on external storage remains unchanged.

STORE STATUS

The store-status facility includes:

1. A change to the operation of the system-reset-normal key. With the store-status facility installed, activating the system-reset-normal key causes a CPU-reset operation and a subsystem-reset operation to be performed; without this facility, an initial-CPU-reset operation and subsystem-reset operation are performed.
2. An operator-initiated store-status function.

The store-status operation places the contents of the CPU registers, except for the TOD clock, in assigned storage locations. The information provided for unassigned control-register positions is unpredictable.

The figure "Assigned Storage Locations for Store Status" lists the fields that are stored, their length, and their location in main storage.

| Field | Length in Bytes | Absolute Address |
|------------------------|-----------------|------------------|
| CPU timer | 8 | 216 |
| Clock comparator | 8 | 224 |
| Current PSW | 8 | 256 |
| Prefix | 4 | 264 |
| Model-dependent feat. | 4 | 268 |
| Fl-pt registers 0-6 | 32 | 352 |
| General registers 0-15 | 64 | 384 |
| Control registers 0-15 | 64 | 448 |

Assigned Storage Locations for Store Status

The word beginning at absolute location 268 is reserved for storing additional status as required by certain model-dependent features. If no feature requiring this location is installed, the contents of the field remain unchanged upon execution of the store-status function.

The contents of the registers are not changed. If an error is encountered during the operation, the CPU enters the check-stop state.

The store-status operation can be initiated manually by use of the store-status key (see Chapter 13, "Operator Facilities"). The store-status operation can also be initiated at the addressed CPU by executing SIGNAL PROCESSOR, specifying the stop-and-store-status order.

MULTIPROCESSING

The multiprocessing feature provides for the interconnection of CPUs, via a common main storage, in order to enhance system availability and to share data and resources. The multiprocessing feature includes the following facilities:

- Shared main storage
- TOD-clock synchronization
- Prefixing
- CPU-address identification
- CPU signaling and response

TOD-clock synchronization is described earlier in this chapter. Prefixing is described in Chapter 3, "Storage." Shared main storage, CPU-address identification, and CPU signaling and response are described in the sections which follow.

Associated with these facilities are four extensions to the external interruption

(external call, emergency signal, TOD-clock-sync check, and malfunction alert), which are described in Chapter 6, "Interruptions"; control-register positions for the TOD-clock-sync-control bit and for the masks for the external-interruption conditions, which are listed in the section "Control Registers" in this chapter; and the instructions SET PREFIX, SIGNAL PROCESSOR, STORE CPU ADDRESS, and STORE PREFIX, which are described in Chapter 10, "Control Instructions."

Channels in a multiprocessing system are connected to a particular CPU. Only that CPU which is connected to a channel can initiate I/O operations at that channel, and all interruption conditions are directed to that CPU. When channel-set switching is installed, the channel-CPU connection can be changed by means of the program.

SHARED MAIN STORAGE

The shared-main-storage facility permits more than one CPU to have access to common main-storage locations. All CPUs having access to a common main-storage location have access to the entire 2,048-byte block containing that location and to the associated storage key. All CPUs and all channels refer to a shared main-storage location using the same absolute address.

CPU-ADDRESS IDENTIFICATION

Each CPU in a multiprocessing configuration has a number assigned, called its CPU address. A CPU address uniquely identifies one CPU within a configuration. The CPU is designated by specifying this address in the CPU-address field of a SIGNAL PROCESSOR instruction. The CPU signaling a malfunction alert, emergency signal, or external call is identified by storing this address in the CPU-address field with the interruption. The CPU address is assigned during system installation and is not changed as a result of configuration changes. The program can determine the address of the CPU by means of the instruction STORE CPU ADDRESS.

CPU SIGNALING AND RESPONSE

The CPU-signaling-and-response facility consists of the instruction SIGNAL PROCESSOR and a mechanism to interpret and act on several order codes. The facility

provides for communications among CPUs, including transmitting, receiving, and decoding a set of assigned order codes; initiating the specified operation; and responding to the signaling CPU. If a CPU has the CPU-signaling-and-response facility installed, it can address the SIGNAL PROCESSOR instruction to itself. The SIGNAL PROCESSOR instruction is described in Chapter 10, "Control Instructions."

SIGNAL-PROCESSOR ORDERS

The signal-processor orders are specified in bit positions 24-31 of the second-operand address of SIGNAL PROCESSOR and are encoded as shown in the figure "Encoding of Orders."

| Code | Order |
|-------|---------------------------|
| 00 | Unassigned |
| 01 | Sense |
| 02 | External call |
| 03 | Emergency signal |
| 04 | Start |
| 05 | Stop |
| 06 | Restart |
| 07 | Initial program reset |
| 08 | Program reset |
| 09 | Stop and store status |
| 0A | Initial microprogram load |
| 0B | Initial CPU reset |
| 0C | CPU reset |
| 0D-FF | Unassigned |

Encoding of Orders

The orders are defined as follows:

Sense: The addressed CPU presents its status to the issuing CPU (see the section "Status Bits" in this chapter for a definition of the bits). No other action is caused at the addressed CPU. The status, if not all zeros, is stored in the general register designated by the R_1 field, and condition code 1 is set; if all status bits are zeros, condition code 0 is set.

External Call: An external-call external-interruption condition is generated at the addressed CPU. The interruption condition becomes pending during the execution of the SIGNAL PROCESSOR instruction. The associated interruption occurs when the CPU is enabled for that condition and does not necessarily occur during the execution of the SIGNAL PROCESSOR instruction. The address of the CPU sending the signal is provided with the interruption code when

the interruption occurs. Only one external-call condition can be kept pending in a CPU at a time.

Emergency Signal: An emergency-signal external-interruption condition is generated at the addressed CPU. The interruption condition becomes pending during the execution of the SIGNAL PROCESSOR instruction. The associated interruption occurs when the CPU is enabled for that condition and does not necessarily occur during the execution of the SIGNAL PROCESSOR instruction. The address of the CPU sending the signal is provided with the interruption code when the interruption occurs. At any one time the receiving CPU can keep pending one emergency-signal condition for each CPU of the multiprocessing system, including the receiving CPU itself.

Start: The addressed CPU performs the start function (see the section "Stopped, Operating, Load, and Check-Stop States" in this chapter). The order is effective only when the addressed CPU is in the stopped state, and the effect is unpredictable when the stopped state has been entered by reset. The CPU does not necessarily enter the operating state during the execution of the SIGNAL PROCESSOR instruction.

Stop: The addressed CPU performs the stop function (see the section "Stopped, Operating, Load, and Check-Stop States" in this chapter). The CPU does not necessarily enter the stopped state during the execution of the SIGNAL PROCESSOR instruction. No action is caused at the addressed CPU if that CPU is in the stopped state when the order code is accepted.

Restart: The addressed CPU performs the restart operation (see the section "Restart Interruption" in Chapter 6, "Interruptions"). The CPU does not necessarily perform the operation during the execution of the SIGNAL PROCESSOR instruction.

Initial Program Reset: The addressed CPU performs initial program reset (see the section "Resets" in this chapter). The execution of the reset does not affect other CPUs. The reset operation is not necessarily completed during the execution of the SIGNAL PROCESSOR instruction.

Program Reset: The addressed CPU performs program reset (see the section "Resets" in this chapter). The execution of the reset does not affect other CPUs. The reset operation is not necessarily completed during the execution of the SIGNAL PROCESSOR instruction.

Stop and Store Status: The addressed CPU performs the stop function, followed by the store-status function (see the section "Store Status" in this chapter). The CPU does not necessarily complete the operation, or even enter the stopped state, during the execution of the SIGNAL PROCESSOR instruction.

Initial Microprogram Load (IML): The addressed CPU performs initial program reset and then initiates the IML function. The latter function is the same as that which is performed as part of manual initial microprogram loading. If the IML function is not provided on the addressed CPU, the order code is treated as unassigned and invalid. The operation is not necessarily completed during the execution of the SIGNAL PROCESSOR instruction.

Initial CPU Reset: The addressed CPU performs initial CPU reset (see the section "Resets" in this chapter). The execution of the reset does not affect other CPUs and does not cause I/O to be reset. If the initial-CPU-reset order is not provided on the addressed CPU, the order is treated as unassigned and invalid. The reset operation is not necessarily completed during the execution of the SIGNAL PROCESSOR instruction.

CPU Reset: The addressed CPU performs CPU reset (see the section "Resets" in this chapter). The execution of the reset does not affect other CPUs and does not cause I/O to be reset. If the CPU-reset order is not provided on the addressed CPU, the order is treated as unassigned and invalid. The reset operation is not necessarily completed during the execution of the SIGNAL PROCESSOR instruction.

CONDITIONS DETERMINING RESPONSE

Conditions Precluding Interpretation of the Order Code

The following situations preclude the initiation of the order. The sequence in which the situations are listed is the order of priority for indicating concurrently existing situations:

1. The access path to the addressed CPU is busy because a concurrently issued SIGNAL PROCESSOR instruction is using the CPU-signaling-and-response facility. The concurrently issued instruction may or may not have been

issued by or to the addressed CPU and may or may not have been issued to this CPU. The order is rejected. Condition code 2 is set.

2. The addressed CPU is not operational; that is, the addressed CPU is not installed, is not configured to the issuing CPU, is in certain customer-engineer test modes, or does not have power on. The order is rejected. Condition code 3 is set. This condition cannot arise as a result of a SIGP by a CPU addressing itself.
3. One of the following conditions exists at the addressed CPU:
 - a. A previously issued start, stop, restart, or stop-and-store-status order has been accepted by the addressed CPU, and execution of the function requested by the order has not yet been completed.
 - b. A manual start, stop, restart, or store-status function has been initiated at the addressed CPU, and the function has not yet been completed. This condition cannot arise as a result of a SIGP by a CPU addressing itself.
 - c. A manual initial-program-load function has been initiated at the addressed CPU, and the reset portion, but not the program-load portion, of the function has been completed. This condition cannot arise as a result of a SIGP by a CPU addressing itself.

If the currently specified order is sense, external call, emergency signal, start, stop, restart, or stop-and-store-status, then the order is rejected, and condition code 2 is set. If the currently specified order is an IML, one of the reset orders, or an unassigned or not-implemented order, the order code is interpreted as described in the section "Status Bits" in this chapter.

4. One of the following conditions exists at the addressed CPU:
 - a. A previously issued initial-program-reset, program-reset, IML, initial-CPU-reset, or CPU-reset order has been accepted by the addressed CPU, and execution of the function requested by the order has not yet been completed.
 - b. A manual-reset or IML function has been initiated at the addressed CPU, and the function has not yet

been completed. The term "manual-reset function" includes the reset portion of IPL. This condition cannot arise as a result of a SIGP by a CPU addressing itself.

If the currently specified order is sense, external call, emergency signal, start, stop, restart, or stop-and-store-status, then the order is rejected, and condition code 2 is set. If the currently specified order is an IML, one of the reset orders, or an unassigned or not-implemented order, either the order is rejected and condition code 2 is set or the order code is interpreted as described in the section "Status Bits" in this chapter.

When any of the conditions described in items 3 and 4 exists, the addressed CPU is referred to as "busy." Busy is not indicated if the addressed CPU is in the check-stop state or when the operator-intervening condition exists. A CPU-busy condition is normally of short duration; however, the conditions described in item 3 may last indefinitely because of a string of interruptions or because of an invalid address in the prefix register. In this situation, however, the CPU does not appear busy to any of the reset orders or to an IML.

When the conditions described in items 1 and 2 above do not apply and operator-intervening and receiver-check status conditions do not exist at the addressed CPU, reset orders may be accepted regardless of whether the addressed CPU has completed a previously accepted order. This may cause the previous order to be lost when it is only partially completed, making unpredictable whether the results defined for the lost order are obtained. However, some reset operations cannot themselves be overridden, as described in the section "Resets" in this chapter.

Status Bits

Various status conditions are defined whereby the issuing and addressed CPUs can indicate their response to the designated order. The status conditions and their bit positions in the general register designated by the R_1 field of the SIGNAL PROCESSOR instruction are shown in the figure "Status Conditions."

| Bit Position | Status Condition |
|--------------|--------------------------|
| 0 | Equipment check |
| 1-23 | Unassigned; zeros stored |
| 24 | External-call pending |
| 25 | Stopped |
| 26 | Operator intervening |
| 27 | Check stop |
| 28 | Not ready |
| 29 | Unassigned; zero stored |
| 30 | Invalid order |
| 31 | Receiver check |

Status Conditions

The status condition assigned to bit position 0 is generated by the CPU executing the SIGNAL PROCESSOR instruction. The remaining status conditions are generated by the addressed CPU.

When the equipment-check condition exists, bit 0 of the general register designated by the R_1 field of the SIGNAL PROCESSOR instruction is set to one, unassigned bits of the status register are set to zeros, and the contents of other status bits are unpredictable. In this case, condition code 1 is set independent of whether the access path to the addressed CPU is busy and independent of whether the addressed CPU is not operational, is busy, or has presented zero status.

When the access path to the addressed CPU is not busy and the addressed CPU is operational and does not indicate busy to the currently specified order, the addressed CPU presents its status to the issuing CPU. These status bits are of two types:

1. Status bits 24-28 indicate the presence of the corresponding conditions in the addressed CPU at the time the order code is received. Except in response to the sense order, each condition is indicated only when the condition precludes the successful execution of the designated order. In the case of sense, all existing status conditions are indicated; the operator-intervening and not-ready conditions each are indicated if these conditions preclude the execution of any installed order.
2. Status bits 30 and 31 indicate that the corresponding conditions were detected by the addressed CPU during reception of the order.

If the presented status is all zeros, the addressed CPU has accepted the order, and condition code 0 is set at the issuing CPU; if the presented status is not all zeros,

the order has been rejected, the status is stored at the issuing CPU in the general register designated by the R₁ field of the SIGNAL PROCESSOR instruction, zeros are stored in the unassigned bit positions of the register, and condition code 1 is set.

The status conditions are defined as follows:

Equipment Check: This condition exists when the CPU executing the instruction detects equipment malfunctioning that has affected only the execution of this instruction and the associated order. The order code may or may not have been transmitted and may or may not have been accepted, and the status bits provided by the addressed CPU may be in error.

External Call Pending: This condition exists when an external-call interruption condition is pending in the addressed CPU because of a previously issued SIGNAL PROCESSOR instruction. The condition exists from the time an external-call order is accepted until the resultant external interruption has been completed. The condition may be due to the issuing CPU or another CPU. The condition, when present, is indicated only in response to sense and to external call.

Stopped: This condition exists when the addressed CPU is in the stopped state. The condition, when present, is indicated only in response to sense. This condition cannot be reported as a result of a SIGP by a CPU addressing itself.

Operator Intervening: This condition exists when the addressed CPU is executing certain operations initiated from local or remote operator facilities. The particular manually initiated operations that cause this condition to be present depend on the model and on the order specified. On machines which do not implement the IML order, the conditions described under "Not Ready" may be indicated as an operator-intervening condition. The operator-intervening condition, when present, can be indicated in response to all orders. Operator intervening is indicated in response to sense if the condition is present and precludes the acceptance of any of the installed orders. The condition may also be indicated in response to unassigned or uninstalled orders. This condition cannot arise as a result of a SIGP by a CPU addressing itself.

Check Stop: This condition exists when the addressed CPU is in the check-stop state. The condition, when present, is indicated only in response to sense, external call, emergency signal, start, stop, restart, and stop and store status. The condition may

also be indicated in response to unassigned or uninstalled orders. This condition cannot be reported as a result of a SIGP by a CPU addressing itself.

Not Ready: This condition exists when the addressed CPU uses reloadable control storage to perform an order and the required microprogram is not loaded. The not-ready condition may be indicated in response to all orders except IML. This condition cannot arise as a result of a SIGP by a CPU addressing itself.

Invalid Order: This condition exists during the communications associated with the execution of SIGNAL PROCESSOR when an unassigned or uninstalled order code is decoded.

Receiver Check: This condition exists when the addressed CPU detects malfunctioning of equipment during the communications associated with the execution of SIGNAL PROCESSOR. When this condition is indicated, the order has not been initiated, and, since the malfunction may have affected the generation of the remaining receiver status bits, these bits are not necessarily valid. A machine-check condition may or may not have been generated at the addressed CPU.

The following chart summarizes which status conditions are presented to the issuing CPU in response to each order code.

| Receiver check# | Invalid order | Not ready | Check stop | Operator intervening# | Stopped | External call pending | Sense | External call | Emergency signal | Start | Stop | Restart | Initial program reset | Program reset | Stop and store status | IML* | Initial CPU reset* | CPU reset* | Unassigned order |
|-----------------|---------------|-----------|------------|-----------------------|---------|-----------------------|---------------|---------------|------------------|---------------|---------------|---------------|-----------------------|---------------|-----------------------|---------------|--------------------|---------------|------------------|
| | | | | | | | X X X X X 0 X | X 0 X X X 0 X | 0 0 X X X 0 X | 0 0 X X X 0 X | 0 0 X X X 0 X | 0 0 X X X 0 X | 0 0 X 0 X 0 X | 0 0 X 0 X 0 X | 0 0 X X X 0 X | 0 0 X 0 0 0 X | 0 0 X 0 X 0 X | 0 0 X 0 X 0 X | 0 0 X 0/X X 1 X |

Explanation:

- 0 A zero is presented in this bit position regardless of the current state of this condition.
- 1 A one is presented in this bit position.

- X A zero or a one is presented in this bit position, reflecting the current state of the corresponding condition.
- 0/X Either a zero or the current state of the corresponding condition is indicated.
- # The current state of the operator-intervening condition may depend on the order code that is being interpreted.
- # If a one is presented in the receiver-check bit position, the values presented in the other bit positions are not necessarily valid.
- * If the order code is implemented, use the line entry for the order code; if the order code is not implemented, use the line entry labeled "Unassigned Order."

If the presented status bits are all zeros, the order has been accepted, and the issuing CPU sets condition code 0. If one or more ones are presented, the order has been rejected, and the issuing CPU stores the status in the general register specified by the R_1 field of the SIGP instruction and sets condition code 1.

Programming Notes

1. A CPU can obtain the following functions by addressing SIGNAL PROCESSOR to itself:
 - a. Sense indicates whether an external-call condition is pending.
 - b. External call and emergency signal cause the corresponding interruption conditions to be generated. External call can be rejected because of a previously generated external-call condition.
 - c. Start sets condition code 0 and has no other effect.
 - d. Stop causes the CPU to set condition code 0, take pending interruptions for which it is enabled, and enter the stopped state.
 - e. Restart provides a means to store the current PSW.
 - f. Stop and store status causes the machine to stop and store all

current status.

2. Two CPUs can simultaneously execute SIGNAL PROCESSOR instructions, with each CPU addressing the other. When this occurs, one CPU, but not both, can find the access path busy because of the transmission of the order code or status bits associated with the SIGNAL PROCESSOR instruction that is being executed by the other CPU. Alternatively, both CPUs can find the access path available and transmit the order codes to each other. In particular, two CPUs can simultaneously stop, restart, or reset each other.

CHANNEL-SET SWITCHING

The channel-set-switching feature permits a collection of channels to be switched from one CPU to another. The collection of channels which are switched as a group is called a channel set. A CPU can be connected to only one channel set at a time, and a channel set can be connected to only one CPU at a time. The switching operation controls only the execution of I/O instructions and I/O interruptions. Other channel activity, such as chaining and data-transfer operations, is not controlled by the switching.

When a channel set is switched to a particular CPU, it is said to be connected to that CPU. Channel-set switching permits any channel set in the configuration to be connected to any CPU in the configuration. However, a channel set can be connected to no more than one CPU at a time, and vice versa. When a channel set is not connected to a CPU, it is said to be disconnected. On a particular CPU, all I/O instructions executed address only the channels within the channel set which is currently connected to that CPU. Initial program reset and program reset issued to a CPU result in the resetting of the CPU and of only those channels which are currently connected to that CPU. Similarly, I/O interruptions caused by a channel which is part of a particular channel set occur on the CPU to which the channel set is currently connected. Chaining and data-transfer operations by the channel continue, independent of whether the channel set is connected to a CPU.

Channel sets can be connected and disconnected by means of two instructions, CONNECT CHANNEL SET (CONCS) and DISCONNECT CHANNEL SET (DISCS), which are defined in Chapter 10, "Control Instructions." These instructions select a particular channel set by means of a 16-bit channel-set

address. When the addressed channel set is not operational, execution of these instructions results in a setting of condition code 3. A channel set is not operational when it is not provided in the system, is not in the configuration, or is in certain customer-engineer test modes. Depending on the model, a channel set may be not operational when all of the channels in the channel set are not operational.

When a channel set is connected to a CPU and the CPU becomes not operational, the channel set may also become not operational, or it may become disconnected and remain in the configuration. A CPU can become not operational because of certain customer-engineer test modes being set, because it is configured out of the configuration, or because its power is off.

The number of CPUs and channel sets in a particular configuration is not necessarily the same.

When system reset normal, system reset clear, load normal, or load clear is activated on any CPU in the configuration, in the absence of any override by model-dependent configuration controls, then:

- All channels within all channel sets in the configuration perform system reset,

- Each channel set which has a home CPU is connected to its home CPU, and
- Each channel set which does not have a home CPU is disconnected.

By definition, the CPU to which a channel set is connected after system reset is called the home CPU for that channel set. The address of the channel set may or may not be the same as the address of its home CPU.

When no channel set is connected to a particular CPU, the execution of any I/O instruction results in a setting of condition code 3. When a channel set is connected to a particular CPU, condition code 3 to an I/O instruction normally indicates that the addressed channel or device is not operational. The I/O instructions are described in Chapter 12, "Input/Output Operations." The connection or disconnection of a channel set is not considered to be a change in the channel state for purposes of setting to one the machine-check external-damage-code bit 3, channel not operational. The setting of this bit, even when a channel set is disconnected, indicates only those changes from the operational state to the not-operational state which would be seen if the channel set were connected to a CPU.

| | |
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calculated from a base address, index, and displacement, designated by the B, X, and D fields, respectively, in the instruction.

To describe the execution of instructions, operands are designated as first and second operands and, in some cases, third operands.

In general, two operands participate in an instruction execution, and the result replaces the first operand. An exception is instructions with "store" in the instruction name, other than STORE THEN AND SYSTEM MASK and STORE THEN OR SYSTEM MASK, where the result replaces the second operand. Except when otherwise stated, the contents of all registers and storage locations participating in the addressing or execution part of an operation remain unchanged.

INSTRUCTION FORMAT

An instruction is one, two, or three halfwords in length and must be located in storage on a halfword boundary. Each instruction is in one of eight basic formats: RR, RRE, RX, RS, SI, S, SSE, and SS, with two variations of SS. (See the figure "Basic Instruction Formats.")

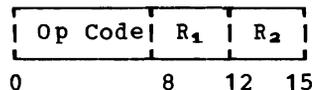
Some instructions contain fields that vary slightly from the basic format, and in some instructions the operation performed does not follow the general rules stated in this section. All of these exceptions are explicitly identified in the individual instruction descriptions.

The format names indicate, in general terms, the classes of operands which participate in the operation:

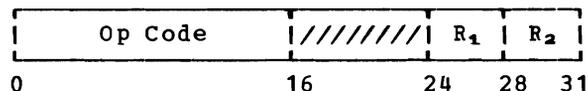
- RR denotes a register-and-register operation.
- RRE denotes a register-and-register operation having an extended op-code field.
- RX denotes a register-and-indexed-storage operation.
- RS denotes a register-and-storage operation.
- SI denotes a storage-and-immediate operation.
- S denotes an operation using an implied operand and storage.
- SS denotes a storage-and-storage operation.

- SSE denotes a storage-and-storage operation having an extended op-code field.

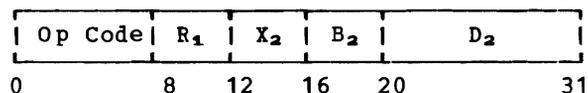
RR Format



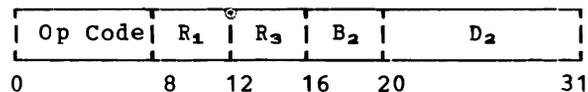
RRE Format



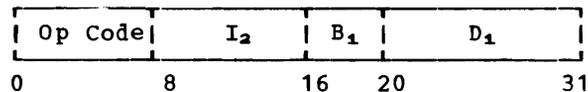
RX Format



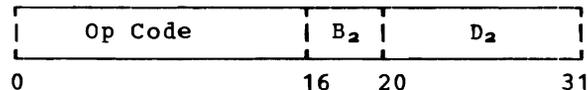
RS Format



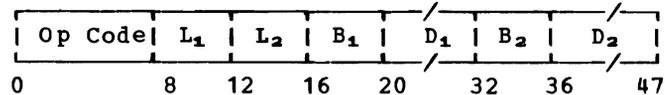
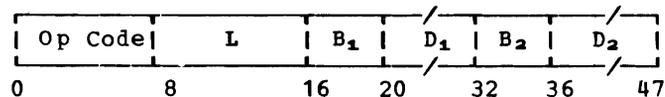
SI Format



S Format



SS Format



the first operand, except for the following instructions: EDIT, EDIT AND MARK, TRANSLATE, and TRANSLATE AND TEST.

ADDRESS GENERATION

Execution of instructions by the CPU involves generation of the addresses of instructions and operands.

SEQUENTIAL INSTRUCTION-ADDRESS GENERATION

When an instruction is fetched from the location designated by the current PSW, the instruction address is increased by the number of bytes in the instruction, and the instruction is executed. The same steps are then repeated by using the new value of the instruction address to fetch the next instruction in the sequence.

Instruction addresses wrap around, with the halfword at location $2^{24}-2$ being followed by the halfword at location 0. Thus, any carry out of PSW bit position 40, as a result of updating the instruction address, is lost.

OPERAND-ADDRESS GENERATION

An operand address that refers to storage either is contained in a register designated by an R field in the instruction or is calculated from the sum of three binary numbers: base address, index, and displacement.

The base address (B) is a 24-bit number contained in a general register specified by the program in a four-bit field, called the B field, in the instruction. Base addresses can be used as a means of independently addressing each program and data area. In array-type calculations, it can specify the location of an array, and, in record-type processing, it can identify the record. The base address provides for addressing the entire storage. The base address may also be used for indexing.

The index (X) is a 24-bit number contained in a general register designated by the program in a four-bit field, called the X field, in the instruction. It is included only in the address specified by the RX instruction format. The RX format instructions permit double indexing; that is, the index can be used to provide the address of an element within an array.

The displacement (D) is a 12-bit number contained in a field, called the D field, in the instruction. The displacement provides for relative addressing of up to 4,095 bytes beyond the location designated by the base address. In array-type calculations, the displacement can be used to specify one of many items associated with an element. In the processing of records, the displacement can be used to identify items within a record.

In forming the address, the base address and index are treated as 24-bit unsigned binary integers. The displacement is similarly treated as a 12-bit unsigned binary integer, and 12 zeros are appended on the left. The three are added as 24-bit binary numbers, ignoring overflow. The sum is always 24 bits long. The bits of the generated address are numbered 8-31, corresponding to the numbering of the base-address and index bits in the general register.

A zero in any of the B₁, B₂, or X₂ fields indicates the absence of the corresponding address component. For the absent component, a zero is used in forming the address, regardless of the contents of general register 0. A displacement of zero has no special significance.

When an instruction description specifies that the contents of a general register designated by an R field are used to address an operand in storage, bit positions 8-31 of the register provide the operand address.

An instruction can designate the same general register both for address computation and as the location of an operand. Address computation is completed prior to the execution of the operation.

Unless otherwise indicated in an individual instruction definition, the generated operand address designates the leftmost byte of an operand in storage.

Programming Note

Negative values may be used in index and base-address registers. Bits 0-7 of these values are always ignored.

BRANCH-ADDRESS GENERATION

For branch instructions, the address of the next instruction to be executed when the branch is taken is called the branch address. Depending on the branch

addressing mode, and address space. The PT instruction also permits a reduction in PSW-key-mask authority and a change from supervisor to problem state. In general, the PT instruction is used to transfer control from one program to another of equal or lower authority. The PT instruction can be used to return from a program called by the PC instruction.

The operation of the PC instruction is controlled by means of an entry-table entry, which is located as part of a table-lookup process during the execution of the instruction. The PC instruction causes the primary address space to be changed only when the ASN in the entry-table entry is nonzero. When the primary address space is changed, the operation is called PROGRAM CALL with space

switching (PC-ss). When the primary address space is not changed, the operation is called PROGRAM CALL to current primary (PC-cp).

The PT instruction specifies an address space which is to become the new primary address space. When the primary address space is changed, the operation is called PROGRAM TRANSFER with space switching (PT-ss). When the primary address space is not changed, the operation is called PROGRAM TRANSFER to current primary (PT-cp).

The linkage instructions provided and the functions performed by each are summarized in the figure "Linkage-Instruction Summary."

| Instruction | Format | Instruction Address PSW Bits 40-63 | | Problem State PSW Bit 15 | | PASN CR4 Bits 16-31 | | PSW-Key Mask Changed in CR3 |
|-------------|--------|---------------------------------------|-----------------------------|-----------------------------|-------------------|---------------------------|-----|-----------------------------------|
| | | Save | Set | Save | Set | Save | Set | |
| BALR* | RR | Yes | R ₂ ¹ | - | - | - | - | - |
| BAL* | RX | Yes | Yes | - | - | - | - | - |
| BASR | RR | Yes | R ₂ ¹ | - | - | - | - | - |
| BAS | RX | Yes | Yes | - | - | - | - | - |
| PC-cp | S | Yes | Yes | Yes | Yes | - | - | "OR" EKM |
| PC-ss | S | Yes | Yes | Yes | Yes | Yes | Yes | "OR" EKM |
| PT-cp | RRE | - | R ₂ | - | R ₂ | - | - | "AND" R ₁ |
| PT-ss | RRE | - | R ₂ | - | R ₂ ** | - | Yes | "AND" R ₁ |
| SVC | RR | Yes | Yes | Yes | Yes | - | - | - |

Explanation:

- No

¹ The action takes place only if the R field in the instruction is not zero.

* BAL and BALR also save the instruction-length code, condition code, and program mask.

** A change from supervisor to problem state is permissible; a privileged-operation exception is recognized when a change from problem to supervisor state is specified.

Linkage-Instruction Summary

Execution of Interruptible Instructions

The execution of an interruptible instruction is completed when all units of operation associated with that instruction are completed. When an interruption occurs after completion, nullification, or suppression of a unit of operation, all preceding units of operation have been completed.

On completion of a unit of operation other than the last one (and on nullification of any unit of operation), the instruction address in the old PSW designates the interrupted instruction, and the operand parameters are adjusted such that the execution of the interrupted instruction is resumed from the point of interruption when the old PSW stored on the interruption is made the current PSW. It depends on the instruction how the operand parameters are adjusted.

When a unit of operation is suppressed, the instruction address in the old PSW designates the next sequential instruction. The operand parameters, however, are adjusted so as to indicate the extent to which instruction execution has been completed. If the instruction is reexecuted after the conditions causing the suppression have been removed, the execution is resumed from the point of interruption. As in the case of completion and nullification, it depends on the instruction how the operand parameters are adjusted.

When an exception which causes termination occurs as part of a unit of operation of an interruptible instruction, the entire operation is terminated, and the contents, in general, of any fields due to be changed by the instruction are unpredictable. On such an interruption, the instruction address in the old PSW designates the next sequential instruction.

Programming Notes

1. Any interruption, other than supervisor call and some program interruptions, can occur after a partial execution of an interruptible instruction. In particular, interruptions for external, I/O, machine-check, restart, and program interruptions for access exceptions and PER events can occur between units of operation.
2. The amount of data processed in a unit of operation of an interruptible

instruction depends on the model and may depend on the type of condition which causes the execution of the instruction to be interrupted or stopped. Thus, when an interruption occurs at the end of the current unit of operation, the length of the unit of operation may be different for different types of interruptions. Also, when the stop function is requested during the execution of an interruptible instruction, the CPU enters the stopped state at the completion of the execution of the current unit of operation. Similarly, in the instruction-step mode, only a single unit of operation is performed, but the unit of operation for the various cases of stopping may be different.

EXCEPTIONS TO NULLIFICATION AND SUPPRESSION

In certain unusual situations, the result fields of an instruction having a store-type operand are changed in spite of the occurrence of an exception which would normally result in nullification or suppression. These situations are exceptions to the general rule that the operation is treated as a no-operation when an exception requiring nullification or suppression is recognized. Each of these situations may result in the turning on of the change bit associated with the store-type operand, even though the final result in storage may appear unchanged. Depending on the particular situation, additional effects may be observable the extent of which is described for each of the situations.

All of these situations are limited to the extent that a store access does not occur and the change bit is not set when the store access is prohibited. For the CPU, a store access is prohibited whenever an access exception exists for that access, or whenever an exception exists which is of higher priority than the priority of an access exception for that access.

When, in these situations, an interruption for an exception requiring suppression occurs, the instruction address in the old PSW designates the next sequential instruction. When an interruption for an exception requiring nullification occurs, the instruction address in the old PSW designates the instruction causing the exception even though partial results may have been stored.

| for an instruction with a store-type
 | operand, an interlocked update which does
 | not change the contents of the location may
 | occur for that portion of the store-type
 | operand, if any, for which no access
 | exception exists. The interlocked update
 | can occur only if the priority of the
 | exception is equal to or lower than the
 | priority of an access exception for the
 | store-type operand.

When the exception is a specification
 exception for a store-type operand which
 requires alignment on integral boundaries,
 the interlocked update which may occur is
 limited to the single byte at the location
 specified by the operand address.

Programming Note

Examples of when an interlocked update may
 occur to the destination-operand location
 in storage are:

- Decimal-divide exception for DIVIDE
DECIMAL
- Specification exception for an odd
register number for COMPARE DOUBLE AND
SWAP
- Data exception for an invalid decimal
sign for ADD DECIMAL

DUAL-ADDRESS-SPACE CONTROL

| The dual-address-space (DAS) facility
 | consists of a number of interrelated
 | functions. Many of these functions are
 | described in this chapter, specifically in
 | these sections: "DAS-Authorization
 | Mechanisms," "PC-Number Translation," "ASN
 | Translation," and "ASN Authorization."
 | Additionally, address spaces are described
 | in Chapter 3, "Storage"; interruptions in
 | Chapter 6, "Interruptions"; and the
 | instructions in Chapter 10, "Control
 | Instructions."

| A complete list of the functions, control-
 | register fields, and instructions which are
 | part of DAS is included in Appendix D,
 | "Facilities."

SUMMARY

| These major functions are provided:

- | 1. Two address spaces for immediate use
 | by the program

2. Means for changing to other spaces
3. Instructions for moving data between
spaces
4. A table-based-subroutine linkage
5. The use of multiple access keys for
key-controlled protection by problem
programs
6. Aids for program-problem analysis

| Additionally, control and authority
 | mechanisms are incorporated to control
 | these functions.

| These functions are intended for use by
 | programs considered to be semiprivileged,
 | that is, programs which are executed in the
 | problem state but which may be authorized
 | to use additional capabilities. With these
 | authorization controls, a hierarchy of
 | programs may be established, with programs
 | at a higher level having a greater degree
 | of privilege or authority than programs at
 | a lower level. The range of functions
 | available at each level, and the ability to
 | transfer control from a lower to a higher
 | level, are prescribed in tables which are
 | managed by the control program.

| The semiprivileged instructions are
 | described in Chapter 10, "Control
 | Instructions." The instructions are:

- EXTRACT PRIMARY ASN (EPAR)
- EXTRACT SECONDARY ASN (ESAR)
- INSERT ADDRESS SPACE CONTROL (IAC)
- INSERT VIRTUAL STORAGE KEY (IVSK)
- LOAD ADDRESS SPACE PARAMETERS (LASP)
- MOVE TO PRIMARY (MVCP)
- MOVE TO SECONDARY (MVCS)
- MOVE WITH KEY (MVCK)
- PROGRAM CALL (PC)
- PROGRAM TRANSFER (PT)
- SET ADDRESS SPACE CONTROL (SAC)
- SET SECONDARY ASN (SSAR)

| In addition, when DAS is installed, two
 | instructions which are not part of DAS are
 | changed to operate in the problem state.
 | These instructions are:

- INSERT PSW KEY (IPK)
- SET PSW KEY FROM ADDRESS (SPKA)

| These instructions remain compatible,
 | however, because the changes are under the
 | control of mode bits in the PSW or in
 | control registers. Furthermore, whenever a
 | program in the problem state issues one of
 | these instructions at a time when the
 | required control registers have not been
 | set up, the program exception which is
 | indicated is an exception which is also
 | available on machines without DAS.

ASN translation.

To obtain the segment-table designation and other information for the new address space, the ASN is translated by using a set of tables whose origin is contained in control register 14. A two-level lookup is used. The ASN value is partitioned into two indexes. The first index selects an entry in the table designated by control register 14, called the ASN first table, or AFT. This entry designates another table, called the ASN second table, or AST, an entry of which is selected by the second index. An entry in the second table contains several parameters about the new address space. The information in a second-table entry includes:

- A validity indicator, generally used to indicate whether the associated address space is immediately accessible. This is useful for managing unassigned numbers and swapped-out spaces.
- The origin and length of a table which provides control over whether three of the instructions are authorized to use the new ASN. This table is called the authority table (AT).
- The authority index (AX), or level, of the new space.
- The origin and length of the segment table to be used by DAT when the new address space is accessed.
- A control over whether a signal, in the form of a space-switch-event program interruption, is given for two of the instructions after a change to a new primary address space is completed.
- The origin of a set of tables which describe the entry points associated with a new primary space. These tables are used by the linkage mechanism provided with DAS. A two-level table structure is provided. The first level is the linkage table (LT), whose entries provide the origins of entry tables (ET).

Changing the Secondary Space: The instruction SET SECONDARY ASN (SSAR) causes the secondary space to be changed to the space associated with the ASN specified by the instruction. The ASN itself is placed in control register 3 and is called the secondary ASN, or SASN. The ASN is translated to obtain the origin of the segment table for the space. This origin is placed in control register 7 as the secondary segment-table origin, or SSTO. Instruction execution is disallowed if the translation is not authorized. The

translation is authorized by a bit in the authority table at an offset determined by the authority index in control register 4. The instruction LOAD ADDRESS SPACE PARAMETERS also can change the secondary space.

Moving Data Between Spaces

DAS provides three instructions for moving information under the control of two access keys.

The instruction MOVE WITH KEY gives a semiprivileged program the capability of moving information to (or from) a caller-specified area from (or to) a semiprivileged-program area. The instruction uses the PSW key for the store accesses associated with the first operand and uses a program-specified key for the fetch accesses associated with the second operand. Thus, a program may set up the PSW key and specify the source key so as to provide appropriate authority checking on a caller-specified address whether it be a source or a target.

The instructions MOVE TO PRIMARY and MOVE TO SECONDARY permit the program to move data from either of the two current address spaces to the other. These instructions have the same general format as MOVE WITH KEY and are defined such that a second access key can be specified in addition to the PSW key. The PSW key in these two instructions is used as the access key for the storage references to the primary address space. Accesses to the secondary address space are made by using a key specified in a general register designated by the instruction. Thus, the program can use the instruction to move data to (or from) a calling program area from (or to) the semiprivileged-program area and to specify the appropriate key to be used in each area.

A third move instruction is used for moving data between differently protected areas, but with both operands appearing in the same address space.

For all three move instructions, the number of bytes to be moved is expressed as a true length. A zero length is allowed, with no movement performed. Up to 256 bytes are moved each time one of these instructions is executed, and a condition code is set to indicate whether the number of bytes moved did or did not exhaust the true length. These capabilities make the instructions suitable for use in a simple program to move a number of bytes from zero up. This is particularly useful when the number of bytes to be moved is calculated dynamically

| called program may be authorized to have
| keys which are not authorized to the
| caller.

| The IVSK instruction is also useful to a
| supervisor program since the instruction
| uses a virtual rather than a real address.
| The sequence LOAD REAL ADDRESS followed by
| INSERT STORAGE KEY does not necessarily
| produce a valid result if the program is
| enabled or running in a multiprocessing
| system. This is true because, in a
| multiprocessing system, an INVALIDATE PAGE
| TABLE ENTRY, followed by a reassignment of
| the page on the other CPU, may occur.

| The SET PSW KEY FROM ADDRESS (SPKA), which
| is changed by DAS to operate in the problem
| state, provides the program in the problem
| state with the capability of changing the
| PSW key, under control of the PSW-key mask,
| and thus permits the program to access
| different data areas protected by different
| keys. Its use, in conjunction with the
| PSW-key mask, permits the program to
| operate with more than one key without
| having authorization to all keys.

| Increased flexibility in key handling is
| controlled by a 16-bit PSW-key mask in
| control register 3. This mask controls the
| problem-program use of keys in the move
| instructions and in the SET PSW KEY FROM
| ADDRESS instruction. Each bit position
| corresponds to a key value. The bit in the
| mask must be one in order for the
| corresponding key to be used.

| Program-Problem Analysis

| To aid program-problem analysis, the option
| is provided of having a trace entry made
| implicitly for three instructions. When
| tracing is activated, a trace entry is made
| each time PROGRAM CALL, PROGRAM TRANSFER,
| or SET SECONDARY ASN is executed.

| As a further analysis aid, PROGRAM CALL and
| PROGRAM TRANSFER are also recognized for
| PER purposes as successful branching
| events. Additionally, for these two
| instructions, a bit called the space-
| switch-event bit is provided both in
| control register 1 and in the second-table
| entry used during ASN translation. When
| either bit is one, a program interruption
| for a space-switch event occurs at the
| completion of the instruction. The effect
| is to provide for an interruption when a
| primary-space switch occurs, allowing
| recognition that a space has been entered,
| left, or both.

| DAS AUTHORIZATION MECHANISMS

| The authorization mechanisms which are
| provided by DAS are as follows. (A summary
| of the authorization mechanisms is given in
| the figure "Summary of DAS Authorization
| Mechanisms.")

| Extraction-Authority Control

| The extraction-authority-control bit is
| located in bit position 4 of control
| register 0. This bit controls whether the
| following instructions are authorized in
| the problem state.

EXTRACT PRIMARY ASN (EPAR)
EXTRACT SECONDARY ASN (ESAR)
INSERT ADDRESS SPACE CONTROL (IAC)
INSERT PSW KEY (IPK)
INSERT VIRTUAL STORAGE KEY (IVSK)

| When the extraction-authority-control bit
| is a one, the instructions can be executed
| in the problem state. When the bit is zero
| and any of the above instructions are
| encountered in the problem state, a
| privileged-operation exception is
| recognized, and the operation is
| suppressed. The extraction-authority-
| control bit is not examined in the
| supervisor state.

| PSW-Key Mask

| The PSW-key mask consists of bits 0-15 in
| control register 3. These bits are used in
| the problem state to control what keys and
| entry points are authorized for the
| program. The PSW-key mask is modified by
| PROGRAM CALL and PROGRAM TRANSFER and is
| loaded by LOAD ADDRESS SPACE PARAMETERS.
| The PSW-key mask is used in the problem
| state to control the following.

- The PSW-key values that can be set by means of the instruction SET PSW KEY FROM ADDRESS.
- The PSW-key values that are valid for the three move instructions that specify a second access key: MOVE WITH KEY, MOVE TO PRIMARY, and MOVE TO SECONDARY.
- The entry points which can be called by means of PROGRAM CALL. In this case, the PSW-key mask is ANDed with the authorization key mask in the entry-table entry, and, if the result is zero, the program is not authorized.

| The instruction PROGRAM CALL with space | program interruption is also indicated at
| switching causes a new authorization index | the completion of a PC-ss or PT-ss if any
| to be loaded from the ASN-second-table | PER event is indicated.
| entry. This permits the program which is
| called to be given an authorization index
| which authorizes it to access more address
| spaces than those authorized for the
| calling program.

| Space-Switch-Event Bit

| Bit 31 of control register 1 is the space-
| switch-event bit. This bit is loaded into
| control register 1, along with the
| remaining bits of the primary-segment-table
| designation, whenever control register 1 is
| loaded. If control register 1 is loaded as
| a result of a PC-ss or PT-ss operation and
| either the old or new value of the space-
| switch-event bit is one or both values are
| ones, then a space-switch-event program
| interruption occurs after the operation has
| been completed. A space-switch-event

| The space-switch event permits the control
| program to gain control whenever a program
| enters or leaves a particular address
| space. Bit 95 of the ASN-second-table
| entry (ASTE) is loaded into bit position 31
| of control register 1 as part of the PC-ss
| and PT-ss operations. If bit 95 of the
| ASTE for a particular address space is set
| to one, then a space-switch event is
| recognized when a program enters the
| address space by means of either a PC-ss or
| a PT-ss.

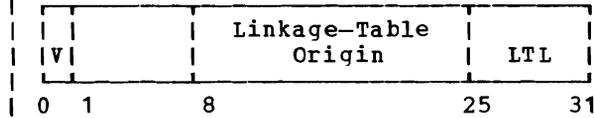
| The space-switch event may be useful in
| causing additional trace information to be
| recorded or in enabling or disabling the
| CPU for PER or tracing.

| Programming Note

| linkage-table entry.

| PC-NUMBER TRANSLATION CONTROL

| PC-number translation is controlled by means of the linkage-table designation in control register 5. The register has the following format:



| Subsystem-Linkage Control (V): Bit 0 is the subsystem-linkage-control bit. When this bit is zero, PROGRAM CALL and PROGRAM TRANSFER are not authorized; a special-operation exception is recognized, and the operation is suppressed.

| Linkage-Table Origin: Bits 8-24, with seven zeros appended on the right, form a 24-bit real address that designates the beginning of the linkage table.

| Linkage-Table Length (LTL): Bits 25-31 designate the length of the linkage table in units of 128 bytes, thus making the length of the linkage table variable in multiples of 32 four-byte entries. The length of the linkage table, in units of 128 bytes, is one more than the value in bit positions 25-31. The linkage-table length is compared against the leftmost seven bits of the linkage-index portion of the PC number to determine whether the linkage index designates an entry within the linkage table.

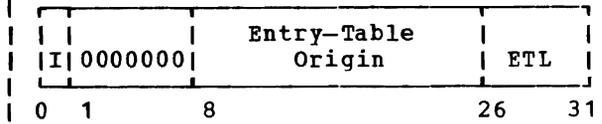
| PC-NUMBER TRANSLATION TABLES

| The PC-number translation process consists in a two-level lookup using two tables: a linkage table and an entry table. These tables reside in real storage.

| Linkage-Table Entries

| The linkage-index portion of the PC number is used to select a linkage-table entry. The entry fetched from the linkage table designates the availability, origin, and length of the corresponding entry table.

| An entry in the linkage table has the following format:



| The fields in the linkage-table entry are allocated as follows:

| LX Invalid Bit (I): Bit 0 controls whether the entry table associated with the linkage-table entry is available.

| When the bit is zero, PC-number translation proceeds by using the linkage-table entry. When the bit is one, an LX-translation exception is recognized, and the operation is nullified.

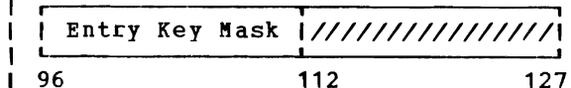
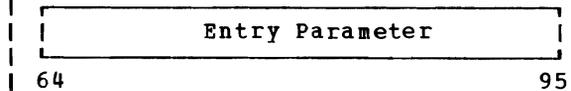
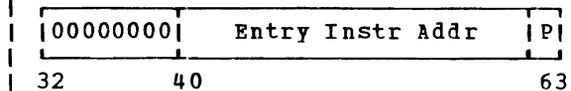
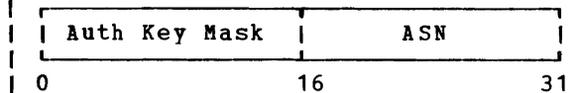
| Entry-Table Origin: Bits 8-25, with six zeros appended on the right, form a 24-bit real address that designates the beginning of the entry table.

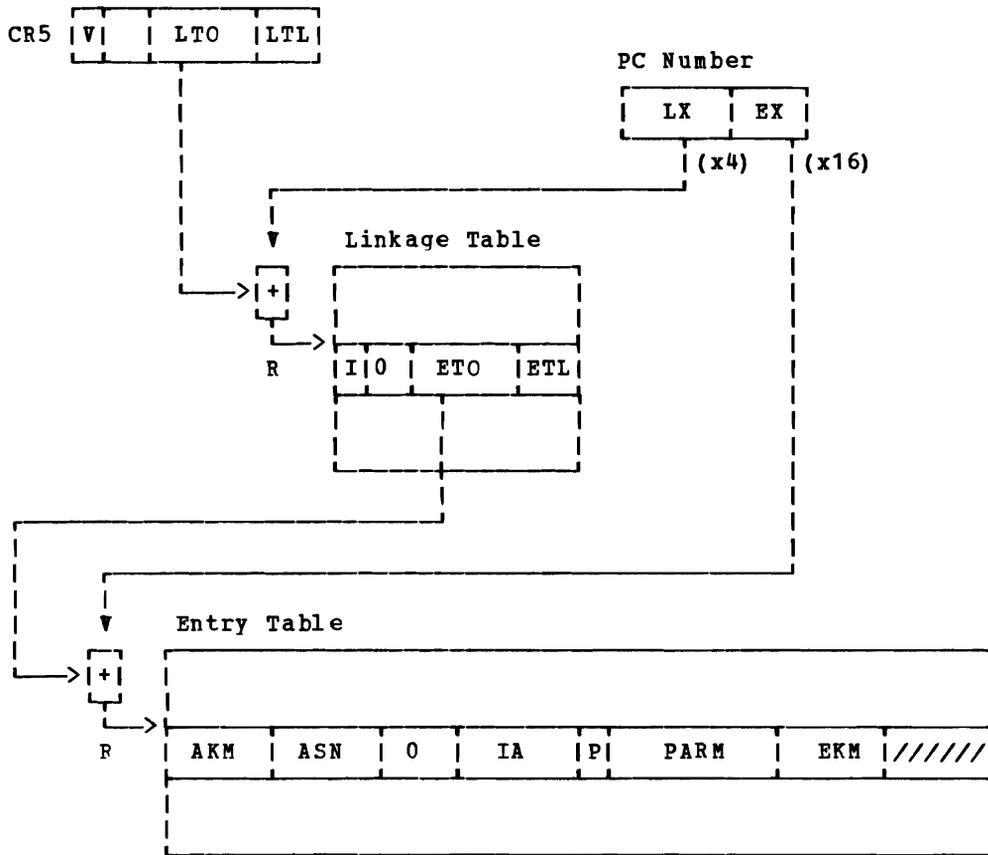
| Entry-Table Length (ETL): Bits 26-31 designate the length of the entry table in units of 64 bytes, thus making the entry table variable in multiples of four 16-byte entries. The length of the entry table, in units of 64 bytes, is one more than the value in bit positions 26-31. The entry-table length is compared against the leftmost six bits of the entry index to determine whether the entry index designates an entry within the entry table.

| Bits 1-7 of the linkage-table entry must be zeros; otherwise, a PC-translation-specification exception is recognized, and the operation is suppressed.

| Entry-Table Entries

| The entry fetched from the entry table is 16 bytes in length and has the following format:





R: Address is real

PC-Number Translation

Linkage-Table Lookup

The linkage-index (LX) portion of the PC number is used to select an entry from the linkage table. The real address of the linkage-table entry is obtained by appending seven zeros on the right to the contents of bit positions 8-24 of control register 5 and adding the linkage index to this value. For this addition, the linkage index is extended with two rightmost and 10 leftmost zeros.

A carry, if any, into bit position 7 is ignored, and the result is a 24-bit real address.

As part of the linkage-table-lookup process, the leftmost seven bits of the linkage index are compared against the linkage-table length, bits 25-31 of control register 5, to establish whether the addressed entry is within the linkage table. If the value in the linkage-table-length field is less than the value in the seven leftmost bits of the linkage index, an LX-translation exception

is recognized, and the operation is nullified.

All four bytes of the linkage-table entry are fetched concurrently. The fetch access is not subject to protection. When the storage address which is generated for fetching the linkage-table entry refers to a location which is not provided, an addressing exception is recognized, and the operation is suppressed.

Bit 0 of the linkage-table entry specifies whether the entry table corresponding to the linkage index is available. This bit is inspected, and, if it is one, an LX-translation exception is recognized, and the operation is nullified.

When no exceptions are recognized in the process of linkage-table lookup, the entry fetched from the linkage table designates the origin and length of the corresponding entry table.

| 12 is one, ASN translation can be performed.

| ASN-First-Table Origin (AFTO): Bits 20-31 of control register 14, with 12 zeros appended on the right, form a 24-bit real address that designates the beginning of the ASN first table.

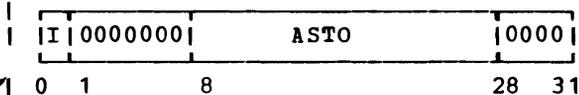
| **ASN-TRANSLATION TABLES**

| The ASN-translation process consists in a two-level lookup using two tables: an ASN first table and an ASN second table. These tables reside in real storage.

| ASN-First-Table Entries

| The entry fetched from the ASN first table (AFT) designates the availability and origin of the corresponding ASN second table.

| An entry in the ASN first table has the following format:



| The fields in the entry are allocated as follows:

| AFX-Invalid Bit (I): Bit 0 controls whether the ASN second table associated with the ASN-first-table entry is available. When bit position 0 contains a zero, ASN translation proceeds by using the designated ASN second table. When it contains a one, an AFX-translation exception is recognized, and the operation is nullified.

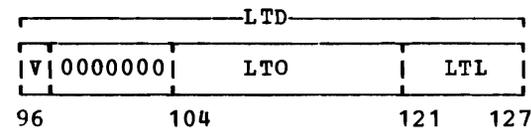
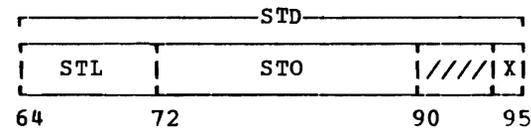
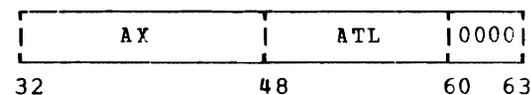
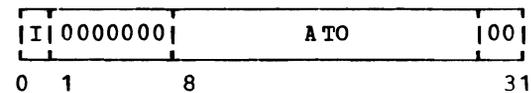
| ASN-Second-Table Origin (ASTO): Bits 8-27, with four zeros appended on the right, are used to form a 31-bit real address that designates the beginning of the ASN second table.

| Bits 1-7 and 28-31 of the AFT entry must be zeros; if they are not zeros, an ASN-translation-specification exception is recognized as part of the execution of the instruction using that entry for ASN translation, and the operation is suppressed.

| ASN-Second-Table Entries

| The entry fetched from the ASN second table indicates the availability of the address space and contains the address-space-control parameters if the address space is available.

| The ASN second-table entry has the following format:



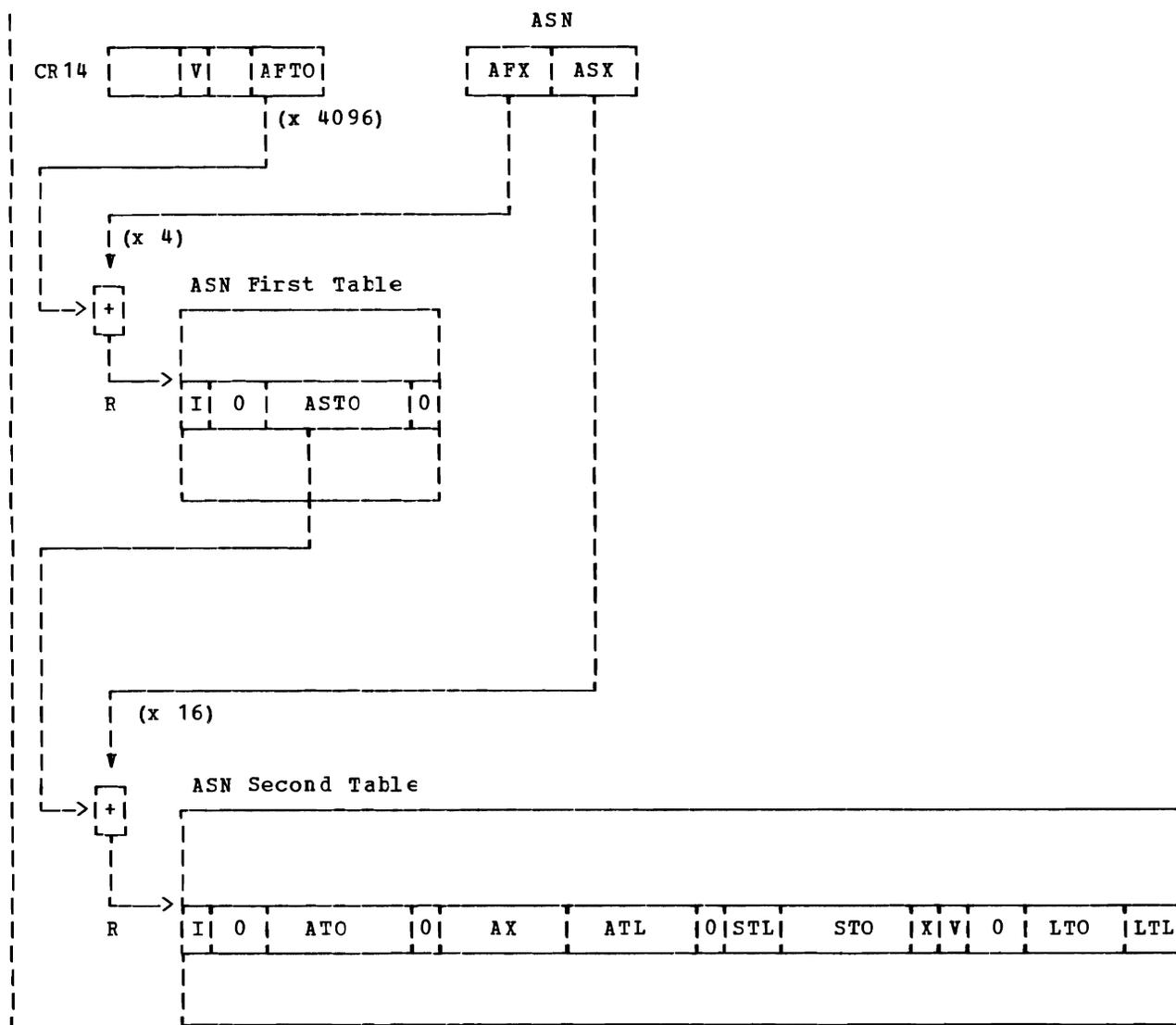
| The fields in the entry are allocated as follows:

| ASX-Invalid Bit (I): Bit 0 controls whether the address space associated with the AST entry is available. When bit position 0 contains a zero, ASN translation proceeds. When the bit is a one, an ASX-translation exception is recognized, and the operation is nullified.

| Authority-Table Origin (ATO): Bits 8-29, with two zeros appended on the right, are used to form a 24-bit real address that designates the beginning of the authority table.

| Authorization Index (AX): Bits 32-47 are used as a result of a successful primary ASN translation by PROGRAM CALL and PROGRAM TRANSFER. The AX field is ignored for secondary ASN translation in SET SECONDARY ASN.

| Authority-Table Length (ATL): Bits 48-59 specify the length of the authority table in units of four bytes, thus making the authority table variable in multiples of 16 entries. The length of the authority table, in units of four bytes, is one more than the ATL value. The contents of the ATL field are used to establish whether the entry designated by a particular AX falls within the authority table.



R: Address is real

ASN Translation

ASN-First-Table Lookup

The AFX portion of the ASN is used to select an ASN-first-table entry that designates the second table (ASN second table) to be used for the second lookup. The 24-bit real address of the ASN first table is obtained by appending 12 zeros on the right to the AFT origin contained in bit positions 20-31 of control register 14. The real address of the AFT entry is obtained by appending two rightmost zeros and 12 leftmost zeros to the AFX and adding this 24-bit value to the real address of the AFT, ignoring any carry into bit position 7. All four bytes of the ASN-first-table entry are fetched concurrently. The fetch access is not

subject to protection. When the storage address which is generated for fetching the ASN-first-table entry refers to a location which is not provided, an addressing exception is recognized, and the operation is suppressed.

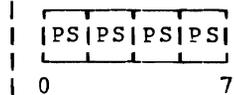
Bit 0 of the four-byte AFT entry specifies whether the corresponding AST is available. If this bit is one, an AFX-translation exception is recognized, and the operation is nullified. If bit positions 1-7 and 28-31 of the AFT entry do not contain zeros, an ASN-translation-specification exception is recognized, and the operation is suppressed. When no exceptions are recognized, the entry fetched from the AFT is used to access the AST.

| table.

| Authority-Table Length (ATL): Bits 48-59 designate the length of the authority table in units of four bytes, thus making the authority table variable in multiples of 16 entries. The length of the authority table, in units of four bytes, is equal to one more than the ATL value. The contents of the length field are used to establish whether the entry designated by the authorization index falls within the authority table.

| Authority-Table Entries

| The authority table consists of entries of two bits each; accordingly, each byte of the authority table contains four entries:



| The fields are allocated as follows:

| Primary Authority (P): The left bit of an authority-table entry controls whether the program with the authorization index corresponding to the entry is permitted to load the address space as a primary address space by using PROGRAM TRANSFER. If the P bit is one, the access is permitted. If the P bit is zero, the access is not permitted; a primary-authority exception is recognized, and the operation is nullified.

| Secondary Authority (S): The right bit of an authority-table entry controls whether the program with the corresponding authorization index is permitted to load the address space as a secondary address space using SET SECONDARY ASN. If the S bit is one, the access is permitted. If the S bit is zero, the access is not permitted; a secondary-authority exception is recognized, and the operation is nullified.

| Programming Note

| The primary- and secondary-authority exceptions cause nullification to permit dynamic modification of the authority table. Thus, when an address space is created or "swapped in," the authority table can first be set to all zeros and the appropriate authority bits set to one only when required.

| ASN-AUTHORIZATION PROCESS

| The ASN-authorization process is performed by using the authorization index currently in control register 4, in conjunction with the authority-table origin and length from the AST entry, to select an authority-table entry.

| The ASN-authorization process is performed by using the authorization index to select an entry from the authority table. The entry is fetched, and either the primary- or secondary-authority bit is examined, depending on whether the primary- or secondary-authorization process is being performed. The ASN-authorization process is shown in the figure "ASN Authorization."

selected from the byte as a function of bits 14 and 15 of the AX in CR4 and the instruction PROGRAM TRANSFER (PT-ss) or SET SECONDARY ASN (SSAR-ss).

| CR4 Bits | | Bit Selected from Authority-Table Byte for Test | |
|----------|---|---|-----------------|
| | | P Bit (PT-ss) | S Bit (SSAR-ss) |
| 0 | 0 | 0 | 1 |
| 0 | 1 | 2 | 3 |
| 1 | 0 | 4 | 5 |
| 1 | 1 | 6 | 7 |

If the selected bit is one, the ASN translation is authorized, and the appropriate address-space-control parameters from the AST entry are loaded into the appropriate control registers. If the selected bit is zero, the ASN translation is not authorized, and a primary-authority exception or secondary-authority exception is recognized for PT-ss or SSAR-ss, respectively.

Recognition of Exceptions During ASN Authorization

The exceptions associated with the primary- and secondary-ASN authorization processes are called primary-authorization-translation exceptions and secondary-authorization-translation exceptions, respectively. A list of these exceptions and their priorities are given in Chapter 6, "Interruptions."

SEQUENCE OF STORAGE REFERENCES

Conceptually, the CPU processes instructions one at a time, with the execution of one instruction preceding the execution of the following instruction. The execution of the instruction specified by a successful branch follows the execution of the branch. Similarly, an interruption takes place between instructions or, for interruptible instructions, between units of operation of such instructions.

The sequence of events implied by the processing just described is sometimes called the conceptual sequence.

Each operation appears to the program to be performed sequentially, with the current instruction being fetched after the preceding operation is completed and before the execution of the current operation is begun. This appearance is maintained, even though the storage-implementation characteristics and overlap of instruction execution with storage accessing may cause actual processing to be different. The results generated are those that would have been obtained had the operations been performed in the conceptual sequence. Thus, it is possible for an instruction to modify the next succeeding instruction in storage.

In simple models in which operations are not overlapped, the conceptual and actual sequences are essentially the same. However, in more complex machines, overlapped operation, buffering of operands and results, and execution times which are comparable to the propagation delays between units can cause the actual sequence to differ considerably from the conceptual sequence. In these machines, special circuitry is employed to detect dependencies between operations and ensure that the results obtained are those that would have been obtained if the operations had been performed in the conceptual sequence. However, other CPUs and channels may, unless otherwise constrained, observe a sequence that differs from the conceptual sequence. Also, in certain situations involving dynamic address translation where different virtual addresses map to the same real address, the effect of overlapped operation may be observable.

It can normally be assumed that the execution of each instruction occurs as an indivisible event. However, in actual operation, the execution of an instruction consists in a series of discrete steps. Depending on the instruction, operands may be fetched and stored in a piecemeal fashion, and some delay may occur between fetching operands and storing results. As a consequence, a channel or another CPU may be able to observe intermediate or partially completed results.

When the program on the CPU interacts with a program on a channel or on another CPU, the programs may have to take into consideration that a single operation may consist in a series of storage references, that a storage reference may in turn consist in a series of accesses, and that the conceptual and actual sequences of these accesses may differ. Storage references associated with instruction execution are of the following types: instruction fetches, DAT-table fetches, storage-key accesses, and storage-operand references.

4. Accesses to storage for the purpose of storing and fetching information for interruptions is performed by means of real addresses, whereas accesses by the program may be by means of virtual addresses.
5. The real-to-absolute mapping may be changed by means of the instruction SET PREFIX.
6. A location may be accessed by I/O by means of an absolute address and by the CPU by means of a real or a virtual address.
7. A location may be accessed by another CPU by means of one type of address and by this CPU by means of a different type of address.
8. The CPU updates the interval timer by means of a real address, and the program may access the location by means of a virtual address.

The primary purpose of this section is to describe the effects caused by case 1 above.

For case 2, the effect is not observable, since prefetched instructions are discarded and the effect of delayed stores is not observable to the CPU itself.

For case 3, those instructions which fetch by using real addresses (for example, LOAD REAL ADDRESS), no effect is observable. This is because the only effect across instructions is the prefetching of instructions, and instructions which fetch by using real addresses thus have no special effect. All instructions which store by using a real address cause prefetched instructions to be discarded, and no effect is observable.

Cases 4 and 5 are situations which are defined to cause serialization, with the result that prefetched instructions are discarded. In these cases, no effect is observable.

The handling of cases 6 and 7 involves accesses as observed by channels and other CPUs and is covered in the following sections in this chapter.

For case 8, the effect of updating the interval timer is observable only if an instruction is fetched from location 80 by using a virtual address which is not 80 but maps to 80.

INSTRUCTION FETCHING

Instruction fetching consists in fetching the one, two, or three halfwords specified by the instruction address in the current PSW. The immediate field of an instruction is accessed as part of an instruction fetch. If, however, an instruction specifies a storage operand at the location occupied by the instruction itself, the location is accessed both as an instruction and as a storage operand. The fetch of the target instruction of EXECUTE is considered to be an instruction fetch.

The bytes of an instruction may be fetched piecemeal and are not necessarily accessed in a left-to-right direction. The instruction may be fetched multiple times for a single execution; for example, it may be fetched for testing the addressability of operands or for inspection of PER events, and it may be refetched for actual execution.

Instructions are not necessarily fetched in the sequence in which they are conceptually executed and are not necessarily fetched for each time they are executed. In particular, the fetching of an instruction may precede the storage-operand references for an instruction that is conceptually earlier. The instruction fetch occurs prior to all storage-operand references for all instructions that are conceptually later.

An instruction may be prefetched by using a virtual address only when the associated DAT table entries are attached and valid. Instructions which are prefetched may be interpreted for execution only for the same virtual address for which the instruction was prefetched.

There is no limit established as to the number of instructions which may be prefetched, and multiple copies of the contents of a single storage location may be fetched. As a result, the instruction executed is not necessarily the most recently fetched copy. Storing caused by channels or by other CPUs does not necessarily change the copy of prefetched instructions. However, if a store that is conceptually earlier occurs on the same CPU using the same logical address as that by which the instruction is subsequently fetched, the updated information is obtained.

All copies of prefetched instructions are discarded when:

- A serializing function is performed
- The CPU enters the operating state

4. The instruction INSERT STORAGE KEY provides a consistent image of the field, which consists of all seven bits of the storage key. The access to the storage key for INSERT STORAGE KEY follows the sequence rules for storage-operand fetch references and is a single-access reference.
5. The instruction RESET REFERENCE BIT modifies only the reference bit. All other bits of the storage key remain unchanged. The reference bit and change bit are examined concurrently to set the condition code. The access to the storage key for RESET REFERENCE BIT follows the sequence rules for storage-operand update references. The reference bit is the only bit which is updated.

The record of references provided by the reference bit is not necessarily accurate, and the handling of the reference bit is not subject to the concurrency rules. However, in the majority of situations, reference recording approximately coincides with the storage reference.

The change bit may be set in cases when no storing has occurred. See the section "Change Recording" in Chapter 3, "Storage."

STORAGE-OPERAND REFERENCES

A storage-operand reference is the fetching or storing of the explicit operand or operands in the storage locations specified by the instruction.

During the execution of an instruction, all or some of the storage operands for that instruction may be fetched, intermediate results may be maintained for subsequent modification, and final results may be temporarily held prior to placing them in storage. Stores caused by channels do not necessarily affect these intermediate results. Storage-operand references are of three types: fetches, stores, and updates.

Storage-Operand Fetch References

When the bytes of a storage operand participate in the instruction execution only as a source, the operand is called a fetch-type operand, and the reference to the location is called a storage-operand fetch reference. A fetch-type operand is identified in individual instruction definitions by indicating that the access

exception is for fetch.

All bits within a single byte of a fetch reference are accessed concurrently. When an operand consists of more than one byte, the bytes may be fetched from storage piecemeal, one byte at a time. Unless otherwise specified, the bytes are not necessarily fetched in any particular sequence.

Storage-Operand Store References

When the bytes of a storage operand participate in the instruction execution only as a destination, to the extent of being replaced by the result, the operand is called a store-type operand, and the reference to the location is called a storage-operand store reference. A store-type operand is identified in individual instruction definitions by indicating that the access exception is for store.

All bits within a single byte of a store reference are accessed concurrently. When an operand consists of more than one byte, the bytes may be placed in storage piecemeal, one byte at a time. Unless otherwise specified, the bytes are not necessarily stored in any particular sequence.

The CPU may delay placing results in storage. There is no defined limit on the length of time that results may remain pending before they are stored.

This delay does not affect the sequence in which results are placed in storage. The results of one instruction are placed in storage after the results of all preceding instructions have been placed in storage and before any results of the succeeding instructions are stored as observed by channels. The results of any one instruction are stored in the sequence specified for that instruction.

The CPU does not fetch operands or DAT-table entries from a storage location until all information destined for that location by the CPU has been stored. Prefetched instructions may appear to be updated before the information appears in storage.

The stores are necessarily completed only as a result of a serializing operation and before the CPU enters the stopped state.

lost, both CPUs must use an instruction providing an interlocked update. It is possible, however, for a channel to make an access to the same storage location between the fetch and store portions of an interlocked update.

not necessarily the same for each store access; thus, intermediate results in a single-byte location may be observed by channels and other CPUs.

STORAGE-OPERAND CONSISTENCY

Single-Access References

A fetch reference is said to be a single-access reference if the value is fetched in a single access to each byte of the data field. In the case of overlapping operands, the location may be accessed once for each operand. A store-type reference is said to be a single-access reference if a single store access occurs to each byte location within the data field. An update reference is said to be single-access if both the fetch and store accesses are each single-access.

Except for the accesses associated with multiple-access operands and the stores associated with storage change and restoration for DAT-associated access exceptions, storage-operand references are single-access references.

Multiple-Access Operands

For some instructions, multiple accesses may be made to all or some of the bytes of a storage operand. The following cases are those storage-operand references which may be multiple-access ones.

1. The storage references associated with the decimal operands of the following instructions are not necessarily single-access references: the decimal instructions and the instructions CONVERT TO BINARY, CONVERT TO DECIMAL, MOVE WITH OFFSET, PACK, and UNPACK.
2. The operands of MOVE INVERSE.
3. The stores into that portion of the first operand of MOVE LONG which is filled with padding bytes.
4. TEST BLOCK.

When a storage-operand store reference to a location is not a single-access reference, the contents placed at a byte location are

Programming Notes

1. When multiple fetch accesses are made to a single byte that is being changed by a channel or another CPU, the result is not necessarily limited to that which could be obtained by fetching the bits individually. For example, the execution of MULTIPLY DECIMAL may consist in repetitive additions and subtractions each of which causes the second operand to be fetched from storage.
2. When CPU instructions are used to modify storage locations being accessed by a channel simultaneously, multiple store accesses to a single byte by the CPU may result in intermediate values being observed by a channel. To avoid these intermediate values (especially when modifying a CCW chain), only instructions making single-access references should be used.

Block-Concurrent References

For some references, the accesses to all bytes within a halfword, word, or doubleword are specified to be concurrent as observed by other CPUs. These accesses do not necessarily appear to a channel to include more than a byte at a time. The halfword, word, or doubleword is referred to in this section as a block. When a fetch-type reference is specified to be concurrent within a block, no store access to the block by another CPU is permitted during the time that bytes contained in the block are being fetched. I/O accesses to the bytes within the block may occur between the fetches. When a store-type reference is specified to be concurrent within a block, no access to the block, either fetch or store, is permitted during the time that the bytes within the block are being stored. I/O accesses to the bytes in the block may occur between the stores.

Consistency Specification

The storage-operand references associated with all S-format instructions and all

necessarily fetched from storage.

Programming Note

The independent fetching of a single location for each of two operands may affect the program execution in the following situation.

When the same storage location is designated by two operand addresses of an instruction, and a channel or another CPU causes the contents of the location to change during execution of the instruction, the old and new values of the location may be used simultaneously. For example, comparison of a field to itself may yield a result other than equal, or EXCLUSIVE-ORing of a field to itself may yield a result other than zero.

OTHER STORAGE REFERENCES

The restart, program, SVC, external, I/O, and machine-check PSWs are accessed doubleword-concurrent as observed by other CPUs. These references occur after the conceptually previous unit of operation and before the conceptually subsequent unit of operation. The relationship between the new-PSW fetch, the old-PSW store, and the interruption-code store is unpredictable.

Store accesses for interruption codes not stored within the old PSW are not necessarily single-access stores. The external and SVC interruption-code stores occur between the conceptually previous and conceptually subsequent operations. The program interruption-code store accesses may precede the storage-operand references associated with the instruction which results in the program interruption.

The CSW and I/O-communication-area stores occur within the conceptual limits of the interruption or I/O instruction with which they are associated.

Updating of the interval timer occurs after storage-operand references for the conceptually previous instruction and before storage-operand references for the conceptually subsequent instruction. Interval-timer updates can also occur within an interruptible instruction between units of operation.

SERIALIZATION

The sequence of functions performed by a CPU is normally independent of the functions performed by channels. Similarly, the sequence of functions performed by a channel is normally independent of the functions performed by other channels and by the CPU. However, at certain points in its execution, serialization of the CPU occurs. Serialization also occurs at certain points for channels.

CPU SERIALIZATION

All interruptions and the execution of certain instructions cause a serialization of CPU operations. A serialization operation consists in completing all conceptually previous storage accesses by the CPU, as observed by channels and other CPUs, before the conceptually subsequent storage accesses occur. Serialization affects the sequence of all CPU accesses to storage and to the storage keys, except for those associated with DAT-table-entry fetching.

Serialization is performed by all interruptions and by the execution of the following instructions:

1. The general instructions BRANCH ON CONDITION (BCR) with the M_1 and R_2 field containing all ones and all zeros, respectively, and COMPARE AND SWAP, COMPARE DOUBLE AND SWAP, STORE CLOCK, SUPERVISOR CALL, and TEST AND SET.
2. LOAD PSW and SET STORAGE KEY.
3. All I/O instructions.
4. PURGE TLB and SET PREFIX, which also cause the translation-lookaside buffer to be purged.
5. SIGNAL PROCESSOR, READ DIRECT, and WRITE DIRECT.
6. INVALIDATE PAGE TABLE ENTRY.
7. TEST BLOCK.
8. MOVE TO PRIMARY, MOVE TO SECONDARY, PROGRAM CALL, PROGRAM TRANSFER, SET ADDRESS SPACE CONTROL, and SET SECONDARY ASN.
9. The ASN-tracing function causes serialization to be performed before the trace action and after completion of the trace action.

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| Source Identification | Interruption Code | PSW-Mask Bits | | Mask Bits in Ctrl Registers | ILC Set | Execution of Instruction Identified by Old PSW |
|--|---|---------------|----|-----------------------------|---------|--|
| | | EC | BC | | | |
| MACHINE CHECK (old PSW 48, new PSW 112) | Locations 232-239 ¹ | | | | | |
| Exigent condition | | 13 | 13 | | x | terminated or nullified ² |
| Repressible cond | | 13 | 13 | 14, 4-7 | x | unaffected ² |
| SUPERVISOR CALL (old PSW 32, new PSW 96) | Locations 138-139 in EC mode and 34-35 in BC mode | | | | | |
| Instruction bits | 00000000 ssssssss | | | | 1,2 | completed |
| PROGRAM (old PSW 40, new PSW 104) | Locations 142-143 in EC mode and 42-43 in BC mode | | | | | |
| Operation | 00000000 p0000001 | | | | 1,2,3 | suppressed |
| Privileged oper | 00000000 p0000010 | | | | 1,2 | suppressed |
| Execute | 00000000 p0000011 | | | | 2 | suppressed |
| Protection | 00000000 p0000100 | | | | 0,1,2,3 | suppressed or terminated |
| Addressing | 00000000 p0000101 | | | | 0,1,2,3 | suppressed or terminated |
| Specification | 00000000 p0000110 | | | | 0,1,2,3 | suppressed or completed |
| Data | 00000000 p0000111 | | | | 2,3 | suppressed or terminated |
| Fixed-pt overflow | 00000000 p0001000 | 20 | 36 | | 1,2 | completed |
| Fixed-point divide | 00000000 p0001001 | | | | 1,2 | suppressed or completed |
| Decimal overflow | 00000000 p0001010 | 21 | 37 | | 2,3 | completed |
| Decimal divide | 00000000 p0001011 | | | | 2,3 | suppressed |
| Exponent overflow | 00000000 p0001100 | | | | 1,2 | completed |
| Exponent underflow | 00000000 p0001101 | 22 | 38 | | 1,2 | completed |
| Significance | 00000000 p0001110 | 23 | 39 | | 1,2 | completed |
| Floating-pt divide | 00000000 p0001111 | | | | 1,2 | suppressed |
| Segment transl | 00000000 p0010000 | | | | 1,2,3 | nullified |
| Page translation | 00000000 p0010001 | | | | 1,2,3 | nullified |
| Translation spec | 00000000 p0010010 | | | | 1,2,3 | suppressed |
| Special operation | 00000000 p0010011 | | | 0, 1 | 2 | suppressed |
| ASN-transl spec | 00000000 p0010111 | | | | 2 | suppressed |
| Space-switch event | 00000000 p0011100 | | | 1, 31 | 2 | completed |
| PC-transl spec | 00000000 p0011111 | | | | 2 | suppressed |
| AFX translation | 00000000 p0100000 | | | | 2 | nullified |
| ASX translation | 00000000 p0100001 | | | | 2 | nullified |
| LX translation | 00000000 p0100010 | | | | 2 | nullified |
| EX translation | 00000000 p0100011 | | | | 2 | nullified |
| Primary authority | 00000000 p0100100 | | | | 2 | nullified |
| Secondary auth | 00000000 p0100101 | | | | 2 | nullified |
| Monitor event | 00000000 p1000000 | | | 8, 16+ | 2 | completed |
| PER event | 00000000 1nnnnnn ³ | 1 | * | 9, 0-3 | 0,1,2,3 | completed ⁴ |

Interruption Action (Part 1 of 2)

SOURCE IDENTIFICATION

The six classes of interruptions (external, I/O, machine check, program, restart, and supervisor call) are distinguished by the storage locations at which the old PSW is stored and from which the new PSW is fetched. For most classes, the causes are further identified by an interruption code and, for some classes, by additional information placed in permanently assigned storage locations during the interruption. (See also the section "Assigned Storage Locations" in Chapter 3, "Storage.") For external, I/O, program, and supervisor-call interruptions, the interruption code consists of 16 bits.

For external interruptions in the EC mode, the interruption code is stored at locations 134-135. In the BC mode, the interruption code is placed in the old PSW.

For I/O interruptions in the EC mode, the interruption code, which contains the I/O address, is stored at locations 186-187. In the BC mode, the interruption code is placed in the old PSW. Additional information is provided by the contents of the channel-status word (CSW) stored at location 64. Further information may be provided by the limited channel logout stored at location 176 and by the I/O extended logout.

For machine-check interruptions, the interruption code consists of 64 bits and is stored at locations 232-239. Additional information for identifying the cause of the interruption and for recovering the state of the machine may be provided by the contents of the machine-check logout and save areas. (See Chapter 11, "Machine-Check Handling.")

For program interruptions in the EC mode, the interruption code is stored at locations 142-143, and the instruction-length code is stored in bit positions 5 and 6 of location 141. In the BC mode, the interruption code and instruction-length code are placed in the old PSW. Further information may be provided in the form of the translation-exception address, monitor-class number, monitor code, PER code, and PER address, which are stored at locations 144-159.

For restart interruptions in the EC mode, no interruption code is stored. In the BC mode, an interruption code of zero is placed in the old PSW.

For supervisor-call interruptions in the EC mode, the interruption code is stored at locations 138-139, and the instruction-length code is stored in bit positions 5 and 6 of location 137. In the BC mode, the

interruption code and instruction-length code are placed in the old PSW.

ENABLING AND DISABLING

By means of mask bits in the current PSW and in control registers, the CPU may be enabled or disabled for all external, I/O, and machine-check interruptions and for some program interruptions. When a mask bit is one, the CPU is enabled for the corresponding class of interruptions, and these interruptions can take place.

When a mask bit is zero, the CPU is disabled for the corresponding interruptions. The conditions that cause I/O interruptions remain pending. External-interruption conditions either remain pending or persist until the cause is removed. Machine-check-interruption conditions, depending on the type, are ignored, remain pending, or cause the CPU to enter the check-stop state. The disallowed program-interruption conditions are ignored, except that some causes are indicated also by the setting of the condition code.

Program interruptions for which mask bits are not provided, as well as the supervisor-call and restart interruptions, are always taken.

The mask bits may allow or disallow all interruptions within the class, or they may selectively allow or disallow interruptions for particular causes. This control may be provided by mask bits in the PSW that are assigned to particular causes, such as the bits assigned to the four maskable program-interruption conditions. Alternatively, there may be a hierarchy of masks, where a mask bit in the PSW controls all interruptions within a type, and mask bits in a control register provide more detailed control over the sources.

When the mask bit is one, the CPU is enabled for the corresponding interruptions. When the mask bit is zero, these interruptions are disallowed. Interruptions that are controlled by a hierarchy of masks are allowed only when all controlling mask bits are ones.

Programming Notes

1. Mask bits in the PSW provide a means of disallowing all maskable interruptions; thus, subsequent interruptions can be disallowed by the new PSW introduced by an interruption.

exception due to a PSW-format error is recognized as part of early exception recognition and the PSW has been introduced by LOAD PSW or an interruption. (See the section "Exceptions Associated with the PSW" later in this chapter.) In the case of LOAD PSW, the address of the instruction has been replaced by the instruction address of the new PSW. When the invalid PSW is introduced by an interruption, the PSW-format error cannot be attributed to an instruction.

On some models without the translation feature, an ILC of zero occurs also when an addressing exception or a protection exception is recognized for a store-type reference. In these cases, the interruption due to the exception is delayed, the length of time or number of instructions of the delay being unpredictable. Neither the location of the instruction causing the exception nor the length of the last-executed instruction is made available to the program. This type of interruption is sometimes referred to as an imprecise program interruption.

In the case of LOAD PSW and the supervisor-call interruption, a PER event may be indicated concurrently with a specification exception having an ILC of 0.

ILC on Instruction-Fetching Exceptions

When a program interruption occurs because of an exception that prohibits access to the instruction, the instruction-length code cannot be set on the basis of the first two bits of the instruction. As far as the significance of the ILC for this case is concerned, the following two situations are distinguished:

1. When an odd instruction address causes a specification exception to be recognized or when an addressing, protection, or translation-specification exception is encountered on fetching an instruction, the ILC is set to 1, 2, or 3, indicating the multiple of 2 by which the instruction address has been incremented. It is unpredictable whether the instruction address is incremented by 2, 4, or 6. By reducing the instruction address in the old PSW by the number of halfword locations indicated in the ILC, the address originally appearing in the PSW may be obtained.
2. When a segment-translation or page-translation exception is recognized while fetching an instruction, including the target instruction of EXECUTE, the ILC is arbitrarily set to

1, 2, or 3. In this case, the operation is nullified, and the instruction address is not incremented.

The ILC is not necessarily related to the first two bits of the instruction when the first halfword of an instruction can be fetched but an access exception is recognized on fetching the second or third halfword. The ILC may be arbitrarily set to 1, 2, or 3 in these cases. The instruction address is or is not updated, as described in situations 1 and 2 above.

When any exceptions other than segment translation or page translation are encountered on fetching the target instruction of EXECUTE, the ILC is 2.

Programming Notes

1. A nonzero instruction-length code for a program interruption indicates the number of halfword locations by which the instruction address in the old PSW must be reduced to obtain the address of the last instruction executed, unless one of the following situations exists:
 - a. The interruption is caused by an exception resulting in nullification.
 - b. An interruption for a PER event occurs before the execution of an interruptible instruction is ended.
 - c. The interruption is caused by a PER event due to LOAD PSW or a branch or linkage instruction, including SUPERVISOR CALL.
 - d. The interruption is caused by an access exception encountered in fetching an instruction, and the instruction address has been introduced into the PSW by a means other than sequential operation (by a branch instruction, LOAD PSW, or an interruption).
 - e. The interruption is caused by a specification exception because of an odd instruction address.
 - f. The interruption is caused by an early specification exception or by an access exception encountered in fetching an instruction, and changes have been made to the parameters that control the relation between the logical and real instruction address. The

one).

- An access exception (addressing, page-translation, protection, segment-translation, or translation-specification) is associated with the location designated by the instruction address or with the location of the second or third halfword of the instruction starting at the designated address.

The instruction-length code and instruction address stored in the program old PSW under these conditions are discussed in the section "ILC on Instruction-Fetching Exceptions" in this chapter.

If the invalid PSW causes the CPU to be enabled for a pending I/O, external, or machine-check interruption, the corresponding interruption occurs, and the PSW invalidity is not recognized. Similarly, the specification or access exception is not recognized in a PSW specifying the wait state.

Programming Notes

1. The execution of LCAD PSW, SET SYSTEM MASK, STORE THEN AND SYSTEM MASK, and STORE THEN OR SYSTEM MASK is suppressed on an addressing or protection exception, and hence the program old PSW provides information concerning the program causing the exception.
2. When the first halfword of an instruction can be fetched but an access exception is recognized on fetching the second or third halfword, the ILC is not necessarily related to the operation code.
3. If the new PSW introduced by an interruption contains a PSW-format error, a string of interruptions occurs. (See the section "Priority of Interruptions" in this chapter.)

EXTERNAL INTERRUPTION

The external interruption provides a means by which the CPU responds to various signals originating either from within or from without the system.

An external interruption causes the old PSW to be stored at location 24 and a new PSW to be fetched from location 88.

The source of the interruption is

identified in the interruption code. When the old PSW specifies the EC mode, the interruption code is stored at locations 134-135. When the old PSW specifies the BC mode, the interruption code is placed in bit positions 16-31 of the old PSW, and the instruction-length code is unpredictable.

Additionally, for the malfunction-alert, emergency-signal, and external-call conditions, a 16-bit CPU address is associated with the source of the interruption and is stored at locations 132-133 in both the EC and BC modes. When the CPU address is stored, bit 6 of the interruption code is set to one. For all other conditions, no CPU address is stored, and bit 6 of the interruption code is set to zero. When bit 6 is zero and the old PSW specifies the EC mode, zeros are stored at locations 132-133. When bit 6 is zero and the old PSW specifies the BC mode, the contents of locations 132-133 remain unchanged.

| For the service-signal interruption, a
| 32-bit parameter is associated with the
| interruption and is stored at locations
| 128-131 in both EC and BC modes. Bit 2 of
| the external-interruption code indicates
| that a parameter has been stored.

External-interruption conditions are of two types: those for which an interruption request condition is held pending, and those for which the condition directly requests the interruption. Clock comparator, CPU timer, and TOD-clock sync check are conditions which directly request external interruptions. If a condition which directly requests an external interruption is removed before the request is honored, the request does not remain pending, and no interruption occurs. Conversely, the request is not cleared by the interruption, and if the condition persists, more than one interruption may result from a single occurrence of the condition.

When several interruption requests for a single source are generated before the interruption is taken, and the interruption condition is of the type which is held pending, only one request for that source is preserved and remains pending.

An external interruption for a particular source can occur only when the CPU is enabled for interruption by that source. The external interruption occurs at the completion of a unit of operation. Whether the CPU is enabled for external interruption is controlled by the external mask, PSW bit 7, and external subclass mask bits in control register 0. Each source for an external interruption has a subclass mask bit assigned to it, and the source can cause an interruption only when the

separate emergency-signal request pending in the receiving CPU for each configured CPU, including the receiving CPU itself.

The emergency signal condition is indicated by an external-interruption code of 1201 (hex). The address of the CPU that issued the SIGNAL PROCESSOR instruction is stored at locations 132-133.

The subclass-mask bit is in bit position 17 of control register 0. This bit is initialized to zero.

EXTERNAL CALL

An interruption request for an external call is generated when the CPU accepts the external-call order specified by a SIGNAL PROCESSOR instruction addressing this CPU. The instruction may have been executed by this CPU or by another CPU configured to this CPU. The request is preserved and remains pending in the receiving CPU until it is cleared. The pending request is cleared when it causes an interruption and by CPU reset.

Only one external-call request, along with the processor address, may be held pending in a CPU at a time.

The external-call condition is indicated by an external-interruption code of 1202 (hex). The address of the CPU that issued the SIGNAL PROCESSOR instruction is stored at locations 132-133.

The subclass-mask bit is in bit position 18 of control register 0. This bit is initialized to zero.

EXTERNAL SIGNAL

An interruption request for an external signal is generated when a signal is received on one or more of the signal-in lines. Up to six signal-in lines may be connected, providing for external signal 2 through external signal 7. The request is preserved and remains pending in the CPU until it is cleared. The pending request is cleared when it causes an interruption and by CPU reset.

Facilities are provided for holding a separate external-signal request pending for each of the six lines.

External signals 2-7 are indicated by setting to one interruption-code bits 10-15, respectively. Bits 0-7 are set to zeros, and any other bits in the rightmost

byte are set to zeros unless set to ones for other conditions that are concurrently indicated.

All external signals are subject to control by the subclass-mask bit in bit position 26 of control register 0. This bit is initialized to one.

External signaling is independent of I/O operations and interruptions.

Programming Note

The pattern presented in bit positions 10-15 of the interruption code depends on the pattern received before the interruption is taken. Because of circuit skew, all simultaneously generated external signals do not necessarily arrive at the same time, and some may not be included in the external interruption resulting from the earliest signals. These late signals may cause another interruption to be taken.

INTERRUPT KEY

An interruption request for the interrupt key is generated when the operator activates that key. The request is preserved and remains pending in the CPU until it is cleared. The pending request is cleared when it causes an interruption and by CPU reset.

When the interrupt key is activated while the CPU is in the load state, it depends on the model whether an interruption request is generated or the condition is lost.

The interrupt-key condition is indicated by setting bit 9 in the interruption code to one and by setting bits 0-7 to zeros. Bits 8 and 10-15 are zeros unless set to ones for other conditions that are concurrently indicated.

The subclass-mask bit is in bit position 25 of control register 0. This bit is initialized to one.

INTERVAL TIMER

An interruption request for the interval timer is generated when the interval timer is decremented from a positive number or zero to a negative number. The request is preserved and remains pending in the CPU until it is cleared. The pending request is cleared when it causes an interruption

condition.

The TOD-clock-sync-check condition is indicated by an external-interruption code of 1003 (hex).

The subclass-mask bit is in bit position 19 of control register 0. This bit is initialized to zero.

INPUT/OUTPUT INTERRUPTION

The input/output (I/O) interruption provides a means by which the CPU responds to conditions in I/O devices and channels.

A request for an I/O interruption may occur at any time, and more than one request may occur at the same time. The requests are preserved and remain pending in channels or devices until accepted by the CPU. The I/O interruption occurs at the completion of a unit of operation. Priority is established among requests so that only one interruption request is processed at a time. For more details, see the section "Input/Output Interruptions" in Chapter 12, "Input/Output Operations."

When the CPU becomes enabled for I/O interruptions and a channel has established priority for a pending I/O-interruption condition, the interruption occurs at the completion of the instruction execution or interruption that causes the enabling.

An I/O interruption causes the old PSW to be stored at location 56, a channel status word to be stored at location 64, and a new PSW to be fetched from location 120. Upon detection of equipment errors, additional information may be stored in the form of a limited channel logout at location 176 and in the form of an I/O extended logout starting at the location designated by the contents of locations 173-175.

When the old PSW specifies the EC mode, the I/O address identifying the channel and device causing the interruption is stored at locations 186-187, and zeros are stored at location 185. When the old PSW specifies the BC mode, the interruption code in PSW bit positions 16-31 contains the I/O address, and the instruction-length code in the PSW is unpredictable.

An I/O interruption can occur only while the CPU is enabled for interruption by the channel presenting the request. Mask bits in the PSW and channel masks in control register 2 determine whether the CPU is enabled for interruption by a channel; the method of control depends on whether the current PSW specifies the EC or BC mode.

The channel-mask bits in control register 2 start at bit position 0 and extend for as many contiguous bit positions as the number of channels provided. The assignment is such that a bit is assigned to the channel whose address is equal to the position of the bit in control register 2. Channel-mask bits for installed channels are initialized to one. The state of the channel-mask bits for unavailable channels is unpredictable.

When the current PSW specifies the EC mode, each channel is controlled by the I/O-mask bit, PSW bit 6, and by the corresponding channel-mask bit in control register 2; the channel can cause an interruption only when the I/O-mask bit is one and the corresponding channel-mask bit is one.

When the current PSW specifies the BC mode, interruptions from channels 6 and up are controlled by the I/O-mask bit, PSW bit 6, in conjunction with the corresponding channel-mask bit: the channel can cause an interruption only when the I/O-mask bit is one and the corresponding channel-mask bit is one. Interruptions from channels 0-5 are controlled by channel-mask bits 0-5 in the PSW: an interruption can occur only when the mask bit corresponding to the channel is one. In the BC mode, bits 0-5 in control register 2 do not participate in controlling I/O interruptions; they are, however, preserved in the control register if the corresponding channels are installed.

MACHINE-CHECK INTERRUPTION

The machine-check interruption is a means for reporting to the program the occurrence of equipment malfunctions. Information is provided to assist the program in determining the location of the fault and extent of the damage.

A machine-check interruption causes the old PSW to be stored at location 48 and a new PSW to be fetched from location 112. When the old PSW specifies the BC mode, the contents of the interruption-code and ILC fields in the old PSW are unpredictable.

The cause and severity of the malfunction are identified by a 64-bit machine-check-interruption code stored at locations 232-239. Further information identifying the cause of the interruption and the location of the fault may be stored at locations 216-511 and in the area starting with the location designated by the contents of control register 15.

The interruption action and the storing of the associated information are under the

of the instruction that caused the reference. However, on some models without the translation feature, an ILC of zero occurs when an addressing exception is recognized for a store-type reference.

fetching of an instruction or during the fetching of a DAT table entry associated with an instruction fetch, it is unpredictable whether the ILC is 1, 2, or 3. When an addressing exception is associated with fetching the target of EXECUTE, the ILC is 2.

When the exception occurs during the

| Exception | Action on | | |
|---|-----------------------|-------------------|---|
| | DAT-Table-Entry Fetch | Instruction Fetch | Operand Reference |
| Addressing exception | Suppress | Suppress | Suppress for LPSW, SCKC, SPT, SPX, SSM, STNSM, STOSM, and TPROT. Terminate for all others ¹ |
| Protection exception for key-controlled protection | — | Suppress | Suppress for LPSW, SCKC, SPT, SPX, SSM, STNSM, and STOSM. Terminate for all others ¹ |
| Protection exception for low-address protection | — | — | Suppress for STNSM and STOSM. Terminate for all others ¹ |
| <u>Explanation:</u> | | | |
| — Not applicable | | | |
| ¹ For termination, changes may occur only to result fields. In this context, "result field" includes condition code, registers, and storage locations, if any, which are designated to be changed by the instruction. However, no change is made to a storage location or a key in storage when the reference causes an access exception. Therefore, if an instruction is due to change only the contents of a field in main storage, and every byte of that field would cause an access exception, the operation is suppressed. | | | |

Summary of Action for Addressing and Protection Exceptions

two conditions are met:

- a. The invalid sign of the source field is not located in the numeric portion of the result field.
- b. The sign code appears in a position specified by the instruction to be checked for a valid sign. (This condition excludes the first operand of ZERO AND ADD and both operands of EDIT AND EDIT AND MARK.)

Decimal-Divide Exception

A decimal-divide exception is recognized when in decimal division the divisor is zero or the quotient exceeds the specified data-field size.

The decimal-divide exception is indicated only if the sign codes of both the divisor and dividend are valid and only if the digit or digits used in establishing the exception are valid.

The operation is suppressed.

The instruction-length code is 2 or 3.

Decimal-Overflow Exception

A decimal-overflow exception is recognized when one or more significant high-order digits are lost because the destination field in a decimal operation is too short to contain the result.

The interruption may be disallowed by PSW bit 21 in the EC mode and by PSW bit 37 in the BC mode.

The operation is completed. The result is obtained by ignoring the overflow information, and condition code 3 is set.

The instruction-length code is 2 or 3.

Execute Exception

The execute exception is recognized when the target instruction of EXECUTE is another EXECUTE.

The operation is suppressed.

The instruction-length code is 2.

Exponent-Overflow Exception

An exponent-overflow exception is recognized when the result characteristic in floating-point addition, subtraction, multiplication, or division exceeds 127 and the result fraction is not zero.

The operation is completed. The fraction is normalized, and the sign and fraction of the result remain correct. The result characteristic is made 128 smaller than the correct characteristic.

The instruction-length code is 1 or 2.

Exponent-Underflow Exception

An exponent-underflow exception is recognized when the result characteristic in floating-point addition, subtraction, multiplication, halving, or division is less than zero and the result fraction is not zero.

The interruption may be disallowed by PSW bit 22 in the EC mode and by PSW bit 38 in the BC mode.

The operation is completed. The exponent-underflow mask also affects the result of the operation. When the mask bit is zero, the sign, characteristic, and fraction are set to zero, making the result a true zero. When the mask bit is one, the fraction is normalized, the characteristic is made 128 larger than the correct characteristic, and the sign and fraction remain correct.

The instruction-length code is 1 or 2.

EX-Translation Exception

| An EX-translation exception is recognized
| during the PC-number translation in PROGRAM
| CALL when the entry-table entry indicated
| by the entry-table index part of the PC
| number is beyond the length of the entry
| table as designated by the linkage-table
| entry.

| The PC number is stored in bit positions
| 12-31 of the word at location 144, and the
| high-order 12 bits of the word are set to
| zeros.

| The operation is nullified, and the
| instruction-length code is 2.

are stored at location 148. The address specified by the B₁ and D₁ fields of the instruction forms the monitor code, which is stored at locations 157-159. Zeros are stored at location 156.

The operation is completed, and the instruction-length code is 2.

Operation Exception

An operation exception is recognized when the CPU encounters an instruction with an invalid operation code. The operation code may not be assigned, or the instruction with that operation code may not be available on the CPU.

For the purpose of checking the operation code of an instruction, the operation code is defined as follows:

1. When the first eight bits of an instruction have the value B2 or E5 (hex), the first 16 bits form the operation code.
2. In all other cases, the first eight bits alone form the operation code.

The operation is suppressed.

The instruction-length code is 1, 2, or 3.

Programming Notes

1. Some models may offer instructions not described in this publication, such as those provided for emulation or as part of special or custom features. Consequently, operation codes not described in this publication do not necessarily cause an operation exception to be recognized. Furthermore, these instructions may cause modes of operation to be set up or may otherwise alter the machine so as to affect the execution of subsequent instructions. To avoid causing such an operation, an instruction with an operation code not described in this publication should be issued only when the specific function associated with the operation code is desired.
2. The operation code 00, with a two-byte instruction format, currently is not assigned. It is improbable that this operation code will ever be assigned.
3. In the case of I/O instructions with the values 9C, 9D, 9E, and 9F in bit

positions 0-7, the value of bit 15 is used to distinguish between two instructions. Bits 8-14, however, are not checked for zeros, and these operation codes never cause an operation exception to be recognized.

To ensure that presently written programs run if and when the I/O operation codes (9C, 9D, 9E, and 9F) are extended further to provide for new functions, only zeros should be placed in the unused bit positions in the second op-code byte. In accordance with these recommendations, the operation codes for the I/O instructions are shown as 9C00, 9C01, 9D00, etc.

Page-Translation Exception

A page-translation exception is recognized when:

1. The page-table entry indicated by the page-index portion of a virtual address is outside the page table.
2. The page-invalid bit is one.

The exception is recognized as part of the execution of the instruction that needs the page-table entry in the translation of either the instruction or operand address, except for the operand address in LOAD REAL ADDRESS and TEST PROTECTION, in which case the condition is indicated by the setting of the condition code.

The unit of operation is nullified.

The segment-and-page portion of the virtual address causing the exception is stored at locations 145-147. With DAS, bit 0 of location 144 is set to zero if the virtual address was relative to the primary address space, and it is set to one if it was relative to the secondary address space. Without DAS, bit 0 of location 144 is set to zero. Bits 1-7 of location 144 are set to zeros. When 2K-byte pages are used, the low-order 11 bits of the address are unpredictable; when 4K-byte pages are used, the low-order 12 bits of the address are unpredictable.

When the exception occurs during a reference to an operand location, the instruction-length code (ILC) is 1, 2, or 3 and indicates the length of the instruction causing the exception.

When the exception occurs during fetching of an instruction, it is unpredictable whether the ILC is 1, 2, or 3. When the exception occurs during a reference to the

Protection Exception

A protection exception is recognized in the following situations:

1. Key-Controlled Protection: The CPU attempts to access a storage location that is protected against the type of reference, and the access key does not match the storage key.
2. Low-Address Protection: The CPU attempts a store that is subject to low-address protection, the address is in the range 0-511, and bit 3 of control register 0 is one.

The execution of an instruction is suppressed when the location of the instruction, including the location of the target instruction of EXECUTE, is protected against fetching.

Except for some specific instructions whose execution is suppressed, the operation is terminated when a protection exception is encountered during a reference to an operand location. See the figure "Summary of Action for Protection and Addressing Exceptions," which is included in the section "Addressing Exception" in this chapter.

On fetching, the protected information is not loaded into an addressable register nor moved to another storage location. When a part of an operand is protected against storing and part is not, storing may be performed in the unprotected part. However, the contents of a protected location remain unchanged.

For a protected operand location, the instruction-length code (ILC) is 1, 2, or 3, designating the length of the instruction that caused the reference. However, on some models without the translation feature, an ILC of zero occurs when a protection exception is recognized for a store-type reference. When the exception occurs during fetching of an instruction, it is unpredictable whether the ILC is 1, 2, or 3.

Secondary-Authority Exception

A secondary-authority exception is recognized during ASN authorization in the SET SECONDARY ASN (SSAR-ss) operation when either:

1. The authority-table entry indicated by the authority index in control

register 4 is beyond the length of the authority table designated by the ASN-second-table entry.

2. The secondary-authority mask bit indicated by the authority index is zero.

The ASN being translated is stored at locations 146-147, and locations 144-145 are set to zeros.

The operation is nullified, and the instruction-length code is 2.

Segment-Translation Exception

A segment-translation exception is recognized when:

1. The segment-table entry indicated by the segment-index portion of a virtual address is outside the segment table.
2. The segment-invalid bit is one.

The exception is recognized as part of the execution of the instruction that needs the segment-table entry in the translation of either the instruction or operand address, except for the operand address in LOAD REAL ADDRESS and TEST PROTECTION, in which case the condition is indicated by the setting of the condition code.

The unit of operation is nullified.

The segment-and-page portion of the virtual address causing the exception is stored at locations 145-147. With DAS, bit 0 of location 144 is set to zero if the virtual address was relative to the primary address space, and it is set to one if it was relative to the secondary address space. Without DAS, bit 0 of location 144 is set to zero. Bits 1-7 of location 144 are set to zeros. When 2K-byte pages are used, the low-order 11 bits of the address are unpredictable; when 4K-byte pages are used, the low-order 12 bits of the address are unpredictable.

When the exception occurs during a reference to an operand location, the instruction-length code (ILC) is 1, 2, or 3 and indicates the length of the instruction causing the exception.

When the exception occurs during fetching of an instruction, it is unpredictable whether the ILC is 1, 2, or 3. When the exception occurs during the fetching of the target of EXECUTE, the ILC is 2.

specified for an extended operand.

6. The multiplier or divisor in decimal arithmetic exceeds 15 digits and sign.
7. The length of the first-operand field is less than or equal to the length of the second-operand field in decimal multiplication or division.
8. Bit positions 8-11 of MONITOR CALL do not contain zeros.
9. A one is introduced into an unassigned bit position of an EC-mode PSW (that is, any of bit positions 0, 2-4, 17, or 24-39, or bit position 16 when DAS is not installed). This is called an early PSW specification exception.
10. A PSW is introduced in which the EC mode is specified (PSW bit 12 is one) in a CPU that does not have the EC facility installed.
11. A one is introduced into an EC-mode PSW bit position, other than in the program-mask field, specifying a mode or facility that is not installed in the CPU. For example, bit 16 is one, and DAS is not installed. This is called an early PSW specification exception.
12. Bits 20-22 of the second-operand address of SET ADDRESS SPACE CONTROL are not zeros.
13. The high-order eight bits of the general register specified by the R_2 field of PROGRAM TRANSFER are not zeros.
14. The instruction PROGRAM CALL, PROGRAM TRANSFER, or SET SECONDARY ASN is encountered with tracing enabled and (1) the address of the trace-header address in location 84 does not specify a doubleword boundary, or (2) the trace-entry address in the trace header does not specify a 32-byte boundary.

The execution of the instruction identified by the old PSW is suppressed. However, for early PSW specification exceptions (causes 9-11), the operation that introduces the new PSW is completed, but an interruption occurs immediately thereafter.

Except as noted below, the ILC is 1, 2, or 3, designating the length of the instruction causing the exception.

When the instruction address is odd (cause 1), it is unpredictable whether the ILC is 1, 2, or 3.

When the exception is recognized because of

an early PSW specification exception and the exception has been introduced by LOAD PSW or an interruption, the ILC is 0. When the exception is introduced by SET SYSTEM MASK or STORE THEN OR SYSTEM MASK, the ILC is 2.

See the section "Exceptions Associated with the PSW" in this chapter for a discussion of when the exceptions associated with the PSW are recognized.

Translation-Specification Exception

A translation-specification exception is recognized when:

1. Bit positions 8-12 of control register 0 do not contain one of the codes 01000, 01010, 10000, or 10010.
2. Bit positions 4-7 and 29-30 in a valid segment-table entry do not contain zeros. (On some models, these bit positions are ignored and not checked for zeros.)
3. Bit position 14, when 2K-byte pages are used, or bit positions 13-14, when 4K-byte pages are used, in a valid page-table entry do not contain zeros.

The exception is recognized only as part of the execution of an instruction using address translation; that is, when DAT is on and an instruction encounters a logical address, instruction address, or virtual address, or when LOAD REAL ADDRESS is executed. Cause 1 is recognized on any translation attempt; causes 2 and 3 are recognized only for table entries that are actually used.

The unit of operation is suppressed.

When the exception occurs during a reference to an operand location, the instruction-length code (ILC) is 1, 2, or 3 and indicates the length of the instruction causing the exception.

When the exception occurs during fetching of an instruction, it is unpredictable whether the ILC is 1, 2, or 3. When the exception occurs during the fetching of the target of EXECUTE, the ILC is 2.

Programming Note

When a translation-specification exception is recognized in the process of translating an instruction address, the operation is suppressed. In this case, the

| Condition | Translation of Logical Address | | Translation of Virtual Address for LRA | | Translation of Logical Address for TPROT | |
|--|--------------------------------|----------|--|----------|--|----------|
| | Indic | Action | Indic | Action | Indic | Action |
| <u>Control-register-0 contents</u> ¹ Invalid encoding of bits 8-12 | TS | Suppress | TS | Suppress | TS | Suppress |
| <u>Segment-table entry</u> Segment-table-length violation | ST | Nullify | cc3 | Complete | cc3 | Complete |
| Entry protected against fetching or storing | - | - | - | - | - | - |
| Invalid address of entry | A | Suppress | A | Suppress | A | Suppress |
| I bit on | ST | Nullify | cc1 | Complete | cc3 | Complete |
| One in an unassigned bit position ² | TS | Suppress | TS | Suppress | TS | Suppress |
| <u>Page-table entry</u> Page-table-length violation | PT | Nullify | cc3 | Complete | cc3 | Complete |
| Entry protected for fetching or storing | - | - | - | - | - | - |
| Invalid address of entry | A | Suppress | A | Suppress | A | Suppress |
| I bit on | PT | Nullify | cc2 | Complete | cc3 | Complete |
| One in an unassigned bit position ² | TS | Suppress | TS | Suppress | TS | Suppress |
| <u>Access for instruction fetch</u> Location protected | P | Suppress | - | - | - | - |
| Invalid address | A | Suppress | - | - | - | - |
| <u>Access for operands</u> Location protected | P | Term.* | - | - | cc set ³ | Complete |
| Invalid address | A | Term.* | - | - | A | Suppress |

Explanation:

TS Translation-specification exception.

ST Segment-translation exception.

PT Page-translation exception.

A Addressing exception.

P Protection exception.

cc1 Condition code 1 set.

cc2 Condition code 2 set.

cc3 Condition code 3 set.

- The condition does not apply.

* Action is to terminate except where otherwise specified in this publication.

¹ A translation-specification exception for an invalid code in control register 0, bit positions 8-12, is recognized as part of the execution of the instruction using address translation; when DAT is on, it is recognized during translation of the instruction address, and, when DAT is off, it is only recognized during translation of the operand address of LRA.

² A translation-specification exception for a format error in a table entry is recognized only when the execution of an instruction requires the entry for the translation of an address.

³ The condition code is set as follows:
0 Operand location not protected
1 Fetches permitted, but stores not permitted
2 Neither fetches or stores permitted

Handling of Access Exceptions

With two conditions of the same priority, it is unpredictable which is indicated. In particular, the priority of access exceptions associated with the two parts of

an operand that crosses a page or protection boundary is unpredictable and is not necessarily related to the sequence specified for the access of bytes within

- 8.A Specification exception due to conditions other than those included in 2, 5, and 7.D above.
- 8.B⁴ Access exceptions for an access to an operand in storage.⁵
- 8.C⁴ Access exceptions for any other access to an operand in main storage.⁵
- 8.D Data exception.⁶
- 8.E Decimal-divide exception.⁷
- 9. Fixed-point divide, floating-point divide, and conditions, other than PER events, which result in completion. Either these conditions are mutually exclusive or their priority is specified in the corresponding definitions.

Explanation:

Numbers indicate priority, with "1" being the highest priority; letters indicate no priority.

- ¹ PSW errors which cause an immediate interruption may be introduced by a new PSW loaded as a result of an interruption or by the instructions LPSW, SSM, and STOSM. The priority shown in the chart is for a PSW error introduced by an interruption and may also be considered as the priority for a PSW error introduced by the previous instruction. The error is introduced only if the instruction encounters no other exceptions. The resulting interruption has a higher priority than any interruption caused by the instruction which would have been executed next; it has a lower priority, however, than any interruption caused by the instruction which introduced the erroneous PSW.
- ² Priorities 3, 4, and 5 are for the EXECUTE instruction, and priorities starting with 6 are for the target instruction. When no EXECUTE is encountered, priorities 3, 4, and 5 do not apply.
- ³ Separate accesses may occur for each halfword of an instruction. The second instruction halfword is accessed only if bits 0-1 of the instruction are not both zeros. The third instruction halfword is accessed only if bits 0-1 of the instruction are both ones. Access exceptions for one of these halfwords are not necessarily recognized if the instruction can be completed without use of the contents of the halfword or if an exception of priority 8 or 9 can be determined without the use of the halfword.
- ⁴ As in instruction fetching, separate accesses may occur for each portion of an operand. Each of these accesses is of equal priority, and the two entries 8.B and 8.C are listed to represent the relative priorities of exceptions associated with any two of these accesses. Access exceptions for INSERT STORAGE KEY, SET STORAGE KEY, RESET REFERENCE BIT, and LOAD REAL ADDRESS are also included in 8.B.
- ⁵ For MOVE LONG and COMPARE LOGICAL LONG, an access exception for a particular operand can be indicated only if the R field for that operand designates an even-numbered register.
- ⁶ The exception can be indicated only if the sign, digit, or digits responsible for the exception were fetched without encountering an access exception.
- ⁷ The exception can be indicated only if the digits used in establishing the exception, and also the signs, were fetched without encountering an access exception, and only if the digits used in establishing the exception are valid.

Priority of Program-Interruption Conditions (Part 2 of 2)

ASN-Translation Exceptions

The ASN-translation exceptions are those exceptions which are common to the process of translating an ASN in the instructions PROGRAM CALL, PROGRAM TRANSFER, and SET SECONDARY ASN. The exceptions and the priority in which they are detected are shown in the following figure.

1. Addressing exception for access to ASN-first-table entry.
2. AFX-translation exception due to I bit (bit 0) in ASN-first-table entry having the value one.
3. ASN-translation-specification exception due to invalid ones (bits 1-7, 28-31) in ASN-first-table entry.
4. Addressing exception for access to ASN-second-table entry.
5. ASX-translation exception due to I bit (bit 0) in ASN-second-table entry having the value one.
6. ASN-translation-specification exception due to invalid ones (bits 1-7, 30, 31, 60-63, 97-103) in ASN-second-table entry.

Priority of ASN-Translation Exceptions

Trace Exceptions

The trace exceptions are those exceptions which can be encountered while performing the implicit tracing function. The exceptions, except for PER storage alteration, and their priority are shown in the following chart. PER storage alteration is presented only if the instruction is completed.

1. Access exceptions (except for protection) for logical address 84.
2. Specification exception due to trace-header address in location 84 not designating a doubleword boundary.
- 3.A Access exceptions (including low-address protection) for first doubleword of trace header.
- 3.B Access exceptions (except for protection) for third word of trace header.
4. Specification exception due to trace-entry address in trace header not designating a 32-byte boundary.
5. Access exceptions (including low-address protection) for the trace entry.

Priority of Trace Exceptions

RESTART INTERRUPTION

The restart interruption provides a means for the operator or another CPU to invoke the execution of a specified program. The CPU cannot be disabled for this interruption.

A restart interruption causes the old PSW to be stored at location 8 and a new PSW, specifying the start of the program to be executed, to be fetched from location 0. The instruction-length code and interruption code are not stored in the EC mode. In the BC mode, the instruction-length code in the PSW is unpredictable, and zeros are stored in the interruption-code field.

If the CPU is in the operating state, the exchange of the PSWs occurs at the completion of the current unit of operation and after all pending interruption conditions for which the CPU is enabled have been taken. In this case, it depends on the model if the CPU temporarily enters the stopped state as part of the execution of the restart operation. If the CPU is in the stopped state, the CPU enters the operating state and exchanges the PSWs without first taking any pending interruptions.

The restart interruption is initiated by activating the restart key. In a

has an odd instruction address or causes an access exception to be recognized, another program interruption occurs. Since this second interruption introduces the same unacceptable PSW, a string of interruptions is established. These program exceptions are recognized as part of the execution of the following instruction, and the string may be broken by an external, I/O, machine-check, or restart interruption or by the stop function.

If the new PSW for a program interruption contains a one in an unassigned bit position of an EC-mode PSW, or if it specifies the EC mode in a CPU that does not have the EC mode, or if it specifies any other facility that is not installed on the CPU, another program interruption occurs. This condition is of higher priority than restart, I/O, external, or repressible machine-check conditions, or the stop function, and CPU reset has to be used to break the string of interruptions.

A string of interruptions for other interruption classes can also exist if the new PSW is enabled for the interruption just taken. These include machine-check interruptions, external interruptions, and I/O interruptions due to PCI conditions generated because of CCWs which form a loop. Furthermore, a string of interruptions involving more than one interruption class can exist. For example, assume that the CPU timer is negative and the CPU-timer subclass mask is one. If the external new PSW has a one in an unassigned bit position in the EC mode, and the program new PSW is enabled for external interruptions, then a string of interruptions occurs, alternating between external and program. Even more complex strings of interruptions are possible. As long as more interruptions must be serviced, the string of interruptions cannot be broken by employing the stop function; CPU reset is required.

Similarly, CPU reset has to be invoked to terminate the condition that exists when an interruption is attempted with a prefix value designating a storage location that is not available to the CPU.

On some models, when an excessive string of consecutive interruptions is detected which cannot be broken by means of the stop function, the CPU enters a special state that can be exited only by use of CPU reset.

Interruptions for all requests for which the CPU is enabled are taken before the CPU is placed in the stopped state. When the CPU is in the stopped state, restart has the highest priority.

Programming Note

The order in which concurrent interruption requests are honored can be changed to some extent by masking.

| | |
|---|------|
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| Binary-Integer Representation | 7-2 |
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complement of the maximum negative number, the result is the maximum negative number, and a fixed-point-overflow exception is recognized. An overflow does not result, however, when the maximum negative number is complemented as an intermediate result but the final result is within the representable range. An example of this case is a subtraction of the maximum negative number from minus one. The product of two maximum negative numbers is representable as a double-length positive number.

In discussions of signed binary integers in this publication, a signed binary integer includes the sign bit. Thus, the expression "32-bit signed binary integer" denotes an integer with 31 numeric bits and a sign bit, and the expression "64-bit signed binary integer" denotes an integer with 63 numeric bits and a sign bit.

In some operations, the result is achieved by the use of the one's complement of the number. The one's complement of a number is obtained by inverting each bit of the number.

In an arithmetic operation, a carry out of the numeric field of a signed binary integer changes the sign. However, in algebraic left-shifting the sign bit does not change even if significant high-order bits are shifted out.

Programming Notes

1. An alternate way of forming the two's complement of a signed binary integer is to invert all bits to the left of the rightmost one bit, leaving the rightmost one bit and all zero bits to the right of it unchanged.
2. The numeric bits of a signed binary integer may be considered to represent a positive value, with the sign representing a value of either zero or the maximum negative number.

SIGNED AND UNSIGNED BINARY ARITHMETIC

Addition of signed binary integers is performed by adding all bits of each operand, including the sign bits. When one of the operands is shorter, the shorter operand is considered to be extended on the left to the length of the longer operand by propagating the sign-bit value. If the carry out of the sign-bit position and the carry out of the high-order numeric bit position disagree, an overflow occurs. The

sign bit is not changed after the overflow.

Subtraction is performed by adding the one's complement of the second operand and a low-order one to the first operand.

Signed addition and subtraction produce an overflow when the result is outside the range of representation for signed binary integers. Specifically, for ADD and SUBTRACT, which operate on 32-bit signed binary integers, there is an overflow when the proper result would be greater than or equal to $+2^{31}$ or less than -2^{31} . The actual result placed in the general register after an overflow differs from the proper result by 2^{32} . An overflow causes a program interruption for fixed-point overflow if it is allowed.

Addition of unsigned binary integers is performed by adding all bits of each operand. When one of the operands is shorter, the shorter operand is considered to be extended on the left with zeros. Unsigned binary arithmetic is used in address arithmetic for adding the X, B, and D fields. It is also used to obtain the addresses of the function bytes in the instructions TRANSLATE and TRANSLATE AND TEST. Furthermore, unsigned binary arithmetic is used on 32-bit unsigned binary integers by the instructions ADD LOGICAL and SUBTRACT LOGICAL. Given the same two operands, ADD and ADD LOGICAL produce the same 32-bit result. The instructions differ only in the interpretation of this result. ADD interprets the result as a signed binary integer and inspects it for sign, magnitude, and overflow to set the condition code accordingly. ADD LOGICAL interprets the result as an unsigned binary integer and sets the condition code according to whether the result is zero and whether there was a carry out of the high-order bit position. Such a carry is not necessarily considered an overflow, and no program interruption can occur for ADD LOGICAL.

SUBTRACT LOGICAL differs from ADD LOGICAL in that the one's complement of the second operand and a low-order one are added to the first operand.

Programming Notes

1. Logical addition and subtraction may be used to program multiple-precision arithmetic. Thus, for multiple-precision binary-integer addition, ADD LOGICAL is used to add the corresponding lower-order parts of the operands. If the condition code indicates a carry, a one is added to

| Name | Mne- monic | Characteristics | | | | | | Op Code |
|---------------------------------------|---------------|-----------------|---|----|----|----|-----|------------|
| ADD | AR | RR | C | | | IF | R | 1A |
| ADD | A | RX | C | A | | IF | R | 5A |
| ADD HALFWORD | AH | RX | C | A | | IF | R | 4A |
| ADD LOGICAL | ALR | RR | C | | | | R | 1E |
| ADD LOGICAL | AL | RX | C | A | | | R | 5E |
| AND | NR | RR | C | | | | R | 14 |
| AND | N | RX | C | A | | | R | 54 |
| AND (character) | NC | SS | C | A | | | | ST D4 |
| AND (immediate) | NI | SI | C | A | | | | ST 94 |
| BRANCH AND LINK | BALR | RR | | | | | B R | 05 |
| BRANCH AND LINK | BAL | RX | | | | | B R | 45 |
| BRANCH AND SAVE | BASR | RR | | BS | | | B R | 0D |
| BRANCH AND SAVE | BAS | RX | | BS | | | B R | 4D |
| BRANCH ON CONDITION | BCR | RR | | | | 21 | B | 07 |
| BRANCH ON CONDITION | BC | RX | | | | | B | 47 |
| BRANCH ON COUNT | BCTR | RR | | | | | B R | 06 |
| BRANCH ON COUNT | BCT | RX | | | | | B R | 46 |
| BRANCH ON INDEX HIGH | BXH | RS | | | | | B R | 86 |
| BRANCH ON INDEX LOW OR EQUAL | BXLE | RS | | | | | B R | 87 |
| COMPARE | CR | RR | C | | | | | 19 |
| COMPARE | C | RX | C | A | | | | 59 |
| COMPARE AND SWAP | CS | RS | C | SW | A | SP | \$ | R ST BA |
| COMPARE DOUBLE AND SWAP | CDS | RS | C | SW | A | SP | \$ | R ST BB |
| COMPARE HALFWORD | CH | RX | C | | A | | | 49 |
| COMPARE LOGICAL | CLR | RR | C | | | | | 15 |
| COMPARE LOGICAL | CL | RX | C | A | | | | 55 |
| COMPARE LOGICAL (character) | CLC | SS | C | A | | | | D5 |
| COMPARE LOGICAL (immediate) | CLI | SI | C | A | | | | 95 |
| COMPARE LOGICAL CHARACTERS UNDER MASK | CLM | RS | C | A | | | | BD |
| COMPARE LOGICAL LONG | CLCL | FR | C | A | SP | | II | R 0F |
| CONVERT TO BINARY | CVB | RX | | A | | D | IK | R 4F |
| CONVERT TO DECIMAL | CVD | RX | | A | | | | ST 4E |
| DIVIDE | DR | FR | | | | SP | IK | R 1D |
| DIVIDE | D | RX | | A | | SP | IK | R 5D |
| EXCLUSIVE OR | XR | FR | C | | | | | R 17 |
| EXCLUSIVE OR | X | RX | C | A | | | | R 57 |
| EXCLUSIVE OR (character) | XC | SS | C | A | | | | ST D7 |
| EXCLUSIVE OR (immediate) | XI | SI | C | A | | | | ST 97 |
| EXECUTE | EX | RX | | AI | SP | | EX | 44 |
| INSERT CHARACTER | IC | RX | | A | | | | R 43 |
| INSERT CHARACTERS UNDER MASK | ICM | RS | C | A | | | | F BF |
| LOAD | LR | FR | | | | | | R 18 |
| LOAD | L | RX | | A | | | | R 58 |
| LOAD ADDRESS | LA | RX | | | | | | R 41 |
| LOAD AND TEST | LTR | FR | C | | | | | R 12 |

Summary of General Instructions (Part 1 of 3)

| Name | Mnemonic | Characteristics | Op Code |
|--------------------|----------|-----------------|---------|
| TRANSLATE AND TEST | TRT | SS C | R DD |
| UNPACK | UNPK | SS | ST F3 |

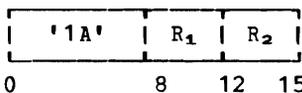
Explanation:

A Access exceptions for logical addresses
 AI Access exceptions for instruction address
 B PER branch event
 BS Branch-and-save feature
 C Condition code is set
 D Data exception
 EX Execute exception
 IF Fixed-point-overflow exception
 II Interruptible instruction
 IK Fixed-point-divide exception
 L New condition code loaded
 MI Move-inverse feature
 MO Monitor event
 R PER general-register-alteration event
 RR RR instruction format
 RS RS instruction format
 RX RX instruction format
 S S instruction format
 SI SI instruction format
 SP Specification exception
 SS SS instruction format
 ST PER storage-alteration event
 SW Conditional-swapping feature
 \$ Causes serialization
 \$1 Causes serialization and checkpoint synchronization
 \$1 Causes serialization and checkpoint synchronization when the M₁ and R₂ fields contain all ones and all zeros, respectively

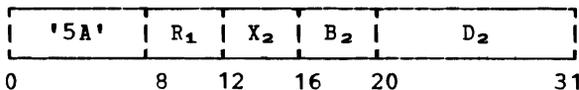
Summary of General Instructions (Part 3 of 3)

ADD

AR R₁, R₂ [RR]



A R₁, D₂ (X₂, B₂) [RX]



The second operand is added to the first operand, and the sum is placed in the first-operand location. The operands and the sum are treated as 32-bit signed binary integers.

An overflow causes a program interruption when the fixed-point-overflow mask bit is one.

Resulting Condition Code:

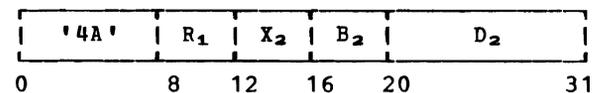
- 0 Sum is zero
- 1 Sum is less than zero
- 2 Sum is greater than zero
- 3 Overflow

Program Exceptions:

Access (fetch, operand 2 of A only)
 Fixed-Point Overflow

ADD HALFWORD

AH R₁, D₂ (X₂, B₂) [RX]



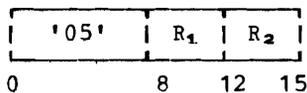
The second operand is added to the first operand, and the sum is placed in the first-operand location. The second operand is two bytes in length and is treated as a

Programming Notes

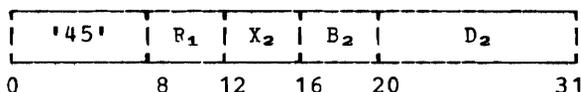
1. An example of the use of the AND instruction is given in Appendix A.
2. The instruction AND may be used to set a bit to zero.
3. Accesses to the first operand of NI and NC consist in fetching a first-operand byte from storage and subsequently storing the updated value. These fetch and store accesses to a particular byte do not necessarily occur one immediately after the other. Thus, the instruction AND cannot be safely used to update a location in storage if the possibility exists that another CPU or a channel may also be updating the location. An example of this effect is shown for the instruction OR (OI) in the section "Multiprogramming and Multiprocessing Examples" in Appendix A.

BRANCH AND LINK

BALR R_1, R_2 [RR]



BAL $R_1, D_2 (X_2, B_2)$ [RX]

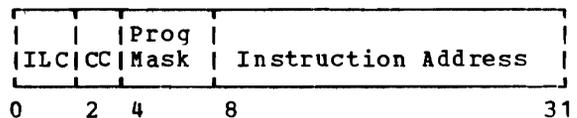


Information from the current PSW, including the updated instruction address, is loaded as link information in the general register designated by R_1 . Subsequently, the instruction address is replaced by the branch address.

In the RX format, the second-operand address is used as the branch address. In the RR format, bits 8-31 of the general register designated by R_2 are used as the branch address; however, when the R_2 field contains zeros, the operation is performed without branching. The branch address is computed before the link information is loaded.

The link information consists of the instruction-length code (ILC), the condition code (CC), the program mask bits, and the updated instruction address,

arranged in the following format:



The instruction-length code is 1 or 2.

Condition Code: The code remains unchanged.

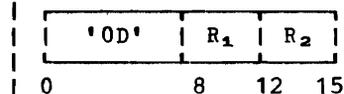
Program Exceptions: None.

Programming Notes

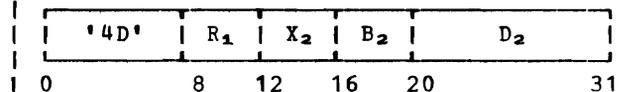
1. An example of the use of BRANCH AND LINK is given in Appendix A.
2. When the R_2 field in the RR format contains all zeros, the link information is loaded without branching.
3. When BRANCH AND LINK is the target instruction of EXECUTE, the instruction-length code is 2.
4. The format and the contents of the link information do not depend on whether the PSW specifies the EC or BC mode. In both modes, the link information is in the format of the rightmost 32 bit positions of the BC-mode PSW.

BRANCH AND SAVE

BASR R_1, R_2 [RR]



BAS $R_1, D_2 (X_2, B_2)$ [RX]



The updated instruction address, with eight high-order zeros appended, is saved as link information in the general register designated by R_1 . Subsequently, the instruction address is replaced by the branch address.

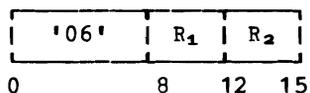
In the RX format, the second-operand

4. Execution of BCR 15,0 (that is, an instruction with a value of 07F0 hex) may result in significant performance degradation. To ensure optimum performance, the program should avoid use of BCR 15,0 except in cases when the serialization or the checkpoint-synchronization function is actually required.

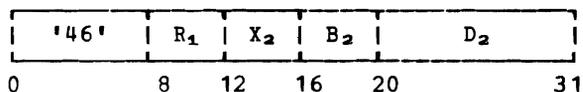
5. Note that the relation between the RR and RX formats in branch-address specification is not the same as in operand-address specification. For branch instructions in the RX format, the branch address is the address specified by X_2 , B_2 , and D_2 ; in the RR format, the branch address is contained in the register specified by R_2 . For operands, the address specified by X_2 , B_2 , and D_2 is the operand address, but the register specified by R_2 contains the operand itself.

BRANCH ON COUNT

BCTR R_1, R_2 [RR]



BCT $R_1, D_2 (X_2, B_2)$ [RX]



A one is subtracted from the first operand, and the result is placed in the first-operand location. The first operand and result are treated as 32-bit binary integers, with overflow ignored. When the result is zero, normal instruction sequencing proceeds with the updated instruction address. When the result is not zero, the instruction address in the current PSW is replaced by the branch address.

In the RX format, the second-operand address is used as the branch address. In the RR format, the contents of bit positions 8-31 of the general register specified by R_2 are used as the branch address; however, when the R_2 field contains zeros, the operation is performed without branching.

The branch address is computed before the counting operation.

Condition Code: The code remains unchanged.

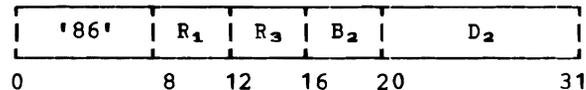
Program Exceptions: None.

Programming Notes

1. An example of the use of BRANCH ON COUNT is given in Appendix A.
2. The first operand and result can be considered as either signed or unsigned binary integers since the result of a binary subtraction is the same in both cases.
3. An initial count of one results in zero, and no branching takes place; an initial count of zero results in -1 and causes branching to be executed; an initial count of -1 results in -2 and causes branching to be executed; and so on. In a loop, branching takes place each time the instruction is executed until the result is again zero. Note that, because of the number range, an initial count of -2^{31} results in a positive value of $2^{31} - 1$.
4. Counting is performed without branching when the R_2 field in the RR format contains zero.

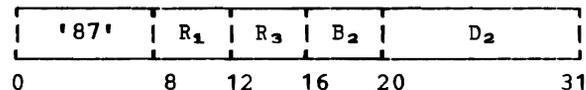
BRANCH ON INDEX HIGH

BXH $R_1, R_3, D_2 (B_2)$ [RS]



BRANCH ON INDEX LOW OR EQUAL

BXLE $R_1, R_3, D_2 (B_2)$ [RS]



An increment is added to the first operand, and the sum is compared with a compare value. The result of the comparison determines whether branching occurs. Subsequently, the sum is placed in the

For CS, the first and third operands are 32 bits in length, with each operand occupying a general register. The second operand is a word in storage.

For CDS, the first and third operands are 64 bits in length, with each operand occupying an even-odd pair of general registers. The second operand is a doubleword in storage.

When the result of the comparison is unequal, the second-operand location remains unchanged. However, on some models, the value may be fetched and subsequently stored back into the second-operand location. No access by another CPU to the second-operand location is permitted between the moment that the second operand is fetched for comparison and it is stored.

When an equal comparison occurs, no access by another CPU to the second-operand location is permitted between the moment that the second operand is fetched for comparison and the moment that the third operand is stored at the second-operand location.

Serialization is performed before the operand is fetched, and again after the operation is completed. CPU operation is delayed until all previous accesses by this CPU to storage have been completed, as observed by channels and other CPUs, and then the second operand is fetched. No subsequent instructions or their operands are accessed by this CPU until the execution of this instruction is completed, including placing the result value, if any, in storage, as observed by channels and other CPUs.

The second operand of CS must be designated on a word boundary. The R_1 and R_3 fields for CDS must each designate an even register, and the second operand for CDS must be designated on a doubleword boundary. Otherwise, a specification exception is recognized.

Resulting Condition Code:

| | |
|---|---|
| 0 | First and second operands equal, second operand replaced by third operand |
| 1 | First and second operands unequal, first operand replaced by second operand |
| 2 | -- |
| 3 | -- |

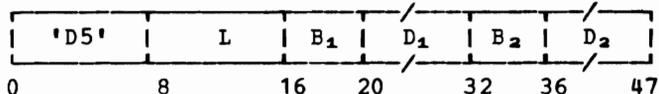
Program Exceptions:

Access (fetch and store, operand 2)
Operation (if the conditional-swapping feature is not installed)
Specification

Programming Notes

1. Several examples of the use of the COMPARE AND SWAP and COMPARE DOUBLE AND SWAP instructions are given in Appendix A.
2. The instruction CS can be used by programs sharing common storage areas in either a multiprogramming or multiprocessing environment. Two examples are:
 - a. By performing the following procedure, a program can modify the contents of a storage location even though the possibility exists that the program may be interrupted by another program that will update the location or even though the possibility exists that another CPU may simultaneously update the location. First, the entire word containing the byte or bytes to be updated is loaded into a general register. Next, the updated value is computed and placed in another general register. Then the instruction CS is executed with the R_1 field designating the register that contains the original value and the R_3 field designating the register that contains the updated value. If condition code 0 is set, the update has been successful. If condition code 1 is set, the storage location no longer contains the original value, the update has not been successful, and the general register designated by the R_1 field of the CS instruction contains the new current value of the storage location. When condition code 1 is set, the program can repeat the procedure using the new current value.
 - b. The instruction CS can be used for controlled sharing of a common storage area in a manner similar to that described in the programming note under TEST AND SET, but it provides the added capability of leaving a message when the common area is in use. To accomplish this, a word in storage can be used as a control word, with a zero value in the word indicating that the common area is not in use, a negative value indicating that the area is in use, and a nonzero positive value indicating that the common area is in use and that the value is the address of the most recent

CLC $D_1(L, B_1), D_2(B_2)$ [SS]



The first operand is compared with the second operand, and the result is indicated in the condition code.

The comparison proceeds left to right, byte by byte, and ends as soon as an inequality is found or the end of the fields is reached. For CL and CLC, access exceptions may or may not be recognized for the portion of a storage operand to the right of the first unequal byte.

Resulting Condition Code:

- 0 Operands are equal
- 1 First operand is low
- 2 First operand is high
- 3 --

Program Exceptions:

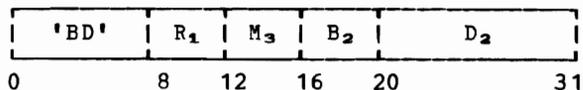
Access (fetch, operand 2, CL and CLC; fetch, operand 1, CLI and CLC)

Programming Notes

1. Examples of the use of the COMPARE LOGICAL instructions are given in Appendix A.
2. The COMPARE LOGICAL instructions treat all bits of each operand alike as part of a field of unstructured logical data. For CLC, the comparison may extend to field lengths of 256 bytes.

COMPARE LOGICAL CHARACTERS UNDER MASK

CLM $R_1, M_3, D_2(B_2)$ [RS]



The first operand is compared with the second operand under control of a mask, and the result is indicated in the condition code.

The contents of the M₃ field are used as a mask. These four bits, left to right, correspond one for one with the four bytes, left to right, of the general register designated by the R₁ field. The byte

positions corresponding to ones in the mask are considered as a contiguous field and are compared with the second operand. The second operand is a contiguous field in storage, starting at the second-operand address and equal in length to the number of ones in the mask. The bytes in the general register corresponding to zeros in the mask do not participate in the operation.

The comparison proceeds left to right, byte by byte, and ends as soon as an inequality is found or the end of the fields is reached.

When the mask is not zero, exceptions associated with storage-operand access are recognized for no more than the number of bytes specified by the mask. Access exceptions may or may not be recognized for the portion of a storage operand to the right of the first unequal byte. When the mask is zero, access exceptions are recognized for one byte.

Resulting Condition Code:

- 0 Selected bytes are equal, or mask is zero
- 1 Selected field of first operand is low
- 2 Selected field of first operand is high
- 3 ---

Program Exceptions:

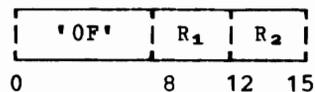
Access (fetch, operand 2)

Programming Note

An example of the use of COMPARE LOGICAL CHARACTERS UNDER MASK is given in Appendix A.

COMPARE LOGICAL LONG

CLCL R_1, R_2 [RR]



The first operand is compared with the second operand, and the result is indicated in the condition code. The shorter operand is considered to be extended on the right with padding bytes.

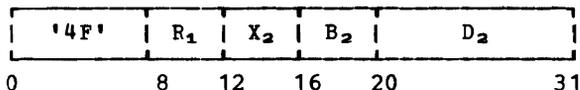
The R₁ and R₂ fields each specify an

registers having the same contents are specified, and, in the absence of dynamic modification of the operand area by another CPU or a channel, condition code 0 is set. However, it is unpredictable whether access exceptions are recognized for the operand since the operation can be completed without storage being accessed.

3. Other programming notes concerning interruptible instructions are included in the section "Interruptible Instructions" in Chapter 5, "Program Execution."
4. Special precautions should be taken when COMPARE LOGICAL LONG is made the target of EXECUTE. See the programming note concerning interruptible instructions under EXECUTE.

CONVERT TO BINARY

CVB $R_1, D_2 (X_2, B_2)$ [RX]



The second operand is changed from decimal to binary, and the result is placed in the first-operand location.

The second operand occupies eight bytes in storage and is treated as packed decimal data, as described in Chapter 8, "Decimal Instructions." It is checked for valid sign and digit codes, and a data exception is recognized when an invalid code is detected.

The result of the conversion is a 32-bit signed binary integer, which is placed in the general register specified by R₁. The maximum positive number that can be converted and still be contained in a 32-bit register is 2,147,483,647; the maximum negative number (the negative number with the greatest absolute value) that can be converted is -2,147,483,648. For any decimal number outside this range, the operation is completed by placing the 32 low-order bits of the binary result in the register, and a fixed-point-divide exception is recognized.

Condition Code: The code remains unchanged.

Program Exceptions:

Access (fetch, operand 2)

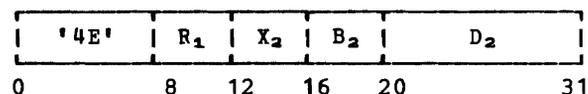
Data Fixed-Point Divide

Programming Notes

1. An example of the use of CONVERT TO BINARY is given in Appendix A.
2. When the second operand is negative, the result is in two's-complement notation.

CONVERT TO DECIMAL

CVD $R_1, D_2 (X_2, B_2)$ [RX]



The first operand is changed from binary to decimal, and the result is stored at the second-operand location. The first operand is treated as a 32-bit signed binary integer.

The result occupies eight bytes in storage and is in the format for packed decimal data, as described in Chapter 8, "Decimal Instructions." The low-order four bits of the result represent the sign. A positive sign is encoded as 1100; a negative sign is encoded as 1101.

Condition Code: The code remains unchanged.

Program Exceptions:

Access (store, operand 2)

Programming Notes

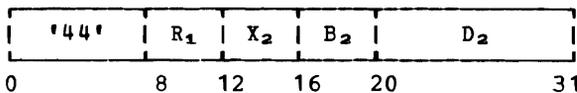
1. An example of the use of CONVERT TO DECIMAL is given in Appendix A.
2. The number to be converted is a 32-bit signed binary integer obtained from a general register. Since 15 decimal digits are available for the result, and the decimal equivalent of 31 bits requires at most 10 decimal digits, an overflow cannot occur.

Programming Notes

1. An example of the use of EXCLUSIVE OR is given in Appendix A.
2. The instruction EXCLUSIVE OR may be used to invert a bit, an operation particularly useful in testing and setting programmed binary bit switches.
3. A field EXCLUSIVE-ORed with itself becomes all zeros.
4. For XR, the sequence A EXCLUSIVE-OR B, B EXCLUSIVE-OR A, A EXCLUSIVE-OR B results in the exchange of the contents of A and B without the use of an additional general register.
5. Accesses to the first operand of XI and XC consist in fetching a first-operand byte from storage and subsequently storing the updated value. These fetch and store accesses to a particular byte do not necessarily occur one immediately after the other. Thus, the instruction EXCLUSIVE OR cannot be safely used to update a location in storage if the possibility exists that another CPU or a channel may also be updating the location. An example of this effect is shown for the instruction OR (OI) in the section "Multiprogramming and Multiprocessing Examples" in Appendix A.

EXECUTE

EX $R_1, D_2 (X_2, B_2)$ [RX]



The single instruction at the second-operand address is modified by the contents of the general register specified by R₁, and the resulting target instruction is executed.

When the R₁ field is not zero, bits 8-15 of the instruction designated by the second-operand address are ORed with bits 24-31 of the register specified by R₁. The ORing does not change either the contents of the register specified by R₁ or the instruction in storage, and it is effective only for the interpretation of the instruction to be executed. When the R₁ field is zero, no ORing takes place.

The target instruction may be two, four, or six bytes in length. The execution and exception handling of the target instruction are exactly as if the target instruction were obtained in normal sequential operation, except for the instruction address and the instruction-length code.

The instruction address of the current PSW is increased by the length of EXECUTE. This updated address and the instruction-length code of EXECUTE are used, for example, as part of the link information when the target instruction is BRANCH AND LINK. When the target instruction is a successful branching instruction, the instruction address of the current PSW is replaced by the branch address specified by the target instruction.

When the target instruction is in turn an EXECUTE, an execute exception is recognized.

The effective address of EXECUTE must be even; otherwise, a specification exception is recognized. When the target instruction is two or three halfwords in length but can be executed without fetching its second or third halfword, it is unpredictable whether access exceptions are recognized for the unused halfwords. Access exceptions are not recognized for the second-operand address when the address is odd.

The second-operand address of EXECUTE is treated as an instruction address rather than a logical address; thus, when DAS is installed and the CPU is in secondary-space mode, it is unpredictable whether the target instruction is fetched from the primary space or the secondary space. When DAS is not installed, an instruction address is treated the same as a logical address.

Condition Code: The code may be set by the target instruction.

Program Exceptions:

- Access (fetch, target instruction)
- Execute
- Specification

Programming Notes

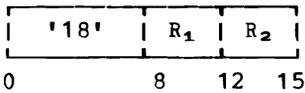
1. An example of the use of EXECUTE is given in Appendix A.
2. The ORing of eight bits from the general register with the designated instruction permits indirect length, index, mask, immediate-data, and

Programming Notes

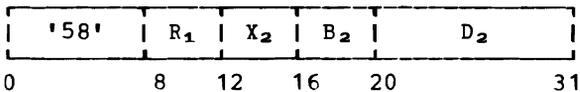
1. Examples of the use of INSERT CHARACTERS UNDER MASK are given in Appendix A.
2. The condition code for INSERT CHARACTERS UNDER MASK (ICM) is defined such that, when the mask is 1111, the instruction causes the same condition code to be set as for LOAD AND TEST. Thus, the instruction may be used as a storage-to-register load-and-test operation.
3. An ICM instruction with a mask of 1111 or 0001 performs a function similar to that of a LOAD (L) or INSERT CHARACTER (IC), respectively, with the exception of the condition-code setting. However, the performance of ICM may be slower.

LOAD

LR R₁,R₂ [RR]



L R₁,D₂(X₂,B₂) [RX]



The second operand is placed unchanged in the first-operand location.

Condition Code: The code remains unchanged.

Program Exceptions:

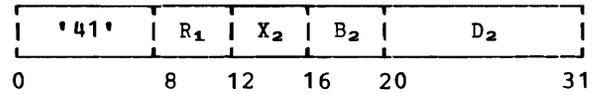
Access (fetch, operand 2 of L only)

Programming Note

An example of the use of LOAD is given in Appendix A.

LOAD ADDRESS

LA R₁,D₂(X₂,B₂) [RX]



The address specified by the X₂, B₂, and D₂ fields is placed in bit positions 8-31 of the general register specified by the R₁ field. Bits 0-7 of the register are set to zeros. The address computation follows the rules for address arithmetic.

No storage references for operands take place, and the address is not inspected for access exceptions.

Condition Code: The code remains unchanged.

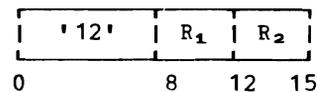
Program Exceptions: None.

Programming Notes

1. An example of the use of the LOAD ADDRESS instruction is given in Appendix A.
2. The same general register may be specified by the R₁, X₂, and B₂ fields, except that general register 0 can be specified only by the R₁ field. In this manner, it is possible to increment the low-order 24 bits of a general register, other than register 0, by the contents of the D₂ field of the instruction. The register to be incremented should be specified by R₁ and by either X₂ (with B₂ set to zero) or B₂ (with X₂ set to zero).

LOAD AND TEST

LTR R₁,R₂ [RR]



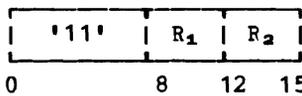
The second operand is placed unchanged in the first-operand location, and the sign and magnitude of the second operand, treated as a 32-bit signed binary integer, are indicated in the condition code.

Programming Note

All combinations of register numbers specified by R₁ and R₂ are valid. When the register numbers are equal, only four bytes are transmitted. When the number specified by R₂ is less than the number specified by R₁, the register numbers wrap around from 15 to 0.

LOAD NEGATIVE

LNR R₁, R₂ [RR]



The two's complement of the absolute value of the second operand is placed in the first-operand location. The second operand and result are treated as 32-bit signed binary integers.

Resulting Condition Code:

- 0 Result is zero
- 1 Result is less than zero
- 2 --
- 3 --

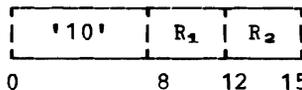
Program Exceptions: None.

Programming Note

The operation complements positive numbers; negative numbers remain unchanged. The number zero remains unchanged.

LOAD POSITIVE

LPR R₁, R₂ [RR]



The absolute value of the second operand is placed in the first-operand location. The second operand and the result are treated as 32-bit signed binary integers.

An overflow causes a program interruption when the fixed-point-overflow mask bit is one.

Resulting Condition Code:

- 0 Result is zero
- 1 --
- 2 Result is greater than zero
- 3 Overflow

Program Exceptions:

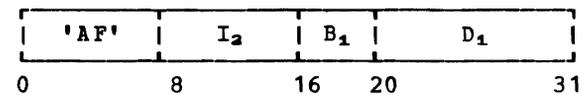
Fixed-Point Overflow

Programming Note

The operation complements negative numbers; positive numbers and zero remain unchanged. An overflow condition occurs when the maximum negative number is complemented; the number remains unchanged.

MONITOR CALL

MC D₁(B₁), I₂ [SI]



A program interruption is caused if the appropriate monitor-mask bit in control register 8 is one.

The monitor-mask bits are in bit positions 16-31 of control register 8, which correspond to monitor classes 0-15, respectively.

Bit positions 12-15 in the I₂ field contain a binary number specifying one of 16 monitoring classes. When the monitor-mask bit corresponding to the class specified by the I₂ field is one, a monitor-event program interruption occurs. The contents of the I₂ field are stored at location 149, with zeros stored at location 148. Bit 9 of the program-interruption code is set to one.

The first-operand address is not used to address data; instead, the address specified by the B₁ and D₁ fields forms the monitor code, which is placed in the word at location 156. Address computation follows the rules of address arithmetic; bits 0-7 are set to zeros.

When the monitor-mask bit corresponding to the class specified by bits 12-15 of the instruction is zero, no interruption occurs, and the instruction is executed as a no-operation.

location 0 to location 16,777,215. The first operand may wrap around from location 16,777,215 to location 0.

When the operands overlap by more than one byte, the contents of the overlapped portion of the result field are unpredictable.

Condition Code: The code remains unchanged.

Program Exceptions:

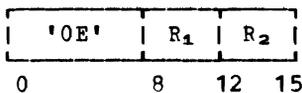
Access (fetch, operand 2; store, operand 1)
 Operation (if move-inverse feature is not installed)

Programming Notes

1. The contents of each byte moved remain unchanged.
2. MOVE INVERSE is the only SS-format instruction for which the second-operand address designates the rightmost, instead of the leftmost, byte of the second operand.

MOVE LONG

MVCL R₁,R₂ [RR]



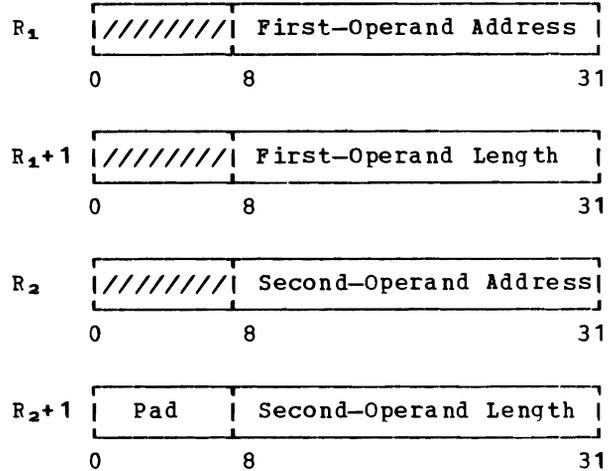
The second operand is placed in the first-operand location, provided overlapping of operand locations does not affect the final contents of the first-operand location. The remaining rightmost byte positions, if any, of the first-operand location are filled with padding bytes.

The R₁ and R₂ fields each specify an even-odd pair of general registers and must designate an even-numbered register; otherwise, a specification exception is recognized.

The location of the leftmost byte of the first operand and second operand is designated by bits 8-31 of the general registers specified by the R₁ and R₂ fields, respectively. The number of bytes in the first-operand and second-operand locations is specified by bits 8-31 of general registers R₁+1 and R₂+1,

respectively. Bit positions 0-7 of register R₂+1 contain the padding byte. The contents of bit positions 0-7 of registers R₁, R₂, and R₁+1 are ignored.

Graphically, the contents of the registers just described are as follows:



The movement starts at the left end of both fields and proceeds to the right. The operation is ended when the number of bytes specified by bit positions 8-31 of register R₁+1 have been moved into the first-operand location. If the second operand is shorter than the first operand, the remaining rightmost bytes of the first-operand location are filled with the padding byte.

As part of the execution of the instruction, the values of the two length fields are compared for the setting of the condition code, and a check is made for destructive overlap of the operands. Operands are said to overlap destructively when the first-operand location is used as a source after data has been moved into it, assuming the inspection for overlap is performed by the use of logical operand addresses. When the operands overlap destructively, no movement takes place, and condition code 3 is set.

Operands do not overlap destructively, and movement is performed, if the leftmost byte of the first operand does not coincide with any of the second-operand bytes participating in the operation other than the leftmost byte of the second operand. When an operand wraps around from location 16,777,215 to location 0, operand bytes in locations up to and including 16,777,215 are considered to be to the left of bytes in locations from 0 up.

When the length specified by bit positions 8-31 of register R₁+1 is zero, no movement takes place, and condition code 0 or 1 is set to indicate the relative values of the lengths.

Similarly, in the case of reconfigurable storage, an addressing exception on a block does not necessarily suppress processing of subsequent blocks which are addressable.

- b. The model may update the general registers only when an I/O interruption occurs or when a program interruption occurs which is required to nullify or suppress. Thus, if after a move into several blocks of the first operand, an addressing or protection exception occurs, the registers remain unchanged.
4. When the first-operand length is zero, the operation consists in setting the condition code and setting the high-order bytes of registers R_1 and R_2 to zero.
5. When the contents of the R_1 and R_2 fields are the same, the operation proceeds the same way as when two distinct pairs of registers having the same contents are specified. Condition code 0 is set.
6. The following is a detailed description of those cases in which movement takes place, that is, where destructive overlap does not exist. Depending on whether the second operand wraps around from location 16,777,215 to location 0, movement takes place in the following cases:
 - a. When the second operand does not wrap around, movement is performed if the leftmost byte of the first operand coincides with or is to the left of the leftmost byte of the second operand, or if the leftmost byte of the first operand is to the right of the rightmost second-operand byte participating in the operation.
 - b. When the second operand wraps around, movement is performed if the leftmost byte of the first operand coincides with or is to the left of the leftmost byte of the second operand, and if the leftmost byte of the first operand is to the right of the rightmost second-operand byte participating in the operation.

The rightmost second-operand byte is determined by using the smaller of the first-operand and second-operand lengths.

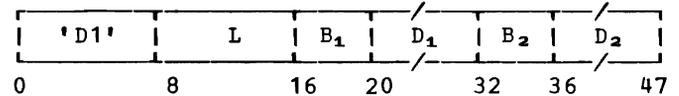
When the second-operand length is one or zero, destructive overlap cannot

exist.

7. Special precautions must be taken if MOVE LONG is made the target of EXECUTE. See the programming note concerning interruptible instructions under EXECUTE.
8. Since the execution of MOVE LONG is interruptible, the instruction cannot be used for situations where the program must rely on uninterrupted execution of the instruction or on the interval timer not being updated during the execution of the instruction. Similarly, the program should normally not let the first operand of MOVE LONG include the location of the instruction since the new contents of the location may be interpreted for a resumption after an interruption, or the instruction may be refetched without an interruption.
9. Further programming notes concerning interruptible instructions are included in the section "Interruptible Instructions" in Chapter 5, "Program Execution."

MOVE NUMERIC

MVN $D_1(L, B_1), D_2(B_2)$ [SS]



The rightmost four bits of each byte in the second operand are placed in the rightmost bit positions of the corresponding bytes in the first operand. The leftmost four bits of each byte in the first operand remain unchanged.

Each operand is processed left to right. When the operands overlap, the result is obtained as if the operands were processed one byte at a time and each result byte were stored immediately after the necessary operand byte is fetched.

Condition Code: The code remains unchanged.

Program Exceptions:

Access (fetch, operand 2; fetch and store, operand 1)

remain unchanged.

Each operand is processed left to right. When the operands overlap, the result is obtained as if the operands were processed one byte at a time and each result byte were stored immediately after the necessary operand byte is fetched.

Condition Code: The code remains unchanged.

Program Exceptions:

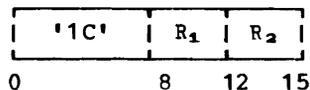
Access (fetch, operand 2; fetch and store, operand 1)

Programming Notes

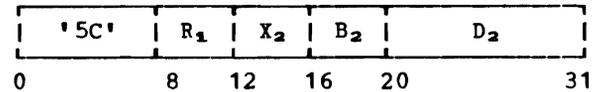
1. An example of the use of MOVE ZONES is given in Appendix A.
2. MVZ moves the zoned portion of a decimal field in the zoned format. The zoned format is described in Chapter 8, "Decimal Instructions." The operands are not checked for valid sign and digit codes.
3. Accesses to the first operand of MVZ consist in fetching the leftmost four bits of each byte in the first operand and subsequently storing the updated value of the byte. These fetch and store accesses to a particular byte do not necessarily occur one immediately after the other. Thus, this instruction cannot be safely used to update a location in storage if the possibility exists that another CPU or a channel may also be updating the location. An example of this effect is shown for the instruction OR (OI) in the section "Multiprogramming and Multiprocessing Examples" in Appendix A.

MULTIPLY

MR R_1, R_2 [RR]



M $R_1, D_2 (X_2, B_2)$ [RX]



The second word of the first operand (multiplicand) is multiplied by the second operand (multiplier), and the doubleword product is placed at the first-operand location.

The R₁ field of the instruction specifies an even-odd pair of general registers and must designate an even-numbered register. When R₁ is odd, a specification exception is recognized.

Both the multiplicand and multiplier are treated as 32-bit signed binary integers. The multiplicand is taken from the odd-numbered register of the pair specified by the R₁ field. The contents of the even-numbered register are ignored. The product is a 64-bit signed binary integer, which replaces the contents of the even-odd pair of general registers specified by the R₁ field. An overflow cannot occur.

The sign of the product is determined by the rules of algebra from the multiplier and multiplicand sign, except that a zero result is always positive.

Condition Code: The code remains unchanged.

Program Exceptions:

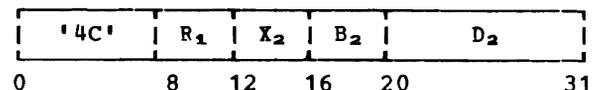
Access (fetch, operand 2 of M only)
Specification

Programming Notes

1. An example of the use of MULTIPLY is given in Appendix A.
2. The significant part of the product usually occupies 62 bits or fewer. Only when two maximum negative numbers are multiplied are 63 significant product bits formed.

MULTIPLY HALFWORD

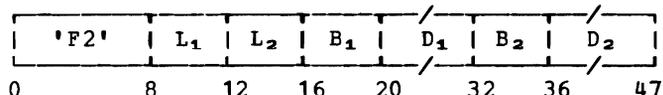
MH $R_1, D_2 (X_2, B_2)$ [RX]



first-operand byte from storage and subsequently storing the updated value. These fetch and store accesses to a particular byte do not necessarily occur one immediately after the other. Thus, the instruction OR cannot be safely used to update a location in storage if the possibility exists that another CPU or a channel may also be updating the location. An example of this effect is shown in the section "Multiprogramming and Multiprocessing Examples" in Appendix A.

PACK

PACK $D_1(L_1, B_1), D_2(L_2, B_2)$ [SS]



The format of the second operand is changed from zoned to packed, and the result is placed in the first-operand location. The zoned and packed formats are described in Chapter 8, "Decimal Instructions."

The second operand is treated as having the zoned format. The numeric bits of each byte are treated as a digit. The zone bits are ignored, except the zone bits in the rightmost byte, which are treated as a sign.

The sign and digits are moved unchanged to the first operand and are not checked for valid codes. The sign is placed in the rightmost four bit positions of the rightmost byte of the result field, and the digits are placed adjacent to the sign and to each other in the remainder of the result field.

The result is obtained as if the operands were processed right to left. When necessary, the second operand is considered to be extended on the left with zeros. If the first operand is too short to contain all digits of the second operand, the remaining leftmost portion of the second operand is ignored. Access exceptions for the unused portion of the second operand may or may not be indicated.

When the operands overlap, the result is obtained as if each result byte were stored immediately after the necessary operand bytes are fetched. Two second-operand bytes are needed for each result byte, except for the rightmost byte of the result field, which requires only the rightmost second-operand byte.

Condition Code: The code remains unchanged.

Program Exceptions:

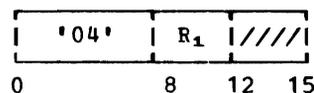
Access (fetch, operand 2; store, operand 1)

Programming Notes

1. An example of the use of PACK is given in Appendix A.
2. The PACK instruction may be used to interchange the two hexadecimal digits in one byte by specifying a zero in the L₁ and L₂ fields and the same address for both operands.
3. To remove the zone bits of all bytes of a field, including the rightmost byte, both operands must be extended on the right with a dummy byte, which subsequently is ignored in the result field.

SET PROGRAM MASK

SPM R₁ [RR]



The contents of the general register specified by the R₁ field are used to set the condition code and the program mask of the current PSW. Bits 12-15 of the instruction are ignored.

Bits 2 and 3 of the register specified by the R₁ field replace the condition code, and bits 4-7 replace the program mask. Bits 0, 1, and 8-31 of the register specified by the R₁ field are ignored.

Resulting Condition Code:

- | | |
|---|----------------------------------|
| 0 | Bit 2 is zero, and bit 3 is zero |
| 1 | Bit 2 is zero, and bit 3 is one |
| 2 | Bit 2 is one, and bit 3 is zero |
| 3 | Bit 2 is one, and bit 3 is one |

Program Exceptions: None.

ignored.

All 64 bits of the first operand participate in the shift. Bits shifted out of bit position 0 of the even-numbered register are not inspected and are lost. Zeros are supplied to the vacated register positions on the right.

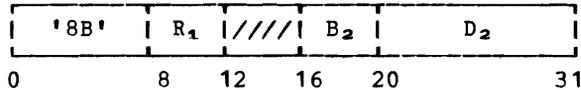
Condition Code: The code remains unchanged.

Program Exceptions:

Specification

SHIFT LEFT SINGLE

SLA R₁, D₂ (B₂) [RS]



The numeric part of the first operand is shifted left the number of bits specified by the second-operand address. Bits 12-15 of the instruction are ignored.

The second-operand address is not used to address data; its low-order six bits indicate the number of bit positions to be shifted. The remainder of the address is ignored.

The first operand is treated as a 32-bit signed binary integer. The sign of the first operand remains unchanged. All 31 numeric bits of the operand participate in the left shift. Zeros are supplied to the vacated register positions on the right.

If one or more bits unlike the sign bit are shifted out of bit position 1, an overflow occurs. The overflow causes a program interruption when the fixed-point-overflow mask bit is one.

Resulting Condition Code:

- 0 Result is zero
- 1 Result is less than zero
- 2 Result is greater than zero
- 3 Overflow

Program Exceptions:

Fixed-Point Overflow

Programming Notes

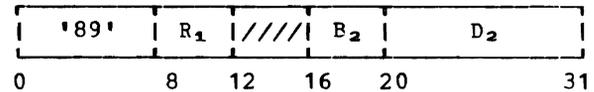
1. An example of the use of SHIFT LEFT SINGLE is given in Appendix A.
2. For numbers with an absolute value of less than 2³⁰, a left shift of one bit position is equivalent to multiplying the number by two.
3. Shift amounts from 31 to 63 cause the entire numeric part to be shifted out of the register, leaving a result of the maximum negative number or zero, depending on whether or not the initial contents were negative.

Engineering Note

An initial value of all ones with a shift amount of 32 or greater results in the maximum negative number and an overflow.

SHIFT LEFT SINGLE LOGICAL

SLL R₁, D₂ (B₂) [RS]



The first operand is shifted left the number of bits specified by the second-operand address. Bits 12-15 of the instruction are ignored.

The second-operand address is not used to address data; its low-order six bits indicate the number of bit positions to be shifted. The remainder of the address is ignored.

All 32 bits of the first operand participate in the shift. Bits shifted out of bit position 0 are not inspected and are lost. Zeros are supplied to the vacated register positions on the right.

Condition Code: The code remains unchanged.

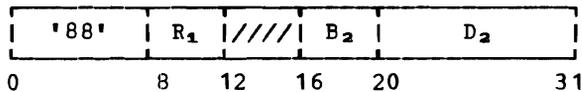
Program Exceptions: None.

Programming Notes

1. A right shift of one bit position is equivalent to division by 2 with rounding downward. When an even number is shifted right one position, the result is equivalent to dividing the number by 2. When an odd number is shifted right one position, the result is equivalent to dividing the .5 next lower number by 2. For example, +5 shifted right by one bit position yields +2, whereas -5 yields -3.
2. Shift amounts from 31 to 63 cause the entire numeric part to be shifted out of the register, leaving a result of -1 or zero, depending on whether or not the initial contents were negative.

SHIFT RIGHT SINGLE LOGICAL

SRL $R_1, D_2 (B_2)$ [RS]



The first operand is shifted right the number of bits specified by the second-operand address. Bits 12-15 of the instruction are ignored.

The second-operand address is not used to address data; its low-order six bits indicate the number of bit positions to be shifted. The remainder of the address is ignored.

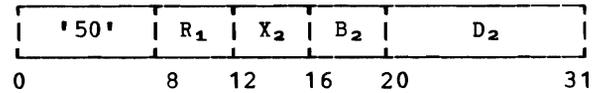
All 32 bits of the first operand participate in the shift. Bits shifted out of bit position 31 are not inspected and are lost. Zeros are supplied to the vacated register positions on the left.

Condition Code: The code remains unchanged.

Program Exceptions: None.

STORE

ST $R_1, D_2 (X_2, B_2)$ [RX]



The first operand is stored at the second-operand location.

The 32 bits in the general register are placed unchanged at the second-operand location.

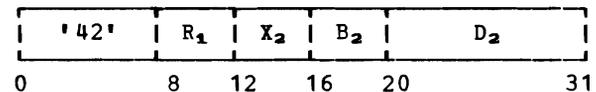
Condition Code: The code remains unchanged.

Program Exceptions:

Access (store, operand 2)

STORE CHARACTER

STC $R_1, D_2 (X_2, B_2)$ [RX]



Bits 24-31 of the general register designated by the R_1 field are placed unchanged at the second-operand location. The second operand is one byte in length.

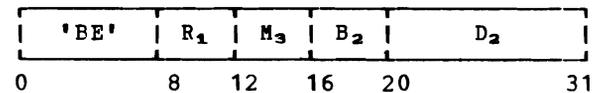
Condition Code: The code remains unchanged.

Program Exceptions:

Access (store, operand 2)

STORE CHARACTERS UNDER MASK

STCM $R_1, M_3, D_2 (B_2)$ [RS]



Bytes selected from the first operand under control of a mask are placed in contiguous byte locations beginning at the second-operand address.

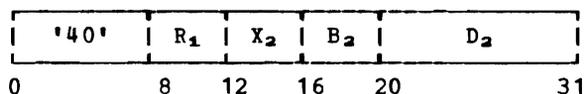
The contents of the M_3 field are used as a

involving human responses, the high-order clock word may provide sufficient resolution.

2. Condition code 0 normally indicates that the clock has been set by the control program. Accordingly, the value may be used in elapsed-time measurements and as a valid time-of-day and calendar indication. Condition code 1 indicates that the clock value is the elapsed time since the power for the clock was turned on. In this case the value may be used in elapsed-time measurements but is not a valid time-of-day indication. Condition codes 2 and 3 mean that the value provided by STORE CLOCK cannot be used for time measurement or indication.
3. Condition code 3 indicates that the clock is either in the stopped state or not-operational state. These two states can normally be distinguished since an all-zero value is stored when in the not-operational state.

STORE HALFWORD

STH $R_1, D_2 (X_2, B_2)$ [RX]



Bits 16-31 of the general register designated by the R₁ field are placed unchanged at the second-operand location. The second operand is two bytes in length.

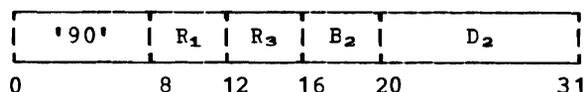
Condition Code: The code remains unchanged.

Program Exceptions:

Access (store, operand 2)

STORE MULTIPLE

STM $R_1, R_3, D_2 (B_2)$ [RS]



The contents of the set of general registers starting with the register specified by R₁ and ending with the

register specified by R₃ are placed in the storage area beginning at the location designated by the second-operand address and continuing through as many locations as needed.

The general registers are stored in the ascending order of register numbers, starting with the register specified by R₁ and continuing up to and including the register specified by R₃, with register 0 following register 15.

Condition Code: The code remains unchanged.

Program Exceptions:

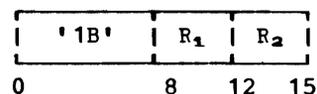
Access (store, operand 2)

Programming Note

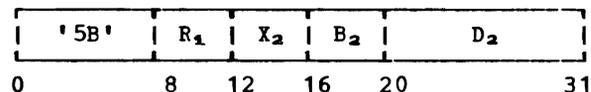
An example of the use of STORE MULTIPLE is given in Appendix A.

SUBTRACT

SR R_1, R_2 [RR]



S $R_1, D_2 (X_2, B_2)$ [RX]



The second operand is subtracted from the first operand, and the difference is placed in the first-operand location. The operands and the difference are treated as 32-bit signed binary integers.

An overflow causes a program interruption when the fixed-point-overflow mask bit is one.

Resulting Condition Code:

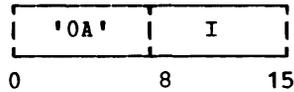
- 0 Difference is zero
- 1 Difference is less than zero
- 2 Difference is greater than zero
- 3 Overflow

Program Exceptions:

Access (fetch, operand 2 of S only)

SUPERVISOR CALL

SVC I [RR]



The instruction causes a supervisor-call interruption, with the I field of the instruction providing the interruption code.

Bits 8-15 of the instruction, with eight high-order zeros appended, are placed in the supervisor-call interruption code that is stored in the course of the interruption. See "Supervisor-Call Interruption" in Chapter 6, "Interruptions."

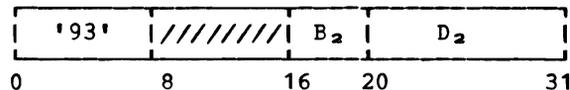
A serialization and a checkpoint-synchronization function is performed. CPU operation is delayed until all previous storage accesses by this CPU to storage have been completed, as observed by channels and other CPUs. All previous checkpoints, if any, are canceled, and the results of all previous stores are released, if held exclusive, to permit channels and other CPUs to access the results. No subsequent instructions or their operands are accessed by this CPU until the execution of this instruction is completed.

Condition Code: The code remains unchanged and is saved as part of the old PSW. A new condition code is loaded as part of the supervisor-call interruption.

Program Exceptions: None.

TEST AND SET

TS D₂(B₂) [S]



The leftmost bit (bit position 0) of the byte located at the second-operand address is used to set the condition code, and then the byte is set to all ones. Bits 8-15 of the instruction are ignored.

The byte in storage is set to all ones as it is fetched for the testing of bit position 0. No access by another CPU to this location is permitted between the moment of fetching and the moment of

storing all ones.

A serialization function is performed before the byte is fetched and again after the storing of all ones. CPU operation is delayed until all previous accesses by this CPU to storage have been completed, as observed by channels and other CPUs, and then the byte is fetched. No subsequent instructions or their operands are accessed by this CPU until the all-ones value has been placed in storage, as observed by channels and other CPUs.

Resulting Condition Code:

- 0 Leftmost bit of byte specified was zero
- 1 Leftmost bit of byte specified was one
- 2 --
- 3 --

Program Exceptions:

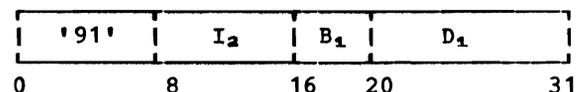
Access (fetch and store, operand 2)

Programming Notes

1. TEST AND SET may be used for controlled sharing of a common storage area by programs operating on different CPUs. This instruction, which is provided primarily for compatibility with programs written for System/360, does not provide suitable functions for sharing between programs on a single CPU or for programs that may be interrupted. The instructions COMPARE AND SWAP and COMPARE DOUBLE AND SWAP provide these functions. See the description of these instructions and the associated programming notes for details.
2. It should be noted that TEST AND SET does not interlock against storage accesses by channels.

TEST UNDER MASK

TM D₁(B₁), I₂ [SI]



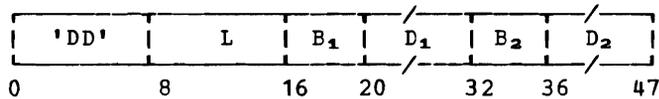
A mask is used to select bits of the first operand, and the result is indicated in the condition code.

is added to the initial second-operand address to obtain the address of a function byte, the list may contain 256 bytes. In cases where it is known that not all eight-bit argument values will occur, it is possible to reduce the size of the list.

6. Significant performance degradation is possible when, with DAT on, the second-operand address of TRANSLATE designates a location that is less than 256 bytes to the left of a 2,048-byte boundary. This is because the machine may perform a trial execution of the instruction to determine if the second operand actually crosses the boundary.

TRANSLATE AND TEST

TRT $D_1(L, B_1), D_2(B_2)$ [SS]



The bytes of the first operand are used as eight-bit arguments to select function bytes from a list designated by the second-operand address. The first nonzero function byte is inserted in general register 2, and the related argument address in general register 1.

The L field designates the length of only the first operand.

The bytes of the first operand are selected one by one for translation, proceeding from left to right. The first operand remains unchanged in storage. Fetching of the function byte from the list is performed as in TRANSLATE. The function byte retrieved from the list is inspected for a value of zero.

When the function byte is zero, the operation proceeds with the next byte of the first operand. When the first-operand field is exhausted before a nonzero function byte is encountered, the operation is completed by setting condition code 0. The contents of general registers 1 and 2 remain unchanged.

When the function byte is nonzero, the operation is completed by inserting the function byte in general register 2 and the related argument address in general register 1. This address points to the argument byte last translated. The function byte replaces bits 24-31 of general register 2. The address replaces

bits 8-31 of general register 1. Bits 0-7 of general register 1 and bits 0-23 of general register 2 remain unchanged.

When the function byte is nonzero, either condition code 1 or 2 is set, depending on whether the argument byte is the rightmost byte of the first operand. Condition code 1 is set if one or more argument bytes remain to be translated. Condition code 2 is set if no more argument bytes remain.

Access exceptions are recognized only for those bytes in the second operand which are actually required. Access exceptions are not recognized for those bytes in the first operand which are to the right of the first byte for which a nonzero function byte is obtained.

Resulting Condition Code:

- 0 All function bytes zero
- 1 Nonzero function byte; first-operand field not exhausted
- 2 Nonzero function byte; first-operand field exhausted
- 3 --

Program Exceptions:

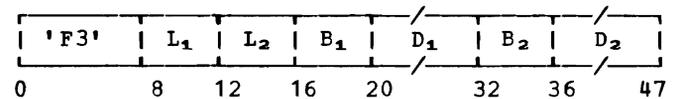
Access (fetch, operands 1 and 2)

Programming Notes

1. An example of the use of TRANSLATE AND TEST is given in Appendix A.
2. The instruction TRANSLATE AND TEST may be used to scan the first operand for characters with special meaning. The second operand, or list, is set with all-zero function bytes for those characters to be skipped over and with nonzero function bytes for the characters to be detected.

UNPACK

UNPK $D_1(L_1, B_1), D_2(L_2, B_2)$ [SS]



The format of the second operand is changed from packed to zoned, and the result is placed in the first-operand location. The packed and zoned formats are described in Chapter 8, "Decimal Instructions."

Decimal-Number Formats8-1
 Zoned Format8-1
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 ADD DECIMAL8-5
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 EDIT AND MARK8-10
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 ZERO AND ADD8-12

The decimal instructions of this chapter perform arithmetic and editing operations on decimal data. Additional operations on decimal data are provided by several of the instructions in Chapter 7, "General Instructions." Decimal operands always reside in storage, and all instructions operating on decimal data use the SS instruction format.

DECIMAL-NUMBER FORMATS

Decimal numbers may be in either the zoned or packed format. Both decimal-number formats have from one to 16 bytes, each byte consisting of a pair of four-bit codes. The four-bit codes include decimal-digit codes, sign codes, and a zone code. Decimal operands occupy storage fields that start on a byte boundary.

ZONED FORMAT

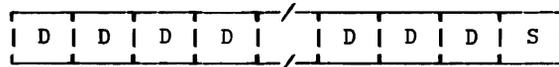


In the zoned format, the rightmost four bits of a byte are called the numeric bits (N) and normally consist of a code representing a decimal digit. The leftmost four bits of a byte are called the zone

bits (Z), except for the rightmost byte of a decimal operand, where these bits may be treated either as a zone or as a sign (S).

Decimal digits in the zoned format may be part of a larger character set, which includes also alphabetic and special characters. The zoned format is, therefore, suitable for input, editing, and output of numeric data in human-readable form. There are no decimal-arithmetic instructions which operate directly on decimal numbers in the zoned format; such numbers must first be converted to the packed format.

PACKED FORMAT



In the packed format, each byte contains two decimal digits (D), except for the rightmost byte, which contains a sign to the right of a decimal digit. Decimal arithmetic is performed with operands in the packed format and generates results in the packed format.

For all decimal instructions in this chapter other than EDIT and EDIT AND MARK, both operands are in the packed format.

DECIMAL CODES

The decimal digits 0-9 have the binary encoding 0000-1001.

The preferred sign codes are 1100 for plus and 1101 for minus. These are the sign codes generated for the results of the decimal-arithmetic instructions and the CONVERT TO DECIMAL instruction.

Alternate sign codes are also recognized as valid when appearing in the sign position: 1010, 1110, and 1111 are alternate codes for plus, and 1011 is an alternate code for minus. Alternate sign codes are accepted for any decimal operand but are never generated or propagated in the signed result of a decimal-arithmetic instruction or CONVERT TO DECIMAL, even when an operand remains otherwise unchanged, such as when adding zero to a number. An alternate sign code is, however, left unchanged by the instructions MOVE NUMERICS, MOVE WITH OFFSET, MOVE ZONES, PACK, and UNPACK.

When an invalid code is detected, a data exception is recognized. For the decimal-arithmetic instructions, the action taken for a data exception depends on whether a sign code is invalid. When a sign code is invalid, the operation is suppressed regardless of whether any other condition causing an exception exists. When no sign code is invalid, the operation is terminated.

For the editing instructions EDIT and EDIT AND MARK, an invalid sign code is not recognized. The operation is terminated for a data exception due to an invalid digit code. No validity checking is performed by the instructions MOVE NUMERICS, MOVE WITH OFFSET, MOVE ZONES, PACK, and UNPACK.

The zone code 1111 appears in the left four bit positions of each byte representing a decimal digit in zoned-format results. Zoned-format results are produced by the instructions EDIT, EDIT AND MARK, and UNPACK, except that the left four bit positions of the rightmost byte produced by UNPACK contain whatever code exists in the sign position of the packed operand. The right four bit positions of each byte in the zoned format contain a decimal-digit code.

The meaning of the decimal codes is summarized in the figure "Summary of Digit and Sign Codes."

Programming Notes

1. Since 1111 is both the zone code and an alternate code for plus, unsigned (positive) decimal numbers may be represented in the zoned format with 1111 codes in all byte positions. The result of the PACK instruction converting such a number to the packed format may be used directly as an operand for decimal instructions.
2. The use of the alternate minus code 1011 is not recommended.

| Code | Recognized As | |
|------|---------------|-------------------|
| | Digit | Sign |
| 0000 | 0 | Invalid |
| 0001 | 1 | Invalid |
| 0010 | 2 | Invalid |
| 0011 | 3 | Invalid |
| 0100 | 4 | Invalid |
| 0101 | 5 | Invalid |
| 0110 | 6 | Invalid |
| 0111 | 7 | Invalid |
| 1000 | 8 | Invalid |
| 1001 | 9 | Invalid |
| 1010 | Invalid | Plus |
| 1011 | Invalid | Minus |
| 1100 | Invalid | Plus (preferred) |
| 1101 | Invalid | Minus (preferred) |
| 1110 | Invalid | Plus |
| 1111 | Invalid | Plus (zone) |

Summary of Digit and Sign Codes

DECIMAL OPERATIONS

The decimal instructions in this chapter consist of two classes, the decimal-arithmetic instructions and the editing instructions.

DECIMAL-ARITHMETIC INSTRUCTIONS

- 1 The decimal-arithmetic instructions perform addition, subtraction, multiplication, division, comparison, and shifting.

Operands of the decimal-arithmetic instructions are in the packed format and are treated as signed decimal integers. A decimal integer is represented in true form as an absolute value with a separate plus or minus sign. It contains an odd number

of decimal digits, from one to 31, and the sign; this corresponds to an operand length of one to 16 bytes.

A decimal zero normally has a plus sign, but multiplication, division, and overflow may produce a zero value with a minus sign. Such a negative zero is a valid operand and is treated as equal to a positive zero by the COMPARE DECIMAL instruction.

The lengths of the two operands specified in the instruction need not be the same. If necessary, the shorter operand is considered to be extended with zeros to the left of the high-order digit. Results, however, cannot exceed the first-operand length as specified in the instruction.

When a carry or some high-order nonzero digits of the result are lost because the first-operand field is too short, the result is obtained by ignoring the overflow information, condition code 3 is set, and, if the decimal-overflow mask bit is one, a program interruption for decimal overflow occurs. The operand lengths alone are not an indication of overflow; significant digits must have been lost during the operation.

The operands of decimal-arithmetic instructions should not overlap at all or should have coincident rightmost bytes. In ZERO AND ADD, the operands may also overlap in such a manner that the rightmost byte of the first operand (which becomes the result) is to the right of the rightmost byte of the second operand. For these cases of proper overlap, the result is obtained as if operands were processed right to left. Because the codes for digits and signs are verified during the performance of the arithmetic, improperly overlapping operands are recognized as data exceptions.

Programming Note

The same decimal field in storage may be specified for both operands of the instructions ADD DECIMAL, COMPARE DECIMAL, DIVIDE DECIMAL, MULTIPLY DECIMAL, and SUBTRACT DECIMAL. Thus, a decimal number may be added to itself, compared to itself, etc. SUBTRACT DECIMAL may be used to set a decimal field in storage to zero.

EDITING INSTRUCTIONS

The editing instructions are EDIT and EDIT AND MARK. For these instructions, only one operand (the pattern) has an explicitly

specified length. The other operand (the source) is considered to have as many digits as necessary for the completion of the operation.

Overlapping operands for the editing instructions yield unpredictable results.

EXECUTION OF DECIMAL INSTRUCTIONS

During the execution of a decimal instruction, all bytes of the operands are not necessarily accessed concurrently, and the fetch and store accesses to a single location do not necessarily occur one immediately after the other. Furthermore, for decimal instructions, intermediate values may be placed in the result field that may differ from the original operand and final result values. Thus, in a multiprocessing system, an instruction such as ADD DECIMAL cannot be safely used to update a shared storage location when the possibility exists that another CPU may also be updating that location.

OTHER INSTRUCTIONS FOR DECIMAL OPERANDS

In addition to the decimal instructions in this chapter, the instructions MOVE NUMERICS and MOVE ZONES are provided for operating on data in the zoned format. Two instructions are provided for converting data between the zoned and packed formats: the PACK instruction transforms zoned data into packed data, and UNPACK performs the reverse transformation. The MOVE WITH OFFSET instruction operates on packed data. Two instructions are provided for conversion between the packed-decimal and binary formats. The CONVERT TO BINARY instruction converts packed decimal to binary, and CONVERT TO DECIMAL converts binary to packed decimal. These seven instructions are not considered to be decimal instructions and are described in Chapter 7, "General Instructions." The editing instructions in this chapter may also be used to change data from the packed to the zoned format.

INSTRUCTIONS

The decimal instructions and their mnemonics, formats, and operation codes are listed in the figure "Summary of Decimal Instructions." The figure also indicates when the condition code is set and the exceptional conditions in operand designations, data, or results that cause a

program interruption.

Note: In the detailed descriptions of the individual instructions, the mnemonic and the symbolic operand designation for the

assembler language are shown with each instruction. For ADD DECIMAL, for example, AP is the mnemonic and $D_1(L_1, B_1), D_2(L_2, B_2)$ the operand designation.

| Name | Mnemonic | Characteristics | Op Code |
|-------------------------|----------|-----------------|---------|
| ADD DECIMAL | AP | SS C A D DF | ST FA |
| COMPARE DECIMAL | CP | SS C A D | F9 |
| DIVIDE DECIMAL | DP | SS C A SP D DK | ST FD |
| EDIT | ED | SS C A D | ST DE |
| EDIT AND MARK | EDMK | SS C A D | R ST DF |
| MULTIPLY DECIMAL | MP | SS A SP D | ST FC |
| SHIFT AND ROUND DECIMAL | SRP | SS C A D DF | ST FO |
| SUBTRACT DECIMAL | SP | SS C A D DF | ST FB |
| ZERO AND ADD | ZAP | SS C A D DF | ST F8 |

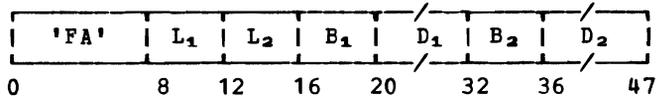
Explanation:

- A Access exceptions
- C Condition code is set
- D Data exception
- DF Decimal-overflow exception
- DK Decimal-divide exception
- R PER general-register-alteration event
- SP Specification exception
- SS SS instruction format
- ST PER storage-alteration event

Summary of Decimal Instructions

ADD DECIMAL

AP $D_1(L_1, B_1), D_2(L_2, B_2)$ [SS]



The second operand is added to the first operand, and the resulting sum is placed in the first-operand location. The operands and result are in the packed format.

Addition is algebraic, taking into account the signs and all digits of both operands. All sign and digit codes are checked for validity.

If the first operand is too short to contain all significant digits of the sum, decimal overflow occurs. The operation is completed. The result is obtained by ignoring the overflow information, and condition code 3 is set. If the decimal-overflow mask is one, a program interruption for decimal overflow takes place.

The sign of the sum is determined by the rules of algebra. When the operation is completed without an overflow, a zero sum has a positive sign. When high-order digits are lost because of an overflow, a zero result may be either positive or negative, as determined by what the sign of the correct sum would have been.

Resulting Condition Code:

- 0 Sum is zero
- 1 Sum is less than zero
- 2 Sum is greater than zero
- 3 Overflow

Program Exceptions:

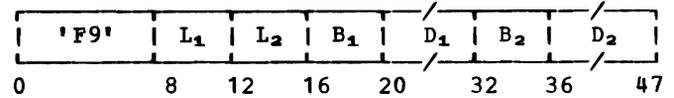
Access (fetch, operand 2; fetch and store, operand 1)
Data
Decimal Overflow

Programming Note

An example of the use of ADD DECIMAL is given in Appendix A.

COMPARE DECIMAL

CP $D_1(L_1, B_1), D_2(L_2, B_2)$ [SS]



The first operand is compared with the second operand, and the result is indicated in the condition code. The operands are in the packed format.

Comparison is algebraic and follows the procedure for decimal subtraction, except that both operands remain unchanged. When the difference is zero, the operands are equal. When a nonzero difference is positive or negative, the first operand is high or low, respectively.

Overflow cannot occur because the difference is discarded.

All sign and digit codes are checked for validity.

Resulting Condition Code:

- 0 Operands are equal
- 1 First operand is low
- 2 First operand is high
- 3 --

Program Exceptions:

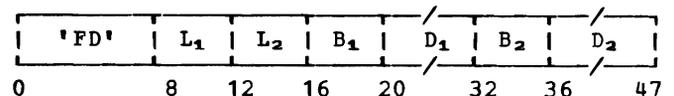
Access (fetch, operands 1 and 2)
Data

Programming Notes

1. An example of the use of COMPARE DECIMAL is given in Appendix A.
2. The comparison operation does not distinguish between valid sign codes. A valid plus or minus sign is equivalent to any other valid plus or minus sign, respectively.

DIVIDE DECIMAL

DP $D_1(L_1, B_1), D_2(L_2, B_2)$ [SS]



The first operand (the dividend) is divided by the second operand (the divisor). The resulting quotient and remainder are placed in the first-operand location. The operands and result are in the packed format.

The quotient is placed leftmost in the first-operand location. The number of bytes in the quotient is equal to the difference between the dividend and divisor lengths ($L_1 - L_2$). The remainder is placed rightmost in the first-operand location and has a length equal to the divisor length. Together, the quotient and remainder occupy the entire first operand; therefore, the address of the quotient is the address of the first operand.

The divisor length cannot exceed 15 digits and sign (L_2 not greater than seven) and must be less than the dividend length (L_2 less than L_1); otherwise, a specification exception is recognized. The operation is suppressed, and a program interruption occurs.

The dividend, divisor, quotient, and remainder are all signed decimal integers, right-aligned in their fields. All sign and digit codes of the dividend and divisor are checked for validity.

The sign of the quotient is determined by the rules of algebra from the dividend and divisor signs. The sign of the remainder has the same value as the dividend sign. These rules hold even when the quotient or remainder is zero.

Overflow cannot occur. If the divisor is zero or the quotient is too large to be represented by the number of digits allowed, a decimal-divide exception is recognized. The operation is suppressed, and a program interruption occurs. The operands remain unchanged in storage. The decimal-divide exception is indicated only if the sign codes of both the dividend and divisor are valid, and only if the digit or digits used in establishing the exception are valid.

Condition Code: The code remains unchanged.

Program Exceptions:

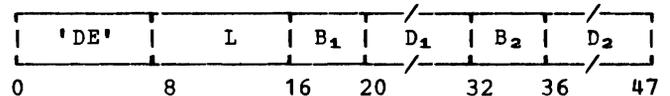
- Access (fetch, operand 2; fetch and store, operand 1)
- Data
- Decimal Divide
- Specification

Programming Notes

1. An example of the use of DIVIDE DECIMAL is given in Appendix A.
2. The dividend cannot exceed 31 digits and sign. Since the remainder cannot be shorter than one digit and sign, the quotient cannot exceed 29 digits and sign.
3. The condition for a decimal-divide exception can be determined by a trial subtraction. The leftmost digit of the divisor is aligned one digit to the right of the leftmost dividend digit. When the divisor, so aligned, is less than or equal to the dividend, a divide exception is indicated.
4. Provided a data exception does not exist, a decimal-divide exception occurs when the leftmost dividend digit is not zero.

EDIT

ED $D_1(L, B_1), D_2(B_2)$ [SS]



The second operand (the source), which normally contains one or more decimal numbers in the packed format, is changed to the zoned format and modified under the control of the first operand (the pattern). The edited result replaces the first operand.

The length field specifies the length of the first operand, which may contain bytes of any value.

The length of the source is determined by the operation according to the contents of the pattern. The source has the packed format. The leftmost four bits of each source byte must specify a decimal digit code (0000-1001); a sign code (1010-1111) is recognized as a data exception. The rightmost four bits may specify either a sign or a decimal digit. Access and data exceptions are recognized only for those bytes in the second operand which are actually required.

The result is obtained as if both operands were processed left to right one byte at a time. Overlapping pattern and source fields give unpredictable results.

During the editing process, each byte of the pattern is affected in one of three ways:

1. It is left unchanged.
2. It is replaced by a source digit expanded to the zoned format.
3. It is replaced by the first byte in the pattern, called the fill byte.

Which of the three actions takes place is determined by one or more of the following: the type of the pattern byte, the state of the significance indicator, and whether the source digit examined is zero.

Pattern Bytes: There are four types of pattern bytes: digit selector, significance starter, field separator, and message byte. Their coding is as follows:

| Name | Code |
|----------------------|-----------|
| Digit selector | 0010 0000 |
| Significance starter | 0010 0001 |
| Field separator | 0010 0010 |
| Message byte | Any other |

The detection of either a digit selector or a significance starter in the pattern causes an examination to be made of the significance indicator and of a source digit. As a result, either the expanded source digit or the fill byte, as appropriate, is selected to replace the pattern byte. Additionally, encountering a digit selector or a significance starter may cause the significance indicator to be changed.

The field separator identifies individual fields in a multiple-field editing operation. It is always replaced in the result by the fill byte, and the significance indicator is always off after the field separator is encountered.

Message bytes in the pattern are either replaced by the fill byte or remain unchanged in the result, depending on the state of the significance indicator. They may thus be used for padding, punctuation, or text in the significant portion of a field or for the insertion of sign-dependent symbols.

Fill Byte: The first byte of the pattern is used as the fill byte. The fill byte can have any code and may concurrently specify a control function. If this byte is a digit selector or significance starter, the indicated editing action is taken after the code has been assigned to the fill byte.

Source Digits: Each time a digit selector or significance starter is encountered in the pattern, a new source digit is examined for placement in the pattern field. Either the source digit is disregarded, or it is expanded to the zoned format, by appending the zone code 1111 on the left, and stored in place of the pattern byte.

The source digits are selected one byte at a time, and a source byte is fetched for inspection only once during an editing operation. Each source digit is examined only once for a zero value. The leftmost four bits of each byte are examined first, and the rightmost four bits, when they represent a decimal-digit code, remain available for the next pattern byte that calls for a digit examination. When the leftmost four bits contain an invalid digit code, the operation is terminated.

At the time the left digit of a source byte is examined, the rightmost four bits are checked for the existence of a sign code. When a sign code is encountered in the rightmost four bit positions, these bits are not treated as a decimal-digit code, and a new source byte is fetched from storage when the next pattern byte calls for a source-digit examination.

When the pattern contains no digit selector or significance starter, no source bytes are fetched and examined.

Significance Indicator: The significance indicator is turned on or off to indicate the significance or nonsignificance, respectively, of subsequent source digits or message bytes. Significant source digits replace their corresponding digit selectors or significance starters in the result. Significant message bytes remain unchanged in the result.

The significance indicator, by its on or off state, indicates also the negative or positive value, respectively, of a completed source field and is used as one factor in the setting of the condition code.

The indicator is set to off at the start of the editing operation, after a field separator is encountered, or after a source byte is examined that has a plus code in the rightmost four bit positions.

The indicator is set to on when a significance starter is encountered whose source digit is a valid decimal digit, or when a digit selector is encountered whose source digit is a nonzero decimal digit, provided that in both instances the source byte does not have a plus code in the rightmost four bit positions.

In all other situations, the indicator is

not changed. A minus sign code has no effect on the significance indicator.

Result Bytes: The result of an editing operation replaces and is equal in length to the pattern. It is composed of pattern bytes, fill bytes, and zoned source digits.

If the pattern byte is a message byte and the significance indicator is on, the message byte remains unchanged in the result. If the pattern byte is a field separator or if the significance indicator is off when a message byte is encountered in the pattern, the fill byte replaces the pattern byte in the result.

If the digit selector or significance starter is encountered in the pattern with the significance indicator off and the source digit zero, the source digit is considered nonsignificant, and the fill byte replaces the pattern byte. If the digit selector or significance starter is encountered with either the significance indicator on or with a nonzero decimal source digit, the source digit is considered significant, is changed to the zoned format, and replaces the pattern byte in the result.

Condition Code: The sign and magnitude of the last field edited are used to set the condition code. The term "last field" refers to those source bytes in the second operand selected by digit selectors or significance starters after the last field separator. When the pattern contains no field separator, there is only one field, which is considered to be the last field. The last field is considered to be of zero length if no digit selectors or significance starters appear in the pattern, if none appear after the last field separator, or if the last byte in the pattern is a field separator.

Condition code 0 is set when the last field is zero or of zero length.

Condition code 1 is set when the last field edited is nonzero and the significance indicator is on, indicating a result less than zero.

Condition code 2 is set when the last field edited is nonzero and the significance indicator is off, indicating a result greater than zero.

The figure "Summary of EDIT Functions" summarizes the functions of the editing operation. The leftmost four columns list all the significant combinations of the four conditions that can be encountered in the execution of an editing operation. The rightmost two columns list the action taken for each case--the type of byte placed in the result field and the new setting of the

significance indicator.

Resulting Condition Code:

- 0 Last field is zero or of zero length
- 1 Last field is less than zero
- 2 Last field is greater than zero
- 3 --

Program Exceptions:

Access (fetch, operand 2; fetch and store, operand 1)
Data

Programming Notes

1. Examples of the use of EDIT are given in Appendix A.
2. Editing includes sign and punctuation control, and the suppression and protection of leading zeros by replacing them with blanks or asterisks. It also facilitates programmed blanking of all-zero fields. Several fields may be edited in one operation, and numeric information may be combined with text.
3. As a rule, the source is shorter than the pattern, because each 4-bit source digit is generally replaced by an 8-bit byte in the result.
4. The total number of digit selectors and significance starters in the pattern must equal the number of source digits to be edited.
5. If the fill byte is a blank, if no significance starter appears in the pattern, and if the source is all zeros, the editing operation blanks the result field.
6. The resulting condition code indicates whether or not the last field is all zeros and, if nonzero, reflects the state of the significance indicator. The significance indicator reflects the sign of the source field only if the last source byte examined contains a sign code in the low-order digit position. For multiple-field editing operations, the condition code reflects the sign and value only of the field following the last field separator.
7. Significant performance degradation is possible when, with DAT on, the second-operand address of EDIT designates a location that is less than the length of the first operand

to the left of a 2,048-byte boundary. This is because the machine may perform a trial execution of the instruction to determine if the second operand actually crosses the boundary.

The second operand of EDIT, while normally shorter than the first operand, can in the extreme case have the same length as the first.

| Conditions | | | | Results | |
|----------------------|--|--------------|--------------------------------------|--------------|---|
| Pattern Byte | Previous State of Significance Indicator | Source Digit | Right Four Source Bits Are Plus Code | Result Byte | State of Significance Indicator at End of Digit Examination |
| Digit selector | Off | 0 | * | Fill byte | Off |
| | | 1-9 | No | Source digit | On |
| | On | 1-9 | Yes | Source digit | Off |
| | | 0-9 | No | Source digit | On |
| | | 0-9 | Yes | Source digit | Off |
| Significance starter | Off | 0 | No | Fill byte | On |
| | | 0 | Yes | Fill byte | Off |
| | | 1-9 | No | Source digit | On |
| | On | 1-9 | Yes | Source digit | Off |
| | | 0-9 | No | Source digit | On |
| | | 0-9 | Yes | Source digit | Off |
| Field separator | * | ** | ** | Fill byte | Off |
| Message byte | Off | ** | ** | Fill byte | Off |
| | On | ** | ** | Message byte | On |

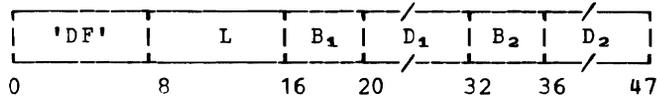
Explanation:

- * No effect on result byte or on new state of significance indicator
- ** Not applicable because source is not examined

Summary of EDIT Functions

EDIT AND MARK

EDMK D₁(L, B₁), D₂(B₂) [SS]



The second operand (the source), which normally contains one or more decimal numbers in the packed format, is changed to the zoned format and modified under the control of the first operand (the pattern). The address of each first significant result byte is inserted in general register 1. The edited result replaces the pattern.

The instruction EDIT AND MARK is identical to EDIT, except for the additional function of inserting the address of the result byte in bit positions 8-31 of general register 1 whenever the result byte is a zoned source digit and the significance indicator was off before the examination. Bits 0-7 of the register are not changed.

Resulting Condition Code:

- 0 Last field is zero or of zero length
- 1 Last field is less than zero
- 2 Last field is greater than zero
- 3 --

Program Exceptions:

Access (fetch, operand 2; fetch and store, operand 1)
Data

Programming Notes

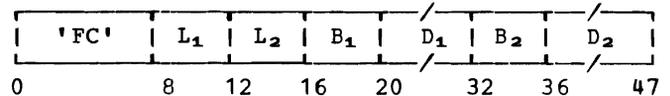
1. Examples of the use of EDIT AND MARK are given in Appendix A.
2. The instruction EDIT AND MARK facilitates the programming of floating currency-symbol insertion. The address inserted in general register 1 is one greater than the address where a floating currency-sign would be inserted. The instruction BRANCH ON COUNT (BCTR), with zero in the R₂ field, may be used to reduce the inserted address by one.
3. No address is inserted in general register 1 when the significance indicator is turned on as a result of encountering a significance starter with the corresponding source digit zero. To ensure that general register 1 contains a valid address when this

occurs, the address of the pattern byte that immediately follows the significance starter should be placed in the register beforehand.

4. When multiple fields are edited with one EDIT AND MARK instruction, the address inserted in general register 1 applies only to the last field edited.
5. See also the programming note under EDIT regarding performance degradation due to a possible trial execution.

MULTIPLY DECIMAL

MP D₁(L₁, B₁), D₂(L₂, B₂) [SS]



The product of the first operand (the multiplicand) and the second operand (the multiplier) is placed in the first-operand location. The operands and result are in the packed format.

The multiplier length cannot exceed 15 digits and sign (L₂ not greater than seven) and must be less than the multiplicand length (L₂ less than L₁); otherwise a specification exception is recognized. The operation is suppressed, and a program interruption occurs.

The multiplicand must have at least as many bytes of high-order zeros as the number of bytes in the multiplier; otherwise, a data exception is recognized, the operation is terminated, and a program interruption occurs. This restriction ensures that no product overflow occurs.

The multiplicand, multiplier, and product are all signed decimal integers, right-aligned in their fields. All sign and digit codes of the multiplicand and multiplier are checked for validity.

The sign of the product is determined by the rules of algebra from the multiplier and multiplicand signs, even if one or both operands are zeros.

Condition Code: The code remains unchanged.

Program Exceptions:

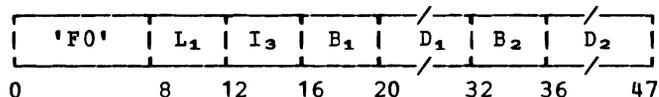
Access (fetch, operand 2; fetch and store, operand 1)
Data
Specification

Programming Notes

1. An example of the use of MULTIPLY DECIMAL is given in Appendix A.
2. The product cannot exceed 31 digits and sign. The leftmost digit of the product is always zero.

SHIFT AND ROUND DECIMAL

SRP $D_1(L_1, B_1), D_2(B_2), I_3$ [SS]



The first operand is shifted in the direction and for the number of decimal-digit positions specified by the second-operand address, and, when shifting to the right is specified, the absolute value of the first operand is rounded by the rounding digit, I₃. The first operand and the result are in the packed format.

The first operand is considered to be in the packed-decimal format. Only its digit portion is shifted; the sign position does not participate in the shifting. Zeros are supplied for the vacated digit positions. The result replaces the first operand. Nothing is stored outside of the specified first-operand location.

The second-operand address, specified by the B₂ and D₂ fields, is not used to address data; bits 26-31 of that address are the shift value, and the high-order bits of the address are ignored.

The shift value is a six-bit signed binary integer, indicating the direction and the number of decimal-digit positions to be shifted. Positive shift values specify shifting to the left. Negative shift values, which are represented in two's complement notation, specify shifting to the right. The following are examples of the interpretation of shift values.

| <u>Shift Value</u> | <u>Amount and Direction</u> |
|--------------------|-----------------------------|
| 011111 | 31 digits to the left |
| 000001 | One digit to the left |
| 000000 | No shift |
| 111111 | One digit to the right |
| 100000 | 32 digits to the right |

For a right shift, the I₃ field, bits 12-15 of the instruction, are used as a decimal rounding digit. The first operand, which is treated as positive by ignoring the

sign, is rounded by decimally adding the rounding digit to the leftmost of the digits to be shifted out and by propagating the carry, if any, to the left. The result of this addition is then shifted right. Except for validity checking and the participation in rounding, the digits shifted out of the low-order decimal-digit position are ignored and are lost.

If one or more significant digits are shifted out of the high-order digit positions during a left shift, decimal overflow occurs. The operation is completed. The result is obtained by ignoring the overflow information, and condition code 3 is set. If the decimal-overflow mask is one, a program interruption for decimal overflow takes place. Overflow cannot occur for a right shift, with or without rounding, or when no shifting is specified.

In the absence of overflow, the sign of a zero result is made positive. Otherwise, the sign of the result is the same as the original sign, but the code is the preferred sign code.

A data exception is recognized when the first operand does not have valid sign and digit codes or when the rounding digit is not a valid digit code. The validity of the first-operand codes is checked even when no shift is specified, and the validity of the rounding digit is checked even when no addition for rounding takes place.

Resulting Condition Code:

- 0 Result is zero
- 1 Result is less than zero
- 2 Result is greater than zero
- 3 Overflow

Program Exceptions:

- Access (fetch and store, operand 1)
- Data
- Decimal Overflow

Programming Notes

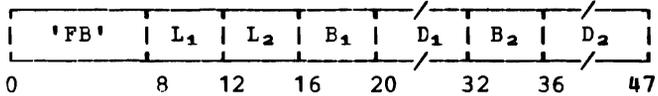
1. Examples of the use of SHIFT AND ROUND are given in Appendix A.
2. SHIFT AND ROUND can be used for shifting up to 31 digit positions left and up to 32 digit positions right. This is sufficient to clear all digits of any decimal number even with rounding.
3. For right shifts, the rounding digit 5 provides conventional rounding of the

result. The rounding digit 0 specifies truncation without rounding.

- When the B₂ field is zero, the six-bit shift value is obtained directly from bits 42-47 of the instruction.

SUBTRACT DECIMAL

SP D₁(L₁,B₁),D₂(L₂,B₂) [SS]



The second operand is subtracted from the first operand, and the resulting difference is placed in the first-operand location. The operands and result are in the packed format.

SUBTRACT DECIMAL is executed the same as ADD DECIMAL, except that the second operand is considered to have a sign opposite to the sign in storage. The second operand in storage remains unchanged.

Resulting Condition Code:

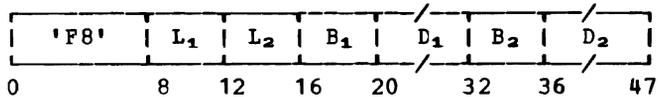
- 0 Difference is zero
- 1 Difference is less than zero
- 2 Difference is greater than zero
- 3 Overflow

Program Exceptions:

Access (fetch, operand 2; fetch and store, operand 1)
Data
Decimal Overflow

ZERO AND ADD

ZAP D₁(L₁,B₁),D₂(L₂,B₂) [SS]



The second operand is placed in the first-operand location. The operation is equivalent to an addition to zero. The operand and result are in the packed format.

Only the second operand is checked for valid sign and digit codes. Extra high-order zeros are supplied for the shorter operand if needed.

If the first operand is too short to contain all significant digits of the second operand, decimal overflow occurs. The operation is completed. The result is obtained by ignoring the overflow information, and condition code 3 is set. If the decimal-overflow mask is one, a program interruption for decimal overflow takes place.

A zero result is positive. However, when significant high-order digits are lost because of overflow, a zero result has the sign of the second operand.

The two operands may overlap, provided the rightmost byte of the first operand is coincident with or to the right of the rightmost byte of the second operand. In this case the result is obtained as if the operands were processed right to left.

Resulting Condition Code:

- 0 Result is zero
- 1 Result is less than zero
- 2 Result is greater than zero
- 3 Overflow

Program Exceptions:

Access (fetch, operand 2; store, operand 1)
Data
Decimal Overflow

Programming Note

An example of the use of ZERO AND ADD is given in Appendix A.

| | |
|--|------|
| Floating-Point Number Representation | 9-1 |
| Normalization | 9-2 |
| Floating-Point-Data Format | 9-2 |
| Instructions | 9-4 |
| ADD NORMALIZED | 9-6 |
| ADD UNNORMALIZED | 9-7 |
| COMPARE | 9-8 |
| DIVIDE | 9-9 |
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| LOAD | 9-10 |
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| MULTIPLY | 9-13 |
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Floating-point instructions are used to perform calculations on operands with a wide range of magnitude and to yield results scaled to preserve precision.

The floating-point instructions provide for loading, rounding, adding, subtracting, comparing, multiplying, dividing, and storing, as well as controlling the sign of short, long, and extended operands. Short operands generally permit faster processing and require less storage than long or extended operands. On the other hand, long and extended operands permit greater precision in computation. Four floating-point registers are provided. Instructions may perform either register-to-register or storage-and-register operations.

Most of the instructions generate normalized results, which preserve the highest precision in the operation. For addition and subtraction, instructions are also provided that generate unnormalized results. Either normalized or unnormalized numbers may be used as operands for any floating-point operation.

The rounding and extended-operand instructions are part of the extended-precision floating-point feature. The other floating-point instructions and the floating-point registers are part of the floating-point feature.

FLOATING-POINT NUMBER REPRESENTATION

A floating-point number consists of a signed hexadecimal fraction and an unsigned seven-bit binary integer called the characteristic. The characteristic represents a signed exponent and is obtained by adding 64 to the exponent value (excess-64 notation). The range of the characteristic is 0 to 127, which corresponds to an exponent range of -64 to +63. The value of a floating-point number is the product of its fraction and the number 16 raised to the power of the exponent which is represented by its characteristic.

The fraction of a floating-point number is treated as a hexadecimal number because it is considered to be multiplied by a number which is a power of 16. The name, fraction, indicates that the radix point is assumed to be immediately to the left of the leftmost fraction digit. The fraction is represented by its absolute value and a separate sign bit. The entire number is positive or negative, depending on whether the sign bit of the fraction is zero or one, respectively.

When a floating-point operation would cause the result exponent to exceed 63, the characteristic wraps around from 127 to 0, and an exponent-overflow condition exists. The result characteristic is then too small by 128. When an operation would cause the exponent to be less than -64, the characteristic wraps around from 0 to 127,

and an exponent-underflow condition exists. The result characteristic is then too large by 128, except that a zero characteristic is produced when a true zero is forced.

A true zero is a floating-point number with a zero characteristic, zero fraction, and plus sign. A true zero may arise as the normal result of an arithmetic operation because of the particular magnitude of the operands. The result is forced to be a true zero when:

1. An exponent underflow occurs and the exponent-underflow mask bit in the PSW is zero,
2. The result fraction of an addition or subtraction operation is zero and the significance mask bit in the PSW is zero, or
3. The operand of HALVE, one or both operands of MULTIPLY, or the dividend in DIVIDE has a zero fraction.

When a program interruption for exponent underflow occurs, a true zero is not forced; instead, the fraction and sign remain correct, and the characteristic is too large by 128. When a program interruption for significance occurs, the fraction remains zero, the sign is positive, and the characteristic remains correct.

The sign of a sum, difference, product, or quotient with a zero fraction is positive. The sign of a zero fraction resulting from other operations is established from the operand sign, the same as for nonzero fractions.

NORMALIZATION

A quantity can be represented with the greatest precision by a floating-point number of a given fraction length when that number is normalized. A normalized floating-point number has a nonzero leftmost hexadecimal fraction digit. If one or more leftmost fraction digits are zeros, the number is said to be unnormalized.

Unnormalized numbers are normalized by shifting the fraction left, one digit at a time, until the leftmost hexadecimal digit is nonzero and reducing the characteristic by the number of hexadecimal digits shifted. A number with a zero fraction cannot be normalized; its characteristic either remains unchanged, or it is made zero when the result is forced to be a true zero.

Floating-point operations may be performed with or without normalization. Most operations are performed only with normalization. Addition and subtraction with short or long operands may be specified as either normalized or unnormalized.

With unnormalized operations, leftmost zeros in the result fraction are not eliminated. The result may or may not be normalized, depending upon the original operands.

In both normalized and unnormalized operations, the initial operands need not be in normalized form. The operands for multiplication and division are normalized before the arithmetic process. For other normalized operations, normalization takes place when the intermediate arithmetic result is changed to the final result.

When the intermediate result of addition, subtraction, or rounding causes the fraction to overflow, the fraction is shifted right by one hexadecimal-digit position and the value one is placed in the vacated leftmost digit position. The fraction is then truncated to the final result length, while the characteristic is increased by one. This adjustment is made for both normalized and unnormalized operations.

Programming Note

Up to three leftmost bits of the fraction of a normalized number may be zeros, since the nonzero test applies to the entire leftmost hexadecimal digit.

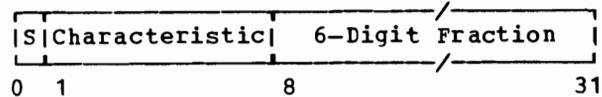
FLOATING-POINT-DATA FORMAT

Floating-point numbers have a 32-bit (short) format, a 64-bit (long) format, or a 128-bit (extended) format. Numbers in the short and long formats may be designated as operands both in storage and in the floating-point registers, whereas operands having the extended format can be designated only in the floating-point registers.

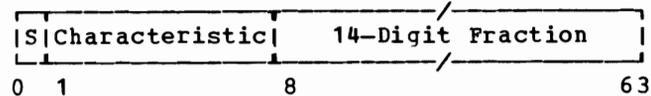
The floating-point registers contain 64 bits each and are numbered 0, 2, 4, and 6. A short or long floating-point number requires a single floating-point register. An extended floating-point number requires a pair of these registers: either registers 0 and 2 or register 4 and 6; the two register pairs are designated as 0 or 4, respectively. When the R_1 or R_2 field

of a floating-point instruction designates any register number other than 0, 2, 4, or 6 for the short or long format, or any register number other than 0 or 4 for the extended format, the operation is suppressed, and a program interruption for specification exception occurs.

Short Floating-Point Number

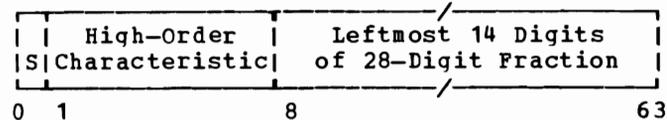


Long Floating-Point Number

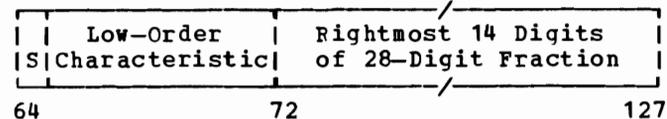


Extended Floating-Point Number

High-Order Part



Low-Order Part



In all formats, the first bit (bit 0) is the sign bit (S). The next seven bits are the characteristic. In the short and long formats, the remaining bits constitute the fraction, which consists of six or 14 hexadecimal digits, respectively.

A short floating-point number occupies only the leftmost 32 bit positions of a floating-point register. The rightmost 32 bit positions of the register are ignored when used as an operand in the short format and remain unchanged when a short result is placed in the register.

An extended floating-point number has a 28-digit fraction and consists of two long floating-point numbers which are called the high-order and low-order parts. The high-order part may be any long floating-point number. The fraction of the high-order part contains the leftmost 14 hexadecimal digits of the 28-digit fraction. The characteristic and sign of the high-order part are the characteristic and sign of the extended floating-point number. If the high-order part is normalized, the extended number is

considered normalized. The fraction of the low-order part contains the rightmost 14 digits of the 28-digit fraction. The sign and characteristic of the low-order part of an extended operand are ignored.

When a result in the extended format is placed in a register pair, the sign of the low-order part is made the same as that of the high-order part, and, unless the result is a true zero, the low-order characteristic is made 14 less than the high-order characteristic. When the subtraction of 14 would cause the low-order characteristic to become less than zero, the characteristic is made 128 greater than its correct value. Exponent underflow is indicated only when the high-order characteristic underflows.

When an extended result is made a true zero, both the high-order and low-order parts are made a true zero.

The range covered by the magnitude (M) of a normalized floating-point number depends on the format.

In the short format:

$$16^{-65} \leq M \leq (1 - 16^{-6}) \times 16^{63}$$

In the long format:

$$16^{-65} \leq M \leq (1 - 16^{-14}) \times 16^{63}$$

In the extended format:

$$16^{-65} \leq M \leq (1 - 16^{-28}) \times 16^{63}$$

In all formats, approximately:

$$5.4 \times 10^{-79} \leq M \leq 7.2 \times 10^{75}$$

Although the final result of a floating-point operation has six hexadecimal fraction digits in the short format, 14 fraction digits in the long format, and 28 fraction digits in the extended format, intermediate results have one additional hexadecimal digit on the right. This digit is called the guard digit. The guard digit may increase the precision of the final result because it participates in addition, subtraction, and comparison operations and in the left shift that occurs during normalization.

The entire set of floating-point operations is available for both short and long operands. These instructions generate a result that has the same format as the operands, except that for MULTIPLY, a long product is produced from a short multiplier and multiplicand. Extended floating-point instructions are provided only for normalized addition, subtraction, and multiplication. Two additional multiplication instructions generate an

extended product from a long multiplier and multiplicand. The rounding instructions provide for rounding from extended to long format and from long to short format.

whether the 15th digit of the normalized 28-digit fraction is nonzero or zero.

Programming Notes

1. A long floating-point number can be converted to the extended format by appending any long floating-point number having a zero fraction, including a true zero. Conversion from the extended to the long format can be accomplished by truncation or by means of LOAD ROUNDED.
2. In the absence of an exponent overflow or exponent underflow, the long floating-point number constituting the low-order part of an extended result correctly expresses the value of the low-order part of the extended result when the characteristic of the high-order part is 14 or higher. This applies also when the result is a true zero. When the high-order characteristic is less than 14 but the number is not a true zero, the low-order part, when addressed as a long floating-point number, does not have the correct characteristic value.
3. The entire fraction of an extended result participates in normalization. The low-order part alone may or may not appear to be a normalized long floating-point number, depending on

INSTRUCTIONS

The floating-point instructions and their mnemonics, formats, and operation codes are listed in the figure "Summary of Floating-Point Instructions." The figure also indicates when the condition code is set and the exceptional conditions in operand designations, data, or results that cause a program interruption.

Mnemonics for the floating-point instructions have an R as the last letter when the instruction is in the RR format. For instructions where all operands are the same length, certain letters are used to represent operand-format length and normalization, as follows:

| | |
|---|---------------------|
| E | short normalized |
| U | short unnormalized |
| D | long normalized |
| W | long unnormalized |
| X | extended normalized |

Note: In the detailed descriptions of the individual instructions, the mnemonic and the symbolic operand designation for the assembler language are shown with each instruction. For a register-to-register operation using LOAD (short), for example, LER is the mnemonic and R_1, R_2 the operand designation.

| Name | Mnemonic | Characteristics | | | | | | | Op Code | |
|---------------------------------|----------|-----------------|---|----|----|----|----|----|---------|----|
| ADD NORMALIZED (extended) | AXR | RR | C | XP | SP | EU | EO | LS | 36 | |
| ADD NORMALIZED (long) | ADR | RR | C | FP | SP | EU | EO | LS | 2A | |
| ADD NORMALIZED (long) | AD | RX | C | FP | A | SP | EU | EO | LS | 6A |
| ADD NORMALIZED (short) | AER | RR | C | FP | SP | EU | EO | LS | 3A | |
| ADD NORMALIZED (short) | AE | RX | C | FP | A | SP | EU | EO | LS | 7A |
| ADD UNNORMALIZED (long) | AWR | RR | C | FP | SP | EO | LS | | 2E | |
| ADD UNNORMALIZED (long) | AW | RX | C | FP | A | SP | EO | LS | 6E | |
| ADD UNNORMALIZED (short) | AUR | RR | C | FP | SP | EO | LS | | 3E | |
| ADD UNNORMALIZED (short) | AU | RX | C | FP | A | SP | EO | LS | 7E | |
| COMPARE (long) | CDR | RR | C | FP | SP | | | | 29 | |
| COMPARE (long) | CD | RX | C | FP | A | SP | | | 69 | |
| COMPARE (short) | CER | RR | C | FP | SP | | | | 39 | |
| COMPARE (short) | CE | RX | C | FP | A | SP | | | 79 | |
| DIVIDE (long) | DDR | RR | | FP | SP | EU | EO | FK | 2D | |
| DIVIDE (long) | DD | RX | | FP | A | SP | EU | EO | FK | 6D |
| DIVIDE (short) | DER | RR | | FP | SP | EU | EO | FK | 3D | |
| DIVIDE (short) | DE | RX | | FP | A | SP | EU | EO | FK | 7D |
| HALVE (long) | HDR | RR | | FP | SP | EU | | | 24 | |
| HALVE (short) | HER | RR | | FP | SP | EU | | | 34 | |
| LOAD (long) | LDR | RR | | FP | SP | | | | 28 | |
| LOAD (long) | LD | RX | | FP | A | SP | | | 68 | |
| LOAD (short) | LER | RR | | FP | SP | | | | 38 | |
| LOAD (short) | LE | RX | | FP | A | SP | | | 78 | |
| LOAD AND TEST (long) | LTD | RR | C | FP | SP | | | | 22 | |
| LOAD AND TEST (short) | LTER | RR | C | FP | SP | | | | 32 | |
| LOAD COMPLEMENT (long) | LCDR | RR | C | FP | SP | | | | 23 | |
| LOAD COMPLEMENT (short) | LCER | RR | C | FP | SP | | | | 33 | |
| LOAD NEGATIVE (long) | LNDR | RR | C | FP | SP | | | | 21 | |
| LOAD NEGATIVE (short) | LNER | RR | C | FP | SP | | | | 31 | |
| LOAD POSITIVE (long) | LPDR | RR | C | FP | SP | | | | 20 | |
| LOAD POSITIVE (short) | LPER | RR | C | FP | SP | | | | 30 | |
| LOAD ROUNDED (extended to long) | LRDR | RR | | XP | SP | EO | | | 25 | |
| LOAD ROUNDED (long to short) | LRER | RR | | XP | SP | EO | | | 35 | |
| MULTIPLY (extended) | MXR | RR | | XP | SP | EU | EO | | 26 | |
| MULTIPLY (long) | MDR | RR | | FP | SP | EU | EO | | 2C | |
| MULTIPLY (long) | MD | RX | | FP | A | SP | EU | EO | 6C | |
| MULTIPLY (long to extended) | MXDR | RR | | XP | SP | EU | EO | | 27 | |
| MULTIPLY (long to extended) | MXD | RX | | XP | A | SP | EU | EO | 67 | |
| MULTIPLY (short to long) | MER | RR | | FP | SP | EU | EO | | 3C | |
| MULTIPLY (short to long) | ME | RX | | FP | A | SP | EU | EO | 7C | |
| STORE (long) | STD | RX | | FP | A | SP | | ST | 60 | |
| STORE (short) | STE | RX | | FP | A | SP | | ST | 70 | |
| SUBTRACT NORMALIZED (extended) | SXR | RR | C | XP | SP | EU | EO | LS | 37 | |
| SUBTRACT NORMALIZED (long) | SDR | RR | C | FP | SP | EU | EO | LS | 2B | |
| SUBTRACT NORMALIZED (long) | SD | RX | C | FP | A | SP | EU | EO | LS | 6B |

Summary of Floating-Point Instructions (Part 1 of 2)

| Name | Mne- monic | Characteristics | | | | | | | Op Code | |
|-------------------------------|---------------|-----------------|---|----|----|----|----|----|------------|----|
| SUBTRACT NORMALIZED (short) | SER | RR | C | FP | SP | EU | EO | LS | 3B | |
| SUBTRACT NORMALIZED (short) | SE | RX | C | FP | A | SP | EU | EO | LS | 7B |
| SUBTRACT UNNORMALIZED (long) | SWR | RR | C | FP | SP | | EO | LS | 2F | |
| SUBTRACT UNNORMALIZED (long) | SW | RX | C | FP | A | SP | | EO | LS | 6F |
| SUBTRACT UNNORMALIZED (short) | SUR | RR | C | FP | SP | | EO | LS | 3F | |
| SUBTRACT UNNORMALIZED (short) | SU | RX | C | FP | A | SP | | EO | LS | 7F |

Explanation:

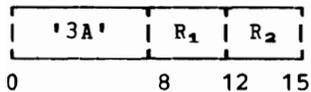
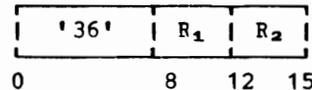
- | A Access exceptions
- | C Condition code is set
- | EO Exponent-overflow exception
- | EU Exponent-underflow exception
- | FK Floating-point-divide exception
- | FP Floating-point feature
- | LS Significance exception
- | RR RR instruction format
- | RX RX instruction format
- | SP Specification exception
- | ST PER storage alteration event
- | XP Extended-precision floating-point feature

Summary of Floating-Point Instructions (Part 2 of 2)

ADD NORMALIZED

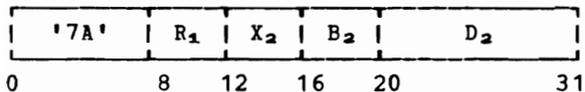
AXR R_1, R_2 [RR, Extended Operands]

AER R_1, R_2 [RR, Short Operands]



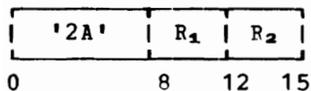
The second operand is added to the first operand, and the normalized sum is placed in the first-operand location.

AE $R_1, D_2 (X_2, B_2)$ [RX, Short Operands]



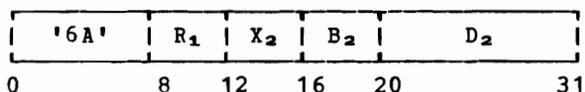
Addition of two floating-point numbers consists in characteristic comparison, fraction alignment, and fraction addition. The characteristics of the two operands are compared, and the fraction accompanying the smaller characteristic is aligned with the other fraction by a right shift, with its characteristic increased by one for each hexadecimal digit of shift until the two characteristics agree.

ADR R_1, R_2 [RR, Long Operands]



When a fraction is shifted right during alignment, the leftmost hexadecimal digit shifted out is retained as a guard digit. The fraction that is not shifted is considered to be extended with a zero in the guard-digit position. When no alignment shift occurs, both operands are considered to be extended with zeros in the guard-digit position. The fractions are then added algebraically to form an intermediate sum.

AD $R_1, D_2 (X_2, B_2)$ [RX, Long Operands]



The intermediate-sum fraction consists of seven (short format), 15 (long format), or 29 (extended format) hexadecimal digits, including the guard digit, and a possible carry. If a carry is present, the sum is

shifted right one digit position so that the carry becomes the leftmost digit of the fraction, and the characteristic is increased by one.

If the addition produces no carry, the intermediate-sum fraction is shifted left as necessary to eliminate any leading hexadecimal zero digits resulting from the addition, provided the fraction is not zero. Vacated rightmost digit positions are filled with zeros, and the characteristic is reduced by the number of hexadecimal digits of shift. The fraction thus normalized is then truncated on the right to six (short format), 14 (long format), or 28 (extended format) hexadecimal digits. In the extended format, a characteristic is generated for the low-order part, which is 14 less than the high-order characteristic.

The sign of the sum is determined by the rules of algebra, unless all digits of the intermediate-sum fraction are zero, in which case the sign is made plus.

An exponent-overflow exception is recognized when a carry from the leftmost position of the intermediate-sum fraction would cause the characteristic of the normalized sum to exceed 127. The operation is completed by making the result characteristic 128 less than the correct value, and a program interruption for exponent overflow takes place. The result sign and fraction remain correct, and, for AXR, the characteristic of the low-order part remains correct.

An exponent-underflow exception is recognized when the characteristic of the normalized sum would be less than zero and the fraction is not zero. If the exponent-underflow mask bit is one, the operation is completed by making the result characteristic 128 greater than the correct value. The result sign and fraction remain correct, and a program interruption for exponent underflow takes place. When exponent underflow occurs and the exponent-underflow mask bit is zero, a program interruption does not take place; instead, the operation is completed by making the result a true zero. For AXR, no exponent underflow is recognized when the characteristic of the low-order part would be less than zero but the characteristic of the high-order part is zero or greater.

The result fraction is zero when the intermediate-sum fraction, including the guard digit, is zero. With a zero result fraction, the action depends on the setting of the significance mask bit. If the significance mask bit is one, no normalization occurs, the intermediate and final result characteristics are the same, and a program interruption for significance

takes place. If the significance mask bit is zero, the program interruption does not occur; instead, the result is made a true zero.

The R_1 field for AER, AE, ADR, and AD, and the R_2 field for AER and ADR must designate register 0, 2, 4, or 6. The R_1 and R_2 fields for AXR must designate register 0 or 4. Otherwise, a specification exception is recognized.

Resulting Condition Code:

- 0 Result fraction is zero
- 1 Result is less than zero
- 2 Result is greater than zero
- 3 --

Program Exceptions:

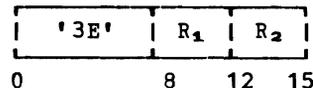
- Access (fetch, operand 2 of AE and AD only)
- Exponent Overflow
- Exponent Underflow
- Operation (if the floating-point feature is not installed, or, for AXR, if the extended-precision floating-point feature is not installed)
- Significance Specification

Programming Notes

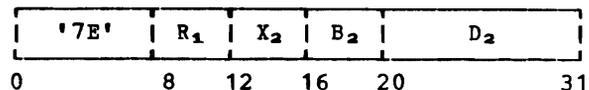
1. Interchanging the two operands in a floating-point addition does not affect the value of the sum.
2. The ADD NORMALIZED instructions normalize the sum but not the operands. Thus, if one or both operands are unnormalized, precision may be lost during fraction alignment.

ADD UNNORMALIZED

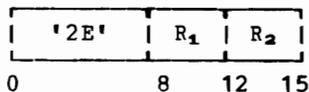
AUR R_1, R_2 [RR, Short Operands]



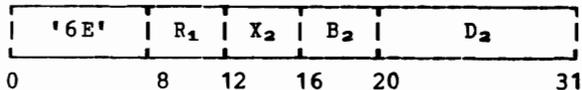
AU $R_1, D_2(X_2, B_2)$ [RX, Short Operands]



AWR R_1, R_2 [RR, Long Operands]



AW $R_1, D_2 (X_2, B_2)$ [RX, Long Operands]



The second operand is added to the first operand, and the unnormalized sum is placed in the first-operand location.

The execution of ADD UNNORMALIZED is identical to that of ADD NORMALIZED, except that:

1. When no carry is present after the addition, the intermediate-sum fraction is truncated to the proper result-fraction length without a left shift to eliminate leading hexadecimal zeros and without the corresponding reduction of the characteristic.
2. Exponent underflow cannot occur.
3. The guard digit does not participate in the recognition of a zero result fraction. A zero result fraction is recognized when the fraction, that is, the intermediate-sum fraction, excluding the guard digit, is zero.

The R_1 and R_2 fields must designate register 0, 2, 4, or 6; otherwise, a specification exception is recognized.

Resulting Condition Code:

- 0 Result fraction is zero
- 1 Result is less than zero
- 2 Result is greater than zero
- 3 --

Program Exceptions:

- Access (fetch, operand 2 of AU and AW only)
- Exponent Overflow
- Operation (if the floating-point feature is not installed)
- Significance
- Specification

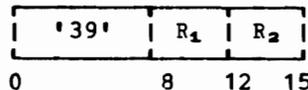
Programming Note

Except when the result is made a true zero, the characteristic of the result of ADD UNNORMALIZED is equal to the greater of the

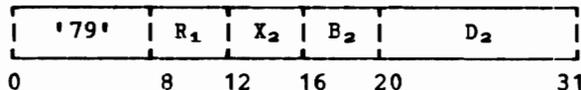
two operand characteristics, increased by one if the fraction addition produced a carry.

COMPARE

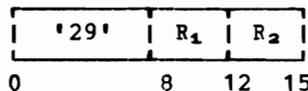
CER R_1, R_2 [RR, Short Operands]



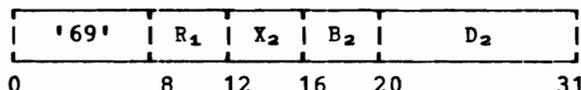
CE $R_1, D_2 (X_2, B_2)$ [RX, Short Operands]



CDR R_1, R_2 [RR, Long Operands]



CD $R_1, D_2 (X_2, B_2)$ [RX, Long Operands]



The first operand is compared with the second operand, and the condition code is set to indicate the result.

The comparison is algebraic and follows the procedure for normalized floating-point subtraction, except that the difference is discarded after setting the condition code and both operands remain unchanged. When the difference, including the guard digit, is zero, the operands are equal. When a nonzero difference is positive or negative, the first operand is high or low, respectively.

An exponent-overflow, exponent-underflow, or significance exception cannot occur.

The R_1 and R_2 fields must designate register 0, 2, 4, or 6; otherwise, a specification exception is recognized.

Resulting Condition Code:

- 0 Operands are equal
- 1 First operand is low
- 2 First operand is high
- 3 --

Program Exceptions:

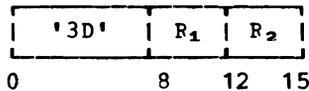
Access (fetch, operand 2 of CE and CD only)
Operation (if the floating-point feature is not installed)
Specification

Programming Notes

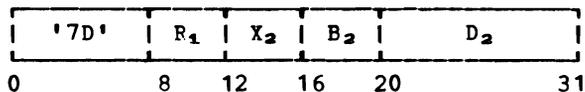
1. An exponent inequality alone is not sufficient to determine the inequality of two operands with the same sign, because the fractions may have different numbers of leading hexadecimal zeros.
2. Numbers with zero fractions compare equal even when they differ in sign or characteristic.

DIVIDE

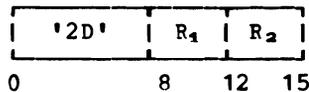
DER R₁, R₂ [RR, Short Operands]



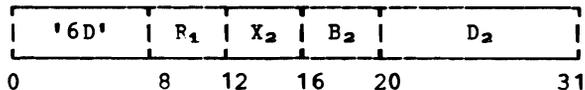
DE R₁, D₂ (X₂, B₂) [RX, Short Operands]



DDR R₁, R₂ [RR, Long Operands]



DD R₁, D₂ (X₂, B₂) [RX, Long Operands]



The first operand (the dividend) is divided by the second operand (the divisor), and the normalized quotient is placed in the first-operand location. No remainder is preserved.

Floating-point division consists in characteristic subtraction and fraction

division. The operands are first normalized to eliminate leading hexadecimal zeros. The difference between the dividend and divisor characteristics of the normalized operands, plus 64, is used as the characteristic of an intermediate quotient.

All dividend and divisor fraction digits participate in forming the fraction of the intermediate quotient. The intermediate-quotient fraction can have no leading hexadecimal zeros, but a right-shift of one digit position may be necessary with an increase of the characteristic by one. The fraction is then truncated to the proper result-fraction length.

An exponent-overflow exception is recognized when the characteristic of the final quotient would exceed 127 and the fraction is not zero. The operation is completed by making the characteristic 128 less than the correct value. The result is normalized, and the sign and fraction remain correct. A program interruption for exponent overflow occurs.

An exponent-underflow exception exists when the characteristic of the final quotient would be less than zero and the fraction is not zero. If the exponent-underflow mask bit is one, the operation is completed by making the characteristic 128 greater than the correct value, and a program interruption for exponent underflow occurs. The result is normalized, and the sign and fraction remain correct. If the exponent-underflow mask bit is zero, a program interruption does not take place; instead, the operation is completed by making the quotient a true zero.

Exponent underflow does not occur when an operand characteristic becomes less than zero during normalization of the operands or when the intermediate-quotient characteristic is less than zero, as long as the final quotient can be represented with the correct characteristic.

When the divisor fraction is zero, the operation is suppressed, and a program interruption for floating-point divide occurs. This includes the division of zero by zero.

When the dividend fraction is zero, but the divisor fraction is nonzero, the quotient is made a true zero. No exponent overflow or exponent underflow occurs.

The sign of the quotient is determined by the rules of algebra, except that the sign is always plus when the quotient is made a true zero.

The R₁ field for DER, DE, DDR, and DD, and

the R_2 field for DER and DDR, must designate register 0, 2, 4, or 6. Otherwise, a specification exception is recognized.

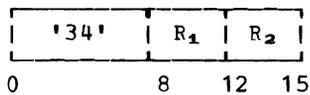
Condition Code: The code remains unchanged.

Program Exceptions:

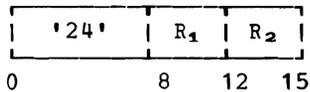
Access (fetch, operand 2 of DD and DE only)
 Exponent Overflow
 Exponent Underflow
 Floating-Point Divide Operation (if the floating-point feature is not installed)
 Specification

HALVE

HER R_1, R_2 [RR, Short Operands]



HDR R_1, R_2 [FR, Long Operands]



The second operand is divided by 2, and the normalized quotient is placed in the first-operand location.

The fraction of the second operand is shifted right one bit position, placing the contents of the rightmost bit position into the leftmost bit position of the guard digit and introducing a zero into the leftmost bit position of the fraction. The intermediate result, including the guard digit, is then normalized, and the final result is truncated to the proper length.

An exponent-underflow exception exists when the characteristic of the final result would be less than zero and the fraction is not zero. If the exponent-underflow mask bit is one, the operation is completed by making the characteristic 128 greater than the correct value, and a program interruption for exponent underflow occurs. The result is normalized, and the sign and fraction remain correct. If the exponent-underflow mask bit is zero, a program interruption does not take place; instead, the operation is completed by making the result a true zero.

When the fraction of the second operand is zero, the result is made a true zero, and no exponent underflow occurs.

The sign of the result is the same as that of the second operand, except that the sign is always plus when the quotient is made a true zero.

The R_1 and R_2 fields must designate register 0, 2, 4, or 6; otherwise, a specification exception is recognized.

Condition Code: The code remains unchanged.

Program Exceptions:

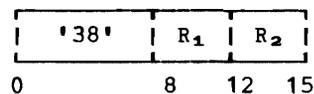
Exponent Underflow
 Operation (if the floating-point feature is not installed)
 Specification

Programming Notes

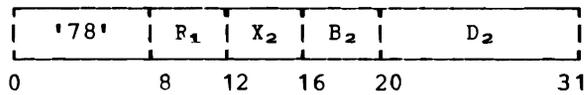
1. With short and long operands, the halve operation is identical to a divide operation with the number 2 as divisor. Similarly, the result of HDR is identical to that of MD or MDR with one-half as a multiplier. No multiply operation corresponds to HER, since no multiply operation produces short results.
2. The result of HALVE is zero only when the second-operand fraction is zero, or when exponent underflow occurs with the exponent-underflow mask set to zero. A fraction with zeros in every bit position, except for a one in the rightmost bit position, does not become zero after the right shift. This is because the one bit is preserved in the guard-digit position and becomes the leftmost bit after normalization of the result.

LOAD

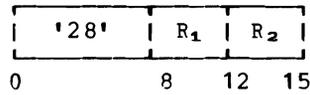
LER R_1, R_2 [RR, Short Operands]



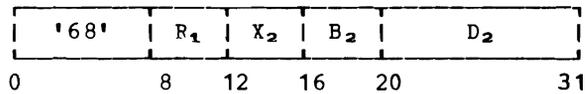
LE $R_1, D_2(X_2, B_2)$ [RX, Short Operands]



LDR R_1, R_2 [RR, Long Operands]



LD $R_1, D_2(X_2, B_2)$ [RX, Long Operands]



The second operand is placed unchanged in the first-operand location.

The R_1 and R_2 fields must designate register 0, 2, 4, or 6; otherwise, a specification exception is recognized.

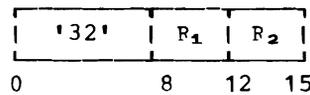
Condition Code: The code remains unchanged.

Program Exceptions:

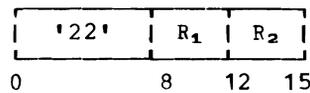
Access (fetch, operand 2 of LE and LD only)
 Operation (if the floating-point feature is not installed)
 Specification

LOAD AND TEST

LTER R_1, R_2 [RR, Short Operands]



LTDR R_1, R_2 [RR, Long Operands]



The second operand is placed unchanged in the first-operand location, and its sign and magnitude are tested to determine the setting of the condition code.

The R_1 and R_2 fields must designate register 0, 2, 4, or 6; otherwise, a

specification exception is recognized.

Resulting Condition Code:

- 0 Result fraction is zero
- 1 Result is less than zero
- 2 Result is greater than zero
- 3 --

Program Exceptions:

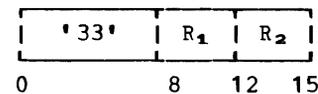
Operation (if the floating-point feature is not installed)
 Specification

Programming Note

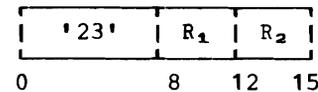
When the same register is specified as the first-operand and second-operand location, the operation is equivalent to a test without data movement.

LOAD COMPLEMENT

LCER R_1, R_2 [RR, Short Operands]



LCDR R_1, R_2 [RR, Long Operands]



The second operand is placed in the first-operand location with the sign bit inverted.

The sign bit is inverted, even if the fraction is zero. The characteristic and fraction are not changed.

The R_1 and R_2 fields must designate register 0, 2, 4, or 6; otherwise, a specification exception is recognized.

Resulting Condition Code:

- 0 Result fraction is zero
- 1 Result is less than zero
- 2 Result is greater than zero
- 3 --

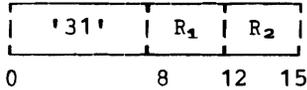
Program Exceptions:

Operation (if the floating-point feature is not installed)

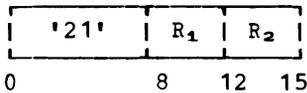
Specification

LOAD NEGATIVE

LNER R_1, R_2 [RR, Short Operands]



LNDR R_1, R_2 [RR, Long Operands]



The second operand is placed in the first-operand location with the sign made minus.

The sign bit is made one, even if the fraction is zero. The characteristic and fraction are not changed.

The R_1 and R_2 fields must designate register 0, 2, 4, or 6; otherwise, a specification exception is recognized.

Resulting Condition Code:

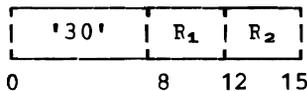
- 0 Result fraction is zero
- 1 Result is less than zero
- 2 --
- 3 --

Program Exceptions:

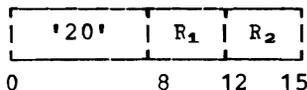
Operation (if the floating-point feature is not installed)
Specification

LOAD POSITIVE

LPER R_1, R_2 [RR, Short Operands]



LPDR R_1, R_2 [RR, Long Operands]



The second operand is placed in the first-operand location with the sign made plus.

The sign bit is made zero. The characteristic and fraction are not changed.

The R_1 and R_2 fields must designate register 0, 2, 4, or 6; otherwise, a specification exception is recognized.

Resulting Condition Code:

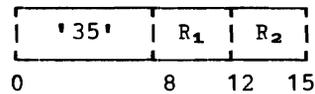
- 0 Result fraction is zero
- 1 --
- 2 Result is greater than zero
- 3 --

Program Exceptions:

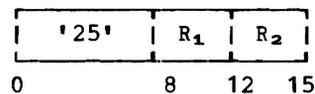
Operation (if the floating-point feature is not installed)
Specification

LOAD ROUNDED

LRER R_1, R_2
[RR, Long Operand 2, Short Operand 1]



LRDR R_1, R_2
[RR, Extended Operand 2, Long Operand 1]



The second operand is rounded to the next shorter format, and the result is placed in the first-operand location.

Rounding consists in adding a one in bit position 32 or 72 of the long or extended second operand, respectively, and propagating any carry to the left. The sign of the fraction is ignored, and addition is performed as if the fractions were positive.

If rounding causes a carry out of the leftmost hexadecimal digit position of the fraction, the fraction is shifted right one digit position so that the carry becomes the leftmost digit of the fraction, and the characteristic is increased by one.

The sign of the result is the same as the sign of the second operand. There is no

normalization to eliminate leading zeros.

An exponent-overflow exception exists when shifting the fraction right would cause the characteristic to exceed 127. The operation is completed by loading a number whose characteristic is 128 less than the correct value, and a program interruption for exponent overflow occurs. The result is normalized, and the sign and fraction remain correct.

Exponent-underflow and significance exceptions cannot occur.

The R_1 field must designate register 0, 2, 4, or 6; the R_2 field of LRER must designate register 0, 2, 4, or 6; and the R_2 field of LRDR must designate register 0 or 4. Otherwise, a specification exception is recognized.

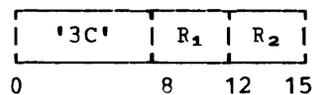
Condition Code: The code remains unchanged.

Program Exceptions:

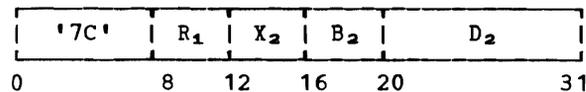
Exponent Overflow
Operation (if the extended-precision floating-point feature is not installed)
Specification

MULTIPLY

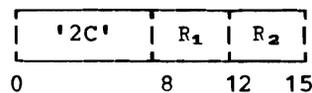
MER R_1, R_2
[RR, Short Multiplier and Multiplicand, Long Product]



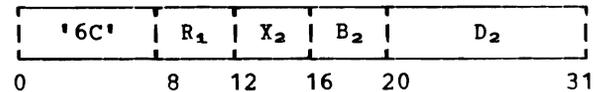
ME $R_1, D_2(X_2, B_2)$
[RX, Short Multiplier and Multiplicand, Long Product]



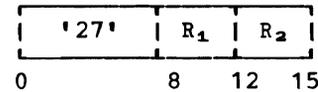
MDR R_1, R_2 [RR, Long Operands]



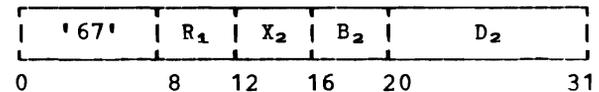
MD $R_1, D_2(X_2, B_2)$ [RX, Long Operands]



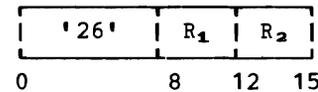
MXDR R_1, R_2
[RR, Long Multiplier and Multiplicand, Extended Product]



MXD $R_1, D_2(X_2, B_2)$
[RX, Long Multiplier and Multiplicand, Extended Product]



MXR R_1, R_2 [RR, Extended Operands]



The normalized product of the second operand (the multiplier) and the first operand (the multiplicand) is placed in the first-operand location.

Multiplication of two floating-point numbers consists in exponent addition and fraction multiplication. The operands are first normalized to eliminate leading hexadecimal zeros. The sum of the characteristics of the normalized operands, less 64, is used as the characteristic of the intermediate product.

The fraction of the intermediate product is the exact product of the normalized operand fractions. When the intermediate-product fraction has one leading hexadecimal zero digit, the fraction is shifted left one digit position, bringing the contents of the guard-digit position into the rightmost position of the result fraction, and the intermediate-product characteristic is reduced by one. The fraction is then truncated to the proper result-fraction length.

For MER and ME, the multiplier and multiplicand fractions have six hexadecimal digits; the product fraction has the full 14 digits of the long format, with the two rightmost fraction digits always zeros. For MDR and MD, the multiplier and multiplicand fractions have 14 digits, and

the final product fraction is truncated to 14 digits. For MXDR and MXD, the multiplier and multiplicand fractions have 14 digits, with the multiplicand occupying the high-order part of the first operand; the final product fraction contains 28 digits and is an exact product of the operand fractions. For MXR, the multiplier and multiplicand fractions have 28 digits, and the final product fraction is truncated to 28 digits.

An exponent-overflow exception is recognized when the characteristic of the final product would exceed 127 and the fraction is not zero. The operation is completed by making the characteristic 128 less than the correct value. If, for extended results, the low-order characteristic would also exceed 127, it, too, is decreased by 128. The result is normalized, and the sign and fraction remain correct. A program interruption for exponent overflow occurs.

Exponent overflow is not recognized when the intermediate-product characteristic is initially 128 but is brought back within range by normalization.

An exponent-underflow exception exists when the characteristic of the final product would be less than zero and the fraction is not zero. If the exponent-underflow mask bit is one, the operation is completed by making the characteristic 128 greater than the correct value, and a program interruption for exponent underflow occurs. The result is normalized, and the sign and fraction remain correct. If the exponent-underflow mask bit is zero, program interruption does not take place; instead, the operation is completed by making the product a true zero. For extended results, exponent underflow is not recognized when the low-order characteristic would be less than zero but the high-order characteristic is equal to or greater than zero.

Exponent underflow does not occur when the characteristic of an operand becomes less than zero during normalization of the operands, as long as the final product can be represented with the correct characteristic.

When either or both operand fractions are zero, the result is made a true zero, and no exponent overflow or exponent underflow occurs.

The sign of the product is determined by the rules of algebra, except that the sign is always zero when the result is made a true zero.

The R₁ field for MER, ME, MDR, and MD, and the R₂ field for MER, MDR, and MXDR must

designate register 0, 2, 4, or 6. The R₁ field for MXDR, MXD, and MXR, and the R₂ field for MXR must designate register 0 or 4. Otherwise, a specification exception is recognized.

Condition Code: The code remains unchanged.

Program Exceptions:

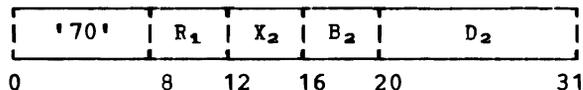
- Access (fetch, operand 2 of ME, MD, and MXD only)
- Exponent Overflow
- Exponent Underflow
- Operation (if the floating-point feature is not installed, or, for MXDR, MXD, and MXR, if the extended-precision floating-point feature is not installed)
- Specification

Programming Note

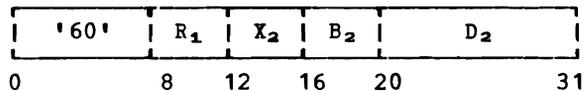
Interchanging the two operands in a floating-point multiplication does not affect the value of the product.

STORE

STE R₁,D₂(X₂,B₂) [RX, Short Operands]



STD R₁,D₂(X₂,B₂) [RX, Long Operands]



The first operand is placed unchanged in the second-operand location.

The R₁ field must designate register 0, 2, 4, or 6; otherwise, a specification exception is recognized.

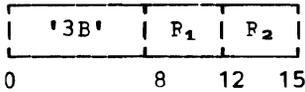
Condition Code: The code remains unchanged.

Program Exceptions:

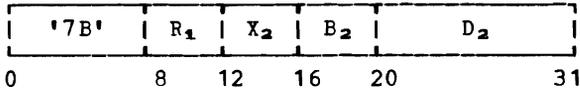
- Access (store, operand 2)
- Operation (if the floating-point feature is not installed)
- Specification

SUBTRACT NORMALIZED

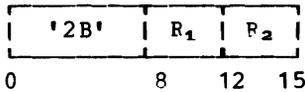
SER R_1, R_2 [RR, Short Operands]



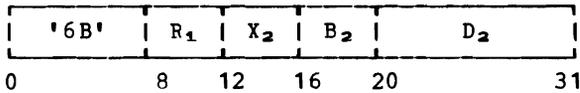
SE $R_1, D_2 (X_2, B_2)$ [RX, Short Operands]



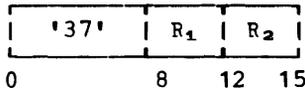
SDR R_1, R_2 [RR, Long Operands]



SD $R_1, D_2 (X_2, B_2)$ [RX, Long Operands]



SXR R_1, R_2 [RR, Extended Operands]



The second operand is subtracted from the first operand, and the normalized difference is placed in the first-operand location.

The execution of SUBTRACT NORMALIZED is identical to that of ADD NORMALIZED, except that the second operand participates in the operation with its sign bit inverted.

The R_1 field of SER, SE, SDR, and SD, and the R_2 field of SER and SDR must designate register 0, 2, 4, or 6. The R_1 and R_2 fields of SXR must designate register 0 or 4. Otherwise, a specification exception is recognized.

Resulting Condition Code:

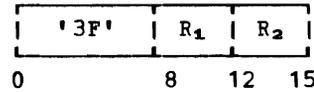
- 0 Result fraction is zero
- 1 Result is less than zero
- 2 Result is greater than zero
- 3 --

Program Exceptions:

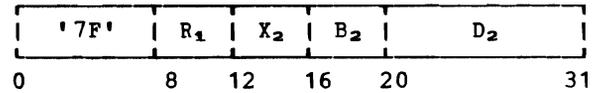
- Access (fetch, operand 2 of SE and SD only)
- Exponent Overflow
- Exponent Underflow
- Operation (if the floating-point feature is not installed, or, for SXR, if the extended-precision floating-point feature is not installed)
- Significance
- Specification

SUBTRACT UNNORMALIZED

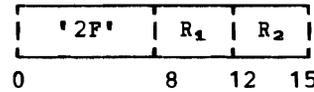
SUR R_1, R_2 [RR, Short Operands]



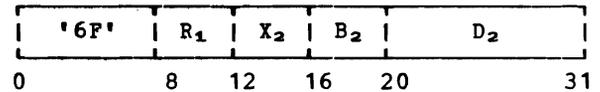
SU $R_1, D_2 (X_2, B_2)$ [RX, Short Operands]



SWR R_1, R_2 [RR, Long Operands]



SW $R_1, D_2 (X_2, B_2)$ [RX, Long Operands]



The second operand is subtracted from the first operand, and the unnormalized difference is placed in the first-operand location.

The execution of SUBTRACT UNNORMALIZED is identical to that of ADD UNNORMALIZED, except that the second operand participates in the operation with its sign bit inverted.

The R_1 and R_2 fields must designate register 0, 2, 4, or 6; otherwise, a specification exception is recognized.

Resulting Condition Code:

- 0 Result fraction is zero

- 1 Result is less than zero
- 2 Result is greater than zero
- 3 --

Program Exceptions:

Access (fetch, operand 2 of SU and SW

only)
Exponent Overflow
Operation (if the floating-point
feature is not installed)
Significance
Specification

CHAPTER 10. CONTROL INSTRUCTIONS

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The control instructions include all privileged and semiprivileged instructions, except the input/output instructions, which

are described in Chapter 12, "Input/Output Operations."

Privileged instructions may be executed only when the CPU is in the supervisor state. An attempt to execute a privileged instruction in the problem state generates a privileged-operation exception.

The semiprivileged instructions are those instructions that can be executed in the problem state when certain authority requirements are met. An attempt to execute a semiprivileged instruction in the problem state when the authority requirements are not met generates a privileged-operation exception or some other program-interruption condition depending on the particular requirement which is violated. Those requirements which cause a privileged-operation exception to be generated in problem state

| are not enforced when executed in the
| supervisor state.

The control instructions and their mnemonics, formats, and operation codes are listed in the figure "Control Instructions." The figure also indicates when the condition code is set and the exceptional conditions in operand designations, data, or results that cause a program interruption.

Note: In the detailed descriptions of the individual instructions, the mnemonic and the symbolic operand designation for the assembler language are shown with each instruction. For LOAD PSW, for example, LPSW is the mnemonic and $D_2(B_2)$ the operand designation.

| Name | Mnemonic | Characteristics | | | | | | | | | | Op Code |
|-------------------------------|----------|-----------------|---|----|----------------|----------------|---------|----|----|-----|----|---------|
| CONNECT CHANNEL SET | CONCS | S | C | CS | P | | | | | | | B200 |
| DIAGNOSE | | | | DM | P | DM | | | | | | 83 |
| DISCONNECT CHANNEL SET | DISCS | S | C | CS | P | | | | | | | B201 |
| EXTRACT PRIMARY ASN | EPAR | RRE | | DU | Q | | | SO | R | | | B226 |
| EXTRACT SECONDARY ASN | ESAR | RRE | | DU | Q | | | SO | R | | | B227 |
| INSERT ADDRESS SPACE CONTROL | IAC | RRE | C | DU | Q | | | SO | R | | | B224 |
| INSERT PSW KEY | IPK | S | | PK | Q | | | | R | | | B20B |
| INSERT STORAGE KEY | ISK | RR | | P | A ¹ | SP | | | R | | | 09 |
| INVALIDATE PAGE TABLE ENTRY | IPTE | RRE | | EP | P | A ¹ | | \$ | | | | B221 |
| INSERT VIRTUAL STORAGE KEY | IVSK | RRE | | DU | Q | A ¹ | | SO | R | | | B223 |
| LOAD CONTROL | LCTL | RS | | P | A | SP | | | | | | B7 |
| LOAD ADDRESS SPACE PARAMETERS | LASP | SSE | C | DU | Q | AS | SP | SO | | | | E500 |
| LOAD PSW | LPSW | S | L | P | A | SP | | \$ | | | | 82 |
| LOAD REAL ADDRESS | LRA | RX | C | TR | P | A ¹ | | | R | | | B1 |
| MOVE TO PRIMARY | MVCP | SS | C | DU | Q | A ¹ | | \$ | SO | | ST | DA |
| MOVE TO SECONDARY | MVCS | SS | C | DU | Q | A ¹ | | \$ | SO | | ST | DB |
| MOVE WITH KEY | MVCK | SS | C | DU | Q | A | | | | | ST | D9 |
| PROGRAM CALL | PC | S | | DU | Q | AT | PC T | \$ | SO | B R | XT | B218 |
| PROGRAM TRANSFER | PT | RRE | | DU | Q | AT | SP PA T | \$ | SO | B | XT | B228 |
| PURGE TLB | PTLB | S | | TR | P | | | \$ | | | | B20D |
| READ DIRECT | RDD | SI | | DC | P | A ¹ | | \$ | | | SD | 85 |
| RESET REFERENCE BIT | RRB | S | C | TR | P | A ¹ | | | | | | B213 |
| SET ADDRESS SPACE CONTROL | SAC | S | | DU | | SP | | \$ | SO | | | B219 |
| SET CLOCK | SCK | S | C | | P | A | SP | | | | | B204 |
| SET CLOCK COMPARATOR | SCKC | S | | CK | P | A | SP | | | | | B206 |
| SET CPU TIMER | SPT | S | | CK | P | A | SP | | | | | B208 |
| SET PREFIX | SPX | S | | MP | P | A | SP | \$ | | | | B210 |
| SET PSW KEY FROM ADDRESS | SPKA | S | | PK | Q | | | | | | | B20A |
| SET SECONDARY ASN | SSAR | RRE | | DU | | AT | SA T | \$ | SO | | ST | B225 |
| SET STORAGE KEY | SSK | RR | | P | A ¹ | SP | | \$ | | | | 08 |
| SET SYSTEM MASK | SSM | S | | P | A | SP | | | SO | | | 80 |
| SIGNAL PROCESSOR | SIGP | RS | C | MP | P | | | \$ | | R | | AE |
| STORE CLOCK COMPARATOR | STCKC | S | | CK | P | A | SP | | | | ST | B207 |
| STORE CONTROL | STCTL | RS | | | P | A | SP | | | | ST | B6 |
| STORE CPU ADDRESS | STAP | S | | MP | P | A | SP | | | | ST | B212 |
| STORE CPU ID | STIDP | S | | | P | A | SP | | | | ST | B202 |
| STORE CPU TIMER | STPT | S | | CK | P | A | SP | | | | ST | B209 |
| STORE PREFIX | STPX | S | | MP | P | A | SP | | | | ST | B211 |
| STORE THEN AND SYSTEM MASK | STNSM | SI | | TR | P | A | | | | | ST | AC |
| STORE THEN OR SYSTEM MASK | STOSM | SI | | TR | P | A | SP | | | | ST | AD |
| TEST BLOCK | TB | RRE | C | TB | P | A ¹ | | \$ | II | R | | B22C |
| TEST PROTECTION | TPROT | SSE | C | EF | P | A ¹ | | | | | | E501 |
| WRITE DIRECT | WRD | SI | | DC | P | A ¹ | | \$ | | | | 84 |

Summary of Control Instructions (Part 1 of 2)

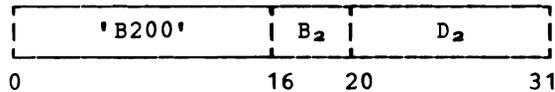
Explanation:

| A Access exceptions for logical address
| A¹ Access exceptions; not all access exceptions may occur; see instruction
| description for details
| AI Access exceptions for instruction address
| AS Access exception and ASN-translation-specification exception; see instruction
| description for details
| AT ASN-translation exceptions (include addressing, ASN-translation specification,
| AFX translation, and ASX translation) *
| B PER branch event
| C Condition code is set
| CK CPU-timer and clock-comparator feature
| CS Channel-set-switching feature
| DC Direct-control feature
| DM Depending on the model, DIAGNOSE may generate various program exceptions
| and may change the condition code.
| DU Dual-address-space facility
| EF Extended facility
| L New condition code loaded
| MP Multiprocessing feature
| P Privileged-operation exception
| PA Additional exceptions for PROGRAM TRANSFER (include addressing and primary
| authority)
| PC Additional exceptions for PROGRAM CALL (include addressing, PC-translation
| specification, LX translation, and EX translation)
| PK PSW-key-handling feature
| Q Privileged-operation exception for semiprivileged instructions
| R PER general-register alteration event
| RR RR instruction format
| RRE RRE instruction format
| RS RS instruction format
| RX RX instruction format
| S S instruction format
| SA Additional exceptions for SET SECONDARY ASN (include addressing and secondary
| authority)
| SD PER storage-alteration event, which can be caused by RDD only when IPTE is
| not installed.
| SI SI instruction format
| SO Special-operation exception
| SP Specification exception
| SS SS instruction format
| SSE SSE instruction format
| ST PER storage-alteration event
| T Trace exceptions (include access and specification)
| TB Test-block feature
| TR Translation feature
| XT Space-switch event and PER storage-alteration event
| * Causes serialization and checkpoint synchronization
| \$ Causes serialization

Summary of Control Instructions (Part 2 of 2)

CONNECT CHANNEL SET

CONCS D₂ (B₂) [S]



The channel set currently connected to this CPU is disconnected, and the addressed channel set, if currently disconnected, is connected to this CPU.

The second-operand address, specified by the B₂ and D₂ fields, is not used to address data; bits 16-31 form the 16-bit channel-set address. Bits 8-15 of the second-operand address are ignored.

When the channel set currently connected to this CPU is not the channel set addressed by the instruction, the currently connected channel set is immediately disconnected from this CPU, regardless of whether the channel set addressed by the instruction is operational or can be connected to this CPU.

If the addressed channel set is currently connected to this CPU, no operation is performed, and condition code 0 is set. If the addressed channel set is operational and currently disconnected, it is connected to this CPU, and condition code 0 is set.

When the addressed channel set is connected to another CPU, it is not connected to this CPU, and condition code 1 is set.

When the addressed channel set is not operational, condition code 3 is set.

A serialization function is performed. That is, CPU operation is delayed until all previous accesses by this CPU to main storage have been completed, as observed by channels and other CPUs. No subsequent instructions or their operands are accessed by this CPU until the execution of this instruction is completed. If a channel in the channel set which is connected by means of this instruction has an I/O interruption pending, and if the CPU is enabled for I/O interruptions, the interruption is recognized at the completion of this instruction.

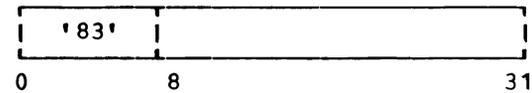
Resulting Condition Code:

| | |
|---|--|
| 0 | Connection operation completed |
| 1 | Connection operation not performed; addressed channel set connected to another CPU |
| 2 | -- |
| 3 | Not operational |

Program Interruptions:

Operation (if the channel-set-switching feature is not installed)
Privileged Operation

DIAGNOSE



The CPU performs built-in diagnostic functions, or other model-dependent functions. The purpose of the diagnostic functions is to verify proper functioning of CPU equipment and to locate faulty components. Other model-dependent functions may include disabling of failing buffers, reconfiguration of storage and channels, and modification of control storage.

Bits 8-31 may be used as in the SI or RS formats, or in some other way, to specify the particular diagnostic function. The use depends on the model.

The execution of the instruction may affect the state of the CPU and the contents of a register or storage location, as well as the progress of an I/O operation. Some diagnostic functions may cause the test indicator to be turned on.

Condition Code: The code is unpredictable.

Program Exceptions:

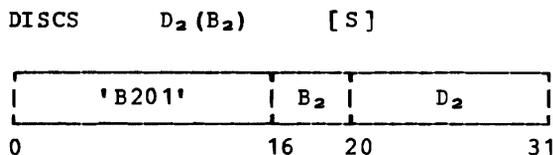
Privileged Operation
Depending on the model, other exceptions may be recognized.

Programming Notes

1. Since the instruction is not intended for problem-program or supervisor-program use, DIAGNOSE has no mnemonic.
2. DIAGNOSE, unlike other instructions, does not follow the rule that programming errors are distinguished from equipment errors. Improper use of DIAGNOSE may result in false machine-check indications or may cause actual machine malfunctions to be ignored. It may also alter other aspects of system operation, including instruction execution and channel operation, to an extent that the

operation does not comply with that specified in this publication. As a result of the improper use of DIAGNOSE, the system may be left in such a condition that the power-on reset or initial-microprogram-loading (IML) function must be performed. Since the function performed by DIAGNOSE may differ from model to model and between versions of a model, the program should avoid issuing DIAGNOSE unless the program recognizes both the model number and version code stored by STORE CPU ID.

DISCONNECT CHANNEL SET



The addressed channel set is disconnected from the CPU to which it is currently connected. If the channel set is not connected, no operation is performed.

The second-operand address, specified by the B₂ and D₂ fields, is not used to address data; bits 16-31 form the 16-bit channel-set address. Bits 8-15 of the second-operand address are ignored.

When the addressed channel set is not connected to any CPU, no operation is performed, and condition code 0 is set.

When the addressed channel set is connected either to the CPU issuing the DISCONNECT CHANNEL SET instruction or to a CPU that is in the stopped or check-stop state, the disconnection operation is performed, and condition code 0 is set.

When the addressed channel set is connected to another CPU which is in the operating state, which is being reset, or for which a SIGP reset is pending, no disconnection operation is performed, and condition code 1 is set.

When the addressed channel set is connected to another CPU which is in the load state or which is in the operator-intervening state, it depends on the model if condition code 0 or 1 is set. The action taken in this case is consistent with the condition code indicated.

When the addressed channel set is not operational, condition code 3 is set.

A serialization function is performed.

That is, CPU operation is delayed until all previous accesses by this CPU to main storage have been completed, as observed by channels and other CPUs. No subsequent instructions or their operands are accessed by this CPU until the execution of this instruction is completed.

Resulting Condition Code:

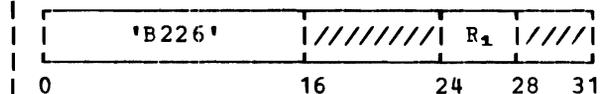
- 0 Disconnection operation completed
- 1 Disconnection operation not performed; addressed channel set connected to another CPU which is not in the proper state
- 2 --
- 3 Not operational

Program Interruptions:

Operation (if the channel-set-switching feature is not installed)
Privileged Operation

| EXTRACT PRIMARY ASN

| EPAR R₁ [RRE]



| The 16-bit PASN, bits 16-31 of control register 4, is placed in bit positions 16-31 of the general register designated by the R₁ field. Bits 0-15 of the general register are set to zeros.

| Bits 16-23 and 28-31 of the instruction are ignored.

| The instruction must be issued with DAT on; otherwise, a special-operation exception is recognized, and the operation is suppressed. The special-operation exception is recognized in both the problem and supervisor states.

| In the problem state, the extraction-authority control, bit 4 of control register 0, must be one; otherwise, a privileged-operation exception is recognized, and the operation is suppressed. In the supervisor state, the extraction-authority-control bit is not examined.

| The priority of recognition of program exceptions for the instruction is shown in the figure "Priority of Execution: EPAR."

| Condition Code: The code remains unchanged.

| Program Exceptions:

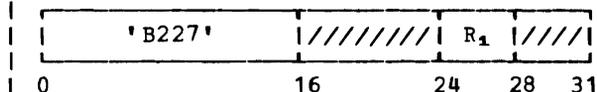
| Operation (if DAS is not installed)
| Privileged Operation (extraction-
| authority control is zero in
| problem state)
| Special Operation

- | | |
|-------|--|
| 1.-6. | Exceptions with the same priority as the priority of program-interruption conditions for the general case. |
| 7.A | Access exceptions for second instruction halfword. |
| 7.B.1 | Operation exception if DAS is not installed. |
| 7.B.2 | Special-operation exception due to DAT being off. |
| 8. | Privileged-operation exception due to extraction-authority control, bit 4 of control register 0, being zero. |

| Priority of Execution: EPAR

| EXTRACT SECONDARY ASN

| ESAR R₁ [RRE]



| The 16-bit SASN, bits 16-31 of control register 3, is placed in bit positions 16-31 of the general register designated by the R₁ field. Bits 0-15 of the general register are set to zeros.

| Bits 16-23 and 28-31 of the instruction are ignored.

| The instruction must be issued with DAT on; otherwise, a special-operation exception is recognized, and the operation is suppressed. The special-operation exception is recognized in both the problem and supervisor states.

| In the problem state, the extraction-authority control, bit 4 of control register 0, must be one; otherwise, a

| privileged-operation exception is recognized, and the operation is suppressed. In the supervisor state, the extraction-authority-control bit is not examined.

| The priority of recognition of program exceptions for the instruction is shown in the figure "Priority of Execution: ESAR."

| Condition Code: The code remains unchanged.

| Program Exceptions:

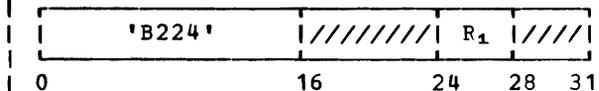
| Operation (if DAS is not installed)
| Privileged Operation (extraction-
| authority control is zero in
| problem state)
| Special Operation

- | | |
|-------|--|
| 1.-6. | Exceptions with the same priority as the priority of program-interruption conditions for the general case. |
| 7.A | Access exceptions for second instruction halfword. |
| 7.B.1 | Operation exception if DAS is not installed. |
| 7.B.2 | Special-operation exception due to DAT being off. |
| 8. | Privileged-operation exception due to extraction-authority control, bit 4 of control register 0, being zero. |

| Priority of Execution: ESAR

| INSERT ADDRESS SPACE CONTROL

| IAC R₁ [RRE]



| The address-space-control bit, bit 16 of the current PSW, is placed in bit position 23 of the general register designated by the R₁ field. Bits 16-22 of the register are set to zeros, and bits 0-15 and 24-31 of the register remain unchanged. The address-space-control bit is also used to set the condition code.

Bits 16-23 and 28-31 of the instruction are ignored.

The instruction must be issued with DAT on; otherwise, a special-operation exception is recognized, and the operation is suppressed. The special-operation exception is recognized in both the problem and supervisor states.

In the problem state, the extraction-authority control, bit 4 of control register 0, must be one; otherwise, a privileged-operation exception is recognized, and the operation is suppressed. In the supervisor state, the extraction-authority-control bit is not examined.

The priority of recognition of program exceptions for the instruction is shown in the figure "Priority of Execution: IAC."

Resulting Condition Code:

- 0 PSW bit 16 is zero
- 1 PSW bit 16 is one
- 2 --
- 3 --

Program Exceptions:

- Operation (if DAS is not installed)
- Privileged Operation (extraction-authority control is zero in problem state)
- Special Operation

| | |
|-------|--|
| 1.-6. | Exceptions with the same priority as the priority of program-interruption conditions for the general case. |
| 7.A | Access exceptions for second instruction halfword. |
| 7.B.1 | Operation exception if DAS is not installed. |
| 7.B.2 | Special-operation exception due to DAT being off. |
| 8. | Privileged-operation exception due to extraction-authority control, bit 4 of control register 0, being zero. |

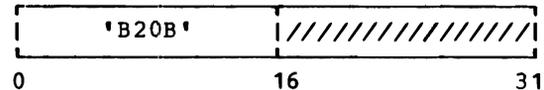
Priority of Execution: IAC

Programming Notes

1. Bits 16-19 of the general register designated by the R₁ field are reserved for expansion for use with possible future facilities. The program should not depend on these bits being set to zero. Similarly, condition codes 2 and 3 may be set as a result of future facilities.
2. The instructions IAC and SAC are defined to operate on the third byte of a general register so that the address-space-control bit can be saved in the same general register as the PSW key, which is placed in the fourth byte of general register 2 by the IPK instruction.

INSERT PSW KEY

IPK [S]



The four-bit PSW-key, bits 8-11 of the current PSW, is inserted in bit positions 24-27 of general register 2, and bits 28-31 of that register are set to zeros. Bits 0-23 of general register 2 remain unchanged.

Bits 16-31 of the instruction are ignored.

In the problem state, when DAS is installed, the extraction-authority control, bit 4 of control register 0, must be one; otherwise, a privileged-operation exception is recognized, and the operation is suppressed. When DAS is not installed, execution of the instruction in the problem state results in a privileged-operation exception regardless of the extraction-authority control. In the supervisor state, the extraction-authority-control bit is not examined.

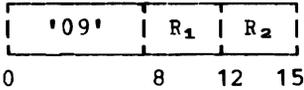
Resulting Condition Code: The code remains unchanged.

Program Exceptions:

- Operation (if the PSW-key-handling feature is not installed)
- Privileged Operation (extraction-authority control is zero in problem state)

INSERT STORAGE KEY

ISK R₁, R₂ [RR]



The storage key associated with the 2K-byte block that is addressed by the contents of the general register designated by the R₂ field is inserted in the general register designated by the R₁ field.

Bits 8-20 of the register designated by the R₂ field designate a block of 2K bytes in real storage. Bits 0-7 and 21-27 of the register are ignored. Bits 28-31 of the register must be zeros; otherwise, a specification exception is recognized, and the operation is suppressed.

The address designating the storage block, being a real address, is not subject to dynamic address translation. The reference to the storage key is not subject to a protection exception.

The execution of the instruction depends on whether the PSW specifies the EC or BC mode. In the EC mode, the seven-bit storage key is inserted in bit positions 24-30 of the register designated by the R₁ field, and bit 31 is set to zero. In the BC mode, bits 0-4 of the storage key are placed in bit positions 24-28 of that register, and bits 29-31 of the register are set to zeros. In both modes, the contents of bit positions 0-23 of the register remain unchanged.

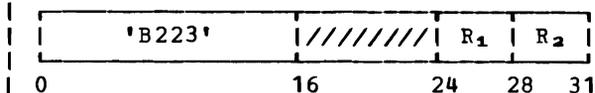
Condition Code: The code remains unchanged.

Program Exceptions:

Addressing (operand 2)
Privileged Operation
Specification

INSERT VIRTUAL STORAGE KEY

IVSK R₁, R₂ [RRE]



The storage key associated with the 2K-byte block addressed by the contents of the general register designated by the R₂ field

is inserted in the general register designated by the R₁ field.

Bits 16-23 of the instruction are ignored.

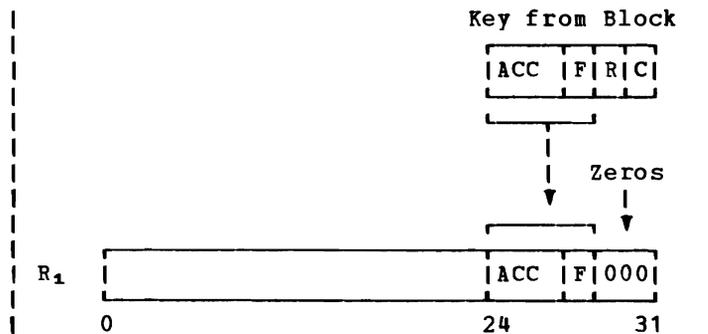
In the problem state, the extraction-authority control, bit 4 of control register 0, must be one; otherwise, a privileged-operation exception is recognized, and the operation is suppressed. In the supervisor state, the extraction-authority-control bit is not examined.

The block is designated by bits 8-20 of the register; bits 0-7 and 21-31 of the register are ignored.

The block address is a virtual address and is subject to the address-space-selection bit, bit 16 of the current PSW. In the primary-space mode, the address is treated as a primary-virtual address; in the secondary mode, the address is treated as a secondary-virtual address. The instruction must be issued with DAT on; otherwise, a special-operation exception is recognized, and the operation is suppressed. The reference to the storage key is subject to the normal access exceptions, except that protection does not apply.

Bits 0-4 of the storage key, which are the access-control bits and the fetch-protection bit, are placed in bit positions 24-28 of the register designated by the R₁ field, with bits 29-31 set to zeros. The change and reference bits in the storage key are not inspected. The change bit is not affected by the operation. The reference bit, depending on the model, may or may not be set to one as a result of the operation.

The following diagram depicts the execution of the IVSK instruction:



The priority of recognition of program exceptions for the instruction is shown in the figure "Priority of Execution: IVSK."

Condition Code: Unchanged.

Program Exceptions:

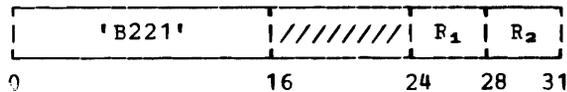
- Access (except for protection, block specified by R₂)
- Operation (if DAS is not installed)
- Privileged Operation (extraction-authority control is zero in problem state)
- Special Operation

| | |
|-------|--|
| 1.-6. | Exceptions with the same priority as the priority of program-interruption conditions for the general case. |
| 7.A | Access exceptions for second instruction halfword. |
| 7.B.1 | Operation exception if DAS is not installed. |
| 7.B.2 | Special-operation exception due to DAT being off. |
| 8. | Privileged-operation exception due to extraction-authority control, bit 4 of control register 0, being zero. |
| 9. | Access exceptions except for protection. |

Priority of Execution: IVSK

INVALIDATE PAGE TABLE ENTRY

IPTE R₁, R₂ [FRE]



The designated page-table entry is invalidated, and the associated translation-lookaside-buffer (TLB) entries in all CPUs of the configured system are purged.

The contents of the register designated by the R₁ field have the format of a segment-table entry with only the page-table origin used. The contents of the register designated by the R₂ field have the format of a virtual address with only the page index used. The contents of fields that are not part of the page-table origin or page index are ignored.

The translation format, contained in bit

positions 8-12 of control register 0, specifies the mode for translation. If an invalid combination is contained in these bit positions, a translation-specification exception is recognized, and the operation is suppressed.

The page-table origin and the page index designate a page-table entry, following the dynamic-address-translation rules for page-table lookup. The address formed from these two components is a real address. The page-invalid bit of this page-table entry is set to one. During this procedure, no page-table-length check is made, and the page-table entry is not inspected for availability or format errors. Additionally, the page-frame real address contained in the entry is not checked for an addressing exception.

The entire page-table entry is fetched concurrently from main storage. Subsequently the byte containing the page-invalid bit is stored.

A serialization function is performed on the CPU which is issuing IPTE. CPU operation is delayed until all previous accesses by this CPU to main storage have been completed, as observed by channels and other CPUs. No subsequent instructions or their operands are accessed by this CPU until the execution of this instruction is completed.

In addition to setting the page-invalid bit to one, this CPU performs a purge of selected entries from its TLB and signals all CPUs configured to it to perform a purge of selected entries from their TLBs. Each TLB is purged of at least those entries that have been formed using all of the following:

- The translation format specified in bit positions 8-12 of control register 0 of the CPU issuing IPTE
- The page-table origin specified by the IPTE instruction
- The page index specified by the IPTE instruction
- The page-frame real address contained in the designated page-table entry

The execution of IPTE is not completed on the CPU which is issuing it until all entries corresponding to the specified parameters have been purged from the TLB on this CPU and until all other configured CPUs have completed any storage accesses, including the updating of the change and reference bits, using TLB entries corresponding to the specified parameters.

When the generated address of the

| bits are used to control portions of the
| operation. The remainder of the address is
| ignored. Bits 29-31 of the second-operand
| address are used as follows:

| Bit | Function Specified When Bit Is One |
|-----|------------------------------------|
| 29 | Force ASN translation |
| 30 | Use AX from first operand |
| 31 | Skip SASN authorization |

| PASN Translation

| In the PASN translation process, the PASN-d
| is translated by means of the ASN first
| table and the ASN second table. The STD
| and LTD fields and, optionally, the AX
| field, obtained from the ASN-second-table
| entry are subsequently used to update the
| corresponding control registers.

| When bit 29 of the second-operand address
| is one, PASN translation is always
| performed. When bit 29 is zero, PASN
| translation is performed only when PASN-d
| is not equal to PASN-old. When bit 29 is
| zero and PASN-d is equal to PASN-old, the
| PSTD-old and LTD-old are left unchanged in
| the control registers and become the
| PSTD-new and LTD-new, respectively. In
| this case, if bit 30 is zero, then the
| AX-old is left unchanged in the control
| register and becomes the AX-new.

| The PASN translation follows the normal
| rules for ASN translation, except that the
| invalid bits, bit 0 in the ASN-first-table
| entry and bit 0 in the ASN-second-table
| entry, when ones, do not result in an ASN-
| translation exception, and the space-
| switch-event bit in the ASN-second-table
| entry, when one, does not result in a
| space-switch event. When either of the
| invalid bits is one, condition code 1 is
| set. When the ASN-second-table entry is
| valid and the space-switch-event bit is
| one, condition code 3 is set. In both
| cases, the control registers remain
| unchanged.

| The contents of the AX, STD, and LTD fields
| in the ASN-second-table entry which is
| accessed as a result of the PASN
| translation are referred to as AX-p, STD-p,
| and LTD-p, respectively.

| SASN Translation

| In the SASN-translation process, the SASN-d
| is translated by means of the ASN first
| table and the ASN second table. The STD
| field obtained from the ASN-second-table

| entry is subsequently used to update the
| secondary-segment-table designation (SSTD)
| in control register 7. The ATO and ATL
| fields obtained are used in the SASN
| authorization, if it occurs.

| SASN translation is performed only when
| SASN-d is not equal to PASN-d. When SASN-d
| is equal to PASN-d, the SSTD-new is set to
| the same value as PSTD-new. When SASN-d is
| equal to SASN-old, bit 29 (force ASN
| translation) is zero, and bit 31 (skip SASN
| authorization) is one, then SASN
| translation is not performed, and SSTD-old
| becomes SSTD-new.

| The SASN translation follows the normal
| rules for ASN translation, except that the
| invalid bits, bit 0 in the ASN-first-table
| entry and bit 0 in the ASN-second-table
| entry, when ones, do not result in an ASN-
| translation exception. When either of the
| invalid bits is one, condition code 2 is
| set, and the control registers remain
| unchanged.

| The contents of the STD, ATO, and ATL
| fields in the ASN-second-table entry which
| is accessed as a result of the SASN
| translation are referred to as STD-s,
| ATO-s, and ATL-s, respectively.

| SASN Authorization

| SASN authorization is performed when bit 31
| of the second-operand address is zero and
| SASN-d is not equal to PASN-d. When SASN-d
| is equal to PASN-d or when bit 31 of the
| second-operand address is one, SASN
| authorization is not performed.

| SASN authorization is performed using
| ATO-s, ATL-s, and the intended value for
| AX-new. When bit 30 of the second-operand
| address is zero and PASN translation was
| performed, the intended value for AX-new is
| AX-p. When bit 30 is zero and PASN
| translation was not performed, the AX is
| not changed, and AX-new is the same as
| AX-old. When bit 30 of the second-operand
| address is one, the intended value for
| AX-new is AX-d. SASN authorization follows
| the normal rules for secondary
| authorization, except that, if the AX is
| not authorized, condition code 2 is set,
| and none of the control registers are
| updated.

| Control-Register Loading

| When the PASN-translation, SASN-
| translation, and SASN-authorization
| functions, if called for in the operation,

| are performed without encountering any
| exceptions, the operation is completed by
| replacing the contents of control registers
| 1, 3, 4, 5, and 7 with the new values, and
| condition code 0 is set. The control
| registers are loaded as follows:

| The PSW-key-mask and SASN fields in control
| register 3 are replaced by the PKM-d and
| SASN-d fields from the first-operand
| location.

| The PASN, bits 16-31 of control register 4,
| is replaced by the PASN-d field from the
| first-operand location.

| The authorization index, bits 0-15 of
| control register 4, is replaced as follows:

- | • When bit 30 of the second-operand
| address is one, from AX-d.
- | • When bit 30 of the second-operand
| address is zero and PASN translation
| is performed, from AX-p.
- | • When bit 30 of the second-operand
| address is zero and PASN translation
| is not performed, the authorization
| index is not changed.

| When PASN translation is performed, the
| primary-segment-table designation in
| control register 1 and the linkage-table
| designation in control register 5 are
| replaced from the STD-p and LTD-p fields,
| respectively, which are obtained during
| PASN translation. When PASN translation is
| not performed, the primary-segment-table-
| designation and linkage-table-designation
| fields remain unchanged.

| The secondary-segment-table designation in
| control register 7 is replaced as follows:

- | • When SASN-d equals PASN-d, from the
| new contents of control register 1,
| the primary-segment-table designation.
- | • When SASN translation is performed,
| from SSTD-s.
- | • The SASN remains unchanged when all of
| the following are true: SASN-d equals
| SASN-old, SASN-d does not equal
| PASN-d, and bits 29 and 31 of the
| second-operand address are zero and
| one, respectively.

| Other Conditions

| When PASN translation is called for and
| cannot be completed because bit 0 is one in
| either the ASN-first-table or the ASN-
| second-table entries, condition code 1 is
| set, and the control registers are not
| changed.

| When PASN translation is called for and the
| translation is completed but the ASN-
| second-table entry specifies a space-switch
| event, condition code 3 is set, and the
| control registers are not changed.

| When SASN translation is called for and the
| translation cannot be completed because bit
| 0 is one in either the ASN-first-table or
| ASN-second-table entries, or because SASN
| authorization is called for and the SASN is
| not authorized, condition code 2 is set,
| and the control registers are not changed.

| The first operand must be designated on a
| doubleword boundary; otherwise, a
| specification exception is recognized, and
| the operation is suppressed. The operation
| is suppressed on all addressing and
| protection exceptions.

| Summary

| The figures "Summary of Actions: IASP" and
| "Priority of Execution: IASP" summarize
| the functions of the instruction and the
| priority of recognition of exceptions and
| condition codes.

| Resulting Condition Code:

- | | |
|---|---|
| 0 | Translation and authorization complete; parameters loaded |
| 1 | Primary ASN not available; parameters not loaded |
| 2 | Secondary ASN not available or not authorized; parameters not loaded |
| 3 | Primary ASN has space-switch event specified; parameters not loaded |

| Program Exceptions:

| Access (fetch, operand 1)
| Addressing (ASN-first-table entry,
| ASN-second-table entry, authority-
| table entry)
| ASN-Translation Specification
| Operation (if DAS is not installed)
| Privileged Operation
| Special Operation
| Specification

- 1.-6. Exceptions with the same priority as the priority of program-interruption conditions for the general case.
- 7.A Access exceptions for second and third instruction halfwords.
- 7.B.1 Operation exception if DAS is not installed.
- 7.B.2 Privileged-operation exception.
- 7.B.3 Special-operation exception due to the ASN-translation control, bit 12 of control register 14, being zero.
- 8. Specification exception.
- 9. Access exceptions for the first operand.
- 10. Execution of PASN translation (when performed).
- 10.1 Addressing exception for access to ASN-first-table entry.
- 10.2 Condition code 1 due to I bit (bit 0) in ASN-first-table entry having the value one.
- 10.3 ASN-translation-specification exception due to invalid ones (bits 1-7, 28-31) in ASN-first-table entry.
- 10.4 Addressing exception for access to ASN-second-table entry.
- 10.5 Condition code 1 due to I bit (bit 0) in ASN-second-table entry having the value one.
- 10.6 ASN-translation-specification exception due to invalid ones (bits 1-7, 30, 31, 60-63, 97-103) in ASN-second-table entry.
- 10.7 Condition code 3 due to space-switch-event bit (bit 95) in ASN-second-table entry having the value one.
- 11. Execution of SASN translation (when performed).
- 11.1 Addressing exception for access to ASN-first-table entry.
- 11.2 Condition code 2 due to I bit (bit 0) in ASN-first-table entry having the value one.
- 11.3 ASN-translation-specification exception due to invalid ones (bits 1-7, 28-31) in ASN-first-table entry.
- 11.4 Addressing exception for access to ASN-second-table entry.
- 11.5 Condition code 2 due to I bit (bit 0) in ASN-second-table entry having the value one.
- 11.6 ASN-translation-specification exception due to invalid ones (bits 1-7, 30, 31, 60-63, 97-103) in ASN-second-table entry.
- 12. Execution of secondary authorization (when performed).
- 12.1 Condition code 2 due to authority-table entry being outside table.
- 12.2 Addressing exception for access to authority-table entry.
- 12.3 Condition code 2 due to S bit in authority-table entry being zero.

Priority of Execution: LASP

| PASN-old Equals PASN-d | Second-Operand- Address Bits* | | PASN Translation Performed | Result Field | | |
|------------------------------|----------------------------------|----|----------------------------------|--------------|--------|---------|
| | 29 | 30 | | PSTD-new | AX-new | LTD-new |
| Yes | 0 | 0 | No | PSTD-old | AX-old | LTD-old |
| Yes | 0 | 1 | No | PSTD-old | AX-d | LTD-old |
| Yes | 1 | 0 | Yes | STD-p | AX-p | LTD-p |
| Yes | 1 | 1 | Yes | STD-p | AX-d | LTD-p |
| No | - | 0 | Yes | STD-p | AX-p | LTD-p |
| No | - | 1 | Yes | STD-p | AX-d | LTD-p |

Explanation:

- Action in this case is the same regardless of the setting of this bit.

* Second-operand-address bits:
 29 Force ASN translation
 30 Use AX from first operand

Summary of Actions: LASP (Part 1 of 2)

| SASN-d Equals PASN-d | SASN-d Equals SASN-old | Second-Operand- Address Bits* | | SASN Translation Performed | SASN Authorizat Performed# | Result Field SSTD-new |
|----------------------------|------------------------------|----------------------------------|----|----------------------------------|----------------------------------|--------------------------|
| | | 29 | 31 | | | |
| Yes | - | - | - | No | No | PSTD-new |
| No | No | - | 0 | Yes | Yes | STD-s |
| No | No | - | 1 | Yes | No | STD-s |
| No | Yes | 1 | 0 | Yes | Yes | STD-s |
| No | Yes | 1 | 1 | Yes | No | STD-s |
| No | Yes | 0 | 0 | Yes | Yes | STD-s |
| No | Yes | 0 | 1 | No | No | SSTD-old |

Explanation:

- Action in this case is the same regardless of the setting of this bit.

SASN authorization is performed using ATO-s, ATL-s, and AX-new.

* Second-operand-address bits:
 29 Force ASN translation
 31 Skip secondary authority test

Summary of Actions: LASP (Part 2 of 2)

Programming Notes

- Bits 29 and 31 in the second-operand address are intended primarily to provide improved performance for those cases where the step may be unnecessary.

When bit 29 is set to zero, the action of the instruction is based on the

assumption that the current values for PSTD-old, LTD-old, and AX-old are consistent with PASN-old and that SSTD-old is consistent with SASN-old. When this is not the case, bit 29 should be set to one.

Bit 31, when one, eliminates the SASN-authorization test. The program may be able to determine in certain cases that the SASN is authorized, either

because of prior use or because the AX being loaded is authorized to access all address spaces.

2. The SASN-translation and SASN-authorization steps are not performed when SASN-d is equal to PASN-d. This is consistent with the action in SET SECONDARY ASN to current primary (SSAR-cp), which does not perform the translation or ASN authorization.
3. The following is a summary of abbreviations used in this instruction description.

| Control-Register Number.Bit | Abbreviation for | |
|-----------------------------|-------------------|---------------------|
| | Previous Contents | Subsequent Contents |
| 1.0-31 | PSTD-old | PSTD-new |
| 3.0-15 | PKM-old | PKM-new |
| 3.16-31 | SASN-old | SASN-new |
| 4.0-15 | AX-old | AX-new |
| 4.16-31 | PASN-old | PASN-new |
| 5.0-31 | LTD-old | LTD-new |
| 7.0-31 | SSTD-old | SSTD-new |

| First-Operand Bit Positions | Abbreviation |
|-----------------------------|--------------|
| 0-15 | PKM-d |
| 16-31 | SASN-d |
| 32-47 | AX-d |
| 48-63 | PASN-d |

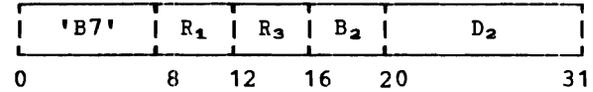
| Field in ASN-Second-Table Entry | Abbreviation Used for the Field When Accessed as Part of | |
|---------------------------------|--|------------------|
| | PASN Translation | SASN Translation |
| 1-31 | - | ATO-s |
| 32-47 | AX-p | - |
| 48-59 | - | ATL-s |
| 64-95 | STD-p | STD-s |
| 96-127 | LTD-p | - |

Explanation:

- The field is not used in this case.

LOAD CONTROL

LCTL $R_1, R_3, D_2(B_2)$ [RS]



The set of control registers starting with the control register designated by the R_1 field and ending with the control register designated by the R_3 field is loaded from the locations designated by the second-operand address.

The storage area from which the contents of the control registers are obtained starts at the location designated by the second-operand address and continues through as many storage words as the number of control registers specified. The control registers are loaded in ascending order of their addresses, starting with the control register designated by the R_1 field and continuing up to and including the control register designated by the R_3 field, with control register 0 following control register 15. The second operand remains unchanged.

The second operand must be designated on a word boundary; otherwise, a specification exception is recognized, and the operation is suppressed.

Condition Code: The code remains unchanged.

Program Exceptions:

Access (fetch, operand 2)
Privileged Operation
Specification

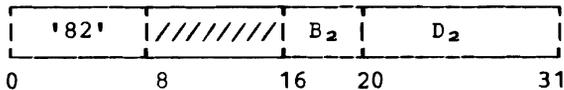
Programming Notes

1. To ensure that existing programs run if and when new facilities using additional control-register positions are defined, only zeros should be loaded in unassigned control-register positions.
2. Loading of control registers on some models may require a significant amount of time. This is particularly true for changes in significant parameters. For example, the TLB may be purged as a result of changing the translation parameters in control register 0 or as a result of changing or enabling the program-event-recording parameters in control

registers 9-11. Where possible, the program should avoid loading unnecessary control registers. In loading control registers 9-11, the model attempts to optimize for the case when the bits of control register 9 are zeros.

LOAD PSW

LPSW D₂(B₂) [S]



The current PSW is replaced by the contents of the doubleword at the location designated by the second-operand address.

If the new PSW specifies the BC mode, information in bit positions 16-33 of the new PSW is not retained as the PSW is loaded. When the PSW is subsequently stored, these bit positions contain the new interruption code and the instruction-length code.

A serialization and checkpoint-synchronization function is performed at the beginning and also at the completion of the operation. The CPU operation is delayed until all storage accesses due to previous instructions by this CPU have been completed, as observed by channels and other CPUs. All previous checkpoints, if any, are canceled, and the results of all previous stores are released, if held exclusive, to permit channels and other CPUs to access the results with no possibility of cache deadlock.

When the operation is completed, a second serialization and checkpoint-synchronization function is performed, as follows. The CPU operation is delayed until all storage accesses due to this instruction have been completed, as observed by channels and other CPUs. All previous checkpoints, if any, for this instruction are canceled.

The operand must be designated on a doubleword boundary; otherwise, a specification exception is recognized, and the operation is suppressed. The operation is suppressed on addressing and protection exceptions.

The value which is to be loaded by the instruction is not checked for validity before it is loaded. However, immediately after loading, a specification exception is recognized and a program interruption

occurs when the newly loaded PSW specifies the EC mode and any of the following are true:

- The EC facility is not installed, or
- The contents of bit positions 0, 2-4, 17, and 24-39 are not all zeros, or
- Bit position 16 is one and DAS is not installed.

In these cases, the operation is completed, and the resulting instruction-length code is zero.

Bits 8-15 of the instruction are ignored.

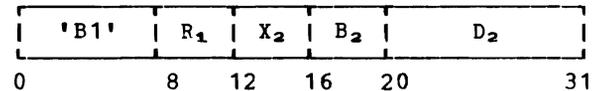
Condition Code: The code is set as specified in the new PSW loaded.

Program Exceptions:

Access (fetch, operand 2)
Privileged Operation
Specification

LOAD REAL ADDRESS

LRA R₁, D₂(X₂, B₂) [RX]



The real address corresponding to the second-operand virtual address is placed in the general register designated by the R₁ field.

The virtual address specified by the X₂, B₂, and D₂ fields is translated by means of the dynamic-address-translation facility, regardless of whether DAT is on or off.

When DAS is not installed, the translation is performed by using the current contents of control registers 0 and 1. When DAS is installed, the translation is performed by using the current translation format in control register 0 and the segment-table designation in either control register 1 or 7. Control register 1 is used if the current PSW specifies BC mode or specifies EC mode with bit 16 set to zero. Control register 7 is used if the current PSW specifies EC mode with bit 16 set to one. In either case, the translation is performed] without the use of the translation-lookaside buffer (TLB). Sufficient high-order zeros are appended on the left of the resultant real address to produce a 32-bit result, which is then placed in the general register designated

by the R_1 field. The translated address is not inspected for boundary alignment or for addressing or protection exceptions.

Condition code 0 is set when translation can be completed, that is, when the entry in each table lies within the specified table length and its I bit is zero.

When the I bit in the segment-table entry is one, condition code 1 is set, and the real address of the segment-table entry is placed in the register designated by the R_1 field. When the I bit in the page-table entry is one, condition code 2 is set, and the real address of the page-table entry is placed in the register designated by the R_1 field. When either the segment-table entry or the page-table entry is outside the table, condition code 3 is set, and the register designated by the R_1 field contains the real address of the entry that would have been referred to if the length violation did not occur. In all these cases, high-order zeros are appended on the left of the real address, and the 32-bit result is placed in the register.

An addressing exception is recognized when the address of the segment-table entry or page-table entry designates a location outside the available main storage of the installed system. A translation-specification exception is recognized when bits 8-12 of control register 0 contain an invalid code, or the segment-table entry or page-table entry has a format error. For all these cases, the operation is suppressed.

Resulting Condition Code:

- 0 Translation available
- 1 Segment-table entry invalid (I bit is one)
- 2 Page-table entry invalid (I bit is one)
- 3 Segment- or page-table length exceeded

Program Exceptions:

- Addressing
- Operation (if the translation feature is not installed)
- Privileged Operation
- Translation Specification

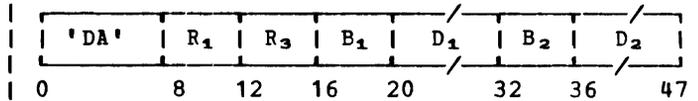
Programming Note

Caution must be observed in the execution of LOAD REAL ADDRESS (LRA) in a multiprocessing system. Since INVALIDATE PAGE TABLE ENTRY (IPTE) may turn on the I bit in storage before broadcasting to purge the entries from the TLBs of other CPUs,

the simultaneous execution of LRA on this CPU and IPTE on another CPU may produce inconsistent results. That is, if LRA accesses the tables in storage, the PTE may appear to be invalid (condition code 2) even though the TLB has not yet been invalidated, and the TLB may remain valid until the completion of IPTE on the other CPU. There is no guaranteed limit to the number of instructions which may occur between the completion of LRA and the TLB being purged.

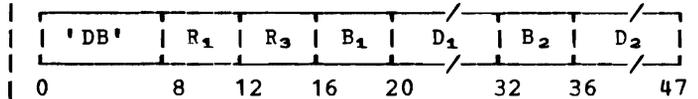
MOVE TO PRIMARY

MVCP $D_1(R_1, B_1), D_2(B_2), R_3$ [SS]



MOVE TO SECONDARY

MVCS $D_1(R_1, B_1), D_2(B_2), R_3$ [SS]



The first operand is replaced by the second operand. One operand is in the primary space, and the other is in the secondary space. The accesses to the operand in the primary space are performed using the PSW key; the accesses to the operand in the secondary space are performed using the key specified in the third operand.

The addresses of the operands are virtual, one operand address being translated by means of the primary segment-table description and the other by means of the secondary segment-table description. Operand-address translation is performed by ignoring the state of the address-space-selection bit in the current PSW.

Since the secondary space is accessed, the operation is performed only when the secondary-space control, bit 5 of control register 0, is one and DAT is on. When either the secondary-space control is zero or DAT is off, a special-operation exception is recognized, and the operation is suppressed. The special-operation exception is recognized in both the problem and supervisor states.

In the problem state, the operation is performed only if the secondary-space-access key is valid. The secondary-space-access key is valid only if the corresponding PSW-key-mask bit in control register 3 is one. Otherwise, a privileged-operation exception is recognized, and instruction execution is suppressed. In supervisor state, any value for the secondary-space-access key is valid.

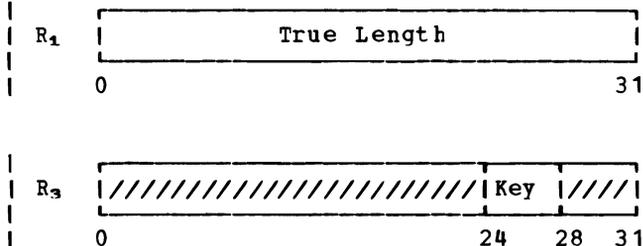
For MVCP, movement is to the primary space from the secondary space. The first-operand address is translated using the primary segment table, and the second-operand address is translated using the secondary segment table.

For MVCS, movement is to the secondary space from the primary space. The first-operand address is translated using the secondary segment table, and the second-operand address is translated using the primary segment table.

Bit positions 24-27 of the general register specified by the R_3 field are used as the secondary-space-access key. Bit positions 0-23 and 28-31 of the register are ignored.

The contents of the general register specified by the R_1 field are a 32-bit unsigned value called the true length.

Graphically, the contents of the general registers just described are as follows:



The first and second operands are the same length, called the effective length. The effective length is equal to the true length, or 256, whichever is less. Access exceptions for the first and second operands are recognized only for that portion of the operand within the effective length. When the effective length is zero, no access exceptions are recognized for the first and second operands, and no movement takes place.

Each storage operand is processed left to right. The storage-operand-consistency rules are the same as for MVC, except that when the operands overlap in virtual or in real storage, the use of the common real-storage location is not necessarily recognized.

As part of the execution of the instruction, the value of the true length is used to set the condition code. If the true length is 256 or less, including zero, the true length and effective length are equal, and condition code 0 is set. If the true length is greater than 256, the effective length is 256, and condition code 3 is set.

For both MVCP and MVCS, a serialization and checkpoint-synchronization function is performed at the beginning and also at the completion of the operation.

The CPU operation is delayed until all storage accesses due to previous instructions by this CPU have been completed, as observed by channels and other CPUs. All previous checkpoints, if any, are canceled, and the results of all previous stores are released, if held exclusive, to permit channels and other CPUs to access the results.

When the operation is completed, a second serialization and checkpoint-synchronization function is performed, as follows. The CPU operation is delayed until all storage accesses due to this instruction have been completed, as observed by channels and other CPUs. All previous checkpoints, if any, for this instruction are canceled, and the results of all stores for this instruction are released, if held exclusive, to permit channels and other CPUs to access the results.

The priority of the recognition of exceptions and condition codes is shown in the figure "Priority of Execution: MVCP and MVCS."

Resulting Condition Code:

- 0 Effective length equal to true length
- 1 --
- 2 --
- 3 Effective length less than true length

Program Exceptions:

- Access (fetch, virtual-primary address, operand 2, MVCS; fetch, virtual-secondary address, operand 2, MVCP; store, virtual-secondary address, operand 1, MVCS; store, virtual-primary address, operand 1, MVCP)
- Operation (if DAS is not installed)
- Privileged Operation (selected PSW key mask is zero in problem state)
- Special Operation

- 1.-6. Exceptions with the same priority as the priority of program-interruption conditions for the general case.
- 7.A Access exceptions for second and third instruction halfwords.
- 7.B.1 Operation exception if DAS is not installed.
- 7.B.2 Special-operation exception due to the secondary-space control, bit 5 of control register 0, being zero, or the translation bit, bit 5 of the PSW, being zero.
- 8. Privileged-operation exception due to selected PSW key mask being zero in problem state.
- 9. Completion due to length zero.
- 10. Access exceptions for operands.

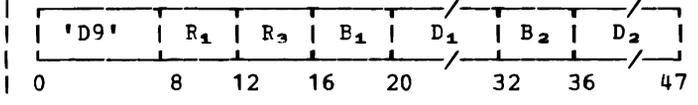
Priority of Execution: MVCP and MVCS

Programming Notes

1. The MVCP and MVCS instructions can be used in a loop to move a variable number of bytes of any length. See the programming note under MOVE WITH KEY.
2. The instructions MVCP and MVCS should be used only when movement is between different spaces. The performance of these instructions on most models may be significantly slower than MVCK, MVC, or MVCL. In addition, the definition of overlapping operands for MVCS and MVCP is not compatible with the more precise definitions for MVCK and MVC.

MOVE WITH KEY

MVCK $D_1(R_1, B_1), D_2(B_2), R_3$ [SS]



The first operand is replaced by the second operand. The fetch accesses to the second-operand location are performed using

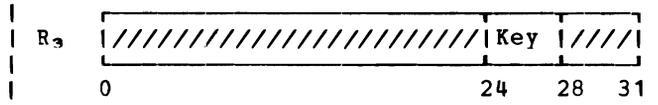
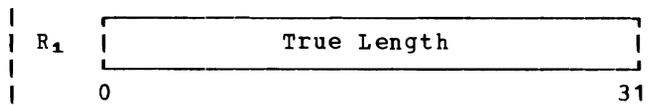
the key specified in the third operand, and the store accesses to the first-operand location are performed using the PSW key.

Bit positions 24-27 of the general register specified by the R_3 field are used as the source access key. Bit positions 0-23 and 28-31 of the register are ignored.

In the problem state, the operation is performed only if the source-access key is valid. The source-access key is valid only if the corresponding PSW-key-mask bit in control register 3 is one. Otherwise, a privileged-operation exception is recognized, and instruction execution is suppressed. In supervisor state, any value for the source access key is valid.

The contents of the general register specified by the R_1 field are a 32-bit unsigned value called the true length.

Graphically, the contents of the general registers just described are as follows:



The first and second operands are the same length, called the effective length. The effective length is equal to the true length, or 256, whichever is less. Access exceptions for the first and second operands are recognized only for that portion of the operand within the effective length. When the effective length is zero, no access exceptions are recognized for the first and second operands, and no movement takes place.

Each storage operand is processed left to right. When the storage operands overlap, the result is obtained as if the operands were processed one byte at a time and each result byte were stored immediately after the necessary operand byte was fetched. The storage-operand-consistency rules are the same as for MVC.

As part of the execution of the instruction, the value of the true length is used to set the condition code. If the true length is 256 or less, including zero, the true length and effective length are equal, and condition code 0 is set. If the true length is greater than 256, the effective length is 256, and condition code 3 is set.

The priority of the recognition of

exceptions and condition codes is shown in the figure "Priority of Execution: MVCK."

Resulting Condition Code:

| | |
|---|--|
| 0 | Effective length equal to true length |
| 1 | -- |
| 2 | -- |
| 3 | Effective length less than true length |

Program Exceptions:

Access (fetch, operand 2; store, operand 1)
Privileged Operation (selected PSW key mask is zero in problem state)
Operation (if DAS is not installed)

- | | |
|-------|--|
| 1.-6. | Exceptions with the same priority as the priority of program-interruption conditions for the general case. |
| 7.A | Access exceptions for second and third instruction halfwords. |
| 7.B | Operation exception if DAS is not installed. |
| 8. | Privileged-operation exception due to selected PSW key mask being zero in problem state. |
| 9. | Completion due to length zero. |
| 10. | Access exceptions for operands. |

Priority of Execution: MVCK

Programming Notes

1. The MVCK instruction can be used in a loop to move a variable number of bytes of any length, as follows:

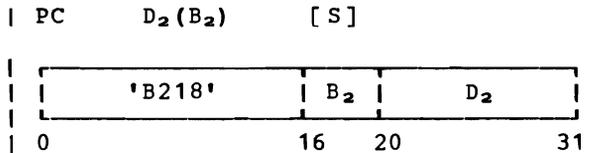
```

START  MVCK  D1(R1,B1),D2(B2),R3
        BZ   END
        LA   B1,256(B1)
        LA   B2,256(B2)
        S    R1,='256'
        B    START
END

```

2. The performance of MVCK on most models may be significantly slower than that of MVC and MVCI. Therefore, MVCK should not be used if the key of the source and the target are the same.

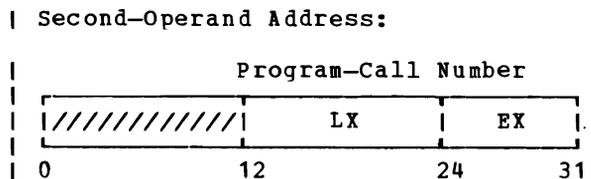
PROGRAM CALL



A two-level lookup is performed to locate an entry-table entry (ETE). The ETE contains an authorization-key mask; an ASN; an entry parameter, which is loaded into general register 4; and information to update the PSW-key masks in control register 3 and to replace the problem bit, and instruction address in the PSW. The original contents of the control register and the PSW are saved in general registers 3 and 14. The ETE also controls whether a space-switching operation is to occur by specifying a nonzero ASN. When space switching is specified, the new PASN is loaded from the ETE and is used in a two-level lookup to locate an ASN-second-table entry (ASTE). From this ASTE, a new PSTD, AX, and LTD are loaded. Whether space switching is specified or not, the previous PASN and PSTD are placed in the SASN and SSTD, respectively, and the previous PASN is saved in general register 3.

The instruction can be executed only when the CPU is in primary-space mode, and when the subsystem-linkage control, bit 0 of control register 5, is one. If the CPU is in real-space mode, or is in secondary-space mode, or the subsystem-linkage control is zero, a special-operation exception is recognized. In addition, PROGRAM CALL with space switching (PC-ss) can be executed only when the ASN control, bit 12 of control register 14, is one. If PC-ss is attempted with the ASN control zero, a special-operation exception is recognized. The special-operation exception is recognized in both the problem and supervisor states and the operation is suppressed.

The second-operand address is not used to access data; instead, the low-order 20 bits of the address is used as a program-call number and has the following format:

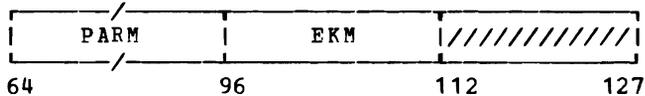
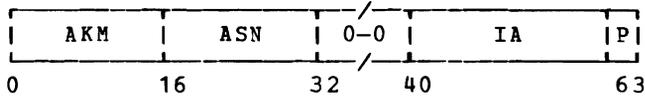


Linkage Index (LX): Bits 12-23 of the second-operand address are the linkage index and are used to select an entry from the linkage table designated by the linkage-table designation in control register 5.

Entry Index (EX): Bits 24-31 of the second-operand address are the entry index and are used to select an entry from the entry table designated by the linkage-table entry.

Bits 0-11 of the second-operand address are ignored.

The linkage-table and entry-table lookup process is depicted in the figure "Execution of PROGRAM CALL (Part 1 of 3)." The detailed definition for this table-lookup process is described in the section "PC-Number Translation" in Chapter 5, "Program Execution." The entry-table entry has the following format:



LTE bits 1-7 and ETE bits 32-39 must be zeros; otherwise, a PC-translation exception is recognized, and the instruction is suppressed.

After the entry-table entry has been fetched, if the current PSW specifies the problem state, the current PSW-key mask in control register 3 is tested against the AKM field in the entry-table entry to determine whether the program is authorized to access this entry. The AKM and PSW-key mask are ANDed and if the result is zero, a privileged-operation exception is recognized, and the operation is suppressed. When PC is executed in supervisor state, the AKM field is ignored.

If the result of the AND of the AKM and the PSW-key mask is not zero, or if the CPU is in the supervisor state, the execution of the instruction continues.

The PSW-key mask (bits 0-15 of control register 3) is placed in bit positions 0-15 of general register 3, and the current PASN (bits 16-31 of control register 4) is placed in bit positions 16-31 of general register 3.

The current PSTD, bits 0-31 of control register 1, are placed in control register 7 to become the current SSTD.

The current PASN, bits 16-31 of control register 4, are placed in bit positions 16-31 of control register 3 to become the current SASN.

Bits 40-62 of the current PSW (the updated instruction address) are placed into bit positions 8-32 of general register 14. Bit 15 of the PSW (the problem-state bit) is placed in bit position 31 of general register 14. Bits 0-7 of general register 14 are set to zeros.

Bits 40-62 of the ETE, with a rightmost zero appended, are placed in PSW bit positions 40-63 (the instruction address). Bit 63 of the ETE is placed in PSW bit position 15 (the problem-state bit).

Bits 64-95 of the ETE (the entry parameter) are loaded into general register 4.

Bits 96-111 of the ETE (the EKM) are ORed with the PSW-key mask, bits 0-15 of control register 3, and the result replaces the PSW-key mask in control register 3.

PROGRAM CALL to Current Primary (PC-cp)

If bits 16-31 of the ETE (the ASN) are zeros, a PROGRAM CALL to current primary (PC-cp) is specified, and the operation is completed.

The PC-cp operation is depicted in the figure "Execution of PROGRAM CALL (Part 2 of 3)."

PROGRAM CALL with Space Switching (PC-ss)

If the ASN is nonzero, a PROGRAM CALL with space switching (PC-ss) is specified, and the ASN is translated by means of a two-level table lookup.

The PC-ss operation is depicted in the figures "Execution of PROGRAM CALL (Part 2 of 3 and Part 3 of 3)." The PC-ss operation is completed as follows:

Bits 16-25 of the ETE are used as a 10-bit AFX to index into the ASN first table, and bits 26-31 are used as a six-bit ASX to index into the ASN second table specified by the AFX. The ASN table-lookup process is described in the section "ASN Translation" in Chapter 5, "Program Execution." The exceptions associated with ASN translation are collectively called ASN-translation exceptions. These exceptions and their priority are described in Chapter 6, "Interruptions."

| Bits 16-31 of the entry-table entry are placed in bit positions 16-31 of control register 4 as the new PASN.

| Bits 64-95 of the ASN-second-table entry (the STD) are loaded into control register 1 as the new PSTD.

| Bits 32-47 of the ASN-second-table entry (the AX) are loaded into bit positions 0-15 of control register 4 as the new authority index.

| Bits 96-127 of the ASN-second-table entry (the LTD) are loaded into control register 5 as the new linkage-table designation.

| When the contents of the space-switch event mask, bit 31 of control register 1 was zero both before and after the operation, the execution of PC-ss is completed. If the space-switch-event mask was one either before or after the operation, or both, then a space-switch-event program interruption is recognized, and the operation is completed.

| For both PC-cp and PC-ss, a serialization and checkpoint-synchronization function is performed at the beginning and also at the completion of the operation.

| The CPU operation is delayed until all storage accesses due to previous instructions by this CPU have been completed, as observed by channels and other CPUs. All previous checkpoints, if

any, are canceled, and the results of all previous stores are released, if held exclusive, to permit channels and other CPUs to access the results.

| When the operation is completed, a second serialization and checkpoint-synchronization function is performed, as follows. The CPU operation is delayed until all storage accesses due to this instruction have been completed, as observed by channels and other CPUs. All previous checkpoints, if any, for this instruction are canceled.

| The priority of recognition of program exceptions for the instruction is shown in the figure "Priority of Execution: PC."

| Condition Code: The code remains unchanged.

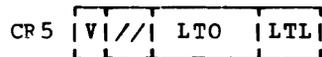
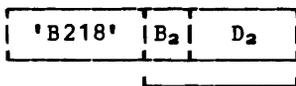
| Program Exceptions:

| ASN Translation (PC-ss only)
| Addressing
| ASN Translation
| EX Translation
| LX Translation
| Operation (if DAS is not installed)
| PC-Translation Specification
| Privileged Operation (AND of AKM and
| PSW-key masks is zero in problem
| state)
| Space-Switch Event (PC-ss only)
| Special Operation
| Trace

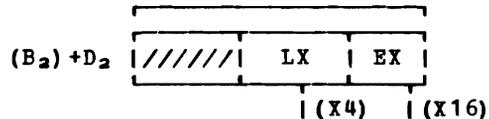
- 1.-6. Exceptions with the same priority as the priority of program-interruption conditions for the general case.
- 7.A Access exceptions for second instruction halfword.
- 7.B.1 Operation exception if DAS is not installed.
- 7.B.2 Special-operation exception due to DAT being off, the CPU being in secondary-space mode, or the subsystem-linkage-control bit in control register 5 being zero.
- 8.A Trace exceptions.
- 8.B.1 LX-translation exception due to linkage-table entry being outside table.
- 8.B.2 Addressing exception for access to linkage-table entry.
- 8.B.3 LX-translation exception due to I bit (bit 0) in linkage-table entry having the value one.
- 8.B.4 PC-translation-specification exception due to invalid ones (bits 1-7) in linkage-table entry.
- 8.B.5 EX-translation exception due to entry-table entry being outside table.
- 8.B.6 Addressing exception for access to entry-table entry.
- 8.B.7 PC-translation-specification exception due to invalid ones (bits 32-39) in entry-table entry.
- 8.B.8 Privileged-operation exception due to a zero result from ANDing PSW-key mask and AKM in problem state.
- 8.B.9 Special-operation exception due to the ASN-translation control, bit 12 of control register 14, being zero.
- 8.B.10 ASN-translation exceptions. (Only for PC-ss.)
- 9. Space-switch event. (Only for PC-ss.)

Priority of Execution: PC

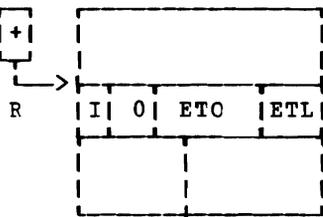
PROGRAM CALL Instruction



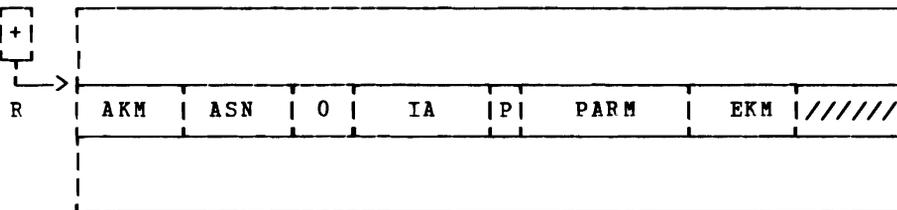
Operand-2 Addr



Linkage Table



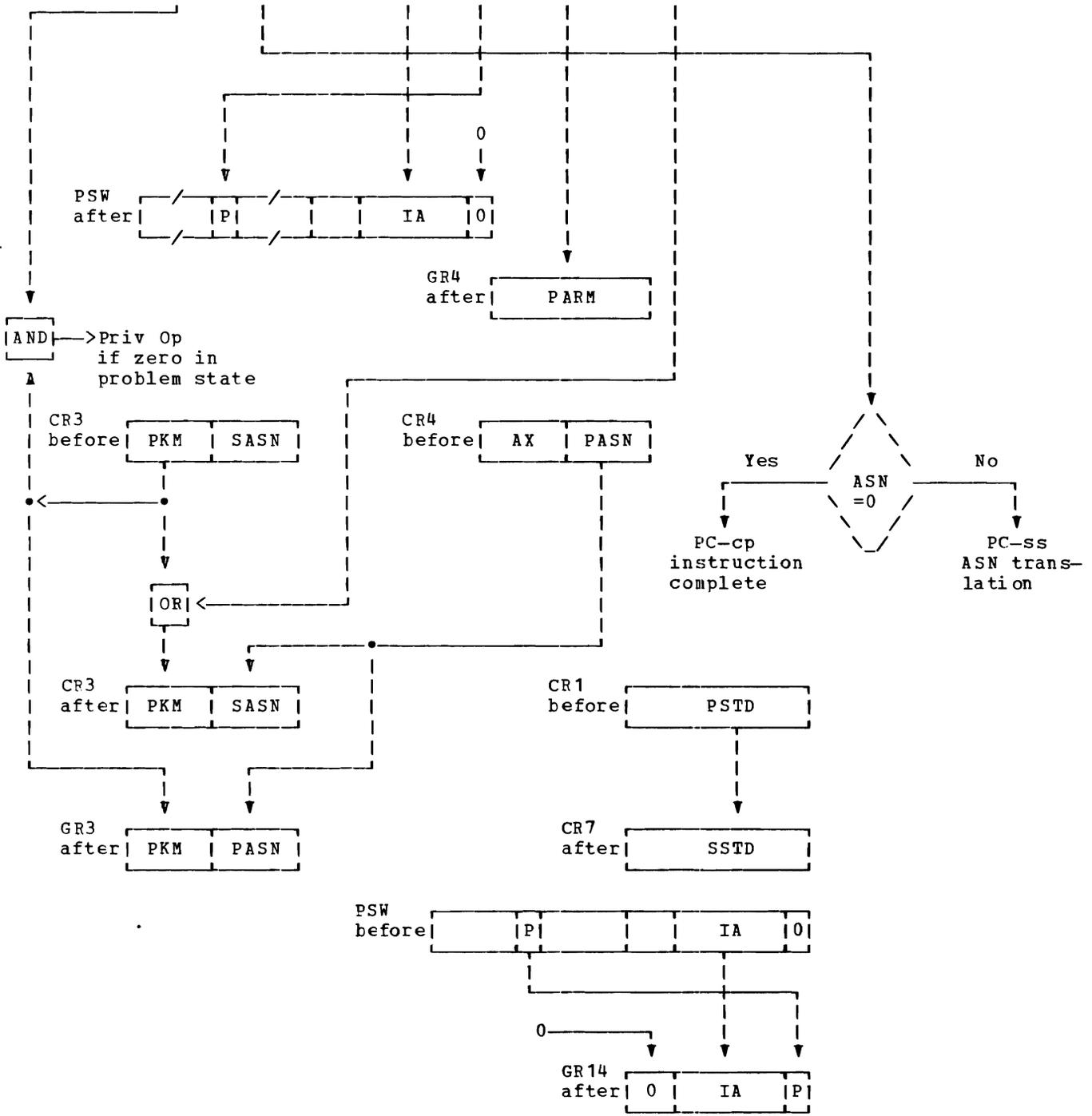
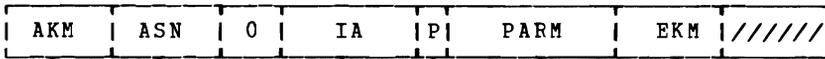
Entry Table



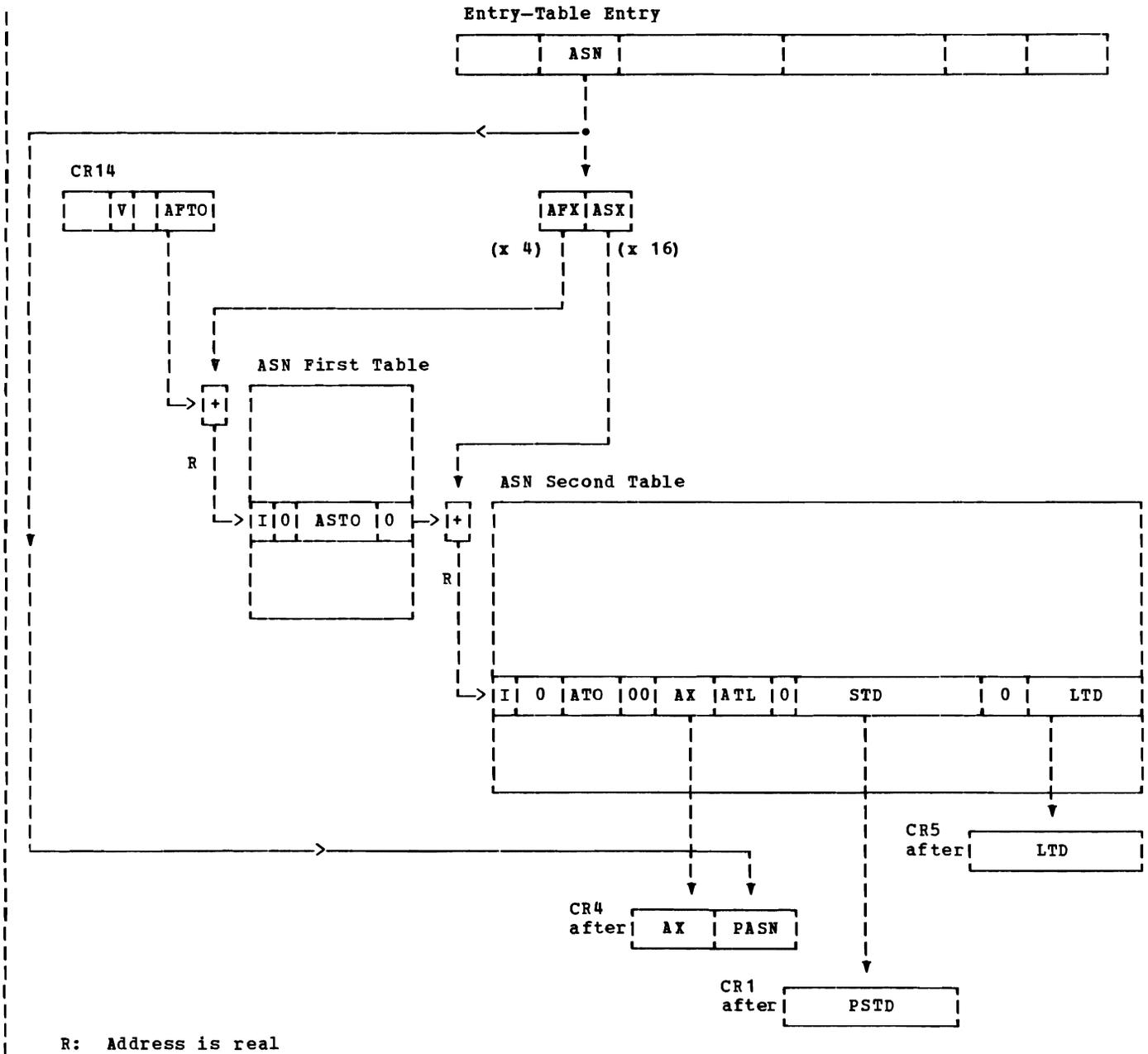
R: Address is real

Execution of PROGRAM CALL (Part 1 of 3): PC-Number Translation

Entry-Table Entry



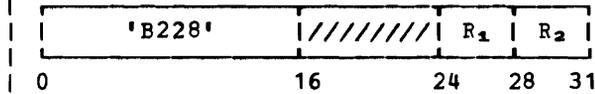
Execution of PROGRAM CALL (Part 2 of 3): PC-cp and PC-ss



| Execution of PROGRAM CALL (Part 3 of 3): ASN Translation for PC-ss

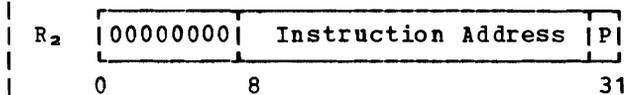
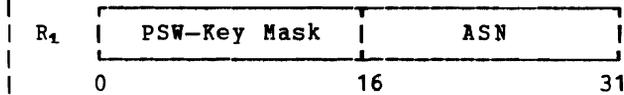
| PROGRAM TRANSFER

| PT R₁,R₂ [RRE]



| The contents of the register specified by the R₁ field is used to update the PSW-key mask and the PASN. The contents of the register specified by the R₂ field is used to update the problem-state bit and instruction address in the current PSW.

| Bits 16-23 of the instruction are ignored.
 | The format of the two registers specified by the R₁ and R₂ fields is as follows:



| When the contents of bit positions 16-31 of the general register specified by the R₁ field are equal to the current PASN, the operation is called PROGRAM TRANSFER to current primary (PT-cp); when the fields are not equal the operation is called PROGRAM TRANSFER with space switching (PT-ss).

| The instruction can be executed only when the CPU is in primary-space mode, and the subsystem-linkage control, bit 0 of control register 5, is one. If the CPU is in real-space mode or is in secondary-space mode, or the subsystem-linkage control is zero, a special-operation exception is recognized, and the operation is suppressed.

| The contents of the register specified by the R₂ field are used to update the instruction address, and the problem-state bit of the current PSW. Bit 31 of the general register specified by the R₂ field is placed in the problem state bit position, PSW bit position 15, unless the operation would cause PSW bit 15 to change from one to zero (problem state to supervisor state). If such a change would occur, a privileged-operation exception is recognized, and the operation is suppressed. Bits 8-30 of the general register specified by the R₂ field replace the instruction address, bits 40-62, of the current PSW. Bit 63 of the PSW is set to

zero. The PSW is updated only if bits 0-7 of the register are all zeros; if not, a specification exception is recognized, and the operation is suppressed.

| In addition to the above requirements, when a PT-ss is specified, the ASN-translation control, bit 12 of control register 14, must be one; otherwise, a special-operation exception is recognized, and the operation is suppressed.

| Bits 0-15 of the general register specified by the R₁ field are ANDed with the PSW-key mask, bits 0-15 of control register 3, and the result replaces the contents of the PSW-key mask.

| In both PT-ss and PT-cp, the ASN specified by bits 16-31 of general register R₁ replaces the SASN in control register 3, and the SSTD in control register 7 is replaced by the final contents of control register 1.

| PROGRAM TRANSFER to Current Primary (PT-cp)

| The PT-cp operation is depicted in Part 1 of the figure "Execution of PROGRAM TRANSFER." On a PT-cp operation, the operation is completed when the common portion of the PT operation, as described above, is completed. The authorization index, PASN, primary STD, and linkage-table designation are not changed by PT-cp.

| PROGRAM TRANSFER with Space Switching (PT-ss)

| The PT-ss operation is depicted in Parts 1 and 2 of the figure "Execution of PROGRAM TRANSFER." For a PT-ss, the contents of bit positions 16-31 of the general register specified by the R₁ field are used as an ASN, which is translated by means of a two-level table lookup.

| Bits 16-25 of the general register are used as a 10-bit AFX to index into the ASN first table. Bits 26-31 are used as a six-bit ASX to index into the ASN second table. The ASN table-lookup process is described in the section "ASN Translation" in Chapter 5, "Program Execution." The exceptions associated with ASN translation are collectively called "ASN-translation exceptions." These exceptions and their priority are described in Chapter 6, "Interruptions."

| The authority-table origin from the second-table entry is used as the base for a third table lookup. The current

authorization index, bits 0-15 of control register 4, is used as the index to look up the entry in the authority table. The authority-table lookup is described in the section "ASN Authorization" in Chapter 5, "Program Execution."

The PT-ss operation is completed by placing bits 64-95 of the ASN second-table entry in both the PSTD and SSTD, bit positions 0-31 of control registers 1 and 7, respectively. The contents of bit positions 32-47 of the ASN second-table entry are placed in the authorization index, bit positions 0-15 of control register 4. The contents of bit positions 96-127 of the ASN second-table entry are placed in the LTD, bit positions 0-31 of control register 5. The ASN, bits 16-31 of the general register specified by the R₁ field, is placed in the SASN and PASN, bit positions 16-31 of control registers 3 and 4.

When the contents of the space-switch-event mask, bit 31 of control register 1, were zero both before and after the execution of the instruction, the execution of PT-ss is completed. If the space-switch-event mask was one either before or after the operation, or both, then a space-switch-event program interruption is recognized, and the operation is completed.

For both PT-cp and PT-ss, a serialization and checkpoint-synchronization function is performed at the beginning and also at the completion of the operation.

The CPU operation is delayed until all

storage accesses due to previous instructions by this CPU have been completed, as observed by channels and other CPUs. All previous checkpoints, if any, are canceled, and the results of all previous stores are released, if held exclusive, to permit channels and other CPUs to access the results.

When the operation is completed, a second serialization and checkpoint-synchronization function is performed, as follows. The CPU operation is delayed until all storage accesses due to this instruction have been completed, as observed by channels and other CPUs. All previous checkpoints, if any, for this instruction are canceled.

The priority of recognition of program exceptions for the instruction is shown in the figures "Priority of Execution: PT-cp" and "Priority of Execution: PT-ss."

Condition Code: The code remains unchanged.

Program Exceptions:

Addressing
ASN Translation
Operation (if DAS is not installed)
Primary Authority
Privileged Operation (attempt to set supervisor state in problem state)
Space-Switch Event
Special Operation
Specification
Trace

- | | |
|-------|---|
| 1.-6. | Exceptions with the same priority as the priority of program-interruption conditions for the general case. |
| 7.A | Access exceptions for second instruction halfword. |
| 7.B.1 | Operation exception if DAS is not installed. |
| 7.B.2 | Special-operation exception due to DAT being off, the CPU being in secondary-space mode, or the subsystem-linkage-control bit in control register 5 being zero. |
| 8.A | Trace exceptions. |
| 8.B.1 | Privileged-operation exception due to attempt to set supervisor state when in problem state. |
| 8.B.2 | Specification exception due to nonzero value in bits 0-7 of R ₂ . |

Priority of Execution: PT-cp

- 1.-6. Exceptions with the same priority as the priority of program-interruption conditions for the general case.
- 7.A Access exceptions for second instruction halfword.
- 7.B.1 Operation exception if DAS is not installed.
- 7.B.2 Special-operation exception due to DAT being off, the CPU being in secondary-space mode, or the subsystem-linkage-control bit in control register 5 being zero.
- 8.A Trace exceptions.
- 8.B.1 Privileged-operation exception due to attempt to set supervisor state when in problem state.
- 8.B.2 Specification exception due to nonzero high-order instruction-address bits with 24-bit addressing mode specified.
- 8.B.3 Special-operation exception due to the ASN-translation control, bit 12 of control register 14, being zero.
- 8.B.4 ASN-translation exceptions.
- 8.B.5 Primary-authorization-translation exceptions.
- 8.B.6 Primary-authority exception due to authority-table entry being outside table.
- 8.B.7 Addressing exception for access to authority-table entry.
- 8.B.8 Primary-authority exception due to P bit in authority-table entry being zero.
- 9. Space-switch event.

Priority of Execution: PT-ss

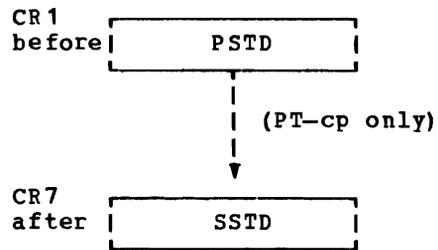
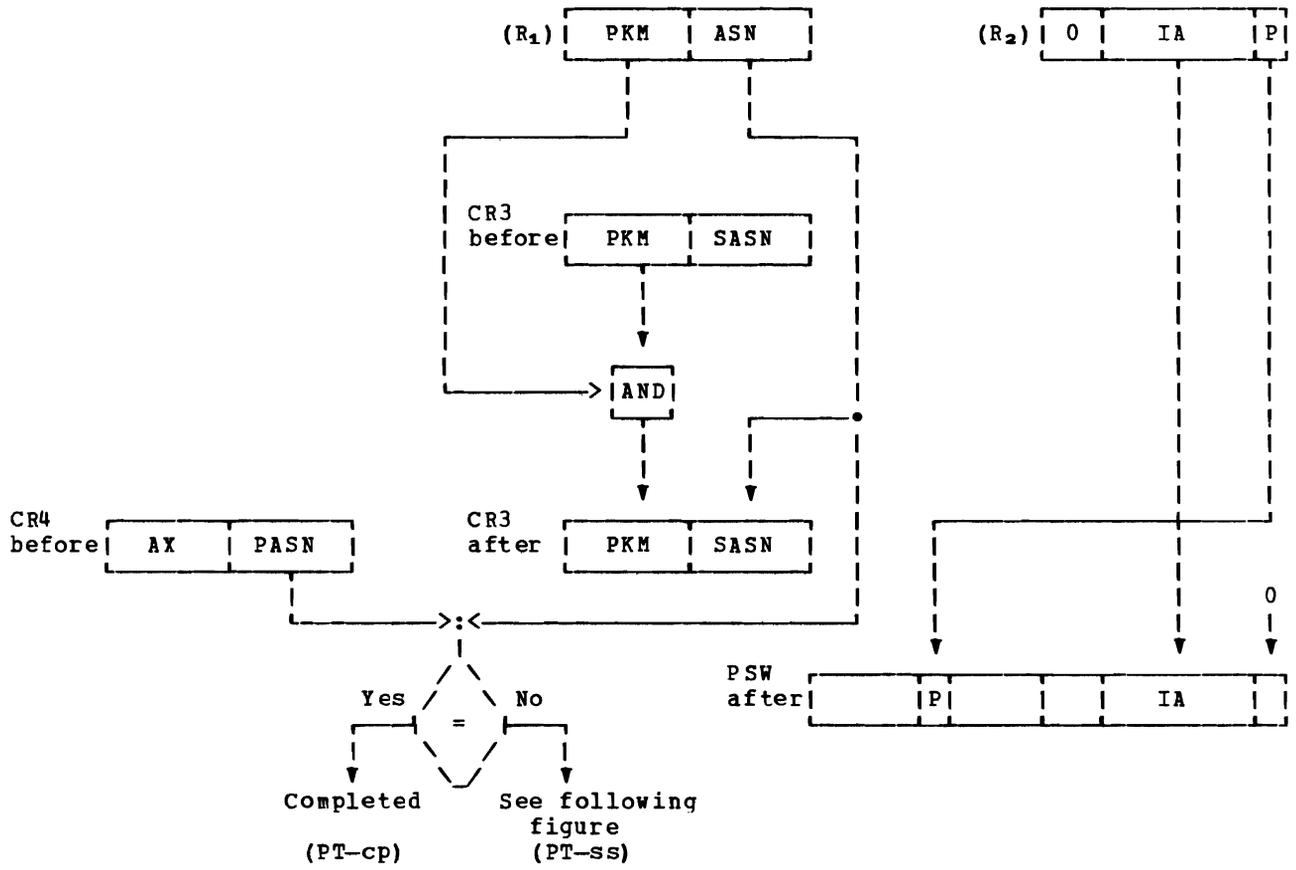
Programming Notes

1. The operation of PT is such that it may be used to restore the CPU to the state saved by a previous PROGRAM CALL instruction. This restoration is accomplished by issuing PT 3,14. Though general registers 3 and 14 are not restored to their original values, the PASN, PSW-key mask, problem bit, and instruction address are restored, and the authorization index, primary STD, and LTD are made consistent with

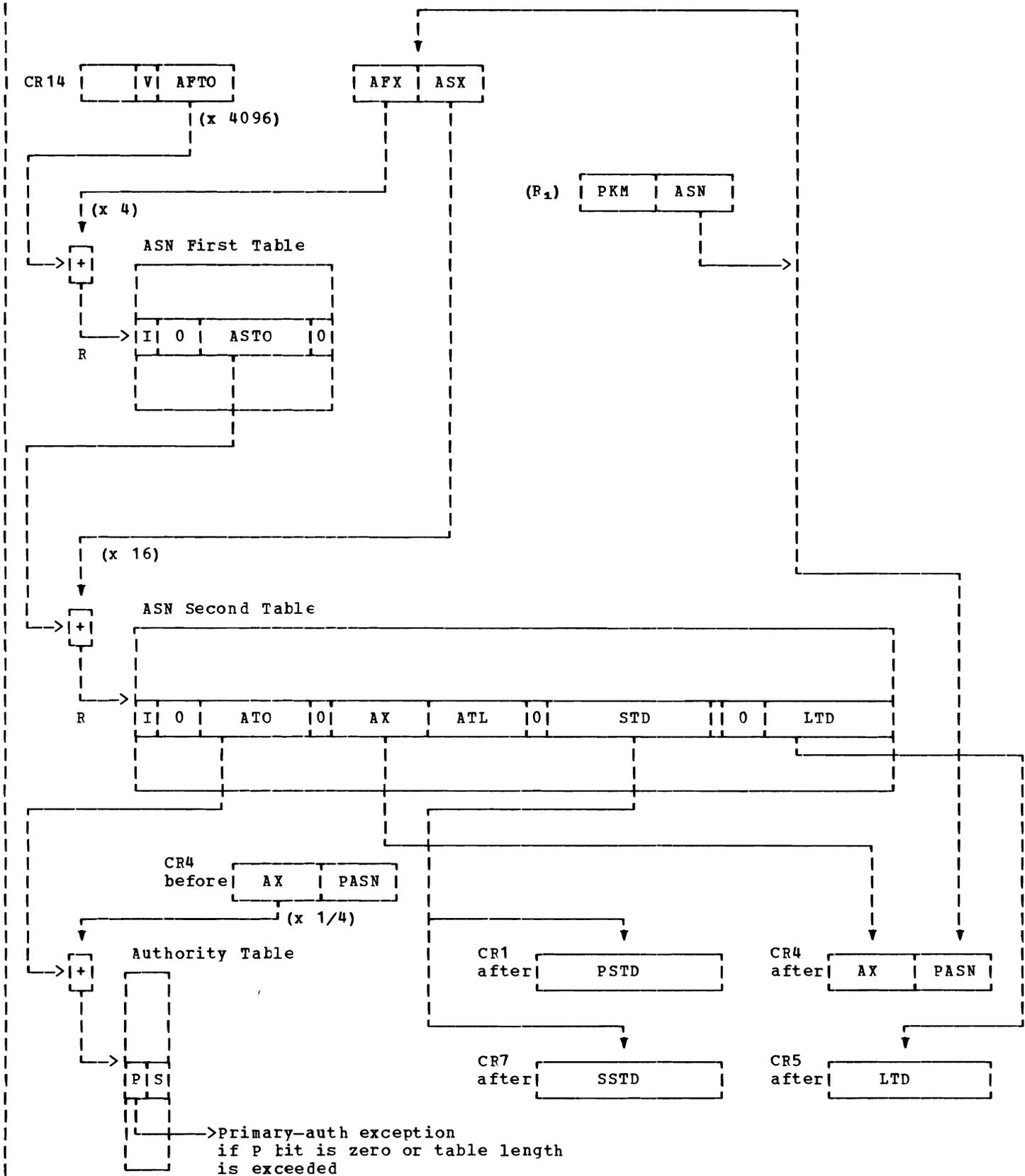
the restored PASN.

- 2. With proper authority, and while executing in a common area, PT may be used to change the primary address space to any desired space. The secondary address space is also changed to be the same as the new PASN.
- 3. Unlike most RR branch instructions, a value of zero in the R₂ field for PT causes a branch.

PROGRAM TRANSFER Instruction



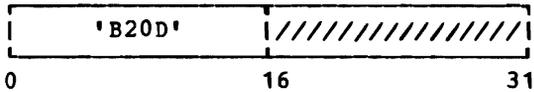
Execution of PROGRAM TRANSFER (Part 1 of 2): PT-cp and PT-ss



| Execution of PROGRAM TRANSFER (Part 2 of 2): PT-ss

PURGE TLB

PTLB [S]



All information in the translation-lookaside buffer (TLB) of this CPU is made invalid. No change is made to the contents of addressable storage or registers.

The TLB appears cleared of its original contents for all following instructions. The invalidation is not signaled to any other CPU.

A serialization function is performed. CPU operation is delayed until all previous accesses by this CPU to storage have been completed, as observed by channels and other CPUs. No subsequent instructions, their operands, or dynamic-address-translation entries are fetched by this CPU until the execution of this instruction is complete.

Bits 16-31 of the instruction are ignored.

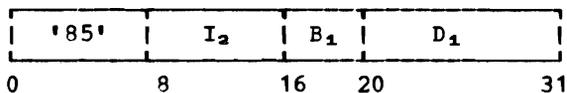
Condition Code: The code remains unchanged.

Program Exceptions:

Operation (if the translation feature is not installed)
Privileged Operation

READ DIRECT

RDD D₁ (B₁), I₂ [SI]



The contents of the I₂ field are made available as signal-out timing signals. A direct-in data byte is accepted from an external device in the absence of a hold signal and is placed in the location designated by the first-operand address.

When the extended facility is not installed, the first-operand address is a logical address, and is subject to the normal access exceptions and to the PER storage-alteration event.

When the extended facility is installed,

the first-operand address is a real address and not subject to dynamic address translation. Addressing and protection exceptions apply, and the PER storage-alteration event does not apply.

The contents of the I₂ field are made available on a set of eight signal-out lines as 0.5-microsecond to 1.0-microsecond timing signals. These signal-out lines are also used in WRITE DIRECT. On a ninth line (read out), a 0.5-microsecond to 1.0-microsecond timing signal is made available coincident with these timing signals. The read-out line is distinct from the write-out line in WRITE DIRECT. No checking bits are made available with the eight instruction bits.

Eight data bits are accepted from a set of eight direct-in lines when the hold signal on the hold-in line is absent. The hold signal is sampled after the read-out signal has been completed and should be absent for at least 0.5 microsecond. No checking bits are accepted with data signals, but a checking-block code is generated as the data is placed in storage. When the hold signal is not removed, the CPU does not complete the instruction.

A serialization function is performed before the signals are made available and again after the first-operand byte is placed in storage. CPU operation is delayed until all previous accesses by this CPU to main storage have been completed, as observed by channels and other CPUs, and then the signal-out timing signals are presented. No subsequent instructions or their operands are accessed by this CPU until the first operand byte has been placed in main storage, as observed by channels and other CPUs.

An excessively long instruction execution may result in incomplete updating of the interval timer.

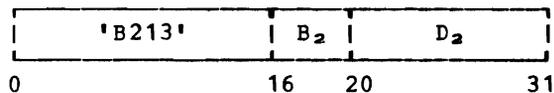
Condition Code: The code remains unchanged.

Program Exceptions:

Access (store, operand 1; access applies only if the extended facility is not installed)
Addressing (operand 1)
Operation (if the direct-control feature is not installed)
Privileged Operation
Protection (store, operand 1; key-controlled protection and low-address protection)

RESET REFERENCE BIT

RRB D₂(B₂) [S]



The reference bit in the storage key associated with the 2K-byte block that is designated by the second-operand address is set to zero.

Bits 8-20 of the second-operand address designate a block of 2K bytes in real storage. Bits 0-7 and 21-31 of the address are ignored.

The address designating the storage block, being a real address, is not subject to dynamic address translation. The reference to the storage key is not subject to a protection exception.

The values of the remaining bits of the storage key, including the change bit, are not affected.

The condition code is set to reflect the state of the reference and change bits before the reference bit is set to zero.

Resulting Condition Code:

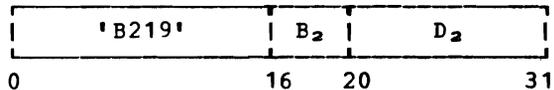
- 0 Reference bit zero, change bit zero
- 1 Reference bit zero, change bit one
- 2 Reference bit one, change bit zero
- 3 Reference bit one, change bit one

Program Exceptions:

Addressing (operand 2)
Operation (if the translation feature is not installed)
Privileged Operation

SET ADDRESS SPACE CONTROL

SAC D₂(B₂) [S]



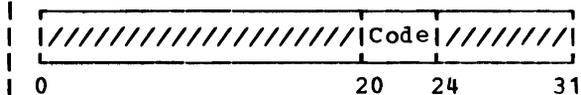
Bits 20-23 of the second-operand address are used as a code to set the address-space-control bit in the PSW. The second-operand address is not used to address data; instead, bits 20-23 form the code. Bits 0-19 and 24-31 of the

second-operand address are ignored. Bits 20-22 of the second-operand address must be zero; otherwise, a specification exception is recognized, and the operation is suppressed.

The operation is performed only when the secondary-space control, bit 5 of control register 0, is one and DAT is on. When either the secondary-space control is zero or DAT is off, a special-operation exception is recognized, and the operation is suppressed. The special-operation exception is recognized in both the problem and supervisor states.

The following diagram and table summarize the operation of SAC:

Second-Operand Address



| <u>Code</u> | <u>Name of Mode</u> | <u>Result in PSW Bit 16</u> |
|-------------|---------------------|-----------------------------|
| 0000 | Primary | 0 |
| 0001 | Secondary | 1 |
| All others | Invalid | Unchanged |

A serialization and checkpoint-synchronization function is performed at the beginning and also at the completion of the operation.

The CPU operation is delayed until all storage accesses due to previous instructions by this CPU have been completed, as observed by channels and other CPUs. All previous checkpoints, if any, are canceled, and the results of all previous stores are released, if held exclusive, to permit channels and other CPUs to access the results.

When the operation is completed, a second checkpoint-synchronization function is performed, as follows. The CPU operation is delayed until all previous checkpoints, if any, for this instruction are canceled.

The priority of recognition of program exceptions for the instruction is shown in the figure "Priority of Execution: SAC."

Condition Code: Unchanged.

Program Exceptions:

Operation (if DAS is not installed)
Special Operation
Specification

- | | |
|-------|--|
| 1.-6. | Exceptions with the same priority as the priority of program-interruption conditions for the general case. |
| 7.A | Access exceptions for second instruction halfword. |
| 7.B.1 | Operation exception if DAS is not installed. |
| 7.B.2 | Special-operation exception due to the secondary-space control, bit 5 of control register 0, being zero, or the translation bit, bit 5 of the PSW, being zero. |

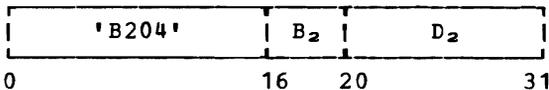
Priority of Execution: SAC

Programming Notes

- SAC is defined in such a way that the mode to be set can be placed directly in the displacement field of the instruction or can be specified from the same bit positions of a general register as saved by the IAC instruction.
- Predictable program operation is ensured in secondary mode only when the instructions are fetched from virtual-address locations which translate to the same real address by means of both the primary and secondary segment tables. Thus, a program should not enter secondary mode if it is not aware of the virtual-to-real mapping in both the primary and secondary spaces.

SET CLOCK

SCK D₂ (B₂) [S]



The current value of the TOD clock is replaced by the contents of the doubleword designated by the second-operand address, and the clock enters the stopped state.

The doubleword operand replaces the contents of the clock, as determined by the

resolution of the clock. Only those bits of the operand are set in the clock that correspond to the bit positions which are updated by the clock; the contents of the remaining rightmost bit positions of the operand are ignored and are not preserved in the clock. In some models, starting at or to the right of bit position 52, low-order bits of the second operand are ignored, and the corresponding positions of the clock which are implemented are set to zeros.

After the clock value is set, the clock enters the stopped state. The clock leaves the stopped state to enter the set state and resume incrementing under control of the TOD-clock sync-check control (bit 2 of control register 0). When the bit is zero or the TOD-clock-synchronization facility is not installed, the clock enters the set state at the completion of the instruction. When the bit is one, the clock remains in the stopped state either until the bit is set to zero or until any other running TOD clock in the configured system is incremented to a value of all zeros in bit positions 32-63.

When the TOD clock is shared by another CPU, the clock remains in the stopped state under control of the TOD-clock sync-check control bit of the CPU which set the clock. If, while the clock is stopped, it is set by another CPU, then the clock comes under control of the TOD-clock sync-check control bit of the CPU which last set the clock.

The value of the clock is changed and the clock is placed in the stopped state only if the manual TOD-clock control of any CPU in the configuration is set to enable-set. If the TOD-clock control is set to secure, the value and the state of the clock are not changed. The two results are distinguished by condition codes 0 and 1, respectively.

When the clock is not operational, the value and state of the clock are not changed, regardless of the setting of the TOD-clock control, and condition code 3 is set.

The operand must be designated on a doubleword boundary; otherwise, a specification exception is recognized, and the operation is suppressed.

Resulting Condition Code:

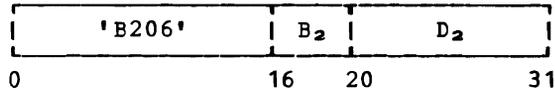
- | | |
|---|--------------------------------|
| 0 | Clock value set |
| 1 | Clock value secure |
| 2 | -- |
| 3 | Clock in not-operational state |

Program Exceptions:

Access (fetch, operand 2)
Privileged Operation
Specification

SET CLOCK COMPARATOR

SCKC D₂(B₂) [S]



The current value of the clock comparator is replaced by the contents of the doubleword designated by the second-operand address.

Only those bits of the operand are set in the clock comparator that correspond to the bit positions to be compared with the TOD clock; the contents of the remaining rightmost bit positions of the operand are ignored and are not preserved in the clock comparator.

The operand must be designated on a doubleword boundary; otherwise, a specification exception is recognized, and the operation is suppressed. The operation is suppressed on addressing and protection exceptions.

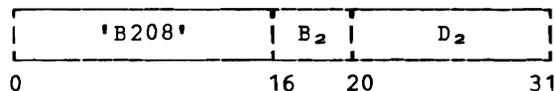
Condition Code: The code remains unchanged.

Program Exceptions:

Access (fetch, operand 2)
Operation (if the CPU-timer and clock-comparator feature is not installed)
Privileged Operation
Specification

SET CPU TIMER

SPT D₂(B₂) [S]



The current value of the CPU timer is replaced by the contents of the doubleword designated by the second-operand address.

Only those bits of the operand are set in

the CPU timer that correspond to the bit positions to be updated; the contents of the remaining rightmost bit positions of the operand are ignored and are not preserved in the CPU timer.

The operand must be designated on a doubleword boundary; otherwise, a specification exception is recognized, and the operation is suppressed. The operation is suppressed on addressing and protection exceptions.

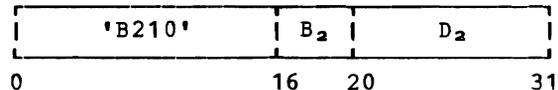
Condition Code: The code remains unchanged.

Program Exceptions:

Access (fetch, operand 2)
Operation (if the CPU-timer and clock-comparator feature is not installed)
Privileged Operation
Specification

SET PREFIX

SPX D₂(B₂) [S]



The contents of the prefix register are replaced by the contents of bit positions 8-19 of the word at the location designated by the second-operand address. All information in the translation-lookaside buffer (TLB) of this CPU is made invalid.

After the second operand is fetched, depending on the model, the prefix value may or may not be tested to determine whether the corresponding block in absolute storage is available before it is used to replace the contents of the prefix register.

On models which do not test the value, the instruction is completed after setting the prefix register. If the address loaded specifies a location which is not available, the machine subsequently hangs up when an instruction or interruption procedure is performed that requires prefixing to be applied to the storage address.

On models which do test the value, some or all of the necessary checks are performed to ensure that the entire 4K-byte block designated by the prefix address is available. If the storage area is not available, an addressing exception is

recognized, and the operation is suppressed. The check to determine that the 4K-byte block is available may involve accessing the location. This access is not subject to protection; however, the access may cause the reference bits to be turned on.

If the operation is completed, the new prefix is used for any interruptions following the execution of the instruction and for the execution of subsequent instructions. The contents of bit positions 0-7 and 20-31 of the operand are ignored.

The TLB appears cleared of its original contents for all following instructions.

A serialization function is performed. CPU operation is delayed until all previous accesses by this CPU to main storage have been completed, as observed by channels and other CPUs. No subsequent instructions, operands, or dynamic-address-translation entries are fetched by this CPU until the execution of this instruction is completed.

The operand must be designated on a word boundary; otherwise, a specification exception is recognized, and the operation is suppressed. The operation is suppressed on protection and addressing exceptions.

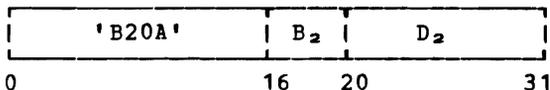
Condition Code: The code remains unchanged.

Program Exceptions:

- Access (fetch, operand 2)
- Addressing (new prefix area)
- Operation (if the multiprocessing feature is not installed)
- Privileged Operation
- Specification

SET PSW KEY FROM ADDRESS

SPKA D₂(B₂) [S]



The four-bit PSW key, bits 8-11 of the current PSW, is replaced by bits 24-27 of the second-operand address.

The second-operand address is not used to address data; instead, bits 24-27 of the address form the new PSW key. Bits 8-23 and 28-31 of the second-operand address are ignored.

In the problem state, when DAS is installed, the execution of the instruction is subject to control by the PSW-key mask in control register 3. When the bit in the PSW-key mask corresponding to the PSW-key value to be set is one, the instruction is executed normally. When the selected bit in the PSW-key mask is zero, a privileged-operation exception is recognized, and the operation is suppressed. When DAS is not installed, execution of the instruction in the problem state results in a privileged-operation exception regardless of the contents of control register 3. In the supervisor state, the PSW key is set with no checking.

Condition Code: The code remains unchanged.

Program Exceptions:

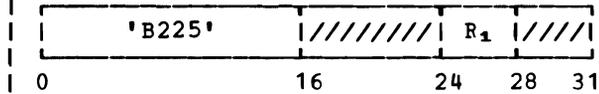
- Operation (if the PSW-key-handling feature is not installed)
- Privileged Operation (selected PSW key mask is zero in problem state)

Programming Notes

1. The format of the SET PSW KEY FROM ADDRESS instruction permits the program to set the PSW key either from the general register designated by the B₂ field or from the D₂ field in the instruction itself.
2. When one program requests another program to access a location specified by the requesting program, the SET PSW KEY FROM ADDRESS instruction can be used by the called program to verify that the requesting program is authorized to make this access, provided the storage location of the called program is not protected against fetching. The called program can perform the verification by replacing the PSW key with the requesting-program PSW key before making the access and subsequently restoring the called-program PSW key to its original value. Caution must be observed, however, in handling any resulting protection exceptions since such exceptions may cause the operation to be terminated. See the instruction TEST PROTECTION and associated programming notes, for an alternative approach to the testing of addresses passed by a calling program.

| SET SECONDARY ASN

| SSAR R₁ [RRE]



| The ASN specified in bit positions 16-31 of the general register specified by the R₁ field replaces the secondary ASN, and the segment-table designation corresponding to that ASN replaces the SSTD.

| Bits 16-23 and 28-31 of the instruction are ignored. The contents of bit positions 0-15 of the register specified by the R₁ field are ignored.

| The operation is performed only when the ASN-translation control, bit 12 of control register 14, is one and DAT is on. When either the ASN-translation-control bit is zero or DAT is off, a special-operation exception is recognized, and the operation is suppressed. The special-operation exception is recognized in both the problem and supervisor states.

| The contents of bit positions 16-31 of the register specified by the R₁ field are called the new ASN. First the new ASN is compared with the current PASN. If the new ASN is equal to the PASN, the operation is called SET SECONDARY ASN to current primary (SSAR-cp). If the new ASN is not equal to the current PASN, the operation is called SET SECONDARY ASN with space switching (SSAR-ss).

| SET SECONDARY ASN to Current Primary (SSAR-cp)

| The new ASN replaces the SASN, bits 16-31 of control register 3; the PSTD, bits 0-31 of control register 1, replaces the SSTD, bits 0-31 of control register 7; and the operation is completed.

| SET SECONDARY ASN with Space Switching (SSAR-ss)

| The new ASN is translated by means of the ASN translation tables, and then the current AX, bits 0-15 of control register 4, is used to test whether the program is authorized to access the specified ASN.

| The new ASN is translated by means of a two-level table lookup. Bits 0-9 of the

| new ASN (bits 16-25 of the register) are used as a 10-bit AFX to index into the first table. Bits 10-15 of the new ASN (bits 26-31 of the register) are used as a six-bit ASX to index into the second table. The two-level lookup is described in the section "ASN Translation" in Chapter 5, "Program Execution." The exceptions associated with ASN translation are collectively called "ASN-translation exceptions." These exceptions and their priority are described in Chapter 6, "Interruptions."

| The AST entry obtained as a result of the second lookup contains the segment-table designation, and authority-table origin and length associated with the ASN. The remaining fields in the AST entry are ignored.

| The authority-table origin from the second-table entry is used as a base for a third table lookup. The current authorization index, bits 0-15 of control register 4, is used, after it has been checked against the authority-table length, as the index to locate the entry in the authority table. The authority-table lookup is described in the section "ASN Translation" in Chapter 5, "Program Execution."

| The ASN, bits 16-31 of the general register specified by the R₁ field, is placed in the SASN, bit positions 16-31 of control register 3. The segment-table designation, bits 64-95 of the AST entry, is placed in the SSTD, bits 0-31 of control register 7.

| For both SSAR-cp and SSAR-ss, a serialization and checkpoint-synchronization function is performed at the beginning and also at the completion of the operation.

| The CPU operation is delayed until all storage accesses due to previous instructions by this CPU have been completed, as observed by channels and other CPUs. All previous checkpoints, if any, are canceled, and the results of all previous stores are released, if held exclusive, to permit channels and other CPUs to access the results.

| When the operation is completed, a second serialization and checkpoint-synchronization function is performed, as follows. The CPU operation is delayed until all storage accesses due to this instruction have been completed, as observed by channels and other CPUs. All previous checkpoints, if any, for this instruction are canceled.

| The priority of recognition of program exceptions for the instruction is shown in the figures "Priority of Execution:

| | |
|--|-------------------------------------|
| SSAR-cp" and "Priority of Execution: | Addressing |
| SSAR-ss." | ASN Translation (SSAR-ss only) |
| | Operation (if DAS is not installed) |
| <u>Condition</u> <u>Code:</u> The code remains | Secondary Authority |
| unchanged. | Special Operation |
| | Trace |
| <u>Program Exceptions:</u> | |

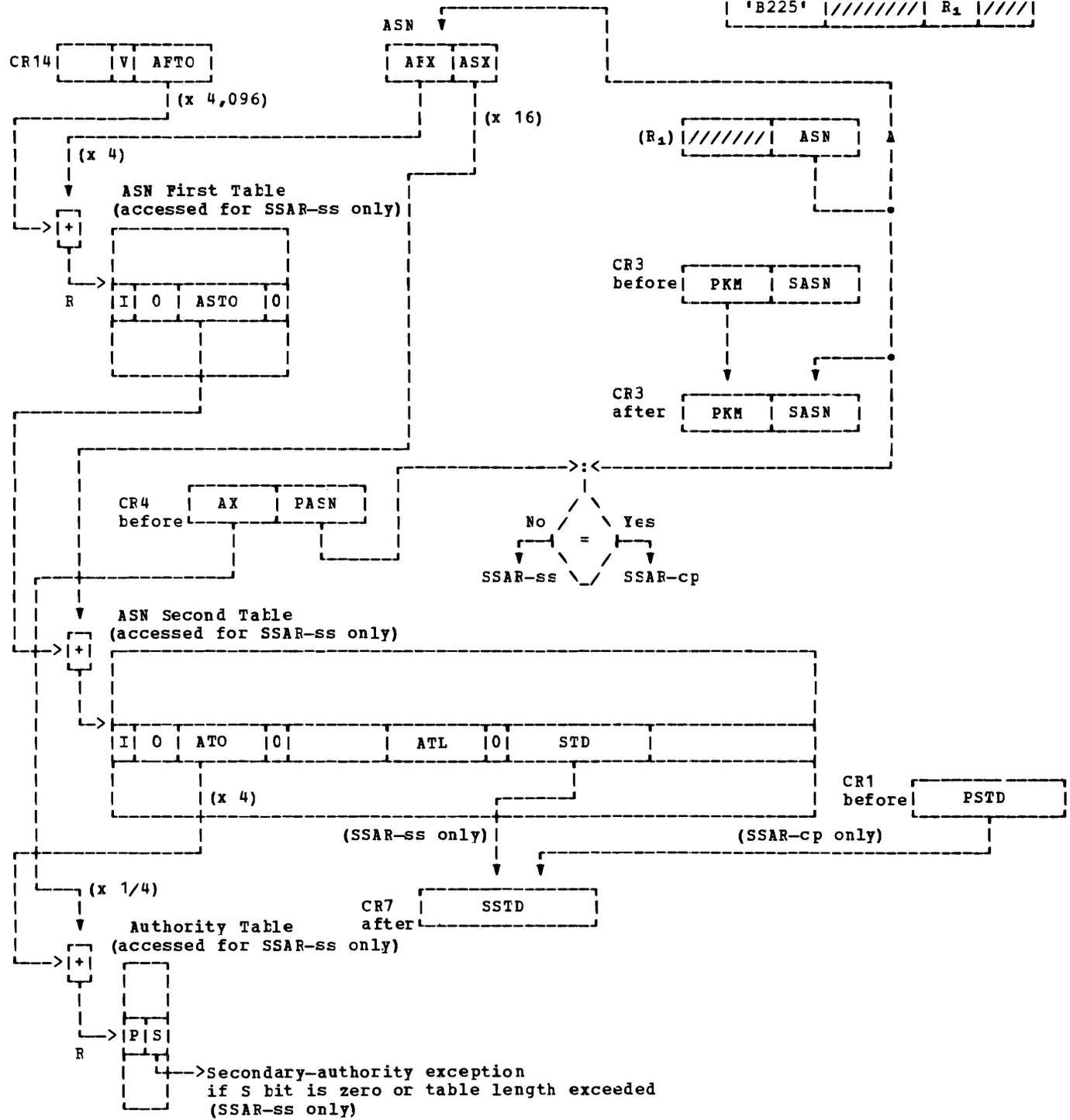
- | |
|--|
| 1.-6. Exceptions with the same priority as the priority of program-interruption conditions for the general case. |
| 7.A Access exceptions for second instruction halfword. |
| 7.B.1 Operation exception if DAS is not installed. |
| 7.B.2 Special-operation exception due to DAT being off, or the ASN-translation control, bit 12 of control register 14, being zero. |
| 8.A Trace exceptions. |

| Priority of Execution: SSAR-cp

- | |
|--|
| 1.-6. Exceptions with the same priority as the priority of program-interruption conditions for the general case. |
| 7.A Access exceptions for second instruction halfword. |
| 7.B.1 Operation exception if DAS is not installed. |
| 7.B.2 Special-operation exception due to DAT being off, or the ASN-translation control, bit 12 of control register 14, being zero. |
| 8.A Trace exceptions. |
| 8.B.1 ASN-translation exceptions. |
| 8.B.2 Secondary-authorization-translation exceptions. |
| 8.B.2 Secondary-authority exception due to authority-table entry being outside table. |
| 8.B.3 Addressing exception for access to authority-table entry. |
| 8.B.4 Secondary-authority exception due to S bit in authority-table entry being zero. |

| Priority of Execution: SSAR-ss

SET SECONDARY ASN Instruction

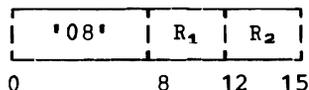


R: Address is real

Execution of SET SECONDARY ASN Instruction

SET STORAGE KEY

SSK R₁, R₂ [RR]



The storage key associated with the 2K-byte block that is addressed by the contents of the general register designated by the R₂ field is replaced by the contents of the general register designated by the R₁ field.

Bits 8-20 of the register designated by the R₂ field designate a block of 2K bytes in real storage. Bits 0-7 and 21-27 of the register are ignored. Bits 28-31 of the register must be zeros; otherwise, a specification exception is recognized, and the operation is suppressed.

The address designating the storage block, being a real address, is not subject to dynamic address translation. The reference to the storage key is not subject to a protection exception.

The new seven-bit storage-key value is obtained from bit positions 24-30 of the register designated by the R₁ field. The contents of bit positions 0-23 and 31 of the register are ignored. When dynamic address translation is not installed, bits 29 and 30 are ignored.

A serialization and checkpoint-synchronization function is performed at the beginning and also at the completion of the operation.

The CPU operation is delayed until all storage accesses due to previous instructions by this CPU have been completed, as observed by channels and other CPUs. All previous checkpoints, if any, are canceled, and the results of all previous stores are released, if held exclusive, to permit channels and other CPUs to access the results.

When the operation is completed, a second serialization and checkpoint-synchronization function is performed at the completion of the operation, as follows. The CPU operation is delayed until all storage accesses due to this instruction have been completed, as observed by channels and other CPUs. All previous checkpoints, if any, for this instruction are canceled.

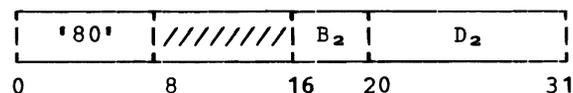
Condition Code: The code remains unchanged.

Program Exceptions:

Addressing (operand 2)
Privileged Operation
Specification

SET SYSTEM MASK

SSM D₂(B₂) [S]



Bits 0-7 of the current PSW are replaced by the byte at the location designated by the second-operand address.

When the SSM-suppression facility is installed, the execution of the instruction is subject to the SSM-suppression bit, bit 1 of control register 0. When the bit is zero, the instruction is executed normally. When the bit is one and the CPU is in the supervisor state, a special-operation exception is recognized, and the operation is suppressed.

The operation is suppressed on protection and addressing exceptions.

The value to be loaded into the PSW is not checked for validity before loading. However, immediately after loading, a specification exception is recognized, and a program interruption occurs, if the CPU is in EC mode and the contents of bit positions 0 and 2-4 of the PSW are not all zeros. In this case, the instruction is completed, and the instruction-length code is set to 2. The specification exception in this case is considered to be caused as part of the execution of the instruction.

Bits 8-15 of the instruction are ignored.

Condition Code: The code remains unchanged.

Program Exceptions:

Access (fetch, operand 2)
Privileged Operation
Special Operation
Specification

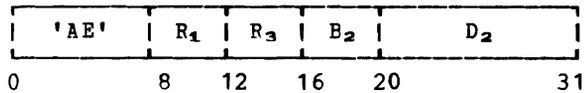
Programming Note

The SSM instruction is frequently used in the BC mode to disable or enable the CPU for I/O or external interruptions. Hence,

suppressing the execution of the SSM instruction by means of the SSM-suppression bit, bit 1 of control register 0, may be useful when converting a program written for a BC-mode PSW to operate with an EC-mode PSW.

SIGNAL PROCESSOR

SIGP R₁, R₃, D₂ (B₂) [RS]



An eight-bit order code is transmitted to the CPU designated by the CPU address contained in the third operand. The result is indicated by the condition code and may be detailed by status assembled in the first-operand location.

The second-operand address is not used to address data; instead, bits 24-31 of the address contain the eight-bit order code. Bits 8-23 of the second-operand address are ignored. The order code specifies the function to be performed by the addressed CPU. The assignment and definition of order codes appear in the section "CPU Signaling and Response" in Chapter 4, "Control."

The 16-bit binary number contained in bit positions 16-31 of the general register designated by the R₃ field forms the CPU address. The high-order 16 bits of the register are ignored.

A serialization function is performed at the beginning and also at the completion of the operation.

The CPU operation is delayed until all storage accesses due to previous instructions by this CPU have been completed, as observed by channels and other CPUs, and then the signaling occurs. No subsequent instructions or their operands are accessed by this CPU until the execution of the instruction is completed.

When the order code is accepted and no nonzero status is returned, condition code 0 is set. When status information is generated by this CPU or returned by the addressed CPU, the status is placed in the general register designated by the R₁ field, and condition code 1 is set.

When the access path to the addressed CPU is busy, or the addressed CPU is operational but in a state where it cannot respond to the order code, condition code 2

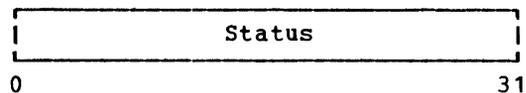
is set.

When the addressed CPU is not operational (that is, it is not provided, or it is not configured to this CPU, or it is in certain customer-engineer test modes, or its power is off), condition code 3 is set.

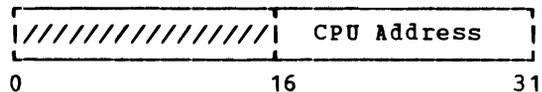
A more detailed discussion of the condition-code settings for SIGNAL PROCESSOR is contained in the section "CPU Signaling and Response" in Chapter 4, "Control."

The format of the operands of the SIGNAL PROCESSOR instruction are illustrated below.

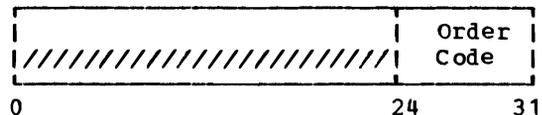
General register designated by R₁:



General register designated by R₃:



Second-operand address:



Resulting Condition Code:

- 0 Order code accepted
- 1 Status stored
- 2 Busy
- 3 Not operational

Program Exceptions:

- Operation (if the multiprocessing feature is not installed)
- Privileged Operation

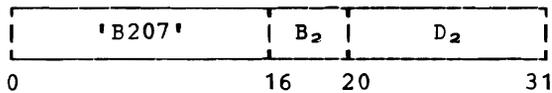
Programming Notes

1. To ensure that presently written programs will be executed properly when new facilities using additional bits are installed, only zeros should appear in the unused bit positions of the second-operand address and in bit positions 0-15 of the register designated by the R₃ field.

2. Certain orders are provided with the expectation that they will be used primarily in special circumstances. Such orders may be implemented with the aid of an auxiliary maintenance or service processor, and, thus, the execution time may take several seconds. Unless all of the functions provided by the order are required, combinations of other orders, in conjunction with appropriate programming support, can be expected to provide a specific function more rapidly. The SIGP orders emergency signal, external call, and sense are the only orders which are intended for frequent use. The following orders are intended for infrequent use, and the performance therefore may be much slower than for the frequently used orders: IML, restart, start, stop, and all the reset orders.

STORE CLOCK COMPARATOR

STCKC $D_2(B_2)$ [S]



The current value of the clock comparator is stored at the doubleword location designated by the second-operand address.

Zeros are provided for the rightmost bit positions of the clock comparator that are not compared with the TOD clock.

The operand must be designated on a doubleword boundary; otherwise, a specification exception is recognized, and the operation is suppressed. The operation is suppressed on addressing and protection exceptions.

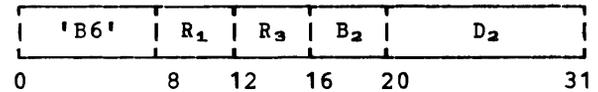
Condition Code: The code remains unchanged.

Program Exceptions:

Access (store, operand 2)
 Operation (if the CPU-timer and clock-comparator feature is not installed)
 Privileged Operation
 Specification

STORE CONTROL

STCTL $R_1, R_3, D_2(B_2)$ [RS]



The set of control registers starting with the control register designated by the R_1 field and ending with the control register designated by the R_3 field is stored at the locations designated by the second-operand address.

The storage area where the contents of the control registers are placed starts at the location designated by the second-operand address and continues through as many storage words as the number of control registers specified. The contents of the control registers are stored in ascending order of their addresses, starting with the control register designated by the R_1 field and continuing up to and including the control register designated by the R_3 field, with control register 0 following control register 15. The contents of the control registers remain unchanged.

The information stored for unassigned control-register positions, or positions associated with a facility which is not installed, is unpredictable.

The second operand must be designated on a word boundary; otherwise, a specification exception is recognized, and the operation is suppressed.

Condition Code: The code remains unchanged.

Program Exceptions:

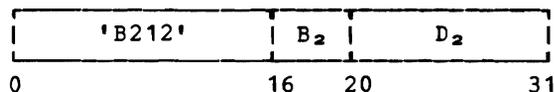
Access (store, operand 2)
 Privileged Operation
 Specification

Programming Note

Although STORE CONTROL may provide zeros in the bit positions corresponding to the unassigned register positions, the program should not depend on such zeros.

STORE CPU ADDRESS

STAP D₂ (B₂) [S]



The CPU address by which this CPU is identified in a multiprocessing system is stored at the halfword location designated by the second-operand address.

The operand must be designated on a halfword boundary; otherwise, a specification exception is recognized, and the operation is suppressed. The operation is suppressed on addressing and protection exceptions.

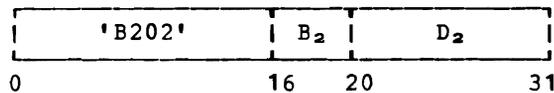
Condition Code: The code remains unchanged.

Program Exceptions:

Access (store, operand 2)
Operation (if the multiprocessing feature is not installed)
Privileged Operation
Specification

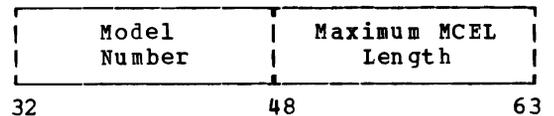
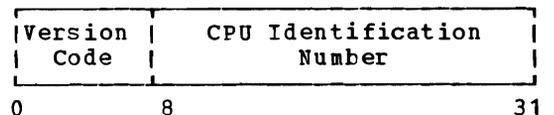
STORE CPU ID

STIDP D₂ (B₂) [S]



Information identifying the CPU is stored at the doubleword location designated by the second-operand address.

The format of the information is as follows:



Bit positions 0-7 contain the version code. The format and significance of the version code depend on the model.

Bit positions 8-31 contain the CPU identification number, consisting of six four-bit digits. Some or all of these digits are selected from the physical serial number stamped on the CPU. The contents of the CPU-identification-number field, in conjunction with the model number, permit unique identification of the CPU.

Bit positions 32-47 contain the model number, consisting of four digits: high-order zero digits, if necessary, followed by the digits of the System/370 model number. For example, a Model 145 or 3033 system would store "0145" or "3033," respectively.

Bit positions 48-63 contain a 16-bit binary value indicating the length in bytes of the longest machine-check extended logout (MCEL) that can be stored by the CPU.

The operand must be designated on a doubleword boundary; otherwise, a specification exception is recognized, and the operation is suppressed. The operation is suppressed on addressing and protection exceptions.

Condition Code: The code remains unchanged.

Program Exceptions:

Access (store, operand 2)
Privileged Operation
Specification

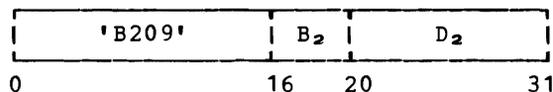
Programming Notes

1. The program should allow for the possibility that the CPU identification number may contain the digits A-F as well as the digits 0-9.
2. The principal uses of the information stored by the instruction STORE CPU ID are the following:
 - a. The CPU identification number, combined with the model number, provides a unique CPU identification that can be used in associating results with an individual system, particularly in regard to functional differences, performance differences, and error handling.
 - b. The model number, in conjunction with the version code, can be used by model-independent programs in determining which model-dependent recovery programs should be called.

- c. The MCEL length can be used by model-independent programs to allocate main storage for the MCEL area.

STORE CPU TIMER

STPT $D_2(B_2)$ [S]



The current value of the CPU timer is stored at the doubleword location designated by the second-operand address.

Zeros are provided for the rightmost bit positions that are not updated by the CPU timer.

The operand must be designated on a doubleword boundary; otherwise, a specification exception is recognized, and the operation is suppressed. The operation is suppressed on addressing and protection exceptions.

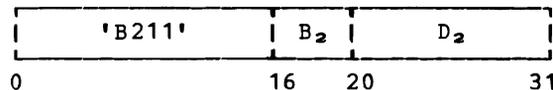
Condition Code: The code remains unchanged.

Program Exceptions:

Access (store, operand 2)
Operation (if the CPU-timer and clock-comparator feature is not installed)
Privileged Operation
Specification

STORE PREFIX

STPX $D_2(B_2)$ [S]



The contents of the prefix register are stored at the word location designated by the second-operand address. Zeros are provided for bit positions 0-7 and 20-31.

The operand must be designated on a word boundary; otherwise, a specification exception is recognized, and the operation is suppressed. The operation is suppressed on addressing and protection exceptions.

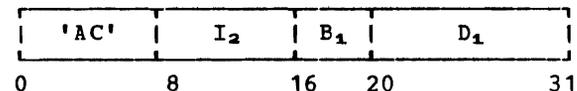
Condition Code: The code remains unchanged.

Program Exceptions:

Access (store, operand 2)
Operation (if the multiprocessing feature is not installed)
Privileged Operation
Specification

STORE THEN AND SYSTEM MASK

STNSM $D_1(B_1), I_2$ [SI]



Bits 0-7 of the current PSW are stored at the first-operand location. Then the contents of bit positions 0-7 of the current PSW are replaced by the logical AND of their original contents and the second operand.

The operation is suppressed on addressing and protection exceptions.

Condition Code: The code remains unchanged.

Program Exceptions:

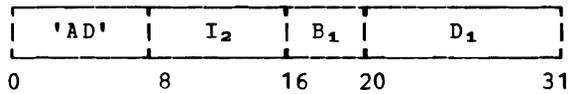
Access (store, operand 1)
Operation (if the translation feature is not installed)
Privileged Operation

Programming Note

The STORE THEN AND SYSTEM MASK instruction permits the program to set selected bits in the system mask to zeros while retaining the original contents for later restoration. For example, it may be necessary that a program, which has no record of the present status, disable program-event recording for a few instructions.

STORE THEN OR SYSTEM MASK

STOSM D₁(B₁), I₂ [SI]



Bits 0-7 of the current PSW are stored at the first-operand location. Then the contents of bit positions 0-7 of the current PSW are replaced by the logical OR of their original contents and the second operand.

The value to be loaded into the PSW is not checked for validity before loading. However, immediately after loading, a specification exception is recognized, and a program interruption occurs, if the CPU is in the EC mode and the contents of bit positions 0 and 2-4 of the PSW are not all zeros. In this case, the instruction is completed, and the instruction-length code is set to 2. The specification exception in this case is considered to be caused as part of the execution of the instruction.

The operation is suppressed on addressing and protection exceptions.

Condition Code: The code remains unchanged.

Program Exceptions:

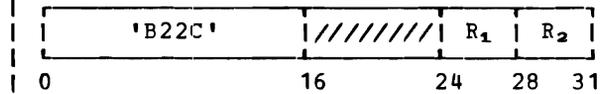
Access (store, operand 1)
 Operation (if the translation feature is not installed)
 Privileged Operation
 Specification

Programming Note

The STORE THEN OR SYSTEM MASK instruction permits the program to set selected bits in the system mask to ones while retaining the original contents for later restoration. For example, the program may enable the CPU for I/O interruptions without having available the current status of the external-mask bit.

TEST BLOCK

TB R₁, R₂ [RRE]



The storage keys and storage locations of the 4K-byte block addressed by the contents of the general register designated by the R₂ field are tested for usability based on the susceptibility to the occurrence of invalid checking-block code. The result of the test is indicated in the condition code. A complete testing operation is necessarily performed only when the initial contents of general register 0 are zero. The contents of general register 0 are set to zero at the completion of the operation.

The contents of the general register designated by the R₁ field are ignored. Bits 16-23 of the instruction are ignored.

If the block is found to be usable, the 4,096 bytes of the block are cleared to zeros, the contents of the storage keys are unpredictable, and the condition code is set to zero. If the block is found to be unusable, the data and the storage keys are set, as far as is possible by the model, to a value such that subsequent fetches to the area do not cause a machine-check condition, and the condition code is set to one.

The contents of the general register designated by the R₁ field are treated as a 31-bit real address of a 4K-byte block in storage. Bits 1-19 of the register designate the block of 4K bytes, and bits 0 and 20-31 of the register are ignored.

The address of the block is a real address, and the accesses to the block designated by the second-operand address are not subject to key-controlled protection. Addressing and low-address protection do apply. The operation is terminated on addressing and protection exceptions; that is, the condition code and the contents of general register 0 are unpredictable. The contents of storage are not changed when these exceptions occur.

Depending on the model, the test for usability may be performed (1) by alternately storing and reading out test patterns to the data and storage key in the block or (2) by reference to an internal record of the usability of the blocks in the system, or (3) by using a combination of both mechanisms.

In models in which an internal record is

used, the block is indicated as unusable if a solid failure has been previously detected, or if intermittent failures in the block have exceeded the threshold implemented by the model. In such models, depending on the error, attempts to store may or may not occur. Thus, if block 0 is not usable, and no store occurs, low-address protection may not be indicated.

In models in which test patterns are used, the TEST BLOCK instruction may be interruptible. When an interruption occurs after a unit of operation, other than the last one, the condition code is unpredictable, and the contents of general register 0 may contain a record of the state of intermediate steps. When execution is resumed after an interruption, the condition code is ignored, but the contents of general register 0 may be used to determine the resumption point.

If (1) TEST BLOCK is issued with an initial value other than zero in general register 0, or (2) the interrupted instruction is resumed after an interruption with a value in general register 0 other than the value which was present at the time of the interruption, or (3) the block is accessed by another CPU or channel during the execution of the instruction, then the results in the storage block and keys and the resultant condition-code setting and the contents of general register 0 are unpredictable.

Invalid checking-block-code errors initially found in the block or encountered during the test do not normally result in machine-check conditions. The test-block function is implemented in such a way that the frequency of machine-check interruptions due to the instruction is not significant. However, if, during the execution of TEST BLOCK for an unusable block, that block is accessed by another CPU or channel, machine-check conditions may result on either processor or both processors.

A serialization function is performed before the block is accessed and again after the operation is completed. CPU operation is delayed until all previous accesses by this CPU to storage have been completed, as observed by channels and other CPUs, and then the accesses, if any, to the block occur. No subsequent instructions or their operands are accessed by this CPU until the execution of this instruction is completed, as observed by channels and other CPUs.

Resulting Condition Code:

0 Block is usable, and the contents of storage in the block have been

set to zeros
1 Block is not usable
2 --
3 --

Program Exceptions:

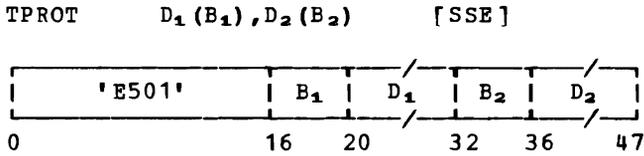
Addressing
Operation (if the instruction is not installed)
Privileged Operation
Protection (operand 2, low-address protection only)

Programming Notes

1. The execution of TEST BLOCK on most models is significantly slower than that of MOVE LONG with padding; therefore, the instruction should not be used for the normal case of clearing storage.
2. The program should use TEST BLOCK at initial program loading and as part of the vary-storage-on-line procedure to determine if blocks of storage exist which should not be used.
3. When an error is detected in either the data or keys of a block that has been in use and the recovery program chooses to mark the block unusable, the TEST BLOCK instruction should be issued to the block. This instruction attempts, as far as is possible on the model, to leave the contents of a block in such a state that subsequent errant fetches or prefetches to the block will not cause machine-check interruptions. The program should ignore the resulting condition code in this case since, depending on the model, on the type of error, and on the threshold implemented by the model, the condition code may indicate a usable block, even though the program has decided otherwise.
4. The model may or may not be successful in removing the errors from a block when the TEST BLOCK instruction is issued. The program therefore should take every reasonable precaution to avoid referencing an unusable block. For example, the program should not place the page-frame real address of an unusable block in an attached page-table entry.
5. On some models, machine checks may be reported for a block even though the block is not referenced by the program. When a machine check is reported for a key error in a block which has been marked as unusable by

the program, it is possible that SET STORAGE KEY may be more effective than TEST BLOCK in validating the key.

TEST PROTECTION



The location specified by the first-operand address is tested for protection exceptions using the access key specified in bits 24-27 of the second-operand address.

The second-operand address is not used to address data; instead, bits 24-27 of the address form the access key to be used in testing. Bits 8-23 and 28-31 of the second-operand address are ignored.

The first-operand address is a logical address and thus is subject to translation when DAT is on. When DAT is on and the first-operand address cannot be translated because of a situation that would normally cause a page-translation or segment-translation exception, the instruction is completed by setting condition code 3.

When translation of the first-operand address can be completed, or when DAT is off, the storage key associated with the first-operand address is tested against the access key specified in bits 24-27 of the second-operand address, and the condition code is set to indicate whether store and fetch accesses are permitted, taking into consideration all applicable protection mechanisms. Thus, for example, if bit 3 of control register 0 is one, indicating that low-address protection is enabled, and if the first-operand address is less than 512, then a store access is not permitted.

The contents of storage, including the change bit, are not affected. Depending on the model, the reference bit associated with the first-operand address may be set to one, even for the case in which the location is protected against fetching.

When DAT is on, an addressing exception is recognized when the address of the segment-table entry, the page-table entry, or the operand real address after translation designates a location outside the available storage of the system. Also, when DAT is on, a translation-specification exception is recognized when the

segment-table entry or page-table entry has a format error. When DAT is off, only the addressing exception due to the operand real address applies. For all of these cases, the operation is suppressed.

Resulting Condition Code:

- 0 Both fetching and storing are permitted
- 1 Fetching is permitted, but storing is not
- 2 Neither fetching nor storing are permitted
- 3 Translation not available

Program Exceptions:

- Addressing (operand 1)
- Operation (if the extended facility is not installed)
- Privileged Operation
- Translation Specification

Programming Notes

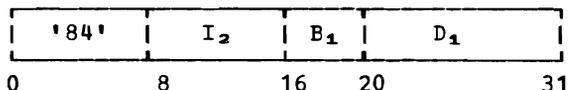
1. The instruction TPROT permits a program to check the validity of an address passed from a calling program without incurring program exceptions. The instruction sets a condition code to indicate whether fetching or storing is permitted at the location specified by the first-operand address of the instruction. The instruction takes into consideration all of the protection mechanisms installed in the machine: key-controlled and low-address protection. Additionally, since segment translation and page translation may be a substitute for a protection violation, these exceptions are used to set the condition code rather than cause an interruption.
2. See the programming notes under SET PSW KEY FROM ADDRESS for more details and for an alternative approach to testing validity of addresses passed by a calling program. The approach using TEST PROTECTION has the advantage of a test which does not result in exceptions; however, the test and use are separated in time and may not be accurate if the possibility exists that the control program can change the storage key of the location in question.
3. In the handling of dynamic address translation, TEST PROTECTION is similar to LOAD REAL ADDRESS in that the instructions do not cause page-translation and segment-translation exceptions. Instead, these situations are indicated by

means of a condition-code setting. Situations which result in condition codes 1, 2, and 3 for LRA result in condition code 3 for TPROT. However, the instructions differ in several respects. TPROT has a logical address and thus is not subject to translation when DAT is off. LRA has a virtual address which is always translated. TPROT may use the TLB for translation of the address, whereas LRA does not use the TLB.

When DAT is off for LRA, the translation specification for an invalid value of bits 8-12 of control register 0 occurs after instruction fetching as part of the execution portion of the instruction. This situation cannot occur for TPROT since the operand address is a logical address and does not examine control register 0 when DAT is off. When DAT is on, the exception would be recognized during instruction fetch. Since the instruction-fetch portion of an instruction is common for all instructions, access exceptions associated with instruction fetching are not described in the individual instruction definition.

WRITE DIRECT

WRD $D_1(B_1), I_2$ [SI]



The byte at the location designated by the first-operand address is made available as a set of direct-out static signals. Eight instruction bits are made available as signal-out timing signals.

When the extended facility is not installed, the first-operand address is a logical address and subject to normal access exceptions. When the extended facility is installed, the first-operand address is a real address and therefore not subject to translation; only addressing and protection exceptions apply.

The eight data bits of the byte fetched from the real storage location specified by the first-operand address are presented on a set of eight direct-out lines as static signals. These signals remain until the next WRITE DIRECT is executed. No checking bits are presented with the eight data bits.

The contents of the I_2 field are made available simultaneously on a set of eight signal-out lines as 0.5-microsecond to 1.0-microsecond timing signals. On a ninth line (write out), a 0.5-microsecond to 1.0-microsecond timing signal is made available concurrently with these timing signals. The eight signal-out lines are also used in READ DIRECT. No checking bits are made available with the eight instruction bits.

A serialization function is performed before the operand is fetched and again after the signals have been presented. CPU operation is delayed until all previous accesses by this CPU to main storage have been completed, as observed by channels and other CPUs, and then the first operand byte is fetched and the signals made available. No subsequent instructions or their operands are fetched by this CPU until the signals have been made available.

Condition Code: The code remains unchanged.

Program Exceptions:

- Access (fetch, operand 1; access applies only if the extended facility is not installed)
- Addressing (operand 1)
- Operation (if the direct-control feature is not installed)
- Privileged Operation
- Protection (fetch, operand 1)



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| | |
|---|-------|
| Machine-Check Detection | 11-2 |
| Correction of Machine Malfunctions | 11-2 |
| Error Checking and Correction | 11-2 |
| CPU Retry | 11-3 |
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The machine-check-handling mechanism provides extensive equipment-malfunction detection to ensure the integrity of system operation and to permit automatic recovery from some malfunctions. Equipment malfunctions and certain external disturbances are reported by means of a machine-check interruption to assist in program-damage assessment and recovery. The interruption supplies the program with information about the extent of the damage and the location and nature of the cause. Equipment malfunctions, errors, and other situations which can cause machine-check interruptions are referred to as machine checks.

bits is included to permit detection of multiple errors, to permit error correction, or both.

For checking purposes, the entire contents of a checking block, including the redundancy, is called a checking-block code (CBC). When a CBC completely meets the checking requirements (that is, no failure is detected), it is said to be valid. When both detection and correction are provided and a CBC is not valid but satisfies the checking requirements for correction (the failure is correctable), it is said to be near-valid. When a CBC does not satisfy the checking requirements (the failure is uncorrectable), it is said to be invalid.

MACHINE-CHECK DETECTION

CORRECTION OF MACHINE MALFUNCTIONS

Machine-check-detection mechanisms may take many forms, especially in control functions for arithmetic and logical processing, addressing, sequencing, and execution. For program-addressable information, detection is normally accomplished by encoding redundancy into the information in such a manner that most failures in the retention or transmission of the information result in an invalid code. The encoding normally takes the form of one or more redundant bits, called check bits, appended to a group of data bits. Such a group of data bits and the associated check bits are called a checking block. The size of the checking block depends on the model.

Three mechanisms may be used to provide recovery from machine-detected malfunctions: error checking and correction, CPU retry, and unit deletion.

Machine failures which are corrected successfully may or may not be reported as machine-check interruptions. If reported, they are system-recovery conditions, which permit the program to note the cause of CPU delay and to keep a log of such incidents.

ERROR CHECKING AND CORRECTION

The inclusion of a single check bit in the checking block allows the detection of any single-bit failure within the checking block. In this arrangement, the check bit is sometimes referred to as a "parity bit." In other arrangements, a group of check

When sufficient redundancy is included in circuitry or in a checking block, failures can be corrected. For example, circuitry can be triplicated, with a voting circuit to determine the correct value by selecting

two matching results out of three, thus correcting a single failure. An arrangement for correction of failures of one order and for detection of failures of a higher order is called error checking and correction (ECC). Commonly, ECC allows correction of single-bit failures and detection of double-bit failures.

Depending on the model and the portion of the machine in which ECC is applied, correction may be reported as a system-recovery machine-check condition or no report may be given.

Uncorrected errors in storage and in the storage key may be reported, along with a failing-storage address, to indicate where the error occurred. Depending on the situation, these errors may be reported along with system recovery, with external secondary report, or with the damage or backup condition resulting from the error.

CPU RETRY

In some models, information about some portion of the state of the machine is saved periodically. The point in the processing at which this information is saved is called a checkpoint. The information saved is referred to as the checkpoint information. The action of saving the information is referred to as establishing a checkpoint. The action of discarding previously saved information is called invalidation of the checkpoint information. The length of the interval between establishing checkpoints is model-dependent. Checkpoints may be established at the beginning of each instruction or several times within a single instruction, or checkpoints may be established less frequently.

Subsequently, this saved information may be used to restore the machine to the state that existed at the time when the checkpoint was established. After restoring the appropriate portion of the machine state, processing continues from the checkpoint. The process of restoring to a checkpoint and then continuing is called CPU retry.

CPU retry may be used for machine-check recovery, to effect nullification and suppression of instruction execution when certain program interruptions occur, and in other model-dependent situations.

Effects of CPU Retry

CPU retry is, in general, performed so that there is no effect on the program. However, change bits which have been changed from zeros to ones are not necessarily set back to zeros. As a result, change bits may appear to be set to ones for blocks which would have been accessed if restoring to the checkpoint had not occurred. If the path taken by the program is dependent on information that may be changed by another CPU or by a channel or if an interruption occurs, then the final path taken by the program may be different from the earlier path; therefore, change bits may be ones because of stores along a path apparently never taken.

Checkpoint Synchronization

Checkpoint synchronization consists in the following steps. The CPU operation is delayed until all conceptually previous storage accesses are completed, both for purposes of machine-check detection and as observed by channels and other CPUs. The checkpoint information for all previous checkpoints, if any, is invalidated. Optionally, a new checkpoint is established. The CPU operation is delayed until all of these actions appear to be completed, as observed by channels and other CPUs.

Handling of Machine Checks During Checkpoint Synchronization

When, in the process of completing all previous stores as part of the checkpoint-synchronization action, the machine is unable to complete all stores successfully but can successfully restore the machine to a previous checkpoint, processing backup is reported.

When, in the process of completing all stores as part of the checkpoint-synchronization action, the machine is unable to complete all stores successfully and cannot successfully restore the machine to a previous checkpoint, the type of machine-check condition reported depends on the origin of the store. Failure to successfully complete stores associated with instruction-execution may be reported as instruction-processing damage, or some less critical machine-check condition may be reported with the storage-logical-validity bit set to zero. A failure to successfully complete stores associated with the execution of an

| interruption, other than program or supervisor call, is reported as system damage.

| When the machine check occurs as part of a checkpoint-synchronization action before the execution of an instruction, the execution of the instruction is nullified. When it occurs before the execution of an interruption, the interruption condition, if the interruption is external, I/O, or restart, is held pending. If the checkpoint-synchronization operation was a machine-check interruption, then along with the originating condition, either the storage-logical-validity bit is set to zero or instruction-processing damage is also reported. Program interruptions, if any, are lost.

| Checkpoint-Synchronization Operations

| All interruptions and the execution of certain instructions cause a checkpoint-synchronization action to be performed. The operations which cause a checkpoint-synchronization action are called checkpoint-synchronization operations and include:

- | 1. All interruptions: external, I/O, machine check, program, restart, and supervisor call.
- | 2. BRANCH ON CONDITION (BCR) with the M_1 and R_2 fields containing all ones and all zeros, respectively.
- | 3. The instructions LOAD PSW, SET STORAGE KEY, and SUPERVISOR CALL.
- | 4. All I/O instructions.
- | 5. The instructions MOVE TO PRIMARY, MOVE TO SECONDARY, PROGRAM CALL, PROGRAM TRANSFER, SET ADDRESS SPACE CONTROL, and SET SECONDARY ASN.
- | 6. The DAS-tracing function.

| Programming Note

| The instructions which are defined to cause the checkpoint-synchronization action invalidate checkpoint information but do not necessarily establish a new checkpoint. Additionally, the machine may establish a checkpoint between any two instructions or units of operation. Thus, the point of interruption for the machine check is not necessarily at an instruction defined to cause a checkpoint-synchronization action.

| Checkpoint-Synchronization Action

| For all interruptions except I/O interruptions, a checkpoint-synchronization action is performed at the completion of the interruption. For I/O interruptions, a checkpoint-synchronization action may or may not be performed at the completion of the interruption. For all interruptions except program, supervisor-call, and exigent machine-check interruptions, a checkpoint-synchronization action is also performed before the interruption. The fetch access to the new PSW may be performed either before or after the first checkpoint-synchronization action. The store accesses and the changing of the current PSW associated with the interruption are performed after the first checkpoint-synchronization action and before the second.

| For all checkpoint-synchronization instructions except BCR, I/O instructions, and SUPERVISOR CALL, checkpoint-synchronization actions are performed before and after the execution of the instruction. For BCR, only one checkpoint-synchronization action is necessarily performed, and it may be performed either before or after the instruction address is updated. For the SUPERVISOR CALL instruction, a checkpoint-synchronization action is performed before the instruction is executed, including the updating of the instruction address in the PSW. The checkpoint-synchronization action taken after the supervisor-call interruption is considered to be part of the interruption action and not part of the instruction execution. For I/O instructions, a checkpoint-synchronization action is always performed before the instruction is executed and may or may not be performed after the instruction is executed.

| The DAS-tracing function causes checkpoint-synchronization actions to be performed before the trace action and after completion of the trace action.

UNIT DELETION

In some models, malfunctions in certain transparent units of the system can be circumvented by discontinuing the use of the unit. Examples of cases where transparent-unit deletion may be used include the disabling of all or a portion of a cache or of a translation-lookaside buffer (TLB). Unit deletion may be reported as a degradation machine-check condition.

HANDLING OF MACHINE CHECKS

A machine check is caused by a machine malfunction and not by data or instructions. This is ensured during the power-on sequence by initializing the machine controls to a valid state and by placing valid CBC in the CPU registers, in the storage keys, and, if it is volatile, also in main storage.

Specification of an unavailable component, such as a storage unit, channel, or I/O device, does not cause a machine-check indication. Instead, such a condition is indicated by the appropriate program or I/O interruption or condition-code setting. In particular, an attempt to access a storage location which has been configured out of the system results in an addressing exception and does not generate a machine-check condition, even though the storage location or its associated storage key has invalid CBC.

A machine check is indicated whenever the result of an operation could be affected by information with invalid CBC, or when any other malfunction makes it impossible to establish reliably that an operation can be, or has been, performed correctly. When information with invalid CBC is fetched but not used, the condition may or may not be indicated, and the invalid CBC is preserved.

When a machine malfunction is detected, the action taken depends on the model, the nature of the malfunction, and the situation in which the malfunction occurs. Malfunctions affecting operator-facility actions may result in machine checks or may be indicated to the operator. Malfunctions affecting certain other operations such as SIGNAL PROCESSOR may be indicated by means of a condition code or may result in a machine-check interruption.

A malfunction detected as part of an I/O operation may cause a machine-check condition, an I/O-error condition, or both. I/O-error conditions are indicated by an I/O interruption or by the appropriate condition-code setting during the execution of an I/O instruction. When the machine reports a failing-storage location detected during an I/O operation, both I/O-error and machine-check conditions may be presented. The I/O-error condition is the primary indication to the program. The machine-check condition is a secondary indication, which is presented as system recovery or as an external secondary report, together with a failing-storage address.

VALIDATION

Machine errors can be generally classified as solid or intermittent, according to the persistence of the malfunction. A persistent machine error is said to be solid, and one that is not persistent is said to be intermittent. In the case of a register or storage location, a third type of error must be considered, called externally generated. An externally generated error is one where no failure exists in the register or storage location but invalid CBC has been introduced into the location from something external to the location. For example, the value could be affected by a power transient, or an incorrect value may have been introduced when the information was placed in the location.

Invalid CBC is preserved as invalid when information with invalid CBC is fetched or when an attempt is made to update only a portion of the checking block. When an attempt is made to replace the contents of the entire checking block and the block contains invalid CBC, it depends on the operation and the model whether the block remains with invalid CBC or is replaced. An operation which replaces the contents of a checking block with valid CBC, while ignoring the current contents, is called a validation operation. Validation is used to introduce a valid CBC into a register or location which is suffering from an intermittent or externally generated error.

Validating a checking block does not ensure that a valid CBC will be observed the next time the checking block is accessed. If the failure is solid, validation is effective only if the information placed in the checking block is such that the failing bits are set to the value to which they fail. If an attempt is made to set the bits to the state opposite to that in which they fail, then the validation will not be effective. Thus, for a solid failure, validation is only useful to eliminate the error condition, even though the underlying failure remains, thereby reducing the exposure to additional reports. The locations, however, cannot be used, since invalid CBC will result from attempts to store other values in the location. For an intermittent failure, however, validation is useful to restore a valid CBC such that a subsequent partial store into the checking block (a store into a checking block without replacing the entire checking block) by either the CPU or a channel will be permitted.

When a checking block consists of multiple bytes in storage, or multiple bits in CPU registers, the invalid CBC can be made valid only when all of the bytes or bits

are replaced simultaneously.

For each type of field in the system, certain instructions are defined to validate the field. Depending on the model, additional instructions may also perform validation; or, in some models, a register is automatically validated as part of the machine-check-interruption sequence after the original contents of the register are placed in the appropriate save area.

When an error occurs in a checking block, the original information contained in the checking block should be considered lost even after validation. Automatic register validation leaves the contents unpredictable. Programmed and manual validation of checking blocks causes the contents to be changed explicitly.

Programming Note

The machine-check-interruption handler must assume that the registers require validation. Thus, each register should be loaded, using an instruction defined to validate, before the register is used or stored.

INVALID CBC IN STORAGE

| The size of the checking block in storage depends on the model but is never more than 2,048 bytes.

| When invalid CBC is detected in storage, a machine-check condition may occur; depending on the circumstances, the machine-check condition may be system damage, instruction-processing damage, external damage, or system recovery. If the invalid CBC is detected as part of an I/O operation, the error is normally reported as an I/O-error condition. When a CCW, indirect-data-address word, or data is prefetched from storage, is found to have invalid CBC, but is not used in an I/O operation, the condition is normally not reported as an I/O-error condition. The condition may or may not be reported as a machine-check interruption. Invalid CBC detected during accesses to storage for other than CPU-related accesses may be reported as system recovery with storage error uncorrected indicated, or as external secondary report, since the primary error indication is reported by some other means.

| When the storage checking block consists of multiple bytes and contains invalid CBC, special storage-validation procedures are generally necessary to restore or place new

| information in the checking block. Validation of storage is provided with the manual clear-reset operation and may also be provided as a program function. Manual storage validation by clear reset validates all blocks.

| A checking block with invalid CBC is never validated unless the entire contents of the checking block are replaced. An attempt to store into a checking block having invalid CBC, without replacing the entire checking block, leaves the data in the checking block (including the check bits) unchanged. Even when an instruction or an I/O input operation specifies that the entire contents of a checking block are to be replaced, validation may or may not occur, depending on the operation and the model.

Programming Note

Machine checks may be reported for prefetched and unused data. Depending on the model, such situations may, or may not, be successfully retried. For example, a BALR instruction which specifies an R₂ field of zero will never branch, but on some models a prefetch of the location specified by register zero may occur. Access exceptions associated with this prefetch will not be reported. However, if an invalid checking-block code is detected, CPU retry may be attempted. Depending on the model, the prefetch may recur as part of the retry, and thus the retry will not be successful. Even when the CPU retry is successful, the performance degradation of such a retry is significant, and system recovery will be presented, normally with a failing-storage address. The program in this case should initiate proceedings to eliminate use of, and validate the location, to avoid continued degradation.

Programmed Validation of Storage

| Provided that an invalid CBC does not exist in the storage key associated with a 4K-byte block, the instruction TEST BLOCK causes the entire 4K-byte block to be set to zeros with a valid CBC, regardless of the current contents of the storage. TEST BLOCK thus removes an invalid CBC from a location in storage which has an intermittent, or one-time, failure. However, if a permanent failure exists in a portion of the storage, a subsequent fetch may find an invalid CBC.

| When the instruction TEST BLOCK is included in a System/370 model, TEST BLOCK will, in most cases, be the most effective

| instruction in validating storage. When
| TEST BLOCK is not included, the instruction
| MOVE LONG, depending on the model, may
| prove effective.

| only if it is required to restore the
| contents of the block without
| introducing intermediate values.

| An interruption or stopping of the CPU
| during execution of MVCL does not affect
| the validation function performed.

| Programming Note

| The effectiveness of the following
| guideline depends on the model. On some
| models instructions may be implemented that
| are more effective than the one listed
| here; however, the following approach is
| recommended when a model-dependent routine
| cannot be justified.

| Execution of the instruction MOVE LONG will
| be most effective in validating the
| main-storage area containing the first
| operand when the following conditions are
| satisfied:

- | • The first-operand field and
| second-operand field participating in
| the operation do not overlap.
- | • The first-operand field starts on a
| 2K-byte boundary and is 2K bytes (or a
| multiple) in length.
- | • The second-operand field, if nonzero
| in length, starts on a 2K-byte
| boundary and is 2K bytes (or a
| multiple) in length.
- | • In general, the validation will be
| more effective if the second-operand
| field is of zero length. A nonzero
| second operand should be specified

INVALID CBC IN STORAGE KEYS

Depending on the model, each storage key
may be contained in a single checking
block, or the access-control and
fetch-protection bits and the reference and
change bits may be in separate checking
blocks.

The figure "Invalid CBC in Storage Keys"
describes the action taken when the storage
key has invalid CBC. The figure indicates
the action taken for the case when the
access-control and fetch-protection bits
are in one checking block and the reference
and change bits are in a separate checking
block. In machines where both fields are
included in a single checking block, the
action taken is the combination of the
actions for each field in error, except
that completion is permitted only if an
error in all affected fields permits
completion. References to main storage to
which protection does not apply are treated
as if an access key of zero is used for the
reference. This includes such references
as channel references during the initial
program load procedure and implicit
references, such as interruption action and
DAT-table accesses.

| Type of Reference | Action Taken on Invalid CBC | |
|-------------------------------------|--|---|
| | For Access-Control and Fetch-Protection Bits | For Reference and Change Bits |
| Set storage key | Complete; validate. | Complete; validate. |
| Insert storage key | PD; preserve. | PD in EC mode, PD or complete in BC mode; preserve. |
| Reset reference bit | PD or complete; preserve. | PD; preserve. |
| CPU prefetch (information not used) | CPF; preserve. | CPF; preserve. |
| I/O prefetch (information not used) | IPF; preserve. | IPF; preserve. |
| Fetch, nonzero access key | MC; preserve. | MC or complete; preserve. |
| Store, nonzero access key | MC ¹ ; preserve. | MC or complete; preserve or correct ³ . |
| Fetch, zero access key ² | MC or complete; preserve. | MC or complete; preserve. |
| Store, zero access key ² | MC or complete; preserve. | MC or complete; preserve or correct ³ . |

Explanation:

Complete The condition does not cause termination of the execution of the instruction and, unless an unrelated condition prohibits it, the execution of the instruction is completed, ignoring the error condition. No machine-check-damage conditions are generated, but a system-recovery condition may be generated.

CPF Invalid CBC in the storage key for a CPU prefetch which is unused may give rise to any of the following:

- Completed operation; no error reported.
- Completed operation; system recovery reported with storage-key error uncorrected and a failing-storage address.
- Instruction-processing damage (either with or without backup); storage-key error uncorrected and a failing-storage address.

Invalid CBC in Storage Keys (Part 1 of 2)

Explanation (Continued):

| | |
|--------------|--|
| IPF | Invalid CBC in the storage key for an I/O prefetch which is unused may result in any of the following: <ul style="list-style-type: none">• Completed operation; no error reported.• Completed operation; system recovery reported with storage-key error uncorrected and a failing-storage address.• I/O-error condition; no machine-check condition.• I/O-error condition; system recovery reported with storage-key error uncorrected and a failing-storage address.• External damage; storage-key error uncorrected and a failing-storage address, or no storage-key error uncorrected; I/O-error condition or no I/O-error condition.• External damage; valid external-damage code, external secondary report, storage-key error uncorrected, and a failing-storage address; I/O-error condition or no I/O-error condition. |
| PD | Instruction-processing-damage; storage-key error uncorrected and a failing-storage address, or no storage-key error uncorrected. |
| MC | Same as PD for CPU references, but an I/O reference may result in the following combinations of I/O-error condition and machine-check interruption. <ul style="list-style-type: none">• I/O-error condition and no machine-check interruption• System recovery, with storage-key error and a failing-storage-address or without storage-key error, and an I/O-error condition• External damage, with storage-key error uncorrected and a failing-storage address or without storage-key error, and with or without an I/O-error condition.• External damage, with a valid external-damage code, external secondary report, storage error, and a failing-storage address, and an I/O-error condition. |
| Validate | The entire key is set to the new value with valid CBC. |
| Preserve | The contents of the entire checking block having invalid CBC are left unchanged. |
| Correct | The reference and change bits are set to ones with valid CBC. |
| ¹ | The contents of the main-storage location are not changed. |
| ² | The action shown for an access key of zero is also applicable to references to which protection does not apply. |
| ³ | The contents of the reference and change bits are preserved if the "MC" action is taken and are converted to ones if the "complete" action is taken. |

Invalid CBC in Storage Keys (Part 2 of 2)

INVALID CBC IN REGISTERS

When invalid CBC is detected in a CPU register, a machine-check condition may be recognized. CPU registers include the general, floating-point, and control registers, the current PSW, the prefix

register, the TOD clock, the CPU timer, and the clock comparator.

When a machine-check interruption occurs, whether or not it is due to invalid CBC in a CPU register, the following actions affecting the CPU registers, other than the prefix register and the TOD-clock, are

taken as part of the interruption.

1. The contents of the registers are saved in assigned storage locations. Any register which is in error is identified by a corresponding validity bit of zero in the machine-check-interruption code. Malfunctions detected during register saving do not result in additional machine-check-interruption conditions; instead, the correctness of all the information stored is indicated by the appropriate setting of the validity bits.
2. On some models, registers with invalid CBC are then validated, their actual contents being unpredictable. On other models, programmed validation is required.

The prefix register and the TOD clock are not stored during a machine-check interruption, have no corresponding validity bit, and are not validated.

On those models in which registers are not automatically validated as part of the machine-check interruption, a register with invalid CBC will not cause a machine-check-interruption condition unless the contents of the register are actually used. In these models, each register may consist of one or more checking blocks, but multiple registers are not included in a single checking block. When only a portion of a register is accessed, invalid CBC in the unused portion of the same register may cause a machine-check-interruption condition. For example, invalid CBC in the right half of a long operand of a floating-point register may cause a machine-check-interruption condition if a LOAD (LE) operation attempts to replace the left half, or short form, of the register.

Invalid CBC associated with the check-stop-control bit (control register 14, bit 0) and with the asynchronous fixed-logout-control bit (control register 14, bit 9) will cause the CPU either to enter the check-stop state immediately or to assume that bits 0 and 9 have their initialized values of one and zero, respectively.

Invalid CBC associated with the prefix register cannot safely be reported by the machine-check interruption, since the interruption itself requires that the prefix value be applied to convert real addresses to the corresponding absolute addresses. Invalid CBC in the prefix register causes the CPU to enter the check-stop state immediately when the check-stop-control bit (control register 14, bit 0) is one. When the check-stop-control bit is zero the machine is permitted to ignore even the most severe errors; thus, invalid CBC in the prefix

register may be ignored or may cause the CPU to enter the check-stop state.

On those models which do not validate registers during a machine-check interruption, the following instructions will cause validation of a register, provided the information in the register is not used before the register is validated. Other instructions, although they replace the entire contents of a register, do not necessarily cause validation.

General registers are validated by BRANCH AND LINK (BAL, BALR), LOAD (LR), and LOAD ADDRESS (LA). LOAD (L) and LOAD MULTIPLE (LM) validate if the operand is on a word boundary, and LOAD HALFWORD (LH) validates if the operand is on a halfword boundary.

Floating-point registers are validated by LOAD (LDR) and, if the operand is on a doubleword boundary, by LOAD (LD).

Control registers may be validated either singly or in groups by using the instruction LOAD CONTROL (LCTL).

The CPU timer and clock comparator are validated by SET CPU TIMER (SPT) and SET CLOCK COMPARATOR (SCKC), respectively.

The TOD clock is validated by SET CLOCK (SCK) if the TOD-clock control is set to enable-set.

Programming Note

Depending on the register, and the model, the contents of a register may be validated by the machine-check interruption or the model may require that a program issue a validating instruction after the machine-check interruption has occurred. In the case of the CPU timer, depending on the model, both the machine-check interruption and validating instructions may be required to restore the CPU timer to full working order.

CHECK-STOP STATE

In certain situations it is impossible or undesirable to continue operation when a machine error occurs. In these cases, the CPU may enter the check-stop state, which is indicated by the check-stop indicator.

In general, the CPU may enter the check-stop state whenever an uncorrectable error or other malfunction occurs and the machine is unable to recognize a specific machine-check-interruption condition.

The CPU always enters the check-stop state if the check-stop-control bit, bit 0 of control register 14, is one and if any of the following conditions exists:

- PSW bit 13 is zero and an exigent machine-check condition is generated.
- During the execution of an interruption due to one exigent machine-check condition, another exigent machine-check condition is detected.
- During a machine-check interruption, the machine-check-interruption code cannot be stored successfully or the new PSW be fetched successfully.
- Invalid CBC is detected in the prefix register.
- A malfunction in the receiving CPU, which is detected after accepting the order, prevents the successful completion of a SIGNAL PROCESSOR order and the order was a reset, or the receiving CPU cannot determine what the order was. The receiving CPU enters the check-stop state.

If the check-stop-control bit is zero when one of these conditions occurs, the CPU may or may not enter the check-stop state, depending on the model. There may be many other conditions for particular models when an error may cause check stop.

When the CPU is in the check-stop state, instructions and interruptions are not executed, the interval timer is not updated, and channel operations may be stopped. In systems with channel-set switching, I/O operations are normally not affected. The TOD clock is normally not affected by the check-stop state. The CPU timer may or may not run in the check-stop state, depending on the error and the model. The start key and stop key are not effective in this state.

The CPU may be removed from the check-stop state by CPU reset.

In a multiprocessing configuration, a CPU entering the check-stop state generates a request for a malfunction-alert external interruption to all CPUs in the configuration. Except for the reception of a malfunction alert, other CPUs and I/O operations are not normally affected by the check-stop state in a CPU. However, depending on the nature of the condition causing the check stop, other CPUs may also be delayed or stopped, and I/O activity for channels connected to other CPUs may be affected.

System Check Stop

In a multiprocessing configuration, some errors, malfunctions, and damage conditions are of such a severity that the condition causes all CPUs in the configuration to enter the check-stop state. This condition is called a system check stop. The state of the channels is unpredictable.

Programming Note

The program should avoid setting the check-stop control, bit 0 of control register 14, to zero, since the machine may continue to operate rather than enter the check-stop state when extremely serious conditions, such as an error in the prefix register, occur.

MACHINE-CHECK INTERRUPTION

A request for a machine-check interruption, which is made pending as the result of a machine check, is called a machine-check-interruption condition. There are two types of machine-check-interruption conditions: exigent conditions and repressible conditions.

EXIGENT CONDITIONS

Exigent machine-check-interruption conditions are those in which damage has or would have occurred such that the current instruction or interruption sequence cannot safely continue. Exigent conditions are of two classes: instruction-processing damage and system damage. In addition to indicating specific exigent conditions, the system-damage bit is used to report any malfunction or error which cannot be isolated to a less severe report.

Exigent conditions for instruction sequences are classified as two types, nullifying exigent conditions and terminating exigent conditions, according to whether the instruction affected is nullified or terminated. Exigent conditions for interruptions are classified as one type, terminating exigent conditions. The terms "nullification" and "termination" have the same meaning as that used in Chapter 6, "Interruptions," except that more than one instruction may be involved. Thus a nullifying exigent condition indicates that the CPU has returned to the beginning of a unit of

operation prior to the error. A terminating exigent condition means that the results of one or more instructions may have unpredictable values.

REPRESSIBLE CONDITIONS

Repressible machine-check-interruption conditions are those in which the results of the instruction-processing sequence have not been affected. Repressible conditions can be delayed, until the completion of the current instruction or even longer, without affecting the integrity of CPU operation. Repressible conditions are of three classes: recovery, alert, and repressible damage. Each class has one or more subclasses.

A malfunction in the CPU, storage, channel, or operator facilities which has been successfully corrected or circumvented internally without logical damage is called a recovery condition. Depending on the model and the type of malfunction, some or all recovery conditions may be discarded and not reported. Recovery conditions that are reported are grouped in one subclass, system recovery.

A machine-check-interruption condition not directly related to a machine malfunction is called an alert condition. The alert conditions are grouped in two subclasses: degradation and warning.

A malfunction resulting in an incorrect state of a portion of the system not directly affecting sequential CPU operation is called a repressible-damage condition. Repressible-damage conditions are divided into three subclasses, according to the function affected: timing-facility damage, interval-timer damage, and external damage.

Programming Notes

1. Even though repressible conditions are usually reported only at normal points of interruption, they may also be reported with exigent machine-check conditions. Thus, if an exigent machine-check condition causes an instruction to be abnormally terminated and a machine-check interruption occurs to report the exigent condition, any pending repressible conditions may also be reported. The meaningfulness of the validity bits depends on what exigent condition is reported.
2. Classification of a damage condition

as repressible does not imply that the damage is necessarily less severe than damage classified as an exigent condition. The distinction is whether action must be taken as soon as the damage is detected (exigent) or whether the CPU can continue processing (repressible). For a repressible condition, the current instruction can be completed before taking the machine-check interruption if the CPU is enabled; if the CPU is disabled for machine checks, the condition can safely be kept pending until the CPU is again enabled for machine checks.

For example, the CPU may be disabled for machine-check interruptions because it is handling an earlier instruction-processing-damage interruption. If, during that time, an I/O operation encounters a storage error, that condition can be kept pending because it is not expected to interfere with the current machine-check processing. If, however, the CPU also makes a reference to the area of storage containing the error before re-enabling machine-check interruptions, another instruction-processing-damage condition is created, which is treated as an exigent condition and causes the CPU to enter the check-stop state, if the check-stop-control bit is set to one.

INTERRUPTION ACTION

A machine-check interruption causes the following actions to be taken. The PSW reflecting the point of interruption is stored as the machine-check old PSW at location 48. The contents of other registers are stored in register-save areas at locations 216-231 and 352-511. After the contents of the registers are stored in register-save areas, depending on the model, the registers may be validated with the contents being unpredictable. A failing-storage address, if any, is stored at location 248, an external-damage code may be stored at location 244, and a region code may be stored at location 252. Then a machine-check-interruption code (MCIC) of eight bytes is placed at location 232. The new PSW is fetched from location 112. Additionally, sometime before the storing of the MCIC, one or more machine-check logouts may have occurred. The machine-generated addresses to access the old and new PSW, the interruption code, extended interruption information, and the fixed-logout area are all real addresses. The machine-check extended-logout address is also a real address.

| Information Stored (Fetched) | Starting Location | Length in Bytes |
|--------------------------------------|-------------------|-----------------|
| Old PSW | 48 | 8 |
| New PSW (fetched) | 112 | 8 |
| Machine-check-interruption code | 232 | 8 |
| Failing-storage address | 248 | 4 |
| Register-save areas | | |
| CPU timer | 216 | 8 |
| Clock comparator | 224 | 8 |
| Floating-point registers 0, 2, 4, 6 | 352 | 32 |
| General registers 0-15 | 384 | 64 |
| Control registers 0-15 | 448 | 64 |
| Extended interruption information | | |
| External-damage code | 244 | 4 |
| Region code | 252 | 4 |
| Logout areas | | |
| Fixed logout | 256 | 96 |
| Machine-check extended logout (MCEL) | Note 1 | Note 2 |

Notes:

1. The starting location of the MCEL is determined by the MCEL address in control register 15.
2. The length of the MCEI is model-dependent.

Machine-Check-Interruption Locations

The fields accessed during the machine-check interruption are summarized in the figure "Machine-Check-Interruption Locations."

If the machine-check-interruption code cannot be stored successfully or the new PSW cannot be fetched successfully, the CPU enters the check-stop state when the check-stop-control bit is one.

A repressible machine-check condition can initiate a machine-check interruption only if both PSW bit 13 is one and the associated subclass mask bit in control register 14 is also one. When it occurs, the interruption does not terminate the execution of the current instruction; the interruption is taken at a normal point of interruption, and no program or supervisor-call interruptions are eliminated. If the machine check occurs during the execution of a machine function, such as a CPU-timer update, the machine-check interruption takes place after the machine function has been completed.

When the CPU is disabled for a particular repressible machine-check condition, the condition remains pending. Depending on the model and the condition, multiple repressible conditions may be held pending for a particular subclass, or only one condition may be held pending for a particular subclass, regardless of the number of conditions that may have been

detected for that subclass. When multiple external-damage conditions occur, each condition is retained.

When a repressible machine-check interruption occurs because the interruption condition is in a subclass for which the CPU is enabled, pending conditions in other subclasses may also be indicated in the same interruption code, even though the CPU is disabled for those subclasses. All indicated conditions are then cleared.

If a machine check which is to be reported as a system-recovery condition is detected during the execution of the interruption procedure due to a previous machine-check condition, the system-recovery condition may be combined with the other conditions, discarded, or held pending.

An exigent machine-check condition can cause a machine-check interruption only when PSW bit 13 is one. When a nullifying exigent condition causes a machine-check interruption, the interruption is taken at a normal point of interruption. When a terminating exigent condition causes a machine-check interruption, the interruption terminates the execution of the current instruction and may eliminate the program and supervisor-call interruptions, if any, that would have occurred if execution had continued. Proper execution of the interruption steps, including the storing of the old PSW and

other information, depends on the nature of the malfunction. When an exigent machine-check condition occurs during the execution of a machine function, such as a CPU-timer update, the sequence is not necessarily completed.

When PSW bit 13 is zero and an exigent machine-check condition is generated, subsequent action depends on the state of the check-stop-control bit, bit 0 of control register 14. When the check-stop-control bit is zero, the machine-check condition is held pending, and an attempt is made to complete the execution of the current instruction and to proceed with the next sequential instruction. When the check-stop-control bit is one, processing stops immediately, and the CPU enters the check-stop state. Depending on the model and the severity of the error, the CPU may enter the check-stop state even when the check-stop-control bit is zero.

Similarly, if, during the execution of an interruption due to one exigent machine-check condition, another exigent machine check is detected, the subsequent action depends on the state of the check-stop-control bit. If the check-stop-control bit is one, the CPU enters the check-stop state; if the bit is zero, an attempt is made to proceed with the condition held pending for subsequent interruption. If an exigent machine check is detected during an interruption due to a repressible machine-check condition, system damage is reported.

Exigent machine-check conditions held pending while the check-stop-control bit is zero remain pending and do not cause the CPU to enter the check-stop state if the check-stop-control bit is subsequently set to one.

Machine-check-interruption conditions are handled in the same manner regardless of whether the wait-state bit in the PSW is one or zero: a machine-check condition causes an interruption if the CPU is enabled for that condition.

Machine checks which occur while the rate control is set to instruction step are handled in the same manner as when the control is set to process; that is, recovery mechanisms are active, and logout and machine-check interruptions occur when allowed. Machine checks occurring during a manual operation may be indicated to the operator, may generate a system-recovery condition, may be reported as an external secondary report, may result in system damage, or may cause a check stop, depending on the model.

Every reasonable attempt is made to limit

the side effects of any machine check and the associated interruption. Normally, interruptions, as well as the progress of I/O operations, remain unaffected. The malfunction, however, may affect these activities, and, if the currently active PSW has bit 13 set to one, the machine-check interruption will indicate the total extent of the damage caused, and not just the damage which originated the condition.

POINT OF INTERRUPTION

The point in the processing which is indicated by the interruption and used as a reference point by the machine to determine and indicate the validity of the status stored is referred to as the point of interruption.

Because of the checkpoint capability in models with CPU retry, the interruption resulting from an exigent machine-check-interruption condition may indicate a point in the CPU processing sequence which is logically prior to the error. Additionally, the model may have some choice as to which point in the CPU processing sequence the interruption is indicated, and, in some cases, the status which can be indicated as valid depends on the point chosen.

Only certain points in the processing may be used as a point of interruption. For repressible machine-check interruptions, the point of interruption must be after one unit of operation is completed and any associated program or supervisor-call interruption is taken, and before the next unit of operation is begun.

| Exigent machine-check conditions for
| instruction sequences are those in which
| damage has or would have occurred to the
| instruction stream. Thus, the damage can
| normally be associated with a point part
| way though an instruction and this point is
| called the point of damage. In some cases
| there may be one or more instructions
| separating the point of damage and the
| point of interruption, and the processing
| associated with one or more instructions
| may be damaged. When the point of
| interruption is a point prior to the point
| of damage due to a nullifiable exigent
| machine-check condition, the point of
| interruption can be only at the same points
| as for repressible machine-check
| conditions.

Exigent machine-check conditions which are delayed (disallowed and presented later when allowed) can be presented only at the same points of interruption as repressible

machine-check conditions. When a terminating exigent machine-check condition is not delayed, the point of interruption may also be after the unit of operation is completed but before any associated program or supervisor-call interruption occurs. In this case, a valid PSW instruction address is defined as that which would have been stored in the old PSW for the program or supervisor-call interruption. Since the operation has been terminated, the values in the result fields, other than the instruction address, are unpredictable. Thus the validity bits associated with fields which are due to be changed by the instruction stream are meaningless when a terminating exigent machine-check condition is reported.

When the point of interruption and the point of damage due to an exigent machine-check condition are separated by a checkpoint-synchronization function, the damage has not been isolated to a particular program, and system damage is indicated.

Programming Note

When an exigent machine-check-interruption

condition occurs, the point of interruption which is chosen affects the amount of damage which must be indicated. An attempt is made, when possible, to choose a point of interruption which permits the minimum indication of damage. In general, the preference is the interruption point immediately preceding the error.

When all the status information stored as a result of an exigent machine-check-interruption condition does not reflect the same point, an attempt is made when possible to choose the point of interruption so that the instruction address which is stored in the machine-check old PSW is valid.

MACHINE-CHECK-INTERRUPTION CODE

On all machine-check interruptions, a machine-check-interruption code (MCIC) is stored at the doubleword starting at location 232 and has the format shown in the figure "Machine-Check Interruption-Code Format."

Bits in the MCIC which are not assigned, or not implemented by a particular model, are stored as zeros.

Instruction-Processing Damage

Bit 1 (PD), when one, indicates that damage has occurred to the instruction processing of the CPU.

The exact meaning of bit 1 depends on the setting of the backed-up bit, bit 14. When the backed-up bit is one, the condition is called processing backup. When the backed-up bit is zero, the condition is called processing damage. These two conditions are described in the section "Synchronous Machine-Check-Interruption Conditions" in this chapter.

Instruction-processing damage is a nullifying or terminating exigent condition.

System Recovery

Bit 2 (SR), when one, indicates that malfunctions were detected but did not result in damage or have been successfully corrected. Some malfunctions detected as part of an I/O operation may result in a system-recovery condition in addition to an I/O-error condition. The presence and extent of the system-recovery capability depend on the model.

System recovery is a repressible condition.

Programming Notes

1. System recovery may be used to report a failing-storage address detected by a CPU prefetch or by an I/O operation.
2. Unless the corresponding validity bits are ones, the indication of system recovery does not imply storage logical validity, or that the fields stored as a result of the machine-check interruption are valid.

Interval-Timer Damage

Bit 3 (TD), when one, indicates that damage has occurred to the interval timer or to storage location 80. Interval-timer damage is a repressible condition.

Timing-Facility Damage

Bit 4 (CD), when one, indicates that damage has occurred to the TOD clock, the CPU timer, the clock comparator, or to the CPU-timer or clock-comparator external-interruption conditions. The timing-facility-damage machine-check condition is set whenever any of the following occurs:

1. The TOD clock accessed by this CPU enters the error or not-operational state.
2. The CPU timer is damaged, and the CPU is enabled for CPU-timer external interruptions. On some models, this condition may be recognized even when the CPU is not enabled for CPU-timer interruptions. Depending on the model, the machine-check condition may be generated only as the CPU timer enters an error state. Or, the machine-check condition may be continuously generated whenever the CPU is enabled for CPU-timer interruptions, until the CPU timer is validated.
3. The clock comparator is damaged, and the CPU is enabled for clock-comparator external interruptions. On some models, this condition may be recognized even when the CPU is not enabled for clock-comparator interruptions.

Timing-facility damage may also be set along with instruction-processing damage when an instruction which accesses the TOD-clock, CPU timer, or clock comparator produces incorrect results. Depending on the model, the CPU timer or clock comparator may be validated by the interruption which reports the CPU timer or clock comparator as invalid.

Timing-facility damage is a repressible condition.

Programming Note

Timing-facility-damage conditions for the CPU timer and the clock comparator are not recognized on most models when these facilities are not in use. The facilities are considered not in use when the CPU is disabled for the corresponding external interruptions (PSW bit 7, or the subclass-mask bits, bits 20 and 21 of control register 0, are zeros), and when the corresponding set and store instructions are not being issued. Timing-facility-damage conditions that are already pending remain pending, however,

when the CPU is disabled for the corresponding external interruption.

Timing-facility-damage conditions due to damage to the TOD clock are always recognized.

External Damage

Bit 5 (ED), when one, indicates that damage has occurred to a channel or to storage during operations not directly associated with processing the current instruction. Channel malfunctions are reported as external damage only when the channel is unable to report the malfunctions by an I/O-error condition. Depending on the model and on the type and extent of the error, an external-damage condition may be indicated as system damage instead of external damage.

When bit 5, external damage, is one and bit 26, external-damage-code validity, is also one, the external-damage code has been stored to indicate, in more detail, the cause of the external-damage machine-check interruption. When the external damage cannot be isolated to one or more of the conditions as defined in the external-damage code, or when the detailed indication for the condition is not implemented by the model, external damage is indicated with bit 26 set to zero.

External damage is a repressible condition.

Degradation

Bit 7 (DG), when one, indicates that continuous degradation of system performance, more serious than that indicated by system recovery, has occurred. Degradation may be reported when system-recovery conditions exceed a machine-preestablished threshold or when unit deletion has occurred. The presence and extent of the degradation-report capability depends on the model.

Degradation is a repressible condition.

Warning

Bit 8 (W), when one, indicates that damage is imminent in some part of the system (for example, that power is about to fail, or that a loss of cooling is occurring). Whether warning conditions are recognized depends on the model.

If the condition responsible for the imminent damage is removed before the interruption request is honored (for example, if power is restored), the request does not remain pending, and no interruption occurs. Conversely, the request is not cleared by the interruption, and, if the condition persists, more than one interruption may result from the same condition.

Warning is a repressible condition.

TIME OF INTERRUPTION OCCURRENCE

Bits 14 and 15 of the machine-check-interruption code indicate when the interruption occurred in relation to the error.

Backed Up

Bit 14 (B), when one, indicates that the point of interruption is at a checkpoint before the point of error. This bit is meaningful only when the instruction-processing-damage bit, bit 1, is also set to one. The presence and extent of the capability to indicate a backed-up condition depends on the model.

Delayed

Bit 15 (D), when one, indicates that some or all of the machine-check conditions were delayed in being reported because the CPU was disabled for that type of interruption at the time the condition occurred. The bit may or may not apply to floating machine-check interruptions.

SYNCHRONOUS MACHINE-CHECK INTERRUPTION CONDITIONS

The instruction-processing damage and backed-up bits, bits 1 and 14 of the machine-check-interruption code, identify, in combination, two conditions.

| <u>Bit 1</u> | <u>Bit 14</u> | <u>Name of Condition</u> |
|--------------|---------------|--------------------------|
| 1 | 0 | Processing damage |
| 1 | 1 | Processing backup |

Processing Backup

The processing-backup condition indicates that the point of interruption is prior to the point, or points, of error. This is a nullifying exigent condition. When all of the validity bits associated with CPU status are indicated as valid, the machine has successfully returned to a checkpoint prior to the malfunction, and no damage has yet occurred. The validity bits in the machine-check-interruption code which must be one for this to be the case are as follows:

| <u>MCIC Bit</u> | <u>Fields Covered by Bit</u> |
|-----------------|---|
| 20 | PSW EMWP bits |
| 21 | PSW mask and key |
| 22 | PSW program mask and condition code |
| 23 | PSW instruction address |
| 27 | Floating-point registers |
| 28 | General registers |
| 29 | Control registers |
| 31 | Storage (result field within current checkpoint interval) |
| 46 | CPU timer |
| 47 | Clock comparator |

Programming Note

The processing-backup condition is reported rather than system recovery to indicate that a malfunction or failure stands in the way of continued operation of the CPU. The malfunction has not been circumvented and damage would have occurred if instruction processing had continued.

Processing Damage

The processing-damage condition indicates that damage has occurred to the instruction processing of the CPU. The point of interruption is a point beyond some or all of the points of damage. Processing damage is a terminating exigent condition; therefore, the contents of result fields may be unpredictable and still indicated as valid.

Processing damage may include malfunctions in PER, monitor call, and dynamic address translation. Processing damage causes any SVC interruption and program interruption to be discarded. However, the contents of the old PSW and interruption-code locations for these interruptions may be set to unpredictable values.

STORAGE-ERROR TYPE

Bits 16-18 of the machine-check-interruption code are used to indicate an invalid CBC or a near-valid CBC detected in main storage or an invalid CBC in a storage key. The failing-storage-address field, when indicated as valid, identifies an address within the storage checking block containing the error, or, for storage-key error uncorrected, within the block associated with the storage key. The portion of the system affected by an invalid CBC is indicated in the subclass field of the machine-check-interruption code. I/O-detected storage errors, when indicated as I/O-error conditions, may also be reported as (1) system recovery, (2) external damage with the external-damage code valid or invalid, or (3) external secondary report. CBC errors that occur in storage or in the storage key and that are detected on prefetched or unused data by the CPU or channel may or may not be reported, depending on the model.

Storage Error Uncorrected

Bit 16 (SE), when one, indicates that a checking block in main storage contained invalid CBC and that the information could not be corrected. The contents of the checking block in main storage have not been changed. The location reported may have been accessed by this CPU or another CPU or by an I/O operation, or its contents may have been prefetched for a program or fetched as the result of a model-dependent storage access.

Storage Error Corrected

Bit 17 (SC), when one, indicates that a checking block in main storage contained near-valid CBC and that the information has been corrected before being used. Depending on the model, the contents of the checking block in main storage may or may not have been restored to valid CBC. The location reported may have been accessed by this CPU or another CPU or by an I/O operation, or its contents may have been prefetched for a program or fetched as the result of a model-dependent storage access. The presence and extent of the storage-error-correction capability depends on the model.

Storage-Key Error Uncorrected

Bit 18 (KE), when one, indicates that a storage key contained invalid CBC and that the information could not be corrected. The contents of the checking block in the storage key has not been changed. The storage key may have been accessed by this CPU or another CPU or by an I/O operation, or its contents may have been prefetched for a program or fetched as the result of a model-dependent storage access.

Programming Note

The storage-error-uncorrected and storage-key-error-uncorrected bits do not in themselves indicate the occurrence of damage because the error detected may not have affected a result. The accompanying subclass bits of the interruption code indicate the area affected by the error.

MACHINE-CHECK INTERRUPTION-CODE VALIDITY BITS

Bits 20-31, 46, and 47 of the machine-check-interruption code are validity bits. Each bit indicates the validity of a particular field in storage. With the exception of the storage-logical-validity bit (bit 31), each bit is associated with a field stored during the machine-check interruption. When a validity bit is one, it indicates that the saved value placed in the corresponding storage field is valid with respect to the indicated point of interruption and that no error was detected when the data was stored.

When a validity bit is zero, one or more of the following conditions may have occurred: the original information was incorrect, the original information had invalid CBC, additional malfunctions were detected while storing the information, or none or only part of the information was stored. Even though the information is unpredictable, the machine attempts, when possible, to place valid CBC in the storage field and thus reduce the possibility of additional machine checks being caused.

The validity bits for the floating-point registers, general registers, control registers, CPU timer, and clock comparator indicate the validity of the saved value placed in the corresponding save area. The information in these registers after the machine-check interruption is not necessarily correct even when the correct value has been placed in the save area and

the validity bit set to one. The use of the registers and the operation of the facility associated with the control registers, CPU timer, and clock comparator, are unpredictable until these registers are validated. (See the section "Invalid CBC in Registers" earlier in this chapter.)

PSW-EMWP Validity

Bit 20 (WP), when one, indicates that the EMWP bits (bits 12-15) of the machine-check old PSW are correct.

PSW Mask and Key Validity

Bit 21, when one, indicates that the system mask, PSW key, and miscellaneous bits of the machine-check old PSW are correct. Specifically, this bit covers bits 0-11 of both EC-mode and BC-mode PSWs, and also bits 16, 17, and 24-39 of the EC-mode PSW.

PSW Program-Mask and Condition-Code Validity

Bit 22 (PM), when one, indicates that the program mask and condition code of the machine-check old PSW are correct.

PSW-Instruction-Address Validity

Bit 23 (IA), when one, indicates that the instruction address (bits 40-63) of the machine-check old PSW is correct.

Programming Note

When a machine check occurs which stores a BC-mode PSW, the contents of the interruption code and ILC in the machine-check old PSW are unpredictable, and no PSW-validity bit covers these bits. The four PSW-validity bits cover all 64 bits of the EC-mode PSW.

Failing-Storage-Address Validity

Bit 24 (FA), when one, indicates that a correct failing-storage address has been placed at location 248 after a storage

error uncorrected or storage-key error uncorrected or storage error corrected. The presence and extent of the capability to identify the failing storage location depend on the model. When no such errors are reported, that is, bits 16-18 of the machine-check-interruption code are zeros, the failing-storage address is meaningless, even though it may be indicated as valid.

Region-Code Validity

Bit 25 (RC), when one, indicates that a correct region code has been stored. The presence of the region code depends on the model. When a model does not provide a region code, bit 25 is set to zero.

External-Damage-Code Validity

Bit 26 (EC), when one, indicates that a valid external-damage code has been stored, provided that bit 5, external damage, is also one. When bit 5 is zero, bit 26 has no meaning.

Floating-Point-Register Validity

Bit 27 (FP), when one, indicates that the contents of the floating-point-register save area at locations 352-383 reflect the correct state of the floating-point registers at the point of interruption. When the floating-point feature is not installed, this bit is set to zero.

General-Register Validity

Bit 28 (GR), when one, indicates that the contents of the general-register save area at locations 384-447 reflect the correct state of the general registers at the point of interruption.

Control-Register Validity

Bit 29 (CR), when one, indicates that the contents of the control-register save area at locations 448-511 reflect the correct state of the control registers at the point of interruption.

Logout Validity

Bit 30 (LG), when one, indicates that the machine-check extended-logout information was correctly stored. When a model does not provide extended-logout information, bit 30 is set to zero.

Storage Logical Validity

Bit 31 (ST), when one, indicates that the storage locations, the contents of which are modified by the instructions being executed, contain the correct information relative to the point of interruption. That is, all stores before the point of interruption are completed, and all stores, if any, after the point of interruption are suppressed. When a store before the point of interruption is suppressed because of an invalid CBC, the storage-logical-validity bit may be indicated as one, provided that the invalid CBC has been preserved as invalid.

When instruction-processing damage, without the backed-up condition, is indicated, the storage logical validity has no meaning.

Storage logical validity reflects only the instruction-processing activity and does not reflect errors in the state of storage as the result of interval-timer update or I/O operations, or of the storing of the old PSW and other interruption information.

CPU-Timer Validity

Bit 46 (CT), when one, indicates that the CPU timer is not in error and that the contents of the CPU-timer save area at location 216 reflect the correct state of the CPU timer at the time the interruption occurred. When the CPU timer is not installed, bit 46 is set to zero.

Clock-Comparator Validity

Bit 47 (CC), when one, indicates that the clock comparator is not in error and that the contents of the clock-comparator save area at location 224 reflect the correct state of the clock comparator. When the clock comparator is not installed, bit 47 is set to zero.

Programming Note

The validity bits must be used in addition to the subclass bits and the backed-up bit in order to determine the extent of the damage caused by a machine-check condition. No damage has occurred to the system when the following are true:

- The four PSW validity bits, the three register validity bits, the two timing-facility-validity bits, and the storage-logical-validity bit must all be ones.
- The damage-subclass bits 0, 3, 4, and 5 must be zeros.
- The instruction-processing-damage bit must be zero or, if one, the backed-up bit must also be one.

Machine-Check Extended-Logout Length

Bits 48-63 of the machine-check-interruption code contain a 16-bit binary value indicating the length in bytes of the information most recently stored in the extended-logout area, starting at the location designated by the machine-check extended-logout address in control register 15. When no extended logout has occurred, this field is set to zero.

Programming Note

When asynchronous machine-check extended logouts are permitted (control register 14, bit 8, is one), more than one extended logout may have occurred. The length stored on interruption does not necessarily indicate the longest logout which has occurred.

MACHINE-CHECK EXTENDED INTERRUPTION INFORMATION

As part of the machine-check interruption, in some cases, extended interruption information is placed in fixed areas assigned in storage. The contents of registers associated with the CPU are placed in register-save areas. For external damage, additional information is provided for some models by storing an external-damage code. When storage error uncorrected, storage error corrected, or storage-key error uncorrected is indicated, the failing-storage address is saved. Some

models store a region code to show the location of the error.

Each of these fields has associated with it a validity bit in the machine-check-interruption code. If, for any reason, the machine cannot store the proper information in the field, the associated validity bit is set to zero.

REGISTER-SAVE AREAS

As part of the machine-check interruption, the current contents of the CPU registers, except for the TOD clock, are stored in five register-save areas assigned in storage. Each of these areas has associated with it a validity bit in the machine-check-interruption code. If, for any reason, the machine cannot store the proper information in the field, the associated validity bit is set to zero.

The following are the five sets of registers and the locations in storage where their contents are saved during a machine-check interruption.

| <u>Locations</u> | <u>Registers</u> |
|------------------|--|
| 216-223 | CPU timer |
| 224-231 | Clock comparator |
| 352-383 | Floating-point registers 0, 2, 4, 6 |
| 384-447 | General registers 0-15 |
| 448-511 | Control registers 0-15 |

When the CPU-timer and clock-comparator feature or the floating-point feature is not installed, the corresponding locations remain unchanged. The information stored for unassigned or uninstalled control-register positions is unpredictable.

EXTERNAL-DAMAGE CODE

The word at location 244 is the external-damage code. This field, when implemented and indicated as valid, describes the cause of external damage. The field is valid only when bit 5, external damage, and bit 26, external-damage validity are both ones. The code provides the following information.

External Secondary Report: Bit 2, when one, indicates that the machine-check interruption has been reported for an external error for which the primary indication of the error has been or will be made by means of some other report. The primary indication may be an I/O-error

condition, an indication to the operator, another machine-check interruption, or even another bit in the same machine-check interruption.

The external secondary report has three main purposes. First, it is used to present the failing-storage address associated with storage errors detected during channel accesses to storage. In this case, the failing-storage address and storage-error-uncorrected, storage-error-corrected, or storage-key-error-uncorrected indication are used to identify the cause of failure and the associated location.

Second, the external secondary report is used to present model-dependent logout information for an error associated with a channel that is physically integrated with the CPU. The machine-check indication in this case is provided so that channels integrated with the CPU can use the normal CPU logout mechanism for presenting the model-dependent logout information.

For these two purposes, the primary error indication is normally by means of an I/O-error condition. These errors include conditions presented as channel-control check, channel-data check, and interface-control check. External secondary reports due to I/O and channel errors (1) may be presented to any or all CPUs in the configuration, (2) are not necessarily presented to the CPU to which the channel is connected, and (3) when channel-set switching is installed, may be presented even when the channel set is disconnected. In some models, external secondary reports due to I/O and channel errors may be broadcast to all CPUs in the configuration.

The third use of external secondary report is to provide a mechanism for presenting logout information associated with errors detected by other external devices or during operator-initiated operations. The primary indication in this case is normally by means of the external device or by an indication to the operator.

Channel Not Operational: Bit 3, when one, indicates that one or more channels in the configuration have entered the not-operational state without performing an I/O system reset on the I/O interface. This situation occurs when these channels have detected an error of such severity that channel operations cannot continue. In systems with channel-set switching, channel-not-operational conditions are reported to all CPUs in the configuration even when the channel set is disconnected. Only those state changes in the channel which would be seen if the channel set were connected to a CPU are considered for purposes of this interruption. The channel-not-operational condition is

reported only on systems in which all channels have implemented the CLEAR CHANNEL (CLRCH) instruction.

Channel-Control Failure: Bit 4, when one, indicates that one or more channels in the configuration have entered the not-operational state and may or may not have performed an I/O system reset on the I/O interface. This situation occurs when the channels have lost power or detected an error of such severity that channel operations cannot continue. In systems with channel-set switching, channel-control-failure conditions are reported to all CPUs in the configuration, even when the channel set is disconnected. The channel-control-failure condition is reported only on systems in which all channels have implemented the CLEAR CHANNEL (CLRCH) instruction.

When the machine can determine that all affected channels actually entered the not-operational state without performing I/O system reset on the I/O interface, the channel-not-operational condition is indicated rather than channel-control failure.

I/O-Instruction Timeout: Bit 5, when one, indicates that the execution time of an I/O instruction has exceeded the maximum allowed by the CPU. The I/O instruction has been completed by setting condition code 3. When the CPU is enabled for external-damage machine-check conditions at the time the timeout occurs, the instruction address stored in the machine-check old PSW (if indicated as valid) points to the instruction following the I/O instruction. In this case, the address of the failing I/O instruction (or of the EXECUTE) can be obtained by subtracting 4 from the instruction address. Timeout of an I/O instruction is reported by means of bit 5 only when the CPU can ensure that the channel has not issued an I/O system reset on the I/O interface. Depending on the channel and the timeout condition, the channel may or may not be operational. The I/O-instruction-timeout condition is reported only on systems in which all channels have implemented the CLEAR CHANNEL (CLRCH) instruction.

I/O-Interruption Timeout: Bit 6, when one, indicates that the channel portion of an I/O interruption has exceeded the time limit established by the CPU and that the CPU has canceled the interruption. The I/O-interruption condition may or may not have been lost, and information may or may not have been stored at the locations of the old PSW, CSW, and other areas associated with an I/O interruption. The I/O interruption was not taken; that is, sequential instruction processing continued without loading the I/O new PSW. Timeout

of an I/O interruption is reported by means of bit 6 only when the CPU can ensure that the channel has not issued an I/O system reset on the I/O interface. Depending on the channel and the timeout condition, the channel may or may not be operational. The I/O-interruption-timeout condition is reported only on systems in which all channels have implemented the CLEAR CHANNEL (CLRCH) instruction.

Reserved: Bits 0, 1, and 7-31 are reserved for future expansion and are always set to zeros.

Programming Notes

1. Bit 0 is reserved for future expansion and possible redefinition of the remaining bits in the external-damage code. Thus, the program should test bit 0 for a zero value before interpreting the other bits in the external-damage code.
2. Bit 3 (channel not operational), bit 4 (channel-control failure), and external damage with the external-damage code invalid, form a set of three errors of increasing severity. When a channel-not-operational or channel-control-failure condition is reported, the affected channels enter the not-operational state. Thus, if the program is aware of the addresses of all channels which have been operational in the system, then, by means of a TEST CHANNEL instruction to all channels in the system, the program can determine which channels have entered the not-operational state. Since the channel-not-operational and channel-control-failure conditions are reported to all CPUs in the configuration, all channels on all CPUs must be tested. When channel-set switching is installed, then all channels, including those not currently connected to any CPU, must be tested.

Channel not operational is the least severe indication of the three. The affected channels can be determined as indicated above, and it is known in this case that I/O system reset has not been performed on the I/O interface.

Channel-control failure is more severe than channel not operational in that I/O system reset may have been

performed on the I/O interface.

External damage with the external-damage code invalid is the most severe indication of the three. All channels in the configuration may have been affected, and the affected channels may or may not appear to be not operational to a TEST CHANNEL instruction. Damage which can be reported by means of this indication includes errors occurring during the execution of an I/O interruption. For example, this indication can be used to report that an I/O interruption occurred with incorrect I/O address, incorrect CSW, incorrect limited-channel-logout information, or channel-control failure.

FAILING-STORAGE ADDRESS

When storage error uncorrected, storage error corrected, or storage-key error uncorrected is indicated in the machine-check-interruption code, the associated address, called the failing-storage address, is stored in bits 8-31 of the word at location 248. Bits 0-7 of that word are set to zeros.

In the case of storage errors, the failing-storage address may designate any byte within the checking block. For storage-key error uncorrected, the failing-storage address may designate any address within the 2,048-byte block of storage associated with the storage key that is in error. When an error is detected in more than one location before the interruption, the failing-storage address may designate any of the failing locations. The address stored is an absolute address; that is, the value stored is the address that is used to reference storage after dynamic address translation and prefixing have been applied.

REGION CODE

Depending on the model, a region code may be stored at the word at location 252. The region code may contain model-dependent information which more specifically defines the location of the error. For example, it may contain a model-dependent address of the unit causing an external damage or recovery report.

HANDLING OF MACHINE-CHECK CONDITIONS

FLOATING INTERRUPTION CONDITIONS

An interruption which is made available to any CPU in a multiprocessing configuration is called a floating interruption condition. The first CPU that accepts the interruption clears the interruption condition, and it is no longer available to any other CPU in the configuration.

A floating interruption is presented to the first CPU in the configuration which is enabled and can accept the interruption. A CPU cannot accept the interruption when it is in the check-stop state, has an invalid prefix, is performing an unending string of interruptions due to a PSW-format error of the type that is recognized early, or is in the stopped state. However, a CPU with the rate control set to instruction step can accept the interruption when the start key is activated.

Programming Note

When a CPU enters the check-stop state in a multiprocessing configuration, the program on another CPU can determine whether a floating interruption may have been reported to the failing CPU and then lost. This can be accomplished if the interruption program places zeros in the storage locations containing old PSWs and interruption codes after the interruption has been accepted (or has been moved into another area for later processing). After a CPU enters the check-stop state, the program in another CPU can inspect the old-PSW and interruption-code locations of the failing CPU. A nonzero value in an old PSW or interruption code indicates that the CPU has begun an interruption but the program did not complete the handling of it.

Architecture Note

The acceptance of a floating interruption should be interlocked in such a way as to minimize the possibility that the interruption is lost. The condition should not be cleared until after the interruption has progressed to the point that the old PSW and interruption code have been stored. Thus, if the CPU enters the check-stop state or a SIGNAL PROCESSOR reset order

causes the CPU to be reset before the old PSW and interruption code are stored, the floating condition is either still pending and will cause an interruption to be made available to another CPU in the configuration, or an indication of the interruption has been placed in main storage.

Floating Machine Check Interruption Conditions

Floating machine-check-interruption conditions are reset only by the manually initiated resets through the operator facilities. When a machine check occurs which prohibits completion of a floating machine-check interruption, the interruption condition is no longer considered a floating interruption condition, and system damage is indicated.

MACHINE-CHECK MASKING

All machine-check interruptions are under control of the machine-check mask, PSW bit 13. In addition, some machine-check conditions are controlled by subclass masks in control register 14.

The exigent machine-check conditions (system damage and instruction-processing damage) are controlled only by the machine-check mask, PSW bit 13. When PSW bit 13 is one, an exigent condition causes a machine-check interruption. When PSW bit 13 is zero and the check-stop-control bit, bit 0 of control register 14, is one, the occurrence of an exigent machine-check condition causes the CPU to enter the check-stop state. When PSW bit 13 is zero and the check-stop-control bit is zero, the machine may attempt to continue or may enter the check-stop state depending on the type of error.

The repressible machine-check conditions are controlled both by the machine-check mask, PSW bit 13, and by four subclass-mask bits in control register 14. If PSW bit 13 is one and one of the subclass-mask bits is one, the associated condition initiates a machine-check interruption. If a subclass-mask bit is zero, the associated condition does not initiate an interruption but is held pending. However, when a machine-check interruption is initiated because of a condition for which the CPU is enabled, those conditions for which the CPU is not enabled may be presented along with the condition which initiates the interruption. All conditions presented are then cleared.

Control Register 14

| | | | |
|---|------|---|---|
| C | RDEW | | |
| S | MMMM | | |
| 0 | 1 | 4 | 7 |

Control register 14 contains mask bits that specify whether certain conditions can cause machine-check interruptions. With the exception of bit 0, which is provided on all models, each of the bits is necessarily provided only if the associated function is provided.

Programming Note

The program should avoid, whenever possible, operating with PSW bit 13, the machine-check mask, set to zero, since any exigent machine-check condition which is recognized during this situation may cause the CPU to enter the check-stop state. In particular, the program should avoid issuing I/O instructions or allowing for I/O interruptions with PSW bit 13 a zero.

Check-Stop Control

Bit 0 (CS) of control register 14, controls the system action taken when an exigent machine-check condition occurs under one of the following two conditions:

1. When the CPU is disabled for machine-check interruptions (that is, PSW bit 13 is zero).
2. When an exigent machine-check condition occurs during the process of storing the machine-check-interruption code, storing the machine-check old PSW, or fetching the machine-check new PSW during a machine-check interruption.

If the check-stop control bit is one and either condition occurs, the machine enters the check-stop state; if the check-stop control bit is zero, the machine may attempt to continue or may enter the check-stop state, depending on the type of error and the model. The check-stop control bit is initialized to one. If damage occurs to control register 14, the check-stop control bit is assumed to be one.

Recovery-Report Mask

Bit 4 (RM) of control register 14 controls system-recovery-interruption conditions. This bit is initialized to zero.

Degradation-Report Mask

Bit 5 (DM) of control register 14 controls degradation-interruption conditions. This bit is initialized to zero.

External-Damage-Report Mask

Bit 6 (EM) of control register 14 controls timing-facility-damage, interval-timer-damage, and external-damage conditions. This bit is initialized to one.

Warning Mask

Bit 7 (WM) of control register 14 controls warning conditions. This bit is initialized to zero.

MACHINE-CHECK LOGOUT

Some models place model-dependent information in main storage as a result of a machine check. This is referred to as a machine-check logout. Machine-check logouts are of four different types: synchronous fixed logout, asynchronous fixed logout, synchronous machine-check extended logout, and asynchronous machine-check extended logout.]

Machine-check-logout information may, depending on the model, be placed in the machine-check extended-logout (MCEL) area. The starting location of the MCEL area is specified by the contents of control register 15. The existence and length of the MCEL are model-dependent.

Some models may place machine-check-logout information in the fixed-logout area. This area is 96 bytes in length and starts at location 256. The fixed logout may be in addition to or instead of an extended logout.

When a machine-check logout occurs during the machine-check interruption it is called a synchronous logout. If a machine-check

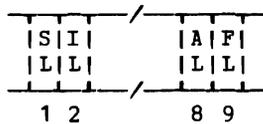
logout occurs without a machine-check interruption, or if the logout and the interruption are separated by instruction processing or by CPU retry, then the logout is called an asynchronous logout.

To preserve the initial machine-check conditions, some models perform an asynchronous logout before invoking CPU retry. Depending on the model, logout may occur before recovery, after recovery, or at both times. If logout occurs at both times it may be into the same portion or two different portions of the logout area.

LOGOUT CONTROLS

Control register 14 contains bits which control when a logout may occur.

Control Register 14



Synchronous Machine-Check Extended-Logout Control

Bit 1 (SL) of control register 14 controls the logout action during a machine-check interruption. When this bit is one, the machine-check extended-logout area may be changed during the interruption; when this bit is zero, the area may be changed only under control of the asynchronous machine-check extended-logout-control bit, bit 8 of control register 14. This bit is initialized to one.

Input/Output Extended-Logout Control

Bit 2 (IL) of control register 14, when one, permits channel logout into the I/O extended-logout area as part of an I/O interruption. When this bit is zero, I/O extended logouts cannot occur. This bit is initialized to zero.

Asynchronous Machine-Check Extended-Logout Control

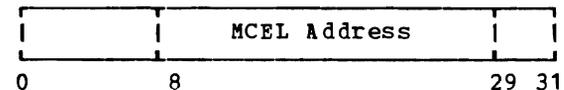
Bit 8 (AL) of control register 14, in

conjunction with PSW bit 13, controls asynchronous change of the machine-check extended-logout area. When this bit and PSW bit 13 are both ones, the machine may change the machine-check extended-logout area at any time; when this bit is zero, the area may be changed only under control of the synchronous machine-check extended-logout-control bit, bit 1 of control register 14. This bit is initialized to zero.

Asynchronous Fixed-Logout Control

Bit 9 (FL) of control register 14, when one, permits the fixed-logout area to be changed at any time. When this bit is zero, the fixed-logout area may be changed only during a machine-check interruption or during an I/O interruption. This bit is initialized to zero.

MACHINE-CHECK EXTENDED-LOGOUT ADDRESS



Bits 8-28 of control register 15, with three low-order zeros appended, specify the starting location of the machine-check extended-logout (MCEL) area. The contents of control register 15 are initialized by setting bit 22 to one and all other bits to zeros, which specifies a starting address of 512 (decimal). The MCEL address is a real address.

When a model provides the machine-check extended logout (MCEL), control register 15 is implemented.

Programming Notes

1. The availability and extent of the machine-check extended-logout area differs among models and, for any particular model, may depend on the features or engineering changes installed. In order to provide for such variations, the program should determine the extent of the logout by means of STORE CPU ID whenever a storage area for the extended logout is to be assigned. A length of zero in the MCEL field that results from executing STORE CPU ID indicates that no MCEL is provided.

2. The maximum logout information is obtained by setting both the synchronous and asynchronous machine-check extended-logout control bits to ones. Both of these bits must be zeros to prevent any changes to the machine-check extended-logout area.
3. Use of the machine-check extended-logout area while asynchronous machine-check extended logout is allowed may produce unpredictable results.
4. When the asynchronous fixed logout control bit is one, program use of the fixed logout area should be restricted to the fetching of data from this area. Store operations or channel

programs reading into the fixed logout area may cause machine checks or undetected errors if the store occurs during CPU retry. Note that this is an exception to the rule that programming errors do not cause machine-check indications.

SUMMARY OF MACHINE-CHECK MASKING AND LOGOUT

A summary of machine-check masking and logout is given in the figures "Machine-Check-Condition Masking," "Machine-Check-Logout Control," and "Machine-Check Control-Register Bits."

| Subclass | Sub-Class Mask | Action When CPU Disabled for Subclass and | |
|-------------------------------|----------------|---|---------------------|
| | | Check-Stop Ctrl = 0 | Check-Stop Ctrl = 1 |
| System damage | - | P* | Check stop |
| Instruction-processing damage | - | P* | Check stop |
| Interval-timer damage | EM | P | P |
| Timing-facility damage | EM | P | P |
| System recovery | RM | Y | Y |
| External damage | EM | P | P |
| Degradation | DM | P | P |
| Warning | WM | P | P |

Explanation:

P Indication held pending.
 Y Indication may be held pending or may be discarded.
 * System integrity may have been lost, and the system cannot be considered dependable.

Machine-Check-Condition Masking

| PSW Bit 13 | CR14 Bit 1 (SL) | CR14 Bit 8 (AL) | MCEL Action |
|---------------|--------------------|--------------------|--|
| 0 | X | X | No MCEL |
| 1 | 0 | 0 | No MCEL |
| 1 | 1 | 0 | MCEL may occur only during machine-check interruption. ¹ |
| 1 | 0 | 1 | MCEL may occur at any time. ² |
| 1 | 1 | 1 | MCEL may occur at any time. |

| CR14 Bit 9 (FL) | Fixed-Logout Action |
|--------------------|---|
| 0 | Fixed-logout area may be changed by the CPU only during machine-check interruption. ¹ |
| 1 | Fixed-logout area may be changed at any time. |

Explanation:

AL Asynchronous machine-check extended-logout control

FL Asynchronous fixed-logout control

MCEL Machine-check extended logout

SL Synchronous machine-check extended-logout control

X Indicates the same action occurs whether the bit is zero or one.

¹ Logout prior to instruction retry is not permissible in this state even though recovery reports are enabled.

² In some models, the asynchronous machine-check extended-logout control (AL) is ignored, and no logout occurs in this state.

Machine-Check-Logout Control

| Bit Description | Control Register 14 Bit Position | State of Bit on Initial CPU Reset |
|-----------------------------------|--|---|
| Check-stop control | 0 | 1 |
| Synchronous MCEL control | 1 | 1 |
| IOEL control | 2 | 0 |
| Recovery-report mask | 4 | 0 |
| Degradation-report mask | 5 | 0 |
| External-damage-report mask | 6 | 1 |
| Warning mask | 7 | 0 |
| Asynchronous MCEL control | 8 | 0 |
| Asynchronous fixed-logout control | 9 | 0 |

Machine-Check Control-Register Bits



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The transfer of information to or from main storage, other than to or from the central processing unit or by means of the direct control path, is referred to as an input or output operation. An input/output (I/O) operation involves the use of an I/O device. Input/output devices perform I/O operations under control of control units, which are attached to the central processing unit (CPU) by means of channels.

This portion of the publication describes the programmed control of I/O devices by the channels and by the CPU. Formats are defined for the various types of I/O control information. The formats apply to all I/O operations and are independent of the type of I/O device, its speed, and its mode of operation.

The formats described include provisions for functions unique to some I/O device types, such as erasing a gap on a magnetic-tape unit. The way in which a device makes use of the format is defined in the System Library (SL) publication for the particular device.

All main-storage references for I/O operations are references to absolute storage. Unless indicated otherwise, "storage" means absolute storage, and "address" means absolute address. The terms "I/O address," "channel address," and "device address" are never abbreviated to "address" in this publication.

ATTACHMENT OF INPUT/OUTPUT DEVICES

INPUT/OUTPUT DEVICES

Input/output devices provide external storage and a means of communication between data-processing systems or between a system and its environment. Input/output devices include such equipment as card readers, card punches, magnetic-tape units, direct-access-storage devices (disks and drums), display units, typewriter-keyboard devices, printers, teleprocessing devices, and sensor-based equipment.

Most types of I/O devices, such as printers, card equipment, or tape devices, deal directly with external media, and these devices are physically distinguishable and identifiable. Other types consist only of electronic equipment and do not directly handle physical recording media. The channel-to-channel adapter, for example, provides a channel-to-channel data-transfer path, and the data never reaches a physical recording medium outside main storage. Similarly, a transmission-control unit handles transmission of information between the data-processing system and a remote station, and its input and output are signals on a transmission line. An I/O

device may be physically distinct equipment, or it may time-share equipment with other I/O devices.

An input/output device ordinarily is attached to one control unit and is accessible from one channel. Switching equipment is available to make some devices accessible to two or more channels by switching devices between control units and control units between channels. The time required for switching occurs during device-selection time and may be ignored.

CONTROL UNITS

A control unit provides the logical capabilities necessary to operate and control an I/O device and adapts the characteristics of each device to the standard form of control provided by the channel.

The control unit accepts control signals from the channel, controls the timing of data transfer, and provides indications concerning the status of the device.

The I/O device attached to the control unit may be designed to perform only certain limited operations, or it may perform many different operations. A typical operation is moving the recording medium and recording data. To accomplish these functions, the device needs detailed signal sequences peculiar to the type of device. The control unit decodes the commands received from the channel, interprets them for the particular type of device, and provides the signal sequence required for execution of the operation.

A control unit may be housed separately, or it may be physically and logically integral with the I/O device or the CPU. In most electromechanical devices, a well-defined interface exists between the device and the control unit because of the difference in the type of equipment the control unit and the device contain. These electromechanical devices often are of a type where only one device of a group attached to a control unit is required to operate at a time (magnetic-tape units or disk-access mechanisms, for example), and the control unit is shared among a number of I/O devices. On the other hand, in some electronic I/O devices such as the channel-to-channel adapter, the control unit does not have an identity of its own.

From the programmer's point of view, most functions performed by the control unit can be merged with those performed by the I/O device. Therefore, this publication normally does not make specific mention of

the control unit function; the execution of I/O operations is described as if the I/O devices communicated directly with the channel. Reference is made to the control unit only when emphasizing a function performed by it or when describing how sharing of the control unit among a number of devices affects the execution of I/O operations.

CHANNELS

A channel directs the flow of information between I/O devices and main storage. It relieves the CPU of the task of communicating directly with the devices and permits data processing to proceed concurrently with I/O operations.

A channel provides a means for connecting different types of I/O devices to the CPU and to storage. The channel accepts control information from the CPU in the format supplied by the program and changes it into a sequence of signals acceptable to a control unit and device. Similarly, when an I/O device provides signals that should be brought to the attention of the program, the channel transforms the signals to information that can be used in the CPU.

A channel contains facilities for the control of I/O operations. During execution of an I/O operation involving data transfer, the channel assembles or disassembles data and synchronizes the transfer of data bytes with storage cycles. To accomplish this, the channel maintains and updates an address and a count that describe the destination or source of data in storage. When the channel facilities are provided in the form of separate autonomous equipment designed specifically to control I/O devices, I/O operations are completely overlapped with the activity in the CPU. The only storage cycles required during I/O operations in such channels are those needed to transfer data and control information to or from the final locations in storage. These cycles do not interfere with the CPU program, except when both the CPU and the channel concurrently attempt to refer to the same storage area.

If separate equipment is not provided, facilities of the CPU are used for controlling I/O devices. When the CPU and channels, or the CPU, channels, and control units, share common facilities, I/O operations cause interference to the CPU, varying in intensity from occasional delay of a CPU cycle to a complete lockout of CPU activity. The intensity depends on the extent of sharing and on the I/O data rate. The sharing of the facilities, however, is accomplished automatically, and the program

is not affected by CPU delays, except for an increase in execution time.

Modes of Operation

An I/O operation occurs in one of two modes: burst or byte-multiplex.

In burst mode, the I/O device monopolizes the channel and stays logically connected to the channel for the transfer of a burst of information. No other device can communicate with the channel during the time a burst is transferred. The burst can consist of a few bytes, a whole block of data, a sequence of blocks with associated control and status information (the block lengths may be zero), or status information which monopolizes the channel. The facilities in a channel capable of operating in burst mode may be shared by a number of concurrently operating I/O devices.

Some channels can tolerate an absence of data transfer during a burst-mode operation, such as occurs when reading a long gap on magnetic tape, for not more than approximately 1/2 minute. Equipment malfunction may be indicated when an absence of data transfer exceeds this time.

In byte-multiplex mode, the I/O device stays logically connected to the channel only for a short interval of time. The facilities in a channel capable of operating in byte-multiplex mode may be shared by a number of concurrently operating I/O devices. In this mode, all I/O operations are split into short intervals of time during which only a segment of information is transferred. During such an interval, only one device is logically connected to the channel. The intervals associated with the concurrent operation of multiple I/O devices are sequenced in response to demands from the devices. The channel controls are occupied with any one operation only for the time required to transfer a segment of information. The segment can consist of a single byte of data, a few bytes of data, a status report from the device, or a control sequence used for initiation of a new operation.

Operation in burst and byte-multiplex modes is differentiated because of the way the channels respond to I/O instructions. A channel operating a device in the burst mode appears busy to new I/O instructions, whereas a channel operating one or more devices in the byte-multiplex mode is capable of initiating an operation on another device. If a channel that can operate in either mode is communicating

with an I/O device at the instant a new I/O instruction is issued, action on the instruction is delayed by the channel until the current mode of operation is established. Furthermore, the new I/O operation is initiated only after the channel has serviced all outstanding requests from devices previously placed in operation.

The distinction between a short burst of data occurring in the byte-multiplex mode and an operation in the burst mode is in the length of the bursts of data. A channel that can operate in either mode determines its mode of operation by timeout. Whenever the burst causes the device to be connected to the channel for more than approximately 100 microseconds, the channel is considered to be operating in the burst mode.

Ordinarily, devices with a high data-transfer rate operate with the channel in burst mode, and slower devices run in byte-multiplex mode. Some control units have a manual switch for setting the mode of operation.

Types of Channels

A system can be equipped with three types of channels: selector, byte multiplexer, and block multiplexer.

The channel facilities required for sustaining a single I/O operation are termed a subchannel. The subchannel consists of internal storage used for recording the addresses, count, and any status and control information associated with the I/O operation. The capability of a channel to permit multiplexing depends upon whether it has more than one subchannel.

A selector channel, which contains a minimum of facilities, has one subchannel and always forces the I/O device to transfer data in the burst mode. The burst extends over the whole block of data, or, when command chaining is specified, over the whole sequence of blocks. A selector channel cannot perform any multiplexing and therefore can be involved in only one I/O operation or chain of operations at a time. In the meantime, other I/O devices attached to the channel can be executing previously initiated operations that do not involve communication with the channel, such as backspacing tape. When the selector channel is not executing an operation or a chain of operations and is not processing an interruption, it monitors the attached devices for status information.

A byte-multiplexer channel contains multiple subchannels and can operate at any one time in either byte-multiplex or burst mode. The channel operates most efficiently when running I/O devices that are designed to operate in byte-multiplex mode. The mode of operation is determined by the I/O device, and, during data transfer, the mode can change at any time. Unless data transfer is occurring, the mode of operation has no meaning. The data transfer associated with an operation can occur partially in the byte-multiplex mode and partially in the burst mode.

A block-multiplexer channel contains multiple subchannels and can only operate in burst mode. The channel operates most efficiently when running devices that are designed to operate in burst mode. When multiplexing is not inhibited, the channel permits multiplexing between bursts, between blocks when command chaining is specified, or when command retry is performed. On most models, the burst is forced to extend over the block of data, and multiplexing occurs between blocks of data when command chaining is specified. Whether or not multiplexing occurs depends on the design of the channel and I/O device and on the state of the block-multiplexing-control bit.

When the block-multiplexing-control bit, bit 0 of control register 0, is zero, multiplexing is inhibited; when it is one, multiplexing is allowed.

Whether a block-multiplexer channel executes an I/O operation with multiplexing inhibited or allowed is determined by the state of the block-multiplexing-control bit at the time the operation is initiated by START I/O or START I/O FAST RELEASE and applies to that operation until the involved subchannel becomes available.

For brevity, the term "multiplexer channel" is used hereafter when describing a function or facility that is common to both the byte-multiplexer and the block-multiplexer channel. Multiplexer channels vary in the number of subchannels they contain. When multiplexing, they can sustain concurrently one I/O operation per subchannel, provided that the total load on the channel does not exceed its capacity. Each subchannel appears to the program as an independent selector channel, except in those aspects of communication that pertain to the physical channel (for example, individual subchannels on a multiplexer channel are not distinguished as such by the TEST CHANNEL instruction or by the masks controlling I/O interruptions from the channel). When a multiplexer channel is not servicing an I/O device, it monitors its devices for data and for status information.

Subchannels on a multiplexer channel may be either nonshared or shared.

A subchannel is referred to as nonshared if it is associated with and can be used only by a single I/O device. A nonshared subchannel is used with devices that do not have any restrictions on the concurrency of channel-program operations, such as a single drive of an IBM 3330 Disk Storage.

A subchannel is referred to as shared if data transfer to or from a set of devices implies the use of the same subchannel. Only one device associated with a shared subchannel may be involved in data transmission at a time. Shared subchannels are used with devices, such as magnetic-tape units or some disk-access mechanisms, that share a control unit. For such devices, the sharing of the subchannel does not restrict the concurrency of I/O operations since the control unit permits only one device to be involved in a data-transfer operation at a time. I/O devices may share a control unit without necessarily sharing a subchannel. For example, each transmission line attached to the IBM 2702 Transmission Control is assigned a nonshared subchannel, although all of the transmission lines share the common control unit.

Programming Notes

A block-multiplexer channel can be made to operate as a selector channel by the appropriate setting of the block-multiplexing-control bit. However, since a block-multiplexer channel inherently can interleave the execution of multiple I/O operations and since the state of the block-multiplexing-control bit can be changed at any time, it is possible to have one or more operations that permit multiplexing and an operation that inhibits multiplexing being executed simultaneously by a channel.

Therefore, to ensure complete compatibility with selector channel operation, all operational subchannels on the block-multiplexer channel must be available or operating with multiplexing inhibited when the use of that channel as a selector channel is begun. All subsequent operations should then be initiated with the block-multiplexing-control bit inhibiting multiplexing.

I/O-SYSTEM OPERATION

Input/output operations are initiated and controlled by information with two types of formats: instructions and channel-command words (CCWs). Instructions are decoded by the CPU and are part of the CPU program. CCWs are decoded and executed by the channels and I/O devices and initiate I/O operations, such as reading and writing. One or more CCWs arranged for sequential execution form a channel program. Both instructions and CCWs are fetched from storage. The formats of CCWs are common for all types of I/O devices, although the modifier bits in the command code of a CCW may specify device-dependent operations.

The CPU program initiates I/O operations with the instruction START I/O or START I/O FAST RELEASE. These instructions identify the channel and the I/O device and cause the channel to fetch the channel-address word (CAW) from a fixed location in storage. The CAW contains the subchannel key and designates the location in storage from which the channel subsequently fetches the first CCW. The CCW specifies the command to be executed and the storage area, if any, to be used.

When START I/O is executed and the addressed channel and subchannel are available, the channel attempts to select the I/O device and sends the command-code part of the CCW to the control unit. The device responds indicating whether it can execute the command.

At this time, the execution of START I/O is completed. The results of the attempt to initiate the execution of the command are indicated by setting the condition code in the PSW and, in certain situations, by storing pertinent information in the channel-status word (CSW).

When START I/O FAST RELEASE is executed, the functions performed during the execution of the instruction depend on the design of the channel. Some channels perform the same functions as for START I/O; other channels release the CPU (that is, complete the execution of the instruction) before the I/O operation has been initiated at the addressed device. Channels are permitted to release the CPU as early as when the CAW has been fetched. Channels designed to release the CPU before the I/O operation is initiated at the I/O device perform the functions associated with I/O operation initiation logically subsequent and asynchronous to the execution of START I/O FAST RELEASE. When the CPU is released, the results of the execution of the instruction to that point

are indicated by setting the condition code in the PSW and, in certain situations, by storing pertinent information in the CSW.

If the I/O operation is initiated at the I/O device and its execution involves transfer of data, the subchannel is set up to respond to service requests from the device and assumes further control of the operation. In operations that do not require any data to be transferred to or from the device, the device may signal the end of the operation immediately on receipt of the command code.

An I/O operation may involve transfer of data to one storage area, designated by a single CCW, or to a number of noncontiguous storage areas. In the latter case, generally a list of CCWs is used for execution of the I/O operation, each CCW designating a contiguous storage area, and the CCWs are said to be coupled by data chaining. Data chaining is specified by a flag in the CCW and causes the channel to fetch another CCW upon the exhaustion or filling of the storage area designated by the current CCW. The storage area designated by a CCW fetched on data chaining pertains to the I/O operation already in progress at the I/O device, and the I/O device is not notified when a new CCW is fetched.

Provision is made in the CCW format for the programmer to specify that, when the CCW is decoded, the channel request an I/O interruption as soon as possible, thereby notifying the CPU program that chaining has progressed at least as far as that CCW.

To complement the dynamic-address-translation facility available in the CPU, channel indirect data addressing is available. A flag in the CCW specifies that an indirect-data-address list is to be used to designate the storage areas for that CCW. Each time the boundary of a 2,048-byte block of storage is reached, the list is referenced to determine the next block of storage to be used. By extending the storage-addressing capabilities of the channel, channel indirect data addressing permits essentially the same CCW sequences to be used for a program running with dynamic address translation in the CPU that would be used if it were operating with equivalent contiguous real storage.

The conclusion of an I/O operation normally is indicated by channel end and device end. When channel end is presented, it means that the I/O device has received or provided all data associated with the operation and no longer needs channel facilities. When device end is presented, it usually means that the I/O device has concluded execution of the I/O operation. On some I/O devices, for reasons of

| performance, device end is presented before
| the I/O operation has been concluded.
Device end can occur concurrently with
channel end or later.

Operations that keep the control unit busy
after releasing channel facilities may, in
some situations, cause a third indication
called control-unit end. Control-unit end
may occur only concurrently with or after
| channel end.

Concurrent with channel end, both the
channel and the I/O device can provide
indications of unusual situations.
Control-unit end and device end can be
accompanied by error indications from the
I/O device.

The indication of the conclusion of an I/O
operation can be brought to the attention
| of the program by an I/O interruption or,
when the CPU is disabled for I/O
interruptions from the channel, by
programmed interrogation of the I/O device.
An indication that will result in an I/O
interruption or that can be observed
through interrogation is called an
interruption condition. In either case, a
CSW is stored, which contains additional
information concerning the execution of the
operation. When channel end is indicated
| in the CSW and no equipment malfunctions
| have been detected, the CSW identifies the
last CCW used and provides its residual
byte count, thus indicating the extent of
storage used.

Facilities are provided for the program to
initiate the execution of a chain of I/O
operations with a single START I/O or START
I/O FAST RELEASE. When the chaining flags
in the current CCW specify command chaining
and no unusual conditions have been
detected in the operation, the receipt of
the device-end signal causes the channel to
| fetch a new CCW and to initiate execution
| of a new command at the device. Execution
| of the new command is initiated by the
| channel in the same way as the previous
| operation. Channel end and device end are
| not presented to the program when command
| chaining causes execution of another I/O
| operation to be initiated. However,
unusual situations can cause premature
termination of command chaining and
generation of an I/O-interruption
condition.

| Activities that generate I/O-interruption
conditions are asynchronous to activity in
the CPU, and more than one I/O-interruption
condition can exist at the same time. The
channel and the CPU establish priority
among the conditions so that only one
| condition is presented to the CPU at a
| time.

The execution of an I/O operation or chain

of I/O operations involves up to four
levels of participation:

1. Except for the effects caused by the
integration of CPU and channel
equipment, the CPU is busy for the
duration of execution of START I/O or
START I/O FAST RELEASE, which lasts at
most until the addressed I/O device
responds to the first command.
2. The subchannel is busy with the
execution from the time condition code
0 is set for the START I/O or START
I/O FAST RELEASE until the CPU has
accepted the I/O interruption
signaling that the I/O operation, or
if a chain of I/O operations, the last
operation, has completed at the
subchannel.
3. The control unit may remain busy after
the execution has completed at the
subchannel and may generate
control-unit end when it becomes free.
4. The I/O device is busy from the
initiation of the first operation at
the I/O device until the interruption
condition caused by the device end
associated with the operation is
cleared from the I/O device.

An interruption condition caused by device
end blocks the initiation of an I/O
operation with the I/O device, but normally
does not affect the state of any other part
of the system. An interruption condition
caused by control-unit end may block
communications through the control unit to
any device attached to it, and an
interruption condition caused by channel
end normally blocks all communications
through the subchannel.

COMPATIBILITY OF OPERATION

The organization of the I/O system provides
for a uniform method of controlling I/O
operations. The capability of a channel,
however, depends on its use and on the CPU
model to which it is attached. Channels
are provided with different data-transfer
capabilities, and an I/O device designed to
transfer data only at a specific rate (a
magnetic-tape unit or a disk storage, for
example) can operate only on a channel that
can accommodate at least this data rate.

The data rate a channel can accommodate
depends also on the way the I/O operation
is programmed. The channel can sustain its
highest data rate when no data chaining is
specified. Data chaining reduces the
maximum allowable rate; and the extent of
the reduction depends on the frequency at

which new CCWs are fetched and on the address resolution of the first byte in each new storage area. Furthermore, since a channel shares storage with the CPU and other channels, activity in the rest of the system affects the accessibility of storage and, hence, the instantaneous load the channel can sustain.

In view of the dependence of channel capacity on programming and on activity in the rest of the system, an evaluation of the ability of elements in a specific I/O configuration to function concurrently must be based on a consideration of both the data rate and the way the I/O operations are programmed. Two systems differing in performance but employing identical complements of I/O devices may be able to execute certain programs in common, but it is possible that other programs requiring, for example, data chaining, may not run on one of the systems because of the increased load caused by the data chaining.

CONTROL OF INPUT/OUTPUT DEVICES

The CPU controls I/O operations by means of nine I/O instructions: CLEAR CHANNEL, CLEAR I/O, HALT DEVICE, HALT I/O, START I/O, START I/O FAST RELEASE, STORE CHANNEL ID, TEST CHANNEL, and TEST I/O.

The instructions TEST CHANNEL, CLEAR CHANNEL, and STORE CHANNEL ID address a channel; they do not address an I/O device. The other six I/O instructions address a channel and a device on that channel.

INPUT/OUTPUT DEVICE ADDRESSING

An I/O device and the associated access path are designated by an I/O address. The 16-bit I/O address consists of two parts: a channel address in the leftmost eight bit positions and a device address in the rightmost eight bit positions.

The channel address provides for identifying up to 256 channels. Channels are numbered 0-255. Channel 0 is a byte-multiplexer channel, and each of channels 1-255 may be a byte-multiplexer, block-multiplexer, or selector channel.

The number and type of channels and subchannels available, as well as their address assignment, depend on the system model and the particular installation.

The device address identifies the particular I/O device and control unit on the designated channel. The address

identifies, for example, a particular magnetic-tape drive, disk-access mechanism, or transmission line. Any number in the range 0-255 can be used as a device address, providing facilities for addressing up to 256 devices per channel. An exception is some multiplexer channels that provide fewer than the maximum configuration of subchannels and hence do not permit use of the corresponding unassignable device addresses.

Devices that do not share a control unit with other devices may be assigned any device address in the range 0-255, provided the address is not recognized by any other control unit. Logically, such devices are not distinguishable from their control unit, and both are identified by the same address.

Devices sharing a control unit (for example, magnetic-tape drives or disk-access mechanisms) are assigned addresses within sets of contiguous numbers. The size of such a set is equal to the maximum number of devices that can share the control unit, or 16, whichever is smaller. Furthermore, such a set starts with an address in which the number of low-order zeros is at least equal to the number of bit positions required for specifying the set size. The high-order bit positions of an address within such a set identify the control unit, and the low-order bit positions designate the device on the control unit.

Control units designed to accommodate more than 16 devices may be assigned nonsequential sets of addresses, each set consisting of 16, or the number required to bring the total number of assigned addresses equal to the maximum number of devices attachable to the control unit, whichever is smaller. The addressing facilities are added in increments of a set so that the number of device addresses assigned to a control unit does not exceed the number of devices attached by more than 15.

The control unit does not respond to any address outside its assigned set or sets. For example, if a control unit is designed to control devices having only the values 0000 to 1001 in the low-order bit positions of the device address, it does not recognize addresses containing 1010 to 1111 in these bit positions. On the other hand, a control unit responds to all addresses in the assigned set, regardless of whether the device associated with the address is installed. If no control unit responds to an address, the I/O device appears not operational. If a control unit responds to an address for which no device is installed, the absent device appears in the not-ready state.

Input/output devices accessible through more than one channel have a distinct address for each path of communications. This address identifies the channel and the control unit. For sets of devices connected to two or more control units, the portion of the address identifying the device on the control unit is fixed, and does not depend on the path of communications.

The assignment of channel and device addresses is arbitrary, subject to the rules described and any model-dependent restrictions. The assignment is made at the time of installation, and the addresses normally remain fixed thereafter.

STATES OF THE INPUT/OUTPUT SYSTEM

The state of the I/O system identified by an I/O address depends on the collective state of the channel, subchannel, and I/O device. Each of these components of the I/O system can have up to four states, as far as the response to an I/O instruction is concerned. These states are listed in the figure "Input/Output System States." The name of the state is followed by its abbreviation and a brief definition.

A channel, subchannel, or I/O device that is available, interruption-pending, or working is called "operational." A channel, subchannel, or I/O device that is interruption-pending, working, or not-operational is called "not available."

In a multiplexer channel, the channel and subchannel are easily distinguishable and, if the channel is operational, any combination of channel and subchannel states is possible. Since the selector channel can have only one subchannel, the channel and subchannel are functionally coupled, and certain states of the channel are related to those of the subchannel. In particular, the working state can occur only concurrently in both the channel and subchannel and, whenever an interruption condition is pending in the subchannel, the channel also is in the same state. The channel and subchannel, however, are not synonymous, and an interruption condition not associated with data transfer, such as attention, may not affect the state of the subchannel. Thus, the subchannel may as a function of the I/O instruction, be available when the channel is interruption-pending or has an interruption condition pending at a device. A consistent distinction between the subchannel and channel permits selector and multiplexer channels to be covered uniformly by a single description.

| Name | Abbreviation | Definition |
|----------------------|--------------|---|
| <u>Channel</u> | | |
| Available | A | None of the following states |
| Interruption pending | I | Interruption condition immediately available from channel |
| Working | W | Channel operating in burst mode |
| Not operational | N | Channel not operational |
| <u>Subchannel</u> | | |
| Available | A | None of the following states |
| Interruption pending | I | Information for CSW available in subchannel |
| Working | W | Subchannel executing an operation |
| Not operational | N | Subchannel not operational |
| <u>I/O Device</u> | | |
| Available | A | None of the following states |
| Interruption pending | I | Interruption condition in device |
| Working | W | Device executing an operation |
| Not operational | N | Device not operational |

Input/Output-System States

The I/O device referred to in the figure "Input/Output-System States" includes both the I/O device proper and its control unit. For some types of I/O devices, such as magnetic-tape units, the working and the interruption-pending states can be caused by activity in the addressed I/O device or control unit. A "not available" shared control unit imposes its state on all devices attached to the control unit. The states of the I/O devices are not related to those of the channel and subchannel.

When the response to an I/O instruction is determined by the state of the channel or subchannel, the components further removed are not interrogated. Thus, 10 composite states may be distinguished as conditions for the execution of I/O instructions. Each composite state is identified by three letters. The first letter specifies the state of the channel, the second letter specifies the state of the subchannel, and the third letter specifies the state of the device. Each letter may be A, I, W, or N, denoting the state of the component. The letter X indicates that the state of the corresponding component is not significant for the execution of the instruction.

Available (AAA): The addressed channel, subchannel, control unit, and I/O device are operational, are not engaged in the execution of any previously initiated operations, and do not contain any pending interruption conditions.

Because of internal activity, some block-multiplexer channels may at times appear to be working even though they are not engaged in the execution of a previously initiated operation and do not contain any interruption condition. This will result in a WXX state instead of the AAA state.

Interruption Pending in Device (AAI) or Device Working (AAW): The addressed channel and subchannel are available. The addressed control unit or I/O device is executing a previously initiated operation or contains an interruption condition. These situations are possible:

1. The device is executing an operation, such as rewinding magnetic tape or seeking on a disk file, after signaling channel end.
2. The control unit associated with the device is executing an operation, such as backspacing file on a magnetic-tape unit, after signaling channel end.
3. The device or control unit is executing an operation with another subchannel or channel.
4. The device or control unit contains

the device-end, control-unit-end, or attention condition or a channel-end condition associated with a terminated operation.

Device Not Operational (AAN): The addressed channel and subchannel are available. The addressed I/O device is not operational. A device appears not operational when no control unit recognizes the address. This occurs when the control unit is not provided in the system, when power is off in the control unit, or when the control unit has been logically disconnected from the system. The not-operational state is indicated also when the control unit is provided and is designed to attach the device, but the device has not been installed and the address has not been assigned to the control unit. (See also the section "Input/Output Device Addressing" in this chapter.)

If the addressed device is not installed or has been logically removed from the control unit, but the associated control unit is operational and the address has been assigned to the control unit, the device is said to be not ready. When an instruction is addressed to a device in the not-ready state, the control unit responds to the selection and indicates unit check whenever the not-ready state precludes a successful execution of the operation. (See the section "Unit Check" in this chapter.)

Interruption Pending in Subchannel (AIX): The addressed channel is available. An interruption condition is pending in the addressed subchannel. The subchannel is able to provide information for a CSW. The interruption information indicates status associated with the addressed I/O device or another I/O device associated with the subchannel. The state of the addressed device is not significant, except when the address specified by TEST I/O is the same as the address of the I/O device for which the subchannel is interruption-pending, in which case the CSW contains status information that has been provided by the device.

The state AIX does not occur on the selector channel. On the selector channel, the existence of an interruption condition in the subchannel immediately causes the channel to assign to this condition the highest priority for I/O interruptions and, hence, leads to the state IIX.

Subchannel Working (AWX): The addressed channel is available. The addressed subchannel is executing a previously initiated START I/O (SIO) or START I/O FAST RELEASE (SIOF) function. The addressed subchannel enters the working state when condition code 0 is set for SIO or SIOF.

The addressed subchannel remains in the working state until the SIO or SIOF function is concluded at the subchannel. Usually the conclusion of the SIO or SIOF function occurs when the I/O operation or chain of operations receives channel end for the last operation. The state of the addressed device is not significant, except when HALT I/O or HALT DEVICE is issued. During the execution of HALT I/O and HALT DEVICE, the state of the device may be interrogated and will then be indicated in either the CSW or the condition code.

The subchannel-working state does not occur on the selector channel since all operations on the selector channel are executed in the burst mode and cause the channel to be in the working state (WWX).

Subchannel Not Operational (ANX): The addressed channel is available. The addressed subchannel on the multiplexer channel is not operational. A subchannel is not operational when it is not provided in the system. This state cannot occur on the selector channel.

Interruption Pending in Channel (IXX): The addressed channel is not working and has established which device will cause the next I/O interruption from this channel. The state in which the channel contains an interruption condition is distinguished only by the instruction TEST CHANNEL. This instruction does not cause the subchannel and I/O device to be interrogated. The other I/O instructions, with the exception of STORE CHANNEL ID, consider the channel available when it contains an interruption condition. A channel with an interruption condition may be considered to be working by the instruction STORE CHANNEL ID. When the channel assigns priority for interruptions among devices, the interruption condition is preserved in the I/O device or subchannel. (See the section "Interruption Conditions" in this chapter.)

Channel Working (WXX): The addressed channel is operating in the burst mode. In the multiplexer channel, a burst of bytes is currently being handled. In the selector channel, an operation or a chain of operations is currently being executed, and the channel end for the last operation has not yet been signaled. The states of the addressed device and, in the multiplexer channel, of the subchannel are not significant. In addition, because of internal activity, some block-multiplexer channels may at times appear to be working even though they are not operating in burst mode. Depending on the model and the channel type, TEST I/O and HALT DEVICE may consider the channel to be available when the channel is working with a device other than the addressed device.

Channel Not Operational (NXX): The addressed channel is not operational. A channel is not operational when it is not provided in the system, when power is off in the channel, when it is not configured to the CPU, or when it detects a channel-check-stop condition. As long as a channel-check-stop condition persists, the channel performs no I/O instructions, with the exception of CLEAR CHANNEL (which may be executed, depending on the system model); performs no I/O interruptions; executes no channel programs; and suspends all I/O-interface activity. When a channel is not operational, the states of the addressed I/O device and subchannel are not significant.

RESETTING OF THE INPUT/OUTPUT SYSTEM

Two types of resetting can occur in the I/O system: an I/O system reset and an I/O selective reset. The response of each type of I/O device to the two kinds of reset is specified in the SL publication for the device.

I/O-System Reset

I/O-system reset is performed in the channel and on the associated I/O interface when the CPU to which the channel is configured executes the instruction CLEAR CHANNEL or a program reset, initial-program reset, clear reset, or power-on reset is performed, when a power-on sequence is performed by the channel, and, under certain conditions on some earlier models, when a channel detects equipment malfunctions and the clear-channel facility is not installed.

I/O-system reset causes the channel to conclude operations on all subchannels. Status information and all interruption conditions in all subchannels are reset, and all operational subchannels are placed in the available state. The channel signals system reset to all I/O devices attached to it.

I/O Selective Reset

The I/O selective reset is performed by some channels when they detect certain equipment malfunctions.

I/O selective reset causes the channel to signal selective reset to the device that is connected to the channel at the time the

malfunction is detected. No subchannels are reset.

Effect of Reset on a Working Device

With either type of reset, if the device is currently communicating with a channel, the device immediately disconnects from the channel. Data transfer and any operation using the facilities of the control unit are immediately concluded, and the I/O device is not necessarily positioned at the beginning of a block. Mechanical motion not involving the use of the control unit, such as rewinding magnetic tape or positioning a disk-access mechanism, proceeds to the normal stopping point, if possible. The device appears in the working state until the termination of mechanical motion or the inherent cycle of operation, if any, whereupon it becomes available. Status information in the device and control unit is reset, but an interruption condition may be generated upon completing any mechanical operation.

Reset Upon Malfunction

When a malfunction occurs and the program is alerted by an I/O interruption, or when a malfunction occurs during the execution of an I/O instruction and the program is alerted by the setting of a condition code, then an I/O selective reset may have been performed. A CSW is stored identifying the cause of the malfunction.

The device addressed by the I/O instruction

is not necessarily the device that is reset.

When a malfunction occurs and the program is alerted by a machine-check interruption, then an I/O selective reset or, on some earlier models, I/O system reset may have been performed. This may or may not be accompanied by an I/O interruption.

CONDITION CODE

The results of certain tests by the channel and device, and the original state of the addressed part of the I/O system are used during the execution of an I/O instruction to set one of four condition codes in the PSW. The condition code is set at the time the execution of the instruction is concluded, that is, the time the CPU is released to proceed with the next instruction. The condition code ordinarily indicates whether or not the function specified by the instruction has been performed and, if not, the reason for the rejection. In the case of START I/O FAST RELEASE executed independent of the device, a condition code 0 may be set that is later superseded by a deferred condition code stored in the CSW.

The figure "Condition-Code Settings for I/O States and Instructions" lists the I/O-system states and the corresponding condition codes for each I/O instruction. The I/O-system states and associated abbreviations are defined in the section "States of the Input/Output System" earlier in this chapter. The digits in the figure represent the decimal value of the code.

| Conditions | I/O State | Condition-Code Settings | | | | | | | | |
|------------------------------------|-----------|-------------------------|-----------------|-------|-----------------|-----------------|-----|---------------------------|-------------------------|--|
| | | SIO SIOF | TIO | CLRIO | HIO | HDV | TCH | STIDC | CLRCH | |
| Available | AAA | 0,1* [@] | 0 | 0 | 1* | 1* | 0 | 0 | 0 | |
| Interruption pending in device | AAI | 1* [@] | 1* | 0 | 1* | 1* | 0 | 0 | 0 | |
| Device working | AAW | 1* [@] | 1* | 0 | 1* | 1* | 0 | 0 | 0 | |
| Device not operational | AAN | 3 [@] | 3 | 0 | 3 | 3 | 0 | 0 | 0 | |
| Interruption pending in subchannel | AIX | | | | | | | | | |
| For the addressed device | | □□ | 1* [#] | 1* | 0 | 0 | 0 | 0 | 0 | |
| For another device | | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Subchannel working | AWX | | | | | | | | | |
| With the addressed device | | 2 | 2 | 1* | 1* [#] | 1* [#] | 0 | 0 | 0 | |
| With another device | | 2 | 2 | 0 | 1* [#] | 0 | 0 | 0 | 0 | |
| Subchannel not operational | ANX | 3 | 3 | 3 | 3 | 3 | 0 | 0 | 0 | |
| Interruption pending in channel | IXX | See Note | | | | | 1 | [#] [#] | 0 | |
| Channel working | WXX | | | | | | | | | |
| With the addressed device | | 2 | 2 | *** | 2 | + | 2 | [#] [#] | 0 ^{&} | |
| With another device | | 2 | 2 [•] | ** | 2 | ≠ | 2 | [#] [#] | 0 ^{&} | |
| Channel not operational | NXX | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 ^{&&} | |

Explanation:

- * Whenever condition code 1 is set, the CSW or its status portion is stored at location 64 during execution of the instruction.
- ** When CLEAR I/O encounters the WXX state, either condition code 2 is set, or the channel is treated as available and the condition code is set according to the state of the subchannel. When the channel is treated as available, the condition codes for the WXX states are the same as for the AXX states.
- *** A condition code 1 (with the CSW stored) or 2 may be set, depending on the channel.
- ≠ The condition code depends on the state of the subchannel, the channel type, and the system model. If the subchannel is not operational, a condition code 2 or 3 is set. If the subchannel is available or working with the addressed device, a condition code 2 is set. Otherwise, a condition code 0 or 2 is set.
- # When a "device not operational" response is received in selecting the addressed device, condition code 3 is set.
- [@] START I/O FAST RELEASE may cause the same condition code to be set as for START I/O or may cause condition code 0 to be set.
- +
- The condition code depends on the I/O interface sequence, the channel type, and the system model. If the channel ascertains that the device received the signal to terminate, a condition code 1 is set and the CSW stored. Otherwise, a condition code 2 is set.
- [#][#] When the channel is unable to store the channel ID because of the working or interruption-pending state, a condition code 2 is set. If the working or interruption-pending state does not preclude storing the channel ID, a condition code 0 is set.

Condition-Code Settings for I/O States and Instructions (Part 1 of 2)

Explanation (Continued):

- If the subchannel is interruption-pending for the addressed device, condition code 1 may be set depending on the channel type.
- 8 On certain channels, when the working state precludes performing the I/O system reset, condition code 2 is set.
- 88 On certain channels, when the not-operational state is due to a channel-check-stop condition, the instruction is executed, and condition code 0 is set.
- If the subchannel is interruption-pending because of the concluding of the portion of the operation involving the use of channel facilities, condition code 2 is set. If the interruption-pending condition exists for other reasons, condition code 1 is set.

Note: For the purpose of executing START I/O, START I/O FAST RELEASE, TEST I/O, CLEAR I/O, HALT DEVICE, and HALT I/O, a channel containing an interruption condition appears the same as an available channel, and the condition-code setting depends on the states of the subchannel and device. The condition codes for the IYY states are the same as for the AYY states, where the Ys represent the states of the subchannel and the device. As an example, the condition code for the IAW state is the same as for AAW.

Condition-Code Settings for I/O States and Instructions (Part 2 of 2)

The available state results in condition code 0 only when no errors are detected during the execution of the I/O instruction.

When a subchannel on a multiplexer channel contains an interruption condition (state AIX), the I/O device associated with the concluded operation normally is in the interruption-pending state. When the channel detects during the execution of TEST I/O that the device is not operational, condition code 3 is set. Similarly, condition code 3 is set when HALT I/O or HALT DEVICE is addressed to a subchannel in the working state (state AWX), but the device is not operational.

Error conditions, including all equipment or programming errors detected by the channel or the I/O device during execution of the I/O instruction, generally cause the CSW to be stored. However, when the nature of the error causes a machine-check interruption, but no I/O interruption, to occur, the CSW is not stored. Three types of errors can occur:

Channel-Equipment Error: The channel can detect the following equipment errors during execution of START I/O, START I/O FAST RELEASE, TEST I/O, CLEAR I/O, HALT I/O, and HALT DEVICE:

1. The channel received an address from the device during initial selection that either had a parity error or was not the same as the one the channel sent out. Some device other than the

one addressed may be malfunctioning.

2. The unit-status byte that the channel received during initial selection had a parity error.
3. A signal from the I/O device occurred at an invalid time or had invalid duration.
4. The channel detected an error in its control equipment. (This is also true for STORE CHANNEL ID and TEST CHANNEL.)

The channel may perform an I/O selective reset or, on some earlier models, may perform an I/O system reset or generate a halt signal, depending on the type of error and the model. If a CSW is stored, channel-control check or interface-control check is indicated, depending on the type of error.

Channel-Programming Error: The channel can detect the following programming errors during execution of START I/O or START I/O FAST RELEASE. All of the errors are indicated during START I/O, and during START I/O FAST RELEASE when it is executed as START I/O, by the condition-code setting and by the status portion of the CSW. When the SIOF function is performed, the first two errors are indicated as for START I/O, and the remaining errors may be indicated as for SIO or may be indicated in a subsequent I/O interruption.

Depending on the model, conditions 9, 10,

11 and 12 may (a) cause an error condition to be recognized and prevent operation initiation or (b) may cause an error condition to be recognized only if the operation causes the device to attempt to transfer data. In case (b), a command that specifies an immediate operation does not cause an error indication for an SIO or SIOF function.

1. Invalid CCW-address specification in CAW
2. Invalid CAW format
3. Invalid CCW address in CAW
4. First-CCW location protected against fetching
5. First CCW specifying transfer in channel
6. Invalid command code in first CCW
7. Invalid count in first CCW
8. Invalid format for first CCW
9. If channel indirect data addressing (CIDA) was specified, an invalid data-address specification in the first CCW
10. If CIDA was specified, an invalid data address in the first CCW
11. If CIDA was specified, the first-IDAW location protected against fetching
12. If CIDA was specified, invalid format for the first IDAW

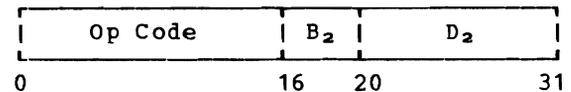
The CSW indicates program check, except for items 4 and 11, for which protection check is indicated.

Device Error: Programming or equipment errors detected by the device as part of the execution of START I/O, or START I/O FAST RELEASE are indicated by unit check or unit exception in the CSW.

The causes of unit check and unit exception for each type of I/O device are detailed in the SL publication for the device.

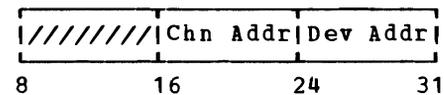
INSTRUCTION FORMATS

All I/O instructions use the following S format:



Except for STORE CHANNEL ID, bit positions 8-14 of these instructions are ignored.

The second-operand address specified by the B₂ and D₂ fields is not used to designate data but instead is used to identify the channel and I/O device. Address computation follows the rules of address arithmetic. The address has the following format:



Bit positions 16-31 contain the 16-bit I/O address. Bit positions 8-15 are ignored.

INSTRUCTIONS

All I/O instructions cause a serialization function to be performed. See the section "Serialization" in Chapter 5, "Program Execution."

The names, mnemonics, format, and operation codes of the I/O instructions are listed in the figure "Input/Output Instructions." The figure also indicates that all I/O instructions cause a program interruption when they are encountered in the problem state, that all I/O instructions set the condition code, and that all I/O instructions are in the S instruction format.

Note: In the detailed descriptions of the individual instructions, the mnemonic and the symbolic operand designation for the assembler language are shown with each instruction. In the case of START I/O, for example, SIO is the mnemonic and D₂(B₂) the operand designation.

| Name | Mnemonic | Characteristics | Op Code |
|------------------------|----------|-----------------|---------|
| CLEAR CHANNEL | CLRCH | S C RE P | 9F01* |
| CLEAR I/O | CLRIO | S C P | 9D01* |
| HALT DEVICE | HDV | S C P | 9E01* |
| HALT I/O | HIO | S C P | 9E00* |
| START I/O | SIO | S C P | 9C00* |
| START I/O FAST RELEASE | SIOF | S C P | 9C01* |
| STORE CHANNEL ID | STIDC | S C P | B203 |
| TEST CHANNEL | TCH | S C P | 9F00* |
| TEST I/O | TIO | S C P | 9D00* |

Explanation:

C Condition code is set.
P Privileged-operation exception.
RE Recovery-extension feature.
S S instruction format.
* Bits 8-14 of the operation code are ignored.
\$ Causes serialization.

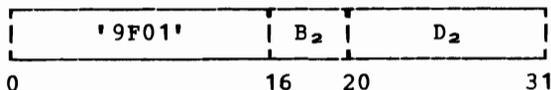
Summary of Input/Output Instructions

Programming Note

The instructions CLEAR I/O, HALT DEVICE, HALT I/O, START I/O, START I/O FAST RELEASE, STORE CHANNEL ID, and TEST I/O may cause a CSW to be stored. To prevent the contents of the CSW stored by the instruction from being destroyed by an immediately following I/O interruption, the CPU must be disabled for all I/O interruptions before CLEAR I/O, HALT DEVICE, HALT I/O, START I/O, START I/O FAST RELEASE, STORE CHANNEL ID, and TEST I/O is issued and must remain disabled until the information in the CSW provided by the instruction has been acted upon or stored elsewhere for later use.

CLEAR CHANNEL

CLRCH D₂ (B₂) [S]



With the clear-channel feature installed, the CLRCH function is performed. Otherwise, the TCH function, which is described in the definition of TEST CHANNEL, is performed.

I/O-system reset is performed in the addressed channel, and system reset is signaled to all I/O devices attached to the addressed channel.

The instruction CLEAR CHANNEL is executed only when the CPU is in the supervisor state.

Bits 8-14 of the instruction are ignored. Bits 16-23 of the second-operand address identify the channel to which the instruction applies. Bits 24-31 of the address are ignored.

The instruction CLEAR CHANNEL inspects only the state of the addressed channel. When the channel is available or interruption-pending, I/O-system reset is performed.

When the channel is working, some channels may indicate busy and cause no I/O-interface action, while other channels cause I/O-system reset to be performed.

When the channel is not operational because of a channel-check-stop condition, some channels cause an I/O-system reset to be performed on the I/O interface. In all other not-operational-state cases, the reset function is inhibited.

Program Exceptions:

Privileged Operation

Resulting Condition Code:

- 0 I/O-system reset was performed on the I/O interface associated with the addressed channel
- 1 --
- 2 Channel busy
- 3 Not operational

The condition code set when CLEAR CHANNEL causes the CLRCH function to be performed

is shown for all possible states of the I/O system in the figure "Condition Codes Set by CLEAR CHANNEL." The condition code set when CLEAR CHANNEL causes the TCH function to be performed is shown for all possible states of the I/O system in the figure "Condition Codes Set by TEST CHANNEL" in the definition of the instruction TEST CHANNEL. See the section "States of the Input/Output System" in this chapter for a detailed definition of the A, I, W, and N states.

| | | | | |
|---------|---|---|----|-----|
| Channel | A | I | W | N |
| | 0 | 0 | 0+ | 3++ |

- A Available
- I Interruption Pending
- W Working
- N Not Operational

- + On certain channels, when the working state precludes performing the I/O system reset on the I/O interface, condition code 2 is set.
- ++ On certain channels, when the not-operational state is due to a channel-check-stop condition, the instruction is executed, and condition code 0 is set.

Condition Codes Set by CLEAR CHANNEL

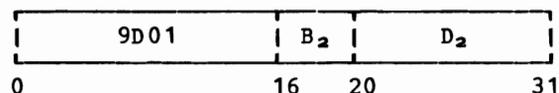
Programming Note

CLEAR CHANNEL should be used to reset an I/O-device association with an I/O interface when I/O devices are shared with other systems or have multiple paths to the same system. In those cases when I/O devices are shared, before using CLEAR CHANNEL, steps should be taken to protect against compromising data integrity until the desired I/O-device association can be reestablished.

| CLEAR CHANNEL may cause a channel that is
 | not-operational because of a channel-check-
 | stop condition to be restored. Before a
 | not-operational channel can be restored or
 | system reset signaled on an I/O interface,
 | on some models CLEAR CHANNEL must be issued
 | to all channels. On other models, CLEAR
 | CHANNEL, when issued to a subset of the
 | channels, can cause a not-operational
 | channel to be restored or system reset to
 | be signaled on an I/O interface. Refer to
 | the SL publication for the model to
 | determine the appropriate recovery action.

CLEAR I/O

CLRIO D₂(B₂) [S]



Either a TIO or CLRIO function is performed, depending on the channel and the block-multiplexing control, bit 0 of control register 0. The TIO function is performed when the CLRIO function is not implemented by the channel or when the block-multiplexing-control bit is zero.

The TIO function is described in the definition of the instruction TEST I/O.

Bits 8-14 of the instruction are ignored. Bit positions 16-31 of the second-operand address identify the channel, subchannel, and I/O device to which the instruction applies.

The CLRIO function causes the current operation with the addressed device to be discontinued and the state of the operation at the time of the discontinuation to be indicated in the stored CSW.

When the subchannel is available, interruption-pending with another device, or working with another device, no channel action is taken, and condition code 0 is set. Channels not capable of determining subchannel states while in the working state may set condition code 2.

When the subchannel is either working with the addressed device or interruption-pending with the addressed device, the CLRIO function causes condition code 1 to be set and causes the channel to discontinue the operation with the addressed device by storing the status of the operation in the CSW and making the subchannel available. When the channel is working with the addressed device, the device is signaled to terminate the current operation. Some channels may, instead, indicate busy and cause no channel action.

When any of the following conditions occurs, the CLRIO function causes the CSW to be stored at real storage locations 64-71. The contents of the entire CSW pertain to the I/O device addressed by the instruction.

1. The channel is available or interruption-pending, and the subchannel (1) contains an interruption condition for the addressed device because of the ending of an I/O operation at the subchannel

or (2) is working with the addressed device. The subchannel-key, command-address, and count fields describe the state of the operation at the time of the execution of the instruction. If the subchannel is interruption-pending for reasons other than the completion of an I/O operation at the subchannel, the fields in the CSW other than the unit-status field are all set to zeros.

2. The channel is working with the addressed device. The subchannel-key, command-address, and count fields describe the state of the operation at the time the instruction is executed. (Some channels alternatively indicate busy under this condition.)

3. The channel is working with a device other than the one addressed, and the subchannel (1) contains an interruption-pending condition for the addressed device because of the ending of an I/O operation at the subchannel or (2) is working with the addressed device. The subchannel-key, command-address, and count fields describe the state of the operation at the time CLEAR I/O is executed. (Some channels alternatively indicate busy under these conditions.) If the subchannel is interruption-pending for reasons other than the completion of an I/O operation at the subchannel, the fields in the CSW other than the unit-status field are all set to zeros.

4. The channel detected an equipment error during the execution of the instruction. The CSW identifies the

error condition. The states of the channel and the I/O operations in progress are unpredictable. The limited channel logout, if stored, indicates a sequence code of 000.

When CLEAR I/O cannot be executed because of a pending logout that affects the operational capability of the channel, a full CSW is stored. The fields in the CSW are all set to zeros, with the exception of the logout-pending and channel-control-check bits, which are set to ones. No channel logout is associated with this status.

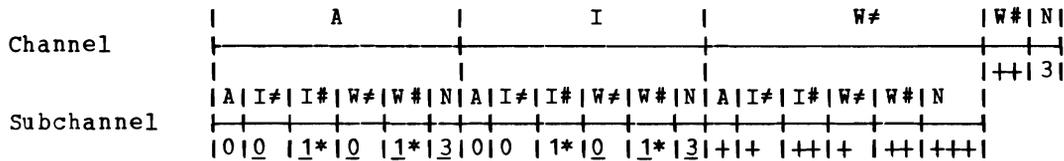
Program Exceptions:

Privileged Operation

Resulting Condition Code:

| | |
|---|---|
| 0 | No operation in progress at the subchannel for the addressed device |
| 1 | CSW stored |
| 2 | Channel busy |
| 3 | Not operational |

The condition code set when CLEAR I/O causes the CLRIO function to be performed is shown for all possible states of the I/O system in the figure "Condition Codes Set by CLEAR I/O." The condition code set when CLEAR I/O causes the TIO function to be performed is shown for all possible state of the I/O system in the figure "Condition Codes Set by TEST I/O" in the definition of the instruction TEST I/O. See the section "States of the Input/Output System" in this chapter for a detailed definition of the A, I, W, and N states.



- A Available
 - I Interruption pending
 - I# = Interruption pending for a device other than the one addressed
 - I# = Interruption pending for the addressed device
 - W Working
 - W# = Working with a device other than the one addressed
 - W# = Working with the addressed device
 - N Not operational
 - * CSW stored
- + In the W#AX, W#I#X, and W#W#X states, a condition code 0 or 2 may be set, depending on the channel.
- ++ In the W#I#X, W#W#X, and W#XX states, a condition code 1 (with the CSW stored) or 2 may be set, depending on the channel.
- +++ In the W#NX state, a condition code 2 or 3 may be set, depending on the channel.

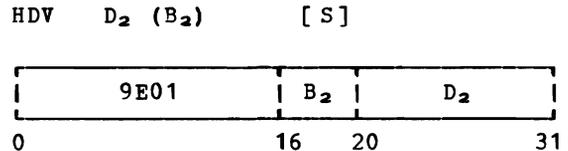
Note: Underscored codes pertain to situations that can occur only on the multiplexer channel.

Condition Codes Set by CLEAR I/O

Programming Notes

1. Since some channels cause a condition code 2 to be set when the instruction is received and the channel is working, it may be useful to issue a halt instruction and then CLEAR I/O to the desired address. Using HALT DEVICE will ensure that condition code 2 is received on the CLEAR I/O only when the channel is working with a device other than the one addressed. Using HALT I/O will ensure that the current working state, if any, is terminated without regard for the address.
2. Because of the inability of CLEAR I/O to terminate operations on some channels when in the working state, the instruction is not a suitable substitute for HALT I/O or HALT DEVICE.
3. The combination of HALT DEVICE followed by CLEAR I/O can be used to clear out all activity on a channel by executing the two instructions for all device addresses on the channel.

HALT DEVICE



The current I/O operation at the addressed I/O device is terminated. The subsequent state of the subchannel depends on the type of channel. Bits 8-14 of the instruction are ignored.

Bits 16-31 of the second-operand address identify the channel, the subchannel, and the I/O device to which the instruction applies.

When the channel is either available or interruption-pending with the subchannel available or working with an I/O operation in progress at the addressed device, HALT DEVICE causes the addressed device to be selected and to be signaled to terminate the current operation, if any. If the subchannel is working with an I/O operation in progress at the addressed device, HALT DEVICE also causes the channel to signal termination of the I/O operation if the device requests or offers a byte of data. If status is presented and command chaining

is indicated for the I/O operation using the subchannel, it is suppressed. If the subchannel is available, the subchannel is not affected.

When the channel is either available or interruption-pending with the subchannel either working with a device other than the one addressed or interruption-pending, no action is taken.

When the channel is working in burst mode with the addressed device, data transfer for the operation is immediately terminated, and the device immediately disconnects from the channel. If chaining is indicated for the I/O operation using the subchannel, it is suppressed.

When the channel is working in burst mode with a device other than the one addressed, and the subchannel is available, interruption-pending, or working with a device other than the one addressed, no action is taken. If the subchannel is working with an I/O operation in progress at the addressed device, the channel signals termination of the device operation the next time the device requests or offers a byte of data, if any. If chaining is indicated for the I/O operation using the subchannel, it is suppressed.

When the channel is working in burst mode with a device other than the one addressed and the subchannel is not operational, is interruption-pending, or is working with a device other than the one addressed, the resulting condition code may, in some channels, be determined by the subchannel state.

Termination of a burst operation by HALT DEVICE on a selector channel causes the channel and subchannel to be placed in the interruption-pending state. Generation of the interruption condition is not contingent on the receipt of status information from the device. When HALT DEVICE causes a burst operation on a byte-multiplexer channel to be terminated, the subchannel associated with the burst operation remains in the working state until the device provides ending status, whereupon the subchannel enters the interruption-pending state. The termination of a burst operation by HALT DEVICE on a block-multiplexer channel may, depending on the model and the type of subchannel, take place as for a selector channel or may allow the subchannel to remain in the working state until the device provides ending status.

When any of the three situations numbered below occurs, HALT DEVICE causes the 16-bit unit-status and channel-status portion of the CSW to be replaced by a new set of status bits. The contents of the other

fields of the CSW are not changed. The CSW stored by HALT DEVICE pertains only to the execution of HALT DEVICE and does not describe the I/O operation, at the addressed subchannel, that is terminated. The extent of data transfer and the status at the termination of the operation at the subchannel are provided in the CSW associated with the interruption condition caused by the termination. The three situations are:

1. The addressed device is selected and signaled to terminate the current operation, if any. The CSW then contains zeros in the status field unless a machine malfunction is detected.
2. The control unit is busy and the device cannot be given the signal to terminate the I/O operation. The CSW unit-status field contains ones in the busy and status-modifier bit positions. The channel-status field contains zeros unless a machine malfunction is detected.
3. The channel detects a machine malfunction during the execution of HALT DEVICE. The status bits in the CSW then identify the type of malfunction. The state of the channel and the progress of the I/O operation are unpredictable.

If HALT DEVICE cannot be executed because of a pending logout which affects the operational capability of the channel or subchannel, a full CSW is stored. The fields in the CSW are all set to zeros, with the exception of the logout-pending bit and the channel-control-check bit, which are set to ones. No channel logout occurs in this case.

When HALT DEVICE causes data transfer to be terminated, the control unit associated with the operation may not become available until the data-handling portion of the operation in the control unit is concluded. Conclusion of this portion of the operation is signaled by the generation of channel end. This may occur at the normal time for the operation, or earlier, or later, depending on the operation and type of device.

When HALT DEVICE causes data transfer to be terminated, the subchannel associated with the operation remains in the working state until the channel-end condition is received and the subchannel enters the interruption-pending state. If the subchannel is shared by other devices attached to the control unit, I/O instructions addressed to those devices set the condition code appropriate to the subchannel states described.

The I/O device executing the terminated operation remains in the working state until the end of the inherent cycle of the operation, at which time device end is generated. If blocks of data at the device are defined, as in read-type operations on magnetic tape, the recording medium is advanced to the beginning of the next block.

When HALT DEVICE is issued at a time when the subchannel is available and no burst operation is in progress, the effect of the HALT DEVICE signal depends partially on the type of device and its state. In all cases, the HALT DEVICE signal has no effect on devices that are not in the working state or are executing a mechanical operation in which data is not transferred, such as rewinding tape or positioning a disk-access mechanism. If the device is executing a type of operation that is unpredictable in duration, or in which data is transferred, the device interprets the

signal as one to terminate the operation. Pending attention or device-end conditions at the device are not reset.

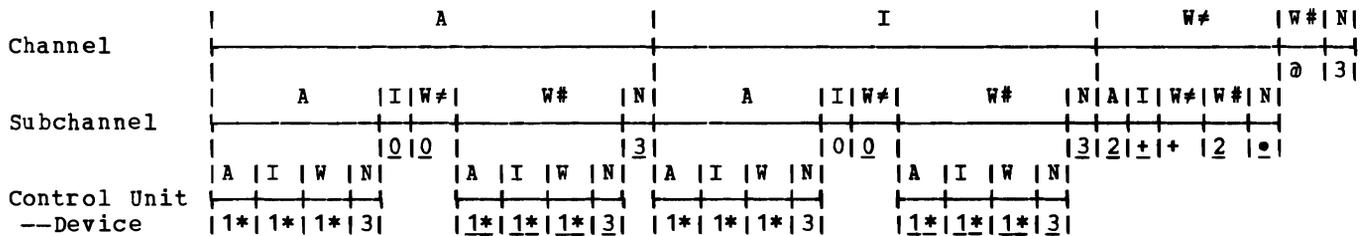
Program Exceptions:

Privileged Operation

Resulting Condition Code:

- 0 Subchannel busy with another device or interruption pending
- 1 CSW stored
- 2 Channel working
- 3 Not operational

The condition code set by HALT DEVICE for all possible states of the I/O system is shown in the figure "Condition Codes Set by HALT DEVICE." See the section "States of the Input/Output System" in this chapter for a detailed definition of the A, I, W, and N states.



- A Available
- I Interruption pending
- W Working
- W# = Working with a device other than the one addressed
- W# = Working with the addressed device
- N Not operational
- * CSW Stored

@ In the W#XX state, either condition code 1 (with CSW stored) or condition code 2 may be set, depending on the channel. However, condition code 1 (with CSW stored) can be set only if the control unit has received the signal to terminate or if control-unit-busy status is received by the channel.

+ In the W#IX and W#W#X states, either condition code 0 or 2 may be set.

• In the W#NX state, either condition code 2 or 3 may be set, depending on the model and the channel type.

Note: Underscored condition codes pertain to situations that can occur only on the multiplexer channel.

Condition Codes Set by HALT DEVICE

Programming Notes

1. Some selector and byte-multiplexer channels designed prior to the defining of HALT DEVICE (for example, the 2860), will execute HALT DEVICE as HALT I/O. A program can ensure complete compatibility between HALT DEVICE and HALT I/O on such channels by observing the following conventions:

- a. On a byte-multiplexer channel, do not issue HALT DEVICE to a multiplexing device when a burst operation is in progress on the channel.
- b. On a byte-multiplexer channel, do not issue HALT DEVICE to a device on a shared subchannel while that subchannel is working with a device other than the one addressed.
- c. On a selector channel in the working state, do not issue HALT DEVICE to any device other than the one with which the channel is working.

2. A block-multiplexer channel may execute HALT DEVICE as a block-multiplexer or selector channel. However, when a block-multiplexer channel is performing as a selector channel, the halt-device function is executed as HALT DEVICE rather than HALT I/O.

3. The execution of HALT DEVICE always causes data transfer between the addressed device and the channel to be terminated. The condition code and the CSW (when stored) indicate whether the control unit was signaled to terminate its operation during the execution of the instruction. If the control unit was not signaled to terminate its operation, the condition code and the CSW (when stored) imply the situations under which the execution of a HALT DEVICE for the same address will cause the control unit to be signaled to terminate.

Condition Code 0 indicates that HALT DEVICE cannot signal the control unit until an interruption condition on the same subchannel is cleared.

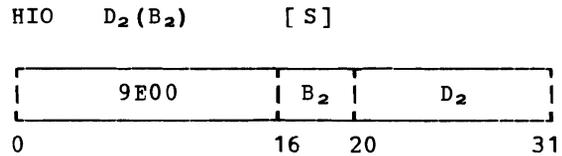
Condition Code 1 with Control-Unit-Busy Status in the CSW indicates that HALT DEVICE cannot signal the control unit until the control-unit-end status is received from that control unit.

Condition Code 1 with Zeros in the Status Field of the CSW indicates that the addressed device was selected and signaled to terminate the current operation, if any.

Condition Code 2 indicates that the control unit cannot be signaled until the channel is not working. The end of the working state can be detected by noting an interruption from the channel or by noting the results of repeatedly executing HALT DEVICE.

Condition Code 3 indicates that manual intervention is required in order to allow HALT DEVICE to signal the control unit to terminate.

HALT I/O



Execution of the current I/O operation at the addressed I/O device, subchannel, or channel is terminated. The subsequent state of the subchannel depends on the type of channel. Bits 8-14 of the instruction are ignored.

Bits 16-31 of the second-operand address identify the channel and, when the channel is not working, identify the subchannel and the I/O device to which the instruction applies.

When the channel is either available or interruption-pending, with the subchannel either available or working, HALT I/O causes the addressed I/O device to be selected and to be signaled to terminate the current operation, if any. If the subchannel is available, its state is not affected. If, on the byte-multiplexer channel, the subchannel is working, data transfer is immediately terminated, but the subchannel remains in the working state until the device provides the next status byte, whereupon the subchannel is placed in the interruption-pending state.

When HALT I/O is issued to a channel operating in the burst mode, data transfer for the burst operation is terminated, and the I/O device performing the burst operation is immediately disconnected from the channel. The subchannel and I/O-device address in the instruction, in this case, is ignored.

The termination of a burst operation by HALT I/O on the selector channel causes the channel and subchannel to be placed in the interruption-pending state. Generation of the interruption condition is not contingent on the receipt of a status byte from the I/O device. When HALT I/O causes a burst operation on the byte-multiplexer channel to be terminated, the subchannel associated with the burst operation remains in the working state until the I/O device signals channel end, whereupon the subchannel enters the interruption-pending state. The termination of a burst operation by HALT I/O on a block-multiplexer channel may, depending on the model and the type of subchannel, take place as for a selector channel or may allow the subchannel to remain in the working state until the device provides ending status.

On the byte-multiplexer channel operating in the byte-multiplex mode, the I/O device is selected and the instruction executed only after the channel has serviced all outstanding requests for data transfer for previously initiated operations, including the operation to be halted. If the control unit does not accept the signal to terminate the operation because it is in the not-operational or control-unit-busy state, the subchannel, if working, is set up to signal termination of device operation the next time the device requests or offers a byte of data. If command chaining is indicated in the subchannel and the device presents status, command chaining is suppressed.

When the addressed subchannel is interruption-pending, with the channel available or interruption-pending, HALT I/O does not cause any action.

When any of the following conditions occurs, HALT I/O causes the status portion, bits 32-47, of the CSW to be replaced by a new set of status bits. The contents of the other fields of the CSW are not changed. The CSW stored by HALT I/O pertains only to the execution of HALT I/O and does not describe the I/O operation that is terminated at the addressed subchannel. The extent of data transfer, and the status at the termination of the operation at the subchannel, are provided in the CSW associated with the interruption condition due to the termination.

1. The addressed device was selected and signaled to terminate the current operation. The CSW contains zeros in the status field unless an equipment error is detected.
2. The channel attempted to select the addressed device, but the control unit could not accept the HALT I/O signal

because it is executing a previously initiated operation or had an interruption condition associated with a device other than the one addressed. The signal to terminate the operation has not been transmitted to the device, and the subchannel, if in the working state, will signal termination the next time the device identifies itself. The CSW unit-status field contains ones in the busy and status-modifier bit positions. The channel-status field contains zeros unless an equipment error is detected.

3. The channel detected an equipment malfunction during the execution of HALT I/O. The status bits in the CSW identify the error condition. The state of the channel and the progress of the I/O operation are unpredictable.

When HALT I/O cannot be executed because of a pending logout which affects the operational capability of the channel or subchannel, a full CSW is stored. The fields in the CSW are all set to zeros, with the exception of the logout-pending bit and the channel-control-check bit, which are set to ones. No channel logout occurs in this case.

When HALT I/O causes data transfer to be terminated, the control unit associated with the operation may not become available until the data-handling portion of the operation in the control unit is terminated. Termination of the data-transfer portion of the operation is signaled by the generation of channel end, which may occur at the normal time for the operation, earlier, or later, depending on the operation and type of device.

When HALT I/O causes data transfer to be terminated, the subchannel associated with the operation remains in the working state until the channel-end condition is received and the subchannel enters the interruption-pending state. If the subchannel is shared by other devices attached to the control unit, I/O instructions addressed to those devices set the condition code appropriate to the subchannel states described.

When HALT I/O causes data transfer to be terminated, the I/O device executing the terminated operation remains in the working state until the end of the inherent cycle of the operation, at which time device end is generated. If blocks of data at the I/O device are defined, such as reading on magnetic tape, the recording medium is advanced to the beginning of the next block.

When HALT I/O is issued at a time when the

subchannel is available and no burst operation is in progress, the effect of the HALT I/O signal depends on the type of I/O device and its state and is specified in the SL publication for the I/O device. The HALT I/O signal has no effect on I/O devices that are not in the working state or are executing a mechanical operation in which data is not transferred, such as rewinding tape or positioning a disk-access mechanism. If the I/O device is executing a type of operation that is variable in duration, the I/O device interprets the signal as one to terminate the operation. Attention or device-end signals at the device are not reset.

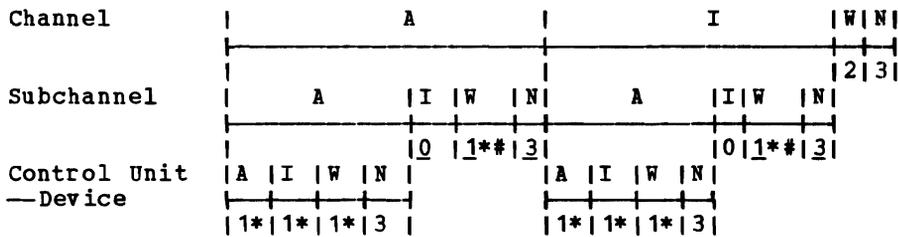
Privileged Operation

Resulting Condition Code:

- 0 Interruption pending in subchannel
- 1 CSW stored
- 2 Burst operation terminated
- 3 Not operational

The condition code set by HALT I/O for all possible states of the I/O system is shown in the figure "Condition Codes Set by HALT I/O." See the section "States of the Input/Output System" in this chapter for a detailed definition of the A, I, W, and N states.

Program Exceptions:



- A Available
- I Interruption pending
- W Working
- N Not operational
- * CSW stored
- # When a device-not-operational response is received in selecting the addressed device, a condition code 3 is set.

Note: Underscored condition codes pertain to situations that can occur only on the multiplexer channel.

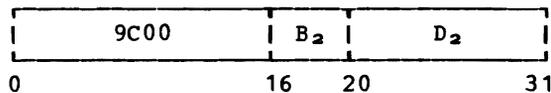
Condition Codes Set by HALT I/O

Programming Note

The instruction HALT I/O provides the program with a means of terminating an I/O operation before all data specified in the operation has been transferred or before the operation at the device has reached its normal ending point. It permits the program to immediately free the selector channel for an operation of higher priority. On the byte-multiplexer channel, HALT I/O provides a means of controlling real-time operations and permits the program to terminate data transmission on a communication line.

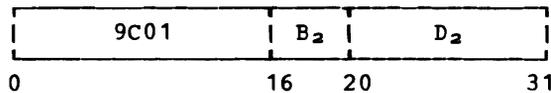
START I/O

SIO $D_2(B_2)$ [S]



START I/O FAST RELEASE

SIOF $D(B_2)$ [S]



A write, read, read backward, control, or sense operation is initiated with the addressed I/O device and subchannel. Bits 8-14 of the instruction are ignored.

Either an SIO or SIOF function is performed, depending on the instruction, the channel, and the block-multiplexing control, bit 0 of control register 0. The instruction START I/O always causes the SIO function to be performed, as does START I/O FAST RELEASE when the block-multiplexing-control bit is zero. When the bit is one, START I/O FAST RELEASE may, depending on the channel, cause either the SIO or the SIOF function to be performed.

Bits 16-31 of the second-operand address identify the channel, subchannel, and I/O device to which the instruction applies. The CAW, at location 72, contains the subchannel key and the address of the first CCW. This CCW specifies the operation to be performed, the storage area to be used, and the action to be taken when the

operation is completed.

For the SIO function, the I/O operation is initiated at the device if the addressed I/O device and subchannel are available, the channel is available or interruption-pending, and errors or exceptional situations have not been detected. The I/O operation is not initiated when the addressed part of the I/O system is in any other state or when the channel or device detects any error or exceptional situations during execution of the instruction.

For the SIOF function, the I/O operation is made pending at the subchannel if the subchannel is available, the channel is available or interruption-pending, and no errors or exceptional conditions are recognized during the execution of SIOF. Selection of the I/O device may be performed during the execution of SIOF or may be performed later. When an SIOF function is performed, initiation of the I/O operation at the I/O device occurs logically subsequent and asynchronous to the execution of SIOF. When the I/O operation is not initiated at the I/O device during the execution of SIOF, the I/O operation is said to be pending at the subchannel until channel and subchannel facilities are available for initiation. When an I/O operation is made pending at the subchannel, the subchannel enters the working state and condition code 0 is set for SIOF.

When the channel attempts to initiate the pending I/O operation at the I/O device, the detection of any error condition by the channel or the I/O device causes the channel to terminate the operation. The detection of any exceptional condition by the channel or the I/O device during the attempt to initiate the I/O operation at the I/O device also causes the channel to terminate the operation.

When the channel is available or interruption-pending, and the subchannel is available before the execution of the instruction, the following situations cause a CSW to be stored. How the CSW is stored depends on whether an SIO or SIOF function is performed. The SIO function causes the status portion of the CSW to be replaced by a new set of status bits. The status bits pertain to the device addressed by the instruction. The contents of the other fields of the CSW are not changed. When the SIOF function is performed, the first situation causes the same action as for the SIO function; also, the control-unit and device state may be tested, and so situation 5 may cause the same action as for the SIO function, or situation 5 may be indicated in a subsequent I/O interruption during which the entire CSW is stored. The remaining situations for the SIOF function

are indicated in a subsequent I/O interruption, during which the entire CSW is stored.

1. The channel detects a programming error in the contents of the CAW or detects an equipment error during execution of the instruction. The CSW identifies the error. If selection of the device occurred prior to detection of the error or if the error condition was detected during the selection of the device, the device status is indicated in the CSW.
2. The channel detects a programming error associated with the first CCW or, if channel indirect data addressing is specified, with the first IDAW; or, for the SIOF function, the channel detects an equipment error after completion of the instruction. The CSW identifies the error. If selection of the device occurred prior to detection of the error, or if the error condition was detected during the selection of the device, the device status is indicated in the CSW.
3. An immediate operation was executed, and either (1) no command chaining is specified and no command retry occurs, or (2) chaining is suppressed because of unusual situations detected during the operation. In the CSW, the channel-end bit is one, the busy bit is zero, and other status may be indicated. The PCI bit is one if PCI was specified in the first CCW. The I/O operation is initiated, but no information has been transferred to or from the storage area designated by the CCW. No interruption conditions are generated at the subchannel, and the subchannel is available for a new I/O operation. If device end is not indicated, the device remains busy, and a subsequent device-end condition is generated.
4. The I/O device is interruption-pending, or the control unit is interruption-pending for the addressed device. The CSW unit-status field contains one in the busy-bit position, identifies the interruption condition, and may contain other bits provided by the device or control unit. The interruption condition is cleared. The I/O operation is not initiated. The channel-status field indicates any errors detected by the channel, and the PCI bit is one if PCI was specified in the first CCW.
5. The I/O device or the control unit is executing a previously initiated operation, or the control unit is interruption-pending for a device

other than the one addressed. The CSW unit-status field contains one in the busy-bit position or, if the control unit is busy, the busy and status-modifier bits are ones. The I/O operation is not initiated. The channel-status field indicates any errors detected by the channel, and the PCI bit is one if specified in the first CCW.

6. The I/O device or control unit detected an equipment or programming error during the initiation, or the addressed device is not ready. The CSW identifies the error. The channel-end and busy bits are zeros, unless the device was busy, in which case the busy bit, as well as any bits causing interruption conditions, are ones. The interruption conditions indicated in the CSW have been cleared at the device. The I/O operation is not initiated. No interruption conditions are generated at the I/O device or subchannel. The PCI bit in the CSW is one if PCI was specified in the first CCW.

When the SIO or SIOF function cannot be executed because of a pending logout which affects the operational capability of the channel or subchannel, a full CSW is stored. The fields in the CSW are all set to zeros, with the exception of the logout-pending bit and the channel-control-check bit, which are set to ones. No channel logout occurs in this case.

When the SIOF function causes condition code 0 to be set and subsequently a situation is encountered which would have caused a condition code 1 to be set had the function been SIO, a deferred-condition-code-1 I/O-interruption condition is generated. When the SIOF function causes condition code 0 to be set and, subsequently, it is determined that the device is not operational, a deferred-condition-code-3 I/O-interruption condition is generated. In both of the above cases, in the resulting I/O interruption, a full CSW is stored, and the deferred condition code appears in the CSW.

On the byte-multiplexer channel, both the SIO and SIOF functions cause the addressed device to be selected and the operation to be initiated only after the channel has serviced all outstanding requests for data transfer for previously initiated operations.

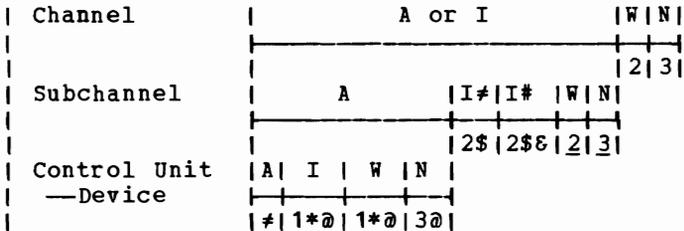
Program Exceptions:

Privileged Operation

Resulting Condition Code:

- 0 I/O operation initiated and channel proceeding with its execution
- 1 CSW stored
- 2 Channel or subchannel busy
- 3 Not operational

The condition code set by START I/O and START I/O FAST RELEASE for all possible states of the I/O system is shown in the figure "Condition Codes Set by START I/O and START I/O FAST RELEASE." See the section "States of the Input/Output System" in this chapter for a detailed definition of the A, I, W, and N states.



- A Available
- I Interruption pending
- I# = Interruption pending for a device other than the one addressed
- I# = Interruption pending for the addressed device
- W Working
- N Not operational
- * CSW stored
- #
 - When a nonimmediate I/O operation has been initiated, and the channel is proceeding with its execution, condition code 0 is set.
 - When an immediate operation has been initiated, and no command chaining or command retry is taking place, or the device is not ready, or an error has been detected by the control unit or device, for the SIO function condition code 1 is set, and the CSW is stored. Under the same circumstances, for the SIOF function, condition code 0 is set, and subsequently an I/O-interruption condition is generated. The CSW stored when the I/O-interruption condition is cleared contains the same information as the CSW stored during the SIO function under the same conditions, plus the deferred-condition-code-1 indication.
- @ The SIOF function may cause condition code 0 to be set, in which case the other condition code shown will be specified as a deferred condition code.
- & When the subchannel is interruption-pending because of the concluding of an I/O operation at the subchannel, condition code 2 is set. When the subchannel is interruption-pending for any other reason, condition code 1 is set and the status portion of the CSW is stored.
- \$ The AIX state only occurs on the multiplexer channel.

Note: Underscored condition codes pertain to situations that can occur only on the multiplexer channel.

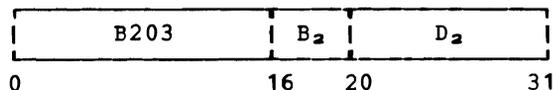
Condition Codes Set by START I/O and START I/O FAST RELEASE

Programming Notes

1. The instruction START I/O FAST RELEASE has the advantage over START I/O that the CPU can be released after the CAW is fetched, rather than after completion of the lengthy device-selection procedure. Thus, the CPU is freed for other activity earlier. A disadvantage, however, is that if a deferred condition code is presented, the resultant CPU execution time may be greater than that required in executing START I/O.
2. When the channel detects a programming error during execution of the SIO function, when the addressed device contains an interruption condition, and when the channel and subchannel are available, the instruction may or may not clear the interruption condition, depending on the type of error and the model. If the instruction has caused the device to be interrogated, as indicated by the presence of the busy bit in the CSW, the interruption condition has been cleared, and the CSW contains program or protection check, as well as the status from the device.
3. Two major differences exist between the SIO and SIOF functions:
 - a. Unchained immediate commands on certain channels (that is, those which execute SIOF independent of the device) result in a condition code 0 for the SICF function, whereas condition code 1 is set for the SIO function. See also Programming Note 2 in the section "Command Retry" of this chapter.
 - b. Condition code 0 is set by these certain channels for the SIOF function, even though the addressed device is not available or the command is rejected by the device. The device information will be supplied by means of an interruption.

STORE CHANNEL ID

STIDC D₂ (B₂) [S]

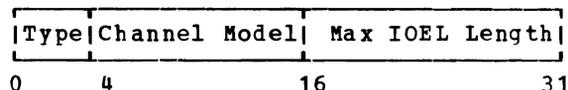


Information identifying the designated

channel is stored in the four-byte field at real storage location 168.

Bits 16-23 of the second-operand address identify the channel to which the instruction applies. Bit positions 24-31 of the address are ignored.

The format of the information stored at location 168 is:



Bits 0-3 specify the channel type. When a channel can operate as more than one type, the code stored identifies the channel type at the time the instruction is executed. The following codes are assigned:

| Bits | Channel Type |
|----------|-------------------|
| 0 1 2* 3 | |
| 0 0 0 0 | Selector |
| 0 0 0 1 | Byte multiplexer |
| 0 0 1 0 | Block multiplexer |

* When STIDC is executed, the setting of bit 2 is unpredictable when bit 3 of the channel type code is stored as zero and bit 0 of control register 0 is (1) currently set to zero or (2) was set to zero when a previous SIO or SIOF was executed and at least one subchannel is currently in the working or interruption pending state because of executing the function of that previous SIO or SIOF.

Bits 4-15 identify the channel model. When the channel model is implied by the channel type and the CPU model, zeros are stored in the field.

Bits 16-31 contain the length in bytes of the longest I/O extended logout that can be stored by the channel during an I/O interruption. If the channel never stores logout information using the IOEL address, then this field is set to zero.

When the channel detects an equipment malfunction during the execution of STORE CHANNEL ID, the channel causes the status portion, bits 32-47, of the CSW to be replaced by a new set of status bits. With the exception of the channel-control-check bit (bit 45), which is stored as a one, all bits in the status field are stored as zeros. The contents of the other fields of the CSW are not changed.

When STORE CHANNEL ID cannot be executed because of a pending logout which affects the operational capability of the channel, a full CSW is stored. The fields in the

CSW are all set to zero, with the exception of the logout-pending bit and the channel-control-check bit, which are set to ones. No channel logout occurs in this case.

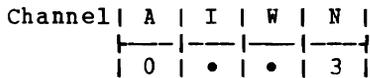
Program Exceptions:

Privileged Operation

Resulting Condition Code:

- 0 Channel ID correctly stored
- 1 CSW stored
- 2 Channel activity prohibited storing ID
- 3 Not operational

The condition code set by STORE CHANNEL ID for all possible states of the I/O system is shown in the figure "Condition Codes Set by STORE CHANNEL ID." See "States of the Input/Output System" for a detailed definition of the A, I, W, and N states.



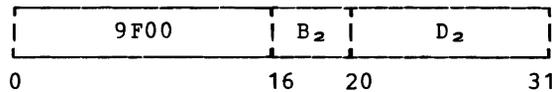
- A Available
- I Interruption pending
- W Working
- N Not operational

- When the channel is unable to store the channel ID because of its working state or because it contains a pending-interruption condition, condition code 2 is set. If the working or interruption-pending state does not preclude the storing of the channel ID, condition code 0 is set.

Condition Codes Set by STORE CHANNEL ID

TEST CHANNEL

TCH D₂(B₂) [S]



The condition code in the PSW is set to indicate the state of the addressed channel. The state of the channel is not affected, and no action is caused. Bits 8-14 of the instruction are ignored.

Bits 16-23 of the second-operand address identify the channel to which the instruction applies. Bit positions 24-31

of the address are ignored.

The instruction TEST CHANNEL inspects only the state of the addressed channel. It tests whether the channel is operating in the burst mode, is interruption-pending, or is not operational. When the channel is operating in the burst mode and contains an interruption condition, the condition code is set as for operation in the burst mode. When none of these situations exist, the available state is indicated. No device is selected, and, on the multiplexer channel, the subchannels are not interrogated.

Program Exceptions:

Privileged Operation

Resulting Condition Code:

- 0 Channel available
- 1 Interruption or logout condition in channel
- 2 Channel operating in burst mode
- 3 Channel not operational

The condition code set by TEST CHANNEL for all possible states of the addressed channel is shown in the figure "Condition Codes Set by TEST CHANNEL." See the section "States of the Input/Output System" in this chapter for a detailed definition of the A, I, W, and N states.

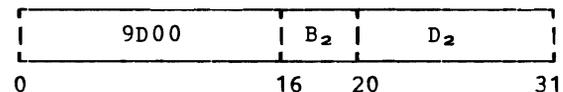


- A Available
- I Interruption pending
- W Working
- N Not operational

Condition Codes Set by TEST CHANNEL

TEST I/O

TIO D₂(B₂) [S]



The state of the addressed channel, subchannel, and device is indicated by setting the condition code in the PSW and, in certain situations, by storing the CSW. Interruption conditions may be cleared. Bits 8-14 of the instruction are ignored.

Bits 16-31 of the second-operand address identify the channel, subchannel, and I/O device to which the instruction applies.

The TIO function is performed by the instruction TEST I/O and, on some channels and under certain circumstances, by CLEAR I/O.

When the channel is operating in burst mode and the addressed subchannel contains an interruption condition for the addressed device, the TIO function causes condition code 1 or 2 to be set, depending on the model and channel type. If condition code 1 is set, the CSW is stored at location 64 to identify the interruption condition, and the interruption condition is cleared. The interruption condition in the subchannel is not cleared, and the CSW is not stored if the channel is working and has not yet accepted the status causing the interruption condition from the device. Condition code 2 is set in this case.

When the channel is either available or interruption-pending and the addressed subchannel is either interruption-pending for a different device or working, the TIO function causes condition code 2 to be set.

When either of the situations described in the following two paragraphs occurs with the channel either available or interruption-pending or, on some channels, working, the TIO function causes the CSW to be stored. The contents of the entire CSW pertain to the I/O device addressed by the instruction.

1. The subchannel is interruption-pending for the addressed device and the interruption condition is due to the termination of an I/O operation at the subchannel. When the CSW is stored, the interruption condition is cleared. The subchannel key, CCW address, and count fields contain the final values for the I/O operation. The unit-status and/or channel-status fields contain indications provided by the device or channel respectively, which identify the interruption condition and any other conditions detected by the channel or device.
2. The subchannel is interruption-pending for the addressed device and the interruption condition is due to the termination of an I/O operation at the device, due to a status indication generated by the control unit or device after the termination of an I/O operation at the subchannel, or due to a status indication which is not associated with any I/O operation. When the CSW is stored, the interruption condition is cleared. The subchannel key, CCW address, and

count fields are stored as zeros. The unit-status field contains indications provided by the device which identify the interruption condition. The channel-status field contains zeros unless a channel equipment error is detected.

When any of the following situations occurs with the channel either available or interruption-pending, the TIO function causes the CSW to be stored. The contents of the entire CSW pertain to the I/O device addressed by the instruction.

1. The subchannel is available, and the I/O device contains an interruption condition or the control unit contains control-unit end for the addressed device. The CSW unit-status field identifies the interruption condition and may contain other bits provided by the device or control unit. The interruption condition is cleared. The busy bit in the CSW is zero. The other fields of the CSW contain zeros unless an equipment error is detected.
2. The subchannel is available, and the I/O device or the control unit is executing a previously initiated operation or the control unit has an interruption condition associated with a device other than the one addressed. The CSW unit-status field contains one in the busy-bit position or, if the control unit is busy, the busy and status-modifier bits are ones. Other fields of the CSW contain zeros unless an equipment error is detected.
3. The subchannel is available, and the I/O device or channel detected an equipment error during execution of the instruction or the addressed device is not ready and does not have any interruption condition. The CSW identifies the error. If the device is not ready, unit check is indicated. No interruption conditions are generated at the I/O device or the subchannel.

When TEST I/O cannot be executed because of a pending logout which affects the operational capability of the channel or subchannel, a full CSW is stored. The fields in the CSW are all set to zeros, with the exception of the logout-pending bit and the channel-control-check bit, which are set to ones. No channel logout is associated with this status.

When the TIO function is used to clear an interruption condition signaling conclusion of an I/O operation at the subchannel and the channel has not yet accepted the condition from the device, the function causes the device to be selected and the

interruption condition in the device to be cleared. During certain I/O operations, some types of devices cannot provide their current status in response to TEST I/O. Some magnetic-tape control units, for example, are in such a state when they have provided channel end and are executing the backspace-file operation. When TEST I/O is issued to a control unit in such a state, the unit-status field of the CSW has the busy and status-modifier bits set to ones, with zeros in the other CSW fields. The interruption condition in the device and in the subchannel is not cleared.

On some types of devices, the device never provides its current status in response to TEST I/O, and an interruption condition can be cleared only by permitting an I/O interruption. When TEST I/O is issued to such a device, the unit-status field has the status-modifier bit set to one, with zeros in the other CSW fields. The interruption condition in the device and in the subchannel, if any, is not cleared.

However, by the time the channel assigns the highest priority for interruptions to a condition associated with an operation at the subchannel, the channel has accepted the status from the device and cleared the corresponding condition at the device. Some channels accept and clear an interruption condition signaling the conclusion of an I/O operation at the subchannel from the device before it is assigned the highest priority for interruptions. Other channels may accept and clear any type of interruption condition from the device prior to assigning it the highest priority for interruptions. The acceptance of an interruption condition from a device causes the associated subchannel to enter the interruption-pending state. When the channel recognizes an interruption condition signaling the conclusion of an I/O operation at the subchannel, the associated subchannel enters the interruption-pending state even when the interruption condition has not yet been accepted from the device.

When the TIO function is addressed to a device for which the channel has already accepted the interruption condition, the device is not selected, and the condition in the subchannel is cleared regardless of the type of device and its present state. The CSW contains unit status and other information associated with the interruption condition.

On the byte-multiplexer channel, the TIO function causes the addressed device to be selected only after the channel has serviced all outstanding requests for data transfer for previously initiated operations.

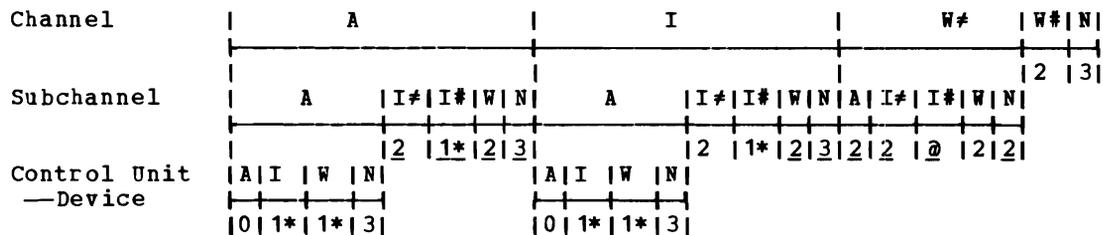
Program Exceptions:

Privileged Operation

Resulting Condition Code:

- 0 Available
- 1 CSW stored
- 2 Channel or subchannel busy
- 3 Not operational

The condition code set by the TIO function for all possible states of the I/O system is shown in the figure "Condition Codes Set by TEST I/O." See the section "States of the Input/Output System" in this chapter for a detailed definition of the A, I, W, and N states.



- A Available
- I Interruption pending
- I# = Interruption pending for a device other than the one addressed
- I# = Interruption pending for the addressed device
- W Working
- W# = Working with a device other than the one addressed
- W# = Working with the addressed device
- N Not operational
- * CSW stored
- @ In the W#I#X state, either condition code 1 may be set with the CSW stored, or condition code 2 may be set, depending on the channel and the activity in the channel.

Note: Underscored condition codes pertain to situations that can occur only on the multiplexer channel.

Condition Codes Set by TEST I/O

Programming Notes

1. Disabling the CPU for I/O interruptions provides the program with a means of controlling the priority of I/O interruptions selectively by channels. The priority of devices attached on a channel cannot be controlled by the program. The instruction TEST I/O in some cases permits the program to clear interruption conditions selectively by I/O device.
2. When a CSW is stored by the TIO function, the interface-control-check and channel-control-check indications may be due to an interruption condition already existing in the channel or may be due to an interruption condition created by the TIO function. Similarly, the unit-check bit set to one with the channel-end, control-unit-end, or device-end bits set to zeros may be due to a situation created by the preceding operation, the I/O device being not ready, or an equipment error detected during the execution of TEST I/O. The instruction TEST I/O cannot be used to clear an interruption condition due to the PCI flag while the subchannel is working.
3. The use of a TEST I/O loop on a multiplexer channel to retrieve ending status for a channel program should, in general, be avoided. TEST I/O

loops may be used to return ending status to a sense command when that command was initiated by a START I/O that received condition code 0. TEST I/O loops under other conditions may result in hang conditions.

INPUT/OUTPUT-INSTRUCTION-EXCEPTION HANDLING

Before the channel is signaled to execute an I/O instruction, the instruction is tested for validity by the CPU. Exceptional situations detected at this time cause a program interruption.

The following exception may cause a program interruption:

Privileged Operation: An I/O instruction is encountered when the CPU is in the problem state. The instruction is suppressed before the channel has been signaled to execute it. The CSW, the condition code in the PSW, and the state of the addressed subchannel and I/O device are not affected by the attempt to execute an I/O instruction while in the problem state.

EXECUTION OF INPUT/OUTPUT OPERATIONS

The channel can execute six commands: write, read, read backward, control, sense, and transfer in channel. Each command

except transfer in channel initiates a corresponding I/O operation. The term "I/O operation" refers to the activity initiated by a command in the I/O device and associated subchannel. The subchannel is involved with the execution of the operation from the initiation of the command until the channel-end signal is received or, in the case of command chaining, until the device-end signal is received. The operation in the device lasts until device end is signaled.

BLOCKING OF DATA

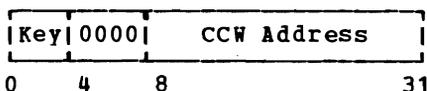
Data recorded by an I/O device may be divided into blocks. The length of a block depends on the device; for example, a block can be a card, a line of printing, or the information recorded between two consecutive gaps on magnetic tape.

The maximum amount of information that can be transferred in one I/O operation is one block. An I/O operation is terminated when the associated storage area is exhausted or the end of the block is reached, whichever occurs first. For some operations, such as writing on a magnetic-tape unit or at an inquiry station, blocks are not defined, and the amount of information transferred is controlled only by the program.

CHANNEL-ADDRESS WORD

The channel-address word (CAW) specifies the subchannel key and the address of the first CCW associated with START I/O or START I/O FAST RELEASE. The channel refers to the CAW only during the execution of START I/O or START I/O FAST RELEASE. The CAW is fetched from real storage location 72 of the CPU issuing the instruction. The pertinent information thereafter is stored in the subchannel, and the program is free to change the contents of the CAW. Fetching of the CAW by the channel does not affect the contents of the location.

The CAW has the following format:



The fields in the CAW are allocated for the following purposes:

Subchannel Key: Bits 0-3 form the access key for all fetching of CCWs, IDAWs, and output data and for the storing of input data associated with START I/O and START

I/O FAST RELEASE. This key is matched with a storage key during these storage references. For details, see the section "Key-Controlled Protection" in Chapter 3, "Storage."

CCW Address: Bits 8-31 designate the location of the first CCW in absolute storage.

Bit positions 4-7 of the CAW must contain zeros. The three low-order bits of the CCW address must be zeros to specify the CCW on integral boundaries for doublewords. If any of these restrictions is violated, or if the CCW address specifies a storage location which is not provided or is protected against fetching, START I/O and, in some cases, START I/O FAST RELEASE, cause the status portion of the CSW to be stored, with the protection-check or program-check bit set to one. In this event, the I/O operation is not initiated.

Programming Note

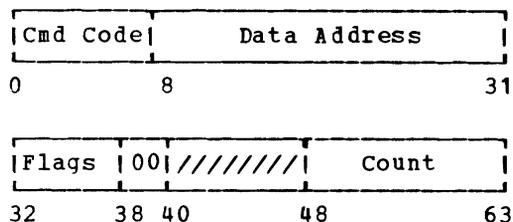
Bit positions 4-7 of the CAW, which presently must contain zeros, may in the future be assigned to the control of new functions. It is, therefore, recommended that these bit positions not be set to ones for the purpose of obtaining an intentional program-check indication.

CHANNEL-COMMAND WORD

The channel-command word (CCW) specifies the command to be executed and, for commands initiating I/O operations, it designates the storage area associated with the operation and the action to be taken whenever transfer to or from the area is completed. The CCWs can be located anywhere in storage, and more than one can be associated with a START I/O or START I/O FAST RELEASE.

The first CCW is fetched during the execution of START I/O or START I/O FAST RELEASE being executed as START I/O. When START I/O FAST RELEASE is executed independent of the device, the first CCW may be fetched subsequent to the execution of START I/O FAST RELEASE. Each additional CCW in the sequence is obtained when the operation has progressed to the point where the additional CCW is needed. Fetching of the CCWs by the channel does not affect the contents of the location in storage.

The CCW has the following format:



The fields in the CCW are allocated for the following purposes:

Command Code: Bits 0-7 specify the operation to be performed.

Data Address: Bits 8-31 specify a location in absolute storage. It is the first location referred to in the area designated by the CCW.

Chain-Data (CD) Flag: Bit 32, when one, specifies chaining of data. It causes the storage area designated by the next CCW to be used with the current operation.

Chain-Command (CC) Flag: Bit 33, when one, and when the CD flag is zero, specifies chaining of commands. It causes the operation specified by the command code in the next CCW to be initiated on normal completion of the current operation.

Suppress-Length-Indication (SLI) Flag: Bit 34 controls whether incorrect-length is to be indicated to the program. When this bit is one and the CD flag is zero, the incorrect-length indication is suppressed. When both the CC and SLI flags are one, command chaining takes place regardless of any incorrect-length situation.

Skip (SKIP) Flag: Bit 35, when one, specifies suppression of the transfer of information to storage during a read, read backward, or sense operation.

Program-Controlled-Interruption (PCI) Flag: Bit 36, when one, causes the channel to generate an interruption condition when the CCW takes control of the channel. When bit 36 is zero, normal operation takes place.

Indirect-Data-Address (IDA) Flag: Bit 37, when one, specifies indirect data addressing.

Count: Bits 48-63 specify the number of bytes in the storage area designated by the CCW.

Bit positions 38-39 of every CCW other than one specifying transfer in channel must contain zeros. Otherwise, a program-check condition is generated. When the first CCW designated by the CAW does not contain zeros in bit positions 38-39, the I/O

operation is not initiated, and the status portion of the CSW with the program-check indication is stored during execution of START I/O or START I/O FAST RELEASE being executed as START I/O. Detection of this condition during data chaining causes the I/O device to be signaled to conclude the operation. When the absence of these zeros is detected during command chaining or subsequent to the execution of START I/O FAST RELEASE, the new operation is not initiated, and an interruption condition is generated.

The contents of bit positions 40-47 of the CCW are ignored.

Programming Note

Bit positions 38-39 of the CCW, which presently must contain zeros, may in the future be assigned to the control of new functions. It is recommended, therefore, that these bit positions not be set to ones for the purpose of obtaining an intentional program-check indication.

COMMAND CODE

The command code, bit positions 0-7 of the CCW, specifies to the channel and the I/O device the operation to be performed. A detailed description of each command appears under "Commands."

The two low-order bits or, when these bits are 00, the four low-order bits of the command code identify the operation to the channel. The channel distinguishes among the following four operations:

- Output forward (write, control)
- Input forward (read, sense)
- Input backward (read backward)
- Branching (transfer in channel)

The channel ignores the high-order bits of the command code.

Commands that initiate I/O operations (write, read, read backward, control, sense, and sense ID) cause all eight bits of the command code to be transferred to the I/O device. In these command codes, the leftmost bit positions contain modifier bits. The modifier bits specify to the device how the command is to be executed. They may, for example, cause the device to compare data received during a write operation with data previously recorded, and they may specify such information as recording density and parity. For the control command, the modifier bits may

contain the order code specifying the control function to be performed. The meaning of the modifier bits depends on the type of I/O device and is specified in the SL publication for the device.

The command-code assignment is listed in the following table. The symbol X indicates that the bit position is ignored; M identifies a modifier bit.

| Code | Command |
|-----------|---------------------|
| XXXX 0000 | Invalid |
| MMMM MM01 | Write |
| MMMM MM10 | Read |
| MMMM 1100 | Read Backward |
| MMMM MM11 | Control |
| MMMM 0100 | Sense |
| 1110 0100 | Sense ID |
| XXXX 1000 | Transfer in Channel |

Whenever the channel detects an invalid command code during the initiation of a command, a program check is generated. When the first CCW designated by the CAW contains an invalid command code, the status portion of the CSW with the program-check indication is stored during execution of START I/O or START I/O FAST RELEASE being executed as START I/O. When the invalid code is detected during command chaining or subsequent to the execution of START I/O FAST RELEASE, the new operation is not initiated, and an interruption condition is generated. The command code is ignored during data chaining, unless it specifies transfer in channel.

DESIGNATION OF STORAGE AREA

The storage area associated with an I/O operation is defined by one or more CCWs. A CCW defines an area by specifying the address of the first byte to be transferred and the number of consecutive bytes contained in the area. The address of the first byte appears in the data-address field of the CCW, except when channel indirect data addressing is specified. Channel indirect data addressing is described in the section "Channel Indirect Data Addressing." The number of bytes contained in the storage area is specified in the count field.

In write, read, control, and sense operations, storage locations are used in ascending order of addresses. As information is transferred to or from storage, the address from the address field is incremented, and the count from the count field is decremented. The read-backward operation places data in

storage in a descending order of addresses, and both the count and the address are decremented. When the count reaches zero, the storage area defined by the CCW is exhausted.

Any storage location that is provided can be used in the transfer of data to or from an I/O device if the location is not protected against the type of reference. Similarly, a CCW can be located in any part of storage if the location is not protected against a fetch-type reference.

When the first CCW is designated by the CAW as being at a storage location that is not provided, the I/O operation is not initiated, and the status portion of the CSW with the program-check indication is stored during the execution of START I/O or START I/O FAST RELEASE being executed as START I/O. When, subsequently, during the operation or chain of operations, the channel refers to a storage location that is not provided, an interruption condition indicating program check is generated, and the device is signaled to terminate the operation.

When the first CCW designated by the CAW is in a location that is protected against a fetch-type reference, the I/O operation is not initiated, and the status portion of the CSW with the protection-check indication is stored during the execution of START I/O or START I/O FAST RELEASE being executed as START I/O. When, subsequently, during the I/O operation or chain of operations, the channel refers to a protected location, an interruption condition indicating protection check is generated, and the device is signaled to terminate the operation.

During an output operation, the channel may fetch data from storage before the time the I/O device requests the data. Any number of bytes specified by the current CCW may thus be prefetched. When data chaining during an output operation, the channel may prefetch the next CCW at any time during the execution of the current CCW.

Prefetching may cause the channel to refer to storage locations that are protected or not provided. Such errors detected during prefetching of data or CCWs do not affect the execution of the operation and do not cause error indications until the I/O operation actually attempts to use the data or until the CCW takes control. If the operation is concluded by the I/O device or by HALT I/O, HALT DEVICE, or CLEAR I/O before the invalid information is needed, no program check or protection check is generated.

The count field in the CCW can specify any number of bytes from one to 65,535. Except

for a CCW specifying transfer in channel, which has no count field, the count field may not contain the value zero. Whenever the count field in the CCW initially contains a zero, a program check is generated. When this occurs in the first CCW designated by the CAW, the operation is not initiated, and the status portion of the CSW with the program-check indication is stored during execution of START I/O or START I/O FAST RELEASE being executed as START I/O. When a count of zero is detected during data chaining, the I/O device is signaled to terminate the operation. Detection of a count of zero during command chaining or subsequent to the execution of START I/O FAST RELEASE suppresses initiation of the new operation and generates an interruption condition.

CHAINING

When the channel has performed the transfer of information specified by a CCW, it can continue the activity initiated by START I/O or START I/O FAST RELEASE by fetching a new CCW. Such fetching of a new CCW is called chaining, and the CCWs belonging to such a sequence are said to be chained.

Chaining takes place between CCWs located in successive doubleword locations in storage. It proceeds in an ascending order of addresses; that is, the address of the new CCW is obtained by adding 8 to the address of the current CCW. Two chains of CCWs located in noncontiguous storage areas can be coupled for chaining purposes by a transfer-in-channel command. All CCWs in a chain apply to the I/O device specified in the original START I/O or START I/O FAST RELEASE.

Two types of chaining are provided: chaining of data and chaining of commands. Chaining is controlled by the chain-data (CD) and chain-command (CC) flags in conjunction with the suppress-length-indication (SLI) flag in the CCW. These flags specify the action to be taken by the channel upon the exhaustion of the current CCW and upon receipt of ending status from the device, as shown in the figure "Channel-Chaining Action."

The specification of chaining is effectively propagated through a transfer-in-channel command. When in the process of chaining a transfer-in-channel command is fetched, the CCW designated by the transfer in channel is used for the type of chaining specified in the CCW preceding the transfer in channel. The CD and CC flags are ignored in the transfer-in-channel command.

Note: For a description of the storage area associated with a CCW when channel indirect data addressing is invoked, see the section "Channel Indirect Data Addressing" later in this chapter.

| Flags in Current CCW | | | | Action in Channel upon Exhaustion of Count or Receipt of Channel End | | |
|----------------------|----|-----|---------------------|--|---------------|---------------|
| | | | | Regular Operation | | |
| CD | CC | SLI | Immediate Operation | I | II | III |
| 0 | 0 | 0 | End, NIL | Stop, IL | End, NIL | End, IL |
| 0 | 0 | 1 | End, NIL | Stop, NIL | End, NIL | End, NIL |
| 0 | 1 | 0 | Chain Command | Stop, IL | Chain command | End, IL |
| 0 | 1 | 1 | Chain Command | Chain command | Chain command | Chain command |
| 1 | 0 | 0 | End, NIL | Chain Data | * | End, IL |
| 1 | 0 | 1 | End, NIL | Chain Data | * | End, IL |
| 1 | 1 | 0 | End, NIL | Chain Data | * | End, IL |
| 1 | 1 | 1 | End, NIL | Chain Data | * | End, IL |

Explanation:

- I Count exhausted, end of block at device not reached.
- II Count exhausted and channel end from device.
- III Count not exhausted and channel end from device.
- End The operation is terminated. If the operation is immediate and has been specified by the first CCW associated with a START I/O, a condition code 1 is set, and the status portion of the CSW is stored as part of the execution of the START I/O. In all other cases, an interruption condition is generated in the subchannel.
- Stop The device is signaled to terminate data transfer, but the subchannel remains in the working state until channel end is received; at this time an interruption condition is generated in the subchannel.
- IL Incorrect length is indicated with the interruption condition.
- NIL Incorrect length is not indicated.
- Chain command The channel performs command chaining upon receipt of device end.
- Chain data The channel immediately fetches a new CCW for the same operation.
- * The situation where the residual count is zero but data chaining is indicated at the time the device provides channel end cannot validly occur. When data chaining is indicated, the channel fetches the new CCW after transferring the last byte of data designated by the current CCW but before the device provides the next request for data or status transfer. As a result, the channel recognizes the channel end from the device only after it has fetched the new CCW, which cannot contain a count of zero unless a programming error has been made.

Channel-Chaining Action

Data Chaining

During data chaining, the new CCW fetched by the channel defines a new storage area for the original I/O operation. Execution of the operation at the I/O device is not affected. When all data designated by the current CCW has been transferred to storage or to the device, data chaining causes the operation to continue, using the storage area designated by the new CCW. The contents of the command-code field of the new CCW are ignored, unless they specify transfer in channel.

Data chaining is considered to occur immediately after the last byte of data designated by the current CCW has been transferred to storage or to the device. When the last byte of the transfer has been placed in storage or accepted by the device, the new CCW takes over the control of the operation and replaces the pertinent information in the subchannel. If the device signals channel end after exhausting the count of the current CCW but before transferring any data to or from the storage area designated by the new CCW, the CSW associated with the concluded operation pertains to the new CCW.

If programming errors are detected in the new CCW or during its fetching, the error indication is generated, and the device is signaled to conclude the operation when it attempts to transfer data designated by the new CCW. If the device signals channel end after the new CCW takes control but before transferring any data designated by the new CCW, program check or protection check is indicated in the CSW associated with the termination. The contents of the CSW pertain to the new CCW unless a program check or protection check is generated while fetching the new CCW or while fetching or executing an intervening transfer-in-channel command. A data address which causes a program check or protection check gives an error indication only after the I/O device has attempted to transfer data to or from the addressed storage location.

Data chaining during an input operation causes the new CCW to be fetched when all data designated by the current CCW has been placed in storage. On an output operation, the channel may fetch the new CCW from storage ahead of the time data chaining occurs. Any programming errors in a prefetched CCW, however, do not affect the execution of the operation until all data designated by the current CCW has been transferred to the I/O device. If the device concludes the operation before all data designated by the current CCW has been transferred or if data chaining is suppressed for any other reason, the errors

associated with the prefetched CCW are not indicated to the program.

Only one CCW describing a data area may be prefetched. If the prefetched CCW specifies transfer in channel, only one more CCW may be fetched before the exhaustion of the current CCW.

Programming Notes

1. Data chaining may be used to rearrange data as it is transferred between storage and an I/O device. Data chaining permits data to be transferred to or from noncontiguous areas of storage, and, when used in conjunction with the skipping function (see the section "Skipping" later in this chapter), data chaining enables the program to place in storage selected portions of a block of data.

When, during an input operation, the program specifies data chaining to a location into which data has been placed under the control of the current CCW, the channel, in fetching the next CCW, fetches the new contents of the location. This is true even if the location contains the last byte transferred under the control of the current CCW. When, on input, a channel program data-chains to a CCW placed in storage by the CCW specifying data chaining, the block is said to be self-describing. A self-describing block contains one or more CCWs that specify storage locations and counts for subsequent data in the same block.

The use of self-describing blocks is equivalent to the use of unchecked data. An I/O data-transfer malfunction that affects validity of a block is signaled only at the completion of data transfer. The error normally does not prematurely terminate or otherwise affect the execution of the operation. Thus, there is no assurance that a CCW read as data is valid until the operation is completed. If the CCW is in error, the use of the CCW in the current operation may cause subsequent data to be placed in wrong storage locations with resultant destruction of the contents of those locations.

2. When, during data chaining, an I/O device transfers data by using the data-streaming feature, an overrun or chaining-check condition may be recognized when a small byte-count value is specified in the CCW. The

minimum acceptable number of bytes that can be specified varies as a function of the system model and system activity. Refer to the appropriate channel SL publication of the using system to determine the most reasonable minimum byte count that can be handled by the channel.

Command Chaining

During command chaining, the new CCW fetched by the channel specifies a new I/O operation. The channel fetches the new CCW and initiates the new operation upon receipt of the device-end signal for the current operation. When command chaining takes place, the completion of the current operation does not generate an interruption condition, and the count indicating the amount of data transferred during the current operation is not made available to the program. For operations involving data transfer, the new command always applies to the next block at the device.

Command chaining takes place and the new operation is initiated only if no unusual situations have been detected in the current operation. In particular, the channel initiates a new I/O operation by command chaining upon receipt of a status byte signaling one of the following status combinations: device end, device end and status modifier, device end and channel end, device end and channel end and status modifier. In the former two cases, channel end must have been signaled before device end, with all other status bits set to zeros. If status such as attention, unit check, unit exception, incorrect length, program check, or protection check has occurred, the sequence of operations is concluded, and the status associated with the current operation causes an interruption condition to be generated. The new CCW in this case is not fetched. Incorrect length does not suppress command chaining if the current CCW has the SLI flag set to one.

An exception to sequential chaining of CCWs occurs when the I/O device presents status modifier with device end. When no unusual conditions have been detected and command chaining is specified or when command retry has been previously signaled and an immediate retry could not be performed, the combination of status modifier and device end causes the channel to alter the sequential execution of CCWs. If command chaining was specified, status modifier and device end cause the channel to chain to the CCW whose storage address is 16 higher

than that of the CCW that specified chaining. If command retry was previously signaled and immediate retry could not be performed, the status causes the channel to command-chain to the CCW whose storage address is 8 higher than that of the CCW for which retry was initially signaled.

When both command and data chaining are used, the first CCW associated with the operation specifies the operation to be executed, and the last CCW indicates whether another operation follows.

Programming Note

Command chaining makes it possible for the program to initiate transfer of multiple blocks by means of a single START I/O or START I/O FAST RELEASE. It also permits a subchannel to be set up for the execution of auxiliary functions, such as positioning the disk-access mechanism, and for data-transfer operations without interference by the program at the end of each operation. Command chaining, in conjunction with the status-modifier condition, permits the channel to modify the normal sequence of operations in response to signals provided by the I/O device.

SKIPPING

Skipping causes the suppression of storage references during an I/O operation. It is defined only for read, read backward, and sense operations and is controlled by the skip flag, which can be specified individually for each CCW. When the skip flag is one, skipping occurs; when zero, normal operation takes place. The setting of the skip flag is ignored in all other operations.

Skipping affects only the handling of information by the channel. The operation at the I/O device proceeds normally, and information is transferred to the channel. The channel keeps updating the count but does not place the information in storage. Chaining is not precluded by skipping. In the case of data chaining, normal operation is resumed if the skip flag in the new CCW is zero.

When the skip flag is set to one, the data address in the CCW is not checked.

Programming Note

Skipping, when combined with data chaining, permits the program to place in storage selected portions of a block from an I/O device.

PROGRAM-CONTROLLED INTERRUPTION

The program-controlled-interruption (PCI) function permits the program to cause an I/O interruption during the execution of an I/O operation. The function is controlled by the PCI flag in the CCW. The flag can be on either in the first CCW specified by START I/O or START I/O FAST RELEASE or in a CCW fetched during chaining. Neither the PCI flag nor the associated interruption affects the execution of the current operation.

Whenever the PCI flag in the CCW is one, an interruption condition is generated in the channel. When the first CCW associated with an operation contains the PCI flag, either initially or upon command chaining, the interruption may occur as early as immediately upon the initiation of the operation. The PCI flag in a CCW fetched on data chaining causes the interruption to occur after all data designated by the preceding CCW has been transferred. The time of the interruption, however, depends on the model and the current activity in the system and may be delayed even if I/O interruptions are allowed. No predictable relationship exists between the time the interruption due to the PCI flag occurs and the progress of data transfer to or from the area designated by the CCW, but the fields within the CSW pertain to the same instant of time.

If chaining occurs before the interruption due to the PCI flag has taken place, the PCI interruption condition is carried over to the new CCW. This carryover occurs both on data and command chaining and, in either case, the interruption condition is propagated through the transfer-in-channel command. The interruption conditions due to the PCI flags are not stacked; that is, if another CCW is fetched with a PCI flag before the interruption due to the PCI flag of the previous CCW has occurred, only one interruption takes place.

A CSW containing the PCI bit set to one may be stored by an interruption while the operation is still proceeding or by an interruption, TEST I/O, or CLEAR I/O upon the termination of the operation. A CSW cannot be stored by TEST I/O while the subchannel is in the working state.

When the CSW is stored by an interruption before the operation or chain of operations has been concluded, the CCW address is 8 greater than the address of the current CCW, and the count is unpredictable. All unit-status bits in the CSW are zero. If the channel has detected any unusual situations, such as channel-data check, program check, or protection check by the time the interruption occurs, the corresponding channel-status bit is one, although the status in the subchannel is not reset and is indicated again upon the termination of the operation.

A unit-status bit set to one in the CSW indicates that the operation or chain of operations has been concluded. The CSW in this case has its regular format with the PCI bit set to one.

However, when the interruption due to the PCI flag is delayed until the operation at the subchannel is concluded, two interruptions from the subchannel may still take place. The first interruption indicates and clears the interruption condition due to the PCI flag, and the second provides the CSW associated with the ending status. Whether one or two interruptions occur depends on the model and on whether the interruption condition due to the PCI flag has been assigned the highest priority for interruption at the time of conclusion. TEST I/O or CLEAR I/O addressed to the device associated with an interruption condition in the subchannel clears the interruption condition due to the PCI flag, as well as the one associated with the conclusion.

The setting of the PCI flag is inspected in every CCW except those specifying transfer in channel, where it is ignored. The PCI flag is also ignored during initial program loading.

Programming Notes

1. Since no unit-status bits are set to ones in the CSW associated with the conclusion of an operation of a selector channel by HALT I/O or HALT DEVICE, unit-status bits and the PCI bit set to ones are not necessary for the operation to be concluded. When status in a selector channel includes PCI at the time the operation is concluded by HALT I/O or HALT DEVICE, the CSW associated with the concluded operation is indistinguishable from the CSW provided by an interruption during execution of the operation.
2. Program-controlled interruption provides a means of alerting the

program to the progress of chaining during an I/O operation. It permits programmed dynamic storage allocation.

CHANNEL INDIRECT DATA ADDRESSING

Channel indirect data addressing permits a single channel-command word to control the transmission of data that spans noncontiguous pages in real storage.

Channel indirect data addressing is specified by a flag bit in the CCW which, when one, indicates that the data address in the CCW is not used to directly address data. Instead, the address specifies the first word in a list of words, called indirect-data-address words (IDAWs), each of which contains an absolute address designating a data area within a 2,048-byte block of storage.

When the indirect-data-addressing bit in the CCW is one, bits 8-31 of the CCW specify the location of the first IDAW to be used for data transfer for the command. Additional IDAWs, if needed for completing the data transfer for the CCW, are in successive storage locations. The number of IDAWs required for a CCW is determined by the count field of the CCW and by the data address in the initial IDAW. When, for example, the CCW count field specifies 4,000 bytes and the first IDAW specifies a location in the middle of a 2,048-byte block, three IDAWs are required.

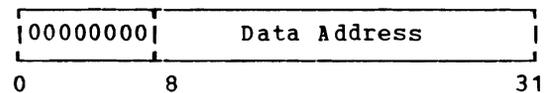
Each IDAW is used for the transfer of up to 2,048 bytes. The IDAW specified by the CCW can designate any location. Data is then transferred, for read, write, control, and sense commands, to or from successively higher storage locations or, for a read backward command, to successively lower storage locations, until a 2,048-byte block boundary is reached. The control of data transfer is then passed to the next IDAW. The second and any subsequent IDAWs must specify, depending on the command, the first or last byte of a 2,048-byte block. Thus, for read, write, control, and sense commands, these IDAWs will have zeros in bit positions 21-31. For a read-backward command, these IDAWs will have ones in bit positions 21-31.

Except for the unique restrictions on the specification of the data address by the IDAW, all other rules for the data address, such as for protected storage and invalid addresses, and the rules for data prefetching, remain the same as when indirect data addressing is not used.

A channel may prefetch any of the IDAWs pertaining to the current CCW or to a

prefetched CCW. An IDAW takes control of the data transfer when the last byte has been transferred for the previous IDAW. The same rules apply as with data chaining regarding when an IDAW takes control of data transfer during an I/O operation. That is, when the count in the CCW has not reached zero, a new IDAW takes control of the data transfer when the last byte has been transferred for the previous IDAW for that CCW, even in situations where (1) channel end, (2) channel end and device end, or (3) channel end, device end, and status modifier are received prior to transfer of any data bytes pertaining to the new IDAW. A prefetched IDAW does not take control of an I/O operation if the count in the CCW reached zero with the transfer of the last byte of data for the previous IDAW for that CCW. Errors detected in prefetched IDAWs are not indicated until the IDAW takes control of the data transfer.

The format of the IDAW and the significance of its fields are as follows:



Bit positions 0-7 are reserved for future use and must contain zeros. If any of the bits is a one, a program check is generated, and the operation is terminated.

Bits 8-31 specify the location of the first byte to be used in the data transfer. In the first IDAW for a CCW, any location can be specified. For subsequent IDAWs, depending on the command, either the first or the last location of a 2,048-byte block located on a 2,048-byte boundary must be specified. For read, write, control, and sense commands, the beginning of the block must be specified, and bits 21-31 of the IDAW will be zeros. For a read-backward command, the end of the block must be specified, and bits 21-31 of the IDAW will be ones. Improper data-address specification causes a program check to be generated and the operation to be terminated.

When the IDAW flag (bit 37) of the CCW is set to one and any of the following conditions occurs:

1. The address in the CCW does not designate the first IDAW on an integral word boundary,
2. The address in the CCW does not designate a valid storage location,
3. Access to the storage location specified by the address in the CCW is prohibited by protection, or

4. Bits 0-7 of the first IDAW are not zeros,

then, depending on the model, the above four conditions may be handled in one of two ways:

1. The channel checks for the above conditions before initiating the operation at the device. If any of these conditions is encountered, the channel indicates program check and does not initiate the operation at the device.
2. The channel initiates the operation at the device prior to checking for these

conditions. In this case, any of these conditions causes the channel to indicate program check only if the device attempts to transfer data. An immediate command does not result in a program-check indication.

COMMANDS

The figure "Channel-Command Codes" lists the command codes for the six commands and indicates which flags are defined for each command. The flags are ignored for all commands for which they are not defined.

| Name | Code | Flags |
|---------------------|---------------------------------|------------------------|
| Write | MMMM MM01 | CD CC SLI PCI IDA |
| Read | MMMM MM10 | CD CC SLI SKIP PCI IDA |
| Read backward | MMMM 1100 | CD CC SLI SKIP PCI IDA |
| Control | MMMM MM11 | CD CC SLI PCI IDA |
| Sense | MMMM 0100 | CD CC SLI SKIP PCI IDA |
| Sense ID | 1110 0100 | CD CC SLI SKIP PCI IDA |
| Transfer in channel | XXXX 1000 | |
| <u>Explanation:</u> | | |
| CD | Chain data | |
| CC | Chain command | |
| SLI | Suppress length indication | |
| SKIP | Skip | |
| PCI | Program-controlled interruption | |
| IDA | Indirect data addressing | |
| M | Modifier bit | |
| X | Ignored | |

Channel-Command Codes

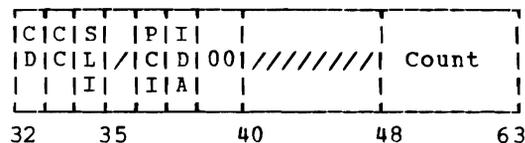
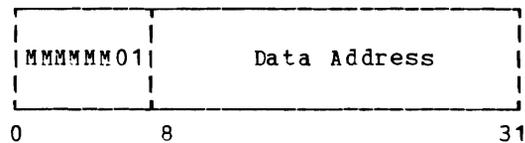
All flags have individual significance, except that the CC and SII flags are ignored when the CD flag is set to one. The SLI flag is ignored on immediate operations, in which case the incorrect-length indication is suppressed, regardless of the setting of the flag. The PCI flag is ignored during initial program loading.

Each command is described below, and the format is illustrated.

Programming Notes

1. A malfunction that affects the validity of data transferred in an I/O operation is signaled at the end of the operation by means of unit check or channel-data check, depending on whether the device (control unit) or the channel detected the error. In order to make use of the checking facilities provided in the system, data read in an input operation should not be used until the end of the operation has been reached and the validity of the data has been checked. Similarly, on writing, the copy of data in storage should not be destroyed until the program has verified that no malfunction affecting the transfer and recording of data was detected.
2. An error condition may be recognized by the channel and the I/O operation terminated when 256 or more chained commands are executed with an I/O device and none of the executed commands result in the transfer of any data.

Write



A write operation is initiated at the I/O device, and the subchannel is set up to transfer data from storage to the I/O

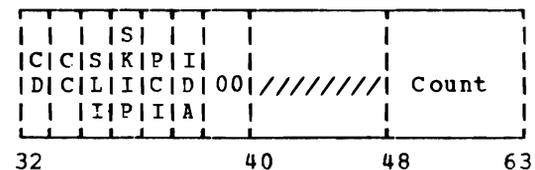
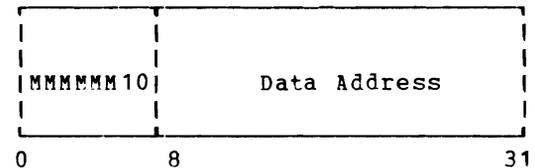
device. Data in storage is fetched in an ascending order of addresses, starting with the address specified in the CCW.

A CCW used in a write operation is inspected for the CD, CC, SLI, PCI, and IDA flags. The setting of the skip flag is ignored. Bit positions 0-5 of the CCW contain modifier bits.

Programming Note

When writing on devices for which block length is not defined, such as a magnetic-tape unit or an inquiry station, the amount of data written is controlled only by the count in the CCW. Every operation terminated under count control causes the incorrect-length indication, unless the indication is suppressed by the SLI flag.

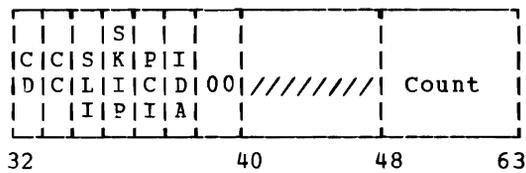
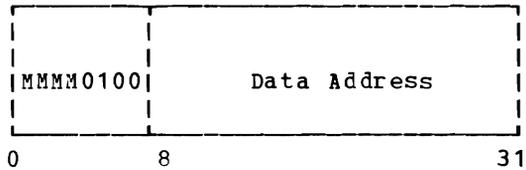
Read



A read operation is initiated at the I/O device, and the subchannel is set up to transfer data from the device to storage. For devices such as magnetic-tape units, disk storage, and card equipment, the bytes of data within a block are provided in the same sequence as written by means of a write command. Data is placed in storage in an ascending order of addresses, starting with the address specified in the CCW.

A CCW used in a read operation is inspected for every flag--CD, CC, SLI, SKIP, PCI, and IDA. Bit positions 0-5 of the CCW contain modifier bits.

Sense



A sense operation is initiated at the I/O device, and the subchannel is set up to transfer up to 32 bytes of sense data from the device to storage. The data is placed in storage in an ascending order of addresses, starting with the address specified in the CCW.

Data transferred during a sense operation provides information concerning unusual conditions detected by the I/O device. The information provided as a result of executing the sense command is more detailed than that supplied by the unit-status byte in the CSW and may describe reasons for the unit-check indication. It may also indicate, for example, if the device is in the not-ready state, if the tape unit is in the file-protected state, or if magnetic tape is positioned beyond the end-of-tape mark.

The first six bits of the first sense data byte (sense byte 0) are common to all I/O devices. The six bits, when set to ones, designate the following:

| Bit | Designation |
|-----|-----------------------|
| 0 | Command reject |
| 1 | Intervention required |
| 2 | Bus-out check |
| 3 | Equipment check |
| 4 | Data check |
| 5 | Overrun |

The following is the meaning of the first six bits:

Command Reject: The device has detected a programming error. A command has been received which the device is not designed to execute, such as read backward issued to a direct-access storage device, or which the device cannot execute because of its present state, such as write issued to a

file-protected tape unit. Command reject is indicated when the program issues an invalid sequence of commands, such as write to a direct-access storage device without previous designation of the block. Command reject may also be indicated when invalid data is transferred and the data is treated as an extension of the command. For example, command reject is indicated when an invalid seek argument is transferred to a direct-access storage device.

Intervention Required: The last operation could not be executed because of a situation requiring some type of intervention at the device. This bit indicates situations such as the hopper in a card punch being empty or the printer being out of paper. It is also turned on when the addressed device is not ready, is in test mode, or is not provided on the control unit.

Bus-Out Check: The device or the control unit has received a data byte or a command code with an invalid parity from the channel. During writing, bus-out check indicates that incorrect data has been recorded at the device, but this does not cause the operation to be terminated prematurely. Parity errors on command codes and control information cause the operation to be immediately terminated and suppress checking for situations that would cause command reject and intervention required.

Equipment Check: During the last operation, the device or the control unit has detected equipment malfunctioning, such as an invalid card-hole count or a printer-buffer parity error.

Data Check: The device or the control unit has detected a data error other than those included in bus-out check. Data check identifies errors associated with the recording medium and includes errors such as reading an invalid card code or detecting invalid parity on data recorded on magnetic tape.

On an input operation, data check indicates that incorrect data may have been placed in storage. The control unit forces correct parity on data sent to the channel. On writing, data check indicates that incorrect data may have been recorded at the device. Unless the operation is of a type where the error precludes meaningful continuation, data errors on reading and writing do not cause the operation to be terminated prematurely.

Overrun: The overrun condition occurs when the channel fails to respond to the control unit in the anticipated time interval to a request for service from the I/O device. When the total activity initiated by the

| program exceeds the capability of the
 | channel, an overrun may occur when data is
 | transferred to or from a control unit that
 | is either using the data-streaming feature
 | or is nonbuffered. An overrun condition
 | also may occur when the I/O device receives
 | the new command too late during command
 | chaining.

When the channel fails to accept a byte on
 an input operation, the following data
 transferred to storage may be used to fill
 the gap. On an output operation, overrun
 indicates that data recorded at the device
 may be invalid.

All information significant to the use of
 the device normally is provided in the
 first byte. Any bit positions following
 those used for programming information may
 contain diagnostic information, and the
 total number of sense bytes may extend up
 to 32 bytes as needed. The number and the
 meaning of the sense bytes extending beyond
 the first byte are peculiar to the type of
 I/O device and are specified in the SL
 publication for the device.

The basic sense command has zero modifier
 bits. This command initiates a sense
 operation on all devices and cannot cause
 the command-reject, intervention-required,
 data-check, or overrun bit to be set to
 one. If the control unit detects an
 equipment malfunction, or invalid parity of
 the sense command code, the equipment-check
 or bus-out-check bit is set to one, and
 unit check is indicated in the unit-status
 byte.

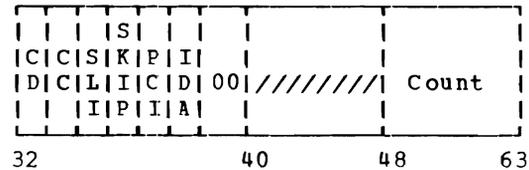
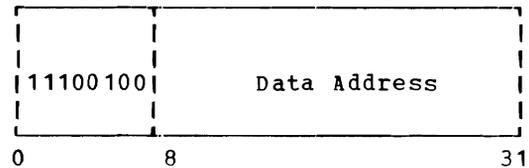
Devices that can provide special diagnostic
 sense information or can be instructed to
 perform other special functions by use of
 the sense command may define modifier bits
 for the control of these functions. The
 special sense operations may be initiated
 by a unique combination of modifier bits,
 or a group of codes may specify the same
 function. Any remaining sense command
 codes may be considered invalid, thus
 causing the unit-check indication, or may
 cause the same action as the basic sense
 command, depending upon the type of device.

The sense information that pertains to the
 last I/O operation or other action at a
 device may be reset any time after the
 completion of a sense command addressed to
 that device. Any command addressed to the
 control unit of a device, other than the
 no-operation command and the command which
 results from a TEST I/O instruction, may be
 allowed to reset the sense information,
 provided that the busy bit is not included
 in the initial status. The sense
 information may also be changed as a result
 of asynchronous actions, for example when
 the device changes from the not-ready to
 ready state. (See "Device End" in this

| chapter.)

A CCW used in a sense operation is
 inspected for every flag--CD, CC, SLI,
 SKIP, PCI, and IDA. Bit positions 0-3 of
 the CCW contain modifier bits.

| Sense ID



| Execution of the sense-ID command proceeds
 | exactly as that of a read command, except
 | that data is obtained from sensing
 | indicators rather than from a record
 | source. The data transferred is seven
 | bytes in length.

| The control unit and I/O device may
 | properly execute the sense-ID command, may
 | execute the command as the basic sense
 | command, or may reject the sense-ID command
 | with unit-check status. Refer to the SL
 | manual for the control unit and I/O device.

| The sense-ID command must not initiate any
 | operations other than the sensing of the
 | type/model number. If the control unit or
 | device is available and not busy, then
 | execution of the sense-ID command is
 | accomplished. Basic sense data may be
 | reset as a result of executing the sense-ID
 | command.

| The sense bytes sent in response to sense
 | ID are defined as follows:

- | byte 0 Hexadecimal 'FF'
- | byte 1 Control-unit type number
- | byte 2 Control-unit type number
- | byte 3 Control-unit model number
- | byte 4 Device type number
- | byte 5 Device type number
- | byte 6 Device model number

| All unused sense bytes are set to zeros.

| Bytes 1 and 2 contain the four-decimal-
 | digit control-unit type number that
 | corresponds directly with the unit type
 | number attached to the unit.

When the channel is not capable of performing command retry, the retry is suppressed, and an interruption condition is generated. The CSW will contain the channel-end, unit-check, and status-modifier status indications, along with any other appropriate status.

During command retry, the channel action is similar to that taken when command chaining. Thus, when command retry is performed, a START I/O initiating an immediate operation for which command chaining is not indicated in the CCW causes a condition code 0, rather than a condition code 1, to be set. The subsequent termination of the I/O operation causes an interruption condition to be generated. During command retry, the CCW may be refetched.

Programming Note

The following possible results of a command retry must be anticipated by the program:

1. A CCW with the PCI flag set to one may, if retried because of command retry, cause multiple PCI interruptions to occur.
2. A channel program consisting of a single, unchained CCW specifying an immediate command may cause a condition code 0 rather than a condition code 1 to be set. This setting of the condition code occurs if the control unit signals command retry at the time initial status is signaled to the channel. An interruption condition is generated upon completion of the operation.
3. If a CCW used in an operation is changed before that operation has been successfully completed, the results are unpredictable.
4. A CSW stored after the initiation of a retry but before the presentation of device end, as when an interruption condition due to the PCI flag is taken, contains the address of the command to be retried plus 8.
5. If a HALT I/O, HALT DEVICE, or CLEAR I/O instruction is issued after the initiation of a retry but before the presentation of device end, the CSW contains the address of the command to be retried plus 8.
6. On a multiplexer channel, chained CCWs which might ordinarily have been executed in a burst may, upon the occurrence of command retry, cause

multiplexing to occur, with the result that the channel becomes unexpectedly available.

7. Command chaining may occur even though the CCW does not indicate command chaining. This can occur if immediate retry is not requested and the control unit or device presents a status of device end and status modifier.

CONCLUSION OF INPUT/OUTPUT OPERATIONS

When the operation or sequence of operations initiated by START I/O or START I/O FAST RELEASE is ended, the channel and the device generate status. Status can be brought to the attention of the program by means of an I/O interruption, by TEST I/O or CLEAR I/O, or, in certain cases, by START I/O or START I/O FAST RELEASE. This status, as well as an address and a count indicating the extent of the operation sequence, are presented to the program in the form of a channel-status word (CSW).

TYPES OF CONCLUSION

Normally an I/O operation at the subchannel lasts until the device signals channel end. Channel end can be signaled during the sequence initiating the operation, or later. When the channel detects equipment malfunctioning or an I/O system reset is performed, the channel disconnects the device without receiving channel end. The program can force a device to be disconnected prematurely by issuing CLEAR CHANNEL, CLEAR I/O, HALT I/O, or HALT DEVICE.

Conclusion at Operation Initiation

After the addressed channel and subchannel have been verified to be in a state where START I/O or START I/O FAST RELEASE can be executed, certain tests are performed on the validity of the information specified by the program and on the availability of the addressed control unit and I/O device. This testing occurs during the execution of START I/O, either during or subsequent to the execution of START I/O FAST RELEASE, and during command chaining.

A data-transfer operation is initiated at the subchannel and device only when no programming or equipment errors are detected by the channel and when the device responds with zero status or signals

| command retry during the initiation sequence. When the channel detects or the device signals any unusual situations during the initiation of an operation, the command is said to be rejected.

Rejection of the command during the execution of START I/O or START I/O FAST RELEASE is indicated by the setting of the condition code in the PSW. Unless the I/O device is not operational, the reasons for the rejection are detailed by the portion of the CSW stored by START I/O or START I/O FAST RELEASE. The I/O device is not started, no interruption conditions are generated, and the subchannel is available subsequent to the initiation sequence. The I/O device is immediately available for the initiation of another operation, provided the command was not rejected because the device or control unit was busy or not operational.

When an unusual situation causes a command to be rejected during initiation of an I/O operation by command chaining, an interruption condition is generated, and the subchannel is not available until the condition is cleared. The reasons for the rejection are indicated to the program by means of the corresponding status bits in the CSW. The not-operational state of the I/O device, which during the execution of START I/O and in some models during the execution of START I/O FAST RELEASE causes condition code 3 to be set, instead causes the interface-control-check bit to be set to one when detected during command chaining. The new operation at the I/O device is not initiated.

When START I/O FAST RELEASE is executed by a channel independent of the addressed device, tests for most program-specified information, for control-unit and device availability, for control-unit and device status, and for most errors may be performed subsequent to the execution of START I/O FAST RELEASE. Some situations which would have caused a condition code 1 or 3 to be set had the instruction been START I/O instead cause an interruption condition to be generated. The CSW, when stored, indicates that the interruption condition is a deferred condition code 1 or 3.

Immediate Operations

| Any command other than the command that results from TFST I/O may cause the I/O device to signal channel end immediately upon receipt of the command code. An I/O operation causing channel end to be signaled during the initiation sequence is called an immediate operation.

When the first CCW designated by the CAW during a START I/O or START I/O FAST RELEASE executed as a START I/O initiates an immediate operation with command chaining not indicated and command retry not occurring, no interruption condition is generated. In this case, channel end is brought to the attention of the program by causing START I/O or START I/O FAST RELEASE to store the CSW status portion. The subchannel is immediately made available to the program. The I/O operation, however, is initiated, and, if channel end is not accompanied by device end, the device remains busy. Device end, when subsequently provided by the device, causes an interruption condition to be generated.

An immediate operation initiated by the first CCW designated by the CAW during a START I/O FAST RELEASE executed independent of the addressed device appears to the program as a nonimmediate command. That is, any status generated by the device for the immediate command, or for a subsequent command if command chaining occurs, causes an interruption condition to be generated.

When command chaining is specified after an immediate operation and no unusual situations have been detected during the execution, or when command retry occurs for an immediate operation, neither START I/O nor START I/O FAST RELEASE causes the immediate storing of CSW status. The subsequent commands in the chain are handled normally, and channel end for the last operation of the chain of CCWs generates an interruption condition even if the I/O device provides the signal immediately upon receipt of the command code.

Whenever immediate completion of an I/O operation is signaled, no data has been transferred to or from the device as a result of that operation.

Since a count of zero is not valid, any CCW specifying an immediate operation must contain a nonzero count. When an immediate operation is executed, however, incorrect length is not indicated to the program, and command chaining is performed when so specified.

Programming Note

Control operations for which the entire operation is specified in the command code may be executed as immediate operations. Whether the control function is executed as an immediate operation depends on the operation and type of device and is specified in the SL publication for the device.

Conclusion of Data Transfer

When the device accepts a command, the subchannel is set up for data transfer. The subchannel is in the working state during this period. Unless the channel detects equipment malfunctioning or the operation is concluded by CLEAR CHANNEL, CLEAR I/O, or, on the selector channel, the operation is concluded by CLEAR CHANNEL, CLEAR I/O, HALT I/O, or HALT DEVICE, the subchannel-working state lasts until the channel receives the channel-end signal from the I/O device. When no command chaining is specified or when chaining is suppressed because of unusual situations, channel end causes the operation at the subchannel to be terminated and an interruption condition to be generated. The status bits in the associated CSW indicate channel end and any unusual situations. The I/O device can signal channel end at any time after initiation of the operation, and the signal may occur before any data has been transferred.

For operations not involving data transfer, the I/O device normally controls the timing of channel end. The duration of data-transfer operations may be variable and may be controlled by the I/O device or the channel.

Excluding equipment errors, CLEAR I/O, HALT DEVICE, and HALT I/O, the channel signals the device to conclude data transfer whenever any of the following events occurs:

1. The storage areas specified for the operation are exhausted or filled.
2. A program check is detected.
3. A protection check is detected.
4. A chaining check is detected.

The first event occurs when the channel has stepped the count to zero in the last CCW associated with the operation. A count of zero indicates that the channel has transferred all information specified by the program. The other three events are due to errors and cause premature conclusion of data transfer. In every case, the conclusion is signaled in response to a service request from the device and causes data transfer to cease. If the device has no blocks defined for the operation (such as writing from magnetic tape), it concludes the operation and generates channel end.

The device can control the duration of an operation and the timing of channel end. On certain operations for which blocks are

defined (such as reading from magnetic tape), the device does not provide the channel-end signal until the end of the block is reached, regardless of whether or not the device has been previously signaled to conclude data transfer.

If the data address in the CCW is invalid, no data is transferred during the operation, and the device is signaled to conclude the operation in response to the first service request. On writing, devices such as magnetic-tape units request the first byte of data before any mechanical motion is started and, if the data address is invalid, the operation is concluded before the recording medium has been advanced. However, since the operation has been initiated at the I/O device the I/O device provides channel end, and an interruption condition is generated. Whether a block at the I/O device is advanced when no data is transferred depends on the type of I/O device and is specified in the SL publication for the I/O device.

When command chaining takes place, the subchannel is in the working state from the time condition code 0 is set for START I/O or START I/O FAST RELEASE until the device signals channel end for the last operation of the chain. On the selector channel, the device executing the I/O operation stays connected to the channel and the channel is in the working state during the entire execution of the chain of I/O operations. On the multiplexer channel, an I/O operation in the burst mode causes the channel to be in the working state only while transferring a burst of data. If channel end and device end do not occur concurrently, the device disconnects from the channel after providing channel end, and the channel can in the meantime communicate with other devices.

Any unusual situations cause command chaining to be suppressed and an interruption condition to be generated. The unusual situations can be detected by either the channel or the device, and the device can provide the indications with channel end, control-unit end, or device end. When the channel is aware of the unusual situation by the time the channel-end signal for the operation is received, the chain is ended as if the operation during which the situation occurred were the last operation of the chain. The device-end signal subsequently is processed as an interruption condition. When the device signals unit check or unit exception with control-unit end or device end, the subchannel terminates the working state upon receipt of the signal from the device. The channel-end indication in this case is not made available to the program.

Termination by HALT I/O or HALT DEVICE

The instructions HALT I/O and HALT DEVICE cause the current operation at the addressed channel or subchannel to be immediately terminated. The method of termination differs from that used upon exhaustion of count or upon detection of programming errors to the extent that termination by HALT I/O or HALT DEVICE is not necessarily contingent on the receipt of a service request from the device.

When HALT I/O is issued to a channel operating in burst mode, the channel issues the halt signal to the device currently operating with the channel, regardless of the device address specified with the HALT I/O instruction. If the channel is involved in the data-transfer portion of an operation, data transfer is immediately terminated, and the device is disconnected from the channel. If HALT I/O is addressed to a selector channel executing a chain of operations and the device has already provided channel end for the current operation, the instruction causes the device to be disconnected and command chaining to be immediately suppressed.

When HALT DEVICE is issued to a channel operating in burst mode, the halt signal is issued to the device involved in the burst-mode operation only if that device is the one to which the HALT DEVICE is addressed. If the operation thus terminated is in the data-transfer portion of the operation, data transfer is immediately terminated, and the device is disconnected from the channel. If the terminated burst involves a selector channel executing a chain of operations and the device has already provided channel end for the current operation, HALT DEVICE causes the device to be disconnected and command chaining to be immediately suppressed. If, on a selector channel, the device involved in the burst is not the one to which the HALT DEVICE is addressed, no action is taken. If, on a multiplexer channel, the device involved in the burst is not the one to which the HALT DEVICE is addressed, HALT DEVICE causes any operation for the addressed device to be terminated at the addressed subchannel and suppresses any further data transfer or command chaining for that device.

When HALT I/O or HALT DEVICE is issued to a channel not operating in burst mode, the addressed device is selected, and the halt signal is issued as the device responds. If the device presents status and if command chaining is indicated in the subchannel, it is suppressed.

The termination of an operation by HALT I/O or HALT DEVICE on the selector channel

results in up to four distinct interruption conditions. The first one is generated by the channel upon execution of the instruction and is not contingent on the receipt of status from the device. The channel-status bits reflect the unusual situations, if any, detected during the operation. If HALT I/O or HALT DEVICE is issued subsequent to the initiation of the I/O operation at the I/O device but before all data specified for the operation has been transferred, incorrect length is indicated, subject to the control of the SLI flag in the current CCW. The execution of HALT I/O or HALT DEVICE itself is not reflected in CSW status, and all status bits in a CSW due to this interruption condition can be zero. The channel is available for the initiation of a new I/O operation as soon as the interruption condition is cleared.

The second interruption condition on the selector channel occurs when the control unit signals channel end. The selector channel handles this condition as any other interruption condition from the device after the device has been disconnected from the channel, and provides zeros in the subchannel-key, CCW-address, count, and channel-status fields of the associated CSW. Channel end is not made available to the program when HALT I/O or HALT DEVICE is issued to a channel executing a chain of operations and the device has already provided channel end for the current operation.

Finally, the third and fourth interruption conditions occur when control-unit end, if any, and device end are signaled. These signals are handled as for any other I/O operation.

The termination of an operation by HALT I/O or HALT DEVICE on a multiplexer channel causes the normal interruption conditions to be generated. If the instruction is issued when the subchannel is in the data-transfer portion of an operation, the subchannel remains in the working state until channel end is signaled by the device, at which time the subchannel is placed in the interruption-pending state. If HALT I/O or HALT DEVICE is issued after the device has signaled channel end and the subchannel is executing a chain of operations, channel-end is not made available to the program, and the subchannel remains in the working state until the next status byte from the device is received. Receipt of a status byte subsequently places the subchannel in the interruption-pending state. The CSW associated with the interruption condition in the subchannel contains the status byte provided by the device and the channel. If HALT I/O or HALT DEVICE is issued before all data areas associated with the current

operation have been exhausted or filled, incorrect length is indicated, subject to the control of the SLI flag in the current CCW. The interruption condition is processed as for any other type of termination.

The termination of a burst operation by HALT I/O or HALT DEVICE on a block-multiplexer channel may, depending on the model and the type of subchannel, take place as for a selector channel or may allow the subchannel to remain in the working state until the device provides ending status.

Programming Note

The count field in the CSW associated with an operation terminated by HALT I/O or HALT DEVICE is unpredictable.

Termination by CLEAR I/O

The termination of an operation by CLEAR I/O causes the subchannel to be set to the available state and causes a CSW to be stored. The validity of the CSW fields is defined in the instruction CLEAR I/O earlier in this chapter.

When CLEAR I/O terminates an operation at a subchannel in the interruption-pending state, up to three subsequent interruption conditions related to the operation can occur. Since CLEAR I/O causes the subchannel to be made available, these interruption conditions will result in only the unit-status portion of the CSW being indicated.

The first interruption condition arises on a selector channel when channel end is signaled to the channel. This occurs only when the interruption-pending states of the channel and subchannel at the execution of CLEAR I/O were due to the previous execution of HALT I/O or HALT DEVICE.

The second and third interruption conditions arise when control-unit end, if any, and device end are signaled to the channel.

When CLEAR I/O terminates an operation at a subchannel in the working state, up to four subsequent interruption conditions related to the operation can occur. For all of these conditions, only the status portion of the CSW is indicated.

The first interruption condition arises on certain channels when the terminated

operation was in the midst of data transfer. Since the device is not signaled to terminate the operation during the execution of CLEAR I/O unless the channel is working with the addressed device when the instruction is received, the device may, subsequent to the CLEAR I/O, attempt to continue the data transfer. The channel responds by signaling the device to terminate data transfer. Depending on the channel, the need to signal the device to terminate data transfer may be ignored or may be considered an interface-control check which creates an interruption condition. Only channel status is indicated in the CSW.

A second interruption condition may occur if channel-end status is received from the device. The third and fourth conditions may occur if control-unit end, and/or device end are presented to the channel. In these three cases, only unit status is indicated in the CSW.

Termination Due to Equipment Malfunction

When channel-equipment malfunctioning is detected or invalid signals are received from a device, the recovery procedure and the subsequent states of the subchannels and devices on the channel depend on the type of error and on the model. Normally, the program is alerted to the termination by an I/O interruption, and the associated CSW indicates channel-control check or interface-control check. However, when the nature of the malfunction prevents an I/O interruption, a machine-check interruption occurs, and a CSW is not stored. A malfunction may cause the channel to perform the I/O selective reset or to generate the halt signal.

INPUT/OUTPUT INTERRUPTIONS

Input/output interruptions provide a means for the CPU to change its state in response to conditions that occur in I/O devices or channels. The conditions are indicated in an associated CSW which is stored at the time of interruption. These conditions can be caused by the program or by an external event at the device.

Interruption Conditions

A request for an I/O interruption is called an I/O-interruption condition, or, in this chapter, simply an interruption condition.

An interruption condition can be brought to the attention of the program only once and is cleared when it causes an interruption. Alternatively, an interruption condition can be cleared by TEST I/O or CLEAR I/O, and conditions generated by the I/O device following the termination of the operation at the subchannel can be cleared by TEST I/O, START I/O, or START I/O FAST RELEASE. The latter include interruption conditions caused by attention, device end, and control-unit end, and channel end when provided by a device after conclusion of the operation at the subchannel.

The device attempts to initiate a request to the channel for an I/O interruption whenever it detects any of the following:

- Channel end
- Control-unit end
- Device end
- Attention

The channel combines the above status with information in the subchannel and either causes an I/O interruption or continues command chaining as a function of the received status. When command chaining takes place, channel end and device end do not cause an interruption and are not made available.

The channel creates an interruption condition when any of the following conditions occurs during command chaining:

- Unit check
- Unit exception
- Busy indication from device
- Program check
- Protection check

When an operation initiated by command chaining is terminated because of an unusual situation detected during the command initiation sequence, the interruption condition may remain pending within the channel, or the channel may create an interruption condition at the device. This interruption condition is created at the device only in response to presentation of status by the device and causes the device subsequently to present the same status for interruption purposes. The interruption condition at the device may or may not be associated with unit status. If the unusual situation is detected by the device (unit check or unit exception) the unit-status field of the associated CSW identifies the condition. If the unusual situation is detected by the channel, as in the case of program and protection check, the identification of the error is preserved in the subchannel and appears in the channel-status field of the associated CSW.

An interruption condition caused by the device may be accompanied by channel and other unit status. Furthermore, more than one condition associated with the same device can be cleared at the same time. As an example, when channel end is not cleared at the device by the time device end is generated, both may be indicated in the CSW and cleared at the device concurrently.

However, either prior to or at the time the channel assigns highest priority for interruptions to an interruption condition associated with an operation at the subchannel, the channel accepts the status from the device and clears the condition at the device. The interruption condition and the associated status indication are subsequently preserved in the subchannel. Any subsequent status generated by the device is not included when the CSW is stored, even if the status is generated before the interruption condition is cleared.

When the channel is not working, a device that is interruption-pending may attempt to initiate a request to the channel for an I/O interruption by presenting a nonzero status byte to the channel. Depending on the channel, some models may accept the status into the subchannel. Alternatively, some models may signal the device to hold the status until the channel is capable of causing an interruption. In this case, the channel selects the device to obtain the status when the interruption occurs. The status stored by the channel is the status presented by the device at interruption time and, because of changed conditions at the device, may not be the same status presented by the device initially. Specifically, a status of zero, busy, or busy and status modifier may be stored.

When the channel detects any of the following, it generates an interruption condition without necessarily communicating with or having received the status byte from the device:

- PCI flag in a CCW
- Execution of HALT I/O or HALT DEVICE on a selector channel
- Channel-available interruption (CAI)
- A programming error associated with the CCW or first IDAW following the SIOF function

The interruption conditions from the channel, except for CAI, can be accompanied by other channel-status indications, but none of the device status bits is on when the channel initiates the interruption in this case.

Channel-Available Interruption

The channel-available-interruption (CAI) condition is provided on all block-multiplexer channels and causes the entire CSW to be replaced by a new set of bits. All fields of the CSW are set to zero. The I/O address stored contains a zero device address and a channel address identifying the interrupting channel.

The channel generates the CAI condition if it previously had responded with a condition code 2 to an I/O instruction other than HALT I/O or HALT DEVICE and if the working state thus indicated no longer exists. When the working state which caused condition code 2 was due to a subchannel busy with a device other than the one addressed, the conclusion of the working state is not signaled by a CAI.

Since any other interruption condition (except PCI) accomplishes the same function as CAI, a CAI condition is reset upon the occurrence of any interruption (except PCI) on that channel. Some channels also reset a CAI condition when another interruption condition (except PCI) is cleared by a TEST I/O on the same channel. The occurrence of another channel-working state before the CAI causes the CAI condition to be suspended until the working state ends.

Programming Note

The CAI is designed to inform the program that a channel which previously indicated busy is no longer busy. The CAI condition pending in a channel does not cause the rejection of a subsequent START I/O or START I/O FAST RELEASE but does cause a condition code 1 to be returned to TEST CHANNEL. The CAI can therefore be used as a tool for keeping I/O requests in sequence by using it in conjunction with TEST CHANNEL. A channel which responded with condition code 2 because the channel was busy does not subsequently respond with a condition code 0 to a TEST CHANNEL without clearing an interruption condition in the interim.

PRIORITY OF INTERRUPTIONS

Generation of interruption conditions is asynchronous to the activity in the CPU, and interruption conditions associated with more than one I/O device can exist at the same time. The priority among interruption conditions is controlled by two types of mechanisms--one establishes the priority

among interruption conditions within a channel, and another establishes priority among interruption conditions from different channels. A channel requests an I/O interruption only after it has established priority among interruption conditions. The status associated with interruption conditions is preserved in the devices or channels until accepted by the CPU.

Assignment of priority among requests for interruption associated with devices on any one channel is a function of the type of channel, the type of interruption condition, and the position of the device on the I/O interface. A device's position on the interface is not related to its address. Interruption conditions from different devices do not necessarily occur in the sequence in which they are generated. However, multiple interruption conditions for a single device are presented in the sequence in which they are generated.

The priorities among requests for I/O interruptions from different channels depend on channel addresses. The priorities of channels 1-15 are in the order of their addresses, with channel 1 having the highest priority. The priority of byte-multiplexer channel 0 is undefined. Its priority may be above, below, or between those priorities of channels 1-15.

Interruption Action

An I/O interruption can occur only when the CPU is enabled for I/O interruptions. The interruption occurs at the completion of a unit of operation. If a channel has established the priority among interruption conditions, while the CPU is disabled for I/O interruptions, the interruption occurs immediately after the completion of the instruction enabling the CPU and before the next instruction is executed. This interruption is associated with the highest priority condition for the channel. If interruptions are allowed from more than one channel concurrently, the interruption occurs from the channel having the highest priority among those requesting interruption.

If the priority among interruption conditions has not yet been established in the channel by the time the interruption is allowed, the interruption does not necessarily occur immediately after the completion of the instruction enabling the CPU. This delay can occur regardless of how long the interruption condition has existed in the device or the subchannel.

The interruption causes the current program-status word (PSW) to be stored as the old PSW at real storage location 56 and causes the CSW associated with the interruption to be stored at real storage location 64. In EC mode, the channel and device causing the interruption are identified by the I/O address which is stored at real storage locations 186-187. In BC mode, the channel and device causing the interruption are identified by the I/O address in bit positions 16-31 of the I/O old PSW.

If a limited-channel logout is present, it is stored at real storage locations 176-179.

Subsequently, a new PSW is loaded from real storage location 120, and processing resumes in the state indicated by this PSW. The CSW associated with the interruption identifies the interruption condition responsible for the interruption and provides further details about the progress of the operation and the status of the device.

Programming Note

When a number of I/O devices on a shared control unit are concurrently executing operations such as rewinding tape or positioning a disk-access mechanism, the initial device-end signals generated on completion of the operations are provided in the order of generation, unless command chaining is specified for the operation last initiated. In the latter case, the control unit provides the device-end signal for the last initiated operation first, and the other signals are delayed until the subchannel is freed. Whenever interruptions due to the device-end signals are delayed because the CPU is disabled for I/O interruptions or the subchannel is busy, the original order of the signals is destroyed.

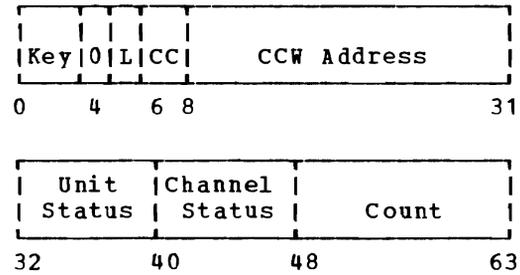
CHANNEL-STATUS WORD

The channel-status word (CSW) provides to the program the status of an I/O device or the indication of the reasons for which an I/O operation has been concluded. The CSW is formed, or parts of it are replaced, in the process of I/O interruptions and possibly during the execution of START I/O, START I/O FAST RELEASE, TEST I/O, CLEAR I/O, HALT I/O, HALT DEVICE, and STORE CHANNEL ID. The CSW is stored at real storage location 64 and is available to the program at this location until the time the

next I/O interruption occurs or until another I/O instruction causes its contents to be replaced, whichever occurs first.

The information placed in the CSW by an I/O interruption pertains to the device which is identified by the I/O address stored during the interruption. The information placed in the CSW by START I/O, START I/O FAST RELEASE, TEST I/O, CLEAR I/O, HALT I/O, or HALT DEVICE pertains to the device addressed by the instruction.

The CSW has the following format:



The fields in the CSW are allocated as follows:

Subchannel Key: Bits 0-3 form the access key used in the chain of operations at the subchannel.

Logout Pending (L): Bit 5, when one, indicates that an I/O instruction cannot be executed until a logout has been cleared. Bit 45, channel-control check, will always be one when bit 5 is one.

Deferred Condition Code (CC): Bits 6 and 7 indicate whether situations have been encountered subsequent to the setting of a condition code 0 for START I/O FAST RELEASE that would have caused a different condition-code setting for START I/O. The possible setting of these bits, and their meanings, are as follows:

| Setting of | Meaning | |
|------------|---------|------------------------------|
| Bit 6 | Bit 7 | |
| 0 | 0 | Normal I/O interruption |
| 0 | 1 | Deferred condition code is 1 |
| 1 | 0 | (Reserved) |
| 1 | 1 | Deferred condition code is 3 |

CCW Address: Bits 8-31 form an absolute address that is 8 higher than the address of the last CCW used.

Status: Bits 32-47 identify the status of the device and the channel that caused the storing of the CSW. Bits 32-39, the unit status, indicate situations detected by the

device or control unit. Bits 40-47, the channel status, are provided by the channel and indicate situations associated with the subchannel. The 16 bits are designated as follows:

| <u>Bit</u> | <u>Designation</u> |
|------------|---------------------------------|
| 32 | Attention |
| 33 | Status modifier |
| 34 | Control-unit end |
| 35 | Busy |
| 36 | Channel end |
| 37 | Device end |
| 38 | Unit check |
| 39 | Unit exception |
| 40 | Program-controlled interruption |
| 41 | Incorrect length |
| 42 | Program check |
| 43 | Protection check |
| 44 | Channel-data check |
| 45 | Channel-control check |
| 46 | Interface-control check |
| 47 | Chaining check |

Count: Bits 48-63 form the residual count for the last CCW used.

UNIT STATUS

The following status indications are generated by the I/O device or control unit. The timing and causes of these status indications for each type of device are specified in the SI publication for the device.

When the I/O device is accessible from more than one channel, status due to channel-initiated operations is signaled to the channel that initiated the associated I/O operation. The handling of status not associated with I/O operations, such as attention, unit exception, and device end because of transition from the not-ready to the ready state, depends on the type of device and situation and is specified in the SI publication for the device. (See "Device End" in this chapter.)

Attention

Attention is signaled when the device detects an asynchronous condition that is significant to the program. The condition may also be described by other status indications that accompany attention. Attention is interpreted by the program and is not associated with the initiation,

execution, or conclusion of an I/O operation.

The device can signal attention to the channel when no operation is in progress at the I/O device, control unit, or subchannel. Attention can be signaled with device end upon completion of an operation, and it can be signaled to the channel during the initiation of a new I/O operation. Attention along with device end and unit exception can also be signaled whenever a device changes from the not-ready to the ready state. The handling and presentation of attention to the channel depends on the type of device.

When the device signals attention during the initiation of an operation, the operation is not initiated. Attention causes command chaining to be suppressed.

An I/O device may present attention accompanied by device end and unit exception when a not-ready-to-ready-state transition is signaled. (See "Device End" in this chapter.)

Status Modifier

Status modifier is generated by the device when the device cannot provide its current status in response to TEST I/O, when the control unit is busy, when the normal sequence of commands has to be modified, or when command retry is to be initiated.

When status modifier is signaled in response to TEST I/O and status modifier is the only status bit that is set to one, this indicates that the device is unable to execute the function specified by the instruction and has not provided its current status. The interruption condition, which may be pending at the device or subchannel, has not been cleared, and the CSW stored by TEST I/O contains zeros in the subchannel-key, CCW-address, and count fields.

When the status-modifier bit in the CSW is set to one together with the busy bit, it indicates that the busy status pertains to the control unit associated with the addressed I/O device. The control unit appears busy when it is executing a type of operation that precludes the acceptance and execution of any command or the instructions TEST I/O, HALT I/O, and HALT DEVICE or when it contains an interruption condition for a device other than the one addressed. The interruption condition may be due to control-unit end, due to channel end following the execution of CLEAR I/O, or, on the selector channel, due to channel end following the execution of HALT I/O or

HALT DEVICE. The busy state occurs for operations such as backspace file, in which case the control unit remains busy after providing channel end, for operations concluded by CLEAR I/O, and for operations concluded on the selector channel by HALT I/O or HALT DEVICE, and temporarily occurs on the 2702 Transmission Control after initiation of an operation on a device accommodated by the control unit. A control unit accessible from two or more channels appears busy when it is communicating with another channel.

Presence of status modifier and device end means that the normal sequence of commands must be modified. The handling of this status combination by the channel depends on the operation. If command chaining is specified in the current CCW and no unusual situations have been detected, presence of status modifier and device end causes the channel to fetch and chain to the CCW whose storage address is 16 higher than that of the current CCW. If the I/O device signals status modifier at a time when no command chaining is specified, or when any unusual situations have been detected, no action is taken in the channel, and the status-modifier bit and any other status bits presented by the device are set to ones in the CSW.

Status modifier is set to one in combination with unit check and channel end to initiate the command-retry procedure.

Control units that recognize special conditions that must be brought to the attention of the program present status modifier along with other status indications in order to modify the meaning of the status. The status presented is unrelated to the execution of an I/O operation.

Control-Unit End

Control-unit end indicates that the control unit has become available for use for another operation.

Control-unit end is provided only by control units shared by I/O devices or control units accessible by two or more channels, and only when one or both of the following have occurred:

1. The program had previously caused the control unit to be interrogated while the control unit was in the busy state. The control unit is considered to have been interrogated in the busy state when a command or the instructions START I/O, START I/O FAST RELEASE (when not executed

independently of the device), TEST I/O, HALT I/O, or HALT DEVICE had been issued to a device on the control unit, and the control unit had responded with busy and status modifier in the unit-status byte. See the section "Status Modifier" earlier in this chapter.

2. The control unit detected an unusual condition during the portion of the operation after channel end had been signaled to the channel. The indication of the unusual situation accompanies control-unit end.

If the control unit remains busy with the execution of an operation after signaling channel end but has not detected any unusual situations and has not been interrogated by the program, control-unit end is not generated. Similarly, control-unit end is not provided when the control unit has been interrogated and could perform the indicated function. The latter case is indicated by the absence of busy and status modifier in the response to the instruction causing the interrogation.

When the busy state of the control unit is temporary, control-unit end is included with busy and status modifier in response to the interrogation even though the control unit has not yet been freed. The busy condition is considered to be temporary if its duration is commensurate with the program time required to handle an I/O interruption. The 2702 Transmission Control is an example of a device in which the control unit may be busy temporarily and which includes control-unit end with busy and status modifier.

Control-unit end can be signaled with channel end, with device end, or between the two. Control-unit end may be signaled at other times and may be accompanied by other status bits. When control-unit end is signaled by means of an I/O interruption in the absence of any other status, the interruption may be identified by any address assigned to the control unit. A control-unit end may cause the control unit to appear busy for the initiation of new operations with any attached device. Alternatively, a control-unit end may be assigned by the control unit to a specific device address, and only that device would appear busy for the initiation of new operations.

Busy

Busy indicates that the I/O device or control unit cannot execute the command or instruction because (1) it is executing a

previously initiated operation, (2) it contains an interruption condition, (3) it is shared by channels or I/O devices and the shared facility is not available, or (4) a self-initiated function is being performed. The status associated with the interruption condition for the addressed device, if any, accompanies the busy status. If busy applies to the control unit, busy is accompanied by status modifier.

The figure "Indications of Busy in CSW" lists the situations for devices connected to only one channel when the busy bit is set to one in the CSW and when busy is accompanied by status modifier. For devices shared by more than one channel, operations related to one channel may cause the control unit or device to appear busy to the other channels.

| Condition | CSW Status Stored by | | | | |
|---|----------------------|-------|--------|------------|-----------|
| | SIO or SIOF# | TIO | CLRIO+ | HIO or HDV | I/O IRPT# |
| Subchannel available | | | | | |
| DE or attention in device | B,cl | NB,cl | * | * | NB,cl |
| Device working, CU available | B | B | * | * | m |
| CU end or channel end in CU: for the addressed device | B,cl | NB,cl | NB | * | NB,cl |
| for another device | & | \$ | NB | * | NB,cl |
| CU working | B,SM | B,SM | NB | * | B,SM |
| Interruption condition in subchannel for the addressed device because of: | | | | | |
| chaining terminated by busy | * | B,cl | NB,cl | * | B,cl |
| other type of termination | * | NB,cl | NB,cl | * | NB,cl |
| asynchronous status@ | B,cl | NB,cl | NB,cl | * | NB,cl |
| Subchannel working | | | | | |
| CU available | * | * | NB | NB | * |
| CU working | * | * | NB | B,SM | * |
| <u>Explanation:</u> | | | | | |
| B Busy bit in CSW is one. | | | | | |
| cl Interruption condition cleared; status is placed in CSW. | | | | | |
| CU Control unit. | | | | | |
| DE Device end. | | | | | |
| NB Busy bit is zero. | | | | | |
| SM Status-modifier bit appears in CSW. | | | | | |
| * CSW not stored, or I/C interruption cannot occur. | | | | | |
| # When a channel executes START I/O FAST RELEASE as START I/O, the CSW status stored for the two instructions is identical. When START I/O FAST RELEASE is executed independently of the device, the same status is stored by an I/O interruption with the CSW also indicating deferred condition code 1. | | | | | |
| & Either a CSW is not stored or busy and status modifier are stored. | | | | | |
| \$ Unit status of either zeros or busy and status modifier is stored. | | | | | |
| m Unit status of busy may be stored or an I/O interruption may not occur. | | | | | |
| @ Asynchronous status is any unit status that is not related to the termination of an I/O operation at the subchannel. | | | | | |
| # Except when the I/C interruption is caused by a deferred condition code 1 for START I/O FAST RELEASE. | | | | | |
| + The entries in this column apply only when the CLRIO function is executed. When CLEAR I/O causes the TIO function to be executed, the entries in the TIO column apply. | | | | | |

Indications of Busy in CSW

Channel End

Channel end is caused by the completion of the portion of an I/O operation involving transfer of data or control information between the I/O device and the channel. The condition indicates that the subchannel has become available for use for another operation.

Each I/O operation initiated at the device causes channel end to be signaled, and there is only one channel end for an operation. Channel end is not signaled when programming errors or equipment malfunctions are detected during initiation of the operation. When command chaining takes place, only the channel end of the last operation of the chain is made available to the program. Channel end is not made available to the program when a chain of commands is prematurely concluded because of an unusual situation indicated with control-unit end or device end or during the initiation of a chained command.

The instant within an I/O operation when channel end is signaled depends on the operation and the type of device. For operations such as writing on magnetic tape, channel end occurs when the block has been written. On devices that verify the writing, channel end may or may not be delayed until verification is performed, depending on the device. When magnetic tape is being read, channel end occurs when the gap on tape reaches the read-write head. On devices equipped with buffers, channel end occurs upon completion of data transfer between the channel and the buffer. During control operations, channel end is generated when the control information has been transferred to the devices, although for short operations channel end may be delayed until completion of the operation. Operations that do not cause any data to be transferred can provide channel end during the initiation sequence.

Channel end in the control unit may cause the control unit to appear busy for the initiation of new operations.

Channel end is presented in combination with status modifier and unit check to initiate the command-retry procedure.

Device End

Device end is indicated (1) when the completion of an I/O operation occurs at the device, (2) when the I/O device signals that a change from the not-ready to the ready state has occurred, (3) when the

termination of an activity has occurred which previously caused a response of busy to the channel, and (4) when the I/O device signals that an asynchronous condition has been recognized. Device end normally indicates that the I/O device has become available for use in another operation.

Each I/O operation initiated at the device causes device end, and there is only one device end for an operation. Device end is not generated when any programming or equipment malfunction is detected during initiation of the operation. When command chaining takes place, only the device end of the last operation of the chain is made available to the program unless an unusual condition is detected during the initiation of a chained command, in which case the chain is concluded without device end.

Device end associated with an I/O operation is generated either simultaneously with channel end or later. For data-transfer operations on some I/O devices, the operation is complete at the time channel end is generated, and both device end and channel end occur together. The time at which device end is presented depends upon the I/O device type and the kind of command executed. For most I/O devices, device end is presented when the I/O operation is completed at the I/O device. In some cases, for reasons of performance, device end is presented before the I/O operation has actually been completed at the I/O device. However, in all cases, when device end is presented, the I/O device is available for execution of an immediately following CCW if command chaining was specified in the previous CCW. During execution of control commands, device end may be presented with channel end or later.

When command chaining is specified, receipt of the device-end signal, in the absence of any unusual situations, causes the channel to initiate a new I/O operation.

When the state of a device is changed from not ready to ready, either device end or device end, attention, and unit exception are indicated. Refer to the SL manual for the I/O device to determine which indication is given.

A device is considered to be not-ready when operator intervention is required in order to make the device ready. A not-ready condition can occur, for example, because of any of the following:

1. An unloaded condition for magnetic tape
2. Card equipment out of cards or with the stacker full
3. A printer out of paper

4. Error conditions that need operator intervention
5. The unit having changed from the enabled to the disabled state

| Device end is also accompanied by other
| status where conditions are recognized that
| are unrelated to the execution of an I/O
| operation.

Unit Check

Unit check indicates that the I/O device or control unit has detected an unusual situation that is detailed by the information available to a sense command. Unit check may indicate that a programming or equipment error has been detected, that the not-ready state of the device has affected the execution of the command or instruction, or that an exceptional situation other than the one identified by unit exception has occurred. The unit-check bit provides a summary indication of the sense data.

An error causes the unit-check indication when it occurs during the execution of a command or TEST I/O, or during some activity associated with an I/O operation. Unless the error pertains to the activity initiated by a command and is of immediate significance to the program, the error does not cause the program to be alerted after device end has been cleared; a malfunction may, however, cause the device to become not ready.

Unit check is indicated when the existence of the not-ready state precludes a satisfactory execution of the command, or when the command, by its nature, tests the state of the device. When no interruption condition is pending for the addressed device at the control unit, the control unit signals unit check when TEST I/O or the no-operation control command is issued to a not-ready device. In the case of no-operation, the command is rejected, and channel end and device end do not accompany unit check.

Unless the command is designed to cause unit check, such as rewind and unload on magnetic tape, unit check is not indicated if the command is properly executed even though the device has become not ready during or as a result of the operation. Similarly, unit check is not indicated if the command can be executed with the device not ready. Selection of a device that is not ready does not cause a unit check when the sense command is issued or when an interruption condition is pending for the addressed device at the control unit.

If the device detects during the initiation sequence that the command cannot be executed, unit check is signaled to the channel without channel end, control-unit end, or device end. Such unit status indicates that no action has been taken at the device in response to the command. If the situation precluding proper execution of the operation occurs after execution has been started, unit check is accompanied by channel end, control-unit end, or device end, depending on when the situation was detected. Any errors associated with an operation, but detected after device end has been cleared, are indicated by signaling unit check with attention.

Errors, such as invalid command code or invalid command-code parity, do not cause unit check when the device is working or contains an interruption condition at the time of selection. Under these circumstances, the device responds by providing busy status and indicating the interruption condition, if any. The command-code invalidity is not indicated.

Concluding an operation with the unit-check indication causes command chaining to be suppressed.

Unit check is presented in combination with channel end and status modifier to initiate the command-retry procedure.

Programming Notes

1. If a device becomes not ready upon completion of a command, the ending interruption condition can be cleared by TEST I/O without generation of unit check due to the not-ready state, but any subsequent TEST I/O issued to the device causes a unit-check indication.
2. In order that sense indications set in conjunction with unit check are preserved by the device until requested by a sense command, some devices inhibit certain functions until a command other than test I/O or no-operation is received. Furthermore, any command other than sense, test I/O, or no-operation causes the device to reset any sense information. To avoid degradation of the device and its control unit and to avoid inadvertent resetting of the sense information, a sense command should be issued immediately to any device signaling unit check.
3. Unit-check status presented either in the absence of or accompanied by other status indicates only that sense information is available to the basic

sense command. Presentation of either channel end and unit check or channel end, device end, and unit check does not provide any indication as to the kind of conditions encountered by the control unit, the state of the I/O device, or whether execution of the I/O operation ever was initiated. Descriptions of these conditions or states are provided in the sense information.

Unit Exception

Unit exception is caused when the I/O device detects a situation that usually does not occur. Unit exception includes situations such as recognition of a tape mark and does not necessarily indicate an error. During execution of an I/O operation, unit exception has only one meaning for any particular command and type of device.

Unit exception may be generated when the device is executing an I/O operation, or when the device is involved with some activity associated with an I/O operation and the condition is of immediate significance to the program. If the device detects during the initiation sequence that the operation cannot be executed, unit exception is presented to the channel and appears without channel end, control-unit end, or device end. Such unit status indicates that no action has been taken at the device in response to the command. If the condition precluding normal execution of the operation occurs after the I/O operation has been initiated, unit exception is accompanied by channel end, control-unit end, or device end, depending on when the situation was detected. Any unusual condition associated with an I/O operation, but detected after device end has been cleared, is indicated by signaling unit exception with attention.

If the I/O device responds with busy status to a command, the generation of unit exception is suppressed even when execution of that command usually causes unit exception to be indicated.

Concluding an operation with the unit-exception indication causes command chaining to be suppressed.

Some devices present unit exception accompanied by device end and attention whenever a device changes from the not-ready state to the ready state. (See "Device End" in this chapter.)

CHANNEL STATUS

The following status bits are generated by the channel. Except for the status bits resulting from equipment malfunction, they can occur only while the subchannel is involved with the execution of an I/O operation.

Program-Controlled Interruption

A program-controlled interruption occurs when the channel fetches a CCW with the program-controlled-interruption (PCI) flag set to one. The I/O interruption due to the PCI flag takes place as soon as possible after the CCW takes control of the operation but may be delayed an unpredictable amount of time because I/O interruptions are disallowed or because of other activity in the system.

The interruption condition due to the PCI flag does not affect the progress of the I/O operation.

Incorrect Length

Incorrect length occurs when the number of bytes contained in the storage areas assigned for the I/O operation is not equal to the number of bytes requested or offered by the I/O device. Incorrect length is indicated for one of the following reasons:

Long Block on Input: During a read, read-backward, or sense operation, the device attempted to transfer one or more bytes to storage after the assigned storage areas were filled. The extra bytes have not been placed in storage. The count in the CSW is zero.

Long Block on Output: During a write or control operation, the device requested one or more bytes from the channel after the assigned storage areas were exhausted. The count in the CSW is zero.

Short Block on Input: The number of bytes transferred during a read, read-backward, or sense operation is insufficient to fill the storage areas assigned to the operation. The count in the CSW is not zero.

Short Block on Output: The device terminated a write or control operation before all information contained in the assigned storage areas was transferred to the device. The count in the CSW is not zero.

Incorrect length is not indicated when the current CCW has the SLI flag set to one and the CD flag set to zero. The indication does not occur for immediate operations and for operations rejected during the initiation sequence.

When incorrect length occurs, command chaining is suppressed, unless the SLI flag in the CCW is one or unless the operation is immediate. See the figure "Channel-Chaining Action" in this chapter for the effect of the CD, CC, and SLI flags on the indication of incorrect length.

Programming Note

The setting of incorrect length is unpredictable in the CSW stored during CLEAR I/O.

Program Check

Program check occurs when programming errors are detected by the channel. Program check can be due to the following causes:

Invalid CCW-Address Specification: The CAW or the transfer-in-channel command does not designate the CCW on integral boundaries for doublewords. The three rightmost bits of the CCW address are not zeros.

Invalid CCW Address: The channel has attempted to fetch a CCW from a storage location which is not available to the channel. An invalid CCW address can occur in the channel because the program has specified an invalid address in the CAW or in the transfer-in-channel command or because on chaining the channel has attempted to fetch a CCW from an unavailable location.

Invalid Command Code: The command code in the first CCW designated by the CAW or in a CCW fetched on command chaining has four low-order zeros. The command code is not tested for validity during data chaining.

Invalid Count: A CCW other than a CCW specifying transfer in channel contains the value zero in bit positions 48-63.

Invalid IDAW-Address Specification: Channel indirect data addressing is specified, and the data address does not designate the first IDAW on an integral word boundary.

Invalid IDAW Address: The channel has attempted to fetch an IDAW from a storage location which is not available to the

channel. An invalid IDAW address can occur in the channel because the program has specified an invalid address in a CCW that specifies indirect data addressing or because the channel, on sequentially fetching IDAWs, has attempted to fetch from an unavailable location.

Invalid Data Address: The channel has attempted to transfer data to or from a storage location which is not available to the channel. An invalid data address can occur in the channel because the program has specified an invalid address in the CCW, or in an IDAW, or because the channel, on sequentially accessing storage, has attempted to access an unavailable location.

Invalid IDAW Specification: Bits 0-7 of the IDAW are not all zeros, or the second or subsequent IDAW does not specify the first or, for read-backward operations, the last byte of a 2,048-byte storage block.

Invalid CAW Format: The CAW does not contain zeros in bit positions 4-7.

Invalid CCW Format: A CCW other than a CCW specifying transfer in channel does not contain zeros in bit positions 38-39.

Invalid Sequence: The first CCW designated by the CAW specifies transfer in channel, or the channel has fetched two successive CCWs both of which specify transfer in channel.

Detection of program check during the initiation of an operation causes execution of the operation to be suppressed. When program check is detected after the operation has been initiated at the device, the device is signaled to conclude the operation the next time it requests or offers a byte of data. Program check causes command chaining to be suppressed.

Protection Check

Protection check occurs when the channel attempts a storage access that is prohibited by key-controlled storage protection. Protection applies to the fetching of CCWs, IDAWs, and output data, and to the storing of input data. Storage accesses associated with each channel program are performed using the subchannel key provided in the CAW associated with that channel program. For details, see the section "Key-Controlled Protection" in Chapter 3, "Storage."

When protection check occurs during the fetching of a CCW that specifies the initiation of an I/O operation, or occurs

during the fetching of the first IDAW, the operation is not initiated. When protection check is detected after the operation has been initiated at the device, the device is signaled to conclude the operation the next time it requests or offers a byte of data. Protection check causes command chaining to be suppressed.

Channel-Data Check

Channel-data check indicates that a machine error has been detected in the information transferred to or from storage during an I/O operation, or that a parity error has been detected on the data on bus-in during an input operation. This information includes the data read or written, as well as the information transferred as data during a sense or control operation. The error may have been detected in the channel, in storage, or on the path between the two. Channel-data check may be indicated for data with an invalid checking-block code in storage when the data is referred to by the channel but the data does not participate in the operation.

Whenever a parity error on I/O input data is indicated by means of channel-data check, the channel forces correct parity on all data received from the I/O device, and all data placed in storage has valid checking-block code. When, on an input operation, the channel attempts to store less than a complete checking block, and when invalid checking-block code is detected on the checking block in storage, the contents of the location remain unchanged with invalid checking-block code. On an output operation, whenever a channel-data check is indicated, all bytes that came from a checking block with invalid checking-block code have been transmitted with parity errors.

Channel-data check causes command chaining to be suppressed but does not affect the execution of the current operation. Data transfer proceeds to normal completion, if possible, and an interruption condition is generated when the device presents channel end. A logout may be performed, depending on the channel. Accordingly, the detection of the error may affect the state of the channel and the device.

Channel-Control Check

Channel-control check is caused by machine malfunction affecting channel controls. It may be caused by invalid checking-block

code on CCW and data addresses and invalid checking-block code on the contents of the CCW. Channel-control check may also include those channel-detected errors associated with data transfer that are not indicated as channel-data check, as well as those I/O interface errors detected by the channel that are not indicated as interface-control check. Errors responsible for channel-control check may cause the contents of the CSW to be invalid and conflicting. The CSW as generated by the channel has valid checking-block code.

Detection of channel-control check causes the current operation, if any, to be immediately concluded.

Channel-control check is set whenever CSW bit 5, logout pending, is set to one.

In some situations, machine malfunctions affecting channel control may instead be reported as an external-damage or system-damage machine-check condition.

Interface-Control Check

Interface-control check indicates that an invalid signal has been received by the channel when communicating with a control unit or device. This check is detected by the channel and usually indicates malfunctioning of an I/O device. It can be due to the following:

1. The address or status byte received from a device has invalid parity.
2. A device responded with an address other than the address specified by the channel during initiation of an operation.
3. During command chaining the device appeared not operational.
4. A signal from a device occurred at an invalid time or had invalid duration.
5. A device signaled I/O error alert.

The interface-control-check condition may also include those channel-detected errors associated with bus-in during data transfer that are not indicated as channel-data check.

Detection of interface-control check causes the current operation, if any, to be immediately concluded.

Chaining Check

Chaining check is caused by channel overrun during data chaining on input operations. Chaining check occurs when the I/O data rate is too high to be handled by the channel and by storage under current conditions. Chaining check cannot occur on output operations.

Chaining check causes the I/O device to be signaled to conclude the operation. It causes command chaining to be suppressed.

CONTENTS OF CHANNEL-STATUS WORD

The contents of the CSW depend on the reason the CSW was stored and on the programming method by which the information is obtained. The status portion always identifies the reason the CSW was stored. The subchannel-key, CCW-address, and count fields may contain information pertaining to the last operation or may be set to zero, or the original contents of these fields at location 64 may be left unchanged.

Information Provided by Channel-Status Word

Interruption conditions resulting from the execution or conclusion of an operation at the subchannel cause the whole CSW to be replaced. Such a CSW can be stored only by an I/O interruption or by TEST I/O or CLEAR I/O. Except for situations associated with command chaining and equipment malfunctioning, the storing can be caused by PCI or channel end and by the execution of HALT I/O or HALT DEVICE on the selector channel. The contents of the CSW are related to the current values of the corresponding quantities, although the count is unpredictable after program check, protection check, and chaining check, and after an interruption due to the PCI flag.

A CSW stored upon the execution of a chain of operations pertains to the last operation which the channel executed or attempted to initiate. Information concerning the preceding operations is not preserved and is not made available to the program.

When an unusual situation causes command chaining to be suppressed, the premature conclusion of the chain is not explicitly indicated in the CSW. A CSW associated with a conclusion due to a situation occurring at channel-end time contains channel end and identifies the unusual

situation. When the device signals the unusual situation with control-unit end or device end, the channel-end indication is not made available to the program, and the channel provides the current subchannel key, CCW address, and count, as well as the unusual indication, with control-unit end or device end in the CSW. The CCW-address and count fields pertain to the operation that was executed.

When the execution of a chain of commands is concluded by an unusual situation detected during initiation of a new operation, the CCW-address and count fields pertain to the rejected command. Except for situations resulting from equipment malfunctioning, conclusion at initiation time can occur because of attention, unit check, unit exception, or program check, and causes both the channel-end and device-end bits in the CSW to be set to zeros.

A CSW associated with status signaled after the operation at the subchannel has been concluded contains zeros in the subchannel-key, CCW-address, and count fields, provided the status is not cleared during START I/O or START I/O FAST RELEASE and provided logout pending is not indicated. This status includes attention, control-unit end, and device end (and channel end when it occurs after the conclusion of an operation on the selector channel by HALT I/O or HALT DEVICE).

When the above status indications, other than logout pending, are cleared during START I/O or START I/O FAST RELEASE, only the status portion of the CSW is stored, and the original contents of the subchannel-key, CCW-address, deferred-condition-code, logout-pending, and count fields in location 64 are preserved. Similarly, only the status bits of the CSW are changed when the command is rejected or the operation at the subchannel is concluded during the execution of START I/O or START I/O FAST RELEASE or whenever HALT I/O or HALT DEVICE causes CSW status to be stored.

Errors detected during execution of the I/O operation do not affect the validity of the CSW unless channel-control check or interface-control check are indicated. Channel-control check indicates that equipment errors have been detected which can cause any part of the CSW, as well as the I/O address, to be invalid. Interface-control check indicates that the address identifying the device or the status bits received from the device may be invalid. The channel forces correct parity on invalid CSW fields. The validity of these fields can be ascertained by inspecting the limited channel logout.

When any I/O instruction cannot be executed because of a pending logout which affects the operational capability of the channel or subchannel, a full CSW is stored. The fields in the CSW are all set to zeros, with the exception of the logout-pending bit and the channel-control-check bit, which are set to ones.

Subchannel Key

A CSW stored to reflect the progress of an operation at the subchannel contains the subchannel key used in that operation. The contents of this field are not affected by programming errors detected by the channel or by the situations causing termination of the operation.

CCW Address

When the CSW is formed to reflect the progress of the I/O operation at the subchannel, the CCW address is normally 8 higher than the address of the last CCW used in the operation.

The figure "Contents of the CCW-Address Field in the CSW" lists the contents of the CCW-address field for all situations that can cause the CSW to be stored. They are listed in order of priority; that is, if two situations occur, the CSW appears as indicated for the situation higher on the list. When a CSW has been stored and the situation exists that a command-retry request has been recognized but the CCW has not been re-executed, the "last-used CCW + 8" is the CCW that is to be retried.

| Situations | Contents of Field |
|--|--|
| Channel-control check | Unpredictable |
| Status stored by START I/O or START I/O FAST RELEASE | Unchanged |
| Status stored by HALT I/O or HALT DEVICE | Unchanged |
| Invalid CCW-address spec in transfer in channel (TIC) | Address of TIC + 8 |
| Invalid CCW address in TIC | Address of TIC + 8 |
| Invalid CCW address generated | First invalid CCW address + 8 |
| Invalid command code | Address of invalid CCW + 8 |
| Invalid count | Address of invalid CCW + 8 |
| Invalid data address | Address of invalid CCW + 8 |
| Invalid CCW format | Address of invalid CCW + 8 |
| Invalid sequence - 2 TICs | Address of second TIC + 8 |
| Invalid key on CCW fetch | Address of protected CCW + 8 |
| Invalid key on data or IDAW access | Address of current CCW + 8 |
| Chaining check | Address of last-used CCW + 8 |
| Termination under count control | Address of last-used CCW + 8 |
| Termination by I/O device | Address of last-used CCW + 8 |
| Termination by HALT I/O | Address of last-used CCW + 8 |
| Termination by CLEAR I/O | Address of last-used CCW + 8 |
| Suppression of command chaining due to unit check or unit exception with de- vice end or control-unit end | Address of last CCW used in the completed operation + 8 |
| Termination on command chaining by busy, unit check, or unit exception | Address of CCW specifying the new operation + 8 |
| Deferred condition code 1 or 3 | Address of CCW specifying the new operation + 8 |
| PCI flag in CCW | Address of last-used CCW + 8 |
| Interface control check | Unpredictable |
| Channel end after HALT I/O on selector channel | Zero |
| Channel end after CLEAR I/O | Zero |
| Control-unit end | Zero |
| Device end | Zero |
| Attention | Zero |
| Busy | Zero |
| Status modifier | Zero |

Contents of the CCW-Address Field in the CSW

Count

The residual count, in conjunction with the original count specified in the last CCW used, indicates the number of bytes transferred to or from the area designated by the CCW. When an input operation is concluded, the difference between the original count in the CCW and the residual count in the CSW is equal to the number of bytes transferred to storage; on an output

operation, the difference is equal to the number of bytes transferred to the I/O device.

The figure "Contents of the Count Field in the CSW" lists the contents of the count field for all situations that can cause the CSW to be stored. They are listed in the order of priority; that is, if two situations occur, the CSW appears as for the situation higher on the list.

| Situations | Contents of Field |
|--|--|
| Channel-control check | Unpredictable |
| Status stored by START I/C or START I/O FAST RELEASE | Unchanged |
| Status stored by HALT I/O or HALT DEVICE | Unchanged |
| Program check | Unpredictable |
| Protection check | Unpredictable |
| Chaining check | Unpredictable |
| Termination under count control | Correct |
| Termination by I/O device | Correct |
| Termination by HALT I/C or HALT DEVICE | Unpredictable |
| Termination by CLEAR I/O | Unpredictable |
| Suppression of command chaining due to unit check or unit exception with device end or control-unit end | Correct. Residual count of last CCW used in the completed operation. |
| Termination on command chaining by busy, unit check, or unit exception | Correct. Original count of CCW specifying the new operation. |
| Deferred condition code 1 or 3 | Correct. Original count of CCW specifying the new operation. |
| PCI flag in CCW | Unpredictable |
| Interface-control check | Unpredictable |
| Channel end after HALT I/C on selector channel | Zero |
| Channel end after CLEAR I/C | Zero |
| Control-unit end | Zero |
| Device end | Zero |
| Attention | Zero |
| Busy | Zero |
| Status modifier | Zero |

Contents of the Count Field in the CSW

Status

The status bits identify the situations that have been detected during the I/O operation, that have caused a command to be rejected, or that have been generated by external events.

When the channel detects several errors, all corresponding status bits in the CSW may be set to ones or only one may be set, depending on the error and model. Errors associated with equipment malfunctioning have precedence, and whenever malfunctioning causes an operation to be terminated, channel-control check, interface-control check, or channel-data check is indicated, depending on the error. When an operation is concluded by program check, protection check, or chaining check, the channel identifies the situation responsible for the conclusion and may or may not indicate incorrect length. When a data error has been detected and the operation is concluded prematurely because of a program check, protection check, or chaining check, both data check and the programming error are identified.

If the CCW fetched on command chaining has the PCI flag set to one but a programming error in the contents of the CCW precludes the initiation of the operation, it is unpredictable whether the PCI bit is one in the CSW associated with the interruption condition. Similarly, if a programming error in the contents of the CCW causes the command to be rejected during execution of START I/O or START I/O FAST RELEASE, the CSW stored by the instruction may or may not have the PCI bit set to one. Furthermore, when the channel detects a programming error in the CAW or in the first CCW, the PCI bit is unpredictable in a CSW stored by START I/O or START I/O FAST RELEASE even when the PCI flag is zero in the first CCW associated with the instruction.

However, if the CCW fetched on command chaining has the PCI flag set to one but an unusual situation detected by the device precludes the initiation of the operation, the PCI bit is one in the CSW associated with the interruption condition. Likewise, if device status causes the command to be rejected during execution of START I/O or START I/O FAST RELEASE, the CSW stored by

the instruction contains the PCI bit set to one.

Situations detected by the channel are not related to those identified by the I/O device.

The figure "Contents of the CSW Status Fields" summarizes the handling of status bits. The figure lists the states and activities that can cause status indications to be created and the methods by which these indications can be placed in the CSW.

CHANNEL LOGOUT

When a channel stores a CSW that indicates channel-control check in the absence of logout pending, or interface-control check, or, on some channels, channel-data check, a channel logout accompanies the storing of the CSW. Such a logout is useful for error recovery. The logout may be a limited channel logout, a full channel logout, or both. The type of logout that occurs and, for the full channel logout, the length of the full channel logout and the location at which it is stored, depend on the channel

type and model number.

The limited channel logout contains model-independent information and is stored at real locations 176-179 of the CPU to which the channel is configured. When it is stored, bit 0 of the logout is always stored as a zero.

The full channel logout contains model-dependent information. When the length of the full channel logout exceeds 96 bytes, it is stored at the location specified by the I/O extended-logout (IOEL) address in real locations 173-175 of the CPU to which the channel is configured. When the length of the full channel logout is 96 bytes or fewer, the channel may either use the IOEL address or store the full channel logout in the fixed-logout area, real locations 256-351 of the CPU to which the channel is configured. The information stored by the STORE CHANNEL ID instruction implies whether the IOEL is used and, if it is used, specifies the maximum full-channel-logout length. The full-channel-logout information may be stored in the IOEL area only when the IOEL-mask bit (control register 14, bit 2) of the CPU to which the channel is configured is one.

| Status | When I/O is Idle | When Subch is Working | Upon Termination of Operation at | | | During Cmd Chain- ing | By SIO or SIOF | | By CLRIO + | By HIO or HDV | By I/O Inter- ruption | |
|---------------------------------|------------------|-----------------------|----------------------------------|-----------|---------|-----------------------|----------------|-----|------------|---------------|-----------------------|----|
| | | | Subch | Ctrl Unit | I/O Dev | | S | S | | | | |
| Attention | C* | | | | | C* | C* | S | S | S | S | |
| Status modifier | | | | | | C | C | CS | CS | S | CS | S |
| Control-unit end | | | | C* | | | | CS | CS | S | CS | S |
| Busy | | | | | | C | | CS | CS | S | CS | S |
| Channel end | | | C* | C*H | | | C*# | CS# | S | S | | S |
| Device end | C* | | | | | C* | C # | CS# | S | S | | S |
| Unit check | C | | C | C | C | C | C* | CS | CS | S | | CS |
| Unit exception | | | C | C | C | C | C* | CS | S | S | | S |
| Program-controlled interruption | | C* | C* | | | C | | CS | S | S | | S |
| Incorrect length | | C | C | | | | | | S | S | | S |
| Program check | | C | C | | | | C* | CS | S | S | | S |
| Protection check | | C | C | | | | C* | CS | S | S | | S |
| Channel-data check | | C | C | | | | | | S | S | | S |
| Channel-control check | C* | C* | C* | C* | C* | C* | C* | CS | CS | CS | CS | CS |
| Interface-control check | C* | C* | C* | C* | C* | C* | C* | CS | CS | CS | CS | CS |
| Chaining check | | C | C | | | | | | S | S | | S |
| Deferred cond code 1 | | | | | | | | C** | S | S | | S |
| Deferred cond code 3 | | | | | | | | C** | S | S | | S |

Explanation:

C The channel or device can create or present status at the indicated time. A CSW or its status portion is not necessarily stored at this time.

Status such as channel end or device end is created at the indicated time. Other status bits may have been created previously but are made accessible to the program only at the indicated time. Examples of such status bits are program check and channel-data check, which are detected while data is transferred but are made available to the program only with channel end, unless the PCI flag or an equipment malfunction has caused an interruption condition to be generated earlier.

S The status indication is stored in the CSW at the indicated time.

An "S" appearing alone indicates that the status has been created previously. The letter "C" appearing with the "S" indicates that the status did not necessarily exist previously in the form that causes the program to be alerted, and may have been created by the I/O instruction or I/O interruption. For example, an equipment malfunction may be detected during an I/O interruption, causing channel-control or interface-control check to be indicated; or a device such as the 2702 may signal control-unit busy in response to interrogation by an I/O instruction, causing status modifier, busy, and control-unit end to be indicated in the CSW.

* The status generates an interruption condition.

Channel end and device end do not result in interruption conditions when command chaining is specified and no unusual situations have been detected.

This indication is created at the indicated time only by an immediate operation.

Applies only to SIOF.

H When an operation on the selector channel has been concluded by HALT DEVICE or HALT I/O, or an operation has been concluded by CLEAR I/O, channel end indicates the conclusion of the data-handling portion of the operation at the control unit.

+ The entries in this column apply only when the CLRIO function is executed. When CLEAR I/O causes the TIO function to be executed, the entries in the TIO column apply.

I/O-COMMUNICATION AREA

Real locations 160-191 of the CPU to which the channel is configured comprise a permanently assigned area of storage used for I/O, designated the I/O-communication area (IOCA). (See the figure "I/O-Communication Area.")

Locations 160-167, 180-184, and 188-191 are reserved for future I/O use.

Channel ID (Locations 168-171): Locations 168-171, when stored during the execution of a STORE CHANNEL ID instruction, contain information which describes the addressed channel.

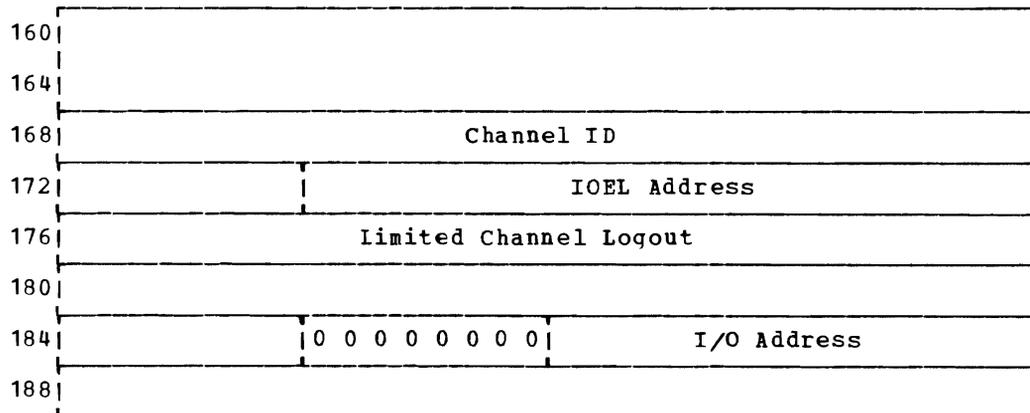
I/O Extended-Logout Address (Locations 173-175): The I/O extended-logout (IOEL) address (locations 173-175) is program-set to designate an area to be used by channels not capable of storing or not choosing to store the full channel logout in the fixed-logout area (locations 256-351). The low-order three bits of the I/O-extended-logout address are reserved

and are ignored by the channel so that the full channel logout always begins on a doubleword boundary.

Whether the IOEL facility is used depends on the channel type and model number. Channels with a full-channel-logout length not exceeding 96 bytes use either the IOEL area or locations 256-351 as the full-channel-logout area. Channels with a full-channel-logout length exceeding 96 bytes use the IOEL area.

Programming Note

The extent of the full-channel-logout area differs among channels and, for any particular channel, may depend on the features or engineering changes installed. In order to provide for such variations, the program should determine the extent of the full channel logout by means of STORE CHANNEL ID whenever a storage area for the full channel logout is to be assigned.



I/O-Communication Area

Limited Channel Logout (Locations 176-179): The limited-channel-logout field (locations 176-179) contains model-independent information related to equipment errors detected by the channel. This information is used to provide detailed machine status when errors have affected I/O operations. The field may be stored only when the CSW or a portion of the CSW is stored.

The limited-channel-logout facility may not be available on all channels. The field, if stored, may or may not be accompanied by the full channel logout. Channels which do not store the limited-channel-logout field instead usually store equivalent information in the full channel logout.

The bits of the field are defined as follows:

0 This bit is always stored as a zero when a limited channel logout is stored. If the program ensures that this bit is set to one and any channel-control check, interface-control check, or channel-data check occurs, a test of this bit can determine if the LCL was stored by the channel. The ICL cannot be stored by a channel unless one of these three channel-status bits is set to one.

1-3 Identity of the storage-control unit (SCU) identifies the SCU through which storage references were directed when an error was detected. This identity is not necessarily the identity of the storage unit involved with the transfer. When only one physical path exists between channel and storage, the storage-control unit has the identity of the CPU. If more than one path exists, the storage-control unit has its own identity.

When bit 3 is zero, bits 1 and 2 are undefined. In this case, the SCU identity is implied to be the same as the CPU identity. When bit 3 is one, the binary value of bits 1 and 2 identifies a physical SCU. Each SCU in the system has a unique identity.

4-7 Detect field identifies the type of unit that detected the error. At least one bit is present in this field, and multiple bits may be set when more than one unit detects the error.

Bit 4 -- CPU
 Bit 5 -- Channel
 Bit 6 -- Main-storage control

Bit 7 -- Main storage

8-12 Source field indicates the most likely source of the error. The determination is made by the channel on the basis of the type of error check, the location of the checking station, the information flow path, and the success or failure of transmission through previous check stations.

Normally, only one bit will be present in this field. However, when interunit communication cannot be resolved to a single unit, such as when the interface between units is at fault, multiple bits (normally two) may be set to ones in this field. When a reasonable determination cannot be made, all bits in this field are set to zeros.

If the detect and source fields indicate different units, the interface between them can also be considered suspect.

Bit 8 -- CPU
 Bit 9 -- Channel
 Bit 10 -- Main-storage control
 Bit 11 -- Main storage
 Bit 12 -- Control unit

13-14 Reserved. Stored zero.

15-23 Field-Validity flags. These bits indicate the validity of the information stored in the designated fields. When the validity bit is set to one, the field is stored and usable. When the validity bit is set to zero, the field is not usable.

The fields designated are:

Bit 15 -- Full channel logout. This bit is set to one, by some models that implement the clear-channel feature, when full-channel-logout information with correct contents is stored by the channel. Otherwise, the bit is stored as zero.

Bit 16 -- Reserved. Stored zero.
 Bit 17 -- Reserved. Stored zero.
 Bit 18 -- Reserved. Stored zero.
 Bit 19 -- Sequence code
 Bit 20 -- Unit status
 Bit 21 -- CCW address and sub-channel key in CSW
 Bit 22 -- Channel address
 Bit 23 -- Device address

24-25 Type of termination that has

occurred is indicated by these two bits.

This encoded field has meaning only when a channel-control check or an interface-control check is indicated in the CSW. When neither of these two checks is indicated, no termination has been forced by the channel.

- 00 Interface disconnect
- 01 Stop, stack, or normal termination
- 10 Selective reset

11 System reset

26 Reserved. Stored zero.

27 Interface Inoperative. When the clear-channel feature is installed, this bit is set to one when the channel detects an I/O-interface malfunction which persists after selective reset is signaled on the interface. Interface-control check is also set when this condition is detected. When the clear-channel feature is not installed, bit 27 is stored as zero.

Programming Note: This bit implies that devices involved in active I/O operations related to the identified channel may have been left in the working state. CLEAR CHANNEL addressed to that channel can be used to relieve the condition.

28 I/O-error alert. This bit, when set to one, indicates that the limited channel logout resulted from the signaling of I/O-error alert by the indicated unit. The I/O-error-alert signal indicates that the control unit has detected a malfunction which prevents it from communicating properly with the channel. The channel, in response, performs a malfunction reset and causes interface-control check to be set.

29-31 Sequence code identifies the I/O sequence in progress at the time of error. It is meaningless if stored during the execution of HALT I/O or HALT DEVICE.

For all cases, the CCW address in the CSW, if validly stored and nonzero, is the address of the current CCW plus 8.

The sequence code assignments are:

- 000 A channel-detected error

occurred during the execution of a TEST I/O or CLEAR I/O instruction.

001 Command-out with a nonzero command byte on bus-out has been sent by the channel, but device status has not yet been analyzed by the channel. This code is set with a command-out response to address-in during initial selection.

010 The command has been accepted by the device, but no data has been transferred. This code is set by a service-out or command-out response to status-in during an initial selection sequence, if the status is either channel end alone, or channel end and device end, or channel end, device end, and status modifier, or all zeros.

011 At least one byte of data has been transferred between the channel and the device. This code is set with a service-out response to service-in and, when appropriate, may be used when the channel is in an idle or polling state.

100 The command in the current CCW has either not yet been sent to the device or else was sent but not accepted by the device. This code is set when one of the following situations occurs:

1. When the CCW address is updated during command chaining or a START I/O.
2. When service-out or command-out is raised in response to status-in during an initial selection sequence with the status on bus-in including attention, control-unit end, unit check, unit exception, busy, status modifier (without channel end and device end), or device end (without channel end).
3. When a short, control-unit-busy sequence is signaled.
4. When command retry is signaled.
5. When the channel issues a test-I/O command rather than the command in the

current CCW.

101 The command has been accepted, but data transfer is unpredictable. This code applies from the time a device comes on the interface until the time it is determined that a new sequence code applies. The code may thus be used when a channel goes into the polling or idle state and it is impossible to determine that code 010 or 011 applies. The code may also be used at other times when a channel cannot distinguish between code 010 or

011.

110 Reserved.

111 Reserved.

Reserved (Location 185): Zero is stored at location 185 whenever an I/O address is stored at locations 186-187.

I/O Address (Locations 186-187): A two-byte field is provided for storing the I/O address on each I/O interruption in the EC mode.

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MANUAL OPERATION

The operator facilities provide functions for the manual operation and control of the machine. The functions include operator-to-machine communication, indication of machine status, control over the setting of the TOD clock, initial program loading, resets, and other manual controls for operator intervention in normal machine operation.

A model may provide additional operator facilities which are not described in this chapter. Examples are the means to indicate specific error conditions in the equipment, to change equipment configurations, and to facilitate maintenance. Furthermore, controls covered in this chapter may have additional settings which are not described here. Such additional facilities and settings are contained in the appropriate System Library (SL) publication.

Most models provide, in association with the operator facilities, a console device which may be used as an I/O device for operator communication with the program; this console device may also be used to implement some or all of the facilities described in this chapter.

The operator facilities may be implemented on different models in various technologies and configurations. On some models, more than one set of physical representations of some keys, controls, and indicators may be provided, such as on multiple local or remote operating stations, which may be effective concurrently.

A machine malfunction that prevents a manual operation from being performed correctly, as defined for that operation, may cause the CPU to enter the check-stop state or give some other indication to the operator that the operation has failed. Alternatively, a machine malfunction may cause a machine-check-interruption condition to be recognized.

BASIC OPERATOR FACILITIES

ADDRESS-COMPARE CONTROLS

The address-compare controls provide a way to stop the CPU when a preset address matches the address used in a specified type of main-storage reference.

One of the address-compare controls is used to set up the address to be compared with the storage address.

Another control provides at least two settings to specify the action, if any, to be taken when the address match occurs. The two settings are normal and stop. When this control is set to stop, the test indicator is turned on.

1. The normal setting disables the address-compare operation.
2. The stop setting causes the CPU to enter the stopped state on an address match. Depending on the model and the type of reference, pending I/O, external, and machine-check interruptions may or may not be taken before entering the stopped state.

A third control may specify the type of storage reference for which the address comparison is to be made. A model may provide one or more of the following settings, as well as others:

1. The any setting causes the address comparison to be performed on all storage references.
2. The data-store setting causes address comparison to be performed when storage is addressed to store data.
3. The I/O setting causes address comparison to be performed when storage is addressed by a channel to transfer data or to fetch a channel-command or indirect-data-address word. Whether references to the channel-address word or the channel-status word cause a match to be indicated depends on the model.
4. The instruction-address setting causes address comparison to be performed when storage is addressed to fetch an instruction. The rightmost bit of the address setting may or may not be ignored. The match is indicated only when the first byte of the instruction is fetched from the selected location. It depends on the model whether a

match is indicated when fetching the target instruction of EXECUTE.

Depending on the model and the type of reference, address comparison may be performed on virtual, real, or absolute addresses, and it may be possible to specify the type of address.

In a multiprocessing configuration, it depends on the model whether the address setting applies to one or all CPUs in the configuration and whether an address match causes one or all CPUs in the configuration to stop.

ALTER-AND-DISPLAY CONTROLS

The operator facilities provide controls and procedures to permit the operator to alter and display the contents of locations in storage, the storage keys, the general, floating-point, and control registers, the prefix, and the PSW.

Before alter-and-display operations may be performed, the CPU must first be placed in the stopped state. During alter-and-display operations, the manual indicator may be turned off temporarily, and the start and restart keys may be inoperative.

Addresses used to select storage locations for alter-and-display operations are real addresses. The capability of specifying logical, virtual, or absolute addresses may also be provided.

CHECK CONTROL

The check control has at least two settings, stop and normal. If the control is set to stop, the CPU enters the check-stop state when either:

1. A machine-check condition is detected and not corrected
2. A channel check occurs which would cause information to be stored in a channel-logout area at real locations 176-179 or 256-351

| The following actions associated with
| entering the check-stop state are model-
| dependent: storing of information in
| assigned storage locations, indicating the
| cause of the stop, and the manner of
| resuming CPU operations.

If the check control is set to normal, the action resulting from the detection of a machine check or channel check is the same

as described in Chapter 11, "Machine-Check Handling," or in Chapter 12, "Input/Output Operations," respectively.

The test indicator is on while the check control is set to stop.

Programming Note

Except that recovery from a machine check or a channel check with logout is not possible, the check control permits a System/360 program, which uses assigned storage locations above 128 as ordinary storage, to be run in the BC mode. The check control also permits running a System/370 program which, while handling a machine check or channel check, expects model-dependent information that is not consistent with the information supplied by the particular model on which the program is to be run.

CHECK-STOP INDICATOR

The check-stop indicator is on when the CPU is in the check-stop state. Reset operations normally cause the CPU to leave the check-stop state and thus turn off the indicator. The manual indicator may also be on in the check-stop state.

IML CONTROLS

The IML controls provided in some models perform initial microprogram loading (IML).

The IML controls are effective while the power is on.

Note: The name IMPL controls was used in earlier descriptions.

INTERRUPT KEY

When the interrupt key is activated, an external-interruption condition indicating the interrupt key is generated. (See the section "Interrupt Key" in Chapter 6, "Interruptions.")

The interrupt key is effective when the CPU is in the operating or stopped state. It depends on the model whether the interrupt key is effective when the CPU is in the load state.

INTERVAL-TIMER CONTROL

The interval-timer control disables or enables operation of the interval timer. Disabling the interval timer does not affect any other facility.

When the control is set to disable the interval timer, updating of assigned storage locations 80-83 ceases. The contents of locations 80-83 remain at the last value to which they were updated, unless changed by a subsequent store operation. Depending on the model, any pending interval-timer-interruption condition is unaffected, is cleared, or is kept pending without regard to the state of the external mask, PSW bit 7, and the interval-timer mask, bit 24 of control register 0.

When the control is set to enable the interval timer, updating of locations 80-83 is resumed using the current contents. If an interval-timer-interruption request existed and was kept pending when the interval-timer control was last set to disable, that condition remains pending until the CPU is enabled for the interruption.

The setting to enable the interval timer is considered the normal setting. The test indicator may or may not be turned on when the interval-timer control is set to disable.

Programming Note

Disabling the interval timer allows execution of a program which uses locations 80-83 as ordinary storage. A program which does not use the interval timer will function correctly with the interval timer disabled, even when the interval timer fails.

LOAD INDICATOR

The load indicator is on during initial program loading, indicating that the CPU is in the load state. The indicator goes on when the load-clear or load-normal key is activated and the corresponding operation is started. It goes off after the new PSW is loaded successfully.

LOAD-CLEAR KEY

Activating the load-clear key causes a clear-reset operation to be performed and initial program loading to be started using the I/O device specified by the load-unit-address controls. In a multiprocessing configuration, a clear reset is propagated to all CPUs in the configuration. For details, see the sections "Resets" and "Initial Program Loading" in Chapter 4, "Control."

The load-clear key is effective when the CPU is in the operating, stopped, load, or check-stop state.

LOAD-NORMAL KEY

Activating the load-normal key causes an initial-CPU-reset and a subsystem-reset operation to be performed and initial program loading to be started using the I/O device specified by the load-unit-address controls. In a multiprocessing configuration, a CPU reset is propagated to all CPUs in the configuration. For details, see the sections "Resets" and "Initial Program Loading" in Chapter 4, "Control."

The load-normal key is effective when the CPU is in the operating, stopped, load, or check-stop state.

LOAD-UNIT-ADDRESS CONTROLS

The load-unit-address controls select three hexadecimal digits, which provide the 12 rightmost I/O address bits used for initial program loading.

MANUAL INDICATOR

The manual indicator is on when the CPU is in the stopped state. Some functions and several manual controls are effective only when the CPU is in the stopped state.

POWER CONTROLS

The power controls are used to turn the power on and off.

The CPUs, storage, channels, operator

facilities, and I/O devices may all have their power turned on and off by common controls, or they may have separate power controls. When a particular unit has its power turned on, that unit is reset. The sequence is performed so that no instructions or I/O operations are performed until explicitly specified. The controls may also permit power to be turned on in stages, but the machine does not become operational until power-on is complete.

When the power is completely turned on, an IML operation is performed on models which have an IML function. A power-on reset is then initiated (see the section "Resets" in Chapter 4, "Control").

RATE CONTROL

The setting of the rate control determines the effect of the start function and the manner in which instructions are executed.

The rate control has at least two settings. The normal setting is process. When the rate control is set to process and the start function is performed, the CPU starts operating at normal speed. When the rate control is set to instruction step, one instruction or, for interruptible instructions, one unit of operation is executed each time the start function is performed. For details, see the section "Stopped, Operating, Load, and Check-Stop States" in Chapter 4, "Control."

The test indicator is on while the rate control is not set to process.

If the setting of the rate control is changed while the CPU is in the operating or load state, the results are unpredictable.

RESTART KEY

Activating the restart key initiates a restart interruption. (See the section "Restart Interruption" in Chapter 6, "Interruptions.")

The restart key is effective when the CPU is in the operating or stopped state. The key is not effective when the CPU is in the check-stop state. It depends on the model whether the restart key is effective when the CPU is in the load state.

START KEY

Activating the start key causes the CPU to perform the start function. (See the section "Stopped, Operating, Load, and Check-Stop States" in Chapter 4, "Control.")

The start key is effective only when the CPU is in the stopped state. The effect is unpredictable when the stopped state has been entered by a reset.

STOP KEY

Activating the stop key causes the CPU to perform the stop function. (See the section "Stopped, Operating, Load, and Check-Stop States" in Chapter 4, "Control.")

The stop key is effective only when the CPU is in the operating state.

Operation Note

Activating the stop key has no effect when:

- An unending string of certain program or external interruptions occurs.
- The prefix register contains an invalid address.
- The CPU is in the load or check-stop state.

STORE-STATUS KEY

Activating the store-status key initiates a store-status operation. (See the section "Store Status" in Chapter 4, "Control.")

The store-status key is effective only when the CPU is in the stopped state.

Operation Note

The store-status operation may be used in conjunction with a standalone dump program for the analysis of major program malfunctions. For such an operation, the following sequence would be called for:

1. Activation of the stop or system-reset-normal key

2. Activation of the store-status key

3. Activation of the load-normal key to enter a standalone dump program

The system-reset-normal key must be activated in step 1 when the stop key is not effective because a continuous string of interruptions occurs, the prefix register contains an invalid address, or the CPU is in the check-stop state.

SYSTEM-RESET-CLEAR KEY

Activating the system-reset-clear key causes a clear-reset operation to be performed. In a multiprocessing configuration, a clear reset is propagated to all CPUs in the configuration. For details, see the section "Resets" in Chapter 4, "Control."

The system-reset-clear key is effective when the CPU is in the operating, stopped, load, or check-stop state.

SYSTEM-RESET-NORMAL KEY

When the store-status facility is not installed, activating the system-reset-normal key causes an initial-CPU-reset operation and a subsystem-reset operation to be performed. When the store-status facility is installed, activating the system-reset-normal key causes a CPU-reset operation and a subsystem-reset operation to be performed. In a multiprocessing configuration, a CPU reset is propagated to all CPUs in the configuration. For details, see the section "Resets" in Chapter 4, "Control."

The system-reset-normal key is effective when the CPU is in the operating, stopped, load, or check-stop state.

TEST INDICATOR

The test indicator is on when a manual control for operation or maintenance is in an abnormal position that can affect the normal operation of a program.

Setting the address-compare controls or the check control to stop or setting the rate control to instruction step turns on the test indicator. Setting the interval-timer control to disable may or may not turn on the test indicator.

The test indicator may be on when one or more diagnostic functions under the control of DIAGNOSE are activated, or when other abnormal conditions occur.

Operation Note

If a manual control is left in a setting intended for maintenance purposes, such an abnormal setting may, among other things, result in false machine-check indications or cause actual machine malfunctions to be ignored. It may also alter other aspects of machine operation, including instruction execution, channel operation, and the functioning of operator controls and indicators, to the extent that operation of the machine does not comply with that described in this publication.

The abnormal setting of a manual control causes the test indicator of the affected CPU to be turned on; however, in a multiprocessing configuration, the operation of other CPUs may be affected even though their test indicators are not turned on.

TOD-CLOCK CONTROL

When the TOD-clock control is not activated, that is, the control is set to secure, the value of the TOD clock is protected against unauthorized or inadvertent change by not permitting the instruction SET CLOCK to change the value.

When the TOD-clock control is activated, that is, the control is set to enable set, alteration of the clock value by means of SET CLOCK is permitted. This setting is temporary, and the control automatically returns to secure.

In a multiprocessing configuration, activating the TOD-clock control enables all TOD clocks in the configuration to be set. If there is more than one physical representation of the TOD-clock control, no TOD clock is secure unless all TOD-clock controls in the configuration are set to secure.

WAIT INDICATOR

The wait indicator is on when the wait-state bit in the current PSW is one.

MULTIPROCESSING CONFIGURATIONS

In a multiprocessing configuration, one of each of the following keys and controls is provided for each CPU: alter and display, interrupt, rate, restart, start, stop, and store status. The load-clear key, load-normal key, and load-unit-address controls are provided for each CPU capable of performing I/O operations. Alternatively, a single set of keys and controls may be used together with a control to select the desired CPU.

There need not be more than one of each of the following keys and controls in a multiprocessing configuration: address compare, check, IML, interval timer, power, system reset clear, system reset normal, and TOD clock.

One check-stop, manual, test, and wait indicator is provided for each CPU. A load indicator is provided only on a CPU capable of performing I/O operations. Alternatively, a single set of indicators may be switched to more than one CPU.

There need not be more than one system indicator in a multiprocessing configuration.

In a system capable of being partitioned, there must be a separate set of keys, controls, and indicators in each configuration.

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NUMBER REPRESENTATION

BINARY INTEGERS

Signed Binary Integers

Signed binary integers are most commonly represented as halfwords (16 bits) or words (32 bits). In both lengths, the leftmost bit (bit 0) is the sign of the number. The remaining bits (bits 1-15 for halfwords and 1-31 for words) are used to designate the magnitude of the number. Binary integers are also referred to as fixed-point numbers, because the radix point is considered to be fixed at the right, and any scaling is done by the programmer.

Positive binary integers are in true binary notation with a zero sign bit. Negative binary integers are in two's-complement notation with a one bit in the sign position. In all cases, the bits between the sign bit and the leftmost significant bit of the integer are the same as the sign bit (that is, all zeros for positive numbers, all ones for negative numbers).

Negative binary integers are formed in

two's-complement notation by inverting each bit of the positive binary integer and adding one. As an example using the halfword format, the binary number with the decimal value +26 is made negative (-26) in the following manner:

```

+26   0 000 0000 0001 1010
Invert 1 111 1111 1110 0101
Add 1   _____ 1
-26   1 111 1111 1110 0110 (Two's complement form)

```

(S is the sign bit.)

This is equivalent to subtracting the number:

```

from      00000000 00011010
          1 00000000 00000000

```

Negative binary integers are changed to positive in the same manner.

The following addition examples illustrate two's-complement arithmetic and overflow conditions. Only eight bit positions are used.

```

1.  +57 = 0011 1001
     +35 = 0010 0011
     -----
     +92 = 0101 1100

```

```

2.  +57 = 0011 1001
    -35 = 1101 1101
    -----
    +22 = 0001 0110

```

No overflow--carry into leftmost position and carry out.

```

3.  +35 = 0010 0011
    -57 = 1100 0111
    -----
    -22 = 1110 1010

```

Sign change only--no carry into leftmost position and no carry out.

```

4.  -57 = 1100 0111
    -35 = 1101 1101
    -----
    -92 = 1010 0100

```

No overflow--carry into leftmost position and carry out.

```

5.  +57 = 0011 1001
    +92 = 0101 1100
    -----
    +149 = *1001 0101

```

*Overflow--carry into leftmost position, no carry out.

```

6.  -57 = 1100 0111
    -92 = 1010 0100
    -----
    -149 = *0110 1011

```

*Overflow--no carry into leftmost position but carry out.

The presence or absence of an overflow condition may be recognized from the carries:

- There is no overflow:
 - a. If there is no carry into the leftmost bit position and no carry out (examples 1 and 3).
 - b. If there is a carry into the leftmost position and also a carry out (examples 2 and 4).
- There is an overflow:
 - a. If there is a carry into the leftmost position but no carry out (example 5).
 - b. If there is no carry into the leftmost position but there is a carry out (example 6).

The following are 16-bit signed binary integers. The first is the maximum positive 16-bit binary integer. The last is the maximum negative 16-bit binary integer (the negative 16-bit binary integer with the greatest absolute value).

```

215 - 1 = 32,767 = 0 111 1111 1111 1111
20      =         1 = 0 000 0000 0000 0001
0       =         0 = 0 000 0000 0000 0000
-20    =        -1 = 1 111 1111 1111 1111
-215   = -32,768 = 1 000 0000 0000 0000

```

The following are several 32-bit signed binary integers arranged in descending order. The first is the maximum positive binary integer that can be represented by 32 bits, and the last is the maximum negative binary integer that can be represented by 32 bits.

```

231 - 1 = 2 147 483 647 = 0 111 1111 1111 1111 1111 1111 1111
216    =         65 536 = 0 000 0000 0000 0001 0000 0000 0000
20     =         1     = 0 000 0000 0000 0000 0000 0000 0001
0       =         0     = 0 000 0000 0000 0000 0000 0000 0000
-20    =        -1    = 1 111 1111 1111 1111 1111 1111 1111
-21    =        -2    = 1 111 1111 1111 1111 1111 1111 1110
-216   =       -65 536 = 1 111 1111 1111 1111 0000 0000 0000
-231 + 1 = -2 147 483 647 = 1 000 0000 0000 0000 0000 0000 0001
-231   = -2 147 483 648 = 1 000 0000 0000 0000 0000 0000 0000

```

Unsigned Binary Integers

Certain instructions, such as ADD LOGICAL, treat binary integers as unsigned rather than signed. Unsigned binary integers have the same format as signed binary integers, except that the leftmost bit is interpreted as another numeric bit rather than a sign bit. There is no complement notation because all unsigned binary integers are considered positive.

The following examples illustrate the addition of unsigned binary integers. Only eight bit positions are used. The examples are numbered the same as the corresponding examples for signed binary integers.

```

1.  57 = 0011 1001
    35 = 0010 0011
    -----
    92 = 0101 1100
  
```

```

2.  57 = 0011 1001
    221 = 1101 1101
    -----
    278 = *0001 0110
  
```

*Carry out of leftmost position

```

3.  35 = 0010 0011
    199 = 1100 0111
    -----
    234 = 1110 1010
  
```

```

4.  199 = 1100 0111
    221 = 1101 1101
    -----
    420 = *1010 0100
  
```

*Carry out of leftmost position

```

5.  57 = 0011 1001
    92 = 0101 1100
    -----
    149 = 1001 0101
  
```

```

6.  199 = 1100 0111
    164 = 1010 0100
    -----
    363 = *0110 1011
  
```

*Carry out of leftmost position

A carry out of the leftmost bit position may or may not imply an overflow, depending on the application.

The following are several 32-bit unsigned binary integers arranged in descending order.

| | | | | |
|---------------------|---|---------------|---|---|
| 2 ³² - 1 | = | 4 294 967 295 | = | 1111 1111 1111 1111 1111 1111 1111 1111 |
| 2 ³¹ | = | 2 147 483 648 | = | 1000 0000 0000 0000 0000 0000 0000 0000 |
| 2 ³¹ - 1 | = | 2 147 483 647 | = | 0111 1111 1111 1111 1111 1111 1111 1111 |
| 2 ¹⁶ | = | 65 536 | = | 0000 0000 0000 0001 0000 0000 0000 0000 |
| 2 ⁰ | = | 1 | = | 0000 0000 0000 0000 0000 0000 0000 0001 |
| 0 | = | 0 | = | 0000 0000 0000 0000 0000 0000 0000 0000 |

DECIMAL INTEGERS

Decimal integers are represented as one or more decimal digits and a sign digit. Each digit is a 4-bit code. The decimal digits are in binary-coded decimal (BCD) form, with the values 0-9 encoded as 0000-1001. The sign is usually represented as 1100 (C hex) for plus and 1101 (D hex) for minus. These are the preferred sign codes, which are generated by the machine for the results of decimal operations. There are also several alternate sign codes (1010, 1110, and 1111 for plus; 1011 for minus). The alternate sign codes are accepted by the machine as valid but are not generated for results.

Decimal integers may have different lengths, from one to 16 bytes. There are two decimal formats: packed and zoned. In the packed format, each byte contains two decimal digits, except for the rightmost byte which contains the sign in its right digit. The number of decimal digits in the packed format can vary from one to 31. Because decimal integers must consist of whole bytes and there must be a sign digit on the right, the number of decimal digits is always odd. If an even number of significant digits is desired, a leading zero must be inserted on the left.

In the zoned format, each byte consists of a decimal digit on the right and the zone code 1111 (F hex) on the left, except for the rightmost byte where the sign code replaces the zone code. Thus, decimal integers in the zoned format can have anywhere from one to 16 digits. The zoned format may be used directly for input and output in the extended binary-coded-decimal interchange code (EBCDIC), except that the sign must be separated from the rightmost digit and handled as a separate character. For positive (unsigned) numbers, however, the sign code of the rightmost digit can simply be replaced by the zone code, which is one of the acceptable alternate codes for plus.

In either format, negative decimal integers are represented in true notation with a separate sign. As for binary integers, the radix point (decimal point) of decimal integers is considered to be fixed at the right, and any scaling is done by the programmer.

The following are some examples of decimal integers shown in hexadecimal notation:

| Value | Packed Format | Zoned Format |
|---------|---------------|---|
| +123 | 12 3C | F1 F2 C3 or F1 F2 F3 |
| -4321 | 04 32 1D | F4 F3 F2 D1 |
| +000050 | 00 00 05 0C | F0 F0 F0 F0 F5 C0 or F0 F0 F0 F0 F5 F0 |
| -7 | 7D | D7 |
| 00000 | 00 00 0C | F0 F0 F0 F0 C0 or F0 F0 F0 F0 F0 |

Under some circumstances, a zero with a minus sign (negative zero) is produced. For example, the multiplicand:

00 12 3D (-123)

times the multiplier:

0C (+0)

generates the product:

00 00 0D (-0)

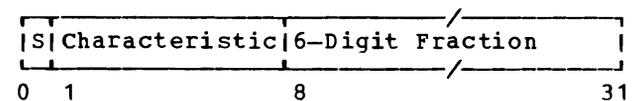
because the product sign follows the algebraic rule of signs even when the value is zero. A negative zero, however, is entirely equivalent to a positive zero; they compare equal in a decimal comparison.

FLOATING-POINT NUMBERS

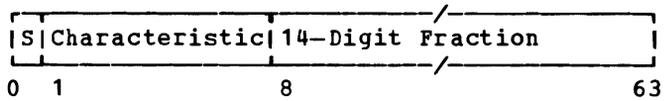
A floating-point number is expressed as a fraction multiplied by a separate power of 16. The term floating point indicates that the radix-point placement, or scaling, is automatically maintained by the machine.

The part of a floating-point number which represents the significant digits of the number is called the fraction. A second part specifies the power (exponent) to which 16 is raised and indicates the location of the radix point of the number. The fraction and exponent may be represented by 32 bits (short format), 64 bits (long format), or 128 bits (extended format).

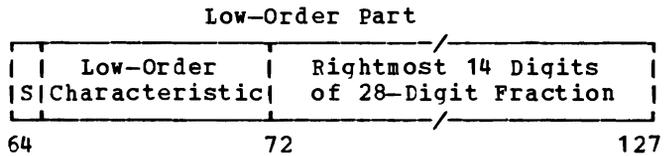
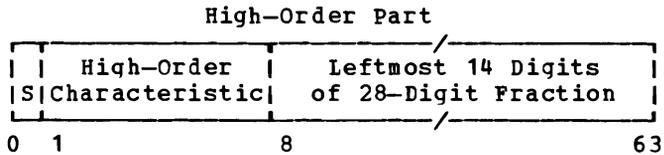
Short Floating-Point Number



Long Floating-Point Number



Extended Floating-Point Number



A floating-point number has two signs: one for the fraction and one for the exponent. The fraction sign, which is also the sign of the entire number, is the leftmost bit of each format (0 for plus, 1 for minus). The numeric part of the fraction is in true notation regardless of the sign. The numeric part is contained in bits 8-31 for the short format, in bits 8-63 for the long format, and in bits 8-63 followed by bits 72-127 for the extended format.

The exponent sign is obtained by expressing the exponent in excess-64 notation; that is, the exponent is added as a signed number to 64. The resulting number is called the characteristic. It is located in bits 1-7 for all formats. The characteristic can vary from 0 to 127, permitting the exponent to vary from -64 through 0 to +63. This provides a scale multiplier in the range of 16^{-64} to 16^{+63} . A nonzero fraction, if normalized, must be less than one and greater than or equal to $1/16$, so that the range covered by the magnitude M of a floating-point number is:

$$16^{-65} \leq M < 16^{63}$$

| | | | | | |
|-----------------------|-----------------------------------|-------------------|---------------------|---------------------|-----------|
| 1.0 | = $+1/16 \times 16^1$ | = 0 100 0001 0001 | 0000 0000 0000 0000 | 0000 0000 0000 0000 | 0000 0000 |
| 0.5 | = $+8/16 \times 16^0$ | = 0 100 0000 1000 | 0000 0000 0000 0000 | 0000 0000 0000 0000 | 0000 0000 |
| 1/64 | = $+4/16 \times 16^{-1}$ | = 0 011 1111 0100 | 0000 0000 0000 0000 | 0000 0000 0000 0000 | 0000 0000 |
| 0.0 | = $+0 \times 16^{-64}$ | = 0 000 0000 0000 | 0000 0000 0000 0000 | 0000 0000 0000 0000 | 0000 0000 |
| -15.0 | = $-15/16 \times 16^1$ | = 1 100 0001 1111 | 0000 0000 0000 0000 | 0000 0000 0000 0000 | 0000 0000 |
| 5.4×10^{-79} | $\approx +1/16 \times 16^{-64}$ | = 0 000 0000 0001 | 0000 0000 0000 0000 | 0000 0000 0000 0000 | 0000 0000 |
| 7.2×10^{75} | $\approx (1-1/16) \times 16^{63}$ | = 0 111 1111 1111 | 1111 1111 1111 1111 | 1111 1111 1111 1111 | 1111 1111 |

In decimal terms:

16^{-65} is approximately equal to 5.4×10^{-79}
 16^{63} is approximately equal to 7.2×10^{75}

More precisely,

In the short format:

$$16^{-65} \leq M \leq (1 - 16^{-6}) \times 16^{63}$$

In the long format:

$$16^{-65} \leq M \leq (1 - 16^{-14}) \times 16^{63}$$

In the extended format:

$$16^{-65} \leq M \leq (1 - 16^{-28}) \times 16^{63}$$

Within a given fraction length (6, 14, or 28 digits), a floating-point operation will provide the greatest precision if the fraction is normalized. A fraction is normalized when the leftmost digit (bit positions 8, 9, 10, and 11) is nonzero. It is unnormalized if the leftmost digit contains all zeros.

If normalization of the operand is desired, the floating-point instructions that provide automatic normalization are used. This automatic normalization is accomplished by left-shifting the fraction (four bits per shift) until a nonzero digit occupies the leftmost digit position. The characteristic is reduced by one for each digit shifted.

The following are sample normalized short floating-point numbers. The last two numbers represent the smallest and the largest positive normalized numbers.

according to the programmer's specifications. Therefore, the actual values for base and displacement are not shown in the assembler-language format or in the machine-language format. For assembler-language formats, in the labels that designate instruction fields, the letter "S" is used to indicate the combination of base and displacement fields for an operand address. (For example, S1 represents the combination of B1 and D1.) In the machine-language format, the base and displacement address components are shown as asterisks (***) .

GENERAL INSTRUCTIONS

(See Chapter 7.)

ADD HALFWORD (AH)

The ADD HALFWORD instruction algebraically adds the halfword contents of a storage location to the contents of a register. The halfword storage operand is expanded to 32 bits after it is fetched and before it is used in the add operation. The expansion consists in propagating the leftmost (sign) bit 16 positions to the left. For example, assume that the contents of storage locations 2000-2001 are to be added to register 5. Initially:

Register 5 contains 00 00 00 19 = 25{10}.
 Storage locations 2000-2001 contain FF FE
 = -2{10}.
 Register 12 contains 00 00 18 00.
 Register 13 contains 00 00 01 50.

The format of the required instruction is:

Machine Format

| Op Code | R ₁ | X ₂ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|
| 4A | 5 | D | C | 6B0 |

Assembler Format

Op Code R₁, D₂(X₂, B₂)
 AH 5, X'6B0' (13, 12)

After the instruction is executed, register 5 contains 00 00 00 17 = 23{10}.

AND (N, NR, NI, NC)

When the Boolean operator AND is applied to two bits, the result is one when both bits are one; otherwise, the result is zero. When two bytes are ANDed, each pair of bits is handled separately; there is no connection from one bit position to another. The following is an example of ANDing two bytes:

First-operand byte: 0011 0101{2}
 Second-operand byte: 0101 1100{2}

 Result byte: 0001 0100{2}

And (NI)

A frequent use of the AND instruction is to set a particular bit to zero. For example, assume that storage location 4891 contains 0100 0011{2}. To set the rightmost bit of this byte to zero without affecting the other bits, the following instruction can be used (assume that register 8 contains 00 00 48 90):

Machine Format

| Op Code | I ₂ | B ₁ | D ₁ |
|---------|----------------|----------------|----------------|
| 94 | FE | 8 | 001 |

Assembler Format

Op Code D₁(B₁), I₂
 NI 1(8), X'FE'

When this instruction is executed, the byte in storage is ANDed with the immediate byte (the I₂ field of the instructions):

Location 4891 0100 0011{2}
 Immediate byte 1111 1110{2}

 Result: 0100 0010{2}

The resulting byte, with bit 7 set to zero, is stored back in location 4891. Condition code 1 is set.

BRANCH AND LINK (BAL, BALR)

The BRANCH AND LINK instructions are commonly used to branch to a subroutine with the option of later returning to the

main instruction sequence. For example, assume that you wish to branch to a subroutine at storage address 1160. Also assume:

The contents of register 2 are not significant.
 Register 5 contains 00 00 11 50.
 Address 00 00 C6 contains the BAL instruction, so that 00 00 CA is the address of the next sequential instruction.

The format of the BAL instruction is:

Machine Format

| Op Code | R ₁ | X ₂ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|
| 45 | 2 | 0 | 5 | 010 |

Assembler Format

Op Code R₁, D₂ (X₂, B₂)
 BAL 2, X'10' (0, 5)

After the instruction is executed:

Register 2 (bits 8-31) contains 00 00 CA.
 PSW bits 40-63 contain 00 11 60.

The programmer can return to the main instruction sequence at any time with a BRANCH ON CONDITION (BCR) instruction that specifies register 2 and a mask of 15{10}, provided that register 2 has not meanwhile been disturbed.

The BALR instruction with the R₂ field set to zero may be used to load a register for use as a base register. For example, in the assembler language, the sequence of statements:

```
BALR 15,0
USING *,15
```

tells the assembler program that register 15 is to be used as the base register in assembling this program and that, when the program is executed, the address of the next sequential instruction following the BALR will be placed in the register. (The USING statement is an "assembler instruction" and is thus not a part of the object program.)

As another example, BALR 6,0 may be used to preserve the current condition code in bits 2 and 3 of register 6 for future inspection.

Note that, in all three examples, a value of zero in the X₂ or R₂ field indicates

that the corresponding function is not performed; it does not refer to register 0. Register 0 can be designated by the R₁ field, however.

BRANCH ON CONDITION (BC, BCR)

The BRANCH ON CONDITION instructions test the condition code to see whether a branch should or should not be taken. The branch is taken only if the condition code is as specified by a mask.

| Mask Value | Condition Code |
|------------|----------------|
| 8 | 0 |
| 4 | 1 |
| 2 | 2 |
| 1 | 3 |

For example, assume that an ADD (A or AR) operation has been performed and that you wish to branch to address 6050 if the sum is zero or less (condition code 0 or 1). Also assume:

Register 10 contains 00 00 50 00.
 Register 11 contains 00 00 10 00.

The RX form of the instruction performs the required test (and branch if necessary) when written as:

Machine Format

| Op Code | M ₁ | X ₂ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|
| 47 | C | B | A | 050 |

Assembler Format

Op Code M₁, D₂ (X₂, B₂)
 BC 12, X'50' (11, 10)

A mask of 15 indicates a branch on any condition (an unconditional branch). A mask of zero indicates that no branch is to occur (a no-operation).

BRANCH ON COUNT (BCT, BCTR)

The BRANCH ON COUNT instructions are often used to execute a program loop for a specified number of times. For example, assume that the following represents some lines of coding in an assembler-language program:

```

.
.
LUPE  AR  8,1
.
.
BACK  BCT  6,LUPE
.
.

```

where register 6 contains 00 00 00 03 and the address of LUPE is 6826. Assume that, in order to address this location, register 10 is used as a base register and contains 00 00 68 00.

The format of the BCT instruction is:

Machine Format

| Op Code | R ₁ | X ₂ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|
| 46 | 6 | 0 | A | 026 |

Assembler Format

```

Op Code  R1,D2(X2,B2)
-----
BCT      6,X'26'(0,10)

```

The effect of the coding is to execute three times the loop defined by locations LUPE through BACK.

BRANCH ON INDEX HIGH (BXH)

The BRANCH ON INDEX HIGH instruction is an index-incrementing and loop-controlling instruction that causes a branch whenever the sum of an index value and an increment value is greater than some compare value. For example, assume that:

- Register 4 contains 00 00 00 8A = 138{10} = the index.
- Register 6 contains 00 00 00 02 = 2{10} = the increment.
- Register 7 contains 00 00 00 AA = 170{10} = the compare value.
- Register 10 contains 00 00 71 30 = the branch address.

The format of the instruction is:

Machine Format

| Op Code | R ₁ | R ₃ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|
| 86 | 4 | 6 | A | 000 |

Assembler Format

```

Op Code  R1,R3,D2(B2)
-----
BXH      4,6,0(10)

```

When the instruction is executed, first the contents of register 6 are added to register 4, second the sum is compared with the contents of register 7, and third the decision whether to branch is made. After execution:

Register 4 contains 00 00 00 8C = 140{10}
Registers 6 and 7 are unchanged.

Since the new value in register 4 is not yet greater than the value in register 7, the branch to address 7130 is not taken. Repeated use of the instruction will eventually cause the branch to be taken when the value in register 4 reaches 172.

When the register used to contain the increment is odd, that register also becomes the compare-value register. The following assembler-language subroutine illustrates how this feature may be used to search a table.

| Table | |
|---------|---------|
| 2 Bytes | 2 Bytes |
| ARG1 | FUNCT1 |
| ARG2 | FUNCT2 |
| ARG3 | FUNCT3 |
| ARG4 | FUNCT4 |
| ARG5 | FUNCT5 |
| ARG6 | FUNCT6 |

Assume that:

- Register 8 contains the search argument.
- Register 9 contains the width of the table in bytes (00 00 00 04).
- Register 10 contains the length of the table in bytes (00 00 00 18).
- Register 11 contains the starting address of the table.
- Register 14 contains the return address to the main program.

As the following subroutine is executed, the argument in register 8 is successively compared with the arguments in the table, starting with argument 6 and working backward to argument 1. If an equality is

found, the corresponding function replaces the argument in register 8. If an equality is not found, FFFF{16} replaces the argument in register 8.

```

SEARCH   LNR  9,9
NOTEQUAL BXH  10,9,LOOP
NOTFOUND LA   8,X'FFFF'
          BCR  15,14
LOOP     CH   8,0(2,3)
          BC   7,NOTEQUAL
          LH   8,2(10,11)
          BCR  15,14

```

The first instruction (INR) causes the value in register 9 to be made negative. After execution of this instruction, register 9 contains FFFFFFFC = -4{10}. Considering the case when no equality is found, the BXH instruction will be executed seven times. Each time BXH is executed, a value of -4 is added to register 10, thus reducing the value in register 10 by 4. The new value in register 10 is compared with the -4 value in register 9. The branch is taken each time until the value in register 10 is -4.

BRANCH ON INDEX LOW OR EQUAL (BXLE)

This instruction is similar to BRANCH ON INDEX HIGH except that the branch is successful when the sum is low or equal compared to the compare value.

COMPARE HALFWORD (CH)

The COMPARE HALFWORD instruction compares a 16-bit signed binary integer in storage with the contents of a register. For example, assume that:

```

Register 4 contains FF FF 80 00 =
-32,768{10}.
Register 13 contains 00 01 60 50.
Storage locations 16080-16081 contain 8000
= -32,768{10}.

```

When the instruction:

Machine Format

| Op Code | R ₁ | X ₂ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|
| 49 | 4 | 0 | D | 030 |

Assembler Format

| Op Code | R ₁ , D ₂ (X ₂ , B ₂) |
|---------|--|
| CH | 4, X'30'(0,13) |

is executed, the contents of locations 16080-16081 are fetched, expanded to 32 bits (the sign bit is propagated to the left), and compared with the contents of register 4. Because the two numbers are equal, condition code 0 is set.

COMPARE LOGICAL (CL, CLC, CLI, CLR)

The COMPARE LOGICAL instructions differ from the signed-binary comparison instructions (C, CH, CR) in that all quantities are handled as unsigned binary integers or as unstructured data.

Compare Logical (CLC)

The COMPARE LOGICAL (CLC) instruction can be used to perform the byte-by-byte comparison of storage fields up to 256 bytes in length. For example, assume that the following two fields of data are in storage:

```

Field 1
1886
1891

```

| | | | | | | | | | | | |
|----|----|----|----|----|----|----|----|----|----|----|----|
| D1 | D6 | C8 | D5 | E2 | D6 | D5 | 6B | C1 | 4B | C2 | 4B |
|----|----|----|----|----|----|----|----|----|----|----|----|

```

Field 2
1900
190B

```

| | | | | | | | | | | | |
|----|----|----|----|----|----|----|----|----|----|----|----|
| D1 | D6 | C8 | D5 | E2 | D6 | D5 | 6B | C1 | 4B | C3 | 4B |
|----|----|----|----|----|----|----|----|----|----|----|----|

Also assume:

```

Register 9 contains 00 00 18 80.
Register 7 contains 00 00 19 00.

```

Execution of the instruction:

Machine Format

| Op Code | L | B ₁ | D ₁ | B ₂ | D ₂ |
|---------|----|----------------|----------------|----------------|----------------|
| D5 | 0B | 9 | 006 | 7 | 000 |

Assembler Format

| Op Code | D ₁ (L, B ₁), D ₂ (B ₂) |
|---------|---|
| CLC | 6 (12, 9), 0 (7) |

sets condition code 1, indicating that the contents of field 1 are lower in value than the contents of field 2.

Because the collating sequence of the EBCDIC code is determined simply by a logical comparison of the bits in the code, the CLC instruction can be used to collate EBCDIC-coded fields. For example, in EBCDIC, the above two data fields are:

Field 1 JOHNSON, A.E.
Field 2 JOHNSON, A.C.

Condition code 1 tells us that A.B. JOHNSON precedes A.C. JOHNSON, thus placing the names in the correct alphabetic sequence.

Compare Logical (CLI)

The COMPARE LOGICAL (CLI) instruction compares a byte from the instruction stream with a byte from storage. For example, assume that:

Register 10 contains 00 00 17 00.
Storage location 1703 contains 7E.

Execution of the instruction:

Machine Format

| Op Code | I ₂ | B ₁ | D ₁ |
|---------|----------------|----------------|----------------|
| 95 | AF | A | 003 |

Assembler Format

| Op Code | D ₁ (B ₁), I ₂ |
|---------|--|
| CLI | 3 (10), X'AF' |

sets condition code 1, indicating that the first operand (the quantity in main storage) is lower than the second (immediate) operand.

Compare Logical (CLR)

Assume that:

Register 4 contains 00 00 00 01 = 1.
Register 7 contains FF FF FF FF = 2³²-1.

Execution of the instruction:

Machine Format

| Op Code | R ₁ | R ₂ |
|---------|----------------|----------------|
| 15 | 4 | 7 |

Assembler Format

| Op Code | R ₁ , R ₂ |
|---------|---------------------------------|
| CLR | 4, 7 |

sets condition code 1. Condition code 1 indicates that the first operand is lower than the second.

If, instead, the signed-binary comparison instruction COMPARE (CR) had been executed, the contents of register 4 would have been interpreted as +1 and the contents of register 7 as -1. Thus, the first operand would have been higher, so that condition code 2 would have been set.

COMPARE LOGICAL CHARACTERS UNDER MASK (CLM)

The COMPARE LOGICAL CHARACTERS UNDER MASK (CLM) instruction provides a means of comparing bytes selected from a general register to a contiguous field of bytes in storage. The M₃ field of the CLM instruction is a four-bit mask that selects zero to four bytes from a general register, each mask bit corresponding, left to right, to a register byte. In the comparison, the register bytes corresponding to ones in the mask are treated as a contiguous field. The operation proceeds left to right. For example, assume that:

Three bytes starting at storage location 10200 contain F0 BC 7B
Register 12 contains 10000
Register 6 contains F0 BC 5C 7B

Execution of the instruction:

Machine Format

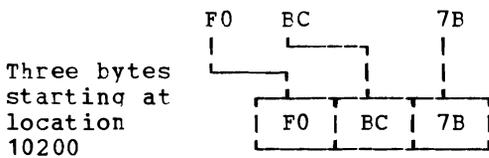
| | | | | |
|---------|----------------|----------------|----------------|----------------|
| Op Code | R ₁ | M ₃ | B ₂ | D ₂ |
| BD | 6 | D | C | 200 |

Assembler Format

| | |
|---------|--|
| Op Code | R ₁ , M ₃ , D ₂ (B ₂) |
| CLM | 6, B'1101', X'200' (12) |

causes the following comparison:

| | | | | |
|-------------|----|----|----|----|
| Register 6: | F0 | BC | 5C | 7B |
| Mask | 1 | 1 | 0 | 1 |

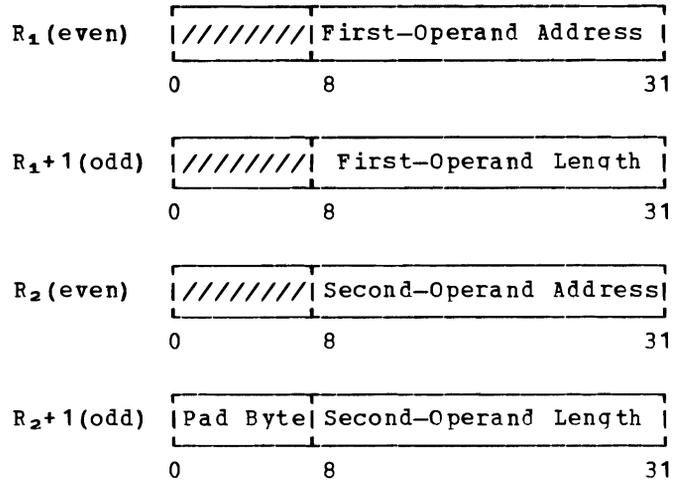


Because the selected bytes are equal, condition code 0 is set.

COMPARE LOGICAL LONG (CICL)

The COMPARE LOGICAL LONG (CICL) instruction is used to compare two operands in storage, byte by byte. Each operand can be of any length. Two even-odd pairs of general registers (four registers in all) are used to locate the operands and to control the execution of the CICL instruction, as illustrated in the following diagram. The first register of each pair must be an even register, and it contains the storage address of the byte currently being compared in each operand. The odd register of each pair contains the length of the operand it covers, and the leftmost byte of the second-operand odd register contains a padding byte which is used to extend the shorter operand, if any, to the same length as the longer operand.

The following illustrates the assignment of registers:



Since the CICL instruction may be interrupted during execution, the interrupting program must preserve the contents of the four registers for use when the instruction is resumed.

The following instructions set up two register pairs to control a text-string comparison. For example, assume:

Operand 1

Address: 20800 (hex)
Length: 100 (dec)

Operand 2

Address: 20A00 (hex)
Length: 132 (dec)

Padding Byte

Address: 20003 (hex)
Length: 1
Value: 40 (hex)

Register 12 contains 00 02 00 00

The setup instructions are:

- LA 4, X'800' (12) Point register 4 to start of first operand
- LA 5, 100 Set register 5 to length of first operand
- LA 8, X'A00' (12) Point register 8 to start of second operand
- LA 9, 132 Set register 9 to length of second operand
- ICM 9, B'1000', 3 (12) Insert padding byte in leftmost byte position of register 9.

Register pair 4,5 defines the first operand. Bits 8-31 of register 4 contain the storage address of the start of an EBCDIC text string, and bits 8-31 of

register 5 contain the length of the string, in this case 100 bytes.

Register pair 8,9 defines the second operand, with bits 8-31 of register 8 containing the starting location of the second operand and bits 8-31 of register 9 containing the length of the second operand, in this case 132 bytes. Bits 0-7 of register 9 contain an EBCDIC blank character (X'40') to pad the shorter operand. In this example, the padding byte is used in the first operand, after the 100th byte, to compare with the remaining bytes in the second operand.

With the register pairs thus set up, the format of the CLCL instruction is:

Machine Format

| Op Code | R ₁ | R ₂ |
|---------|----------------|----------------|
| 0F | 4 | 8 |

Assembler Format

| Op Code | R ₁ ,R ₂ |
|---------|--------------------------------|
| CLCL | 4,8 |

When this instruction is executed, the comparison starts at the left end of each operand and proceeds to the right. The operation ends as soon as an inequality is detected or the end of the longer operand is reached.

If this CLCL instruction is interrupted after 60 bytes have compared equal, the operand lengths in registers 5 and 9 will have been decremented to X'28' and X'48', respectively, and the operand addresses in registers 4 and 8 will have been incremented to X'2083C' and X'20A3C'. The padding byte X'40' remains in register 9. When the CLCL instruction is reissued with these register contents, the comparison resumes at the point of interruption.

Now, assume that the instruction is interrupted after 110 bytes. That is, the first 100 bytes of the second operand have compared equal to the first operand, and the next 10 bytes of the second operand have compared equal to the padding byte (blank). The residual operand lengths in registers 5 and 9 are 0 and X'16', respectively, and the operand addresses in registers 4 and 8 are X'20864' (the value when the first operand was exhausted, and X'20A6E' (the current value for the second operand).

When the comparison ends, the condition

code is set to 0, 1, or 2, depending on whether the first operand is equal to, less than, or greater than the second operand, respectively.

When the operands are unequal, the addresses in registers 4 and 8 locate the bytes that caused the mismatch.

CONVERT TO BINARY (CVB)

The CONVERT TO BINARY instruction converts an eight-byte, packed-decimal number into a signed binary integer and loads the result into a general register. After the conversion operation is completed, the number is in the proper form for use as an operand in signed binary arithmetic. For example, assume:

Storage locations 7608-760F contain a decimal number in the packed format: 00 00 00 00 25 59 4C (+25,594). The contents of register 7 are not significant. Register 13 contains 00 00 76 00.

The format of the conversion instruction is:

Machine Format

| Op Code | R ₁ | X ₂ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|
| 4F | 7 | 0 | D | 008 |

Assembler Format

| Op Code | R ₁ ,D ₂ (X ₂ ,B ₂) |
|---------|--|
| CVB | 7,8(0,13) |

After the instruction is executed, register 7 contains 00 00 63 FA.

CONVERT TO DECIMAL (CVD)

The CONVERT TO DECIMAL instruction performs functions exactly opposite to those of the CONVERT TO BINARY instruction. CVD converts a signed binary integer in a register to packed decimal and stores the eight-byte result. For example, assume:

Register 1 contains the signed binary integer: 00 00 0F 0F.
Register 13 contains 00 00 76 00.

The format of the instruction is:

Machine Format

| Op Code | R ₁ | X ₂ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|
| 4E | 1 | 0 | D | 008 |

Assembler Format

| Op Code | R ₁ , D ₂ (X ₂ , B ₂) |
|---------|--|
| CVD | 1, 8(0, 13) |

After the instruction is executed, storage locations 7608-760F contain 00 00 00 00 00 03 85 5C (+3855).

The plus sign generated is the preferred plus sign, 1100{2}.

DIVIDE (D, DR)

The DIVIDE instruction divides the dividend in an even-odd register pair by the divisor in a register or in storage. Since the dividend is assumed to be 64 bits long, it is important that the proper sign be first affixed. For example, assume that:

Storage locations 3550-3553 contain 00 00 08 DE = 2270{10} = the dividend.
 Storage locations 3554-3557 contain 00 00 00 32 = 50{10} = the divisor.
 The initial contents of registers 6 and 7 are not significant.
 Register 8 contains 00 00 35 50.

The following assembler language statements load the registers properly and perform the divide operation:

| Statement | Comments |
|--------------|--|
| L 6,0(0,8) | Places 00 00 08 DE into register 6. |
| SRDA 6,32(0) | Shifts 00 00 08 DE into register 7. Register 6 is filled with zeros (sign bits). |
| D 6,4(0,8) | Performs the division. |

The machine format of the above DIVIDE instruction is:

Machine Format

| Op Code | R ₁ | X ₂ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|
| 5D | 6 | 0 | 8 | 004 |

After all the foregoing instructions are executed:

Register 6 contains 00 00 00 14 = 20{10} = the remainder.
 Register 7 contains 00 00 00 2D = 45{10} = the quotient.

Note that if the dividend had not been first placed in register 6 and shifted into register 7, register 6 might not have been filled with the proper sign bits (zeros in this example), and the DIVIDE instruction might not have given the expected results.

EXCLUSIVE OR (X, XC, XI, XR)

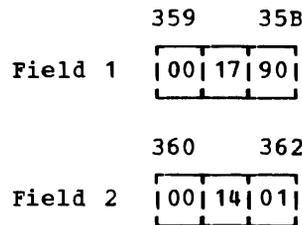
When the Boolean operator EXCLUSIVE OR is applied to two bits, the result is one when either, but not both, of the two bits is one; otherwise, the result is zero. When two bytes are EXCLUSIVE Ored, each pair of bits is handled separately; there is no connection from one bit position to another. The following is an example of the EXCLUSIVE OR of two bytes:

First-operand byte: 0011 0101{2}
 Second-operand byte: 0101 1100{2}

 Result byte: 0110 1001{2}

Exclusive Or (XC)

The EXCLUSIVE OR (XC) instruction can be used to exchange the contents of two areas in storage without the use of an intermediate storage area. For example, assume two three-byte fields in storage:



Execution of the instruction (assume that register 7 contains 00 00 03 58):

Machine Format

| Op Code | L | B ₁ | D ₁ | B ₁ | D ₂ |
|---------|----|----------------|----------------|----------------|----------------|
| D7 | 02 | 7 | 001 | 7 | 008 |

Assembler Format

| Op Code | D ₁ (L, B ₁), D ₂ (B ₂) |
|---------|---|
| XC | 1(3,7),8(7) |

Field 1 is EXCLUSIVE ORed with field 2 as follows:

```
Field 1: 0000 0000 0001 0111 1001 0000{2}
          = 00 17 90
Field 2: 0000 0000 0001 0100 0000 0001{2}
          = 00 14 01
-----
Result:  0000 0000 0000 0011 1001 0001{2}
          = 00 03 91
```

The result replaces the former contents of field 1.

Now, execution of the instruction:

Machine Format

| Op Code | L | B ₁ | D ₁ | B ₂ | D ₂ |
|---------|----|----------------|----------------|----------------|----------------|
| D7 | 02 | 7 | 008 | 7 | 001 |

Assembler Format

| Op Code | D ₁ (L, B ₁), D ₂ (B ₂) |
|---------|---|
| XC | 8(3,7),1(7) |

produces the following result:

```
Field 1: 0000 0000 0000 0011 1001 0001{2}
          = 00 03 91
Field 2: 0000 0000 0001 0100 0000 0001{2}
          = 00 14 01
-----
Result:  0000 0000 0001 0111 1001 0000{2}
          = 00 17 90
```

The result of this operation replaces the former contents of field 2. Field 2 now contains the original value of field 1.

Lastly, execution of the instruction:

Machine Format

| Op Code | L | B ₁ | D ₁ | B ₂ | D ₂ |
|---------|----|----------------|----------------|----------------|----------------|
| D7 | 02 | 7 | 001 | 7 | 008 |

Assembler Format

| Op Code | D ₁ (L, B ₁), D ₂ (B ₂) |
|---------|---|
| XC | 1(3,7),8(7) |

produces the following result:

```
Field 1: 0000 0000 0000 0011 1001 0001{2}
          = 00 03 91
Field 2: 0000 0000 0001 0111 1001 0000{2}
          = 00 17 90
-----
Result:  0000 0000 0001 0100 0000 0001{2}
          = 00 14 01
```

The result of this operation replaces the former contents of field 1. Field 1 now contains the original value of field 2.

Exclusive Or (XI)

A frequent use of the EXCLUSIVE OR (XI) instruction is to invert a bit (change a zero bit to a one or a one bit to a zero). For example, assume that storage location 8082 contains 0110 1001{2}. To invert the leftmost and rightmost bits without affecting any of the other bits, the following instruction can be used (assume that register 9 contains 00 00 80 80):

Machine Format

| Op Code | I ₂ | B ₁ | D ₁ |
|---------|----------------|----------------|----------------|
| 97 | 81 | 9 | 002 |

Assembler Format

| Op Code | D ₁ (B ₁), I ₂ |
|---------|--|
| XI | 2(9),X'81' |

When the instruction is executed, the byte in storage is EXCLUSIVE ORed with the immediate byte (the I₂ field of the instruction):

Location 8082: 0110 1001{2}
 Immediate byte: 1000 0001{2}

 Result: 1110 1000{2}

The resulting byte is stored back in location 8082. Condition code 1 is set to indicate a nonzero result.

Notes:

1. With the XC instruction, fields up to 256 bytes in length can be exchanged.
2. With the XR instruction, the contents of two registers can be exchanged.
3. Because the X instruction operates storage to register only, an exchange cannot be made solely by the use of X.
4. A field EXCLUSIVE Ored with itself is cleared to zeros.
5. For additional examples of the use of EXCLUSIVE OR, see the section "Floating-Point-Number Conversion" later in this appendix.

EXECUTE (EX)

The EXECUTE instruction causes one target instruction in main storage to be executed out of sequence without actually branching to the target instruction. Unless the R₁ field of the EXECUTE instruction is zero, bits 8-15 of the target instruction are Ored with bits 24-31 of the R₁ register before the target instruction is executed. Thus, EXECUTE may be used to supply the length field for an SS instruction without modifying the SS instruction in storage. For example, assume that a MOVE (MVC) instruction is the target that is located at address 3820, with a format as follows:

Machine Format

| Op Code | L | B ₁ | D ₁ | B ₂ | D ₂ |
|---------|----|----------------|----------------|----------------|----------------|
| D2 | 00 | C | 003 | D | 000 |

Assembler Format

Op Code D₁ (L, B₁), D₂ (B₂)
 MVC 3(1,12),0(13)

where register 12 contains 00 00 89 13 and register 13 contains 00 00 90 A0.

Further assume that at storage address

5000, the following EXECUTE instruction is located:

Machine Format

| Op Code | R ₁ | X ₂ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|
| 44 | 1 | 0 | A | 000 |

Assembler Format

Op Code R₁, D₂ (X₂, B₂)
 EX 1,0(0,10)

where register 10 contains 00 00 38 20 and register 1 contains 00 0F F0 03.

When the instruction at 5000 is executed, the rightmost byte of register 1 is Ored with the second byte of the target instruction:

Register byte: 0000 0000{2} = 00
 Instruction byte: 0000 0011{2} = 03

 Result: 0000 0011{2} = 03

causing the instruction at 3820 to be executed as if it originally were:

Machine Format

| Op Code | L | B ₁ | D ₁ | B ₂ | D ₂ |
|---------|----|----------------|----------------|----------------|----------------|
| D2 | 03 | C | 003 | D | 000 |

Assembler Format

Op Code D₁ (L, B₁), D₂ (B₂)
 MVC 3(4,12),0(13)

However, after execution:

Register 1 is unchanged.
 The instruction at 3820 is unchanged.
 The contents of the four bytes starting at location 90A0 have been moved to the four bytes starting at location 8916.
 The CPU next executes the instruction at address 5004 (PSW bits 40-63 contain 00 50 04).

INSERT CHARACTERS UNDER MASK (ICM)

The INSERT CHARACTERS UNDER MASK (ICM) instruction may be used to replace all or

selected bytes in a general register with bytes from storage and to set the condition code to indicate the value of the inserted field.

For example, if it is desired to insert a three-byte address from FIELD A into register 5 and leave the leftmost byte of the register unchanged, assume:

Machine Format

| Op Code | R ₁ | M ₃ | S ₂ |
|---------|----------------|----------------|----------------|
| BF | 5 | 7 | * * * * |

Assembler Format

Op Code R₁, M₃, S₂
 ICM 5, B'0111', FIELD A

FIELD A: FE DC BA
 Register 5 (before): 12 34 56 78
 Register 5 (after): 12 FE DC BA
 Condition code (after): 1 (leftmost bit of inserted field is one)

As another example:

Machine Format

| Op Code | R ₁ | M ₃ | S ₂ |
|---------|----------------|----------------|----------------|
| BF | 6 | 9 | * * * * |

Assembler Format

Op Code R₁, M₃, S₂
 ICM 6, B'1001', FIELD B

FIELD B: 12 34
 Register 6 (before): 00 00 00 00
 Register 6 (after): 12 00 00 34
 Condition code (after): 2 (inserted field is nonzero with leftmost zero bit)

When the mask field contains 1111, the ICM instruction produces the same result as LOAD (L) (provided that the indexing capability of the RX format is not needed), except that ICM also sets the condition code. The condition-code setting is useful when an all-zero field (condition code 0) or a leftmost one bit (condition code 1) is

used as a flag.

LOAD (L, LR)

The LOAD instructions take four bytes from storage or from a general register and place them unchanged into a general register. For example, assume that the four bytes starting with location 21003 are to be loaded into register 10. Initially:

Register 5 contains 00 02 00 00.
 Register 6 contains 00 00 10 03.
 The contents of register 10 are not significant.
 Storage locations 21003-21006 contain 00 00 AB CD.

To load register 10, the RX form of the instruction can be used:

Machine Format

| Op Code | R ₁ | X ₂ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|
| 58 | A | 5 | 6 | 000 |

Assembler Format

Op Code R₁, D₂ (X₂, B₂)
 L 10, 0(5, 6)

After the instruction is executed, register 10 contains 00 00 AB CD.

LOAD ADDRESS (LA)

The LOAD ADDRESS instruction provides a convenient way to place a nonnegative binary integer up to 4095{10} in a register without first defining a constant and then using it as an operand. For example, the following instruction places the number 2048{10} in register 1:

Machine Format

| Op Code | R ₁ | X ₂ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|
| 41 | 1 | 0 | 0 | 800 |

Assembler Format

Op Code R₁, D₂ (X₂, B₂)
 LA 1, 2048 (0, 0)

The LOAD ADDRESS instruction can also be used to increment a register by an amount up to 4095{10} specified in the D₂ field. Only the rightmost 24 bits of the result are retained, however. For example, assume that register 5 contains 00 12 34 56.

The instruction:

Machine Format

| Op Code | R ₁ | X ₂ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|
| 41 | 5 | 0 | 5 | 00A |

Assembler Format

Op Code R₁, D₂ (X₂, B₂)
 LA 5, 10 (0, 5)

adds 10 (decimal) to the contents of register 5 as follows:

Register 5 (old): 00 12 34 56
 D₂ field: 00 00 00 0A

 Register 5 (new): 00 12 34 60

The register may be specified as either B₂ or X₂. Thus, the instruction LA 5, 10 (5, 0) produces the same result.

As the most general example, the instruction LA 6, 10 (5, 4) adds the displacement, in this case 10, to the contents of register 4 and to the contents of register 5 and places the 24-bit sum of these three values in register 6.

LOAD HALFWORD (LH)

The LOAD HALFWORD instruction places unchanged a halfword from storage into the right half of a register. The left half of the register is loaded with zeros or ones according to the sign (leftmost bit) of the

halfword.

For example, assume that the two bytes in storage locations 1803-1804 are to be loaded into register 6. Also assume:

The contents of register 6 are not significant.

Register 14 contains 00 00 18 03.

Locations 1803-1804 contain 00 20.

The instruction required to load the register is:

Machine Format

| Op Code | R ₁ | X ₂ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|
| 48 | 6 | 0 | E | 000 |

Assembler Format

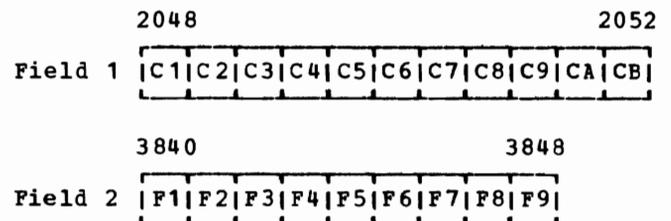
Op Code R₁, D₂ (X₂, B₂)
 LH 6, 0 (0, 14)

After the instruction is executed, register 6 contains 00 00 00 20. If locations 1803-1804 had contained a negative number, for example, A7 B6, a minus sign would have been propagated to the left, giving FF FF A7 B6 as the final result in register 6.

MOVE (MVC, MVI)

Move (MVC)

The MOVE (MVC) instruction can be used to move data from one storage location to another. For example, assume that the following two fields are in storage:



Also assume:

Register 1 contains 00 00 20 48.

Register 2 contains 00 00 38 40.

With the following instruction, the first

eight bytes of field 2 replace the first eight bytes of field 1:

Machine Format

| Op Code | L | B ₁ | D ₁ | B ₂ | D ₂ |
|---------|----|----------------|----------------|----------------|----------------|
| D2 | 07 | 1 | 000 | 2 | 000 |

Assembler Format

| Op Code | D ₁ (L, B ₁), D ₂ (B ₂) |
|---------|---|
| MVC | 0 (8, 1), 0 (2) |

After the instruction is executed, field 1 becomes:

| | | | |
|---------|----------------------------------|--|------|
| | 2048 | | 2052 |
| Field 1 | F1 F2 F3 F4 F5 F6 F7 F8 C9 CA CB | | |

Field 2 is unchanged.

MVC can also be used to propagate a byte through a field by starting the first-operand field one byte location to the right of the second-operand field. For example, suppose that an area in storage starting with address 358 contains the following data:

| | | |
|----------------------------|--|-----|
| 358 | | 360 |
| 00 F1 F2 F3 F4 F5 F6 F7 F8 | | |

With the following MVC instruction, the zeros in location 358 can be propagated throughout the entire field (assume that register 11 contains 00 00 03 58):

Machine Format

| Op Code | L | B ₁ | D ₁ | B ₂ | D ₂ |
|---------|----|----------------|----------------|----------------|----------------|
| D2 | 07 | B | 001 | B | 000 |

Assembler Format

| Op Code | D ₁ (L, B ₁), D ₂ (B ₂) |
|---------|---|
| MVC | 1 (8, 11), 0 (11) |

Because the MVC handles one byte at a time, the above instruction essentially takes the byte at address 358 and stores it at 359 (359 now contains 00), takes the byte at 359 and stores it at 35A, and so on, until the entire field is filled with zeros.

Note that an MVI instruction could have been used originally to place the byte of zeros in location 358.

Notes:

1. Although the field occupying locations 358-360 contains nine bytes, the length coded in the assembler format is equal to the number of moves (one less than the field length).
2. The order of operands is important even though only one field is involved.

Move (MVI)

The MOVE (MVI) instruction places one byte of information from the instruction stream into storage. For example, the instruction:

Machine Format

| Op Code | I ₂ | B ₁ | D ₁ |
|---------|----------------|----------------|----------------|
| 92 | 5B | 1 | 000 |

Assembler Format

| Op Code | D ₁ (B ₁), I ₂ |
|---------|--|
| MVI | 0 (1), C '\$' |

may be used, in conjunction with the instruction EDIT AND MARK, to insert a dollar symbol at the storage address contained in general register 1 (see also the example for EDIT AND MARK).

MOVE LONG (MVCL)

The MOVE LONG (MVCL) instruction can be used for moving data in storage as in the first example of the MVC instruction, provided that the two operands do not overlap. MVCL differs from MVC in that the address and length of each operand are specified in an even-odd pair of general registers. Consequently, MVCL can be used to move more than 256 bytes of data with one instruction. As an example, assume:

- Register 2 contains 00 0A 00 00.
- Register 3 contains 00 00 08 00.
- Register 8 contains 00 06 00 00.
- Register 9 contains 00 00 08 00.

Execution of the instruction:

Machine Format

| Op Code | R ₁ | R ₂ |
|---------|----------------|----------------|
| 0E | 8 | 2 |

Assembler Format

| Op Code | R ₁ , R ₂ |
|---------|---------------------------------|
| MVCL | 8,2 |

moves 2,048{10} bytes from locations A0000-A07FF to location 60000-607FF. Condition code 0 is set to indicate that the operand lengths are equal.

If register 3 had contained F0 00 04 00, only the 1,024{10} bytes from locations A0000-A03FF would have been moved to locations 60000-603FF. The remaining locations 60400-607FF of the first operand would have been filled with 1,024 copies of the padding byte X'F0', as specified by the leftmost byte of register 3. Condition code 2 is set to indicate that the first operand is longer than the second.

The technique for setting a field to zeros that is illustrated in the second example of MVC cannot be used with MVCL. If the registers were set up to attempt such an operation with MVCL, no data movement would take place and condition code 3 would indicate destructive overlap.

Instead, MVCL may be used to clear a storage area to zeros as follows. Assume register 8 and 9 are set up as before. Register 3 contains only zeros, specifying zero length for the second operand and a zero padding byte. The contents of register 2 are not significant. Executing the instruction MVCL 8,2 causes locations 60000-607FF to be filled with zeros. Condition code 2 is set.

MOVE NUMERICS (MVN)

Two related instructions, MOVE NUMERICS and MOVE ZONES, may be used with decimal data in the zoned format to operate separately on the rightmost four bits (the numeric bits) and the leftmost four bits (the zone bits) of each byte. Both are similar to MOVE (MVC), except that MOVE NUMERICS moves only the numeric bits and MOVE ZONES moves only the zone bits.

To illustrate the operation of the MOVE

NUMERICS instruction, assume that the following two fields are in storage:

| | | | |
|---------|-------------------|------|--|
| | 7090 | 7093 | |
| Field A | C6 C7 C8 C9 | | |
| | 7041 | 7046 | |
| Field B | F0 F1 F2 F3 F4 F5 | | |

Also assume:

Register 14 contains 00 00 70 90.
Register 15 contains 00 00 70 40.

After the instruction:

Machine Format

| Op Code | L | B ₁ | D ₁ | B ₂ | D ₂ |
|---------|----|----------------|----------------|----------------|----------------|
| D1 | 03 | F | 001 | E | 000 |

Assembler Format

| Op Code | D ₁ (L, B ₁), D ₂ (B ₂) |
|---------|---|
| MVN | 1(4, 15), 0(14) |

is executed, field B becomes:

| | |
|-------------------|------|
| 7041 | 7046 |
| F6 F7 F8 F9 F4 F5 | |

The numeric bits of the bytes at locations 7090-7093 have been stored in the numeric bits of the bytes at locations 7041-7044. The contents of locations 7090-7093 and 7045-7046 are unchanged.

MOVE WITH OFFSET (MVO)

MOVE WITH OFFSET may be used to shift a packed-decimal number an odd number of digit positions or to concatenate a sign to an unsigned packed-decimal number.

Assume that the three-byte unsigned packed-decimal number in storage locations 4500-4502 is to be moved to locations 5600-5603 and given the sign of the packed-decimal number ending at location 5603. Also assume:

Register 12 contains 00 00 56 00.
Register 15 contains 00 00 45 00.
Storage locations 5600-5603 contain 77 88

99 0C.
Storage locations 4500-4502 contain 12 34 56.

After the instruction:

Machine Format

| Op Code | L ₁ | L ₂ | B ₁ | D ₁ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|----------------|----------------|
| F1 | 3 | 2 | C | 000 | F | 000 |

Assembler Format

Op Code D₁(L₁,B₁),D₂(L₂,B₂)
MVO 0(4,12),0(3,15)

is executed, the storage locations 5600-5603 contain 01 23 45 6C. Note that the second operand is extended on the left with one zero to fill out the first-operand field.

MOVE ZONES (MVZ)

The MOVE ZONES instruction can, similarly to MOVE (MVC) and MOVE NUMERICS, operate on overlapping or nonoverlapping fields. When operating on nonoverlapping fields, MOVE ZONES works like the MOVE NUMERICS instruction (see the example for MOVE NUMERICS), except that MOVE ZONES moves only the zone bits of each byte. To illustrate the use of MOVE ZONES with overlapping fields, assume that the following data field is in storage:

| 800 | 805 |
|-------------------|-----|
| F1 C2 F3 C4 F5 C6 | |

Also assume that register 15 contains 00 00 08 00. The instruction:

Machine Format

| Op Code | L | B ₁ | D ₁ | B ₂ | D ₂ |
|---------|----|----------------|----------------|----------------|----------------|
| D3 | 04 | F | 001 | F | 000 |

Assembler Format

Op Code D₁(L,B₁),D₂(B₂)
MVZ 1(5,15),0(15)

propagates the zone bits from the byte at address 800 through the entire field, so that the field becomes:

| 800 | 805 |
|-------------------|-----|
| F1 F2 F3 F4 F5 F6 | |

MULTIPLY (M, MR)

Assume that a number in register 5 is to be multiplied by the contents of a word at address 3750. Initially:

The contents of register 4 are not significant.
Register 5 contains 00 00 00 9A = 154{10} = the multiplicand.
Register 11 contains 00 00 06 00.
Register 12 contains 00 00 30 00.
Storage locations 3750-3753 contain 00 00 00 83 = 131{10} = the multiplier.

The instruction required for performing the multiplication is:

Machine Format

| Op Code | R ₁ | X ₂ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|
| 5C | 4 | B | C | 150 |

Assembler Format

Op Code R₁,D₂(X₂,B₂)
M 4,X'150'(11,12)

After the instruction is executed, the product is in the register pair 4 and 5:

Register 4 contains 00 00 00 00.
Register 5 contains 00 00 4E CE = 20,174{10}.
Storage locations 3750-3753 are unchanged.

The RR format of the instruction can be used to square the number in a register. Assume that register 7 contains 00 01 00 05. The instruction:

Machine Format

| Op Code | R ₁ | R ₂ |
|---------|----------------|----------------|
| 1C | 6 | 7 |

Assembler Format

| Op Code | R ₁ , R ₂ |
|---------|---------------------------------|
| MR | 6,7 |

multiplies the number in register 7 by itself and places the result in the pair of registers 6 and 7:

Register 6 contains 00 00 00 01.
Register 7 contains 00 0A 00 19.

MULTIPLY HALFWORD (MH)

The MULTIPLY HALFWORD instruction is used to multiply the contents of a register by a halfword in storage. For example, assume that:

Register 11 contains 00 00 00 15 = 21{10} = the multiplicand.
Register 14 contains 00 00 01 00.
Register 15 contains 00 00 20 00.
Storage locations 2102-2103 contain FF D9 = -39 = the multiplier.

The instruction:

Machine Format

| Op Code | R ₁ | X ₂ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|
| 4C | B | E | F | 002 |

Assembler Format

| Op Code | R ₁ , D ₂ (X ₂ , B ₂) |
|---------|--|
| MH | 11,2 (14,15) |

multiplies the two numbers. The product, FF FF FC CD = -819{10}, replaces the original contents of register 11.

Only the rightmost 32 bits of a product are stored in a register; any significant bits on the left are lost. No program interruption occurs on overflow.

OR (O, OR, OI, OC)

When the Boolean operator OR is applied to two bits, the result is one when either bit is one; otherwise, the result is zero. When two bytes are ORed, each pair of bits is handled separately; there is no connection from one bit position to another. The following is an example of ORing two bytes:

First-operand byte: 0011 0101{2}
Second-operand byte: 0101 1100{2}

Result byte: 0111 1101{2}

Or (OI)

A frequent use of the OR instruction is to set a particular bit to one. For example, assume that storage location 4891 contains 0100 0010{2}. To set the rightmost bit of this byte to one without affecting the other bits, the following instruction can be used (assume that register 8 contains 00 00 48 90):

Machine Format

| Op Code | I ₂ | B ₁ | D ₁ |
|---------|----------------|----------------|----------------|
| 96 | 01 | 8 | 001 |

Assembler Format

| Op Code | D ₁ (B ₁), I ₂ |
|---------|--|
| OI | 1(8), X'01' |

When this instruction is executed, the byte in storage is ORed with the immediate byte (the I₂ field of the instruction):

Location 4891: 0100 0010{2}
Immediate byte: 0000 0001{2}

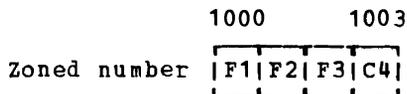
Result: 0100 0011{2}

The resulting byte with bit 7 set to one is stored back in location 4891. Condition code 1 is set.

PACK (PACK)

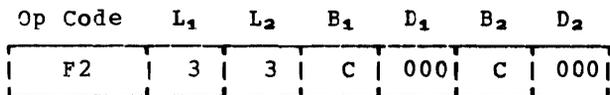
Assume that storage locations 1000-1003 contain the following zoned-decimal number that is to be converted to a packed-decimal

number and left in the same location:

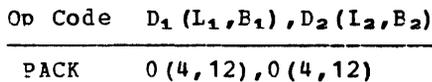


Also assume that register 12 contains 00 00 10 00. After the instruction:

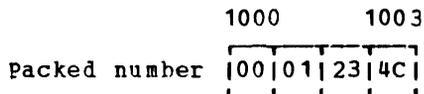
Machine Format



Assembler Format



is executed, the result in locations 1000-1003 is in the packed-decimal format:



Notes:

1. This example illustrates the operation of PACK when the first- and second-operand fields overlap completely.
2. During the operation, the second operand was extended on the left with zeros.

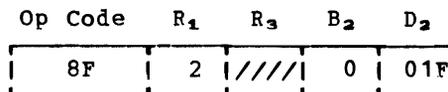
SHIFT LEFT DOUBLE (SLDA)

The SHIFT LEFT DOUBLE instruction is similar to SHIFT LEFT SINGLE except that SLDA shifts the 63 bits (not including the sign) of an even-odd register pair. The R₁ field of this instruction must be even. For example, if the contents of registers 2 and 3 are:

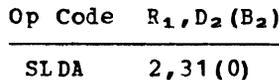
00 7F 0A 72 FE DC BA 98 =
 0000 0000 0111 1111 0000 1010 0111 0010
 1111 1110 1101 1100 1011 1010 1001 1000{2}

The instruction:

Machine Format



Assembler Format



results in registers 2 and 3 both being left-shifted 31 bit positions, so that their new contents are:

7F 6E 5D 4C 00 00 00 00 =
 0111 1111 0110 1110 0101 1101 0100 1100
 0000 0000 0000 0000 0000 0000 0000 0000{2}

In this case, a significant bit is shifted out of bit position 1 of register 2. Condition code 3 is set to indicate this overflow and, if the fixed-point-overflow mask bit in the PSW is one, a fixed-point overflow interruption occurs.

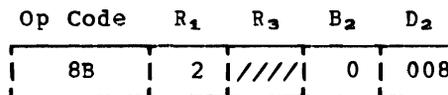
SHIFT LEFT SINGLE (SLA)

Because SHIFT LEFT SINGLE leaves the sign bit unchanged, this instruction performs an algebraic shift. For example, if the contents of register 2 are:

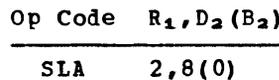
00 7F 0A 72 = 0000 0000 0111 1111 0000 1010
 0111 0010{2}

The instruction:

Machine Format



Assembler Format



results in register 2 being shifted left eight bit positions so that its new contents are:

7F 0A 72 00 = 0111 1111 0000 1010 0111 0010
 0000 0000{2}

Condition code 2 is set to indicate that

the result is nonzero and positive.

If a left shift of nine places had been specified, a significant bit would have been shifted out of bit position 1. Condition code 3 would have been set to indicate this overflow and, if the fixed-point-overflow mask bit in the PSW is one, a fixed-point overflow interruption would have occurred.

STORE CHARACTERS UNDER MASK (STCM)

STORE CHARACTERS UNDER MASK (STCM) may be used to place selected bytes from a register into storage. For example, if it is desired to store a three-byte address from general register 8 into location FIELD3, assume:

Machine Format

| Op Code | R ₁ | M ₃ | S ₂ |
|---------|----------------|----------------|----------------|
| BE | 8 | 7 | * * * * |

Register Format

| Op Code | R ₁ , M ₃ , S ₂ |
|---------|--|
| STCM | 8, B'0111', FIELD3 |

Register 8: 12 34 56 78
 FIELD3 (before): not significant
 FIELD3 (after): 34 56 78

As another example:

Machine Format

| Op Code | R ₁ | M ₃ | S ₂ |
|---------|----------------|----------------|----------------|
| BE | 9 | 5 | * * * * |

Register Format

| Op Code | R ₁ , M ₃ , S ₂ |
|---------|--|
| STCM | 9, B'0101', FIELD2 |

Register 9: 01 23 45 67
 FIELD2 (before): not significant
 FIELD2 (after): 23 67

STORE MULTIPLE (STM)

Assume that the contents of general registers 14, 15, 0, and 1 are to be stored in consecutive words starting with location 4050 and that:

Register 14 contains 00 00 25 63.
 Register 15 contains 00 01 27 36.
 Register 0 contains 12 43 00 62.
 Register 1 contains 73 26 12 57.
 Register 6 contains 00 00 40 00.
 The initial contents of locations 4050-405F are not significant.

The STORE MULTIPLE instruction allows the use of just one instruction to store the contents of the four registers:

Machine Format

| Op Code | R ₁ | R ₃ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|
| 90 | E | 1 | 6 | 050 |

Assembler Format

| Op Code | R ₁ , R ₃ , D ₂ (B ₂) |
|---------|--|
| STM | 14, 1, X'50'(6) |

After the instruction is executed:

Locations 4050-4053 contain 00 00 25 63.
 Locations 4054-4057 contain 00 01 27 36.
 Locations 4058-405B contain 12 43 00 62.
 Locations 405C-405F contain 73 26 12 57.

TEST UNDER MASK (TM)

The TEST UNDER MASK instruction examines selected bits of a byte and sets the condition code accordingly. For example, assume that:

Storage location 9999 contains FB.
 Register 7 contains 00 00 99 90.

Execution of the instruction:

Machine Format

| Op Code | I ₂ | B ₁ | D ₁ |
|---------|----------------|----------------|----------------|
| 91 | C3 | 7 | 009 |

Assembler Format

| Op Code | D ₁ (B ₁), I ₂ |
|---------|--|
| TM | 9(7),B'11000011' |

produces the following result:

```

FB      = 1111 1011{2}
Mask    = 1100 0011{2}
-----
Result  = 11xx xx11{2}
    
```

Condition code 3 is set: all selected bits are ones.

If location 9999 had contained B9, the result would have been:

```

B9      = 1011 1001{2}
Mask    = 1100 0011{2}
-----
Result  = 10xx xx01{2}
    
```

Condition code 1 is set: the selected bits are both zeros and ones.

If location 9999 had contained 3C, the result would have been:

```

3C      = 0011 1100{2}
Mask    = 1100 0011{2}
-----
Result  = 00xx xx00{2}
    
```

Condition code 0 is set: all selected bits are zeros.

Note: Storage location 9999 remains unchanged.

TRANSLATE (TR)

The TRANSLATE instruction can be used to translate data from any character code to any other desired code, provided that each coded character consists of eight bits or fewer. In the following example, EBCDIC is translated to ASCII. The first step is to create a 256-byte table in storage locations 1000-10FF. This table contains the characters of the target code in the sequence of the binary representation of the source code; that is, the ASCII representation of a character is placed in storage at the starting address of the table plus the binary value of the EBCDIC representation of the same character. For

simplicity, the example shows only the part of the table containing the decimal digits:

Translate Table for Decimal Digits:

| 10F0 | | | | 10F9 | | | | | |
|------|----|----|----|------|----|----|----|----|----|
| 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 |

Assume that the four-byte field at storage location 2100 contains the EBCDIC code for the digits 1984:

Locations 2100-2103 contain F1 F9 F8 F4.
 Register 12 contains 00 00 21 00.
 Register 15 contains 00 00 10 00.

As the instruction:

Machine Format

| Op Code | L | B ₁ | D ₁ | B ₂ | D ₂ |
|---------|----|----------------|----------------|----------------|----------------|
| DC | 03 | C | 000 | F | 000 |

Assembler Format

| Op Code | D ₁ (L, B ₁), D ₂ (B ₂) |
|---------|---|
| TR | 0(4,12),0(15) |

is executed, the binary value of each source byte is added to the starting address of the table, and the resulting address is used to fetch a target byte:

```

Table starting address: 1000
First source byte:      F1
-----
Address of target byte: 10F1
    
```

After execution of the instruction:

Locations 2100-2103 contain 31 39 38 34.

Thus, the ASCII code for the digits 1984 has replaced the EBCDIC code in the four-byte field at storage location 2100.

TRANSLATE AND TEST (TRT)

The TRANSLATE AND TEST instruction can be used to scan a data field for characters with a special meaning. To indicate which characters have a special meaning, a table similar to the one used for the TRANSLATE instruction is set up, except that zeros in the table indicate characters without any special meaning and nonzero values indicate characters with a special meaning.

The figure "Translate-and-Test Table" that follows has been set up to distinguish

alphanumeric characters (A to Z and 0 to 9) invalid. EBCDIC coding is assumed. The
 from blanks, certain special symbols, and 256-byte table is assumed stored at
 all other characters which are considered locations 2000-20FF.

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F |
|------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 200_ | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| 201_ | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| 202_ | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| 203_ | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| 204_ | 04 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 08 | 40 | 0C | 10 | 40 |
| 205_ | 14 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 18 | 1C | 20 | 40 | 40 |
| 206_ | 24 | 28 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 2C | 40 | 40 | 40 | 40 |
| 207_ | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 30 | 34 | 38 | 3C | 40 |
| 208_ | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| 209_ | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| 20A_ | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| 20B_ | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| 20C_ | 40 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 40 | 40 | 40 | 40 | 40 | 40 |
| 20D_ | 40 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 40 | 40 | 40 | 40 | 40 | 40 |
| 20E_ | 40 | 40 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 40 | 40 | 40 | 40 | 40 | 40 |
| 20F_ | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 40 | 40 | 40 | 40 | 40 | 40 |

Note: If the character codes in the statement being translated occupy a range smaller than 00 through FF{16}, a table of fewer than 256 bytes can be used.

Translate and Test Table

The table entries for the alphameric characters in EBCDIC are 00; thus, the letter A (code C1) corresponds to byte location 20C1, which contains 00.

The 15 special symbols have nonzero entries from 04{16} to 3C{16} in increments of 4. Thus, the blank (code 40) has the entry 04{16}, the period (code 4B) has the entry 08{16}, and so on.

All other table positions have the entry 40{16} to indicate an invalid character.

The table entries are chosen so that they may be used to select one of a list of 16 words containing addresses of different routines to be entered for each special symbol or invalid character encountered during the scan.

Assume that this list of 16 branch addresses is stored at locations 3004-3043.

Starting at storage location CA80, there is the following sequence of 21{10} EBCDIC characters:

Locations CA80-CA94: UNPKbPROUT(9),WORD(5)

Also assume:

- | Register 1 contains 00 00 CA 7F.
- Register 2 contains 00 00 30 00.
- Register 15 contains 00 00 20 00.

As the instruction:

Machine Format

| Op Code | L | B ₁ | D ₁ | B ₂ | D ₂ |
|---------|----|----------------|----------------|----------------|----------------|
| DD | 14 | 1 | 001 | F | 000 |

Assembler Format

| Op Code | D ₁ (L, B ₁), D ₂ (B ₂) |
|---------|---|
| TRT | 1(21,1),0(15) |

is executed, the value of the first argument byte, the letter U, is added to the starting address of the table to produce the address of the table entry to be examined:

| | |
|-------------------------|------|
| Table starting address | 2000 |
| First argument byte (U) | E4 |
| ----- | |
| Address of table entry | 20E4 |

Because zeros were placed in storage location 20E4, no special action occurs. The operation continues with the second and subsequent argument bytes until it reaches the blank in location CA84. When this symbol is reached, its value is added to

the starting address of the table, as usual:

| | |
|------------------------|------|
| Table starting address | 2000 |
| Argument byte (blank) | 40 |
| ----- | |
| Address of table entry | 2040 |

Because location 2040 contains a nonzero value, the following actions occur:

1. The address of the argument byte, 00CA84, is placed in the rightmost 24 bits of register 1.
2. The table entry, 04, is placed in the rightmost eight bits of register 2, which now contains 00 00 30 04.
3. Condition code 1 is set (scan not completed).

The TRANSLATE AND TEST instruction may be followed by instructions to branch to the routine at the address found at location 3004, which corresponds to the blank character encountered in the scan. When this routine is completed, program control may return to the TRANSLATE AND TEST instruction to continue the scan, except that the length must first be adjusted for the characters already scanned.

For this purpose, the TRANSLATE AND TEST may be executed by the use of an EXECUTE instruction, which supplies the length specification from a general register. In this way, a complete statement scan can be performed with a single TRANSLATE AND TEST instruction repeated over and over by means of EXECUTE, and without modifying any instructions in storage. In the example, after the first execution of TRANSLATE AND TEST, register 1 contains the address of the last argument byte translated. It is then a simple matter to subtract this address from the address of the last argument byte (CA94) to produce a length specification. This length minus one is placed in the register that is referenced as the R1 field of the EXECUTE instruction. (Note that the length code in the machine format is one less than the total number of bytes in the field.) The second-operand address of the EXECUTE instruction points to the TRANSLATE AND TEST instruction, which is the same as illustrated above, except for the length (L) which is set to zero.

UNPACK (UNPK)

Assume that storage locations 2501-2502 contain a signed, packed-decimal number that is to be unpacked and placed in storage locations 1000-1004. Also assume:

Register 12 contains 00 00 10 00.
 Register 13 contains 00 00 25 00.
 Storage locations 2501-2502 contain 12 3D.
 The initial contents of storage locations
 1000-1004 are not significant.

After the instruction:

Machine Format

| Op Code | L ₁ | L ₂ | B ₁ | D ₁ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|----------------|----------------|
| F3 | 4 | 1 | C | 000 | D | 001 |

Assembler Format

Op Code D₁(L₁,B₁),D₂(L₂,B₂)
 UNPK 0(5,12),1(2,13)

is executed, the storage locations
 1000-1004 contain F0 F0 F1 F2 D3.

DECIMAL INSTRUCTIONS

(See Chapter 8.)

ADD DECIMAL (AP)

Assume that the signed, packed-decimal
 number at storage locations 500-503 is to
 be added to the signed, packed-decimal
 number at locations 2000-2002. Also
 assume:

Register 12 contains 00 00 20 00.
 Register 13 contains 00 00 05 00.
 Storage locations 2000-2002 contain 38 46
 0D (a negative number).
 Storage locations 500-503 contain 01 12 34
 5C (a positive number).

After the instruction:

Machine Format

| Op Code | L ₁ | L ₂ | B ₁ | D ₁ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|----------------|----------------|
| FA | 2 | 3 | C | 000 | D | 000 |

Assembler Format

Op Code D₁(L₁,B₁),D₂(L₂,B₂)
 AP 0(3,12),0(4,13)

is executed, the storage locations
 2000-2002 contain 73 88 5C; condition code
 2 is set to indicate that the sum is

positive. Note that:

1. Because the two numbers had different signs, they were in effect subtracted.
2. Although the second operand is longer than the first operand, no overflow interruption occurs because the result can be entirely contained within the first operand.

COMPARE DECIMAL (CP)

Assume that the signed, packed-decimal
 contents of storage locations 700-703 are
 to be algebraically compared with the
 signed, packed-decimal contents of
 locations 500-502. Also assume:

Register 12 contains 00 00 06 00.
 Register 13 contains 00 00 03 00.
 Storage locations 700-703 contain 17 25 35
 6D.
 Storage locations 500-502 contain 72 14
 2D.

After the instruction:

Machine Format

| Op Code | L ₁ | L ₂ | B ₁ | D ₁ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|----------------|----------------|
| F9 | 3 | 2 | C | 100 | D | 200 |

Assembler Format

Op Code D₁(L₁,B₁),D₂(L₂,B₂)
 CP X'100'(4,12),X'200'(3,13)

is executed, condition code 1 is set,
 indicating that the first operand (the
 contents of locations 700-703) is less than
 the second.

DIVIDE DECIMAL (DP)

Assume that the signed, packed-decimal
 number at storage locations 2000-2004 (the
 dividend) is to be divided by the signed,
 packed-decimal number at locations
 3000-3001 (the divisor). Also assume:

Register 12 contains 00 00 20 00.
 Register 13 contains 00 00 30 00.
 Storage locations 2000-2004 contain 01 23
 45 67 8C.
 Storage locations 3000-3001 contain 32 1D.

After the instruction:

Machine Format

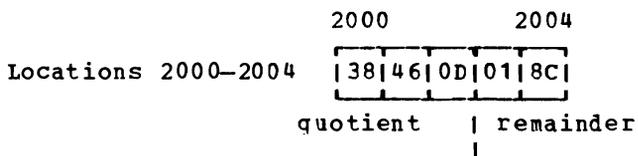
| Op Code | L ₁ | L ₂ | B ₁ | D ₁ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|----------------|----------------|
| FD | 4 | 1 | C | 000 | D | 000 |

Assembler Format

Op Code D₁(L₁,B₁),D₂(L₂,B₂)

DP 0(5,12),0(2,13)

is executed, the dividend is entirely replaced by the signed quotient and remainder, as follows:



Notes:

1. Because the dividend and divisor have different signs, the quotient receives a negative sign.
2. The remainder receives the sign of the dividend and the length of the divisor.
3. If an attempt were made to divide the dividend by the one-byte field at location 3001, the quotient would be too long to fit within the four bytes allotted to it. A decimal-divide exception would exist, causing a program interruption.

EDIT (ED)

Before decimal data in the packed format can be used in a printed report, digits and signs must be converted to printable characters. Moreover, punctuation marks, such as commas and decimal points, may have to be inserted in appropriate places. The highly flexible EDIT instruction performs these functions in a single instruction execution.

This example shows step-by-step one way that the EDIT instruction can be used. The field to be edited (the source) is four bytes long; it is edited against a pattern 13 bytes long. The following symbols are used:

| Symbol | Meaning |
|--------------------|----------------------|
| b (Hexadecimal 40) | Blank character |
| ((Hexadecimal 21) | Significance starter |
| d (Hexadecimal 20) | Digit selector |

Assume that the source and pattern fields are:

Source

1200 1203

| |
|-------------|
| 02 57 42 6C |
|-------------|



Pattern

1000 100C

| |
|--|
| 40 20 20 6B 20 21 20 4B 20 20 40 C3 D9 |
|--|

b d d , d (d . d d b C F

Execution of the instruction (assume that register 12 contains 00 00 10 00):

Machine Format

| Op Code | L | B ₁ | D ₁ | B ₂ | D ₂ |
|---------|----|----------------|----------------|----------------|----------------|
| DE | 0C | C | 000 | C | 200 |

Assembler Format

Op Code D₁(L,B₁),D₂(B₂)

ED 0(13,12),X'200'(12)

alters the pattern field as follows:

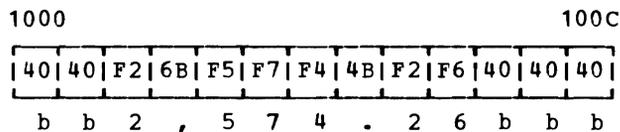
| Pattern | Digit | Significance Indicator (Before/After) | Rule | Location 1000-100C |
|---------|-------|---------------------------------------|-----------|--------------------|
| b | | off/off | leave (1) | bdd,d(d.ddbCR |
| d | 0 | off/off | fill | bbd,d(d.ddbCR |
| d | 2 | off/on(2) | digit | bb2,d(d.ddbCR |
| , | | on/on | leave | same |
| d | 5 | on/on | digit | bb2,5(d.ddbCR |
| (| 7 | on/on | digit | bb2,57d.ddbCR |
| d | 4 | on/on | digit | bb2,574.ddbCR |
| . | | on/on | leave | same |
| d | 2 | on/on | digit | bb2,574.2dbCR |
| d | 6+ | on/off(3) | digit | bb2,574.26bCR |
| b | | off/off | fill | same |
| C | | off/off | fill | bb2,574.26bbR |
| R | | off/off | fill | bb2,574.26bbb |

Notes:

1. This character is the fill byte.
2. First nonzero decimal source digit turns on significance indicator.
3. Plus sign in the four rightmost bits of the byte turns off significance indicator.

Thus, after the instruction is executed, the pattern field contains the result as follows:

Pattern



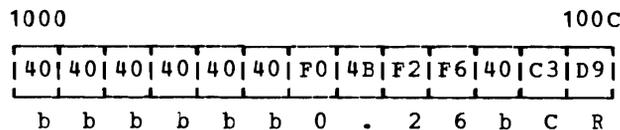
When printed, the new pattern field appears as:

2,574.26

The source field remains unchanged. Condition code 2 is set because the number was greater than zero.

If the number in the source field is changed to 00 00 02 6D, a negative number, and the original pattern is used, the edited result this time is:

Pattern



This pattern field prints as:

0.26 CR

The significance starter forces the significance indicator to the on state and hence causes the decimal point to be preserved. Because the minus-sign code has no effect on the significance indicator, the characters CR are printed to show a negative (credit) amount.

Condition code 1 is set (number less than zero).

EDIT AND MARK (EDMK)

The EDIT AND MARK instruction may be used, in addition to the functions of EDIT, to insert a currency symbol, such as a dollar sign, at the appropriate position in the edited result. Assume the same source in storage locations 1200-1203, the same pattern in locations 1000-100C, and the same contents of general register 12 as for the EDIT instruction above. The previous contents of general register 1 are immaterial; a LOAD ADDRESS instruction is used to set up the first digit position that is forced to print if no significant digits occur to the left.

The instructions:

- | | |
|--------------------------|--|
| LA 1,6(0,12) | Load address of forced significant digit into GR1. |
| EDMK 0(13,12),X'200'(12) | Leave address of first significant |

FIELD1 (before): 00 01 23 45 67 8C

FIELD1 (after): 12 34 56 78 00 0C

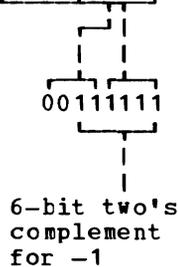
The second-operand address in this instruction specifies the shift amount (three places). The rounding factor, I₃, is not used in left shift, but it must be a valid decimal digit. After execution, condition code 2 is set to show that the result is greater than zero.

Decimal Right Shift

In this example, the contents of storage location FIELD2 are shifted one place to the right, effectively dividing the contents of FIELD2 by 10 and discarding the remainder. FIELD2 is five bytes in length. The following instruction performs this operation:

Machine Format

| Op Code | L ₁ | I ₃ | S ₁ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|----------------|
| F0 | 4 | 0 | **** | 0 | 03F |



Assembler Format

| Op Code | S ₁ (L ₁), S ₂ , I ₃ |
|---------|---|
| SRP | FIELD2 (5), 64-1, 0 |

FIELD 2 (before): 01 23 45 67 8C

FIELD 2 (after): 00 12 34 56 7C

In the SRP instruction, shifts to the right are specified in the second-operand address by negative shift values, which are represented as a six-bit value in two's complement form.

The six-bit two's complement of a number, n, can be specified as 64 - n. In this example, a right shift of one is represented as 64 - 1.

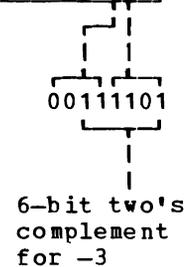
Condition code 2 is set.

Decimal Right Shift and Round

In this example, the contents of storage location FIELD3 are shifted three places to the right and rounded, effectively dividing by 1000 and rounding to the nearest whole number. FIELD3 is four bytes in length.

Machine Format

| Op Code | L ₁ | I ₃ | S ₁ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|----------------|
| F0 | 3 | 5 | **** | 0 | 03D |



Assembler Format

| Op Code | S ₁ (L ₁), S ₂ , I ₃ |
|---------|---|
| SRP | FIELD3 (4), 64-3, 5 |

FIELD 3 (before): 12 39 60 0D

FIELD 3 (after): 00 01 24 0D

The shift amount (three places) is specified in the D₂ field. The I₃ field specifies the rounding factor of 5. The rounding factor is added to the last digit shifted out (which is a 6), and the carry is propagated to the left. The sign is ignored during the addition.

Condition code 1 is set because the result is less than zero.

Multiplying by a Variable Power of 10

Since the shift value designated by the SRP instruction specifies both the direction and amount of the shift, the operation is equivalent to multiplying the decimal first operand by 10 raised to the power specified by the shift value.

If the shift value is variable, it may be specified by the B₂ field instead of the displacement D₂ of the SRP instruction. The general register designated by B₂ should contain the shift value (power of 10) as a signed binary integer.

A fixed scale factor modifying the variable

power of 10 may be specified by using both the B₂ field (variable part in a general register) and the D₂ field (fixed part in the displacement).

The SRP instruction uses only the rightmost six bits of the effective address D₂(B₂) and interprets them as a six-bit signed binary integer to control the left or right shift as in the previous two examples.

ZERO AND ADD (ZAP)

Assume that the signed, packed-decimal number at storage locations 4500-4502 is to be moved to locations 4000-4004 with four leading zeros in the result field. Also assume:

Register 9 contains 00 00 40 00.
 Storage locations 4000-4004 contain 12 34
 56 78 90.
 Storage locations 4500-4502 contain 38 46
 0D.

After the instruction:

Machine Format

| Op Code | L ₁ | L ₂ | B ₁ | D ₁ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|----------------|----------------|
| F8 | 4 | 2 | 9 | 000 | 9 | 500 |

Assembler Format

Op Code D₁(L₁,B₁),D₂(L₂,B₂)
 ZAP 0(5,9),X'500'(3,9)

is executed, the storage locations 4000-4004 contain 00 00 38 46 0D; condition code 1 is set to indicate a negative result.

Note that, because the first operand is not checked for valid sign and digit codes, it may contain any combination of hexadecimal digits before the operation.

FLOATING-POINT INSTRUCTIONS

(See Chapter 9.)

In this section, the abbreviations FPR0, FPR2, FPR4, and FPR6 stand for floating-point registers 0, 2, 4, and 6 respectively.

ADD NORMALIZED (AD, ADR, AE, AER, AXR)

The ADD NORMALIZED instructions perform the addition of two floating-point numbers and place the normalized result in a floating-point register. Neither of the two numbers to be added must necessarily be normalized before addition occurs. For example, assume that:

FPR6 contains C3 08 21 00 00 00 00 =
 -82.1{16} = -130.06{10} approximately
 (unnormalized).
 Storage locations 2000-2007 contain 41 12
 34 56 00 00 00 00 = +1.23456{16} =
 +1.14{10} (normalized).
 Register 13 contains 00 00 20 00.

The instruction:

Machine Format

| Op Code | R ₁ | X ₂ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|
| 7A | 6 | 0 | D | 000 |

Assembler Format

Op Code R₁,D₂(X₂,B₂)
 AE 6,0(0,13)

performs the short-precision addition of the two operands, as follows.

The characteristics of the two numbers (43 and 41) are compared. Since the number in storage has a characteristic that is smaller by 2, it is right-shifted two hexadecimal digit positions. The two numbers are then added:

| | |
|---------------------------|-----------------|
| | GD ¹ |
| FPR6: | -43 08 21 00 |
| Shifted no. from storage: | +43 00 12 34 5 |
| ----- | |
| Intermediate sum: | -43 08 0E CB B |

¹ Guard digit

Because the intermediate sum is unnormalized, it is left-shifted to form the normalized floating-point number -42 80 EC BB = -80.ECBB{16} = -128.92. Combining the sign with the characteristic, the result is C2 80 EC BB, which replaces the left half of FPR6. The right half of FPR6 and the contents of storage locations 2000-2007 are unchanged. Condition code 1 is set to indicate a negative result.

If the long-precision instruction AD is used, the result in FPR6 is C2 80 EC BA A0 00 00 00. Note that the long-precision instruction avoids a loss of precision in this example.

ADD UNNORMALIZED (AU, AUR, AW, AWR)

The ADD UNNORMALIZED instructions operate identically to the ADD NORMALIZED instructions, except that the final result is not normalized. For example, using the same operands as in the example for ADD NORMALIZED, when the short-precision instruction:

Machine Format

| Op Code | R ₁ | X ₂ | B ₂ | D ₂ |
|---------|----------------|----------------|----------------|----------------|
| 7E | 6 | 0 | D | 000 |

Assembler Format

Op Code R₁, D₂ (X₂, B₂)

AU 6, 0(0, 13)

is executed, the two numbers are added as follows:

| | | |
|---------------------------|--------------|-----------------|
| FPR6: | -43 08 21 00 | GD ¹ |
| Shifted no. from storage: | +43 00 12 34 | 5 |
| ----- | | |
| Sum: | -43 08 0E CB | B |

¹ Guard digit

The guard digit participates in the addition but is discarded. The unnormalized sum replaces the left half of FPR6. Condition code 1 is set because the result is negative.

The result in FPR6 (C3 08 0E CB 00 00 00) shows a loss of a significant digit when compared to the result of short-precision normalized addition.

COMPARE (CD, CDR, CE, CER)

Assume that FPR4 contains 43 00 00 00 00 00 00 00 (=0), and FPR6 contains 34 12 34 56 78 9A BC DE (a positive number). The contents of the two registers are to be compared using a long-precision COMPARE instruction.

Machine Format

| Op Code | R ₁ | R ₂ |
|---------|----------------|----------------|
| 29 | 4 | 6 |

Assembler Format

Op Code R₁, R₂

CDR 4, 6

The number with the smaller characteristic, which is the one in register FPR6, is right-shifted 15 hexadecimal digit positions so that the two characteristics agree. The shifted contents of FPR6 are 43 00 00 00 00 00 00, with a guard digit of zero. Therefore, when the two numbers are compared, condition code 0 is set, indicating an equality.

As the above example implies, when floating-point numbers are compared, more than two numbers may compare equal if one of the numbers is unnormalized. For example, the unnormalized floating-point number 41 00 12 34 56 78 9A BC compares equal to all numbers of the form 3F 12 34 56 78 9A BC 0X (X represents any hexadecimal digit). When the COMPARE instruction is executed, the two rightmost digits are shifted right two places, the 0 becomes the guard digit, and the X does not participate in the comparison.

However, when two normalized floating-point numbers are compared, the relationship between numbers that compare equal is unique: each digit in one number must be identical to the corresponding digit in the other number.

FLOATING-POINT-NUMBER CONVERSION

The following examples illustrate one method of converting between binary fixed-point numbers (32-bit signed binary integers) and normalized floating-point numbers. Conversion must provide for the different representations used with negative numbers: the two's-complement form for signed binary integers, and the signed-absolute-value form for the fractions of floating-point numbers.

Fixed Point to Floating Point

The method used here inverts the leftmost bit of the signed binary integer which, after appending additional zero bits on the

left as necessary, is equivalent to adding 2^{31} to the number. This changes it from a signed integer in the range $2^{31} - 1$ through -2^{31} to an unsigned integer in the range $2^{32} - 1$ through 0. After conversion to the long floating-point format, the value 2^{31} is subtracted again.

Assume that general register 9 (GR9) contains the integer -59 in two's-complement form:

```
GR9      FF FF FF C5
```

Further, assume two eight-byte fields in storage: TEMP, for use as temporary storage, and TWO31, which contains the floating-point constant 2^{31} in the following format:

```
TWO31    4E 00 00 00 80 00 00 00
```

This is an unnormalized long floating-point number with the characteristic 4E, which corresponds to a radix point to the right of the number.

The following instruction sequence performs the conversion:

| | <u>Result</u> |
|-------------------|----------------------------------|
| X 9,TWO31+4 | GR9: 7F FF FF C5 |
| ST 9,TEMP+4 | TEMP: -- -- -- -- 7F FF FF C5 |
| MVC TEMP(4),TWO31 | TEMP: 4E 00 00 00 7F FF FF C5 |
| LD 2,TEMP | FPR2: 4E 00 00 00 7F FF FF C5 |
| SD 2,TWO31 | FPR2: C2 3B 00 00 00 00 00 00 |

The EXCLUSIVE OR (X) instruction inverts the leftmost bit in general register 9, using the right half of the constant as the source for a leftmost one bit. The next two instructions assemble the modified number in an unnormalized long floating-point format, using the left half of the constant as the plus sign, the characteristic, and the leading zeros of the fraction. LOAD (LD) places the number unchanged in floating-point register 2. The SUBTRACT NORMALIZED (SD) instruction performs the final two steps by subtracting 2^{31} in floating-point form and normalizing the result.

Floating Point to Fixed Point

The procedure described here consists basically in reversing the steps of the previous procedure. Two additional considerations must be taken into account. First: the floating-point number may not

be an exact integer. Truncating the excess hexadecimal digits on the right requires shifting the number one digit position farther to the right than desired for the final result, so that the units digit occupies the position of the guard digit. Second: the floating-point number may have to be tested as to whether it is outside the range of numbers representable as a signed binary integer.

Assume that floating-point register 6 contains the number $59.25_{10} = 3B.4_{16}$ in normalized form:

```
FPR6     42 3B 40 00 00 00 00 00
```

Further, assume three eight-byte fields in storage: TEMP, for use as temporary storage, and the constants 2^{32} (TWO32) and 2^{31} (TWO31R) in the following formats:

```
TWO32    4E 00 00 01 00 00 00 00
TWO31R   4F 00 00 00 08 00 00 00
```

The constant TWO31R is shifted right one more position than the constant TWO31 of the previous example, so as to force the units digit into the guard-digit position.

The following instruction sequence performs the integer truncation, range tests, and conversion to a signed binary integer in general register 8 (GR8):

| | <u>Result</u> |
|-----------------|---|
| SD 6,TWO31R | FPR6: C8 7F FF FF C5 00 00 00 |
| BC 11,OVERFLOW | Branch to overflow routine if result non-negative |
| AW 6,TWO32 | FPR6: 4E 00 00 00 80 00 00 3B |
| BC 4,OVERFLOW | Branch to overflow routine if result negative |
| STD 6,TEMP | TEMP: 4E 00 00 00 80 00 00 3B |
| XI TEMP+4,X'80' | TEMP: 4E 00 00 00 00 00 00 3B |
| L 8,TEMP+4 | GR8: 00 00 00 3B |

The SUBTRACT NORMALIZED (SD) instruction shifts the fraction of the number to the right until it lines up with TWO31R, which causes the fraction digit 4 to fall to the right of the guard digit and be lost; the result of subtracting 2^{31} from the remaining digits is renormalized. The result should be negative; if not, the original number was too large in the positive direction. The first BRANCH ON CONDITION (BC) performs this test.

The ADD UNNORMALIZED (AW) instruction adds 2^{32} : 2^{31} to correct for the previous subtraction and another 2^{31} to change to an

all-positive range. The second BC tests for a negative result, showing that the number was too large in the negative direction. The unnormalized result is placed in temporary storage by the STORE (STD) instruction. There the leftmost bit of the binary integer is inverted by the EXCLUSIVE OR (XI) instruction before being loaded into GR8.

The problem shown here is that the value stored by the OI instruction executed on CPU A overlays the value that was stored by CPU B. The X'80' flag bit was erroneously turned off, and the date is now invalid.

The COMPARE AND SWAP instruction has been provided to overcome this and similar problems.

MULTIPROGRAMMING AND MULTIPROCESSING EXAMPLES

COMPARE AND SWAP (CS, CDS)

When two or more programs sharing common storage locations are running concurrently in a multiprogramming or multiprocessing environment, one program may, for example, set a flag bit in the common-storage area for testing by another program. It should be noted that the instructions AND (NI or NC), EXCLUSIVE OR (XI or XC), and OR (OI or OC) could be used to set flag bits in a multiprogramming environment; but the same instructions may cause program logic errors in a multiprocessing system where two or more CPUs can fetch, modify, and store data in the same storage locations simultaneously.

The COMPARE AND SWAP (CS) and COMPARE DOUBLE AND SWAP (CDS) instructions can be used in multiprogramming or multiprocessing environments to serialize access to counters, flags, control words, and other common storage areas.

The following examples of the use of the COMPARE AND SWAP and COMPARE DOUBLE AND SWAP instructions illustrate the applications for which the instructions are intended. It is important to note that these are examples of functions that can be performed by programs running enabled for interruption (multiprogramming) or by programs that are running on a multiprocessing configuration. That is, the routine allows a program to modify the contents of a storage location while running enabled, even though the routine may be interrupted by another program on the same CPU that will update the location, and even though the possibility exists that another CPU may simultaneously update the same location.

EXAMPLE OF A PROGRAM FAILURE USING OR IMMEDIATE

Assume that two independent programs try to set different bits to one in a common byte in storage. The following example shows how the use of the instruction OR immediate (OI) can fail to accomplish this, if the programs are executed nearly simultaneously on two different CPUs. One of the possible error situations is depicted.

The CS instruction first checks the value of a storage location and then modifies it only if the value is what the program expects; normally this would be a previously fetched value. If the value in storage is not what the program expects, then the location is not modified; instead, the current value of the location is loaded into a general register, in preparation for the program to loop back and try again. During the execution of CS, no other CPU can access the specified location.

| Execution of instruction OI FLAGS,X'01' on CPU A | FLAGS | Execution of instruction OI FLAGS,X'80' on CPU B |
|--|-------|--|
| Fetch FLAGS X'00' | X'00' | Fetch FLAGS X'00' |
| OR X'01' into X'00' | X'00' | OR X'80' into X'00' |
| Store X'01' into FLAGS | X'80' | Store X'80' into FLAGS |
| | X'01' | |
| FLAGS should have value of X'81' following both updates. | | |

Setting a Single Bit

The following instruction sequence shows how the CS instruction can be used to set a single bit in storage to one. Assume that FLAGS is the first byte of a word in storage called "WORD."

| | | |
|----------|----------|--|
| LA | 6,X'80' | Put bit to be ORed into GR6 |
| SLI | 6,24 | Shift left 24 places to align the byte to be ORed with the location of FLAGS within WORD |
| L | 7,WORD | Get original flag bit values |
| RETRY LR | 8,7 | Put flags to be modified into GR8 |
| OR | 8,6 | Set bit to one in new copy of flags |
| CS | 7,8,WORD | Store new flags unless original flags were changed |
| BC | 4,RETRY | If new flags are not stored, try again |

The format of the CS instruction is:

Machine Format

| Op Code | R ₁ | R ₃ | S ₂ |
|---------|----------------|----------------|----------------|
| BA | 7 | 8 | **** |

Assembler Format

| Op Code | R ₁ ,R ₃ ,S ₂ |
|---------|--|
| CS | 7,8,WORD |

The CS instruction compares the first operand (general register 7 containing the original flag values) to the second operand (WORD) while storage access to the specified location is not permitted to any CPU other than the one executing the CS instruction.

If the comparison is successful, indicating that FLAGS still has the same value that it originally had, the modified copy in general register 8 is stored into FLAGS. If FLAGS has changed since it was loaded, the compare will not be successful, and the current value of FLAGS is loaded into general register 7.

The CS instruction sets condition code 0 to indicate a successful compare and swap, and condition code 1 to indicate an unsuccessful compare and swap.

The program executing the sample instructions tests the condition code following the CS instruction and reexecutes the flag-modifying instructions if the CS instruction indicated an unsuccessful comparison. When the CS instruction is successful, the program continues execution outside the loop and FLAGS contains valid data.

The branch to RETRY will be taken only if some other program modifies the update

location. This type of a loop differs from the typical "bit-spin" loop. In a bit-spin loop, the program continues to loop until the bit changes. In this example, the program continues to loop only if the value does change during each iteration. If a number of CPUs simultaneously attempt to modify a single location by using the sample instruction sequence, one CPU will fall through on the first try, another will loop once, and so on until all CPUs have succeeded.

Updating Counters

In this example, a 32-bit counter is updated by a program using the CS instruction to ensure that the counter will be correctly updated. The original value of the counter is obtained by loading the word containing the counter into general register 7. This value is moved into general register 8 to provide a modifiable copy, and general register 6 (containing an increment to the counter) is added to the modifiable copy to provide the updated counter value. The CS instruction is used to ensure valid storing of the counter.

The program updating the counter checks the result by examining the condition code. The condition code 0 indicates a successful update, and the program can proceed. If the counter had been changed between the time that the program loaded its original value and the time that it executed the CS instruction, the CS instruction would have loaded the new counter value into general register 7 and set the condition code to 1, indicating an unsuccessful update. The program then must update the new counter value in general register 7 and retry the CS instruction, retesting the condition code, and retrying until a successful update is completed.

The following instruction sequence performs the above procedure:

| | | |
|---------|----------|---|
| LA | 6,1 | Put increment (1) into GR6 |
| L | 7,CNTR | Put original counter value into GR7 |
| LOOP LR | 8,7 | Set up copy in GR8 to modify |
| AR | 8,6 | Increment copy |
| CS | 7,8,CNTR | Update counter in storage |
| BC | 4,LOOP | If original value had changed, update new value |

The following shows two CPUs, A and B, executing this instruction sequence simultaneously: both CPUs attempt to add one to CNTR.

| <u>CPU A</u> | | <u>CNTR</u> | <u>CPU B</u> | | <u>Comments</u> |
|--------------|------------|-------------|--------------|------------|--|
| <u>GR7</u> | <u>GR8</u> | | <u>GR7</u> | <u>GR8</u> | |
| | | 16 | | | CPU A loads GR7 and GR8 from CNTR |
| 16 | 16 | | 16 | 16 | CPU B loads GR7 and GR8 from CNTR |
| | | | | 17 | CPU B adds one to GR8 |
| | | | | 17 | CPU A adds one to GR8 |
| | | 17 | | | CPU A executes CS; successful match, store |
| | | | | 17 | CPU B executes CS; no match, GR7 changed to CNTR value |
| | | | | 18 | CPU B loads GR8 from GR7, adds one to GR8 |
| | | 18 | | | CPU B executes CS; successful match, store |

```

HSPOST  SR  3,3
        CS  3,0,0(1)
        BE  EXITHP
        POST (1),(0)
EXITHP  [Any instruction]

```

BYPASS WAIT Routine

A BYPASS WAIT function, corresponding to the BYPASS POST, does not use the CS instruction, but the FIFO LOCK/UNLOCK routines which follow assume its use.

```

HSWAIT  TM  0(1),X'40'
        BO  EXITHW  If bit 1 is one,
                    then ECB is already
                    posted; branch to
                    to exit
                    WAIT ECB=(1)
EXITHW  [Any instruction]

```

BYPASSING POST AND WAIT

BYPASS POST Routine

The following routine allows the SVC "POST" as used in CS/VS to be bypassed whenever the corresponding WAIT has not yet been issued, provided that the supervisor WAIT and POST routines use COMPARE AND SWAP to manipulate event control blocks (ECBs).

Initial Conditions:

GR1 contains the address of the ECB.
GR0 contains the POST code.

```

HSPOST  L  3,0(1)  GR3 = contents of
                    ECB
        LTR 3,3     ECB marked 'wait-
                    ing'?
        RM  PSVC   Yes, issue post
                    SVC
        CS  3,0,0(1) No, store post
                    code
        BE  EXITHP  Continue
PSVC    POST (1),(0) ECB address is in
                    GR1, post code in
                    GR0
EXITHP  [Any instruction]

```

The following routine may be used in place of the previous HSPOST routine if the ECB is assumed to contain zeros when it is not marked "WAITING."

LOCK/UNLOCK

When a common storage area larger than a doubleword is to be updated, it is usually necessary to provide special interlocks to ensure that a single program at a time updates the common area. Such an area is called a serially reusable resource (SRR).

In general, updating a list, or even scanning a list, cannot be safely accomplished without first "freezing" the list. However, the COMPARE AND SWAP instructions can be used in certain restricted situations to perform queuing and list manipulation. Of prime importance is the capability to perform the lock/unlock functions and to provide sufficient queuing to resolve contentions, either in a LIFO or FIFO manner. The lock/unlock functions can then be used as the interlock mechanism for updating an SRR of any complexity.

The lock/unlock functions are based on the use of a "header" associated with the SRR. The header is the common starting point for determining the states of the SRR, either free or in use, and also is used for queuing requests when contentions occur. Contentions are resolved using WAIT and POST. The general programming technique requires that the program that encounters a "locked" SRR must "leave a mark on the wall" indicating the address of an ECB on which it will WAIT. The program "unlocking" sees the mark and posts the ECB, thus permitting the waiting program to continue. In the two examples given, all programs using a particular SRR must use

either the LIFO queuing scheme or the FIFO scheme; the two cannot be mixed. When more complex queuing is required, it is suggested that the queue for the SRR be locked using one of the two methods shown.

LOCK/UNLOCK with LIFO Queuing for Contentions

The header consists of a word, which can contain zero, a positive value, or a negative value.

- A zero value indicates that the SRR is free.
- A negative value indicates that the SRR is in use but no additional programs are waiting for the SRR.

- A positive value indicates that the SRR is in use and that one or more additional programs are waiting for the SRR. Each waiting program is identified by an element in a chained list. The positive value in the header is the address of the element most recently added to the list.

Each element consists of two words. The first word is used as an ECB; the second word is used as a pointer to the next element in the list. A negative value in a pointer indicates that the element is the last element in the list. The element is required only if the program finds the SRR locked and desires to be placed in the list.

The following chart describes the action taken for LIFO LOCK and LIFO UNLOCK routines.

| Function | Action | | |
|--|---|---|--|
| | Header Contains Zero | Header Contains Positive Value | Header Contains Negative Value |
| LIFO LOCK (the incoming element is at location A) | SRR is free. Set the header to a negative value. Use the SRR. | SRR is in use. Store the contents of the header into location A+4. Store address A into the header. WAIT; the ECB is at location A. | |
| LIFO UNLOCK | Error | Someone is waiting for the SRR. Move the pointer from the "last in" element into the header. POST; the ECB is in the "last in" element. | The list is empty. Store zeros into the header. The SRR is free. |

The following routines allow enabled code to perform the actions described in the previous chart.

LIFO LOCK Routine:

Initial Conditions:

GR1 contains the address of the incoming element.
GR2 contains the address of the header.

| | | | |
|--------|------|-------------------|--|
| LLOCK | SR | 3,3 | GR3 = 0 |
| | ST | 3,0(1) | Initialize the ECB |
| | LNR | 0,1 | GR0 = a negative value |
| TRYAGN | CS | 3,0,0(2) | Set the header to a negative value if the header contains zeros |
| | BE | USE | Did the header contain zeros? |
| | ST | 3,4(1) | No, store the value of the header into the pointer in the incoming element |
| | CS | 3,1,0(2) | Store the address of the incoming element into the header |
| | LA | 3,0(0) | GR3 = 0 |
| | BNE | TFYAGN | Did the header get updated? |
| | WAIT | ECB=(1) | Yes, wait for the resource; The ECB is in the incoming element |
| USE | | [Any instruction] | |

LIFO UNLOCK Routine:

Initial Conditions:

GR2 contains the address of the header.

| | | | |
|-------|------|-------------------|--|
| LUNLK | L | 1,0(2) | GR1 = the contents of the header |
| A | LTR | 1,1 | Does the header contain a negative value? |
| | BM | B | No, load the pointer from the "last in" element and store it in the header |
| | L | 0,4(1) | Did the header get updated? |
| | CS | 1,0,0(2) | Yes, post the "last in" element |
| | BNE | A | Continue |
| | POST | (1) | The header contains a negative value; free the header and continue |
| B | SR | 0,0 | |
| | CS | 1,0,0(2) | |
| | BNE | A | |
| EXIT | | [Any instruction] | |

Note that the L 1,0(2) instruction at location LUNLK would have to be CS 1,1,0(2) if it were not for the rule that a word fetch starting on a word boundary must

fetch the word such that if another CPU changes the word being fetched, either the entire new or the entire old value of the word, and not a combination of the two, is obtained.

LOCK/UNLOCK with FIFO Queuing for Contentions

The header always contains the address of the most recently entered element. The header is originally initialized to contain the address of a posted ECB. Each program using the serially reusable resource (SRR) must provide an element regardless of whether contention occurs. Each program then enters the address of the element which it has provided into the header, while simultaneously it removes the address previously contained in the header. Thus, associated with any particular program attempting to use the SRR are two elements, called the "entered element" and the "removed element." The "entered element" of one program becomes the "removed element" for the immediately following program. Each program then waits on the removed element, uses the SRR, and then posts the entered element.

When no contention occurs, that is, when the second program does not attempt to use the SRR until after the first program is finished, then the POST of the first program occurs before the WAIT of the second program. In this case, the bypass-post and bypass-wait routines described in the preceding section are applicable. For simplicity, these two routines are shown only by name rather than as individual instructions.

In the example, the element need be only a single word, that is, an ECB. However, in actual practice, the element could be made larger to include a pointer to the previous element, along with a program identification. Such information would be useful in an error situation to permit starting with the header and chaining through the list of elements to find the program currently holding the SRR.

It should be noted that the element provided by the program remains pointed to by the header until the next program attempts to lock. Thus, in general, the entered element cannot be reused by the program. However, the removed element is available, so each program gives up one element and gains a new one. It is expected that the element removed by a particular program during one use of the SRR would then be used by that program as the entry element for the next request to the SRR.

It should be noted that, since the elements are exchanged from one program to the next, the elements cannot be allocated from storage that would be freed and reused when the program ends. It is expected that a program would obtain its first element and release its last element by means of the routines described in the section "Free-Pool Manipulation" in this appendix.

The following chart describes the action taken for FIFO LOCK and FIFO UNLOCK.

| Function | Action |
|--|---|
| FIFO LOCK (the incoming element is at location A) | Store address A into the header. WAIT; the ECB is at the location addressed by the contents of the header. |
| FIFO UNLOCK | POST; the ECB is at location A. |

The following routines allow enabled code to perform the actions described in the previous chart.

FIFO LOCK Routine:

Initial conditions:

GR3 contains the address of the header.
GR4 contains the address, A, of the element currently owned by this program. This element becomes the entered element.

```

FLOCK  LR   2,4          GR2 now contains
                        address of element
                        to be entered
                        SR   1,1          GR1 = 0
                        ST   1,0(2)      Initialize the ECB
                        L    1,0(3)      GR1 = contents of
                        the header
TRYAGN CS   1,2,0(3)    Enter address A
                        into header while
                        remembering old
                        contents of
                        header into GR1;
                        GR1 now contains
                        address of
                        removed element
                        LR   4,1          Removed element
                        becomes new cur-
                        rently owned
                        element
                        HSWAIT          Perform bypass-
                        wait routine; if
                        ECB already
                        posted, continue;
                        if not, wait; GR1
                        contains the ad-
                        dress of the ECB
USE    [Any instruction] The SRR may now be
                        used

```

FIFO UNLOCK Routine:

Initial conditions:

GR2 contains the address of the removed element, obtained during the FLOCK routine.

```

FUNLK  LR   1,2          Place address of en-
                        tered element in GR1;
                        GR1 = address of ECB
                        to be posted
                        SR   0,0          GR0 = 0; GR0 has a
                        post code of zero
                        HSPPOST          Perform bypass-post
                        routine; if ECB has
                        not been waited on,
                        then mark posted and
                        continue; if it has
                        been waited on, then
                        post
CONTINUE [Any instruction]

```

FREE-POOL MANIPULATION

It is anticipated that a program will need to add and delete items from a free list without using the lock/unlock routines. This is especially likely since the lock/unlock routines require storage elements for queuing and may require working storage. The lock/unlock routines discussed previously allow simultaneous lock routines but permit only one unlock routine at a time. In such a situation, multiple additions and a single deletion to the list may all occur simultaneously, but multiple deletions cannot occur at the same time. In the case of a chain of pointers containing free storage buffers, multiple deletions along with additions can occur simultaneously. In this case, the removal cannot be done using the CS instruction without a certain degree of exposure.

Consider a chained list of the type used in the LIFO lock/unlock example. Assume that the first two elements are at locations A and B, respectively. If one program attempted to remove the first element and was interrupted between the fourth and fifth instructions of the LUNLK routine, the list could be changed so that elements A and C are the first two elements when the interrupted program resumes execution. The CS instruction would then succeed in storing the value B into the header, thereby destroying the list.

The probability of the occurrence of such list destruction can be reduced to near zero by appending to the header a counter that indicates the number of times elements have been added to the list. The use of a 32-bit counter guarantees that the list

will not be destroyed unless the following events occur, in the exact sequence:

1. An unlock routine is interrupted between the fetch of the pointer from the first element and the update of the header.
2. The list is manipulated, including the deletion of the element referenced in 1, and exactly $2^{32}-1$ additions to the list are performed. Note that this takes on the order of days to perform in any practical situation.
3. The element referenced in 1 is added to the list.
4. The unlock routine interrupted in 1 resumes execution.

The following routines use such a counter in order to allow multiple, simultaneous additions and removals at the head of a chain of pointers.

The list consists of a doubleword header and a chain of elements. The first word of the header contains a pointer to the first element in the list. The second word of the header contains a 32-bit counter indicating the number of additions that have been made to the list. Each element contains a pointer to the next element in the list. A zero value indicates the end of the list.

The following chart describes the free-pool-list manipulation.

| Function | Action | |
|--|--|---|
| | Header = 0, Count | Header = A, Count |
| ADD TO LIST (the incoming element is at location A) | Store the first word of the header into location A. Store the address A into the first word of the header. Decrement the second word of the header by one. | |
| DELETE FROM LIST | The list is empty. | Set the first word of the header to the value of the contents of location A. Use element A. |

The following routines allow enabled code to perform the free-pool-list manipulation described in the above chart.

ADD TO FREE LIST Routine:

Initial Conditions:

GR2 contains the address of the element to be added.
 GR4 contains the address of the header.

```

ADDQ  LM  0,1,0(4)  GR0,GR1 = contents of
                    the header
TRYAGN ST  0,0(2)   Point the new element
                    to the top of the list
                    LR  3,1      Move the count to GR3
                    BCTR 3,0     Decrement the count
                    CDS  0,2,0(4) Update the header
                    BNE  TRYAGN
  
```

DELETE FROM FREE LIST Routine:

Initial conditions:

GR4 contains the address of the header.

```

DELETQ LM  2,3,0(4)  GR2,GR3 = contents
                    of the header
TRYAGN LTR  2,2      Is the list empty?
                    BZ  EMPTY   Yes, get help
                    L   0,0(2)  No, GR0 = the
                                pointer from the
                                first element
                                LR  1,3      Move the count to
                                GR1
                                CDS  2,0,0(4) Update the header
                                BNE  TRYAGN
USE      [Any instruction] The address of the
                                removed element is
                                in GR2
  
```

Note that the LM instructions at locations ADDQ and DELETQ would have to be CDS instructions if it were not for the rule that a doubleword fetch starting on a doubleword boundary must fetch the doubleword such that if another CPU changes the doubleword being fetched, either the entire new or the entire old value of the doubleword, and not a combination of the two, is obtained.

APPENDIX B. LISTS OF INSTRUCTIONS

The following four figures list instructions arranged by name, mnemonic, operation code, and feature. Some models may offer instructions that do not appear in the figures, such as those provided for emulation or as part of special or custom features.

The operation code 00 with a two-byte instruction format is allocated for use by the program when an indication of an invalid operation is required. It is improbable that this operation code will ever be assigned to an instruction implemented in the CPU.

Explanation of Symbols in "Characteristics" and "Op Code" Columns

| | |
|----------------|--|
| A | Access exceptions for logical addresses |
| AI | Access exceptions for instruction address |
| AT | ASN-translation exceptions (include addressing, ASN-translation specification, AFX translation, and ASX translation) |
| A ¹ | Access exceptions; not all access exceptions may occur; see instruction description for details |
| B | PER branch event |
| BS | Branch-and-save feature |
| C | Condition code is set |
| CK | CPU-timer and clock-comparator feature |
| CS | Channel-set-switching feature |
| D | Data exception |
| DC | Direct-control feature |
| DF | Decimal-overflow exception |
| DK | Decimal-divide exception |
| DM | Depending on the model, DIAGNOSE may generate various program exceptions and may change the condition code |
| DU | Dual-address-space facility |
| EF | Extended facility |
| EO | Exponent-overflow exception |
| EU | Exponent-underflow exception |
| EX | Execute exception |
| FK | Floating-point-divide exception |
| FP | Floating-point feature |
| IF | Fixed-point-overflow exception |
| II | Interruptible instruction |

| | |
|----------------|--|
| IK | Fixed-point-divide exception |
| L | New condition code loaded |
| LS | Significance exception |
| MI | Move-inverse feature |
| MO | Monitor event |
| MP | Multiprocessing feature |
| P | Privileged-operation |
| PA | Primary-authorization translation exceptions (include addressing and primary authority) |
| PC | PC-number-translation exceptions (include addressing, PC-translation specification, LX translation, and EX translation) |
| PK | PSW-key-handling feature |
| Q | Privileged-operation exception for semiprivileged instructions |
| R | PER general-register-alteration event |
| RE | Recovery-extension feature |
| BR | RR instruction format |
| RRE | RRE instruction format |
| RS | FS instruction format |
| RX | RX instruction format |
| S | S instruction format |
| SA | Secondary-authorization translation exceptions (include addressing and secondary authority) |
| SD | PER storage-alteration event, which can be caused by RDD only when IPTE is not installed |
| SI | SI instruction format |
| SO | Special-operation exception |
| SP | Specification exception |
| SS | SS instruction format |
| SSE | SSE instruction format |
| ST | PER storage-alteration event |
| SW | Conditional-swapping feature |
| T | Trace exceptions (include access and specification) |
| TB | Test-block feature |
| TR | Translation feature |
| XT | Space-switch event and PER storage-alteration event |
| XP | Extended-precision floating-point feature |
| \$ | Causes serialization |
| # | Causes serialization and checkpoint synchronization |
| # ¹ | Causes serialization and checkpoint synchronization when the M ₁ and R ₂ fields contain all ones and all zeros, respectively |
| * | Bits 8-14 of the operation code are ignored |

| Name | Mne- monic | Characteristics | | | | | | | | Op Code | Page No. |
|---------------------------------------|---------------|-----------------|---|----|---|----|----|----|------|------------|-------------|
| ADD | AR | RR | C | | | | | IF | R | 1A | 7-7 |
| ADD | A | RX | C | | A | | | IF | R | 5A | 7-7 |
| ADD DECIMAL | AP | SS | C | | A | D | DF | | ST | FA | 8-5 |
| ADD HALFWORD | AH | RX | C | | A | | IF | | R | 4A | 7-7 |
| ADD LOGICAL | ALR | RR | C | | | | | | R | 1E | 7-8 |
| ADD LOGICAL | AL | RX | C | | A | | | | R | 5E | 7-8 |
| ADD NORMALIZED (extended) | AXR | RR | C | XP | | SP | EU | EO | LS | 36 | 9-6 |
| ADD NORMALIZED (long) | ADR | RR | C | FP | | SP | EU | EO | LS | 2A | 9-6 |
| ADD NORMALIZED (long) | AD | RX | C | FP | A | SP | EU | EO | LS | 6A | 9-6 |
| ADD NORMALIZED (short) | AER | RR | C | FP | | SP | EU | EO | LS | 3A | 9-6 |
| ADD NORMALIZED (short) | AE | RX | C | FP | A | SP | EU | EO | LS | 7A | 9-6 |
| ADD UNNORMALIZED (long) | AWR | RR | C | FP | | SP | EO | EO | LS | 2E | 9-7 |
| ADD UNNORMALIZED (long) | AW | RX | C | FP | A | SP | EO | EO | LS | 6E | 9-7 |
| ADD UNNORMALIZED (short) | AUR | RR | C | FP | | SP | EO | EO | LS | 3E | 9-7 |
| ADD UNNORMALIZED (short) | AU | RX | C | FP | A | SP | EO | EO | LS | 7E | 9-7 |
| AND | NR | RR | C | | | | | | R | 14 | 7-8 |
| AND | N | RX | C | | A | | | | R | 54 | 7-8 |
| AND (character) | NC | SS | C | | A | | | | ST | D4 | 7-8 |
| AND (immediate) | NI | SI | C | | A | | | | ST | 94 | 7-8 |
| BRANCH AND LINK | BALR | RR | | | | | | | B R | 05 | 7-9 |
| BRANCH AND LINK | BAL | RX | | | | | | | B R | 45 | 7-9 |
| BRANCH AND SAVE | BASR | RR | | BS | | | | | B R | 0D | 7-9 |
| BRANCH AND SAVE | BAS | RX | | BS | | | | | B R | 4D | 7-9 |
| BRANCH ON CONDITION | BCR | RR | | | | | | | B | 07 | 7-10 |
| BRANCH ON CONDITION | BC | RX | | | | | | | B | 47 | 7-10 |
| BRANCH ON COUNT | BCTR | RR | | | | | | | B R | 06 | 7-11 |
| BRANCH ON COUNT | BCT | RX | | | | | | | B R | 46 | 7-11 |
| BRANCH ON INDEX HIGH | BXH | RS | | | | | | | B R | 86 | 7-11 |
| BRANCH ON INDEX LOW OR EQUAL | BXLE | RS | | | | | | | B R | 87 | 7-11 |
| CLEAR CHANNEL | CLRCH | S | C | RE | P | | | \$ | | 9F01* | 12-16 |
| CLEAR I/O | CLRIO | S | C | | P | | | \$ | | 9D01* | 12-17 |
| COMPARE | CR | RR | C | | | | | | | 19 | 7-12 |
| COMPARE | C | RX | C | | A | | | | | 59 | 7-12 |
| COMPARE (long) | CDR | RF | C | FP | | SP | | | | 29 | 9-8 |
| COMPARE (long) | CD | RX | C | FP | A | SP | | | | 69 | 9-8 |
| COMPARE (short) | CER | RR | C | FP | | SP | | | | 39 | 9-8 |
| COMPARE (short) | CE | RX | C | FP | A | SP | | | | 79 | 9-8 |
| COMPARE AND SWAP | CS | RS | C | SW | A | SP | | \$ | R ST | BA | 7-12 |
| COMPARE DECIMAL | CP | SS | C | | A | | D | | | F9 | 8-5 |
| COMPARE DOUBLE AND SWAP | CDS | RS | C | SW | A | SP | | \$ | R ST | BB | 7-12 |
| COMPARE HALFWORD | CH | RX | C | | A | | | | | 49 | 7-14 |
| COMPARE LOGICAL | CLR | RR | C | | | | | | | 15 | 7-14 |
| COMPARE LOGICAL | CL | RX | C | | A | | | | | 55 | 7-14 |
| COMPARE LOGICAL (character) | CLC | SS | C | | A | | | | | D5 | 7-14 |
| COMPARE LOGICAL (immediate) | CLI | SI | C | | A | | | | | 95 | 7-14 |
| COMPARE LOGICAL CHARACTERS UNDER MASK | CLM | RS | C | | A | | | | | BD | 7-15 |
| COMPARE LOGICAL LONG | CLCL | RR | C | | A | SP | | II | R | 0F | 7-15 |
| CONNECT CHANNEL SET | CONCS | S | C | CS | P | | | | | B200 | 10-5 |
| CONVERT TO BINARY | CVB | RX | | | A | | D | IK | R | 4F | 7-17 |
| CONVERT TO DECIMAL | CVD | RX | | | A | | | | ST | 4E | 7-17 |

Instructions Arranged by Name (Part 1 of 5)

| Name | Mne- monic | Characteristics | | | | | | | | | | Op Code | Page No. |
|-------------------------------|---------------|-----------------|---|----|----|----------------|----|----|----|----|------|------------|-------------|
| DIAGNOSE | | | | DM | P | DM | | | | | | 83 | 10-5 |
| DISCONNECT CHANNEL SET | DISCS | S | C | CS | P | | | | | | | B201 | 10-6 |
| DIVIDE | DR | RR | | | | SP | | IK | | | R | 1D | 7-18 |
| DIVIDE | D | RX | | | A | SP | | IK | | | R | 5D | 7-18 |
| DIVIDE (long) | DDR | RR | | FP | | SP | EU | EO | FK | | | 2D | 9-9 |
| DIVIDE (long) | DD | RX | | FP | A | SP | EU | EO | FK | | | 6D | 9-9 |
| DIVIDE (short) | DER | RR | | FP | | SP | EU | EO | FK | | | 3D | 9-9 |
| DIVIDE (short) | DE | RX | | FP | A | SP | EU | EO | FK | | | 7D | 9-9 |
| DIVIDE DECIMAL | DP | SS | | | A | SP | D | | DK | | ST | FD | 8-5 |
| EDIT | ED | SS | C | | A | | D | | | | ST | DE | 8-6 |
| EDIT AND MARK | EDMK | SS | C | | A | | D | | | | R ST | DF | 8-10 |
| EXCLUSIVE OR | XR | RR | C | | | | | | | | R | 17 | 7-18 |
| EXCLUSIVE OR | X | RX | C | | A | | | | | | R | 57 | 7-18 |
| EXCLUSIVE OR (character) | XC | SS | C | | A | | | | | | ST | D7 | 7-18 |
| EXCLUSIVE OR (immediate) | XI | SI | C | | A | | | | | | ST | 97 | 7-18 |
| EXECUTE | EX | RX | | | AI | SP | | | | EX | | 44 | 7-19 |
| EXTRACT PRIMARY ASN | EPAR | RRE | | DU | Q | | | | | SO | R | B226 | 10-6 |
| EXTRACT SECONDARY ASN | ESAR | RRE | | DU | Q | | | | | SO | R | B227 | 10-7 |
| HALT DEVICE | HDV | S | C | | P | | | | | \$ | | 9E01* | 12-19 |
| HALT I/O | HIO | S | C | | P | | | | | \$ | | 9E00* | 12-22 |
| HALVE (long) | HDR | RR | | FP | | SP | EU | | | | | 24 | 9-10 |
| HALVE (short) | HER | RR | | FP | | SP | EU | | | | | 34 | 9-10 |
| INSERT ADDRESS SPACE CONTROL | IAC | RRE | C | DU | Q | | | | | SO | R | B224 | 10-7 |
| INSERT CHARACTER | IC | RX | | | A | | | | | | R | 43 | 7-20 |
| INSERT CHARACTERS UNDER MASK | ICM | RS | C | | A | | | | | | R | BF | 7-20 |
| INSERT PSW KEY | IPK | S | | PK | Q | | | | | | R | B20B | 10-8 |
| INSERT STORAGE KEY | ISK | RR | | | P | A ¹ | SP | | | | R | 09 | 10-9 |
| INSERT VIRTUAL STORAGE KEY | IVSK | RRE | | DU | Q | A ¹ | | | | SO | R | B223 | 10-9 |
| INVALIDATE PAGE TABLE ENTRY | IPTE | RRE | | EF | P | A ¹ | | | | \$ | | B221 | 10-10 |
| LOAD | LR | RR | | | | | | | | | R | 18 | 7-21 |
| LOAD | L | RX | | | A | | | | | | R | 58 | 7-21 |
| LOAD (long) | LDR | RR | | FP | | SP | | | | | | 28 | 9-10 |
| LOAD (long) | LD | RX | | FP | A | SP | | | | | | 68 | 9-10 |
| LOAD (short) | LER | RR | | FP | | SP | | | | | | 38 | 9-10 |
| LOAD (short) | LE | RX | | FP | A | SP | | | | | | 78 | 9-10 |
| LOAD ADDRESS | LA | RX | | | | | | | | | R | 41 | 7-21 |
| LOAD ADDRESS SPACE PARAMETERS | LASP | SSE | C | DU | Q | AS | SP | | | SO | | E500 | 10-11 |
| LOAD AND TEST | LTR | RR | C | | | | | | | | R | 12 | 7-21 |
| LOAD AND TEST (long) | LTDR | RR | C | FP | | SP | | | | | | 22 | 9-11 |
| LOAD AND TEST (short) | LTER | RR | C | FP | | SP | | | | | | 32 | 9-11 |
| LOAD COMPLEMENT | LCR | RR | C | | | | | IF | | | R | 13 | 7-22 |
| LOAD COMPLEMENT (long) | LCDR | RR | C | FP | | SP | | | | | | 23 | 9-11 |
| LOAD COMPLEMENT (short) | LCER | RR | C | FP | | SP | | | | | | 33 | 9-11 |
| LOAD CONTROL | LCTL | RS | | | P | A | SP | | | | | B7 | 10-16 |
| LOAD HALFWORD | LH | RX | | | A | | | | | | R | 48 | 7-22 |
| LOAD MULTIPLE | LM | RS | | | A | | | | | | R | 98 | 7-22 |
| LOAD NEGATIVE | LNR | RR | C | | | | | | | | R | 11 | 7-23 |
| LOAD NEGATIVE (long) | LNDR | RR | C | FP | | SP | | | | | | 21 | 9-12 |
| LOAD NEGATIVE (short) | LNER | RR | C | FP | | SP | | | | | | 31 | 9-12 |
| LOAD POSITIVE | LPR | RR | C | | | | | IF | | | R | 10 | 7-23 |

Instructions Arranged by Name (Part 2 of 5)

| Name | Mne- monic | Characteristics | | | | | | | | | | Op Code | Page No. | | |
|---------------------------------|---------------|-----------------|---|----|----------------|----------------|----|----|----|----|----|------------|-------------|-------|-------|
| LOAD POSITIVE (long) | LPDR | RR | C | FP | | SP | | | | | | 20 | 9-12 | | |
| LOAD POSITIVE (short) | LPER | RR | C | FP | | SP | | | | | | 30 | 9-12 | | |
| LOAD PSW | LPSW | S | L | P | A | SP | | | | | | 82 | 10-17 | | |
| LOAD REAL ADDRESS | LRA | RX | C | TR | P | A ¹ | | | | R | | B1 | 10-17 | | |
| LOAD ROUNDED (extended to long) | LRDR | RR | | XP | | SP | EO | | | | | 25 | 9-12 | | |
| LOAD ROUNDED (long to short) | LRER | RR | | XP | | SP | EO | | | | | 35 | 9-12 | | |
| MONITOR CALL | MC | SI | | | | SP | | MO | | | | AF | 7-23 | | |
| MOVE (character) | MVC | SS | | | | A | | | | | ST | D2 | 7-24 | | |
| MOVE (immediate) | MVI | SI | | | | A | | | | | ST | 92 | 7-24 | | |
| MOVE INVERSE | MVCIN | SS | | MI | | A | | | | | ST | E8 | 7-24 | | |
| MOVE LONG | MVCL | RR | C | | | A | SP | | II | R | ST | 0E | 7-25 | | |
| MOVE NUMERICS | MVN | SS | | | | A | | | | | ST | D1 | 7-27 | | |
| MOVE TO PRIMARY | MVCP | SS | C | DU | Q | A ¹ | | | SO | | ST | DA | 10-18 | | |
| MOVE TO SECONDARY | MVCS | SS | C | DU | Q | A ¹ | | | SO | | ST | DB | 10-18 | | |
| MOVE WITH KEY | MVCK | SS | C | DU | Q | A | | | | | ST | D9 | 10-20 | | |
| MOVE WITH OFFSET | MVO | SS | | | | A | | | | | ST | F1 | 7-28 | | |
| MOVE ZONES | MVZ | SS | | | | A | | | | | ST | D3 | 7-28 | | |
| MULTIPLY | MR | RR | | | | | SP | | | R | | 1C | 7-29 | | |
| MULTIPLY | M | RX | | | | A | SP | | | R | | 5C | 7-29 | | |
| MULTIPLY (extended) | MXR | RR | | XP | | | SP | EU | EO | | | 26 | 9-13 | | |
| MULTIPLY (long to extended) | MXDR | RR | | XP | | | SP | EU | EO | | | 27 | 9-13 | | |
| MULTIPLY (long to extended) | MXD | RX | | XP | | A | SP | EU | EO | | | 67 | 9-13 | | |
| MULTIPLY (long) | MDR | RR | | FP | | | SP | EU | EO | | | 2C | 9-13 | | |
| MULTIPLY (long) | MD | RX | | FP | | A | SP | EU | EO | | | 6C | 9-13 | | |
| MULTIPLY (short to long) | MER | RR | | FP | | | SP | EU | EO | | | 3C | 9-13 | | |
| MULTIPLY (short to long) | ME | RX | | FP | | A | SP | EU | EO | | | 7C | 9-13 | | |
| MULTIPLY DECIMAL | MP | SS | | | | A | SP | D | | | ST | FC | 8-10 | | |
| MULTIPLY HALFWORD | MH | RX | | | | A | | | | R | | 4C | 7-29 | | |
| OR | OR | RR | C | | | | | | | R | | 16 | 7-30 | | |
| OR | O | RX | C | | | A | | | | R | | 56 | 7-30 | | |
| OR (character) | OC | SS | C | | | A | | | | | ST | D6 | 7-30 | | |
| OR (immediate) | OI | SI | C | | | A | | | | | ST | 96 | 7-30 | | |
| PACK | PACK | SS | | | | A | | | | | ST | F2 | 7-31 | | |
| PROGRAM CALL | PC | S | | DU | Q | AT | | PC | T | SO | B | R | XT | B218 | 10-21 |
| PROGRAM TRANSFER | PT | RRE | | DU | Q | AT | SP | PA | T | SO | B | XT | B228 | 10-28 | |
| PURGE TLB | PTLB | S | | TR | P | | | | \$ | | | B20D | 10-33 | | |
| READ DIRECT | RDD | SI | | DC | P | A ¹ | | | | | SD | 85 | 10-33 | | |
| RESET REFERENCE BIT | RRB | S | C | TR | P | A ¹ | | | | | | B213 | 10-34 | | |
| SET ADDRESS SPACE CONTROL | SAC | S | | DU | | | SP | | \$ | SO | | B219 | 10-34 | | |
| SET CLOCK | SCK | S | C | | P | A | SP | | | | | B204 | 10-35 | | |
| SET CLOCK COMPARATOR | SCKC | S | | CK | P | A | SP | | | | | B206 | 10-36 | | |
| SET CPU TIMER | SPT | S | | CK | P | A | SP | | | | | B208 | 10-36 | | |
| SET PREFIX | SPX | S | | MP | P | A | SP | | \$ | | | B210 | 10-36 | | |
| SET PROGRAM MASK | SPM | RR | L | | | | | | | | | 04 | 7-31 | | |
| SET PSW KEY FROM ADDRESS | SPKA | S | | PK | Q | | | | | | | B20A | 10-37 | | |
| SET SECONDARY ASN | SSAR | RRE | | DU | | AT | | SA | T | SO | | ST | B225 | 10-38 | |
| SET STORAGE KEY | SSK | RR | | P | A ¹ | SP | | | | | | 08 | 10-41 | | |
| SET SYSTEM MASK | SSM | S | | P | A | SP | | | SO | | | 80 | 10-41 | | |
| SHIFT AND ROUND DECIMAL | SRP | SS | C | | | A | | D | DF | | ST | F0 | 8-11 | | |
| SHIFT LEFT DOUBLE | SLDA | RS | C | | | | SP | | IF | | R | 8F | 7-32 | | |

Instructions Arranged by Name (Part 3 of 5)

| Name | Mne- monic | Characteristics | | | | | | | | | | Op Code | Page No. | |
|--------------------------------|---------------|-----------------|---|----|---|----------------|----|----|----|----|---|------------|-------------|-------|
| SHIFT LEFT DOUBLE LOGICAL | SLDL | RS | | | | | SP | | | | | R | 8D | 7-32 |
| SHIFT LEFT SINGLE | SLA | RS | C | | | | | IF | | | | R | 8B | 7-33 |
| SHIFT LEFT SINGLE LOGICAL | SLL | RS | | | | | | | | | | R | 89 | 7-33 |
| SHIFT RIGHT DOUBLE | SRDA | RS | C | | | | SP | | | | | R | 8E | 7-34 |
| SHIFT RIGHT DOUBLE LOGICAL | SRDL | RS | | | | | | | | | | R | 8C | 7-34 |
| SHIFT RIGHT SINGLE | SRA | RS | C | | | | | | | | | R | 8A | 7-34 |
| SHIFT RIGHT SINGLE LOGICAL | SRL | RS | | | | | | | | | | R | 88 | 7-35 |
| SIGNAL PROCESSOR | SIGP | RS | C | MP | P | | | \$ | | | | R | AE | 10-42 |
| START I/O | SIO | S | C | | P | | | \$ | | | | | 9C00* | 12-25 |
| START I/O FAST RELEASE | SIOF | S | C | | P | | | \$ | | | | | 9C01* | 12-25 |
| STORE | ST | RX | | | | A | | | | | | ST | 50 | 7-35 |
| STORE (long) | STD | RX | | FP | | A | SP | | | | | ST | 60 | 9-14 |
| STORE (short) | STE | RX | | FP | | A | SP | | | | | ST | 70 | 9-14 |
| STORE CHANNEL ID | STIDC | S | C | | P | | | \$ | | | | | B203 | 12-28 |
| STORE CHARACTER | STC | RX | | | | A | | | | | | ST | 42 | 7-35 |
| STORE CHARACTERS UNDER MASK | STCM | RS | | | | A | | | | | | ST | BE | 7-35 |
| STORE CLOCK | STCK | S | C | | | A | | \$ | | | | ST | B205 | 7-36 |
| STORE CLOCK COMPARATOR | STCKC | S | | CK | P | A | SP | | | | | ST | B207 | 10-43 |
| STORE CONTROL | STCTL | RS | | | P | A | SP | | | | | ST | B6 | 10-43 |
| STORE CPU ADDRESS | STAP | S | | MP | P | A | SP | | | | | ST | B212 | 10-44 |
| STORE CPU ID | STIDP | S | | | P | A | SP | | | | | ST | B202 | 10-44 |
| STORE CPU TIMER | STPT | S | | CK | P | A | SP | | | | | ST | B209 | 10-45 |
| STORE HALFWORD | STH | RX | | | | A | | | | | | ST | 40 | 7-37 |
| STORE MULTIPLE | STM | RS | | | | A | | | | | | ST | 90 | 7-37 |
| STORE PREFIX | STPX | S | | MP | P | A | SP | | | | | ST | B211 | 10-45 |
| STORE THEN AND SYSTEM MASK | STNSM | SI | | TR | P | A | | | | | | ST | AC | 10-45 |
| STORE THEN OR SYSTEM MASK | STOSM | SI | | TR | P | A | SP | | | | | ST | AD | 10-46 |
| SUBTRACT | SR | RR | C | | | | | IF | | | | R | 1B | 7-37 |
| SUBTRACT | S | RX | C | | | A | | IF | | | | R | 5B | 7-37 |
| SUBTRACT DECIMAL | SP | SS | C | | | A | D | DF | | | | ST | FB | 8-12 |
| SUBTRACT HALFWORD | SH | RX | C | | | A | | IF | | | | R | 4B | 7-38 |
| SUBTRACT LOGICAL | SLR | RR | C | | | | | | | | | R | 1F | 7-38 |
| SUBTRACT LOGICAL | SL | RX | C | | | A | | | | | | R | 5F | 7-38 |
| SUBTRACT NORMALIZED (extended) | SXR | RR | C | XP | | | SP | EU | EO | LS | | | 37 | 9-15 |
| SUBTRACT NORMALIZED (long) | SDR | RR | C | FP | | | SP | EU | EO | LS | | | 2B | 9-15 |
| SUBTRACT NORMALIZED (long) | SD | RX | C | FP | | A | SP | EU | EO | LS | | | 6B | 9-15 |
| SUBTRACT NORMALIZED (short) | SER | RR | C | FP | | | SP | EU | EO | LS | | | 3B | 9-15 |
| SUBTRACT NORMALIZED (short) | SE | RX | C | FP | | A | SP | EU | EO | LS | | | 7B | 9-15 |
| SUBTRACT UNNORMALIZED (long) | SWR | RR | C | FP | | | SP | EO | LS | | | | 2F | 9-15 |
| SUBTRACT UNNORMALIZED (long) | SW | RX | C | FP | | A | SP | EO | LS | | | | 6F | 9-15 |
| SUBTRACT UNNORMALIZED (short) | SUR | RR | C | FP | | | SP | EO | LS | | | | 3F | 9-15 |
| SUBTRACT UNNORMALIZED (short) | SU | RX | C | FP | | A | SP | EO | LS | | | | 7F | 9-15 |
| SUPERVISOR CALL | SVC | RR | | | | | | \$ | | | | | 0A | 7-39 |
| TEST AND SET | TS | S | C | | | A | | \$ | | | | ST | 93 | 7-39 |
| TEST BLOCK | TB | RRE | C | TB | P | A ¹ | | \$ | II | | R | | B22C | 10-46 |
| TEST CHANNEL | TCH | S | C | | P | | | \$ | | | | | 9F00* | 12-29 |
| TEST I/O | TIO | S | C | | P | | | \$ | | | | | 9D00* | 12-29 |
| TEST PROTECTION | TPROT | SSE | C | EF | P | A ¹ | | | | | | | E501 | 10-48 |
| TEST UNDER MASK | TM | SI | C | | | A | | | | | | | 91 | 7-39 |
| TRANSLATE | TR | SS | | | | A | | | | | | ST | DC | 7-40 |

Instructions Arranged by Name (Part 4 of 5)

| Name | Mne- monic | Characteristics | | | | | Op Code | Page No. |
|--------------------|---------------|-----------------|---|------|----------------|------|------------|-------------|
| TRANSLATE AND TEST | TRT | SS | C | | A | | R DD | 7-41 |
| UNPACK | UNPK | SS | | | A | | ST F3 | 7-41 |
| WRITE DIRECT | WRD | SI | | DC P | A ¹ | \$ | 84 | 10-49 |
| ZERO AND ADD | ZAP | SS | C | | A | D DF | ST F8 | 8-12 |

Instructions Arranged by Name (Part 5 of 5)

| Mne- Mnemonic | Name | Characteristics | | | | | | | | Op Code | Page No. |
|------------------|---------------------------------------|-----------------|----|----|----|----|-------|----|------|------------|-------------|
| | DIAGNOSE | | DM | P | DM | | | | | 83 | 10-5 |
| A | ADD | RX | C | | A | | IF | | R | 5A | 7-7 |
| AD | ADD NORMALIZED (long) | RX | C | FP | A | SP | EU EO | LS | | 6A | 9-6 |
| ADR | ADD NORMALIZED (long) | RR | C | FP | | SP | EU EO | LS | | 2A | 9-6 |
| AE | ADD NORMALIZED (short) | RX | C | FP | A | SP | EU EO | LS | | 7A | 9-6 |
| AER | ADD NORMALIZED (short) | RR | C | FP | | SP | EU EO | LS | | 3A | 9-6 |
| AH | ADD HALFWORD | RX | C | | A | | IF | | R | 4A | 7-7 |
| AL | ADD LOGICAL | RX | C | | A | | | | R | 5E | 7-8 |
| ALR | ADD LOGICAL | RR | C | | | | | | R | 1E | 7-8 |
| AP | ADD DECIMAL | SS | C | | A | | D DF | | ST | FA | 8-5 |
| AR | ADD | RR | C | | | | IF | | R | 1A | 7-7 |
| AU | ADD UNNORMALIZED (short) | RX | C | FP | A | SP | EO | LS | | 7E | 9-7 |
| AUR | ADD UNNORMALIZED (short) | RR | C | FP | | SP | EO | LS | | 3E | 9-7 |
| AW | ADD UNNORMALIZED (long) | RX | C | FP | A | SP | EO | LS | | 6E | 9-7 |
| AWR | ADD UNNORMALIZED (long) | RR | C | FP | | SP | EO | LS | | 2E | 9-7 |
| AXR | ADD NORMALIZED (extended) | RR | C | XP | | SP | EU EO | LS | | 36 | 9-6 |
| BAL | BRANCH AND LINK | RX | | | | | | | B R | 45 | 7-9 |
| BALR | BRANCH AND LINK | RR | | | | | | | B R | 05 | 7-9 |
| BAS | BRANCH AND SAVE | RX | | BS | | | | | B R | 4D | 7-9 |
| BASR | BRANCH AND SAVE | RR | | BS | | | | | B R | 0D | 7-9 |
| BC | BRANCH ON CONDITION | RX | | | | | | | B | 47 | 7-10 |
| BCR | BRANCH ON CONDITION | RR | | | | | | 1 | B | 07 | 7-10 |
| BCT | BRANCH ON COUNT | RX | | | | | | | B R | 46 | 7-11 |
| BCTR | BRANCH ON COUNT | RR | | | | | | | B R | 06 | 7-11 |
| BXH | BRANCH ON INDEX HIGH | RS | | | | | | | B R | 86 | 7-11 |
| BXLE | BRANCH ON INDEX LOW OR EQUAL | RS | | | | | | | B R | 87 | 7-11 |
| C | COMPARE | RX | C | | A | | | | | 59 | 7-12 |
| CD | COMPARE (long) | RX | C | FP | A | SP | | | | 69 | 9-8 |
| CDR | COMPARE (long) | RR | C | FP | | SP | | | | 29 | 9-8 |
| CDS | COMPARE DOUBLE AND SWAP | RS | C | SW | A | SP | | \$ | R ST | BB | 7-12 |
| CE | COMPARE (short) | RX | C | FP | A | SP | | | | 79 | 9-8 |
| CER | COMPARE (short) | RR | C | FP | | SP | | | | 39 | 9-8 |
| CH | COMPARE HALFWORD | RX | C | | A | | | | | 49 | 7-14 |
| CL | COMPARE LOGICAL | RX | C | | A | | | | | 55 | 7-14 |
| CLC | COMPARE LOGICAL (character) | SS | C | | A | | | | | D5 | 7-14 |
| CLCL | COMPARE LOGICAL LONG | RR | C | | A | SP | | II | R | 0F | 7-15 |
| CLI | COMPARE LOGICAL (immediate) | SI | C | | A | | | | | 95 | 7-14 |
| CLM | COMPARE LOGICAL CHARACTERS UNDER MASK | RS | C | | A | | | | | BD | 7-15 |
| CLR | COMPARE LOGICAL | RR | C | | | | | | | 15 | 7-14 |
| CLRCH | CLEAR CHANNEL | S | C | RE | P | | | \$ | | 9F01* | 12-16 |
| CLRIO | CLEAR I/O | S | C | | P | | | \$ | | 9D01* | 12-17 |
| CONCS | CONNECT CHANNEL SET | S | C | CS | P | | | | | B200 | 10-5 |
| CP | COMPARE DECIMAL | SS | C | | A | | D | | | F9 | 8-5 |
| CR | COMPARE | RR | C | | | | | | | 19 | 7-12 |
| CS | COMPARE AND SWAP | RS | C | SW | A | SP | | \$ | R ST | BA | 7-12 |
| CVB | CONVERT TO BINARY | RX | | | A | | D IK | | R | 4F | 7-17 |
| CVD | CONVERT TO DECIMAL | RX | | | A | | | | ST | 4E | 7-17 |
| D | DIVIDE | RX | | | A | SP | | IK | R | 5D | 7-18 |
| DD | DIVIDE (long) | RX | | FP | A | SP | EU EO | FK | | 6D | 9-9 |
| DDR | DIVIDE (long) | RR | | FP | | SP | EU EO | FK | | 2D | 9-9 |

Instructions Arranged by Mnemonic (Part 1 of 5)

| Mne- monic | Name | Characteristics | | | | | | | | | | Op Code | Page No. | | |
|---------------|---------------------------------|-----------------|----|----|----|----------------|----|----|--|----|----|------------|-------------|-------|------|
| DE | DIVIDE (short) | RX | FP | A | SP | EU | EO | FK | | | | 7D | 9-9 | | |
| DER | DIVIDE (short) | RR | FP | | SP | EU | EO | FK | | | | 3D | 9-9 | | |
| DISCS | DISCONNECT CHANNEL SET | S | C | CS | P | | | | | | | B201 | 10-6 | | |
| DP | DIVIDE DECIMAL | SS | | | | A | SP | D | | DK | | ST | FD | 8-5 | |
| DR | DIVIDE | RR | | | | | SP | | | IK | | R | 1D | 7-18 | |
| ED | EDIT | SS | C | | | A | | D | | | | ST | DE | 8-6 | |
| EDMK | EDIT AND MARK | SS | C | | | A | | D | | | | R | ST | DF | 8-10 |
| EPAR | EXTRACT PRIMARY ASN | FRE | | DU | Q | | | | | | SO | R | B226 | 10-6 | |
| ESAR | EXTRACT SECONDARY ASN | RRE | | DU | Q | | | | | | SO | R | B227 | 10-7 | |
| EX | EXECUTE | RX | | | | AI | SP | | | | | | 44 | 7-19 | |
| HDR | HALVE (long) | RR | | FP | | | SP | EU | | | | | 24 | 9-10 | |
| HDV | HALT DEVICE | S | C | | P | | | | | | \$ | | 9E01* | 12-19 | |
| HER | HALVE (short) | RR | | FP | | | SP | EU | | | | | 34 | 9-10 | |
| HIO | HALT I/O | S | C | | P | | | | | | \$ | | 9E00* | 12-22 | |
| IAC | INSERT ADDRESS SPACE CONTROL | RRE | C | DU | Q | | | | | | SO | R | B224 | 10-7 | |
| IC | INSERT CHARACTER | RX | | | | A | | | | | | R | 43 | 7-20 | |
| ICM | INSERT CHARACTERS UNDER MASK | RS | C | | | A | | | | | | R | BF | 7-20 | |
| IPK | INSERT PSW KEY | S | | PK | Q | | | | | | | R | B20B | 10-8 | |
| IPTE | INVALIDATE PAGE TABLE ENTRY | RRE | | EF | P | A ¹ | | | | | \$ | | B221 | 10-10 | |
| ISK | INSERT STORAGE KEY | RR | | | P | A ¹ | SP | | | | | R | 09 | 10-9 | |
| IVSK | INSERT VIRTUAL STORAGE KEY | RRE | | DU | Q | A ¹ | | | | | SO | R | B223 | 10-9 | |
| L | LOAD | RX | | | | A | | | | | | R | 58 | 7-21 | |
| LA | LOAD ADDRESS | RX | | | | | | | | | | R | 41 | 7-21 | |
| LASP | LOAD ADDRESS SPACE PARAMETERS | SSE | C | DU | Q | AS | SP | | | | SO | | E500 | 10-11 | |
| LCDR | LOAD COMPLEMENT (long) | RR | C | FP | | | SP | | | | | | 23 | 9-11 | |
| LCER | LOAD COMPLEMENT (short) | RR | C | FP | | | SP | | | | | R | 33 | 9-11 | |
| LCP | LOAD COMPLEMENT | RR | C | | | | | | | IF | | R | 13 | 7-22 | |
| LCTL | LOAD CONTROL | RS | | | P | A | SP | | | | | | B7 | 10-16 | |
| LD | LOAD (long) | RX | | FP | | A | SP | | | | | | 68 | 9-10 | |
| LDR | LOAD (long) | RR | | FP | | | SP | | | | | | 28 | 9-10 | |
| LE | LOAD (short) | RX | | FP | | A | SP | | | | | | 78 | 9-10 | |
| LER | LOAD (short) | RR | | FP | | | SP | | | | | | 38 | 9-10 | |
| LH | LOAD HALFWORD | RX | | | | A | | | | | | R | 48 | 7-22 | |
| LM | LOAD MULTIPLE | RS | | | | A | | | | | | R | 98 | 7-22 | |
| LNDR | LOAD NEGATIVE (long) | RR | C | FP | | | SP | | | | | | 21 | 9-12 | |
| LNER | LOAD NEGATIVE (short) | RR | C | FP | | | SP | | | | | | 31 | 9-12 | |
| LNR | LOAD NEGATIVE | RR | C | | | | | | | | | R | 11 | 7-23 | |
| LPDR | LOAD POSITIVE (long) | RR | C | FP | | | SP | | | | | | 20 | 9-12 | |
| LPER | LOAD POSITIVE (short) | RR | C | FP | | | SP | | | | | | 30 | 9-12 | |
| LPR | LOAD POSITIVE | RR | C | | | | | | | IF | | R | 10 | 7-23 | |
| LPSW | LOAD PSW | S | L | | P | A | SP | | | | | | 82 | 10-17 | |
| LR | LOAD | RR | | | | | | | | | | R | 18 | 7-21 | |
| LRA | LOAD REAL ADDRESS | RX | C | TR | P | A ¹ | | | | | | R | B1 | 10-17 | |
| LPDR | LOAD ROUNDED (extended to long) | RR | | XP | | | SP | | | EO | | | 25 | 9-12 | |
| LRER | LOAD ROUNDED (long to short) | RR | | XP | | | SP | | | EO | | | 35 | 9-12 | |
| LTDR | LOAD AND TEST (long) | RR | C | FP | | | SP | | | | | | 22 | 9-11 | |
| LTER | LOAD AND TEST (short) | RR | C | FP | | | SP | | | | | | 32 | 9-11 | |
| LTR | LOAD AND TEST | FR | C | | | | | | | | | R | 12 | 7-21 | |
| M | MULTIPLY | RX | | | | A | SP | | | | | R | 5C | 7-29 | |
| MC | MONITOR CALL | SI | | | | | SP | | | MO | | | AF | 7-23 | |

Instructions Arranged by Mnemonic (Part 2 of 5)

| Mne- monic | Name | Characteristics | | | | | | | | | | Op Code | Page No. | | | |
|---------------|-----------------------------|-----------------|----|----|----|----------------|----|----|----|---|----|------------|-------------|-------|-------|-------|
| MD | MULTIPLY (long) | RX | FP | A | SP | EU | EO | | | | | 6C | 9-13 | | | |
| MDR | MULTIPLY (long) | RR | FP | | SP | EU | EO | | | | | 2C | 9-13 | | | |
| ME | MULTIPLY (short to long) | RX | FP | A | SP | EU | EO | | | | | 7C | 9-13 | | | |
| MER | MULTIPLY (short to long) | RR | FP | | SP | EU | EO | | | | | 3C | 9-13 | | | |
| MH | MULTIPLY HALFWORD | RX | | A | | | | | | | R | 4C | 7-29 | | | |
| MP | MULTIPLY DECIMAL | SS | | A | SP | D | | | | | ST | FC | 8-10 | | | |
| MR | MULTIPLY | RR | | | SP | | | | | | R | 1C | 7-29 | | | |
| MVC | MOVE (character) | SS | | A | | | | | | | | ST | D2 | 7-24 | | |
| MVCIN | MOVE INVERSE | SS | MI | A | | | | | | | | ST | E8 | 7-24 | | |
| MVCK | MOVE WITH KEY | SS | C | DU | Q | A | | | | | | ST | D9 | 10-20 | | |
| MVCL | MOVE LONG | RR | C | A | SP | | | II | | R | ST | 0E | 7-25 | | | |
| MVCP | MOVE TO PRIMARY | SS | C | DU | Q | A ¹ | | | SO | | ST | DA | 10-18 | | | |
| MVCS | MOVE TO SECONDARY | SS | C | DU | Q | A ¹ | | | SO | | ST | DB | 10-18 | | | |
| MVI | MOVE (immediate) | SI | | A | | | | | | | | ST | 92 | 7-24 | | |
| MVN | MOVE NUMERICS | SS | | A | | | | | | | | ST | D1 | 7-27 | | |
| MVO | MOVE WITH OFFSET | SS | | A | | | | | | | | ST | F1 | 7-28 | | |
| MVZ | MOVE ZONES | SS | | A | | | | | | | | ST | D3 | 7-28 | | |
| MXD | MULTIPLY (long to extended) | RX | XP | A | SP | EU | EO | | | | | | 67 | 9-13 | | |
| MXDR | MULTIPLY (long to extended) | RR | XP | | SP | EU | EO | | | | | | 27 | 9-13 | | |
| MXR | MULTIPLY (extended) | RR | XP | | SP | EU | EO | | | | | | 26 | 9-13 | | |
| N | AND | RX | C | A | | | | | | R | | 54 | 7-8 | | | |
| NC | AND (character) | SS | C | A | | | | | | | ST | D4 | 7-8 | | | |
| NI | AND (immediate) | SI | C | A | | | | | | | | ST | 94 | 7-8 | | |
| NR | AND | RR | C | | | | | | | R | | 14 | 7-8 | | | |
| O | OR | RX | C | A | | | | | | R | | 56 | 7-30 | | | |
| OC | OR (character) | SS | C | A | | | | | | | ST | D6 | 7-30 | | | |
| OI | OR (immediate) | SI | C | A | | | | | | | | ST | 96 | 7-30 | | |
| OR | OR | RR | C | | | | | | | R | | 16 | 7-30 | | | |
| PACK | PACK | SS | | A | | | | | | | | ST | F2 | 7-31 | | |
| PC | PROGRAM CALL | S | | DU | Q | AT | | PC | T | | SO | B | R | XT | B218 | 10-21 |
| PT | PROGRAM TRANSFER | RRE | | DU | Q | AT | SP | PA | T | | SO | B | XT | B228 | 10-28 | |
| PTLB | PURGE TLB | S | | TR | P | | | | | | | | | B20D | 10-33 | |
| RDD | READ DIRECT | SI | | DC | P | A ¹ | | | | | | SD | 85 | 10-33 | | |
| RRB | RESET REFERENCE BIT | S | C | TR | P | A ¹ | | | | | | | | B213 | 10-34 | |
| S | SUBTRACT | RX | C | A | | | | IF | | R | | 5B | 7-37 | | | |
| SAC | SET ADDRESS SPACE CONTROL | S | | DU | | SP | | | | | | | | B219 | 10-34 | |
| SCK | SET CLOCK | S | C | P | A | SP | | | | | | | | B204 | 10-35 | |
| SCKC | SET CLOCK COMPARATOR | S | | CK | P | A | SP | | | | | | | B206 | 10-36 | |
| SD | SUBTRACT NORMALIZED (long) | RX | C | FP | A | SP | EU | EO | LS | | | | | 6B | 9-15 | |
| SDR | SUBTRACT NORMALIZED (long) | RR | C | FP | | SP | EU | EO | LS | | | | | 2B | 9-15 | |
| SE | SUBTRACT NORMALIZED (short) | RX | C | FP | A | SP | EU | EO | LS | | | | | 7B | 9-15 | |
| SER | SUBTRACT NORMALIZED (short) | RR | C | FP | | SP | EU | EO | LS | | | | | 3B | 9-15 | |
| SH | SUBTRACT HALFWORD | RX | C | A | | | | IF | | R | | 4B | 7-38 | | | |
| SIGP | SIGNAL PROCESSOR | RS | C | MP | P | | | | | | | | | AE | 10-42 | |
| SIO | START I/O | S | C | P | | | | | | | | | | 9C00* | 12-25 | |
| SIOF | START I/O FAST RELEASE | S | C | P | | | | | | | | | | 9C01* | 12-25 | |
| SL | SUBTRACT LOGICAL | RX | C | A | | | | | | R | | 5F | 7-38 | | | |
| SLA | SHIFT LEFT SINGLE | RS | C | | | | | IF | | R | | 8B | 7-33 | | | |
| SLDA | SHIFT LEFT DOUBLE | RS | C | | | SP | | IF | | R | | 8F | 7-32 | | | |
| SLDL | SHIFT LEFT DOUBLE LOGICAL | RS | | | | SP | | | | R | | 8D | 7-32 | | | |

Instructions Arranged by Mnemonic (Part 3 of 5)

| Mne- Mnemonic | Name | Characteristics | | | | | | | | | | Op Code | Page No. | |
|------------------|--------------------------------|-----------------|---|----|---|----------------|----|----|----|----|---|------------|-------------|-------|
| SLL | SHIFT LEFT SINGLE LOGICAL | RS | | | | | | | | | | R | 89 | 7-33 |
| SLR | SUBTRACT LOGICAL | RR | C | | | | | | | | | R | 1F | 7-38 |
| SP | SUBTRACT DECIMAL | SS | C | | A | D | DF | | | | | ST | FB | 8-12 |
| SPKA | SET PSW KEY FROM ADDRESS | S | | PK | Q | | | | | | | | B20A | 10-37 |
| SPM | SET PROGRAM MASK | RR | L | | | | | | | | | | 04 | 7-31 |
| SPT | SET CPU TIMER | S | | CK | P | A | SP | | | | | | B208 | 10-36 |
| SPX | SET PREFIX | S | | MP | P | A | SP | | \$ | | | | B210 | 10-36 |
| SR | SUBTRACT | RR | C | | | | | IF | | | | R | 1B | 7-37 |
| SRA | SHIFT RIGHT SINGLE | RS | C | | | | | | | | | R | 8A | 7-34 |
| SRDA | SHIFT RIGHT DOUBLE | RS | C | | | | SP | | | | | R | 8E | 7-34 |
| SRDL | SHIFT RIGHT DOUBLE LOGICAL | RS | | | | | SP | | | | | R | 8C | 7-34 |
| SRL | SHIFT RIGHT SINGLE LOGICAL | RS | | | | | | | | | | R | 88 | 7-35 |
| SRP | SHIFT AND ROUND DECIMAL | SS | C | | A | D | DF | | | | | ST | F0 | 8-11 |
| SSAR | SET SECONDARY ASN | RRE | | DU | | AT | | SA | T | SO | | ST | B225 | 10-38 |
| SSK | SET STORAGE KEY | RR | | | P | A ¹ | SP | | | | | | 08 | 10-41 |
| SSM | SET SYSTEM MASK | S | | | P | A | SP | | | SO | | | 80 | 10-41 |
| ST | STORE | RX | | | | A | | | | | | ST | 50 | 7-35 |
| STAP | STORE CPU ADDRESS | S | | MP | P | A | SP | | | | | ST | B212 | 10-44 |
| STC | STORE CHARACTER | RX | | | | A | | | | | | ST | 42 | 7-35 |
| STCK | STORE CLOCK | S | C | | | A | | | \$ | | | ST | B205 | 7-36 |
| STCKC | STORE CLOCK COMPARATOR | S | | CK | P | A | SP | | | | | ST | B207 | 10-43 |
| STCM | STORE CHARACTERS UNDER MASK | RS | | | | A | | | | | | ST | BE | 7-35 |
| STCTL | STORE CONTROL | RS | | | P | A | SP | | | | | ST | B6 | 10-43 |
| STD | STORE (long) | RX | | FP | | A | SP | | | | | ST | 60 | 9-14 |
| STE | STORE (short) | RX | | FP | | A | SP | | | | | ST | 70 | 9-14 |
| STH | STORE HALFWORD | RX | | | | A | | | | | | ST | 40 | 7-37 |
| STIDC | STORE CHANNEL ID | S | C | | P | | | | \$ | | | | B203 | 12-28 |
| STIDP | STORE CPU ID | S | | | P | A | SP | | | | | ST | B202 | 10-44 |
| STM | STORE MULTIPLE | RS | | | | A | | | | | | ST | 90 | 7-37 |
| STNSM | STORE THEN AND SYSTEM MASK | SI | | TR | P | A | | | | | | ST | AC | 10-45 |
| STOSM | STORE THEN OR SYSTEM MASK | SI | | TR | P | A | SP | | | | | ST | AD | 10-46 |
| STPT | STORE CPU TIMER | S | | CK | P | A | SP | | | | | ST | B209 | 10-45 |
| STPX | STORE PREFIX | S | | MP | P | A | SP | | | | | ST | B211 | 10-45 |
| SU | SUBTRACT UNNORMALIZED (short) | RX | C | FP | | A | SP | EO | LS | | | | 7F | 9-15 |
| SUR | SUBTRACT UNNORMALIZED (short) | RR | C | FP | | | SP | EO | LS | | | | 3F | 9-15 |
| SVC | SUPERVISOR CALL | RR | | | | | | | | | | | 0A | 7-39 |
| SW | SUBTRACT UNNORMALIZED (long) | RX | C | FP | | A | SP | EO | LS | | | | 6F | 9-15 |
| SWR | SUBTRACT UNNORMALIZED (long) | RR | C | FP | | | SP | EO | LS | | | | 2F | 9-15 |
| SXR | SUBTRACT NORMALIZED (extended) | RR | C | XP | | | SP | EU | EO | LS | | | 37 | 9-15 |
| TB | TEST BLOCK | RRE | C | TB | P | A ¹ | | \$ | II | | R | | B22C | 10-46 |
| TCH | TEST CHANNEL | S | C | | P | | | \$ | | | | | 9F00* | 12-29 |
| TIO | TEST I/O | S | C | | P | | | \$ | | | | | 9D00* | 12-29 |
| TM | TEST UNDER MASK | SI | C | | | A | | | | | | | 91 | 7-39 |
| TPROT | TEST PROTECTION | SSE | C | EF | P | A ¹ | | | | | | | E501 | 10-48 |
| TR | TRANSLATE | SS | | | | A | | | | | | ST | DC | 7-40 |
| TRT | TRANSLATE AND TEST | SS | C | | | A | | | | | R | | DD | 7-41 |
| TS | TEST AND SET | S | C | | | A | | \$ | | | | ST | 93 | 7-39 |
| UNPK | UNPACK | SS | | | | A | | | | | | ST | F3 | 7-41 |
| WRD | WRITE DIRECT | SI | | DC | P | A ¹ | | \$ | | | | | 84 | 10-49 |
| X | EXCLUSIVE OR | RX | C | | | A | | | | | R | | 57 | 7-18 |

Instructions Arranged by Mnemonic (Part 4 of 5)

| Mnemonic | Name | Characteristics | | | | Op Code | Page No. |
|----------|--------------------------|-----------------|---|---|------|---------|----------|
| XC | EXCLUSIVE OR (character) | SS | C | A | | ST D7 | 7-18 |
| XI | EXCLUSIVE OR (immediate) | SI | C | A | | ST 97 | 7-18 |
| XR | EXCLUSIVE OR | RR | C | | | R 17 | 7-18 |
| ZAP | ZERO AND ADD | SS | C | A | D DF | ST F8 | 8-12 |

Instructions Arranged by Mnemonic (Part 5 of 5)

| Op Code | Name | Mne- monic | Characteristics | | | | | Page No. |
|---------|---------------------------------|---------------|-----------------|----|------------------|----|----------|-------------|
| 04 | SET PROGRAM MASK | SPM | RR | L | | | | 7-31 |
| 05 | BRANCH AND LINK | BALR | RR | | | | B R | 7-9 |
| 06 | BRANCH ON COUNT | BCTR | RR | | | | B R | 7-11 |
| 07 | BRANCH ON CONDITION | BCR | RR | | | | B | 7-10 |
| 08 | SET STORAGE KEY | SSK | RR | | P A ¹ | SP | | 10-41 |
| 09 | INSERT STORAGE KEY | ISK | RR | | P A ¹ | SP | R | 10-9 |
| 0A | SUPERVISOR CALL | SVC | RR | | | | | 7-39 |
| 0D | BRANCH AND SAVE | BASR | RR | BS | | | B R | 7-9 |
| 0E | MOVE LONG | MVCL | RR | C | A | SP | II R ST | 7-25 |
| 0F | COMPARE LOGICAL LONG | CLCL | RR | C | A | SP | II R | 7-15 |
| 10 | LOAD POSITIVE | LPR | RR | C | | | IF R | 7-23 |
| 11 | LOAD NEGATIVE | LNR | RR | C | | | R | 7-23 |
| 12 | LOAD AND TEST | LTR | RR | C | | | R | 7-21 |
| 13 | LOAD COMPLEMENT | LCR | RR | C | | | IF R | 7-22 |
| 14 | AND | NR | RR | C | | | R | 7-8 |
| 15 | COMPARE LOGICAL | CLR | RR | C | | | | 7-14 |
| 16 | OR | OR | RR | C | | | R | 7-30 |
| 17 | EXCLUSIVE OR | XR | RR | C | | | R | 7-18 |
| 18 | LOAD | LR | RR | | | | R | 7-21 |
| 19 | COMPARE | CR | RR | C | | | | 7-12 |
| 1A | ADD | AR | RR | C | | | IF R | 7-7 |
| 1B | SUBTRACT | SR | RR | C | | | IF R | 7-37 |
| 1C | MULTIPLY | MR | RR | | | SP | R | 7-29 |
| 1D | DIVIDE | DR | RR | | | SP | IK R | 7-18 |
| 1E | ADD LOGICAL | ALR | RR | C | | | R | 7-8 |
| 1F | SUBTRACT LOGICAL | SLR | RR | C | | | R | 7-38 |
| 20 | LOAD POSITIVE (long) | LPDR | RR | C | FP | SP | | 9-12 |
| 21 | LOAD NEGATIVE (long) | LNDR | RR | C | FP | SP | | 9-12 |
| 22 | LOAD AND TEST (long) | LTDR | RR | C | FP | SP | | 9-11 |
| 23 | LOAD COMPLEMENT (long) | LCDR | RR | C | FP | SP | | 9-11 |
| 24 | HALVE (long) | HDR | RR | | FP | SP | EU | 9-10 |
| 25 | LOAD ROUNDED (extended to long) | LRDR | RR | | XP | SP | EO | 9-12 |
| 26 | MULTIPLY (extended) | MXR | RR | | XP | SP | EU EO | 9-13 |
| 27 | MULTIPLY (long to extended) | MXDR | RR | | XP | SP | EU EO | 9-13 |
| 28 | LOAD (long) | LDR | RR | | FP | SP | | 9-10 |
| 29 | COMPARE (long) | CDR | RR | C | FP | SP | | 9-8 |
| 2A | ADD NORMALIZED (long) | ADR | RR | C | FP | SP | EU EO LS | 9-6 |
| 2B | SUBTRACT NORMALIZED (long) | SDR | RR | C | FP | SP | EU EO LS | 9-15 |
| 2C | MULTIPLY (long) | MDR | RR | | FP | SP | EU EO | 9-13 |
| 2D | DIVIDE (long) | DDR | RR | | FP | SP | EU EO FK | 9-9 |
| 2E | ADD UNNORMALIZED (long) | AWR | RR | C | FP | SP | EO LS | 9-7 |
| 2F | SUBTRACT UNNORMALIZED (long) | SWR | RR | C | FP | SP | EO LS | 9-15 |
| 30 | LOAD POSITIVE (short) | LPER | RR | C | FP | SP | | 9-12 |
| 31 | LOAD NEGATIVE (short) | LNER | RR | C | FP | SP | | 9-12 |
| 32 | LOAD AND TEST (short) | LTER | RR | C | FP | SP | | 9-11 |
| 33 | LOAD COMPLEMENT (short) | LCER | RR | C | FP | SP | | 9-11 |
| 34 | HALVE (short) | HER | RR | | FP | SP | EU | 9-10 |
| 35 | LOAD ROUNDED (long to short) | LRER | RR | | XP | SP | EO | 9-12 |
| 36 | ADD NORMALIZED (extended) | AXR | RR | C | XP | SP | EU EO LS | 9-6 |
| 37 | SUBTRACT NORMALIZED (extended) | SXR | RR | C | XP | SP | EU EO LS | 9-15 |

Instructions Arranged by Operation Code (Part 1 of 5)

| Op Code | Name | Mnemonic | Characteristics | | | | | | Page No. |
|---------|-------------------------------|----------|-----------------|------|-------|----------|-----|------|----------|
| 38 | LOAD (short) | LER | RR | FP | SP | | | 9-10 | |
| 39 | COMPARE (short) | CER | RR | C FP | SP | | | 9-8 | |
| 3A | ADD NORMALIZED (short) | AER | RR | C FP | SP | EU EO | LS | 9-6 | |
| 3B | SUBTRACT NORMALIZED (short) | SER | RR | C FP | SP | EU EO | LS | 9-15 | |
| 3C | MULTIPLY (short to long) | MER | RR | FP | SP | EU EO | | 9-13 | |
| 3D | DIVIDE (short) | DER | RR | FP | SP | EU EO FK | | 9-9 | |
| 3E | ADD UNNORMALIZED (short) | AUR | RR | C FP | SP | EO | LS | 9-7 | |
| 3F | SUBTRACT UNNORMALIZED (short) | SUR | RR | C FP | SP | EO | LS | 9-15 | |
| 40 | STORE HALFWORD | STH | RX | | A | | ST | 7-37 | |
| 41 | LOAD ADDRESS | LA | RX | | | | R | 7-21 | |
| 42 | STORE CHARACTER | STC | RX | | A | | ST | 7-35 | |
| 43 | INSERT CHARACTER | IC | RX | | A | | R | 7-20 | |
| 44 | EXECUTE | EX | RX | | AI SP | | EX | 7-19 | |
| 45 | BRANCH AND LINK | BAL | RX | | | | B R | 7-9 | |
| 46 | BRANCH ON COUNT | BCT | RX | | | | B R | 7-11 | |
| 47 | BRANCH ON CONDITION | BC | RX | | | | B | 7-10 | |
| 48 | LOAD HALFWORD | LH | RX | | A | | R | 7-22 | |
| 49 | COMPARE HALFWORD | CH | RX | C | A | | | 7-14 | |
| 4A | ADD HALFWORD | AH | RX | C | A | IF | R | 7-7 | |
| 4B | SUBTRACT HALFWORD | SH | RX | C | A | IF | R | 7-38 | |
| 4C | MULTIPLY HALFWORD | MH | RX | | A | | R | 7-29 | |
| 4D | BRANCH AND SAVE | BAS | RX | BS | | | B R | 7-9 | |
| 4E | CONVERT TO DECIMAL | CVD | RX | | A | | ST | 7-17 | |
| 4F | CONVERT TO BINARY | CVB | RX | | A | D IK | R | 7-17 | |
| 50 | STORE | ST | RX | | A | | ST | 7-35 | |
| 54 | AND | N | RX | C | A | | R | 7-8 | |
| 55 | COMPARE LOGICAL | CL | RX | C | A | | | 7-14 | |
| 56 | OR | O | RX | C | A | | R | 7-30 | |
| 57 | EXCLUSIVE OR | X | RX | C | A | | R | 7-18 | |
| 58 | LOAD | L | RX | | A | | R | 7-21 | |
| 59 | COMPARE | C | RX | C | A | | | 7-12 | |
| 5A | ADD | A | RX | C | A | IF | R | 7-7 | |
| 5B | SUBTRACT | S | RX | C | A | IF | R | 7-37 | |
| 5C | MULTIPLY | M | RX | | A SP | | R | 7-29 | |
| 5D | DIVIDE | D | RX | | A SP | IK | R | 7-18 | |
| 5E | ADD LOGICAL | AL | RX | C | A | | R | 7-8 | |
| 5F | SUBTRACT LOGICAL | SL | RX | C | A | | R | 7-38 | |
| 60 | STORE (long) | STD | RX | FP | A SP | | ST | 9-14 | |
| 67 | MULTIPLY (long to extended) | MXD | RX | XP | A SP | EU EO | | 9-13 | |
| 68 | LOAD (long) | LD | RX | FP | A SP | | | 9-10 | |
| 69 | COMPARE (long) | CD | RX | C FP | A SP | | | 9-8 | |
| 6A | ADD NORMALIZED (long) | AD | RX | C FP | A SP | EU EO | LS | 9-6 | |
| 6B | SUBTRACT NORMALIZED (long) | SD | RX | C FP | A SP | EU EO | LS | 9-15 | |
| 6C | MULTIPLY (long) | MD | RX | FP | A SP | EU EO | | 9-13 | |
| 6D | DIVIDE (long) | DD | RX | FP | A SP | EU EO FK | | 9-9 | |
| 6E | ADD UNNORMALIZED (long) | AW | RX | C FP | A SP | EO | LS | 9-7 | |
| 6F | SUBTRACT UNNORMALIZED (long) | SW | RX | C FP | A SP | EO | LS | 9-15 | |
| 70 | STORE (short) | STE | RX | FP | A SP | | ST | 9-14 | |
| 78 | LOAD (short) | LE | RX | FP | A SP | | | 9-10 | |
| 79 | COMPARE (short) | CE | RX | C FP | A SP | | | 9-8 | |

Instructions Arranged by Operation Code (Part 2 of 5)

| Op Code | Name | Mnemonic | Characteristics | | | | | | | | | | Page No. |
|---------|-------------------------------|----------|-----------------|---|----|---|----------------|----|----|----|----|-----|----------|
| 7A | ADD NORMALIZED (short) | AE | RX | C | FP | A | SP | EU | EO | LS | | | 9-6 |
| 7B | SUBTRACT NORMALIZED (short) | SE | RX | C | FP | A | SP | EU | EO | LS | | | 9-15 |
| 7C | MULTIPLY (short to long) | ME | RX | | FP | A | SP | EU | EO | | | | 9-13 |
| 7D | DIVIDE (short) | DE | RX | | FP | A | SP | EU | EO | FK | | | 9-9 |
| 7E | ADD UNNORMALIZED (short) | AU | RX | C | FP | A | SP | | EO | LS | | | 9-7 |
| 7F | SUBTRACT UNNORMALIZED (short) | SU | RX | C | FP | A | SP | | EO | LS | | | 9-15 |
| 80 | SET SYSTEM MASK | SSM | S | | | P | A | SP | | SO | | | 10-41 |
| 82 | LOAD PSW | LPSW | S | L | | P | A | SP | | | | | 10-17 |
| 83 | DIAGNOSE | | | | DM | P | DM | | | | | | 10-5 |
| 84 | WRITE DIRECT | WRD | SI | | DC | P | A ¹ | | | \$ | | | 10-49 |
| 85 | READ DIRECT | RDD | SI | | DC | P | A ¹ | | | \$ | | SD | 10-33 |
| 86 | BRANCH ON INDEX HIGH | BXH | RS | | | | | | | | | B R | 7-11 |
| 87 | BRANCH ON INDEX LOW OR EQUAL | BXLE | RS | | | | | | | | | B R | 7-11 |
| 88 | SHIFT RIGHT SINGLE LOGICAL | SRL | RS | | | | | | | | | R | 7-35 |
| 89 | SHIFT LEFT SINGLE LOGICAL | SLL | RS | | | | | | | | | R | 7-33 |
| 8A | SHIFT RIGHT SINGLE | SRA | RS | C | | | | | | | | R | 7-34 |
| 8B | SHIFT LEFT SINGLE | SLA | RS | C | | | | | IF | | | R | 7-33 |
| 8C | SHIFT RIGHT DOUBLE LOGICAL | SRDL | RS | | | | | SP | | | | R | 7-34 |
| 8D | SHIFT LEFT DOUBLE LOGICAL | SLDL | RS | | | | | SP | | | | R | 7-32 |
| 8E | SHIFT RIGHT DOUBLE | SRDA | RS | C | | | | SP | | | | R | 7-34 |
| 8F | SHIFT LEFT DOUBLE | SLDA | RS | C | | | | SP | IF | | | R | 7-32 |
| 90 | STORE MULTIPLE | STM | RS | | | | A | | | | | ST | 7-37 |
| 91 | TEST UNDER MASK | TM | SI | C | | | A | | | | | | 7-39 |
| 92 | MOVE (immediate) | MVI | SI | | | | A | | | | | ST | 7-24 |
| 93 | TEST AND SET | TS | S | C | | | A | | | \$ | | ST | 7-39 |
| 94 | AND (immediate) | NI | SI | C | | | A | | | | | ST | 7-8 |
| 95 | COMPARE LOGICAL (immediate) | CLI | SI | C | | | A | | | | | | 7-14 |
| 96 | OF (immediate) | OI | SI | C | | | A | | | | | ST | 7-30 |
| 97 | EXCLUSIVE OR (immediate) | XI | SI | C | | | A | | | | | ST | 7-18 |
| 98 | LOAD MULTIPLE | LM | RS | | | | A | | | | | R | 7-22 |
| 9C00* | START I/O | SIO | S | C | | P | | | | \$ | | | 12-25 |
| 9C01* | START I/O FAST RELEASE | SIOF | S | C | | P | | | | \$ | | | 12-25 |
| 9D00* | TEST I/O | TIO | S | C | | P | | | | \$ | | | 12-29 |
| 9D01* | CLEAR I/O | CLRIO | S | C | | P | | | | \$ | | | 12-17 |
| 9E00* | HALT I/O | HIO | S | C | | P | | | | \$ | | | 12-22 |
| 9E01* | HALT DEVICE | HDV | S | C | | P | | | | \$ | | | 12-19 |
| 9F00* | TEST CHANNEL | TCH | S | C | | P | | | | \$ | | | 12-29 |
| 9F01* | CLEAR CHANNEL | CLRCH | S | C | RE | P | | | | \$ | | | 12-16 |
| AC | STORE THEN AND SYSTEM MASK | STNSM | SI | | TR | P | A | | | | | ST | 10-45 |
| AD | STORE THEN OR SYSTEM MASK | STOSM | SI | | TR | P | A | SP | | | | ST | 10-46 |
| AE | SIGNAL PROCESSOR | SIGP | RS | C | MP | P | | | | \$ | | R | 10-42 |
| AF | MONITOR CALL | MC | SI | | | | | SP | | | MO | | 7-23 |
| B1 | LOAD REAL ADDRESS | LRA | RX | C | TR | P | A ¹ | | | | | R | 10-17 |
| B200 | CONNECT CHANNEL SET | CONCS | S | C | CS | P | | | | | | | 10-5 |
| B201 | DISCONNECT CHANNEL SET | DISCS | S | C | CS | P | | | | | | | 10-6 |
| B202 | STORE CPU ID | STIDP | S | | | P | A | SP | | | | ST | 10-44 |
| B203 | STORE CHANNEL ID | STIDC | S | C | | P | | | | \$ | | | 12-28 |
| B204 | SET CLOCK | SCK | S | C | | P | A | SP | | | | | 10-35 |
| B205 | STORE CLOCK | STCK | S | C | | | A | | | \$ | | ST | 7-36 |
| B206 | SET CLOCK COMPARATOR | SCKC | S | | CK | P | A | SP | | | | | 10-36 |

Instructions Arranged by Operation Code (Part 3 of 5)

| Op Code | Name | Mnemonic | Characteristics | | | | | | | | | | Page No. | | |
|---------|---------------------------------------|----------|-----------------|----|----|----------------|----------------|----|---|---|----|----|----------|----|-------|
| B207 | STORE CLOCK COMPARATOR | STCKC | S | CK | P | A | SP | | | | | ST | 10-43 | | |
| B208 | SET CPU TIMER | SPT | S | CK | P | A | SP | | | | | | 10-36 | | |
| B209 | STORE CPU TIMER | STPT | S | CK | P | A | SP | | | | | ST | 10-45 | | |
| B20A | SET PSW KEY FROM ADDRESS | SPKA | S | PK | Q | | | | | | | | 10-37 | | |
| B20B | INSERT PSW KEY | IPK | S | PK | Q | | | | | | | R | 10-8 | | |
| B20D | PURGE TLB | PTLB | S | TR | P | | | | | | \$ | | 10-33 | | |
| B210 | SET PREFIX | SPX | S | MP | P | A | SP | | | | \$ | | 10-36 | | |
| B211 | STORE PREFIX | STPX | S | MP | P | A | SP | | | | | ST | 10-45 | | |
| B212 | STORE CPU ADDRESS | STAP | S | MP | P | A | SP | | | | | ST | 10-44 | | |
| B213 | RESET REFERENCE BIT | RRB | S | C | TR | P | A ¹ | | | | | | 10-34 | | |
| B218 | PROGRAM CALL | PC | S | DU | Q | AT | | PC | T | ≠ | SO | B | R | XT | 10-21 |
| B219 | SET ADDRESS SPACE CONTROL | SAC | S | DU | | | SP | | | | ≠ | SO | | | 10-34 |
| B221 | INVALIDATE PAGE TABLE ENTRY | IPTE | RRE | EF | P | A ¹ | | | | | \$ | | | | 10-10 |
| B223 | INSERT VIRTUAL STORAGE KEY | IVSK | RRE | DU | Q | A ¹ | | | | | | SO | R | | 10-9 |
| B224 | INSERT ADDRESS SPACE CONTROL | IAC | RRE | C | DU | Q | | | | | | SO | R | | 10-7 |
| B225 | SET SECONDARY ASN | SSAR | RRE | DU | | AT | | SA | T | ≠ | SO | | ST | | 10-38 |
| B226 | EXTRACT PRIMARY ASN | EPAR | RRE | DU | Q | | | | | | | SO | R | | 10-6 |
| B227 | EXTRACT SECONDARY ASN | ESAR | RRE | DU | Q | | | | | | | SO | R | | 10-7 |
| B228 | PROGRAM TRANSFER | PT | RRE | DU | Q | AT | SP | PA | T | ≠ | SO | B | XT | | 10-28 |
| B22C | TEST BLOCK | TB | RRE | C | TB | P | A ¹ | | | | \$ | II | R | | 10-46 |
| B6 | STORE CONTROL | STCTL | RS | | P | A | SP | | | | | | ST | | 10-43 |
| B7 | LOAD CONTROL | LCTL | RS | | P | A | SP | | | | | | | | 10-16 |
| BA | COMPARE AND SWAP | CS | RS | C | SW | | A | SP | | | \$ | | R | ST | 7-12 |
| BB | COMPARE DOUBLE AND SWAP | CDS | RS | C | SW | | A | SP | | | \$ | | R | ST | 7-12 |
| BD | COMPARE LOGICAL CHARACTERS UNDER MASK | CLM | RS | C | | | A | | | | | | | | 7-15 |
| BE | STORE CHARACTERS UNDER MASK | STCM | RS | | | | A | | | | | | ST | | 7-35 |
| BF | INSERT CHARACTERS UNDER MASK | ICM | RS | C | | | A | | | | | | R | | 7-20 |
| D1 | MOVE NUMERICS | MVN | SS | | | | A | | | | | | ST | | 7-27 |
| D2 | MOVE (character) | MVC | SS | | | | A | | | | | | ST | | 7-24 |
| D3 | MOVE ZONES | MVZ | SS | | | | A | | | | | | ST | | 7-28 |
| D4 | AND (character) | NC | SS | C | | | A | | | | | | ST | | 7-8 |
| D5 | COMPARE LOGICAL (character) | CLC | SS | C | | | A | | | | | | | | 7-14 |
| D6 | OR (character) | OC | SS | C | | | A | | | | | | ST | | 7-30 |
| D7 | EXCLUSIVE OR (character) | XC | SS | C | | | A | | | | | | ST | | 7-18 |
| D9 | MOVE WITH KEY | MVCK | SS | C | DU | Q | A | | | | | | ST | | 10-20 |
| DA | MOVE TO PRIMARY | MVCP | SS | C | DU | Q | A ¹ | | | | ≠ | SO | | ST | 10-18 |
| DB | MOVE TO SECONDARY | MVCS | SS | C | DU | Q | A ¹ | | | | ≠ | SO | | ST | 10-18 |
| DC | TRANSLATE | TR | SS | | | | A | | | | | | ST | | 7-40 |
| DD | TRANSLATE AND TEST | TRT | SS | C | | | A | | | | | | R | | 7-41 |
| DE | EDIT | ED | SS | C | | | A | | | | D | | ST | | 8-6 |
| DF | EDIT AND MARK | EDMK | SS | C | | | A | | | | D | | R | ST | 8-10 |
| E500 | LOAD ADDRESS SPACE PARAMETERS | LASP | SSE | C | DU | Q | AS | SP | | | | SO | | | 10-11 |
| E501 | TEST PROTECTION | TPROT | SSE | C | EF | P | A ¹ | | | | | | | | 10-48 |
| E8 | MOVE INVERSE | MVCIN | SS | | MI | | A | | | | | | ST | | 7-24 |
| F0 | SHIFT AND ROUND DECIMAL | SRP | SS | C | | | A | | | | D | DF | | ST | 8-11 |
| F1 | MOVE WITH OFFSET | MVO | SS | | | | A | | | | | | ST | | 7-28 |
| F2 | PACK | PACK | SS | | | | A | | | | | | ST | | 7-31 |
| F3 | UNPACK | UNPK | SS | | | | A | | | | | | ST | | 7-41 |
| F8 | ZERO AND ADD | ZAP | SS | C | | | A | | | | D | DF | ST | | 8-12 |
| F9 | COMPARE DECIMAL | CP | SS | C | | | A | | | | D | | | | 8-5 |

Instructions Arranged by Operation Code (Part 4 of 5)

| Op Code | Name | Mne- monic | Characteristics | | | | Page No. |
|---------|------------------|---------------|-----------------|---|---|---------|-------------|
| FA | ADD DECIMAL | AP | SS | C | A | D DF | ST 8-5 |
| FB | SUBTRACT DECIMAL | SP | SS | C | A | D DF | ST 8-12 |
| FC | MULTIPLY DECIMAL | MP | SS | | A | SP D | ST 8-10 |
| FD | DIVIDE DECIMAL | DP | SS | | A | SP D DK | ST 8-5 |

Instructions Arranged by Operation Code (Part 5 of 5)

| Name | Mne- monic | Characteristics | | | | Op Code | Page No. |
|-----------------|---------------|-----------------|----|--|-----|------------|-------------|
| BRANCH AND SAVE | BASR | RR | BS | | B R | 0D | 7-9 |
| BRANCH AND SAVE | BAS | RX | BS | | B R | 4D | 7-9 |

Instructions Arranged by Feature: Branch and Save

| Name | Mne- monic | Characteristics | | | | Op Code | Page No. |
|------------------------|---------------|-----------------|---|----|---|------------|-------------|
| CONNECT CHANNEL SET | CONCS | S | C | CS | P | B200 | 10-5 |
| DISCONNECT CHANNEL SET | DISCS | S | C | CS | P | B201 | 10-6 |

Instructions Arranged by Feature: Channel-Set Switching

| Name | Mne- monic | Characteristics | | | | | Op Code | Page No. | | |
|---------------------------------------|---------------|-----------------|----|---|-------------------|----|------------|-------------|-------|-------|
| ADD | AR | RR | C | | | IF | R | 1A | 7-7 | |
| ADD | A | RX | C | A | | IF | R | 5A | 7-7 | |
| ADD DECIMAL | AP | SS | C | A | D | DF | ST | FA | 8-5 | |
| ADD HALFWORD | AH | RX | C | A | | IF | R | 4A | 7-7 | |
| ADD LOGICAL | ALR | RR | C | | | | R | 1E | 7-8 | |
| ADD LOGICAL | AL | RX | C | A | | | R | 5E | 7-8 | |
| AND | NR | RR | C | | | | R | 14 | 7-8 | |
| AND | N | RX | C | A | | | R | 54 | 7-8 | |
| AND (character) | NC | SS | C | A | | | ST | D4 | 7-8 | |
| AND (immediate) | NI | SI | C | A | | | ST | 94 | 7-8 | |
| BRANCH AND LINK | BALR | RR | | | | | B R | 05 | 7-9 | |
| BRANCH AND LINK | BAL | RX | | | | | B R | 45 | 7-9 | |
| BRANCH ON CONDITION | BCR | RR | | | | 1 | B | 07 | 7-10 | |
| BRANCH ON CONDITION | BC | RX | | | | | B | 47 | 7-10 | |
| BRANCH ON COUNT | BCTR | RR | | | | | B R | 06 | 7-11 | |
| BRANCH ON COUNT | BCT | RX | | | | | B R | 46 | 7-11 | |
| BRANCH ON INDEX HIGH | BXH | RS | | | | | B R | 86 | 7-11 | |
| BRANCH ON INDEX LOW OR EQUAL | BXLE | RS | | | | | B R | 87 | 7-11 | |
| CLEAR I/O | CLRIO | S | C | P | | \$ | | 9D01* | 12-17 | |
| COMPARE | CR | RR | C | | | | | 19 | 7-12 | |
| COMPARE | C | RX | C | A | | | | 59 | 7-12 | |
| COMPARE DECIMAL | CP | SS | C | A | D | | | F9 | 8-5 | |
| COMPARE HALFWORD | CH | RX | C | A | | | | 49 | 7-14 | |
| COMPARE LOGICAL | CLR | RR | C | | | | | 15 | 7-14 | |
| COMPARE LOGICAL | CL | RX | C | A | | | | 55 | 7-14 | |
| COMPARE LOGICAL (character) | CLC | SS | C | A | | | | D5 | 7-14 | |
| COMPARE LOGICAL (immediate) | CLI | SI | C | A | | | | 95 | 7-14 | |
| COMPARE LOGICAL CHARACTERS UNDER MASK | CLM | RS | C | A | | | | BD | 7-15 | |
| COMPARE LOGICAL LONG | CLCL | RR | C | A | SP | | II | R | 0F | 7-15 |
| CONVERT TO BINARY | CVB | RX | | A | D | IK | | R | 4F | 7-17 |
| CONVERT TO DECIMAL | CVD | RX | | A | | | | ST | 4E | 7-17 |
| DIAGNOSE | | | DM | P | DM | | | | 83 | 10-5 |
| DIVIDE | DR | RR | | | SP | IK | | R | 1D | 7-18 |
| DIVIDE | D | RX | | A | SP | IK | | R | 5D | 7-18 |
| DIVIDE DECIMAL | DP | SS | | A | SP | D | DK | ST | FD | 8-5 |
| EDIT | ED | SS | C | A | D | | | ST | DE | 8-6 |
| EDIT AND MARK | EDMK | SS | C | A | D | | | R ST | DF | 8-10 |
| EXCLUSIVE OR | XR | RR | C | | | | | R | 17 | 7-18 |
| EXCLUSIVE OR | X | RX | C | A | | | | R | 57 | 7-18 |
| EXCLUSIVE OR (character) | XC | SS | C | A | | | | ST | D7 | 7-18 |
| EXCLUSIVE OR (immediate) | XI | SI | C | A | | | | ST | 97 | 7-18 |
| EXECUTE | EX | RX | | A | AI SP | | EX | | 44 | 7-19 |
| HALT DEVICE | HDV | S | C | P | | \$ | | | 9E01* | 12-19 |
| HALT I/O | HIO | S | C | P | | \$ | | | 9E00* | 12-22 |
| INSERT CHARACTER | IC | RX | | A | | | | R | 43 | 7-20 |
| INSERT CHARACTERS UNDER MASK | ICM | RS | C | A | | | | R | BF | 7-20 |
| INSERT STORAGE KEY | ISK | RR | | P | A ¹ SP | | | R | 09 | 10-9 |
| LOAD | LR | RR | | | | | | R | 18 | 7-21 |
| LOAD | L | RX | | A | | | | R | 58 | 7-21 |
| LOAD ADDRESS | LA | RX | | | | | | R | 41 | 7-21 |

Instructions Arranged by Feature: Commercial Instruction Set (Part 1 of 3)

| Name | Mnemonic | Characteristics | | | | | | Op Code | Page No. | | |
|-----------------------------|----------|-----------------|---|---|---|----|----|---------|----------|-------|------|
| LOAD AND TEST | LTR | RR | C | | | | R | 12 | 7-21 | | |
| LOAD COMPLEMENT | LCR | RR | C | | | IF | R | 13 | 7-22 | | |
| LOAD CONTROL | LCTL | RS | | P | A | SP | | B7 | 10-16 | | |
| LOAD HALFWORD | LH | RX | | | A | | R | 48 | 7-22 | | |
| LOAD MULTIPLE | LM | RS | | | A | | R | 98 | 7-22 | | |
| LOAD NEGATIVE | LNR | RR | C | | | | R | 11 | 7-23 | | |
| LOAD POSITIVE | LPR | RR | C | | | IF | R | 10 | 7-23 | | |
| LOAD PSW | LPSW | S | L | P | A | SP | | 82 | 10-17 | | |
| MONITOR CALL | MC | SI | | | | SP | MO | AF | 7-23 | | |
| MOVE (character) | MVC | SS | | | A | | ST | D2 | 7-24 | | |
| MOVE (immediate) | MVI | SI | | | A | | ST | 92 | 7-24 | | |
| MOVE LONG | MVCL | RR | C | | A | SP | II | R ST | 0E | 7-25 | |
| MOVE NUMERICS | MVN | SS | | | A | | ST | D1 | 7-27 | | |
| MOVE WITH OFFSET | MVO | SS | | | A | | ST | F1 | 7-28 | | |
| MOVE ZONES | MVZ | SS | | | A | | ST | D3 | 7-28 | | |
| MULTIPLY | MR | RR | | | | SP | R | 1C | 7-29 | | |
| MULTIPLY | M | RX | | | A | SP | R | 5C | 7-29 | | |
| MULTIPLY DECIMAL | MP | SS | | | A | SP | D | ST | FC | 8-10 | |
| MULTIPLY HALFWORD | MH | RX | | | A | | R | 4C | 7-29 | | |
| OR | OR | RR | C | | | | R | 16 | 7-30 | | |
| OR (character) | O | RX | C | | A | | R | 56 | 7-30 | | |
| OR (immediate) | OC | SS | C | | A | | ST | D6 | 7-30 | | |
| PACK | OI | SI | C | | A | | ST | 96 | 7-30 | | |
| PACK | PACK | SS | | | A | | ST | F2 | 7-31 | | |
| SET CLOCK | SCK | S | C | P | A | SP | | B204 | 10-35 | | |
| SET PROGRAM MASK | SPM | RR | L | | | | | 04 | 7-31 | | |
| SET STORAGE KEY | SSK | RR | | P | A | SP | | 08 | 10-41 | | |
| SET SYSTEM MASK | SSM | S | | P | A | SP | SO | 80 | 10-41 | | |
| SHIFT AND ROUND DECIMAL | SRP | SS | C | | A | D | DF | ST | F0 | 8-11 | |
| SHIFT LEFT DOUBLE | SLDA | RS | C | | | SP | IF | R | 8F | 7-32 | |
| SHIFT LEFT DOUBLE LOGICAL | SLDL | RS | | | | SP | | P | 8D | 7-32 | |
| SHIFT LEFT SINGLE | SLA | RS | C | | | | IF | R | 8B | 7-33 | |
| SHIFT LEFT SINGLE LOGICAL | SLL | RS | | | | | | R | 89 | 7-33 | |
| SHIFT RIGHT DOUBLE | SRDA | RS | C | | | SP | | R | 8E | 7-34 | |
| SHIFT RIGHT DOUBLE LOGICAL | SRDL | RS | | | | SP | | R | 8C | 7-34 | |
| SHIFT RIGHT SINGLE | SRA | RS | C | | | | | R | 8A | 7-34 | |
| SHIFT RIGHT SINGLE LOGICAL | SRL | RS | | | | | | R | 88 | 7-35 | |
| START I/O | SIO | S | C | P | | | \$ | | 9C00* | 12-25 | |
| START I/O FAST RELEASE | SIOF | S | C | P | | | \$ | | 9C01* | 12-25 | |
| STORE | ST | RX | | | A | | | ST | 50 | 7-35 | |
| STORE CHANNEL ID | STIDC | S | C | P | | | \$ | | B203 | 12-28 | |
| STORE CHARACTER | STC | RX | | | A | | | ST | 42 | 7-35 | |
| STORE CHARACTERS UNDER MASK | STCM | RS | | | A | | | ST | BE | 7-35 | |
| STORE CLOCK | STCK | S | C | | A | | \$ | | ST | B205 | 7-36 |
| STORE CONTROL | STCTL | RS | | P | A | SP | | ST | B6 | 10-43 | |
| STORE CPU ID | STIDP | S | | P | A | SP | | ST | B202 | 10-44 | |
| STORE HALFWORD | STH | RX | | | A | | | ST | 40 | 7-37 | |
| STORE MULTIPLE | STM | RS | | | A | | | ST | 90 | 7-37 | |
| SUBTRACT | SR | RR | C | | | | IF | R | 1B | 7-37 | |
| SUBTRACT | S | RX | C | | A | | IF | R | 5B | 7-37 | |

Instructions Arranged by Feature: Commercial Instruction Set (Part 2 of 3)

| Name | Mne- monic | Characteristics | | | | | | Op Code | Page No. |
|--------------------|---------------|-----------------|---|---|---|----|-------|------------|-------------|
| SUBTRACT DECIMAL | SP | SS | C | A | D | DF | ST FB | 8-12 | |
| SUBTRACT HALFWORD | SH | RX | C | A | | IF | R 4B | 7-38 | |
| SUBTRACT LOGICAL | SLR | RR | C | | | | R 1F | 7-38 | |
| SUBTRACT LOGICAL | SL | RX | C | A | | | R 5F | 7-38 | |
| SUPERVISOR CALL | SVC | RR | | | | | 0A | 7-39 | |
| TEST AND SET | TS | S | C | A | | \$ | ST 93 | 7-39 | |
| TEST CHANNEL | TCH | S | C | P | | \$ | 9F00* | 12-29 | |
| TEST I/O | TIO | S | C | P | | \$ | 9D00* | 12-29 | |
| TEST UNDER MASK | TM | SI | C | A | | | 91 | 7-39 | |
| TRANSLATE | TR | SS | | A | | | ST DC | 7-40 | |
| TRANSLATE AND TEST | TRT | SS | C | A | | | R DD | 7-41 | |
| UNPACK | UNPK | SS | | A | | | ST F3 | 7-41 | |
| ZERO AND ADD | ZAP | SS | C | A | D | DF | ST F8 | 8-12 | |

Instructions Arranged by Feature: Commercial Instruction Set (Part 3 of 3)

| Name | Mne- monic | Characteristics | | | | | | Op Code | Page No. |
|-------------------------|---------------|-----------------|---|----|---|----|----|------------|-------------|
| COMPARE AND SWAP | CS | RS | C | SW | A | SP | \$ | R ST BA | 7-12 |
| COMPARE DOUBLE AND SWAP | CDS | RS | C | SW | A | SP | \$ | R ST BB | 7-12 |

Instructions Arranged by Feature: Conditional Swapping

| Name | Mne- monic | Characteristics | | | | | | Op Code | Page No. |
|------------------------|---------------|-----------------|--|----|---|---|----|------------|-------------|
| SET CLOCK COMPARATOR | SCKC | S | | CK | P | A | SP | B206 | 10-36 |
| SET CPU TIMER | SPT | S | | CK | P | A | SP | B208 | 10-36 |
| STORE CLOCK COMPARATOR | STCKC | S | | CK | P | A | SP | ST B207 | 10-43 |
| STORE CPU TIMER | STPT | S | | CK | P | A | SP | ST B209 | 10-45 |

Instructions Arranged by Feature: CPU Timer and Clock Comparator

| Name | Mne- monic | Characteristics | | | | | | Op Code | Page No. |
|--------------|---------------|-----------------|--|----|---|----------------|----|------------|-------------|
| READ DIRECT | RDD | SI | | DC | P | A ¹ | \$ | SD 85 | 10-33 |
| WRITE DIRECT | WRD | SI | | DC | P | A ¹ | \$ | 84 | 10-49 |

Instructions Arranged by Feature: Direct Control

| Name | Mne- monic | Characteristics | | | | | | Op Code | Page No. |
|-------------------------------|---------------|-----------------|----|---|----------------|------|-----------|------------|-------------|
| EXTRACT PRIMARY ASN | EPAR | RRE | DU | Q | | | SO R | B226 | 10-6 |
| EXTRACT SECONDARY ASN | ESAR | RRE | DU | Q | | | SO R | B227 | 10-7 |
| INSERT ADDRESS SPACE CCNTROL | IAC | FRE C | DU | Q | | | SO R | B224 | 10-7 |
| INSERT VIRTUAL STORAGE KEY | IVSK | RRE | DU | Q | A ¹ | | SO R | B223 | 10-9 |
| LOAD ADDRESS SPACE PARAMETERS | LASP | SSE C | DU | Q | AS SP | | SO | E500 | 10-11 |
| MOVE TO PRIMARY | MVCP | SS C | DU | Q | A ¹ | | SO | ST DA | 10-18 |
| MOVE TO SECONDARY | MVCS | SS C | DU | Q | A ¹ | | SO | ST DB | 10-18 |
| MOVE WITH KEY | MVCK | SS C | DU | Q | A | | | ST D9 | 10-20 |
| PROGRAM CALL | PC | S | DU | Q | AT | PC T | SO B R XT | B218 | 10-21 |
| PROGRAM TRANSFER | PT | RRE | DU | Q | AT SP | PA T | SO B XT | B228 | 10-28 |
| SET ADDRESS SPACE CONTROL | SAC | S | DU | | SP | | SO | B219 | 10-34 |
| SET SECONDARY ASN | SSAR | RRE | DU | | AT | SA T | SO | ST B225 | 10-38 |

Instructions Arranged by Feature: Dual-Address-Space (DAS) Facility

| Name | Mne- monic | Characteristics | | | | | | Op Code | Page No. |
|-----------------------------|---------------|-----------------|----|---|----------------|----|--|------------|-------------|
| INVALIDATE PAGE TABLE ENTRY | IPTE | RRE | EF | P | A ¹ | \$ | | B221 | 10-10 |
| TEST PROTECTION | TPROT | SSE C | EF | P | A ¹ | | | E501 | 10-48 |

Note: The extended facility actually consists of 14 instructions 12 of which are MVS-dependent.

Instructions Arranged by Feature: Extended Facility (without MVS Assist)

| Name | Mne- monic | Characteristics | | | | | | Op Code | Page No. |
|---------------------------------|---------------|-----------------|----|---|----|----------|--|------------|-------------|
| ADD NORMALIZED (extended) | AXR | RR C | XP | | SP | EU EO LS | | 36 | 9-6 |
| LOAD ROUNDED (extended to long) | LRDR | RR | XP | | SP | EO | | 25 | 9-12 |
| LOAD ROUNDED (long to short) | LRER | RR | XP | | SP | EO | | 35 | 9-12 |
| MULTIPLY (extended) | MXR | RR | XP | | SP | EU EO | | 26 | 9-13 |
| MULTIPLY (long to extended) | MXDR | RR | XP | | SP | EU EO | | 27 | 9-13 |
| MULTIPLY (long to extended) | MXD | RX | XP | A | SP | EU EO | | 67 | 9-13 |
| SUBTRACT NORMALIZED (extended) | SXR | RR C | XP | | SP | EU EO LS | | 37 | 9-15 |

Instructions Arranged by Feature: Extended-Precision Floating Point

| Name | Mne- monic | Characteristics | | | | | | | | Op Code | Page No. |
|-------------------------------|---------------|-----------------|---|----|---|----|----|----|----|------------|-------------|
| ADD NORMALIZED (long) | ADR | RR | C | FP | | SP | EU | EO | LS | 2A | 9-6 |
| ADD NORMALIZED (long) | AD | RX | C | FP | A | SP | EU | EO | LS | 6A | 9-6 |
| ADD NORMALIZED (short) | AER | RR | C | FP | | SP | EU | EO | LS | 3A | 9-6 |
| ADD NORMALIZED (short) | AE | RX | C | FP | A | SP | EU | EO | LS | 7A | 9-6 |
| ADD UNNORMALIZED (long) | AWR | RR | C | FP | | SP | | EO | LS | 2E | 9-7 |
| ADD UNNORMALIZED (long) | AW | RX | C | FP | A | SP | | EO | LS | 6E | 9-7 |
| ADD UNNORMALIZED (short) | AUR | RR | C | FP | | SP | | EO | LS | 3E | 9-7 |
| ADD UNNORMALIZED (short) | AU | RX | C | FP | A | SP | | EO | LS | 7E | 9-7 |
| COMPARE (long) | CDR | RR | C | FP | | SP | | | | 29 | 9-8 |
| COMPARE (long) | CD | RX | C | FP | A | SP | | | | 69 | 9-8 |
| COMPARE (short) | CER | RR | C | FP | | SP | | | | 39 | 9-8 |
| COMPARE (short) | CE | RX | C | FP | A | SP | | | | 79 | 9-8 |
| DIVIDE (long) | DDR | RR | | FP | | SP | EU | EO | FK | 2D | 9-9 |
| DIVIDE (short) | DER | RR | | FP | | SP | EU | EO | FK | 3D | 9-9 |
| DIVIDE (short) | DE | RX | | FP | A | SP | EU | EO | FK | 7D | 9-9 |
| HALVE (long) | HDR | RR | | FP | | SP | EU | | | 24 | 9-10 |
| HALVE (short) | HER | RR | | FP | | SP | EU | | | 34 | 9-10 |
| LOAD (long) | LDR | RR | | FP | | SP | | | | 28 | 9-10 |
| LOAD (long) | LD | RX | | FP | A | SP | | | | 68 | 9-10 |
| LOAD (short) | LER | RR | | FP | | SP | | | | 38 | 9-10 |
| LOAD (short) | LE | RX | | FP | A | SP | | | | 78 | 9-10 |
| LOAD AND TEST (long) | LTDR | RR | C | FP | | SP | | | | 22 | 9-11 |
| LOAD AND TEST (short) | LTER | RR | C | FP | | SP | | | | 32 | 9-11 |
| LOAD COMPLEMENT (long) | LCDR | RR | C | FP | | SP | | | | 23 | 9-11 |
| LOAD COMPLEMENT (short) | LCER | RR | C | FP | | SP | | | | 33 | 9-11 |
| LOAD NEGATIVE (long) | LNDR | RR | C | FP | | SP | | | | 21 | 9-12 |
| LOAD NEGATIVE (short) | LNER | RR | C | FP | | SP | | | | 31 | 9-12 |
| LOAD POSITIVE (long) | LPDR | RR | C | FP | | SP | | | | 20 | 9-12 |
| LOAD POSITIVE (short) | LPER | RR | C | FP | | SP | | | | 30 | 9-12 |
| MULTIPLY (long) | MDR | RR | | FP | | SP | EU | EO | | 2C | 9-13 |
| MULTIPLY (long) | MD | RX | | FP | A | SP | EU | EO | | 6C | 9-13 |
| MULTIPLY (short to long) | MER | RR | | FP | | SP | EU | EO | | 3C | 9-13 |
| MULTIPLY (short to long) | ME | RX | | FP | A | SP | EU | EO | | 7C | 9-13 |
| STORE (long) | STD | RX | | FP | A | SP | | | | ST 60 | 9-14 |
| STORE (short) | STE | RX | | FP | A | SP | | | | ST 70 | 9-14 |
| SUBTRACT NORMALIZED (long) | SDR | RR | C | FP | | SP | EU | EO | LS | 2B | 9-15 |
| SUBTRACT NORMALIZED (long) | SD | RX | C | FP | A | SP | EU | EO | LS | 6B | 9-15 |
| SUBTRACT NORMALIZED (short) | SER | RR | C | FP | | SP | EU | EO | LS | 3B | 9-15 |
| SUBTRACT NORMALIZED (short) | SE | RX | C | FP | A | SP | EU | EO | LS | 7B | 9-15 |
| SUBTRACT UNNORMALIZED (long) | SWR | RR | C | FP | | SP | | EO | LS | 2F | 9-15 |
| SUBTRACT UNNORMALIZED (long) | SW | RX | C | FP | A | SP | | EO | LS | 6F | 9-15 |
| SUBTRACT UNNORMALIZED (short) | SUR | RR | C | FP | | SP | | EO | LS | 3F | 9-15 |
| SUBTRACT UNNORMALIZED (short) | SU | RX | C | FP | A | SP | | EO | LS | 7F | 9-15 |

Instructions Arranged by Feature: Floating Point

| Name | Mne- monic | Characteristics | | | | | Op Code | Page No. |
|--------------|---------------|-----------------|----|---|--|-------|------------|-------------|
| MOVE INVERSE | MVCIN | SS | MI | A | | ST E8 | 7-24 | |

Instructions Arranged by Feature: Move Inverse

| Name | Mne- monic | Characteristics | | | | | Op Code | Page No. |
|-------------------|---------------|-----------------|----|-----|----|----|------------|-------------|
| SET PREFIX | SPX | S | MP | P A | SP | \$ | B210 | 10-36 |
| SIGNAL PROCESSOR | SIGP | RS | C | MP | P | \$ | R AE | 10-42 |
| STORE CPU ADDRESS | STAP | S | MP | P A | SP | | ST B212 | 10-44 |
| STORE PREFIX | STPX | S | MP | P A | SP | | ST B211 | 10-45 |

Instructions Arranged by Feature: Multiprocessing

| Name | Mne- monic | Characteristics | | | | | Op Code | Page No. |
|--------------------------|---------------|-----------------|----|---|--|--|------------|-------------|
| INSERT PSW KEY | IPK | S | PK | Q | | | R B20B | 10-8 |
| SET PSW KEY FROM ADDRESS | SPKA | S | PK | Q | | | B20A | 10-37 |

Instructions Arranged by Feature: PSW-Key Handling

| Name | Mne- monic | Characteristics | | | | | Op Code | Page No. |
|---------------|---------------|-----------------|---|----|---|----|------------|-------------|
| CLEAR CHANNEL | CLRCH | S | C | RE | P | \$ | 9F01* | 12-16 |

Instructions Arranged by Feature: Recovery Extensions

| Name | Mne- monic | Characteristics | | | | | Op Code | Page No. |
|------------|---------------|-----------------|---|----|------------------|-------|------------|-------------|
| TEST BLOCK | TB | RRE | C | TB | P A ¹ | \$ II | R B22C | 10-46 |

Instructions Arranged by Feature: Test Block

| Name | Mnemonic | Characteristics | | | | | | Op Code | Page No. |
|----------------------------|----------|-----------------|---|----|---|----------------|---|---------|----------|
| LOAD REAL ADDRESS | LRA | RX | C | TR | P | A ¹ | R | B1 | 10-17 |
| PURGE TLB | PTLB | S | | TR | P | | | B20D | 10-33 |
| RESET REFERENCE BIT | RRB | S | C | TR | P | A ¹ | | B213 | 10-34 |
| STORE THEN AND SYSTEM MASK | STNSM | SI | | TR | P | A | | STAC | 10-45 |
| STORE THEN OR SYSTEM MASK | STOSM | SI | | TR | P | A SP | | STAD | 10-46 |

Instructions Arranged by Feature: Translation



APPENDIX C. CONDITION-CODE SETTINGS

| Instruction | Condition Code | | | |
|--|------------------------------|-----------------------------|----------------------|---------------------|
| | 0 | 1 | 2 | 3 |
| ADD, ADD HALFWORD | zero | < zero | > zero | overflow |
| ADD DECIMAL | zero | < zero | > zero | overflow |
| ADD LOGICAL | zero, no carry | not zero, no carry | zero, carry | not zero, carry |
| ADD NORMALIZED | zero | < zero | > zero | — |
| ADD UNNORMALIZED | zero | < zero | > zero | — |
| AND | zero | not zero | — | — |
| CLEAR CHANNEL | reset signaled | — | — | not operational |
| CLEAR I/O | no operation in progress | CSW stored | channel busy | not operational |
| COMPARE, COMPARE HALFWORD | equal | low | high | — |
| COMPARE AND SWAP | equal | not equal | — | — |
| COMPARE DECIMAL | equal | low | high | — |
| COMPARE DOUBLE AND SWAP | equal | not equal | — | — |
| COMPARE LOGICAL | equal | low | high | — |
| COMPARE LOGICAL CHARACTERS UNDER MASK | equal | low | high | — |
| COMPARE LOGICAL LONG | equal | low | high | — |
| CONNECT CHANNEL SET | successful | connected to another CPU | — | not operational |
| DISCONNECT CHANNEL SET | successful | connected to another CPU | — | not operational |
| EDIT, EDIT AND MARK | zero | < zero | > zero | — |
| EXCLUSIVE OR | zero | not zero | — | — |
| HALT DEVICE | interruption pending/busy | CSW stored | channel working | not operational |
| HALT I/O | interruption pending | CSW stored | burst op. stopped | not operational |
| INSERT ADDRESS SPACE CONTROL | zero | one | — | — |
| INSERT CHARACTERS UNDER MASK | all zeros | 1st bit one | 1st bit zero | — |
| LOAD AND TEST | zero | < zero | > zero | — |
| LOAD COMPLEMENT (fixed point) | zero | < zero | > zero | overflow |
| LOAD COMPLEMENT (floating point) | zero | < zero | > zero | — |
| LOAD NEGATIVE | zero | < zero | — | — |
| LOAD POSITIVE (fixed point) | zero | — | > zero | overflow |
| LOAD POSITIVE (floating point) | zero | — | > zero | — |
| LOAD REAL ADDRESS | translation available | ST entry invalid | PT entry invalid | length violation |

Summary of Condition-Code Settings (Part 1 of 2)

| Instruction | Condition Code | | | |
|--|-----------------------------|-----------------------|-----------------------|----------------------|
| | 0 | 1 | 2 | 3 |
| MOVE LONG | length equal | length low | length high | destr overlap |
| MOVE TO PRIMARY, MOVE TO SECONDARY | length =< 256 | — | — | length > 256 |
| MOVE WITH KEY | length =< 256 | — | — | length > 256 |
| OR | zero | not zero | — | — |
| RESET REFERENCE BIT | R bit zero, C bit zero | R bit zero, C bit one | R bit one, C bit zero | R bit one, C bit one |
| SET CLOCK | set | secure | — | not operational |
| SHIFT AND ROUND DECIMAL | zero | < zero | > zero | overflow |
| SHIFT LEFT (DOUBLE or SINGLE) | zero | < zero | > zero | overflow |
| SHIFT RIGHT (DOUBLE or SINGLE) | zero | < zero | > zero | — |
| SIGNAL PROCESSOR | order code accepted | status stored | busy | not operational |
| START I/O, START I/O PAST RELEASE | successful | CSW stored | busy | not operational |
| STORE CHANNEL ID | ID stored | CSW stored | busy | not operational |
| STORE CLOCK | set | not set | error | not operational |
| SUBTRACT, SUBTRACT HALFWORD | zero | < zero | > zero | overflow |
| SUBTRACT DECIMAL | zero | < zero | > zero | overflow |
| SUBTRACT LOGICAL | — | not zero, no carry | zero, carry | not zero, carry |
| SUBTRACT NORMALIZED | zero | < zero | > zero | — |
| SUBTRACT UNNORMALIZED | zero | < zero | > zero | — |
| TEST AND SET | left zero | left one | — | — |
| TEST BLOCK | usable | not usable | — | — |
| TEST CHANNEL | available | interruption pending | burst mode | not operational |
| TEST I/O | available | CSW stored | busy | not operational |
| TEST PROTECTION | fetch and store | no store | no fetch, no store | no translation |
| TEST UNDER MASK | all zeros | mixed | — | all ones |
| TRANSLATE AND TEST | zero | incomplete | complete | — |
| ZERO AND ADD | zero | < zero | > zero | overflow |
| Explanation: | | | | |
| — | Not applicable | | | |
| > zero | Result is greater than zero | | | |
| < zero | Result is less than zero | | | |
| =< 256 | Equal to, or less than, 256 | | | |
| high | First operand compares high | | | |
| low | First operand compares low | | | |
| length | Length of first operand | | | |
| Note: The condition code may also be changed by DIAGNOSE, EXECUTE, LOAD PSW, SET PROGRAM MASK, and SUPERVISOR CALL, and by an interruption. | | | | |

Summary of Condition-Code Settings (Part 2 of 2)

Commercial Instruction SetD-1
 Floating-Point FeatureD-1
 Universal Instruction SetD-2
 Extended-Precision Floating-Point FeatureD-2
 External-Signal FeatureD-2
 Direct-Control FeatureD-2
 Translation FeatureD-2
 CPU-Timer and Clock-Comparator FeatureD-2
 Conditional-Swapping FeatureD-2
 PSW-Key-Handling FeatureD-2
 Move-Inverse FeatureD-2
 Multiprocessing FeatureD-2
 Dual-Address-Space (DAS) FacilityD-3
 Service-Signal FeatureD-4
 Test-Block FeatureD-4
 Branch-and-Save FeatureD-4
 Extended FacilityD-4
 Recovery-Extension FeatureD-4
 Channel-Set-Switching FeatureD-4
 Fast-Release FeatureD-4
 Clear-I/O FeatureD-4
 Channel-Indirect-Data-Addressing FeatureD-4
 Command-Retry FeatureD-4
 Limited-Channel-Logout FeatureD-4
 I/O-Extended-Logout FeatureD-5
 Availability of FeaturesD-5
 Features Not Described in the Principles of OperationD-7

This appendix lists the facilities in System/370, shows how they are grouped, and indicates their availability as features on models implementing the System/370 architecture. A facility is an architectural grouping of functions.

COMMERCIAL INSTRUCTION SET

Every CPU incorporates the commercial instruction set (listed in Appendix B) and the associated basic computing functions, including:

- Byte-oriented operands
- General registers
- Basic-control (BC) mode
- Control registers, with bit positions for the block-multiplexing control bit (if block multiplexing is provided), for the interrupt-key and interval-timer masks, for channel masks associated with installed channels, for monitor masks, for control of installed machine-check-handling facil-

ities, and for the IOEL control (if an installed channel has the I/O-extended-logout facility)

- Key-controlled protection
- Interval timer
- TOD clock
- Basic operator facilities

Every system also includes the capability for at least one byte-multiplexer, block-multiplexer, or selector channel. The capability may be implemented as a separate physical unit or may be provided by sharing the physical unit with the CPU.

Additionally, the following features may be available:

FLOATING-POINT FEATURE

Includes the floating-point instructions (listed in Appendix B) and the floating-point registers.

UNIVERSAL INSTRUCTION SET

Includes the instructions of the commercial instruction set and the floating-point feature.

EXTENDED-PRECISION FLOATING-POINT FEATURE

Includes the extended-precision floating-point instructions (listed in Appendix B).

EXTERNAL-SIGNAL FEATURE

Includes the extension to external interruptions for external signals, the control-register position for the external-signal mask, and the means to accept external signals.

DIRECT-CONTROL FEATURE

Includes the external-signal feature and the instructions READ DIRECT and WRITE DIRECT.

TRANSLATION FEATURE

Includes the following facilities:

- Dynamic Address Translation (DAT). The DAT facility includes the translation mechanism, with the associated control-register positions and program-interruption codes, and reference and change recording. Includes controls for 4K-byte and 2K-byte page size and 64K-byte and 1M-byte segment size.
- Program-Event Recording (PER). The PER facility includes the associated control-register positions and extensions to the program-interruption code.
- Extended-Control (EC) Mode.
- SSM Suppression. This facility includes the control-register position for the SSM-suppression-control bit and the program-interruption code for special operation.
- Store Status and Noninitializing Manual Reset.

As part of these facilities, the following instructions are provided: LOAD REAL ADDRESS, PURGE TLB, RESET REFERENCE BIT, STORE THEN AND SYSTEM MASK, and STORE THEN OR SYSTEM MASK.

| On some models, no provision is made to
| include controls for the 1M-byte-segment
| size in dynamic address translation.
| Controls are provided for 4K-byte and
| 2K-byte page size and 64K-byte segment
| size.

CPU-TIMER AND CLOCK-COMPARATOR FEATURE

Includes the clock comparator, the CPU timer, the associated extensions to external interruption, control-register positions for the clock-comparator and CPU-timer masks, and the instructions SET CLOCK COMPARATOR, STORE CLOCK COMPARATOR, SET CPU TIMER, and STORE CPU TIMER.

CONDITIONAL-SWAPPING FEATURE

Includes the instructions COMPARE AND SWAP and COMPARE DOUBLE AND SWAP.

PSW-KEY-HANDLING FEATURE

Includes the instructions SET PSW KEY FROM ADDRESS and INSERT PSW KEY.

MOVE-INVERSE FEATURE

Includes the instruction MOVE INVERSE.

MULTIPROCESSING FEATURE

Includes the following facilities, which permit the formation of a multiprocessing system:

- Shared Main Storage
- Prefixing
- CPU Signaling and Response
- TOD-Clock Synchronization

These facilities include four extensions to the external interruption (external call, emergency signal, TOD-clock-sync check, and

malfunction alert), control-register positions for the TOD-clock-sync-control bit and for the masks for the four external-interruption conditions, and the instructions SET PREFIX, SIGNAL PROCESSOR, STORE CPU ADDRESS, and STORE PREFIX.

DUAL-ADDRESS-SPACE (DAS) FACILITY

The dual-address-space (DAS) facility includes the following:

1. Dual-space control, which includes:

- a. An address-space control, PSW bit 16.
- b. A primary ASN, bits 16-31 of control register 4.
- c. A secondary ASN, bits 16-31 of control register 3.
- d. A secondary-segment-table designation, in control register 7.

2. DAS authorization mechanisms, which include the following:

- a. An extraction-authority control, bit 4 of control register 0.
- b. A PSW-key mask, bits 0-15 of control register 3.
- c. A secondary-space control, bit 5 of control register 0.
- d. A subsystem-linkage control, bit 0 of control register 5.
- e. An ASN-translation control, bit 12 of control register 14.
- f. An authorization index, bits 0-15 of control register 4.
- g. A space-switch-event bit, bit 31 of control register 1.

3. PC-number translation, which uses the linkage-table designation in control register 5.

4. ASN translation, which uses an ASN-first-table origin, bits 13-31 of control register 14.

5. ASN authorization.

6. DAS tracing.

7. The following instructions:

EXTRACT PRIMARY ASN (EPAR)
EXTRACT SECONDARY ASN (ESAR)

INSERT ADDRESS SPACE CONTROL (IAC)
INSERT VIRTUAL STORAGE KEY (IVSK)
LOAD ADDRESS SPACE PARAMETERS (LASP)
MOVE TO PRIMARY (MVCP)
MOVE TO SECONDARY (MVCS)
MOVE WITH KEY (MVKC)
PROGRAM CALL (PC)
PROGRAM TRANSFER (PT)
SET ADDRESS SPACE CONTROL (SAC)
SET SECONDARY ASN (SSAR)

8. Nine new exception or event conditions which result in a program interruption. These conditions are:

AFX-translation exception
ASN-translation-specification exception
ASX-translation exception
EX-translation exception
LX-translation exception
PC-translation-specification exception
Primary-authority exception
Secondary-authority exception
Space-switch event

For page- and segment-translation exceptions, a bit is stored with the translation-exception address. This bit indicates whether the address was translated by using the primary or secondary segment-table designation.

The following System/370 instructions are changed or affected by the installation of DAS, as noted:

- Execution of the SET PSW KEY FROM ADDRESS instruction is permitted in the problem state, subject to the contents of bit positions 0-15 of control register 3. When the bit in the control register corresponding to the PSW-key value to be set is one, execution is allowed; otherwise, a privileged-operation exception is recognized. The contents of control register 3 are ignored in the supervisor state.
- Execution of the INSERT PSW KEY instruction is permitted in the problem state when bit 4 of control register 0, the extraction-authority control, is one. When the bit is zero and the problem state is specified, the operation is suppressed, and a privileged-operation exception is recognized. The extraction-authority control is ignored in the supervisor state.
- LOAD REAL ADDRESS uses the contents of control register 7, instead of the contents of control register 1, when PSW bit 16 is one. Thus the second operand is translated either as a primary virtual address or as a secondary virtual address, depending on the mode specified in the PSW.

| • The second-operand address of EXECUTE is defined to be an instruction address rather than a logical address. In secondary-space mode, it is thus unpredictable whether the target instruction is fetched from the primary space or the secondary space.

| SERVICE-SIGNAL FEATURE

| Provides an external interruption which is used by the service processor to signal model-dependent information to the control program.

| TEST-BLOCK FEATURE

| Includes the instruction TEST BLOCK for testing the usability of a 4K-byte block of main storage.

| BRANCH-AND-SAVE FEATURE

| Includes the instruction BRANCH AND SAVE (BAS and BASR).

EXTENDED FACILITY

Includes the instructions INVALIDATE PAGE TABLE ENTRY and TEST PROTECTION, the common-segment facility and the associated bit position in the segment-table entry, low-address protection and the associated control-register position for the control bit, and 12 MVS-dependent instructions.

RECOVERY-EXTENSION FEATURE

Includes the following:

- Machine-check external-damage code in storage at location 244, the external-damage-code-validity bit (bit 26 of the machine-check-interruption code), and the channel-not-operational indication in the machine-check external-damage code
- The CLEAR CHANNEL instruction
- The logout-valid bit (bit 15) and the interface-inoperative bit (bit 27) in the limited channel logout

CHANNEL-SET-SWITCHING FEATURE

| Provides the ability to connect a channel set to any CPU in a multiprocessing configuration. It includes the instructions CONNECT CHANNEL SET and DISCONNECT CHANNEL SET.

FAST-RELEASE FEATURE

Provides for fast release of the CPU by the channel during the execution of the START I/O FAST RELEASE instruction. The release occurs before the device-selection procedure is completed, reducing the CPU delay associated with the initiation of the I/O operation. When the fast release is not implemented, START I/O FAST RELEASE is executed as START I/O.

CLEAR-I/O FEATURE

Provides the clear-I/O function in a channel when the CLEAR I/O instruction is executed. When the clear-I/O function is not implemented, CLEAR I/O is executed as TEST I/O.

CHANNEL-INDIRECT-DATA-ADDRESSING FEATURE

Includes indirect-data-address words and the associated CCW flag, which facilitate storage addressing when virtual addresses are used.

COMMAND-RETRY FEATURE

Provides the capability in a channel to retry a command without the occurrence of an I/O interruption. The retry is initiated by the control unit.

LIMITED-CHANNEL-LOGOUT FEATURE

Provides four bytes of channel-status information for model-independent recovery from channel errors.

I/O-EXTENDED-LOGOUT FEATURE

Provides for the storing of detailed channel-error information in a storage area designed by a pointer.

AVAILABILITY OF FEATURES

| Feature | 115 | 125 | 135 | 135-3 | 138 | 145 | 145-3 | 148 | 155 | 158 | 158-3 |
|-----------------------------------|-----|-----|-----|-------|-----|-----|-------|-----|-----|-----|-------|
| Commercial instruction set | S | S | S | S | S | S | S | S | S | S | S |
| Floating point | FP | FXP | FP | S | S | FXP | S | S | S | S | S |
| Extended-precision floating point | FXP | FXP | XP | XP | S | FXP | S | S | XP | XP | XP |
| Direct control | ES | ES | DC | DC | DC | DC | DC | DC | DC | DC | DC |
| Translation | S | S | S | S | S | S | S | S | PQ | S | S |
| CPU timer and clock comparator | S | S | CK | S | S | CK | CK | S | PQ | S | S |
| Conditional swapping | S | S | SW | S | S | SW | S | S | PQ | S | S |
| PSW-key handling | - | - | - | S | S | APS | S | S | PQ | S | S |
| Move inverse | - | - | - | - | - | - | - | - | - | - | - |
| Multiprocessing | - | - | - | - | - | - | - | - | - | AMP | AMP |
| Extended facility | - | - | - | - | - | - | - | - | - | EF | EF |
| Recovery extensions | - | - | - | - | - | - | - | - | - | - | - |
| Dual address space | - | - | - | - | - | - | - | - | - | - | - |
| Test block | - | - | - | - | - | - | - | - | - | - | - |
| Branch and save | - | - | - | - | - | - | - | - | - | - | - |
| Service signal | - | - | - | - | - | - | - | - | - | - | - |
| Channel-set switching | - | - | - | - | - | - | - | - | - | - | - |
| Fast release | - | - | - | - | - | - | - | - | - | S | S |
| Clear I/O | - | - | - | - | - | APS | S | S | PQ | S | S |
| Channel indirect data addressing | S | S | S | S | S | S | S | S | PQ | S | S |
| Command retry | - | - | S | S | S | S | S | S | S | S | S |
| Limited channel logout | S | S | S | S | S | S | S | S | S | S | S |
| I/O extended logout | - | - | - | - | - | S | S | S | - | - | - |

Feature Availability (Part 1 of 2)

| Feature | 165 | 168 | 168-3 | 195 | 3031 | 3032 | 3033 | 3081 | 4331 | 4341 |
|-----------------------------------|-----|-----|-------|-----|------|------|------|------|------|------|
| | | | | | | | | | See | Note |
| Commercial instruction set | S* | S | S | S | S | S | S | S | S | S |
| Floating point | S | S | S | S | S | S | S | S | S | S |
| Extended-precision floating point | S | S | S | S | S | S | S | S | S | S |
| Direct control | S | S | S | S | DC | S | S | - | ES | ES |
| Translation | PQ | S | S | - | S | S | S | S# | S | S |
| CPU timer and clock comparator | PQ | S | S | - | S | S | S | S | S | S |
| Conditional swapping | PQ | S | S | - | S | S | S | S | S | S |
| PSW-key handling | PQ | S | S | - | S | S | S | S | S | S |
| Move inverse | - | - | - | - | - | - | - | - | S | S |
| Multiprocessing | - | MP | AMP | - | AP | - | AMP | S | - | - |
| Extended facility | - | EF | EF | - | S | S | S | S | - | - |
| Recovery extensions | - | - | - | - | S | S | S | S | - | - |
| Dual address space | - | - | - | - | - | - | 33X | S | - | - |
| Test block | - | - | - | - | - | - | - | S | - | - |
| Branch and save | - | - | - | - | - | - | - | S | - | - |
| Service signal | - | - | - | - | - | - | - | S | - | - |
| Channel-set switching | - | - | - | - | - | - | CSS | S | - | - |
| Fast release | B | B | B | B | S | S | S | S | - | - |
| Clear I/O | - | B | B | - | S | S | S | S | S | S |
| Channel indirect data addressing | A | A | A | - | S | S | S | S | S | S |
| Command retry | B | B | B | B | S | S | S | S | S | S |
| Limited channel logout | - | - | - | - | S | S | S | S | S | S |
| I/O extended logout | B | B | B | B | S | S | S | S | - | - |

Explanation:

- A Channel indirect data addressing is available as an option on the 2860, 2870, and 2880 channels.
- AMP Multiprocessing feature is provided in an attached-processor configuration and a multiprocessor configuration.
- AP Multiprocessing feature is provided in an attached-processor configuration.
- APS Advanced-control-program-support feature.
- B Feature is only available as a standard part of the 2880 channel.
- CK CPU-timer and clock-comparator feature.
- CSS Channel-set-switching feature is provided along with the multiprocessing feature.
- DC Direct-control feature.
- EF Extended facility.
- ES External-signal feature; does not include the READ DIRECT and WRITE DIRECT instructions.
- FP Floating-point feature.
- FXP Floating-point and extended-precision floating-point feature.
- MP Multiprocessing feature is provided in a multiprocessor configuration.
- PQ These items are available for field installation only on purchased models.
- S Facility is standard.
- S# The translation feature is standard, except that controls for the 1M-byte-segment size are not provided.
- SW Conditional-swapping feature.
- XP Extended-precision floating-point feature.
- Feature is not available.
- * The 165 includes MONITOR CALL only as part of the translation feature.
- 33X 3033 extension feature.

Note: The figure shows the features provided by the 4300 Processors operating in System/370 mode.

FEATURES NOT DESCRIBED IN THE PRINCIPLES OF OPERATION

The following additional features are available on some models. Included with each entry are references indicating where additional information can be found on the subject.

APL Assist

"An APL Emulator on System/370," A. Hassitt and L. E. Lyon, IBM Systems Journal, Volume 15, Number 4, 1976. Article available in reprint, G321-5041.

| ECPS:MVS (MVS-Dependent Instructions)

| Those MVS-dependent instructions that
| are part of the ECPS:MVS facility are
| described in Assists for MVS,
| GA22-7079.

ECPS:VM/370

IBM Virtual Machine Facility/370: System Programmer's Guide, GC20-1807

IBM Virtual Machine Facility/370: System Logic and Problem Determination Guide, Volume 1, Appendix A, SY20-0886

ECPS:VS1

IBM OS/VS1 Supervisor Logic, SY24-5155, and IBM OS/VS1 I/O Supervisor Logic, SY24-5156

| Extended Facility (MVS-Dependent Instructions)

| Those MVS-dependent instructions that
| are part of the extended facility are
| described in Assists for MVS,
| GA22-7079.

OS/DOS Compatibility

DOS to OS/VS Emulation: Logic, Prog. No. 5744-AS1, SY33-7015

Shadow-Table-Bypass Assist

IBM Virtual-Machine Assist and Shadow-Table-Bypass Assist, GA22-7074

Virtual-Machine Assist (VMA)

IBM Virtual-Machine Assist and Shadow-Table-Bypass Assist, GA22-7074

| 3033 Extension Feature (MVS-Dependent Instructions)

| Those MVS-dependent instructions that
| are part of the 3033 extension feature
| are described in Assists for MVS,
| GA22-7079.



| | |
|---|-----|
| 18,446,744,073,709,551,616 | 64 |
| 36,893,488,147,419,107,232 | 65 |
| 73,786,976,294,839,216,464 | 66 |
| 147,573,952,589,676,412,928 | 67 |
| 295,147,905,179,352,825,856 | 68 |
| 590,295,810,358,705,651,712 | 69 |
| 1,180,591,620,717,411,303,424 | 70 |
| 2,361,183,241,434,822,606,848 | 71 |
| 4,722,366,482,869,645,213,696 | 72 |
| 9,444,732,965,739,290,427,392 | 73 |
| 18,889,465,931,479,590,854,784 | 74 |
| 37,778,931,862,957,161,709,568 | 75 |
| 75,557,863,725,914,323,419,136 | 76 |
| 151,115,727,451,828,646,838,272 | 77 |
| 302,231,454,903,657,293,676,544 | 78 |
| 604,462,909,807,314,587,153,088 | 79 |
| 1,208,925,819,614,629,174,706,176 | 80 |
| 2,417,851,639,229,258,749,412,352 | 81 |
| 4,835,703,278,458,516,698,824,704 | 82 |
| 9,671,406,556,917,033,397,649,408 | 83 |
| 19,342,813,113,834,066,795,298,816 | 84 |
| 38,685,626,227,668,133,590,597,632 | 85 |
| 77,371,252,455,336,267,181,195,264 | 86 |
| 154,742,504,910,672,534,362,390,528 | 87 |
| 309,485,009,821,345,068,724,781,056 | 88 |
| 618,970,019,642,690,137,449,562,112 | 89 |
| 1,237,940,039,285,380,274,899,124,224 | 90 |
| 2,475,880,078,570,760,549,798,248,448 | 91 |
| 4,951,760,157,141,521,099,596,496,896 | 92 |
| 9,903,520,314,283,042,193,192,993,792 | 93 |
| 19,807,040,628,566,084,398,385,987,584 | 94 |
| 39,614,081,257,132,169,796,771,975,168 | 95 |
| 79,228,162,514,264,337,593,543,950,336 | 96 |
| 158,456,325,028,528,675,187,087,900,672 | 97 |
| 316,912,650,057,057,350,374,175,801,344 | 98 |
| 633,825,300,114,114,700,748,351,602,688 | 99 |
| 1,267,650,600,228,229,401,496,703,205,376 | 100 |
| 2,535,301,200,456,458,802,993,406,410,752 | 101 |
| 5,070,602,400,912,917,605,986,812,821,504 | 102 |
| 10,141,204,801,825,835,211,973,625,643,008 | 103 |
| 20,282,409,603,651,670,423,947,251,286,016 | 104 |
| 40,564,819,207,303,340,847,894,502,572,032 | 105 |
| 81,129,638,414,606,681,695,789,005,144,064 | 106 |
| 162,259,276,829,213,363,391,578,010,288,128 | 107 |
| 324,518,553,658,426,726,783,156,020,576,256 | 108 |
| 649,037,107,316,853,453,566,312,041,152,512 | 109 |
| 1,298,074,214,633,706,907,132,624,082,305,024 | 110 |
| 2,596,148,429,267,413,814,265,248,164,610,048 | 111 |
| 5,192,296,858,534,827,628,530,496,329,220,096 | 112 |
| 10,384,593,717,069,655,257,060,992,658,440,192 | 113 |
| 20,769,187,434,139,310,514,121,985,316,880,384 | 114 |
| 41,538,374,868,278,621,028,243,970,633,760,768 | 115 |
| 83,076,749,736,557,247,056,487,941,267,521,536 | 116 |
| 166,153,499,473,114,484,112,975,882,535,043,072 | 117 |
| 332,306,998,946,228,969,225,951,765,070,386,144 | 118 |
| 664,613,997,892,457,936,451,903,530,140,172,288 | 119 |
| 1,329,227,995,784,915,872,903,807,060,280,344,576 | 120 |
| 2,658,455,991,569,831,745,907,614,120,560,689,152 | 121 |
| 5,316,911,983,139,663,491,615,228,241,121,378,304 | 122 |
| 10,633,823,966,279,326,983,230,456,482,242,756,608 | 123 |
| 21,267,647,932,558,653,966,460,312,964,485,513,216 | 124 |
| 42,535,295,965,117,307,932,521,825,928,971,026,432 | 125 |
| 85,070,591,730,234,615,865,843,651,857,942,052,864 | 126 |
| 170,141,183,460,469,231,731,687,303,715,884,105,728 | 127 |
| 340,282,366,920,938,463,463,374,607,431,768,211,456 | 128 |

Powers of 2 (Part 2 of 2)

The following tables aid in converting hexadecimal values to decimal values, or the reverse.

Direct Conversion Table

This table provides direct conversion of decimal and hexadecimal numbers in these ranges:

| | |
|-------------|--------------|
| Hexadecimal | Decimal |
| 000 to FFF | 0000 to 4095 |

To convert numbers outside these ranges, and to convert fractions, use the hexadecimal and decimal conversion tables that follow the direct conversion table in this Appendix.

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 00_ | 0000 | 0001 | 0002 | 0003 | 0004 | 0005 | 0006 | 0007 | 0008 | 0009 | 0010 | 0011 | 0012 | 0013 | 0014 | 0015 |
| 01_ | 0016 | 0017 | 0018 | 0019 | 0020 | 0021 | 0022 | 0023 | 0024 | 0025 | 0026 | 0027 | 0028 | 0029 | 0030 | 0031 |
| 02_ | 0032 | 0033 | 0034 | 0035 | 0036 | 0037 | 0038 | 0039 | 0040 | 0041 | 0042 | 0043 | 0044 | 0045 | 0046 | 0047 |
| 03_ | 0048 | 0049 | 0050 | 0051 | 0052 | 0053 | 0054 | 0055 | 0056 | 0057 | 0058 | 0059 | 0060 | 0061 | 0062 | 0063 |
| 04_ | 0064 | 0065 | 0066 | 0067 | 0068 | 0069 | 0070 | 0071 | 0072 | 0073 | 0074 | 0075 | 0076 | 0077 | 0078 | 0079 |
| 05_ | 0080 | 0081 | 0082 | 0083 | 0084 | 0085 | 0086 | 0087 | 0088 | 0089 | 0090 | 0091 | 0092 | 0093 | 0094 | 0095 |
| 06_ | 0096 | 0097 | 0098 | 0099 | 0100 | 0101 | 0102 | 0103 | 0104 | 0105 | 0106 | 0107 | 0108 | 0109 | 0110 | 0111 |
| 07_ | 0112 | 0113 | 0114 | 0115 | 0116 | 0117 | 0118 | 0119 | 0120 | 0121 | 0122 | 0123 | 0124 | 0125 | 0126 | 0127 |
| 08_ | 0128 | 0129 | 0130 | 0131 | 0132 | 0133 | 0134 | 0135 | 0136 | 0137 | 0138 | 0139 | 0140 | 0141 | 0142 | 0143 |
| 09_ | 0144 | 0145 | 0146 | 0147 | 0148 | 0149 | 0150 | 0151 | 0152 | 0153 | 0154 | 0155 | 0156 | 0157 | 0158 | 0159 |
| 0A_ | 0160 | 0161 | 0162 | 0163 | 0164 | 0165 | 0166 | 0167 | 0168 | 0169 | 0170 | 0171 | 0172 | 0173 | 0174 | 0175 |
| 0B_ | 0176 | 0177 | 0178 | 0179 | 0180 | 0181 | 0182 | 0183 | 0184 | 0185 | 0186 | 0187 | 0188 | 0189 | 0190 | 0191 |
| 0C_ | 0192 | 0193 | 0194 | 0195 | 0196 | 0197 | 0198 | 0199 | 0200 | 0201 | 0202 | 0203 | 0204 | 0205 | 0206 | 0207 |
| 0D_ | 0208 | 0209 | 0210 | 0211 | 0212 | 0213 | 0214 | 0215 | 0216 | 0217 | 0218 | 0219 | 0220 | 0221 | 0222 | 0223 |
| 0E_ | 0224 | 0225 | 0226 | 0227 | 0228 | 0229 | 0230 | 0231 | 0232 | 0233 | 0234 | 0235 | 0236 | 0237 | 0238 | 0239 |
| 0F_ | 0240 | 0241 | 0242 | 0243 | 0244 | 0245 | 0246 | 0247 | 0248 | 0249 | 0250 | 0251 | 0252 | 0253 | 0254 | 0255 |
| 10_ | 0256 | 0257 | 0258 | 0259 | 0260 | 0261 | 0262 | 0263 | 0264 | 0265 | 0266 | 0267 | 0268 | 0269 | 0270 | 0271 |
| 11_ | 0272 | 0273 | 0274 | 0275 | 0276 | 0277 | 0278 | 0279 | 0280 | 0281 | 0282 | 0283 | 0284 | 0285 | 0286 | 0287 |
| 12_ | 0288 | 0289 | 0290 | 0291 | 0292 | 0293 | 0294 | 0295 | 0296 | 0297 | 0298 | 0299 | 0300 | 0301 | 0302 | 0303 |
| 13_ | 0304 | 0305 | 0306 | 0307 | 0308 | 0309 | 0310 | 0311 | 0312 | 0313 | 0314 | 0315 | 0316 | 0317 | 0318 | 0319 |
| 14_ | 0320 | 0321 | 0322 | 0323 | 0324 | 0325 | 0326 | 0327 | 0328 | 0329 | 0330 | 0331 | 0332 | 0333 | 0334 | 0335 |
| 15_ | 0336 | 0337 | 0338 | 0339 | 0340 | 0341 | 0342 | 0343 | 0344 | 0345 | 0346 | 0347 | 0348 | 0349 | 0350 | 0351 |
| 16_ | 0352 | 0353 | 0354 | 0355 | 0356 | 0357 | 0358 | 0359 | 0360 | 0361 | 0362 | 0363 | 0364 | 0365 | 0366 | 0367 |
| 17_ | 0368 | 0369 | 0370 | 0371 | 0372 | 0373 | 0374 | 0375 | 0376 | 0377 | 0378 | 0379 | 0380 | 0381 | 0382 | 0383 |
| 18_ | 0384 | 0385 | 0386 | 0387 | 0388 | 0389 | 0390 | 0391 | 0392 | 0393 | 0394 | 0395 | 0396 | 0397 | 0398 | 0399 |
| 19_ | 0400 | 0401 | 0402 | 0403 | 0404 | 0405 | 0406 | 0407 | 0408 | 0409 | 0410 | 0411 | 0412 | 0413 | 0414 | 0415 |
| 1A_ | 0416 | 0417 | 0418 | 0419 | 0420 | 0421 | 0422 | 0423 | 0424 | 0425 | 0426 | 0427 | 0428 | 0429 | 0430 | 0431 |
| 1B_ | 0432 | 0433 | 0434 | 0435 | 0436 | 0437 | 0438 | 0439 | 0440 | 0441 | 0442 | 0443 | 0444 | 0445 | 0446 | 0447 |
| 1C_ | 0448 | 0449 | 0450 | 0451 | 0452 | 0453 | 0454 | 0455 | 0456 | 0457 | 0458 | 0459 | 0460 | 0461 | 0462 | 0463 |
| 1D_ | 0464 | 0465 | 0466 | 0467 | 0468 | 0469 | 0470 | 0471 | 0472 | 0473 | 0474 | 0475 | 0476 | 0477 | 0478 | 0479 |
| 1E_ | 0480 | 0481 | 0482 | 0483 | 0484 | 0485 | 0486 | 0487 | 0488 | 0489 | 0490 | 0491 | 0492 | 0493 | 0494 | 0495 |
| 1F_ | 0496 | 0497 | 0498 | 0499 | 0500 | 0501 | 0502 | 0503 | 0504 | 0505 | 0506 | 0507 | 0508 | 0509 | 0510 | 0511 |

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 20_ | 0512 | 0513 | 0514 | 0515 | 0516 | 0517 | 0518 | 0519 | 0520 | 0521 | 0522 | 0523 | 0524 | 0525 | 0526 | 0527 |
| 21_ | 0528 | 0529 | 0530 | 0531 | 0532 | 0533 | 0534 | 0535 | 0536 | 0537 | 0538 | 0539 | 0540 | 0541 | 0542 | 0543 |
| 22_ | 0544 | 0545 | 0546 | 0547 | 0548 | 0549 | 0550 | 0551 | 0552 | 0553 | 0554 | 0555 | 0556 | 0557 | 0558 | 0559 |
| 23_ | 0560 | 0561 | 0562 | 0563 | 0564 | 0565 | 0566 | 0567 | 0568 | 0569 | 0570 | 0571 | 0572 | 0573 | 0574 | 0575 |
| 24_ | 0576 | 0577 | 0578 | 0579 | 0580 | 0581 | 0582 | 0583 | 0584 | 0585 | 0586 | 0587 | 0588 | 0589 | 0590 | 0591 |
| 25_ | 0592 | 0593 | 0594 | 0595 | 0596 | 0597 | 0598 | 0599 | 0600 | 0601 | 0602 | 0603 | 0604 | 0605 | 0606 | 0607 |
| 26_ | 0608 | 0609 | 0610 | 0611 | 0612 | 0613 | 0614 | 0615 | 0616 | 0617 | 0618 | 0619 | 0620 | 0621 | 0622 | 0623 |
| 27_ | 0624 | 0625 | 0626 | 0627 | 0628 | 0629 | 0630 | 0631 | 0632 | 0633 | 0634 | 0635 | 0636 | 0637 | 0638 | 0639 |
| 28_ | 0640 | 0641 | 0642 | 0643 | 0644 | 0645 | 0646 | 0647 | 0648 | 0649 | 0650 | 0651 | 0652 | 0653 | 0654 | 0655 |
| 29_ | 0656 | 0657 | 0658 | 0659 | 0660 | 0661 | 0662 | 0663 | 0664 | 0665 | 0666 | 0667 | 0668 | 0669 | 0670 | 0671 |
| 2A_ | 0672 | 0673 | 0674 | 0675 | 0676 | 0677 | 0678 | 0679 | 0680 | 0681 | 0682 | 0683 | 0684 | 0685 | 0686 | 0687 |
| 2B_ | 0688 | 0689 | 0690 | 0691 | 0692 | 0693 | 0694 | 0695 | 0696 | 0697 | 0698 | 0699 | 0700 | 0701 | 0702 | 0703 |
| 2C_ | 0704 | 0705 | 0706 | 0707 | 0708 | 0709 | 0710 | 0711 | 0712 | 0713 | 0714 | 0715 | 0716 | 0717 | 0718 | 0719 |
| 2D_ | 0720 | 0721 | 0722 | 0723 | 0724 | 0725 | 0726 | 0727 | 0728 | 0729 | 0730 | 0731 | 0732 | 0733 | 0734 | 0735 |
| 2E_ | 0736 | 0737 | 0738 | 0739 | 0740 | 0741 | 0742 | 0743 | 0744 | 0745 | 0746 | 0747 | 0748 | 0749 | 0750 | 0751 |
| 2F_ | 0752 | 0753 | 0754 | 0755 | 0756 | 0757 | 0758 | 0759 | 0760 | 0761 | 0762 | 0763 | 0764 | 0765 | 0766 | 0767 |
| 30_ | 0768 | 0769 | 0770 | 0771 | 0772 | 0773 | 0774 | 0775 | 0776 | 0777 | 0778 | 0779 | 0780 | 0781 | 0782 | 0783 |
| 31_ | 0784 | 0785 | 0786 | 0787 | 0788 | 0789 | 0790 | 0791 | 0792 | 0793 | 0794 | 0795 | 0796 | 0797 | 0798 | 0799 |
| 32_ | 0800 | 0801 | 0802 | 0803 | 0804 | 0805 | 0806 | 0807 | 0808 | 0809 | 0810 | 0811 | 0812 | 0813 | 0814 | 0815 |
| 33_ | 0816 | 0817 | 0818 | 0819 | 0820 | 0821 | 0822 | 0823 | 0824 | 0825 | 0826 | 0827 | 0828 | 0829 | 0830 | 0831 |
| 34_ | 0832 | 0833 | 0834 | 0835 | 0836 | 0837 | 0838 | 0839 | 0840 | 0841 | 0842 | 0843 | 0844 | 0845 | 0846 | 0847 |
| 35_ | 0848 | 0849 | 0850 | 0851 | 0852 | 0853 | 0854 | 0855 | 0856 | 0857 | 0858 | 0859 | 0860 | 0861 | 0862 | 0863 |
| 36_ | 0864 | 0865 | 0866 | 0867 | 0868 | 0869 | 0870 | 0871 | 0872 | 0873 | 0874 | 0875 | 0876 | 0877 | 0878 | 0879 |
| 37_ | 0880 | 0881 | 0882 | 0883 | 0884 | 0885 | 0886 | 0887 | 0888 | 0889 | 0890 | 0891 | 0892 | 0893 | 0894 | 0895 |
| 38_ | 0896 | 0897 | 0898 | 0899 | 0900 | 0901 | 0902 | 0903 | 0904 | 0905 | 0906 | 0907 | 0908 | 0909 | 0910 | 0911 |
| 39_ | 0912 | 0913 | 0914 | 0915 | 0916 | 0917 | 0918 | 0919 | 0920 | 0921 | 0922 | 0923 | 0924 | 0925 | 0926 | 0927 |
| 3A_ | 0928 | 0929 | 0930 | 0931 | 0932 | 0933 | 0934 | 0935 | 0936 | 0937 | 0938 | 0939 | 0940 | 0941 | 0942 | 0943 |
| 3B_ | 0944 | 0945 | 0946 | 0947 | 0948 | 0949 | 0950 | 0951 | 0952 | 0953 | 0954 | 0955 | 0956 | 0957 | 0958 | 0959 |
| 3C_ | 0960 | 0961 | 0962 | 0963 | 0964 | 0965 | 0966 | 0967 | 0968 | 0969 | 0970 | 0971 | 0972 | 0973 | 0974 | 0975 |
| 3D_ | 0976 | 0977 | 0978 | 0979 | 0980 | 0981 | 0982 | 0983 | 0984 | 0985 | 0986 | 0987 | 0988 | 0989 | 0990 | 0991 |
| 3E_ | 0992 | 0993 | 0994 | 0995 | 0996 | 0997 | 0998 | 0999 | 1000 | 1001 | 1002 | 1003 | 1004 | 1005 | 1006 | 1007 |
| 3F_ | 1008 | 1009 | 1010 | 1011 | 1012 | 1013 | 1014 | 1015 | 1016 | 1017 | 1018 | 1019 | 1020 | 1021 | 1022 | 1023 |

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 40_ | 1024 | 1025 | 1026 | 1027 | 1028 | 1029 | 1030 | 1031 | 1032 | 1033 | 1034 | 1035 | 1036 | 1037 | 1038 | 1039 |
| 41_ | 1040 | 1041 | 1042 | 1043 | 1044 | 1045 | 1046 | 1047 | 1048 | 1049 | 1050 | 1051 | 1052 | 1053 | 1054 | 1055 |
| 42_ | 1056 | 1057 | 1058 | 1059 | 1060 | 1061 | 1062 | 1063 | 1064 | 1065 | 1066 | 1067 | 1068 | 1069 | 1070 | 1071 |
| 43_ | 1072 | 1073 | 1074 | 1075 | 1076 | 1077 | 1078 | 1079 | 1080 | 1081 | 1082 | 1083 | 1084 | 1085 | 1086 | 1087 |
| 44_ | 1088 | 1089 | 1090 | 1091 | 1092 | 1093 | 1094 | 1095 | 1096 | 1097 | 1098 | 1099 | 1100 | 1101 | 1102 | 1103 |
| 45_ | 1104 | 1105 | 1106 | 1107 | 1108 | 1109 | 1110 | 1111 | 1112 | 1113 | 1114 | 1115 | 1116 | 1117 | 1118 | 1119 |
| 46_ | 1120 | 1121 | 1122 | 1123 | 1124 | 1125 | 1126 | 1127 | 1128 | 1129 | 1130 | 1131 | 1132 | 1133 | 1134 | 1135 |
| 47_ | 1136 | 1137 | 1138 | 1139 | 1140 | 1141 | 1142 | 1143 | 1144 | 1145 | 1146 | 1147 | 1148 | 1149 | 1150 | 1151 |
| 48_ | 1152 | 1153 | 1154 | 1155 | 1156 | 1157 | 1158 | 1159 | 1160 | 1161 | 1162 | 1163 | 1164 | 1165 | 1166 | 1167 |
| 49_ | 1168 | 1169 | 1170 | 1171 | 1172 | 1173 | 1174 | 1175 | 1176 | 1177 | 1178 | 1179 | 1180 | 1181 | 1182 | 1183 |
| 4A_ | 1184 | 1185 | 1186 | 1187 | 1188 | 1189 | 1190 | 1191 | 1192 | 1193 | 1194 | 1195 | 1196 | 1197 | 1198 | 1199 |
| 4B_ | 1200 | 1201 | 1202 | 1203 | 1204 | 1205 | 1206 | 1207 | 1208 | 1209 | 1210 | 1211 | 1212 | 1213 | 1214 | 1215 |
| 4C_ | 1216 | 1217 | 1218 | 1219 | 1220 | 1221 | 1222 | 1223 | 1224 | 1225 | 1226 | 1227 | 1228 | 1229 | 1230 | 1231 |
| 4D_ | 1232 | 1233 | 1234 | 1235 | 1236 | 1237 | 1238 | 1239 | 1240 | 1241 | 1242 | 1243 | 1244 | 1245 | 1246 | 1247 |
| 4E_ | 1248 | 1249 | 1250 | 1251 | 1252 | 1253 | 1254 | 1255 | 1256 | 1257 | 1258 | 1259 | 1260 | 1261 | 1262 | 1263 |
| 4F_ | 1264 | 1265 | 1266 | 1267 | 1268 | 1269 | 1270 | 1271 | 1272 | 1273 | 1274 | 1275 | 1276 | 1277 | 1278 | 1279 |
| 50_ | 1280 | 1281 | 1282 | 1283 | 1284 | 1285 | 1286 | 1287 | 1288 | 1289 | 1290 | 1291 | 1292 | 1293 | 1294 | 1295 |
| 51_ | 1296 | 1297 | 1298 | 1299 | 1300 | 1301 | 1302 | 1303 | 1304 | 1305 | 1306 | 1307 | 1308 | 1309 | 1310 | 1311 |
| 52_ | 1312 | 1313 | 1314 | 1315 | 1316 | 1317 | 1318 | 1319 | 1320 | 1321 | 1322 | 1323 | 1324 | 1325 | 1326 | 1327 |
| 53_ | 1328 | 1329 | 1330 | 1331 | 1332 | 1333 | 1334 | 1335 | 1336 | 1337 | 1338 | 1339 | 1340 | 1341 | 1342 | 1343 |
| 54_ | 1344 | 1345 | 1346 | 1347 | 1348 | 1349 | 1350 | 1351 | 1352 | 1353 | 1354 | 1355 | 1356 | 1357 | 1358 | 1359 |
| 55_ | 1360 | 1361 | 1362 | 1363 | 1364 | 1365 | 1366 | 1367 | 1368 | 1369 | 1370 | 1371 | 1372 | 1373 | 1374 | 1375 |
| 56_ | 1376 | 1377 | 1378 | 1379 | 1380 | 1381 | 1382 | 1383 | 1384 | 1385 | 1386 | 1387 | 1388 | 1389 | 1390 | 1391 |
| 57_ | 1392 | 1393 | 1394 | 1395 | 1396 | 1397 | 1398 | 1399 | 1400 | 1401 | 1402 | 1403 | 1404 | 1405 | 1406 | 1407 |
| 58_ | 1408 | 1409 | 1410 | 1411 | 1412 | 1413 | 1414 | 1415 | 1416 | 1417 | 1418 | 1419 | 1420 | 1421 | 1422 | 1423 |
| 59_ | 1424 | 1425 | 1426 | 1427 | 1428 | 1429 | 1430 | 1431 | 1432 | 1433 | 1434 | 1435 | 1436 | 1437 | 1438 | 1439 |
| 5A_ | 1440 | 1441 | 1442 | 1443 | 1444 | 1445 | 1446 | 1447 | 1448 | 1449 | 1450 | 1451 | 1452 | 1453 | 1454 | 1455 |
| 5B_ | 1456 | 1457 | 1458 | 1459 | 1460 | 1461 | 1462 | 1463 | 1464 | 1465 | 1466 | 1467 | 1468 | 1469 | 1470 | 1471 |
| 5C_ | 1472 | 1473 | 1474 | 1475 | 1476 | 1477 | 1478 | 1479 | 1480 | 1481 | 1482 | 1483 | 1484 | 1485 | 1486 | 1487 |
| 5D_ | 1488 | 1489 | 1490 | 1491 | 1492 | 1493 | 1494 | 1495 | 1496 | 1497 | 1498 | 1499 | 1500 | 1501 | 1502 | 1503 |
| 5E_ | 1504 | 1505 | 1506 | 1507 | 1508 | 1509 | 1510 | 1511 | 1512 | 1513 | 1514 | 1515 | 1516 | 1517 | 1518 | 1519 |
| 5F_ | 1520 | 1521 | 1522 | 1523 | 1524 | 1525 | 1526 | 1527 | 1528 | 1529 | 1530 | 1531 | 1532 | 1533 | 1534 | 1535 |

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 60_ | 1536 | 1537 | 1538 | 1539 | 1540 | 1541 | 1542 | 1543 | 1544 | 1545 | 1546 | 1547 | 1548 | 1549 | 1550 | 1551 |
| 61_ | 1552 | 1553 | 1554 | 1555 | 1556 | 1557 | 1558 | 1559 | 1560 | 1561 | 1562 | 1563 | 1564 | 1565 | 1566 | 1567 |
| 62_ | 1568 | 1569 | 1570 | 1571 | 1572 | 1573 | 1574 | 1575 | 1576 | 1577 | 1578 | 1579 | 1580 | 1581 | 1582 | 1583 |
| 63_ | 1584 | 1585 | 1586 | 1587 | 1588 | 1589 | 1590 | 1591 | 1592 | 1593 | 1594 | 1595 | 1596 | 1597 | 1598 | 1599 |
| 64_ | 1600 | 1601 | 1602 | 1603 | 1604 | 1605 | 1606 | 1607 | 1608 | 1609 | 1610 | 1611 | 1612 | 1613 | 1614 | 1615 |
| 65_ | 1616 | 1617 | 1618 | 1619 | 1620 | 1621 | 1622 | 1623 | 1624 | 1625 | 1626 | 1627 | 1628 | 1629 | 1630 | 1631 |
| 66_ | 1632 | 1633 | 1634 | 1635 | 1636 | 1637 | 1638 | 1639 | 1640 | 1641 | 1642 | 1643 | 1644 | 1645 | 1646 | 1647 |
| 67_ | 1648 | 1649 | 1650 | 1651 | 1652 | 1653 | 1654 | 1655 | 1656 | 1657 | 1658 | 1659 | 1660 | 1661 | 1662 | 1663 |
| 68_ | 1664 | 1665 | 1666 | 1667 | 1668 | 1669 | 1670 | 1671 | 1672 | 1673 | 1674 | 1675 | 1676 | 1677 | 1678 | 1679 |
| 69_ | 1680 | 1681 | 1682 | 1683 | 1684 | 1685 | 1686 | 1687 | 1688 | 1689 | 1690 | 1691 | 1692 | 1693 | 1694 | 1695 |
| 6A_ | 1696 | 1697 | 1698 | 1699 | 1700 | 1701 | 1702 | 1703 | 1704 | 1705 | 1706 | 1707 | 1708 | 1709 | 1710 | 1711 |
| 6B_ | 1712 | 1713 | 1714 | 1715 | 1716 | 1717 | 1718 | 1719 | 1720 | 1721 | 1722 | 1723 | 1724 | 1725 | 1726 | 1727 |
| 6C_ | 1728 | 1729 | 1730 | 1731 | 1732 | 1733 | 1734 | 1735 | 1736 | 1737 | 1738 | 1739 | 1740 | 1741 | 1742 | 1743 |
| 6D_ | 1744 | 1745 | 1746 | 1747 | 1748 | 1749 | 1750 | 1751 | 1752 | 1753 | 1754 | 1755 | 1756 | 1757 | 1758 | 1759 |
| 6E_ | 1760 | 1761 | 1762 | 1763 | 1764 | 1765 | 1766 | 1767 | 1768 | 1769 | 1770 | 1771 | 1772 | 1773 | 1774 | 1775 |
| 6F_ | 1776 | 1777 | 1778 | 1779 | 1780 | 1781 | 1782 | 1783 | 1784 | 1785 | 1786 | 1787 | 1788 | 1789 | 1790 | 1791 |
| 70_ | 1792 | 1793 | 1794 | 1795 | 1796 | 1797 | 1798 | 1799 | 1800 | 1801 | 1802 | 1803 | 1804 | 1805 | 1806 | 1807 |
| 71_ | 1808 | 1809 | 1810 | 1811 | 1812 | 1813 | 1814 | 1815 | 1816 | 1817 | 1818 | 1819 | 1820 | 1821 | 1822 | 1823 |
| 72_ | 1824 | 1825 | 1826 | 1827 | 1828 | 1829 | 1830 | 1831 | 1832 | 1833 | 1834 | 1835 | 1836 | 1837 | 1838 | 1839 |
| 73_ | 1840 | 1841 | 1842 | 1843 | 1844 | 1845 | 1846 | 1847 | 1848 | 1849 | 1850 | 1851 | 1852 | 1853 | 1854 | 1855 |
| 74_ | 1856 | 1857 | 1858 | 1859 | 1860 | 1861 | 1862 | 1863 | 1864 | 1865 | 1866 | 1867 | 1868 | 1869 | 1870 | 1871 |
| 75_ | 1872 | 1873 | 1874 | 1875 | 1876 | 1877 | 1878 | 1879 | 1880 | 1881 | 1882 | 1883 | 1884 | 1885 | 1886 | 1887 |
| 76_ | 1888 | 1889 | 1890 | 1891 | 1892 | 1893 | 1894 | 1895 | 1896 | 1897 | 1898 | 1899 | 1900 | 1901 | 1902 | 1903 |
| 77_ | 1904 | 1905 | 1906 | 1907 | 1908 | 1909 | 1910 | 1911 | 1912 | 1913 | 1914 | 1915 | 1916 | 1917 | 1918 | 1919 |
| 78_ | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | 1930 | 1931 | 1932 | 1933 | 1934 | 1935 |
| 79_ | 1936 | 1937 | 1938 | 1939 | 1940 | 1941 | 1942 | 1943 | 1944 | 1945 | 1946 | 1947 | 1948 | 1949 | 1950 | 1951 |
| 7A_ | 1952 | 1953 | 1954 | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 |
| 7B_ | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 |
| 7C_ | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
| 7D_ | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
| 7E_ | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 |
| 7F_ | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 |

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 80_ | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 | 2055 | 2056 | 2057 | 2058 | 2059 | 2060 | 2061 | 2062 | 2063 |
| 81_ | 2064 | 2065 | 2066 | 2067 | 2068 | 2069 | 2070 | 2071 | 2072 | 2073 | 2074 | 2075 | 2076 | 2077 | 2078 | 2079 |
| 82_ | 2080 | 2081 | 2082 | 2083 | 2084 | 2085 | 2086 | 2087 | 2088 | 2089 | 2090 | 2091 | 2092 | 2093 | 2094 | 2095 |
| 83_ | 2096 | 2097 | 2098 | 2099 | 2100 | 2101 | 2102 | 2103 | 2104 | 2105 | 2106 | 2107 | 2108 | 2109 | 2110 | 2111 |
| 84_ | 2112 | 2113 | 2114 | 2115 | 2116 | 2117 | 2118 | 2119 | 2120 | 2121 | 2122 | 2123 | 2124 | 2125 | 2126 | 2127 |
| 85_ | 2128 | 2129 | 2130 | 2131 | 2132 | 2133 | 2134 | 2135 | 2136 | 2137 | 2138 | 2139 | 2140 | 2141 | 2142 | 2143 |
| 86_ | 2144 | 2145 | 2146 | 2147 | 2148 | 2149 | 2150 | 2151 | 2152 | 2153 | 2154 | 2155 | 2156 | 2157 | 2158 | 2159 |
| 87_ | 2160 | 2161 | 2162 | 2163 | 2164 | 2165 | 2166 | 2167 | 2168 | 2169 | 2170 | 2171 | 2172 | 2173 | 2174 | 2175 |
| 88_ | 2176 | 2177 | 2178 | 2179 | 2180 | 2181 | 2182 | 2183 | 2184 | 2185 | 2186 | 2187 | 2188 | 2189 | 2190 | 2191 |
| 89_ | 2192 | 2193 | 2194 | 2195 | 2196 | 2197 | 2198 | 2199 | 2200 | 2201 | 2202 | 2203 | 2204 | 2205 | 2206 | 2207 |
| 8A_ | 2208 | 2209 | 2210 | 2211 | 2212 | 2213 | 2214 | 2215 | 2216 | 2217 | 2218 | 2219 | 2220 | 2221 | 2222 | 2223 |
| 8B_ | 2224 | 2225 | 2226 | 2227 | 2228 | 2229 | 2230 | 2231 | 2232 | 2233 | 2234 | 2235 | 2236 | 2237 | 2238 | 2239 |
| 8C_ | 2240 | 2241 | 2242 | 2243 | 2244 | 2245 | 2246 | 2247 | 2248 | 2249 | 2250 | 2251 | 2252 | 2253 | 2254 | 2255 |
| 8D_ | 2256 | 2257 | 2258 | 2259 | 2260 | 2261 | 2262 | 2263 | 2264 | 2265 | 2266 | 2267 | 2268 | 2269 | 2270 | 2271 |
| 8E_ | 2272 | 2273 | 2274 | 2275 | 2276 | 2277 | 2278 | 2279 | 2280 | 2281 | 2282 | 2283 | 2284 | 2285 | 2286 | 2287 |
| 8F_ | 2288 | 2289 | 2290 | 2291 | 2292 | 2293 | 2294 | 2295 | 2296 | 2297 | 2298 | 2299 | 2300 | 2301 | 2302 | 2303 |
| 90_ | 2304 | 2305 | 2306 | 2307 | 2308 | 2309 | 2310 | 2311 | 2312 | 2313 | 2314 | 2315 | 2316 | 2317 | 2318 | 2319 |
| 91_ | 2320 | 2321 | 2322 | 2323 | 2324 | 2325 | 2326 | 2327 | 2328 | 2329 | 2330 | 2331 | 2332 | 2333 | 2334 | 2335 |
| 92_ | 2336 | 2337 | 2338 | 2339 | 2340 | 2341 | 2342 | 2343 | 2344 | 2345 | 2346 | 2347 | 2348 | 2349 | 2350 | 2351 |
| 93_ | 2352 | 2353 | 2354 | 2355 | 2356 | 2357 | 2358 | 2359 | 2360 | 2361 | 2362 | 2363 | 2364 | 2365 | 2366 | 2367 |
| 94_ | 2368 | 2369 | 2370 | 2371 | 2372 | 2373 | 2374 | 2375 | 2376 | 2377 | 2378 | 2379 | 2380 | 2381 | 2382 | 2383 |
| 95_ | 2384 | 2385 | 2386 | 2387 | 2388 | 2389 | 2390 | 2391 | 2392 | 2393 | 2394 | 2395 | 2396 | 2397 | 2398 | 2399 |
| 96_ | 2400 | 2401 | 2402 | 2403 | 2404 | 2405 | 2406 | 2407 | 2408 | 2409 | 2410 | 2411 | 2412 | 2413 | 2414 | 2415 |
| 97_ | 2416 | 2417 | 2418 | 2419 | 2420 | 2421 | 2422 | 2423 | 2424 | 2425 | 2426 | 2427 | 2428 | 2429 | 2430 | 2431 |
| 98_ | 2432 | 2433 | 2434 | 2435 | 2436 | 2437 | 2438 | 2439 | 2440 | 2441 | 2442 | 2443 | 2444 | 2445 | 2446 | 2447 |
| 99_ | 2448 | 2449 | 2450 | 2451 | 2452 | 2453 | 2454 | 2455 | 2456 | 2457 | 2458 | 2459 | 2460 | 2461 | 2462 | 2463 |
| 9A_ | 2464 | 2465 | 2466 | 2467 | 2468 | 2469 | 2470 | 2471 | 2472 | 2473 | 2474 | 2475 | 2476 | 2477 | 2478 | 2479 |
| 9B_ | 2480 | 2481 | 2482 | 2483 | 2484 | 2485 | 2486 | 2487 | 2488 | 2489 | 2490 | 2491 | 2492 | 2493 | 2494 | 2495 |
| 9C_ | 2496 | 2497 | 2498 | 2499 | 2500 | 2501 | 2502 | 2503 | 2504 | 2505 | 2506 | 2507 | 2508 | 2509 | 2510 | 2511 |
| 9D_ | 2512 | 2513 | 2514 | 2515 | 2516 | 2517 | 2518 | 2519 | 2520 | 2521 | 2522 | 2523 | 2524 | 2525 | 2526 | 2527 |
| 9E_ | 2528 | 2529 | 2530 | 2531 | 2532 | 2533 | 2534 | 2535 | 2536 | 2537 | 2538 | 2539 | 2540 | 2541 | 2542 | 2543 |
| 9F_ | 2544 | 2545 | 2546 | 2547 | 2548 | 2549 | 2550 | 2551 | 2552 | 2553 | 2554 | 2555 | 2556 | 2557 | 2558 | 2559 |

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| A0_ | 2560 | 2561 | 2562 | 2563 | 2564 | 2565 | 2566 | 2567 | 2568 | 2569 | 2570 | 2571 | 2572 | 2573 | 2574 | 2575 |
| A1_ | 2576 | 2577 | 2578 | 2579 | 2580 | 2581 | 2582 | 2583 | 2584 | 2585 | 2586 | 2587 | 2588 | 2589 | 2590 | 2591 |
| A2_ | 2592 | 2593 | 2594 | 2595 | 2596 | 2597 | 2598 | 2599 | 2600 | 2601 | 2602 | 2603 | 2604 | 2605 | 2606 | 2607 |
| A3_ | 2608 | 2609 | 2610 | 2611 | 2612 | 2613 | 2614 | 2615 | 2616 | 2617 | 2618 | 2619 | 2620 | 2621 | 2622 | 2623 |
| A4_ | 2624 | 2625 | 2626 | 2627 | 2628 | 2629 | 2630 | 2631 | 2632 | 2633 | 2634 | 2635 | 2636 | 2637 | 2638 | 2639 |
| A5_ | 2640 | 2641 | 2642 | 2643 | 2644 | 2645 | 2646 | 2647 | 2648 | 2649 | 2650 | 2651 | 2652 | 2653 | 2654 | 2655 |
| A6_ | 2656 | 2657 | 2658 | 2659 | 2660 | 2661 | 2662 | 2663 | 2664 | 2665 | 2666 | 2667 | 2668 | 2669 | 2670 | 2671 |
| A7_ | 2672 | 2673 | 2674 | 2675 | 2676 | 2677 | 2678 | 2679 | 2680 | 2681 | 2682 | 2683 | 2684 | 2685 | 2686 | 2687 |
| A8_ | 2688 | 2689 | 2690 | 2691 | 2692 | 2693 | 2694 | 2695 | 2696 | 2697 | 2698 | 2699 | 2700 | 2701 | 2702 | 2703 |
| A9_ | 2704 | 2705 | 2706 | 2707 | 2708 | 2709 | 2710 | 2711 | 2712 | 2713 | 2714 | 2715 | 2716 | 2717 | 2718 | 2719 |
| AA_ | 2720 | 2721 | 2722 | 2723 | 2724 | 2725 | 2726 | 2727 | 2728 | 2729 | 2730 | 2731 | 2732 | 2733 | 2734 | 2735 |
| AB_ | 2736 | 2737 | 2738 | 2739 | 2740 | 2741 | 2742 | 2743 | 2744 | 2745 | 2746 | 2747 | 2748 | 2749 | 2750 | 2751 |
| AC_ | 2752 | 2753 | 2754 | 2755 | 2756 | 2757 | 2758 | 2759 | 2760 | 2761 | 2762 | 2763 | 2764 | 2765 | 2766 | 2767 |
| AD_ | 2768 | 2769 | 2770 | 2771 | 2772 | 2773 | 2774 | 2775 | 2776 | 2777 | 2778 | 2779 | 2780 | 2781 | 2782 | 2783 |
| AE_ | 2784 | 2785 | 2786 | 2787 | 2788 | 2789 | 2790 | 2791 | 2792 | 2793 | 2794 | 2795 | 2796 | 2797 | 2798 | 2799 |
| AF_ | 2800 | 2801 | 2802 | 2803 | 2804 | 2805 | 2806 | 2807 | 2808 | 2809 | 2810 | 2811 | 2812 | 2813 | 2814 | 2815 |
| B0_ | 2816 | 2817 | 2818 | 2819 | 2820 | 2821 | 2822 | 2823 | 2824 | 2825 | 2826 | 2827 | 2828 | 2829 | 2830 | 2831 |
| B1_ | 2832 | 2833 | 2834 | 2835 | 2836 | 2837 | 2838 | 2839 | 2840 | 2841 | 2842 | 2843 | 2844 | 2845 | 2846 | 2847 |
| B2_ | 2848 | 2849 | 2850 | 2851 | 2852 | 2853 | 2854 | 2855 | 2856 | 2857 | 2858 | 2859 | 2860 | 2861 | 2862 | 2863 |
| B3_ | 2864 | 2865 | 2866 | 2867 | 2868 | 2869 | 2870 | 2871 | 2872 | 2873 | 2874 | 2875 | 2876 | 2877 | 2878 | 2879 |
| B4_ | 2880 | 2881 | 2882 | 2883 | 2884 | 2885 | 2886 | 2887 | 2888 | 2889 | 2890 | 2891 | 2892 | 2893 | 2894 | 2895 |
| B5_ | 2896 | 2897 | 2898 | 2899 | 2900 | 2901 | 2902 | 2903 | 2904 | 2905 | 2906 | 2907 | 2908 | 2909 | 2910 | 2911 |
| B6_ | 2912 | 2913 | 2914 | 2915 | 2916 | 2917 | 2918 | 2919 | 2920 | 2921 | 2922 | 2923 | 2924 | 2925 | 2926 | 2927 |
| B7_ | 2928 | 2929 | 2930 | 2931 | 2932 | 2933 | 2934 | 2935 | 2936 | 2937 | 2938 | 2939 | 2940 | 2941 | 2942 | 2943 |
| B8_ | 2944 | 2945 | 2946 | 2947 | 2948 | 2949 | 2950 | 2951 | 2952 | 2953 | 2954 | 2955 | 2956 | 2957 | 2958 | 2959 |
| B9_ | 2960 | 2961 | 2962 | 2963 | 2964 | 2965 | 2966 | 2967 | 2968 | 2969 | 2970 | 2971 | 2972 | 2973 | 2974 | 2975 |
| BA_ | 2976 | 2977 | 2978 | 2979 | 2980 | 2981 | 2982 | 2983 | 2984 | 2985 | 2986 | 2987 | 2988 | 2989 | 2990 | 2991 |
| BB_ | 2992 | 2993 | 2994 | 2995 | 2996 | 2997 | 2998 | 2999 | 3000 | 3001 | 3002 | 3003 | 3004 | 3005 | 3006 | 3007 |
| BC_ | 3008 | 3009 | 3010 | 3011 | 3012 | 3013 | 3014 | 3015 | 3016 | 3017 | 3018 | 3019 | 3020 | 3021 | 3022 | 3023 |
| BD_ | 3024 | 3025 | 3026 | 3027 | 3028 | 3029 | 3030 | 3031 | 3032 | 3033 | 3034 | 3035 | 3036 | 3037 | 3038 | 3039 |
| BE_ | 3040 | 3041 | 3042 | 3043 | 3044 | 3045 | 3046 | 3047 | 3048 | 3049 | 3050 | 3051 | 3052 | 3053 | 3054 | 3055 |
| BF_ | 3056 | 3057 | 3058 | 3059 | 3060 | 3061 | 3062 | 3063 | 3064 | 3065 | 3066 | 3067 | 3068 | 3069 | 3070 | 3071 |

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| C0_ | 3072 | 3073 | 3074 | 3075 | 3076 | 3077 | 3078 | 3079 | 3080 | 3081 | 3082 | 3083 | 3084 | 3085 | 3086 | 3087 |
| C1_ | 3088 | 3089 | 3090 | 3091 | 3092 | 3093 | 3094 | 3095 | 3096 | 3097 | 3098 | 3099 | 3100 | 3101 | 3102 | 3103 |
| C2_ | 3104 | 3105 | 3106 | 3107 | 3108 | 3109 | 3110 | 3111 | 3112 | 3113 | 3114 | 3115 | 3116 | 3117 | 3118 | 3119 |
| C3_ | 3120 | 3121 | 3122 | 3123 | 3124 | 3125 | 3126 | 3127 | 3128 | 3129 | 3130 | 3131 | 3132 | 3133 | 3134 | 3135 |
| C4_ | 3136 | 3137 | 3138 | 3139 | 3140 | 3141 | 3142 | 3143 | 3144 | 3145 | 3146 | 3147 | 3148 | 3149 | 3150 | 3151 |
| C5_ | 3152 | 3153 | 3154 | 3155 | 3156 | 3157 | 3158 | 3159 | 3160 | 3161 | 3162 | 3163 | 3164 | 3165 | 3166 | 3167 |
| C6_ | 3168 | 3169 | 3170 | 3171 | 3172 | 3173 | 3174 | 3175 | 3176 | 3177 | 3178 | 3179 | 3180 | 3181 | 3182 | 3183 |
| C7_ | 3184 | 3185 | 3186 | 3187 | 3188 | 3189 | 3190 | 3191 | 3192 | 3193 | 3194 | 3195 | 3196 | 3197 | 3198 | 3199 |
| C8_ | 3200 | 3201 | 3202 | 3203 | 3204 | 3205 | 3206 | 3207 | 3208 | 3209 | 3210 | 3211 | 3212 | 3213 | 3214 | 3215 |
| C9_ | 3216 | 3217 | 3218 | 3219 | 3220 | 3221 | 3222 | 3223 | 3224 | 3225 | 3226 | 3227 | 3228 | 3229 | 3230 | 3231 |
| CA_ | 3232 | 3233 | 3234 | 3235 | 3236 | 3237 | 3238 | 3239 | 3240 | 3241 | 3242 | 3243 | 3244 | 3245 | 3246 | 3247 |
| CB_ | 3248 | 3249 | 3250 | 3251 | 3252 | 3253 | 3254 | 3255 | 3256 | 3257 | 3258 | 3259 | 3260 | 3261 | 3262 | 3263 |
| CC_ | 3264 | 3265 | 3266 | 3267 | 3268 | 3269 | 3270 | 3271 | 3272 | 3273 | 3274 | 3275 | 3276 | 3277 | 3278 | 3279 |
| CD_ | 3280 | 3281 | 3282 | 3283 | 3284 | 3285 | 3286 | 3287 | 3288 | 3289 | 3290 | 3291 | 3292 | 3293 | 3294 | 3295 |
| CE_ | 3296 | 3297 | 3298 | 3299 | 3300 | 3301 | 3302 | 3303 | 3304 | 3305 | 3306 | 3307 | 3308 | 3309 | 3310 | 3311 |
| CF_ | 3312 | 3313 | 3314 | 3315 | 3316 | 3317 | 3318 | 3319 | 3320 | 3321 | 3322 | 3323 | 3324 | 3325 | 3326 | 3327 |
| D0_ | 3328 | 3329 | 3330 | 3331 | 3332 | 3333 | 3334 | 3335 | 3336 | 3337 | 3338 | 3339 | 3340 | 3341 | 3342 | 3343 |
| D1_ | 3344 | 3345 | 3346 | 3347 | 3348 | 3349 | 3350 | 3351 | 3352 | 3353 | 3354 | 3355 | 3356 | 3357 | 3358 | 3359 |
| D2_ | 3360 | 3361 | 3362 | 3363 | 3364 | 3365 | 3366 | 3367 | 3368 | 3369 | 3370 | 3371 | 3372 | 3373 | 3374 | 3375 |
| D3_ | 3376 | 3377 | 3378 | 3379 | 3380 | 3381 | 3382 | 3383 | 3384 | 3385 | 3386 | 3387 | 3388 | 3389 | 3390 | 3391 |
| D4_ | 3392 | 3393 | 3394 | 3395 | 3396 | 3397 | 3398 | 3399 | 3400 | 3401 | 3402 | 3403 | 3404 | 3405 | 3406 | 3407 |
| D5_ | 3408 | 3409 | 3410 | 3411 | 3412 | 3413 | 3414 | 3415 | 3416 | 3417 | 3418 | 3419 | 3420 | 3421 | 3422 | 3423 |
| D6_ | 3424 | 3425 | 3426 | 3427 | 3428 | 3429 | 3430 | 3431 | 3432 | 3433 | 3434 | 3435 | 3436 | 3437 | 3438 | 3439 |
| D7_ | 3440 | 3441 | 3442 | 3443 | 3444 | 3445 | 3446 | 3447 | 3448 | 3449 | 3450 | 3451 | 3452 | 3453 | 3454 | 3455 |
| D8_ | 3456 | 3457 | 3458 | 3459 | 3460 | 3461 | 3462 | 3463 | 3464 | 3465 | 3466 | 3467 | 3468 | 3469 | 3470 | 3471 |
| D9_ | 3472 | 3473 | 3474 | 3475 | 3476 | 3477 | 3478 | 3479 | 3480 | 3481 | 3482 | 3483 | 3484 | 3485 | 3486 | 3487 |
| DA_ | 3488 | 3489 | 3490 | 3491 | 3492 | 3493 | 3494 | 3495 | 3496 | 3497 | 3498 | 3499 | 3500 | 3501 | 3502 | 3503 |
| DB_ | 3504 | 3505 | 3506 | 3507 | 3508 | 3509 | 3510 | 3511 | 3512 | 3513 | 3514 | 3515 | 3516 | 3517 | 3518 | 3519 |
| DC_ | 3520 | 3521 | 3522 | 3523 | 3524 | 3525 | 3526 | 3527 | 3528 | 3529 | 3530 | 3531 | 3532 | 3533 | 3534 | 3535 |
| DD_ | 3536 | 3537 | 3538 | 3539 | 3540 | 3541 | 3542 | 3543 | 3544 | 3545 | 3546 | 3547 | 3548 | 3549 | 3550 | 3551 |
| DE_ | 3552 | 3553 | 3554 | 3555 | 3556 | 3557 | 3558 | 3559 | 3560 | 3561 | 3562 | 3563 | 3564 | 3565 | 3566 | 3567 |
| DF_ | 3568 | 3569 | 3570 | 3571 | 3572 | 3573 | 3574 | 3575 | 3576 | 3577 | 3578 | 3579 | 3580 | 3581 | 3582 | 3583 |

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| E0_ | 3584 | 3585 | 3586 | 3587 | 3588 | 3589 | 3590 | 3591 | 3592 | 3593 | 3594 | 3595 | 3596 | 3597 | 3598 | 3599 |
| E1_ | 3600 | 3601 | 3602 | 3603 | 3604 | 3605 | 3606 | 3607 | 3608 | 3609 | 3610 | 3611 | 3612 | 3613 | 3614 | 3615 |
| E2_ | 3616 | 3617 | 3618 | 3619 | 3620 | 3621 | 3622 | 3623 | 3624 | 3625 | 3626 | 3627 | 3628 | 3629 | 3630 | 3631 |
| E3_ | 3632 | 3633 | 3634 | 3635 | 3636 | 3637 | 3638 | 3639 | 3640 | 3641 | 3642 | 3643 | 3644 | 3645 | 3646 | 3647 |
| E4_ | 3648 | 3649 | 3650 | 3651 | 3652 | 3653 | 3654 | 3655 | 3656 | 3657 | 3658 | 3659 | 3660 | 3661 | 3662 | 3663 |
| E5_ | 3664 | 3665 | 3666 | 3667 | 3668 | 3669 | 3670 | 3671 | 3672 | 3673 | 3674 | 3675 | 3676 | 3677 | 3678 | 3679 |
| E6_ | 3680 | 3681 | 3682 | 3683 | 3684 | 3685 | 3686 | 3687 | 3688 | 3689 | 3690 | 3691 | 3692 | 3693 | 3694 | 3695 |
| E7_ | 3696 | 3697 | 3698 | 3699 | 3700 | 3701 | 3702 | 3703 | 3704 | 3705 | 3706 | 3707 | 3708 | 3709 | 3710 | 3711 |
| E8_ | 3712 | 3713 | 3714 | 3715 | 3716 | 3717 | 3718 | 3719 | 3720 | 3721 | 3722 | 3723 | 3724 | 3725 | 3726 | 3727 |
| E9_ | 3728 | 3729 | 3730 | 3731 | 3732 | 3733 | 3734 | 3735 | 3736 | 3737 | 3738 | 3739 | 3740 | 3741 | 3742 | 3743 |
| EA_ | 3744 | 3745 | 3746 | 3747 | 3748 | 3749 | 3750 | 3751 | 3752 | 3753 | 3754 | 3755 | 3756 | 3757 | 3758 | 3759 |
| EB_ | 3760 | 3761 | 3762 | 3763 | 3764 | 3765 | 3766 | 3767 | 3768 | 3769 | 3770 | 3771 | 3772 | 3773 | 3774 | 3775 |
| EC_ | 3776 | 3777 | 3778 | 3779 | 3780 | 3781 | 3782 | 3783 | 3784 | 3785 | 3786 | 3787 | 3788 | 3789 | 3790 | 3791 |
| ED_ | 3792 | 3793 | 3794 | 3795 | 3796 | 3797 | 3798 | 3799 | 3800 | 3801 | 3802 | 3803 | 3804 | 3805 | 3806 | 3807 |
| EE_ | 3808 | 3809 | 3810 | 3811 | 3812 | 3813 | 3814 | 3815 | 3816 | 3817 | 3818 | 3819 | 3820 | 3821 | 3822 | 3823 |
| EF_ | 3824 | 3825 | 3826 | 3827 | 3828 | 3829 | 3830 | 3831 | 3832 | 3833 | 3834 | 3835 | 3836 | 3837 | 3838 | 3839 |
| F0_ | 3840 | 3841 | 3842 | 3843 | 3844 | 3845 | 3846 | 3847 | 3848 | 3849 | 3850 | 3851 | 3852 | 3853 | 3854 | 3855 |
| F1_ | 3856 | 3857 | 3858 | 3859 | 3860 | 3861 | 3862 | 3863 | 3864 | 3865 | 3866 | 3867 | 3868 | 3869 | 3870 | 3871 |
| F2_ | 3872 | 3873 | 3874 | 3875 | 3876 | 3877 | 3878 | 3879 | 3880 | 3881 | 3882 | 3883 | 3884 | 3885 | 3886 | 3887 |
| F3_ | 3888 | 3889 | 3890 | 3891 | 3892 | 3893 | 3894 | 3895 | 3896 | 3897 | 3898 | 3899 | 3900 | 3901 | 3902 | 3903 |
| F4_ | 3904 | 3905 | 3906 | 3907 | 3908 | 3909 | 3910 | 3911 | 3912 | 3913 | 3914 | 3915 | 3916 | 3917 | 3918 | 3919 |
| F5_ | 3920 | 3921 | 3922 | 3923 | 3924 | 3925 | 3926 | 3927 | 3928 | 3929 | 3930 | 3931 | 3932 | 3933 | 3934 | 3935 |
| F6_ | 3936 | 3937 | 3938 | 3939 | 3940 | 3941 | 3942 | 3943 | 3944 | 3945 | 3946 | 3947 | 3948 | 3949 | 3950 | 3951 |
| F7_ | 3952 | 3953 | 3954 | 3955 | 3956 | 3957 | 3958 | 3959 | 3960 | 3961 | 3962 | 3963 | 3964 | 3965 | 3966 | 3967 |
| F8_ | 3968 | 3969 | 3970 | 3971 | 3972 | 3973 | 3974 | 3975 | 3976 | 3977 | 3978 | 3979 | 3980 | 3981 | 3982 | 3983 |
| F9_ | 3984 | 3985 | 3986 | 3987 | 3988 | 3989 | 3990 | 3991 | 3992 | 3993 | 3994 | 3995 | 3996 | 3997 | 3998 | 3999 |
| FA_ | 4000 | 4001 | 4002 | 4003 | 4004 | 4005 | 4006 | 4007 | 4008 | 4009 | 4010 | 4011 | 4012 | 4013 | 4014 | 4015 |
| FB_ | 4016 | 4017 | 4018 | 4019 | 4020 | 4021 | 4022 | 4023 | 4024 | 4025 | 4026 | 4027 | 4028 | 4029 | 4030 | 4031 |
| FC_ | 4032 | 4033 | 4034 | 4035 | 4036 | 4037 | 4038 | 4039 | 4040 | 4041 | 4042 | 4043 | 4044 | 4045 | 4046 | 4047 |
| FD_ | 4048 | 4049 | 4050 | 4051 | 4052 | 4053 | 4054 | 4055 | 4056 | 4057 | 4058 | 4059 | 4060 | 4061 | 4062 | 4063 |
| FE_ | 4064 | 4065 | 4066 | 4067 | 4068 | 4069 | 4070 | 4071 | 4072 | 4073 | 4074 | 4075 | 4076 | 4077 | 4078 | 4079 |
| FF_ | 4080 | 4081 | 4082 | 4083 | 4084 | 4085 | 4086 | 4087 | 4088 | 4089 | 4090 | 4091 | 4092 | 4093 | 4094 | 4095 |

Conversion Table: Hexadecimal and Decimal Integers

| HALFWORD | | | | | | | | HALFWORD | | | | | | | |
|------------|---------------|------|-------------|------|------------|------|---------|----------|---------|------|---------|------|---------|------|---------|
| BYTE | | | | BYTE | | | | BYTE | | | | BYTE | | | |
| BITS: 0123 | | 4567 | | 0123 | | 4567 | | 0123 | | 4567 | | 0123 | | 4567 | |
| Hex | Decimal | Hex | Decimal | Hex | Decimal | Hex | Decimal | Hex | Decimal | Hex | Decimal | Hex | Decimal | Hex | Decimal |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 268,435,456 | 1 | 16,777,216 | 1 | 1,048,576 | 1 | 65,536 | 1 | 4,096 | 1 | 256 | 1 | 16 | 1 | 1 |
| 2 | 536,870,912 | 2 | 33,554,432 | 2 | 2,097,152 | 2 | 131,072 | 2 | 8,192 | 2 | 512 | 2 | 32 | 2 | 2 |
| 3 | 805,306,368 | 3 | 50,331,648 | 3 | 3,145,728 | 3 | 196,608 | 3 | 12,288 | 3 | 768 | 3 | 48 | 3 | 3 |
| 4 | 1,073,741,824 | 4 | 67,108,864 | 4 | 4,194,304 | 4 | 262,144 | 4 | 16,384 | 4 | 1,024 | 4 | 64 | 4 | 4 |
| 5 | 1,342,177,280 | 5 | 83,886,080 | 5 | 5,242,880 | 5 | 327,680 | 5 | 20,480 | 5 | 1,280 | 5 | 80 | 5 | 5 |
| 6 | 1,610,612,736 | 6 | 100,663,296 | 6 | 6,291,456 | 6 | 393,216 | 6 | 24,576 | 6 | 1,536 | 6 | 96 | 6 | 6 |
| 7 | 1,879,048,192 | 7 | 117,440,512 | 7 | 7,340,032 | 7 | 458,752 | 7 | 28,672 | 7 | 1,792 | 7 | 112 | 7 | 7 |
| 8 | 2,147,483,648 | 8 | 134,217,728 | 8 | 8,388,608 | 8 | 524,288 | 8 | 32,768 | 8 | 2,048 | 8 | 128 | 8 | 8 |
| 9 | 2,415,919,104 | 9 | 150,994,944 | 9 | 9,437,184 | 9 | 589,824 | 9 | 36,864 | 9 | 2,304 | 9 | 144 | 9 | 9 |
| A | 2,684,354,560 | A | 167,772,160 | A | 10,485,760 | A | 655,360 | A | 40,960 | A | 2,560 | A | 160 | A | 10 |
| B | 2,952,790,016 | B | 184,549,376 | B | 11,534,336 | B | 720,896 | B | 45,056 | B | 2,816 | B | 176 | B | 11 |
| C | 3,221,225,472 | C | 201,326,592 | C | 12,582,912 | C | 786,432 | C | 49,152 | C | 3,072 | C | 192 | C | 12 |
| D | 3,489,660,928 | D | 218,103,808 | D | 13,631,488 | D | 851,968 | D | 53,248 | D | 3,328 | D | 208 | D | 13 |
| E | 3,758,096,384 | E | 234,881,024 | E | 14,680,064 | E | 917,504 | E | 57,344 | E | 3,584 | E | 224 | E | 14 |
| F | 4,026,531,840 | F | 251,658,240 | F | 15,728,640 | F | 983,040 | F | 61,440 | F | 3,840 | F | 240 | F | 15 |
| 8 | | 7 | | 6 | | 5 | | 4 | | 3 | | 2 | | 1 | |

TO CONVERT HEXADECIMAL TO DECIMAL

1. Locate the column of decimal numbers corresponding to the left-most digit or letter of the hexadecimal; select from this column and record the number that corresponds to the position of the hexadecimal digit or letter.
2. Repeat step 1 for the next (second from the left) position.
3. Repeat step 1 for the units (third from the left) position.
4. Add the numbers selected from the table to form the decimal number.

| EXAMPLE | |
|---------------------------------|------|
| Conversion of Hexadecimal Value | D34 |
| 1. D | 3328 |
| 2. 3 | 48 |
| 3. 4 | 4 |
| 4. Decimal | 3380 |

To convert integer numbers greater than the capacity of table, use the techniques below:

HEXADECIMAL TO DECIMAL

Successive cumulative multiplication from left to right, adding units position.

Example: $D34_{16} = 3380_{10}$

$$\begin{array}{r}
 D = 13 \\
 \times 16 \\
 \hline
 208 \\
 3 = + 3 \\
 \hline
 211 \\
 \times 16 \\
 \hline
 3376 \\
 4 = + 4 \\
 \hline
 3380
 \end{array}$$

TO CONVERT DECIMAL TO HEXADECIMAL

1. (a) Select from the table the highest decimal number that is equal to or less than the number to be converted.
(b) Record the hexadecimal of the column containing the selected number.
(c) Subtract the selected decimal from the number to be converted.
2. Using the remainder from step 1(c) repeat all of step 1 to develop the second position of the hexadecimal (and a remainder).
3. Using the remainder from step 2 repeat all of step 1 to develop the units position of the hexadecimal.
4. Combine terms to form the hexadecimal number.

| EXAMPLE | |
|-----------------------------|--------------|
| Conversion of Decimal Value | 3380 |
| 1. D | <u>-3328</u> |
| | 52 |
| 2. 3 | <u>-48</u> |
| | 4 |
| 3. 4 | <u>-4</u> |
| 4. Hexadecimal | D34 |

DECIMAL TO HEXADECIMAL

Divide and collect the remainder in reverse order.

Example: $3380_{10} = X_{16}$

$$\begin{array}{r}
 16 \overline{) 3380} \\
 \underline{16 \ 211} \\
 16 \overline{) 211} \\
 \underline{16 \ 13} \\
 4 \\
 3 \\
 D
 \end{array}$$

$3380_{10} = D34_{16}$

POWERS OF 16 TABLE

Example: $268,435,456_{10} = (2.68435456 \times 10^8)_{10} = 1000\ 0000_{16} = (10^7)_{16}$

| 16^n | n |
|---------------------------|--------|
| 1 | 0 |
| 16 | 1 |
| 256 | 2 |
| 4 096 | 3 |
| 65 536 | 4 |
| 1 048 576 | 5 |
| 16 777 216 | 6 |
| 268 435 456 | 7 |
| 4 294 967 296 | 8 |
| 68 719 476 736 | 9 |
| 1 099 511 627 776 | 10 = A |
| 17 592 186 044 416 | 11 = B |
| 281 474 976 710 656 | 12 = C |
| 4 503 599 627 370 496 | 13 = D |
| 72 057 594 037 927 936 | 14 = E |
| 1 152 921 504 606 846 976 | 15 = F |

Decimal Values

Conversion Table: Hexadecimal and Decimal Fractions

| HALFWORD | | | | | | | | | | | | | | | | | |
|----------|---------|------|---------|------|------|-------|---------|------|-------|-------|--------------------|------|------|--|--|--|--|
| BYTE | | | | | | BYTE | | | | | | | | | | | |
| BITS | | 0123 | | | | 4567 | | | | 0123 | | 4567 | | | | | |
| Hex | Decimal | Hex | Decimal | | | Hex | Decimal | | | Hex | Decimal Equivalent | | | | | | |
| .0 | .0000 | .00 | .0000 | 0000 | .000 | .0000 | 0000 | 0000 | .0000 | .0000 | 0000 | 0000 | 0000 | | | | |
| .1 | .0625 | .01 | .0039 | 0625 | .001 | .0002 | 4414 | 0625 | .0001 | .0000 | 1525 | 8789 | 0625 | | | | |
| .2 | .1250 | .02 | .0078 | 1250 | .002 | .0004 | 8828 | 1250 | .0002 | .0000 | 3051 | 7578 | 1250 | | | | |
| .3 | .1875 | .03 | .0117 | 1875 | .003 | .0007 | 3242 | 1875 | .0003 | .0000 | 4577 | 6367 | 1875 | | | | |
| .4 | .2500 | .04 | .0156 | 2500 | .004 | .0009 | 7656 | 2500 | .0004 | .0000 | 6103 | 5156 | 2500 | | | | |
| .5 | .3125 | .05 | .0195 | 3125 | .005 | .0012 | 2070 | 3125 | .0005 | .0000 | 7629 | 3945 | 3125 | | | | |
| .6 | .3750 | .06 | .0234 | 3750 | .006 | .0014 | 6484 | 3750 | .0006 | .0000 | 9155 | 2734 | 3750 | | | | |
| .7 | .4375 | .07 | .0273 | 4375 | .007 | .0017 | 0898 | 4375 | .0007 | .0001 | 0681 | 1523 | 4375 | | | | |
| .8 | .5000 | .08 | .0312 | 5000 | .008 | .0019 | 5312 | 5000 | .0008 | .0001 | 2207 | 0312 | 5000 | | | | |
| .9 | .5625 | .09 | .0351 | 5625 | .009 | .0021 | 9726 | 5625 | .0009 | .0001 | 3732 | 9101 | 5625 | | | | |
| .A | .6250 | .0A | .0390 | 6250 | .00A | .0024 | 4140 | 6250 | .000A | .0001 | 5258 | 7890 | 6250 | | | | |
| .B | .6875 | .0B | .0429 | 6875 | .00B | .0026 | 8554 | 6875 | .000B | .0001 | 6784 | 6679 | 6875 | | | | |
| .C | .7500 | .0C | .0468 | 7500 | .00C | .0029 | 2968 | 7500 | .000C | .0001 | 8310 | 5468 | 7500 | | | | |
| .D | .8125 | .0D | .0507 | 8125 | .00D | .0031 | 7382 | 8125 | .000D | .0001 | 9836 | 4257 | 8125 | | | | |
| .E | .8750 | .0E | .0546 | 8750 | .00E | .0034 | 1796 | 8750 | .000E | .0002 | 1362 | 3046 | 8750 | | | | |
| .F | .9375 | .0F | .0585 | 9375 | .00F | .0036 | 6210 | 9375 | .000F | .0002 | 2888 | 1835 | 9375 | | | | |
| 1 | | 2 | | | | 3 | | | | 4 | | | | | | | |

TO CONVERT .ABC HEXADECIMAL TO DECIMAL

Find .A in position 1 .6250
 Find .0B in position 2 .0429 6875
 Find .00C in position 3 .0029 2968 7500
 .ABC Hex is equal to .6708 9843 7500

TO CONVERT .13 DECIMAL TO HEXADECIMAL

- Find .1250 next lowest to .1300
 subtract $-.1250$ = .2 Hex
- Find .0039 0625 next lowest to .0050 0000
 subtract $-.0039 0625$ = .01
- Find .0009 7656 2500 .0010 9375 0000
 subtract $-.0009 7656 2500$ = .004
- Find .0001 0681 1523 4375 .0001 1718 7500 0000
 subtract $-.0001 0681 1523 4375$ = .0007
 .0000 1037 5976 5625 = .2147 Hex
- .13 Decimal is approximately equal to \rightarrow

To convert fractions beyond the capacity of table, use techniques below:

HEXADECIMAL FRACTION TO DECIMAL

Convert the hexadecimal fraction to its decimal equivalent using the same technique as for integer numbers. Divide the results by 16^n (n is the number of fraction positions).

Example: $.8A7_{16} = .540771_{10}$

$$8A7_{16} = 2215_{10}$$

$$16^3 = 4096 \quad 4096 \overline{)2215.000000}$$

DECIMAL FRACTION TO HEXADECIMAL

Collect integer parts of product in the order of calculation.

Example: $.5408_{10} = .8A7_{16}$

$$.5408 \times 16 = 8.6528$$

$$.6528 \times 16 = 10.4448$$

$$.4448 \times 16 = 7.1168$$

Hexadecimal Addition and Subtraction Table

Example: $6 + 2 = 8$, $8 - 2 = 6$, and $8 - 6 = 2$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F |
|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 1 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 0A | 0B | 0C | 0D | 0E | 0F | 10 |
| 2 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 0A | 0B | 0C | 0D | 0E | 0F | 10 | 11 |
| 3 | 04 | 05 | 06 | 07 | 08 | 09 | 0A | 0B | 0C | 0D | 0E | 0F | 10 | 11 | 12 |
| 4 | 05 | 06 | 07 | 08 | 09 | 0A | 0B | 0C | 0D | 0E | 0F | 10 | 11 | 12 | 13 |
| 5 | 06 | 07 | 08 | 09 | 0A | 0B | 0C | 0D | 0E | 0F | 10 | 11 | 12 | 13 | 14 |
| 6 | 07 | 08 | 09 | 0A | 0B | 0C | 0D | 0E | 0F | 10 | 11 | 12 | 13 | 14 | 15 |
| 7 | 08 | 09 | 0A | 0B | 0C | 0D | 0E | 0F | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 8 | 09 | 0A | 0B | 0C | 0D | 0E | 0F | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| 9 | 0A | 0B | 0C | 0D | 0E | 0F | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| A | 0B | 0C | 0D | 0E | 0F | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| B | 0C | 0D | 0E | 0F | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 1A |
| C | 0D | 0E | 0F | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 1A | 1B |
| D | 0E | 0F | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 1A | 1B | 1C |
| E | 0F | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 1A | 1B | 1C | 1D |
| F | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 1A | 1B | 1C | 1D | 1E |

Hexadecimal Multiplication Table

Example: $2 \times 4 = 08$, $F \times 2 = 1E$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F |
|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 1 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 0A | 0B | 0C | 0D | 0E | 0F |
| 2 | 02 | 04 | 06 | 08 | 0A | 0C | 0E | 10 | 12 | 14 | 16 | 18 | 1A | 1C | 1E |
| 3 | 03 | 06 | 09 | 0C | 0F | 12 | 15 | 18 | 1B | 1E | 21 | 24 | 27 | 2A | 2D |
| 4 | 04 | 08 | 0C | 10 | 14 | 18 | 1C | 20 | 24 | 28 | 2C | 30 | 34 | 38 | 3C |
| 5 | 05 | 0A | 0F | 14 | 19 | 1E | 23 | 28 | 2D | 32 | 37 | 3C | 41 | 46 | 4B |
| 6 | 06 | 0C | 12 | 18 | 1E | 24 | 2A | 30 | 36 | 3C | 42 | 48 | 4E | 54 | 5A |
| 7 | 07 | 0E | 15 | 1C | 23 | 2A | 31 | 38 | 3F | 46 | 4D | 54 | 5B | 62 | 69 |
| 8 | 08 | 10 | 18 | 20 | 28 | 30 | 38 | 40 | 48 | 50 | 58 | 60 | 68 | 70 | 78 |
| 9 | 09 | 12 | 1B | 24 | 2D | 36 | 3F | 48 | 51 | 5A | 63 | 6C | 75 | 7E | 87 |
| A | 0A | 14 | 1E | 28 | 32 | 3C | 46 | 50 | 5A | 64 | 6E | 78 | 82 | 8C | 96 |
| B | 0B | 16 | 21 | 2C | 37 | 42 | 4D | 58 | 63 | 6E | 79 | 84 | 8F | 9A | A5 |
| C | 0C | 18 | 24 | 30 | 3C | 48 | 54 | 60 | 6C | 78 | 84 | 90 | 9C | AB | B4 |
| D | 0D | 1A | 27 | 34 | 41 | 4E | 5B | 68 | 75 | 82 | 8F | 9C | A9 | B6 | C3 |
| E | 0E | 1C | 2A | 38 | 46 | 54 | 62 | 70 | 7E | 8C | 9A | AB | B6 | C4 | D2 |
| F | 0F | 1E | 2D | 3C | 4B | 5A | 69 | 78 | 87 | 96 | A5 | B4 | C3 | D2 | E1 |

Extended Binary-Coded-Decimal Interchange Code (EBCDIC)

The 256-position EBCDIC table, outlined by the heavy black lines, shows the graphic characters and control character representations for EBCDIC. The bit-position numbers, bit patterns, hexadecimal representations and card hole patterns for these and other possible EBCDIC characters are also shown.

To find the card hole patterns for most characters, partition the 256-position table into four blocks as follows:

| | |
|---|---|
| 1 | 3 |
| 2 | 4 |

Block 1: Zone punches at top of table; digit punches at left

Block 2: Zone punches at bottom of table; digit punches at left

Block 3: Zone punches at top of table; digit punches at right

Block 4: Zone punches at bottom of table; digit punches at right

Fifteen positions in the table are exceptions to the above arrangement. These positions are indicated by small numbers in the upper right corners of their boxes in the table. The card hole patterns for these positions are given at the bottom of the table. Bit-position numbers, bit patterns, and hexadecimal representations for these positions are found in the usual manner.

Following are some examples of the use of the EBCDIC chart:

| Character | Type | Bit Pattern | Hex | Hole Pattern | |
|-----------|--|-------------|-----|-----------------|---------------|
| | | | | Zone Punches | Digit Punches |
| Pf | Control Character | 00 00 0100 | 04 | 12 - 9 | - 4 |
| % | Special Graphic | 01 10 1100 | 6C | 0 | - 8 - 4 |
| R | Upper Case | 11 01 1001 | D9 | 11 | - 9 |
| a | Lower Case | 10 00 0001 | 81 | 12 - 0 | - 1 |
| | Control Character, function not yet assigned | 00 11 0000 | 30 | 12 - 11 - 0 - 9 | - 8 - 1 |

Bit Positions
01 23 4567

| | | 00 | | | | 01 | | | | 10 | | | | 11 | | | | Bit Positions 0,1 | |
|--------------------------|---|---------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-------------------------|--|
| | | 00 | 01 | 10 | 11 | 00 | 01 | 10 | 11 | 00 | 01 | 10 | 11 | 00 | 01 | 10 | 11 | Bit Positions 2,3 | |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F | First Hexadecimal Digit | |
| Bit Positions 4, 5, 6, 7 | | Zone Punches | | | | | | | | | | | | | | | | | |
| Second Hexadecimal Digit | | Digit Punches | | | | | | | | | | | | | | | | | |
| 0000 | 0 | 12 | | | | 12 | 12 | | | 12 | 12 | | | 12 | 12 | | | | |
| 0001 | 1 | | 11 | | | | 11 | 11 | 11 | | 11 | 11 | 11 | | | | | | |
| 0010 | 2 | | | 0 | | | 0 | 0 | 0 | | 0 | 0 | 0 | | | | | | |
| 0011 | 3 | | | | 9 | | | | | | | | | | | | | | |
| 0100 | 4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | | | | | 9 | 10 | 11 | 12 | | |
| 0101 | 5 | | | | | | | | | | | | | | | | | | |
| 0110 | 6 | | | | | | | | | | | | | | | | | | |
| 0111 | 7 | | | | | | | | | | | | | | | | | | |
| 1000 | 8 | | | | | | | | | | | | | | | | | | |
| 1001 | 9 | | | | | | | | | | | | | | | | | | |
| 1010 | A | | | | | | | | | | | | | | | | | | |
| 1011 | B | | | | | | | | | | | | | | | | | | |
| 1100 | C | | | | | | | | | | | | | | | | | | |
| 1101 | D | | | | | | | | | | | | | | | | | | |
| 1110 | E | | | | | | | | | | | | | | | | | | |
| 1111 | F | | | | | | | | | | | | | | | | | | |

Card Hole Patterns

- ① 12-0-9-8-1
- ② 12-11-9-8-1
- ③ 11-0-9-8-1
- ④ 12-11-0-9-8-1
- ⑤ No Punches
- ⑥ 12
- ⑦ 11
- ⑧ 12-11-0
- ⑨ 12-0
- ⑩ 11-0
- ⑪ 0-8-2
- ⑫ 0
- ⑬ 0-1
- ⑭ 11-0-9-1
- ⑮ 12-11

Control Character Representations

| | | | | | |
|---------|-----------------------------|---------|--|---------|-----------------------------|
| ACK | Acknowledge | ETB | End of Transmission Block | RES/ENP | Restore/Enable Presentation |
| BEL | Bell | ETX | End of Text | RFF | Required Form Feed |
| BS | Backspace | FF | Form Feed | RNL | Required New Line |
| BYP INP | Bypass/Inhibit Presentation | FS | Field Separator | RPT | Repeat |
| CAN | Cancel | GE | Graphic Escape | SA | Set Attribute |
| CR | Carriage Return | HT | Horizontal Tab | SBS | Subscript |
| CSP | Control Sequence Prefix | IFS | Interchange File Separator | SEL | Select |
| CL1 | Customer Use 1 | IGS | Interchange Group Separator | SI | Shift In |
| CL3 | Customer Use 3 | IR | Index Return | SM/SW | Set Mode/Switch |
| DC1 | Device Control 1 | IRS | Interchange Record Separator | SO | Shift Out |
| DC2 | Device Control 2 | IT | Indent Tab | SOH | Start of Heading |
| DC3 | Device Control 3 | IUS/ITB | Interchange Unit Separator/Intermediate Transmission Block | SOS | Start of Significance |
| DC4 | Device Control 4 | LF | Line Feed | SP | Space |
| DEL | Delete | MFA | Modify Field Attribute | SPS | Superscript |
| DLE | Data Link Escape | NAK | Negative Acknowledge | STX | Start of Text |
| DS | Digit Select | NBS | Numeric Backspace | SUB | Substitute |
| EM | End of Medium | NL | New Line | SYN | Synchronous Idle |
| ENQ | Enquiry | NUL | Null | VT | Vertical Tab |
| EO | Eight Ones | POC | Program-Operator Communication | WUS | Word Underscore |
| EOT | End of Transmission | PP | Presentation Position | | |
| ESC | Escape | | | | |

Special Graphic Characters

| | | | |
|----|-----------------------|---|--------------------|
| ¢ | Cent Sign | > | Greater-than Sign |
| . | Period, Decimal Point | ? | Question Mark |
| < | Less-than Sign | ˘ | Grave Accent |
| (| Left Parenthesis | # | Number Sign |
| + | Plus Sign | @ | At Sign |
| | Logical OR | ' | Prime, Apostrophe |
| ∧ | Asterisk | = | Equal Sign |
| ! | Exclamation Point | ~ | Tilde |
| \$ | Dollar Sign | { | Opening Brace |
| ~ | Right Parenthesis | } | Closing Brace |
| | Semicolon | ⋈ | Chair |
| ∩ | Logical NOT | ⋈ | Long Vertical Mark |
| - | Minus Sign, Hyphen | | |
| / | Slash | | |
| : | Vertical Line | | |
| , | Comma | | |
| % | Percent | | |
| _ | Underscore | | |

APPENDIX H. CHANGES AFFECTING COMPATIBILITY BETWEEN SYSTEM/360 AND SYSTEM/370

This appendix summarizes those changes included in the System/370 architecture that may affect whether or not a program written according to the System/360 architecture runs on machines implementing the System/370 architecture described in this publication. Not included are descriptions of System/370 functions which are compatible extensions, that is, (1) those that are suppressed on initialization, such as block multiplexing, and (2) those that are specified in such a manner that they cause program exceptions on System/360, such as new instructions.

REMOVAL OF USASCII-8 MODE

System/360 provides for USASCII-8 by a mode under control of PSW bit 12. USASCII-8 was a proposed zoned-decimal code that has since been rejected. When bit 12 of the System/360 PSW is one, the preferred codes for the USASCII-8 are generated for decimal results. When PSW bit 12 is zero, the preferred codes for EBCDIC are generated.

In System/370, the USASCII-8 mode and the associated meaning of PSW bit 12 are removed. In System/370, all instructions whose execution in System/360 depends on the setting of PSW bit 12 are executed generating the preferred codes for EBCDIC.

Bit 12 of the PSW is handled in System/370 as follows:

- In models that do not have the extended-control (EC) mode installed, a one in PSW bit position 12 causes a program interruption for specification exception.
- In models that have the EC mode installed, a one in PSW bit position 12 causes the CPU to operate in the EC mode.

OPERATION CODE FOR HALT DEVICE AND FOR CLEAR CHANNEL

In System/370, the first eight bits of the operation code assigned to HALT DEVICE (HDV) are the same as those assigned to HALT I/O (HIO), the distinction between the two instructions being specified by bit position 15. In System/360, bit position 15 is ignored, and the HIO function is

performed for both instructions.

In System/370, the first eight bits of the operation code assigned to CLEAR CHANNEL (CLRCH) are the same as those assigned to TEST CHANNEL, the distinction between the two instructions being specified by bit position 15. In System/360, and also in those System/370 machines which do not have CLRCH installed, bit position 15 is ignored, and the TCH function is performed for both instructions.

LOGOUT

In System/360, the logout area starts with location 128 and extends through as many locations as the given model requires. Portions of this area are used for machine-check logout, and other portions may be used for channel logout. While no limit is set on the size of the logout area, the extent of the area used on most System/360 models is less than that stored by a comparable System/370 model.

On System/370, the machine-check interruption causes information to be stored at locations 216-239, 248-255, and 352-511. Additionally, the model may store logout information in the fixed logout area, locations 256-351, and the model may also have a machine-check extended logout (MCEL) area, which, on initialization, is specified to start at location 512. Channels may place logout information in the limited channel logout area, locations 176-179, and in the fixed logout area, locations 256-351.

In System/360, logout is not permitted on data check. System/370 permits logout to occur when the channel causes an I/O interruption with the data-check indication.

COMMAND RETRY

System/370 channels may provide command retry, whereby the channel, in response to a signal from the device, can retry the execution of a channel command. Since I/O devices announced prior to System/370 do not signal for command retry, no problem of compatibility exists on these devices. However, some new devices, which would otherwise be compatible with former

devices, do signal for command retry.

The effects of command retry usually are not significant; however, the following is a list of some of the differences which command retry can cause:

1. An immediate command specifying no chaining may result in setting condition code 0 rather than condition code 1.
2. Multiple PCI interruptions may be generated for a single CCW with the PCI flag.
3. Since CCWs may be refetched, programs which dynamically modify CCWs may be affected.
4. The residual count in the CSW reflects only the last execution of the command and does not necessarily reflect the maximum storage used in previous executions.

CHANNEL PREFETCHING

In System/360, on an output operation, as many as 16 bytes may be prefetched and buffered; similarly, with data chaining specified, the channel may prefetch the new CCW when up to 16 bytes remain to be transferred under control of the current CCW. In System/370, the restriction of 16 bytes is removed.

VALIDITY OF DATA

In System/360, the contents of main storage are preserved when power is turned off. In System/370, because main storage may be volatile or nonvolatile, the program must not depend on the validity of data in main storage after system power has been lost or turned off and then restored.

APPENDIX I. CHANGES AFFECTING COMPATIBILITY WITHIN SYSTEM/370

This appendix summarizes those changes included in the System/370 architecture that may affect whether or not a program written according to the original System/370 architecture runs on machines implementing the architecture described in this publication. Not included here are descriptions of compatible extensions, such as new facilities incorporated in System/370 that make use of unassigned operation codes and format.

READ DIRECT AND WRITE DIRECT

When the instruction INVALIDATE PAGE TABLE ENTRY is installed, the following changes apply:

- Both READ DIRECT and WRITE DIRECT are changed to use real instead of logical addresses.
- Program-event recording does not apply to the storage alteration performed by READ DIRECT.

STORE ACCESSES

The following changes are made as to when an access to storage for storing can take place.

- When the execution of the instruction is nullified or suppressed because of certain program exceptions, an update may occur at the operand location. Originally no storage access was permitted. In some of these situations, the channel may observe intermediate results which differ from the final result. See the section "Exceptions to Nullification and Suppression" in Chapter 5, "Program Execution."
- When the mask in STORE CHARACTERS UNDER MASK is zero, an update may occur at the byte location designated by the operand address. Originally no storage access was permitted.
- When the result of comparison in COMPARE AND SWAP or COMPARE DOUBLE AND SWAP is unequal, an update may occur at the operand location. Originally no storage access was permitted.

- When the result of the store operation is defined to be unpredictable, such as for STORE CLOCK with the clock in the error state, the store access may be omitted. How whether or not a store access takes place is visible to the program in four ways: an access exception may be indicated, the change bit may be set, a PER storage-alteration event may be indicated, and, for stores that are part of an update, the channel may observe the distinct accesses for fetching and storing. The fetch and store parts of an update appear interlocked to another CPU.

Whether or not a store access takes place is visible to the program in four ways: an access exception may be indicated, the change bit may be set, a PER storage-alteration event may be indicated, and, for stores that are part of an update, the channel may observe the distinct accesses for fetching and storing. The fetch and store parts of an update appear interlocked to another CPU.

FETCH ACCESS

Originally the definition required that, with the exception of some compare instructions, access exceptions on fetching be indicated for the unused portion of an operand. The changed definition permits the indication of the access exception for the unused parts to be unpredictable, except that an access exception still must be indicated for TEST UNDER MASK, INSERT CHARACTERS UNDER MASK, and COMPARE LOGICAL CHARACTERS UNDER MASK when the mask is zero.

OPERAND-ACCESS CONSISTENCY

Originally the access for the operand of LOAD MULTIPLE was specified to be doubleword-concurrent; that is, all bytes within a doubleword appear to all CPUs to be accessed concurrently. This definition is changed to require doubleword concurrency only if the operand is designated on a word boundary.

The restriction is removed that, during the padding portion of a MOVE LONG execution, another CPU can observe the operand to be

stored only once and only in the left-to-right sequence.

in the section "Store Accesses" in this appendix.

- Because of CPU retry, the change bit may be set to one for locations which the program has not accessed.

CHANGE BIT

Originally the System/370 architecture specified that the change bit be set to one each time information is stored in the corresponding storage block. This definition is changed as follows:

- The change bit now is necessarily set to one only when the contents of the corresponding storage block are changed. In situations where execution of the instruction can be completed without making a store access, such as in MOVE (MVC) with coincident operands or in OR (OI) with an immediate operand of zeros, the change bit may be unaffected. However, even when the change bit is not set, any applicable access exceptions or PER storage-alteration events are still indicated.
- The change bit may be set to one as a result of those situations described

SUBCHANNEL INTERRUPTION STATE

Originally only status associated with the termination of an I/O operation could cause the subchannel to enter the interruption-pending state. Status not associated with the termination of an I/O operation was held pending at the device, and the subchannel would be available. The changed definition allows status not associated with the termination of an I/O operation to be accepted into the subchannel. As a result of this change, a subchannel that is shared among multiple devices may cause condition code 2 to be returned to a START I/O or TEST I/O instruction even if no previous START I/O had been issued to the addressed device. This busy state persists until the interruption condition is cleared.

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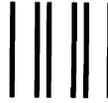
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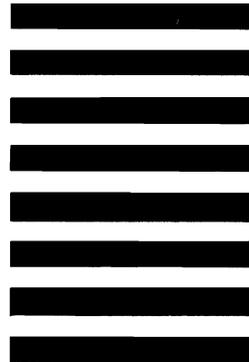
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