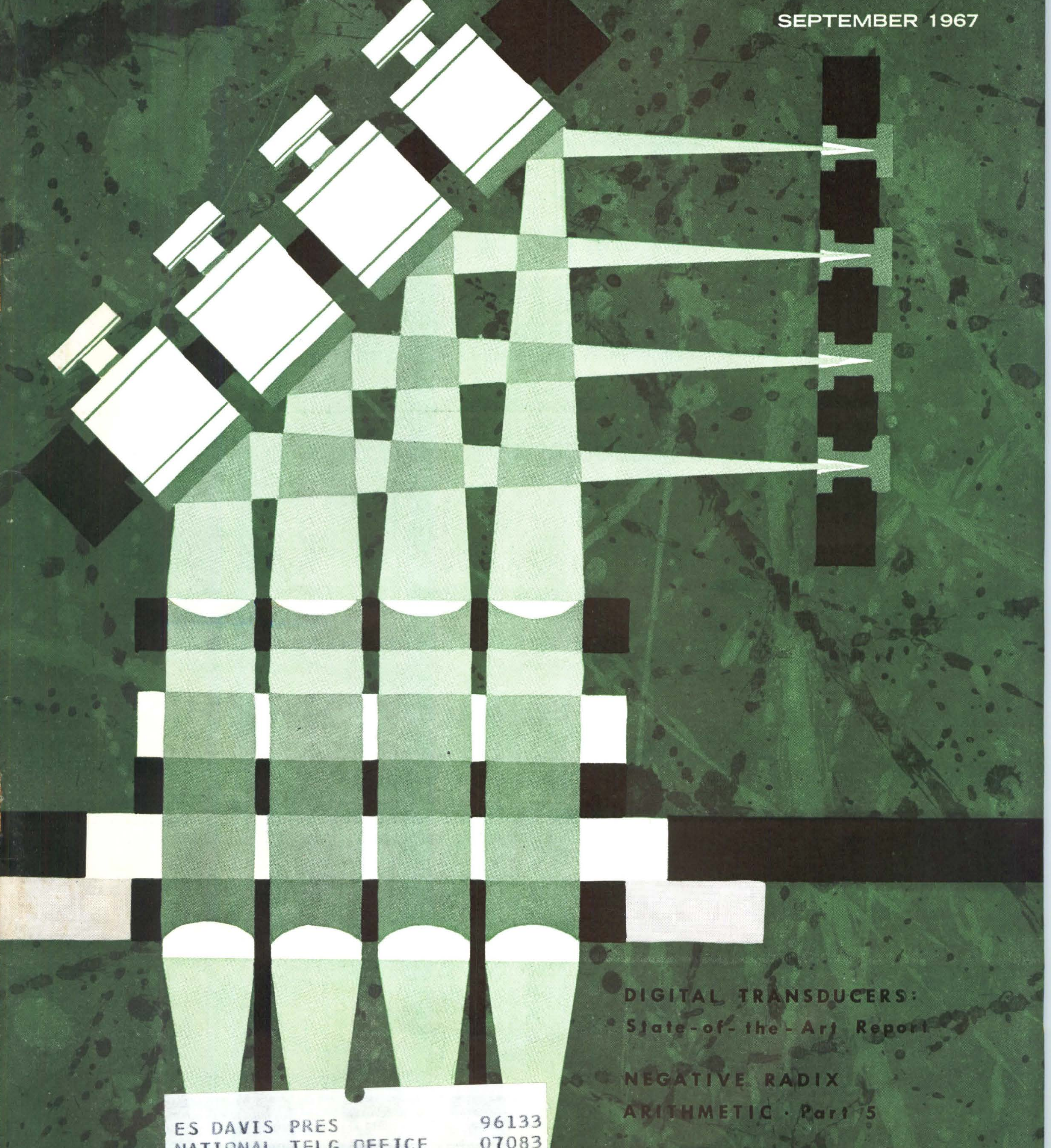
COMPUTER DESIGN

THE MAGAZINE OF MODERN DIGITAL ELECTRONICS

SEPTEMBER 1967



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CIRCLE NO. 1 ON INQUIRY CARD

SEPTEMBER 1967 • VOLUME 6 • NUMBER 9

COMPUTER DESIGN

THE MAGAZINE OF MODERN DIGITAL ELECTRONICS

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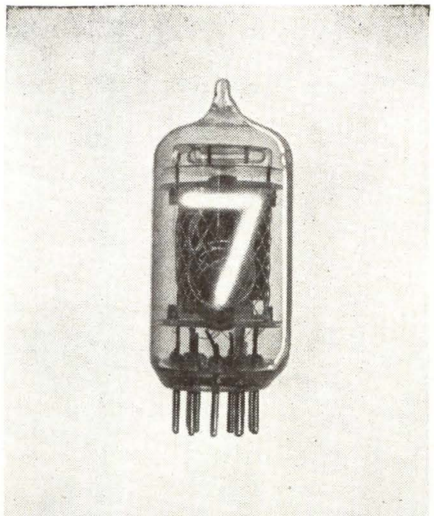
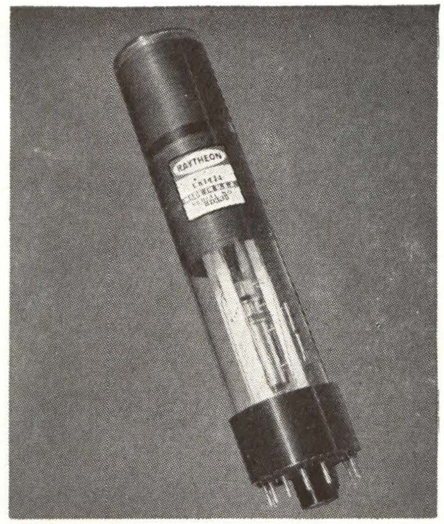
FEATURES

DEPARTMENTS

Raytheon Decade Counter Tubes are gas-filled, cold-cathode, glow discharge, bi-directional stepping devices, capable of operation at frequencies up to 100 kilocycles/sec. They provide both electrical and visual readout and are characterized by very long life, low current requirements, relatively few external components necessary for proper operation, and low operating temperature. These characteristics make them very useful as counters in such applications as radiation measuring equipment, timers, programmable counters and scalers, sorting apparatus, and many others. In these applications they can be used as scale-of-ten counters or as devices capable of operation at any desired preset scale.



Datavue* Side-View Tubes. New type CK8650, with numerals close to front, permits wide-angle viewing. These side-view, in-line visual readout tubes display singly numerals 0 through 9 or preselected symbols such as + and − signs. Their 5/8" high characters are easily read from a distance of 30 feet. Less than $5 in 500 lots, they also cost less to use because the bezel and filter assembly can be eliminated and because their mating sockets are inexpensive.



New Symbolray* CRT. This new tube provides alphanumeric inputs for computer readout devices. The tube's 2" target can be scanned electronically to select symbols, characters, and punctuation marks in sequence to form readout on a display tube. Designated type CK1414, this tube provides an economical method of generating characters for hard copy print-out or for cathode-ray display. Designs with 64 or 100 characters are available.

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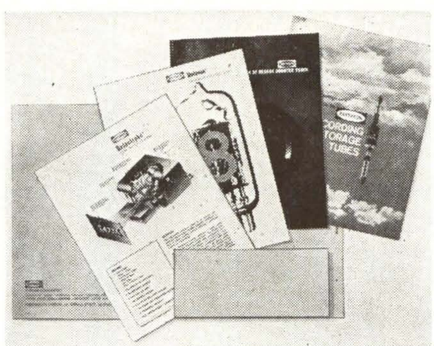

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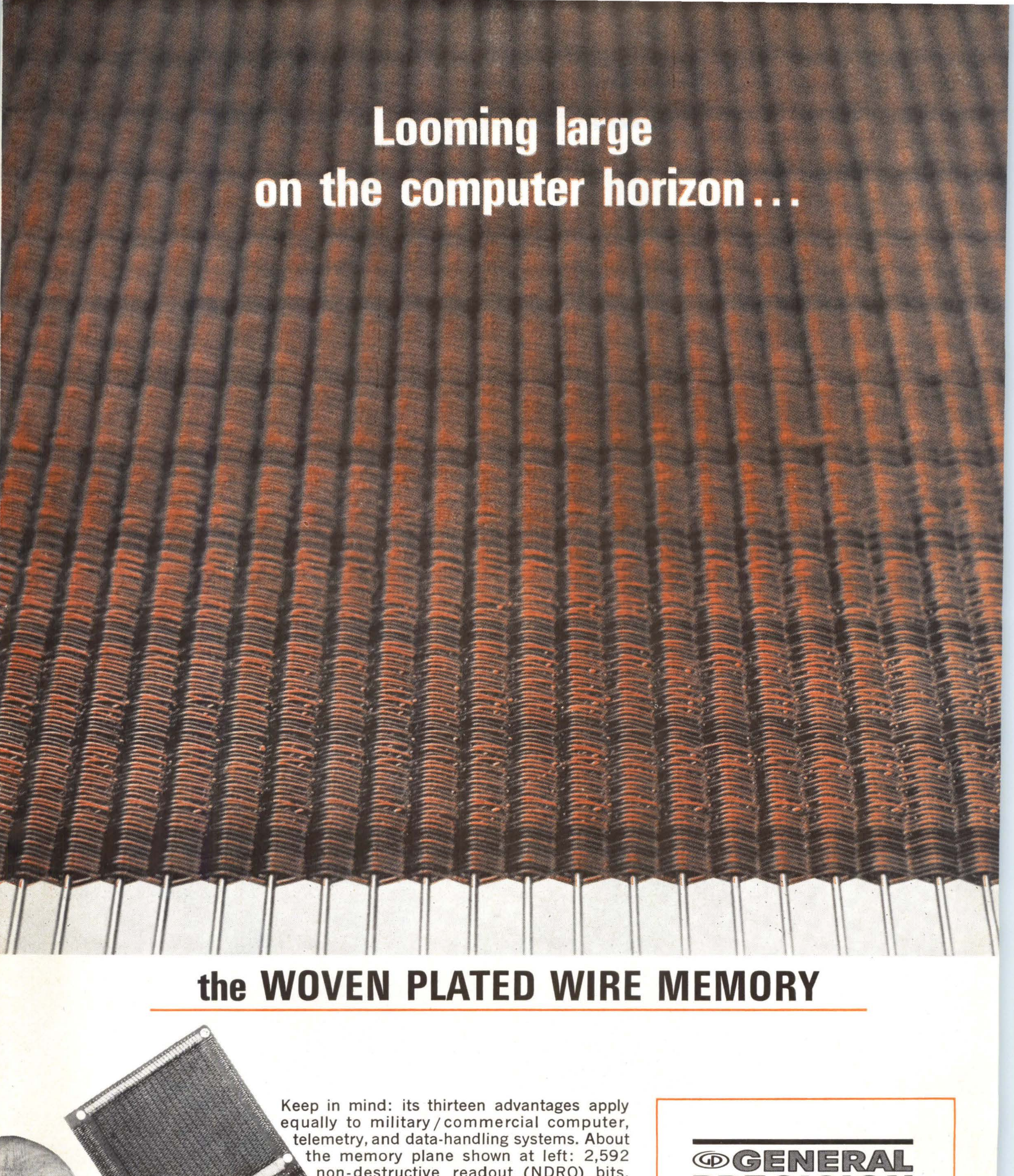
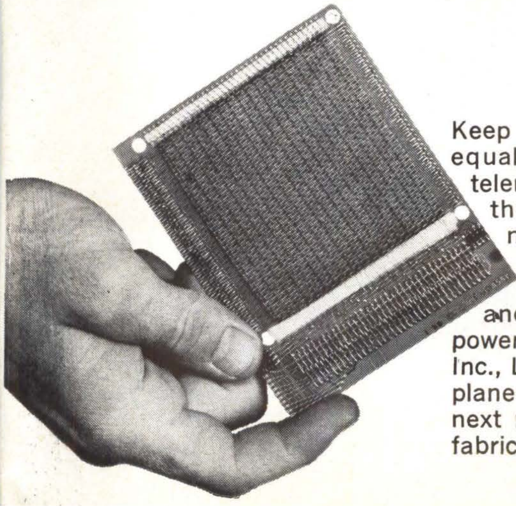


the WOVEN PLATED WIRE MEMORY



Keep in mind: its thirteen advantages apply equally to military/commercial computer, telemetry, and data-handling systems. About the memory plane shown at left: 2,592 non-destructive readout (NDRO) bits. Completely potted to withstand aerospace environments of shock, vibration, and temperature. Ultra-high-speed, low-power operation. ■ Keep General Precision, Inc., Librascope Group in mind to stack some planes or supply a complete system for your next memory application. Plated, woven, and fabricated in the U. S. A. Write for brochure.

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Now there are four reliable computer tapes

(Delivery is another matter)

As you may surmise from the name at the bottom of this message, CEC is the new challenger in the computer tape field.

We would like to add that the performance of our tape is demonstrably superior to our three competitors'. But that would not be true. All four are well within allowable tolerances of the reference tape used by the computer industry. And all are certified "drop-out free" for the first pass, and remain so for many more.

Obviously, since CEC had no exclusive on excellence, we had to have a pretty compelling reason for climbing on the totem pole.

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From the time you place your order, you should receive your CEC computer tape within 24 hours — virtually anywhere in the United States.

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Quite a difference, we suspect, from the delays you've become accustomed to.

This is no miraculous achievement on CEC's part. The advantage was already there. Namely, the largest established field force in the industry. Plus — the only warehousing facilities strategically located to serve the entire nation.

P.S. One more benefit: if you order CEC Analog Tape along with the new computer tape, you'll also realize some significant savings.

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Please send me complete information about CEC's new Computer Tape.
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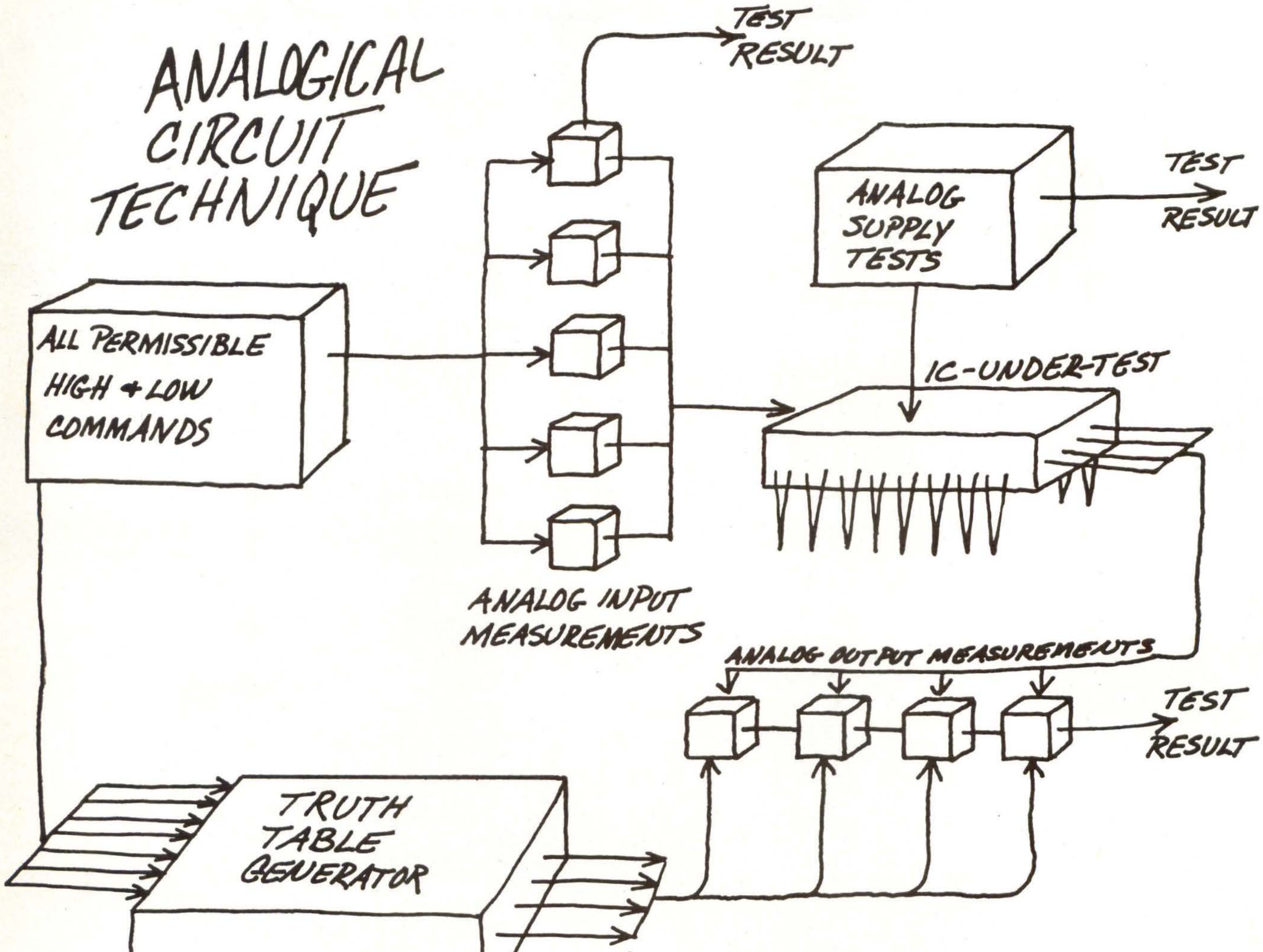

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I IN LO	1.1 mA MAX @ 1.1 V
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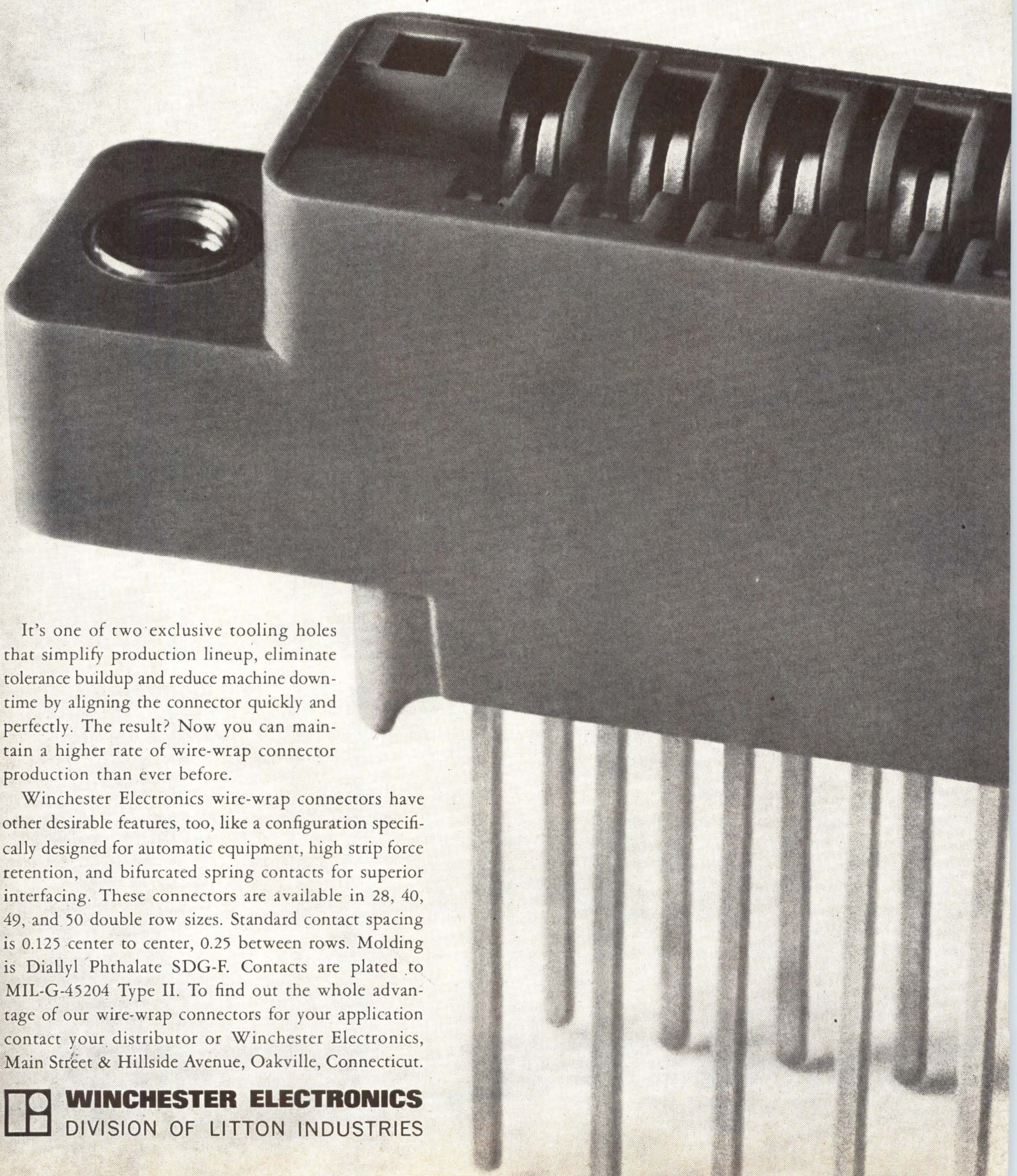

It's one of two exclusive tooling holes that simplify production lineup, eliminate tolerance buildup and reduce machine downtime by aligning the connector quickly and perfectly. The result? Now you can maintain a higher rate of wire-wrap connector production than ever before.

Winchester Electronics wire-wrap connectors have other desirable features, too, like a configuration specifically designed for automatic equipment, high strip force retention, and bifurcated spring contacts for superior interfacing. These connectors are available in 28, 40, 49, and 50 double row sizes. Standard contact spacing is 0.125 center to center, 0.25 between rows. Molding is Diallyl Phthalate SDG-F. Contacts are plated to MIL-G-45204 Type II. To find out the whole advantage of our wire-wrap connectors for your application contact your distributor or Winchester Electronics, Main Street & Hillside Avenue, Oakville, Connecticut.

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1968 SJCC CALL FOR PAPERS

The Technical Program Committee for the 1968 Spring Joint Computer Conference to be held in Convention Hall, Atlantic City, New Jersey, from Tuesday through Thursday, April 30th to May 2nd, has announced their call for papers. Contributors are invited to submit an original paper, reporting on any aspect of the computer or information processing field in breadth or depth, from hardware to software, and theory to practice.

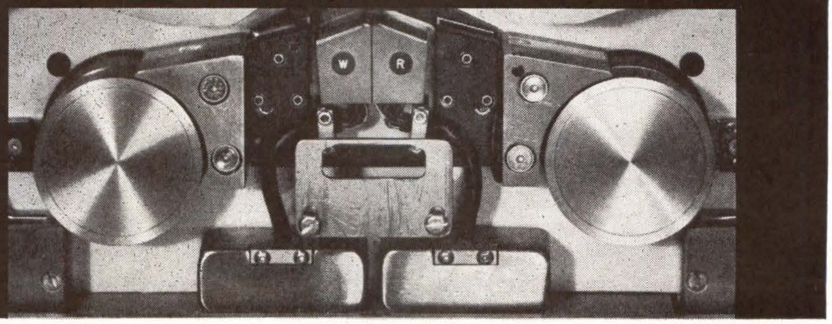
A contribution might be concerned with such topics of current interest as computer utilities, time sharing, the man-machine interface, computers and communications, computers and control, design automation, but need not be limited to them. Survey, tutorial, and interdisciplinary papers are also welcome.

Five copies of complete, but not necessarily final, drafts must be submitted by October 30, 1967. These must be typewritten double-spaced on one side only, should not exceed 6,000 words, and must include copies of all figures properly numbered. Each page should contain the name of the senior author and be sequentially numbered. The title page must include the full name of author, co-authors and their affiliation, city and state, as well as the title.

The senior author should list his mail address and phone number and will be assumed to be empowered to make all decisions regarding the paper. A 100-150 word abstract summarizing the contents of the paper should be attached. In the event of selection, a final draft complete with original drawings and photographs will be required by January 29, 1968 in order to meet publication deadlines for the 1968 SJCC AFIPS Conference Proceedings. All copies should be sent to: Professor T. R. Bashkow, Technical Program Committee Chairman, 1968 SJCC Department of Electrical Engineering, 1312 S. W. Mudd, Columbia University, New York, New York 10027.

IBM STARTED SOMETHING WITH ITS DUAL-CAPSTAN TAPE DRIVE.

(MIDWESTERN FINISHED THE JOB.)



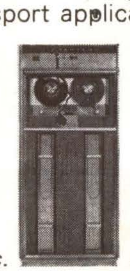
In the field of high performance digital tape transports for use with computer systems, there are really only four names to consider: IBM, Midwestern Instruments, Ampex and Potter. If it's an IBM system you're working with, there are only two logical choices: IBM and Midwestern. If data reliability to the order of 10^9 data bits is any criteria, there's only *one* choice: Midwestern's 4000 series transport.

Both IBM and Midwestern tape transport designs utilize a rapid-response, dual-capstan drive. This eliminates the necessity for programmed delays which are required by single-capstan drive systems. But not even IBM's original equipment can equal the trouble-free performance, the extended tape life and the data reliability of the patented, positive-pressure dual-capstan drive developed by Midwestern.

Midwestern's 4000 series transports cover the complete range of operating speeds required by various computer systems, from a low of 25 ips to a high of 150 ips, at bit densities of 200, 556 or 800 bpi (1600 bpi on special order). These units can be provided in either 7 track or 9 track configurations, and all are available to interface with either discrete component or integrated circuitry.

These Midwestern 4000 series transports and IBM original equipment units are the *only* field-proven IBM-compatible digital tape transports—the only units actually working on line with IBM computers at various customer installations. What's more, no other unit (*including* IBM) can guarantee data reliability in the order of one transient error per 10^9 data bits. If the 4000 series can out-perform IBM units on their own computing systems, doesn't it stand to reason they're the best choice for *your* system application?

If you'd like to hear more about our 'small wonder' 4000 series digital tape transports, just give us a call (collect) at 918-627-1111. We're programmed for fast analysis of any digital tape transport application, no matter how unique.



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CIRCLE NO. 18 ON INQUIRY CARD

commentary

Comments and opinions on topics of current interest to digital design engineering personnel. A monthly column organized and prepared under the direction of **T. PAUL BOTHWELL, Contributing Editor.**

COMPUTER SOFTWARE: PROBLEMS AND SOLUTIONS

Dr. Robert A. Cowan

Since the computer industry was founded there has been considerable discussion about software problems. Initially, computer manufacturers supplied a minimal software package, if any at all, and the computers were programmed using machine language — a grueling process, to say the least. As the programming process matured, aids such as assemblers and compilers were developed. Through the pressures of competition and user requirements, these software aids have now become a part of the standard software package supplied with most computers. However, the picture does not end here. Currently, many manufacturers offer "canned" solutions to specific application problems apparently free-of-charge. In addition, there is custom programming — usually available for a fee.

There is no question as to whether software is important or not. After all, a computer can't do useful work until is has been programmed. But all too often the degree of importance has been sorely underestimated by all concerned. Some of this has been due to treating software as a service to the hardware instead of as a product having its own significant, identifiable value. Current trends indicate that the computer community is now treating software as a product — an important conceptual change with many ramifications. One example is the growth of software companies. Most often software is their major or only product.

Critical Software Problems

Several problems concerning software have reached a critical state in today's computer world. First, there is a tremendous need for software products in all areas of computer applications. These needs range from programming aids such as better compilers to solutions to special problems. The obvious way to satisfy these needs would be an increased supply of talented programmers. But, let's not kid ourselves. Realization of this solution will be a long time in coming, according to the present growth rate of computer utilization. This lack of sufficient programming talent, combined with a need for improved methods, results in software's being a very expensive product. It is not uncommon to have the total software development bill exceed the hardware development cost.

Because of the nature of software, and the attitudes and capabilities of the people involved, quality control has not been as successful as it has been in hardware. Part of this is due to the intricacies of computer programs, to the considerable time required to check out and qualify the software, and to the verification of the accuracy of the reproduction process. In the past, part of the poor quality control resulted from inadequate emphasis on software, insufficient funding, and limited talented manpower.

Another situation which does not lend itself to a simple solution is the proliferation of special software and jury-rigged versions of standard software used to handle specific problems. Then, of course, there are the slight variations from so-called standard arrangements. Some people may say that this is a result of a lack of standards, but I believe the problem goes deeper than that. Standards are an excellent way to provide solutions to common problems. However, when you consider the growth of new problems today, the application of computers in new areas, and the development of new hardware and software techniques which are not compatible with the common areas of the past, adoption of a universal set of standards becomes illogical. It is highly probable that the best solution will result in several different kinds of standards for different problem areas (i.e., current efforts to establish standards for the FORTRAN and COBOL languages), and in a constant effort to find and develop

The author of this month's CD Commentary, Dr. Robert A. Cowan, is Marketing Manager, Systems Software, at Honeywell's Computer Control Division.

more comprehensive and less restrictive programming methods.

One must also consider the problem of who is responsible for the software, and just what software should be supplied with the computer. Some say that the customer should get a total hardware/software package that will solve his particular set of problems. Others feel that the customer buys an equipment capability, and how he applies it for problem-solving is his own responsibility. In either case, the software costs money — which raises a second question: **How should it be paid for: directly, or buried in the price of the hardware?**

The solution to these questions is simplified, although not resolved, by considering software as a product. Obviously, the vendor is responsible for providing products which perform according to specification. In addition, this makes it easier to specify the total hardware/software package required and to relate this package to the price tag. Under these conditions it doesn't really matter how the software is paid for if the resultant price is the same.

No Simple Answer

It would be gratifying if one could analyze the situation and arrive at a simple, single answer to the software quandary. But there are no such answers to complex problems. One can only conclude that the finding of solutions will require an intensive effort on the part of both manufacturers of hardware and software and their customers. Several factors listed below can be of help.

- An acceptance of software as a valuable product by management in the computer community and not just as a service to go with the hardware. Just considering it as a product leads to better planning, scheduling, documentation, funding, and budgeting. Now, all too frequently, a piecemeal approach to software results in many of these factors going out of control.

- Hardware and software should be planned, designed, and developed as a single integrated product to obtain the best total system performance and ease of use, instead of developing the hardware to its ultimate and then developing the software as best one can. After all, in some cases, a simple hardware change can result in a significant simplification in the software and, hence, an improvement in the total system performance.

- A better delineation between standard programs that are made available with the hardware, and special software that must be developed or adapted for individual applications. Standard software should be a part of the package; special software and adaptation, something for which the customer pays.

- An understanding between the parties that major improvements in software are not available to the customer in perpetuity, but are "products" that he must buy. It makes no sense to say that a computer manufacturer should spend substantial sums to develop and distribute new software just because a user has previously purchased hardware. The user should pay for state-of-the-art improvements in software, just as he does for hardware.

- A greater effort to define exactly what the customer is to receive before he signs the purchase order. This probably never can be done to everyone's complete satisfaction. But unlike the situation that sometimes has occurred in the past, when the customer has expected a problem-solving package and instead has received a tool kit, the difficulties will be fewer and easier to resolve, and both parties will be better satisfied with the results.

- A more realistic — or let's say less optimistic — release date for the introduction of new hardware and software. The development sequence on new computers mitigates against the total software packages being ready at the same time the initial machines are. We shall never reach the millennium when everything is ready on the first day, but we can do better. When one thinks of the problems that have been associated with new computers, it becomes apparent that many were caused by unfamiliarity with equipment capabilities and, therefore, inaccurate and incomplete software at the time of introduction.

When you sell 650 PDP-8/S computers in the 8 months since it was introduced, you develop a little confidence, and you start doing things differently.

(The PDP-8/S is a full, general purpose, 4096 12 bit word core memory, FORTRAN-speaking, expandable digital computer complete with ASR-33 teletype and software. It sells for $10,000 each. Generous quantity discounts.)

For one thing, you think about stocking the computer, like other instrument makers stock voltmeters, even if nobody has ever done that before. And that's exactly what we've done. Effective now, small quantity orders of the PDP-8/S are available off-the-shelf. Instantaneous delivery. Larger quantities still require a short delivery schedule.

And secondly, we've put at least one in every field office we have — 22 of them. If you must have the computer that's in the field office, you back up your car open your trunk, and take it. We'll send the field office a replacement. That way, it becomes off-the-shelf instantaneous delivery not only in Maynard, Mass., but around the country.

Mail and phone orders will be filled promptly, too.

Gentlemen:

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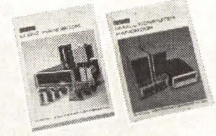
Send computer.

______Send sales engineer.

______Just send free books, now.
Maybe computer later.



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DC OUTPUT

from our man in Washington

U. S. manufacturers sold $48 million worth of semiconductor integrated circuits during the first quarter of 1967, up 59% from sales of $30 million during this period last year, reports the Electronic Industries Association. With an average value decline of 33%, unit sales climbed 136% to reach 11.9 million during the January-March 1967 period. Sales of digital IC's amounted to 10.6 million units valued at $35.9 million during the first quarter of this year, rising by 123% and 48%, respectively, from unit and dollar sales during this period in 1966. At 1.3 million units valued at $12 million, analog IC's were up 344% and 107% in unit and dollar sales, respectively, during the 1967 first quarter.

The Air Resources Laboratory of the Institute for Environmental Research and the Weather Bureau have devised a plan designed to bring computerized pollution potential forecasts to every major U. S. city. The Weather Bureau and the Institute are branches of the Department of Commerce's Environmental Science Services Administration. A major first step is the use of giant computers at the Bureau's National Meteorological Center to forecast weather conditions related to the buildup of pollution.

MILSCAP (Military Standard Contract Administration Procedures), a standard information system, has been developed by the Defense Department for use by the military services, the Defense Supply Agency, and the Defense Contract Administration Services. MILSCAP is designed for high-speed digital data transmission and EDP, and to standardize information data in the functional areas of procurement, contract administration, inventory control, storage, and financial accounting. The new system replaces a variety of non-standard procedures currently in use by procurement and contract administration activities throughout Defense. MILSCAP will be installed progressively because of its impact on existing procedures and may require two or three years for complete implementation.

A recent study of magnetic computer tape by the General Services Administration recommended the procurement and acceptance testing of new tape and that cleaning of tape, now in inventory, be centralized. It is estimated that a potential savings of $8 million a year can result from centralized inventories. Plans are now being made to implement this project.

A survey of comprehensive software systems for handling information-retrieval and data-management application is being conducted by the National Bureau of Standards' Center for Computer Science and Technology. Purpose of the survey is to obtain information on the state-of-the-art for dissemination to the technical community and for use by the Center in fulfilling its mission. To assist the survey, all organizations having software systems of the type mentioned are urged to send the latest descriptive information on them to A. Severo, Systems Research and Development Division, Center for Computer Sciences and Technology, National Bureau of Standards, Washington, D. C. 20234.

Recent Government Contracts

SYSTEMS DEVELOPMENT CORP., Santa Monica, Calif., has received a $2,835,350 cost-plus-fixed-fee contract for advanced development work on a prototype data management system by the Army. The Defense Supply Service, Washington, D. C., is the contracting agency.

BENDIX CORP., Davenport, Iowa, has been awarded a $1,410,717 fixed-price contract for production of airborne computer components by the Air Force. Work will be done at Denver, Colorado. The contract is being awarded by the Aeronautical Systems Division.

SYLVANIA ELECTRONICS SYSTEMS, Needham Heights, Mass., has been awarded a $1,783,923 fixed-price incentive contract for a research tool digital computer system by the Navy. The Naval Training Device Center, Orlando, Fla. is awarding the contract.

MIT, Cambridge, Mass., has been issued a $2,950,000 cost-reimbursement contract for additional multi-access computer study by the Navy. The Office of Naval Research is the contracting agency.

IBM CORP., El Paso, Texas, has been issued a $1,358,102 contract order for purchase of EDP equipment. Work will be done at White Sands Missile Range, N. M. The Philadelphia Procurement Division, Army Electronics Command is issuing the contract.

SPERRY RAND CORP., UNIVAC DIV., St. Paul, Minn., has been issued a $4,372,575 fixed-price contract for computers with peripheral equipment and engineering services for Navy surface vessels. The contract is being issued by the Naval Ship Systems Command.

TEXAS INSTRUMENTS, INC., Dallas, Texas, has been awarded a $3,378,512 firm, fixed-price contract for the design, development, and production of a tactical information processing sub-system by the Aeronautical Systems Division, Wright-Patterson AFB, Ohio.

GOVERNMENT REPORTS ★★

STANDARDIZATION OF COMPUTER SYSTEMS

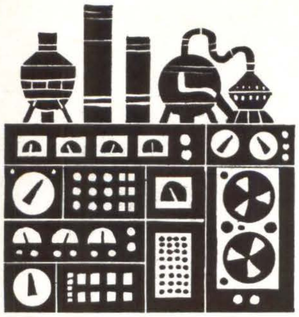
On the standardization of computer systems, E. Morenoff and J. B. McLean, Air Force Systems Command, Griffiss Air Force Base, N. Y., Apr. 67, 22p. Examines the relationship of program compatibility (ability to execute programs written for one computer system on another computer system without any reprogramming) to the evolutionary modernization of computer installations.

Order from Clearinghouse, U.S. Dept. of Commerce, Springfield, Va. 22151. Order No. AD-651-861. Price: $3.00.

BATCH-PROCESSING TECHNIQUES FOR IC's

The development of batch-processing techniques for passivating and terminating silicon integrated circuits has been released in a report of work performed for the U.S. Army. The report summarizes a project undertaken to develop circuits that could be direct-mounted and interconnected with several other circuits on a single substrate. A general process was established for glass coating silicon integrated circuit chips and attaching them in batches to an appropriately processed substrate. The techniques were demonstrated by the delivery of four 10-chip arrays of glassed silicon microcircuit flip-chips assembled on a plug-in printed circuit board. The report also provides information on wafer glassing and the other processes involved in flip-chip assembly as well as the results of a test sequence demonstrating the effectiveness of the process.

Order from Clearinghouse, U.S. Dept. of Commerce, Springfield, Va. 22151. Order No. AD-652-699. Price: $3.00.



INDUSTRY NEWS

INDUSTRY SALES OF MAGNETIC RECORDING TAPE ARE EXPECTED TO REGISTER A 20 PER CENT GAIN THIS YEAR OVER 1966, it was predicted by William T. Hack, president of Audio Devices, Inc., at the company's annual meeting. He said that tape sales would approach the level of $200 million in 1967 as compared to about $165 million for the previous year, a gain of 20 per cent for the year. The sales figure for 1966 represented a 30 per cent increase over 1965. Mr. Hack stated that manufacturers sales of digital and audio tapes would continue during 1967 to be the most rapidly growing segment of the market. He estimated 1966 sales were about $65 million for digital, $50 million for audio, $30 million for instrumentation, and $20 million for TV tape.

RCA DELIVERED THE LAST OF 30 COMPUTERS THAT CHECK OUT NASA APOLLO PROGRAM SATURN 1 AND SATURN 5 ROCKETS. The systems were built for Marshall Space Flight Center under contracts totaling $75 million. The computers check rockets during countdown before launch. The RCA computer systems are designed for use at all levels of the program—research and development, production and ultimate launch of uprated Saturn 1 and Saturn 5 rockets. The systems were built by RCA's West Coast Division, Van Nuys, Calif., under contract to NASA's Marshall Space Flight Center, Huntsville, Ala. RCA will continue to provide maintenance and support services on the systems under a separate contract. NASA facilities at which the computers are installed are at the Kennedy Space Center, the Marshall Space Flight Center, Michoud Assembly Facility in Louisiana, and the Mississippi Test Operations site. At the Kennedy Space Center, two computers are located at each uprated Saturn 1 and Saturn 5 launch site. Tied together by a digital data link, they check out the launch vehicles and ground support equipment during count-down prior to launch. The computers are designed to operate with one computer checking the vehicle by commanding it to perform functions such as exercising valves and measuring the resultant performance. Should a problem arise, the launch pad computer uses the data link to inform its "twin" in the Launch Control Center, which in turn initiates a search to pinpoint the trouble and specify what corrective action must be taken. The remaining computers are used for various types of checkouts during assembly and tests of the rockets. Each Saturn ground support computer has a high speed memory of 32,768 words. Auxiliary drum storage of 32,768 words also is provided.

DIGITAL INTEGRATED CIRCUIT TESTER

New Testing Concept Greatly Simplifies The Programming Of Logical Requirements.

A new concept for testing complex electronic components and circuits has been announced by Teradyne of Boston, Mass. The name given to this concept is "Analogical Circuit Technique." Its announcement coincides with the introduction of Teradyne's Act I instrument, the first commercial application of the technique. The instrument is for the testing of digital integrated circuits.

Teradyne described the necessity behind the development in these terms: "When purely logical functional tests are performed on workable circuits, test conditions are not critical; the workable circuits pass the tests. But when performing tests on catastrophically defective circuits, the test conditions (actual analog values) must be specified and controlled before the logical cause of the defect can be determined. Since a high percentage of defects are analog in nature, purely logical testing by itself will not satisfy inspection needs.

"However, the realities of the market place imposed overriding economic necessities: testing must be fast and programming (establishing the test plan) must be simple. Ways had to be found to make it easy to establish the test conditions precisely so that causes of defects could be economically determined; in effect, to bridge the gap between parameter and functional testing."

Teradyne's approach is through

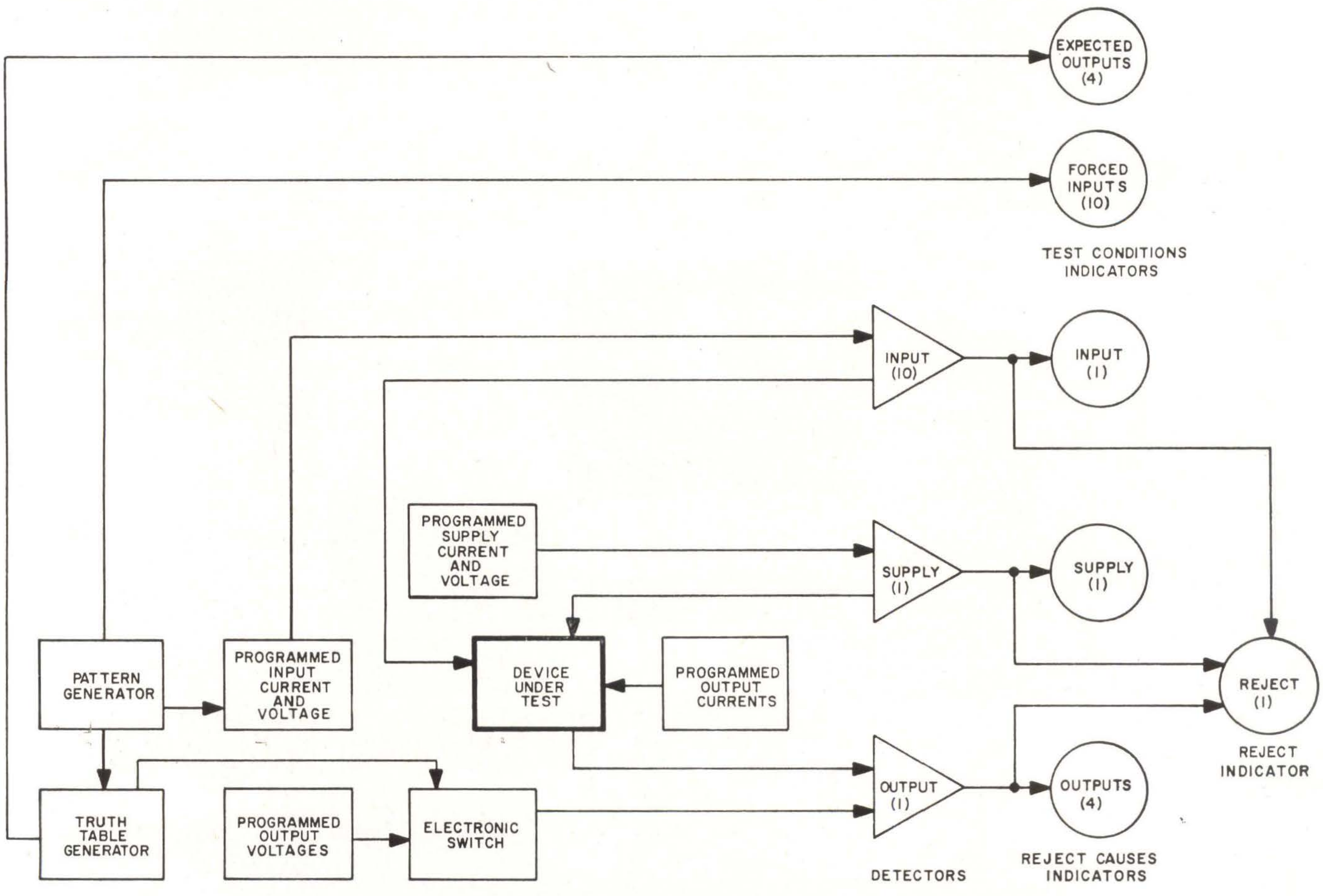


Fig. 1. Simplified conceptual block diagram of Teradyne's new digital integrated circuit tester, called Act 1. In operation, the Pattern Generator continuously steps through all the possible desirable combinations of digital input commands which drive programmed-forcing functions that imposed on the device-under-test. The same commands simultaneously drive a Truth Table Generator; the analogous circuit, selected to produce the same truth table as is expected from the device-under-test. The truth table outputs then select the appropriate high-or-low limits to be compared at the Output Detector to the actual outputs of the device-under-test. Thus, the proper output tests are always made for each input combination. A programmed source similarly provides the appropriate supply voltage. The voltages or currents resulting from the forced inputs and the supply source are similarly compared to the programmed limits at Detectors for each step of the Pattern Generator. In this way, all the tests are made under all possible desirable conditions of digital input. Failure of any measurement test to pass a test is indicated on the one or more Reject Causes lamps. From the Pattern Generator, the combination of input commands, high or low, are displayed on the Forced Inputs lamps; and the expected outputs on their lamps. From this display of the test conditions and the source of the reject signal, the cause of defect can usually be determined.

the Analogical Circuit Technique. It can be stated in a way which indicates the source of its name: "Exercise the inputs and outputs of the device-under-test and examine them according to the LOGICAL truth table of the device. Execute these inputs and outputs as carefully-defined ANALOG forcing functions and examine them as ANALOG measurements, both with significant precision."

According to one Teradyne spokesman, the synergistic aspect of parameter and functional testing makes Act I a very powerful little machine. In Act I, the technique is implemented, according to the company, in a conceptually elegant manner, making possible, for the first time, an inexpensive instrument for valid testing of digital integrated circuits. For example, to produce truth table inputs, a modified counter with as many stages as the device has inputs produces the desired 1's and 0's. Also, to establish the expected truth table outputs, a circuit is employed whose **logical** performance is analogous to the acceptable performance of the device-under-test, but whose analog properties are **not** significant. The simplified conceptual block diagram of Fig. 1 illustrates these examples and the application of the Analogical Circuit Technique.

Act I, shown in Fig. 2, can do up to 10,000 parameter measurements in 1000 steps and in only 1/100 of a second. Up to fifteen simultaneous analog measurements can be made at a ten-microsecond logical step. Programming is done by two 5" x 6" circuit cards, one covering all devices within a particular family and grade, the other the individual model to be tested. To ease the common burden of programming integrated circuit tests, Teradyne offers a new mail-order service. Cards are available programmed for the specifications of popular integrated circuits, or blank cards are offered with instructions for self-programming. Act I handles circuits with up to 16 leads, comprising up to 10 inputs, up to four outputs, one supply and one ground lead in standard TO-5, dual-in line, and flat packs. More complex circuits are handled with external connections. Testing is completely automatic. Test sequencing occurs continuously. When a circuit is inserted in the test, the reject lamp goes out if the device passes, stays on if the device fails. Productivity is limited only by the handling time. According to the company, manual operators test an Act I at about 400 circuits per hour. Combining Act I with a bowl-fed automatic handler will test over 7000 circuits per hour.

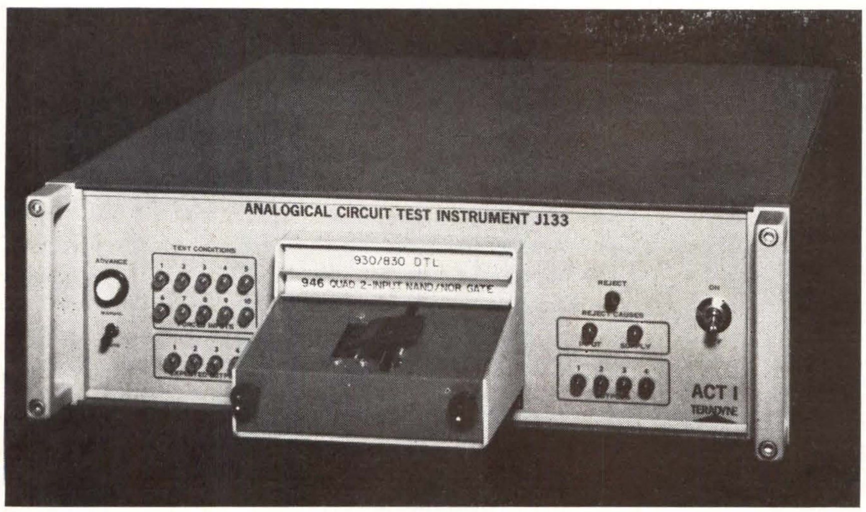
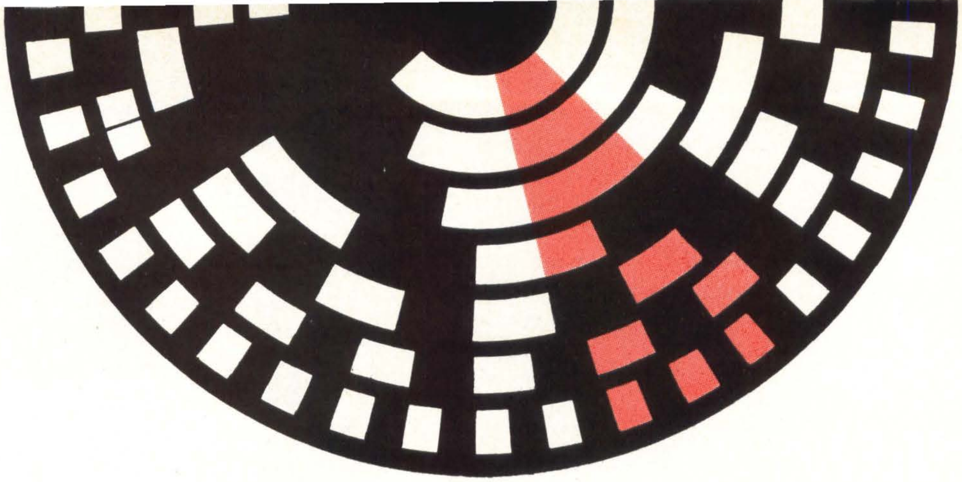


Fig. 2. This new test instrument makes 15,000 analog and logical tests on digital integrated circuits in 1/100 of a second.

Causes of rejects are displayed on front panel lamps. A rejected circuit is stepped through each failed test as the lamps display input and output logical conditions and whether defects occur at the input, output, or the supply.

Range and accuracy depend on the particular parameter to be measured. In summary, voltage range is 0 to 8 volts; current, 0 to 50 milliamperes. Measurement accuracy of the instrument is 3% to 5%. Act I is warranted for 10 years; cards, for one year. For more information:

Circle No. 106 on Inquiry Card



DIGITAL TRANSDUCERS:

State-of-the-Art Report

This article is based on Summary Report No. 1 of the Transducer Information Center (TIC) at the Columbus Laboratories of the Battelle Memorial Institute. A complete list of references and a bibliography for this article are contained in the TIC report which is available from the Defense Documentation Center, under AD-480006, Alexandria, Va.

Many of the outstanding advancements in the sciences and technologies associated with aerospace research and development, and industrial controls and automation, can be attributed in part to transducers. Since most physical phenomena are of an analog character, most transducers were originally of the analog type. However, as scientific and technological advances were made, the need for data application to systems for telemetering storage and computation clearly emphasized the advantages inherent in handling data in the digital form. The initial method of digitizing the data produced by analog transducers was to convert the conditioned signal to digital form through the use of electronic analog-to-digital converters. Ever since this need for data in digital form has been recognized, however, attempts have been made to develop transducers that would sense analog-type variables and convert the measurement immediately into digital signals. During the past decade, many techniques were developed for digitally quantizing closer to, or even in, the sensor.

There has been a strong tendency to define the transducers with quantized-signal outputs as true digital transducers, however, they are fundamentally different from transducers that originate quantized signals, and this has caused some confusion in the definition. An objective of this article is to review various techniques which typify the trend toward the use of digital transducers. Reviewing the principles and applications will lead to a better understanding of the various digital-transduction techniques, and some agreement can be reached concerning definitions. Another objective of this article is to review current and past research and development programs that have contributed to the advancement of the state-of-the-art of digital transducers.

CLASSIFICATIONS OF TRANSDUCERS

The problem of investigating the current state-of-the-art for digital transducers is complicated by the fact that practically all forms of physical phenomena are of analog nature, and conversion to digital form must take place at some point between the energy sampling of the stimuli and the subsequent transformation to a measurable signal. Thus, if a definition were formulated on the basis of stimuli characteristics, there would be practically no digital transducers. When transducers are examined to determine their basic operational differences, it becomes possible to divide the entire group into two distinct classifications. The larger group contains transducers whose output signals are a function of voltage or current amplitudes proportional to the summed forces or energy sampled by the sensor. The second, smaller group consists of transducers that provide outputs of a frequency or pulse characteristic; and a variation in the sampled stimuli magnitude would be reflected by a change in frequency, pulse rate, pulse position, pulse width, or pulse coding. With these two broad groupings, it now becomes possible to classify the

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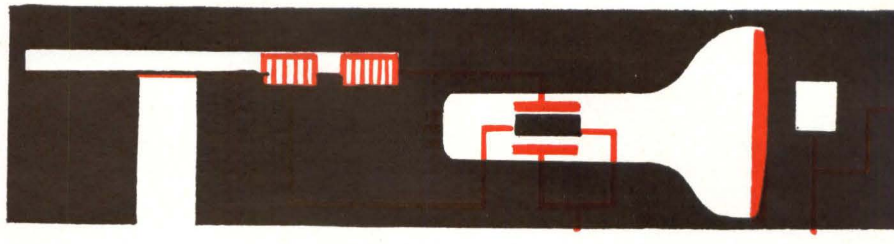


THE TRANSDUCER INFORMATION CENTER

The Transducer Information Center, TIC, was established in 1963 at the Battelle Memorial Institute, by the Air Force Flight Dynamics Laboratory at Wright-Patterson Air Force Base; its mission is to collect, analyze, store, and disseminate transducer information and data to government agencies, contractors, and subcontractors, at the Air Force. The TIC is concerned with all kinds of transducers for use in all environments and applications.

Transducer information is collected from all possible sources (manufacturer's data, technical articles and papers, laboratory reports, patents), both foreign and domestic, by the TIC; it is analyzed, evaluated, and the significant information is filed by "clue words" in an information storage and retrieval system. The information is then used in the three ways listed below.

- Reports — A Quarterly Accession List is distributed; state-of-the-art reports are prepared, summarizing information and data in a particular area. (This article is based on one such report.)
- Inquiry Service — Written or telephoned requests are researched and reported on by technical specialists, using the TIC information file.
- Personal Access — The information in the TIC is available for visitor use, and the assistance of technical and information specialists and clerical personnel is provided to Air Force agencies and their contractors.

first group as **analog** transducers, and the second group temporarily as **digital** transducers.

When the second group of transducers is closely examined, a difference is observed in operational principles. The majority of these transducers have a signal output which is characterized by **frequency signals** or **a series of pulses** requiring some form of counting over a precise period of time; to obtain data in a digital form, an electronic counter is frequently used. The other, smaller portion of the digital transducers is characterized by a signal output which appears as a **discrete code;** this coded signal can be obtained when the system is interrogated, and does not involve a count over a period of time. **In this respect, the transducer possessing a discretely-coded output can be described as the true digital transducer.** The most common example of a true digital transducer is the shaft-position encoder.

The three types of transducers can be somewhat arbitrarily classified into three domains of state: the analog transducer falls in the voltage- and current-amplitude domain; the intermediate class of transducer falls in the time-domain and, as such, will be called a **semi-digital transducer;** the true digital transducer falls in the space domain.

Advantages Of Digital Transducers

It is appropriate to explore briefly why digital transducers are necessary since the input variable is normally analog in character, and since digital coding is an invention of man for the convenience of man. There are four main reasons normally given to justify the need for digital sensors. These are (1) ease of signal handling, (2) reduced sensitivity to noise, (3) relative precision of digital time and displacement measurements, and (4) direct compatibility with digital systems.

- **Signal Handling** — Digital signals can be stored for any length of time, transmitted and detected, or read out as many times as necessary without inherent loss of accuracy. Analog signals are distorted by each of these processes and overall accuracy is lost. This inherent advantage of the digital-signal form applies primarily to the transmission and computing portions of the control or monitoring system; however, it does tend to support the conclusion that, if digital computation or long-distance signal transmission is involved, the analog-to-digital conversion should be accomplished as close as practical to the point of actual measurement.

• **Noise Insensitivity** — Digitally-coded signals are inherently less sensitive to noise pickup, sensitivity drift in the pick-off, environmental effects on the pick-off, signal-level drops through commutators, and other forms of irregularities that cause errors in measurements. The reduced sensitivity to noise results from the readout being concerned with the presence or absence of a signal condition, rather than being a precise measure of signal strength as in analog transducers.

• **Precision** — The precision with which time can be measured electronically makes measurement through semi-digital transducers possible. There are a large number of precise commercial devices available for direct digital encoding of large displacements, both angular and linear.

• **Compatibility With Digital Computers** — The most obvious advantage of digital sensors is the elimination of the need for A-D conversion equipment. There are two main factors involved in the discussion of this advantage. First, the advantage is probably lost if the A-D conversion function is simply removed from the computer to the individual sensors or to some other location in the processing system, particularly if the input converter was used for a number of input channels. Second, since there is no standard digital format for computer use, the need for A-D conversion at the computer input may be replaced by the need for a digital-to-digital conversion, which in some cases may involve more volume, weight, and power consumption than the A-D conversion that the digital sensor output eliminates. It is apparent then, that the best location for the A-D conversion function in a real system will be determined by a combination of factors (sensor environment, input parameters, sensing technique, transmission distances involved, computer type, etc.), and a true digital sensor is not clearly superior for all systems.

DIGITAL TRANSDUCER TECHNIQUES

If no further consideration is given to strict separation between semi-digital and true digital transducers, many transducers can be included in the basically-digital category of sensors which function within the time and space domains. The most common types of digital transducers are those that function according to such basic principles as (1) frequency modulation, (2) frequency or pulse generation (including nuclear particle counting and optical sensing), (3) photo-elasticity, (4) optical interference fringes, (5) optical sensing, and (6) position encoders. Although some of these techniques have long been associated with analog-digital systems, they have sufficient differences to merit discussion because of the advantages they possess for providing digital signals.

Frequency-Modulated Transducers

The forms of frequency modulation for generating digital signals include the vibrating-wire, variable-reluctance, synchro-inductive, and variable-capacitance types of transducers. Transducers that utilize these principles have a frequency output which varies as a function of continuously-changing physical stimuli; these variations in frequency are associated with a time base and can be counted accurately. One basic advantage of frequency-modulation techniques is that they can easily be adapted to FM-FM telemetry systems without additional subcarrier oscillators.

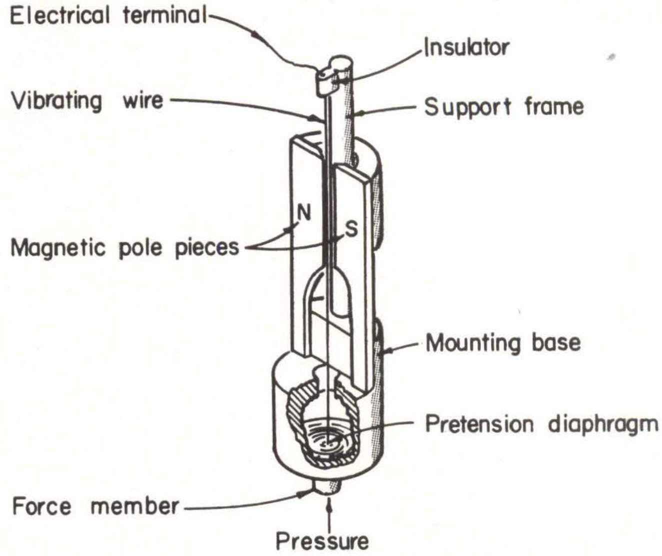


Fig. 1. Sectional view of a vibrating-wire transducer.

The **vibrating-wire** pressure transducer consists of a tungsten wire held in tension and suspended in a magnetic field between an anchor point and a diaphragm (see Fig. 1). The natural frequency of the taut wire is determined by relationships between tension (which depends upon the position of the diaphragm), length, and lineal density of the wire. The vibration of the wire is maintained by passing a current through it from a feedback amplifier forming an oscillator circuit. When a change of pressure causes a displacement of the diaphragm, a change in frequency takes place that is inversely proportional to the positive displacement. Under ordinary structural conditions, the vibrating-wire transducer has a linearity that is slightly greater than 2 per cent of bandwidth, but electric improvement in linearity can be made. In some system applications, calibration curves for the vibrating-wire transducer are programmed into a computer. With this arrangement, some oceanographic projects use a computer to relate count-to-pressure automatically, and write directly in pressure or ocean-depth units.

A number of manufacturers have utilized the vibrating-wire technique in development and production of pressure sensors and transmitters. The technique was originally developed by the Southwest Research Institute for use in oceanographic research, and found application in the missile field on the Atlas and Saturn programs. It has been used to measure temperature, displacement, and acceleration. The Digitran pressure transducer (Wright Engineering Company) is manufactured in ranges of 3-5000 psi absolute in a physical size of 1 x 1 x 4 inches. The Vibrotron pressure transducer (Borg-Warner Corporation) consists of the sensing transducer, a matched amplifier, and, when specified, a constant-temperature heater chamber that houses the transducer. Tests on Vibrotron transducers that have been in service for over 7 years, with actual operation in excess of 1000

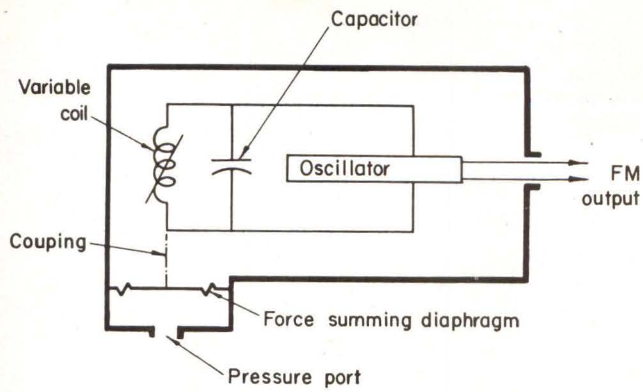


Fig. 2. Variable-reluctance digital transducer with internal oscillator.

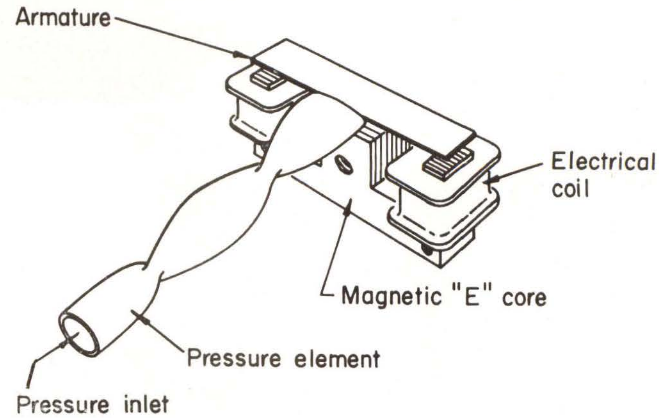


Fig. 3. The twisted-tube variable-reluctance transducer.

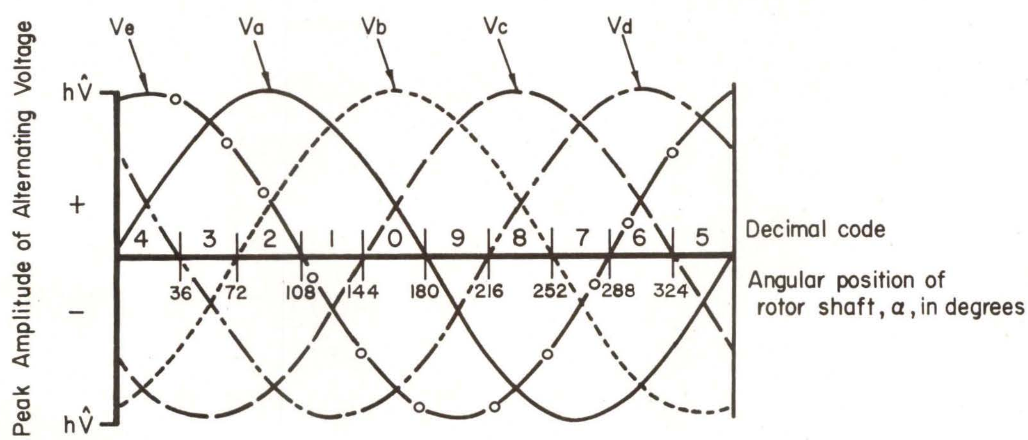


Fig. 4. Output voltages of interconnected mixing transformer secondaries.

hours, indicated a count difference of approximately one count.

The **variable-reluctance** transducer utilizes an inductive element which is part of a resonant circuit. It falls within the time-domain classification of the semi-digital transducer. Electromechanical relationships of a variable-reluctance transducer are shown in Fig. 2. By applying a force to the diaphragm, the inductance changes, causing a proportional change in the output frequency. A well-known application of an available variable-reluctance pressure transducer that has potential for adaptation to digital output is the twisted Bourdon-tube force-summing device. A length of hollow tubing, as shown in Fig. 3, has been flattened and twisted about its longitudinal axis. One end is sealed and allowed to rotate partially when pressure is applied. A flat magnetic element is fastened to this sealed end so that it rotates, causing the air gap in the electromagnetic circuit to change and thereby affecting the circuit inductance. Wiancko Engineering manufactures a large number of models that use a variable-reluctance bridge technique in conjunction with the twisted Bourdon-tube pressure element for measuring gage pressure. The system uses an FM oscillator whose frequency changes in direct proportion to pressure applied to the pressure transducer. The Solid State Electronics Company manufactures a series of absolute, gage, and differential pressure transducers under the trade name of Osciducer, for use with FM-FM telemetering systems. The transducer has a variable-reluctance diaphragm pressure element that controls the frequency of a silicon transistor oscillator.

Certain principles associated with states of temporal phase and antiphase, as related to a reference polarity, lend themselves ideally to digitizing the angular displacement of a shaft. The method of deriving a series of such phase states by using **synchro transmitters** has been found feasible. In practice, the technique employs four synchro transmitters that are geared to a 10:1 train. Each synchro transmitter energizes mixing transformers which have three secondary windings that are interconnected to produce five output voltages having phase relations as shown in Fig. 4. These are fed to a phase detector and bistable circuit that produces a decimal digital code. The bistable circuit feeds a telephone-type relay that facilitates other forms of coded output and provides for freezing the output while the digitizer is rotating. The use of one synchro transmitter to form a digitizer head would have very limited application since it revolves every 10 counts, but the use of multiple synchros on 10:1 gearing provides additional decades. Thus the synchros that have widespread usage in analog-data transmission chains can be combined with fairly simple circuits to produce remote digitally-coded representation of linear or angular position. The inherent robustness, reliability, and versatility of the system make it attractive.

The accuracy and linearity of the variable-reluctance digital transducer, which incorporates a complete oscillator circuit, is affected by mechanical and electrical changes that are functions of temperature. The **variable-capacitance** approach, where the coil is external to the transducer, gives some improvement in stability as well as other inherent advantages, such as application in areas requiring a wide range of frequencies, and good response characteristics from zero to several thousand cycles per second. Capacitive transducers are generally associated with measurement of small mechanical displacements and, therefore, can be adapted to units with pressure ranges on the order of a few microns. The ruggedness of the variable-capacitance transducer makes it desirable in applications requiring resistance to shock, vibration, and acceleration damage.

The basic configuration of a variable-capacitance transducer consists of a plate on a flexible metal diaphragm, or bellows, which is mounted near a rigid or fixed plate. The diaphragm responds to the pressure applied (the distance between the movable plate and the fixed plate varies) and the capacitance, therefore, changes as a function of the applied pressure. When used as a component part in an oscillator circuit, the oscillator is of a type that can be turned with a changing capacitor, such as a simple Hartley oscillator circuit. Either static or dynamic pressure can be monitored with this arrangement. A variable-capacitance transducer, manufactured by Glassco, contains a Bourdon helix with the pressure coil end attached to the rotor of an air-dielectric capacitor; when pressure is applied to the Bourdon tube, the capacitance at the output terminals changes proportionally.

Frequency- Or Pulse-Generating Transducers

In frequency- or pulse-generating digital transducers, the units of measurement are events-per-unit time and the transducers thus fall within the time domain. With the availability of electronic counting and precise time-interval measurement circuitry, digital measurements of many physical phenomena can be accomplished readily. An ideal digital-measurement system will produce a pulse or a cycle of alternating current each time an event occurs or a reference point is passed where the signal amplitude remains constant and independent of the number of events and of changes in stimuli energy. If the signal amplitude varies due to extraneous factors, such as changes in environment, the system will remain operative and accurate as long as the signal does not drop below the level of the system noise or below the threshold of the recognition circuits. This allows a wide range of operating conditions that an analog system does not possess and, thus, the pulse generating transducer system permits wide design freedom of the transducer and broadens the range of signal amplitude variation that is permissible.

The most important characteristic of the pulse-generating semi-digital transducer is the type of energy that is sampled and measured; the three main types are reluctance-pulse generators, optical sensors, and nuclear-radiation transducers.

The **reluctance-pulse** sensor consists of a permanent magnet with a coil. It senses the motion of an external magnetic element placed in its vicinity by generating a voltage pulse in the coil. This principle is frequently utilized to measure shaft speed as the sensor responds to the motion of a gear tooth or the spokes of a wheel. In many instances, the signal output is averaged as an analog signal to provide some indication of velocity; contactless tachometry usually employs reluctance-type sensors in this way.

The same principle is used in the turbine-type liquid-flow transducer which is an ideal example of a semi-digital transducer. The typical turbine flowmeter consists of a housing with end fittings to match those of the piping in which the element is to be installed. A hydraulic, self-positioning rotor is suspended within the housing. A reluctance-type magnetic sensor is incorporated into the housing, and consists of a permanent magnet with an externally-mounted coil. As the fluid flows through the element, the rotor spins at a speed determined by the fluid velocity and the angle of the rotor blades, inducing voltage pulses in the sensor coil. The total output pulses counted during a precise time period are proportional to the flow rate and, therefore, the flow transducer can provide a digital readout. Transducers of this type obtain a measure of velocity of the flow; mass or volumetric flow is calculable, since it is equal to the velocity multiplied by the cross-sectional area of the flow stream. Turbine-flow sensors are ideal for use in measuring the flow of fuels and hydraulic fluids in aircraft and missiles, and in ground-support applications. They have been produced for measurement of flow rates as low as 0.004 gallon per minute and as high as 50,000 gallons per minute. A significant advantage claimed for the turbine-type transducer is that it can be constructed to withstand severe environmental conditions. It has been temperature rated at 430 F to +1100 F while operating. Units that operate in pressure systems as high as 35,000 psi are also being manufactured.

The use of the magnetic sensor for generating pulses as described for the flow transducer has been extended to many other applications for measuring rotational speed, for example in a tachometer-type speed indicator manufactured by the Westinghouse Electric Corporation. The tachometer comprises a toothed wheel and a magnetic-reluctance sensor that generates a pulse as each wheel tooth passes the sensor head. The instrument obtains a digital-speed indication in rpm or feet-per-minute by counting the number of pulses of the output signal for a definite time. Individual tachometer units are produced to provide measurements in rotational speeds between 15 and 40,000 rpm with accuracies that depend primarily on the frequency meter or counter with which they are used.

Optical sensors are often used to detect motion and rotation by the generation of pulses through the interruption of light-beam reflections from a bright spot on a rotating member. The transducer for transmission of light and reception of incident reflection can be two separately-bound fibers of glass, thus enabling the light source and photocells to be housed within the pulse-counter assembly. In operation, the series of discrete pulses received by the photocell are counted over a precise time interval.

A new entry to the pulse-generating category of semi-digital transducers is the type that employs **ultrasonic** principles. In particular, a manometer, manufactured by Pulse and Digital Laboratories, Incorporated, employs the sonar principle in conjunction with two vertical columns. When a pressure difference is applied to the U-tube, the mercury rises in one leg and falls in the other. Sonar pulses are transmitted from transducers at the base of the U-tube column, and pass through the mercury to its surface where they are reflected back again to the transducer and to the display assembly. The time interval indicated by the reflected sonic pulse is measured by standard electronic circuits to determine the mercury height and, thus, the pressure difference between the two columns. An accuracy of 0.002-inch and repeatability of 0.001-inch are indicated by the manufacturer.

Many applications of digital transduction can take advantage of the phenomena related to **nuclear radiations** from radioactive materials. The nuclear-radiation technique has been described as ideal because radiation from natural and artificial radio-nuclides occurs at a rate that is random but substantially invariant over a long period of time, and the phenomenon is so stable that it has been applied as the basis for calibration standards involving time and frequency. Adequate counting statistics can be expected from any radio-nuclide possessing sufficiently-long half-life and high-specific activity. Radioactive particles can be detected either by the excitation that they produce in passing through matter or by secondary charged particles that they produce by interaction with matter in an ionization chamber. These devices provide a pulse for each ionizing event, and their output is a series of pulses that can be totaled through use of a digital counter for conversion to a decimal code. An ideal example in the use of radiation detectors as a nuclear semi-digital transducer is in the variable-shutter type of sensor, which is based on the inherently discrete or digital properties of radio isotope decay. This transducer permits physical data to be digitized at the source, thus preserving the initial accuracy of measurement during telemetry and data processing, and is a system that, once calibrated during assembly, retains its accuracy indefinitely. Particles from the nuclear source pass through a variable aperture controlled by a shutter and reach the detector where they generate electrical pulses. The number of particles reaching the detector is directly proportional to the size of the aperture; they are counted by a conventional digital counter over a pre-set time base. The nuclear source selected for this type of semi-digital transducer has been alpha particles which are preferred to beta-type radiation because they are essentially monoenergetic and their differential spectrum shows a single peak; this simplifies the discriminator setting for elimination of noise, so that each alpha particle reaching the detector generates only one pulse. One practical application of this nuclear technique is a digital accelerometer, which comprises a nuclear source, a calibrated aperture, and a detector. It is shown in Fig. 5. The radioactive source and detector are positioned on opposite sides of an aperture or shutter so that the number of particles impinging upon the detector is a function of aperture geometry. Two springs provide positioning of the shutter and dynamic loading for the mass carrying the aperture, and the spring-mass dynamics govern the range of accelerations provided by the transducer. Similar techniques can be applied to measurements of displacement, temperature, pressure, fluid flow, etc. By using a system

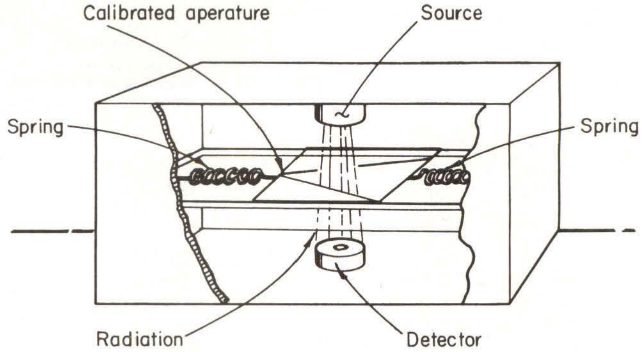


Fig. 5. Nuclear techniques applied to acceleration measurement.

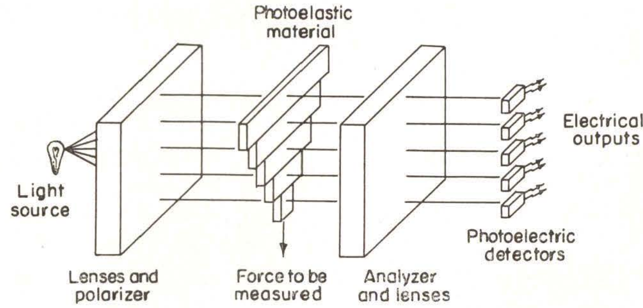


Fig. 6. Digital techniques for measuring force by the photoelastic method.

containing a small-size source and solid-state detector, the transducer is made practical for compact aerospace sensors that are highly reliable. There are numerous cases where nuclear transducers have been used for measuring altitude, density of the atmosphere, level of liquids and solids, thickness of materials, gas and moisture compositions, and detection of chemical conditions.

Development of nuclear digital transducers to a manufacturing phase has been carried out by Charter Laboratories. The transducer is based on mechanical modulation of a beam of alpha particles; pressure, temperature, and displacement transducers with digital outputs are available. Models of the nuclear digital pressure-transducer function at pulse rates between 0 and 1000 pulses per second depending on the pressure range of the devices. Maximum rms counting error, as stated by the manufacturer, is 0.1 per cent of full scale for 100 seconds of counting time. If a 1.0 per cent error can be tolerated, the counting time can be reduced to approximately 8 seconds.

Photoelastic-Digital Techniques

The techniques and concepts applicable to the photoelastic phenomenon lend themselves ideally to what can be described as a true digital transducer. With the device shown in Fig. 6, direct entry to digital data processing systems can be made. This digital transducer depends upon the significant rotation of the plane of light polarization by transparent materials as a function of stress. The combination of this effect with a particular structural configuration and light-detector characteristic results in a device that possesses a binary-coded output as a function of applied force. By proper alignment of bellows, seismic masses, fluid-displacement mechanisms, and other force-summing schemes, the force transducer can be designed to measure pressure, acceleration, temperature, load, and other physical variables. The binary-coded output is obtained by mounting several movable rulings, as shown in Fig. 6, on a nonlinear flexure member so that the relative motion of the movable rulings to the fixed rulings has a ratio of 1:2:4: . . .:n. The light transmitted by each section is focussed on a separate detector. A unit load, defined as the load that stresses a designated section sufficiently to change its respective detector's output from one state to another, divided by the cross-sectional area, represents a unit of stress. As the load increases, the detector output, summing the 2-state characteristic, varies. Early prototypes of force transducers using photoelastic techniques have been evaluated as having an accuracy of 1 per cent; however, a 0.1 per cent accuracy is believed possible.

Direct-Optical Techniques

An optical technique that is well adapted to digital transducers is typified by the digital-solar-aspect transducer used in Explorer X, which provided measurements of elevation and azimuth angles as small as 2 degrees at a distance of 140,000 miles. In this case, the digital-solar-aspect sensor, shown in Fig. 7, consisted of a number of photo-duo-diodes placed behind a light mask with slit openings. Opaque separators are located between the diodes so that each sensor is affected only by the portion of the light mask directly in front of it. The slits and photodiodes are aligned so that each diode has a diverging or fan field of vision lying in a plane parallel to the field of vision of the other photodiodes. When the sensor is rotated about a vertical axis, the fan field of vision of the diodes will sweep out a solid angle. When this fan passes across the solar disk, one or more of the diodes will be illuminated. The time at which this illumination occurs provides a measurement of azimuth angle of the sun in a sensor-fixed coordinate system. The particular combination of diodes illuminated provides a digital measurement of the elevation angle of the sun in sensor coordinates. The accuracy of the measurements depends on how many binary sensors are used. A fan field can be quantized into as many as 2^n-1 segments when there are n binary sensors.

Optical techniques have been used extensively for converting angular and linear displacements into digital-type signals. A typical example of an adaptation is noted in the digitizing and integrating of galvanometer deflections. In this instance, the normal scale of a reflecting galvanometer was replaced with a scale having alternate and equal opaque and transparent lines, 50 lines to the inch. The projection lamp in the galvanometer was provided with a slit, the width of which was set so that the lamp image in the mirror at the scale distance employed had the same width as a scale line. Thus, when the galvanometer was deflected, a series of optical pulses was available behind the gridded scale, and the number of pulses was a measure of the reflection magnitude. This arrangement has been used successfully for obtaining hourly and daily totals of solar and terrestrial radiation differences from thermocouples,

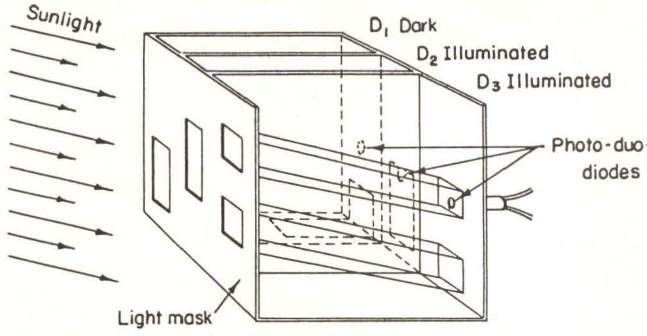


Fig. 7. Digital solar aspect sensor with Gray code light mask.

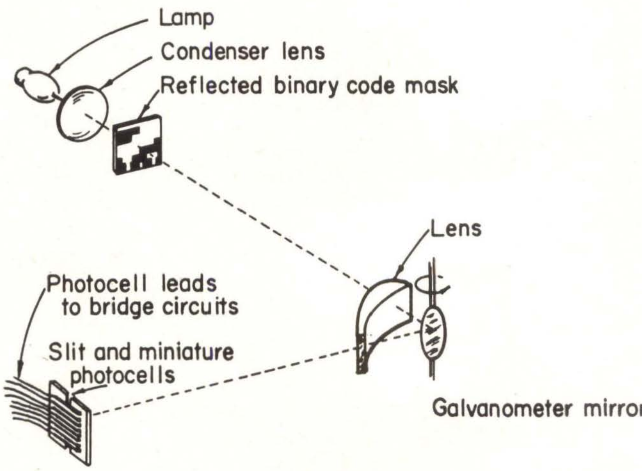


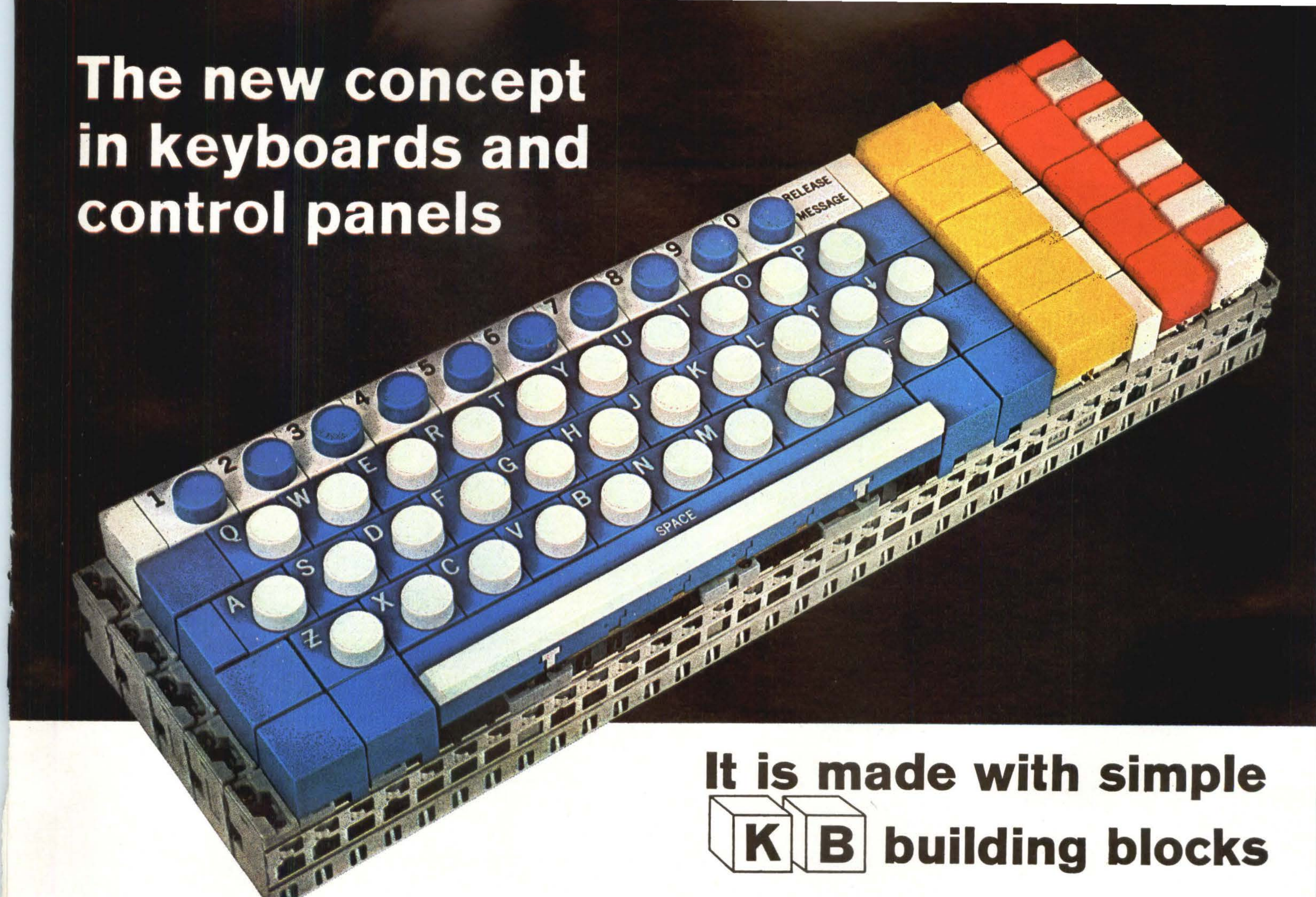
Fig. 8. Modified digitizer optical arrangement for obtaining seismic measurements.

and heatflux measurements in the ground under various natural covers. It is a convenient and economical technique for time-averaging quantities.

The need for digitized information in the seismological field has resulted in research and development of digitizing equipment for field or seismic observatory application. Researchers at the Geotechnical Corporation constructed a digital seismometer that utilized a long-period galvanometer, phototube amplifier, and a code plate. This arrangement is shown in Fig. 8. Here, the image of a lighted code plate is moved across a slit by the galvanometer mirror, whose rotation is a function of the seismometer output. Behind the slit are photocells that encode the galvanometer motion. The primary advantage of the system is that a long-period galvanometer could be used normally to construct any desired seismograph response curve.

A similar technique is used by the Allied Research Associates, Inc., in the Digizet, which uses a reflecting raster mounted above the analog-type scale of a deflection instrument. The raster consists of a cylindrical mirror provided with a grating of reflecting and non-reflecting vertical lines. A photocell is fixed in the focal line of this mirror above the measuring element of the instrument. A schematic arrangement of components is shown in Fig. 9. When the light spot deflects, it sweeps over the raster from where it is intermittently reflected to the photocell which converts the pulses of light into voltage pulses. One hundred reflecting lines of the raster have been assigned to the full scale value, con-

The new concept in keyboards and control panels



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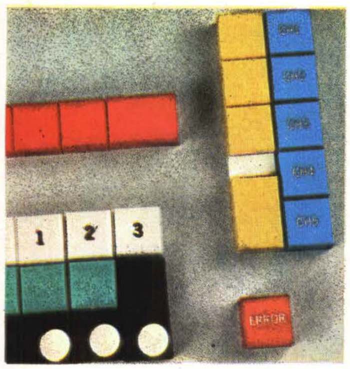

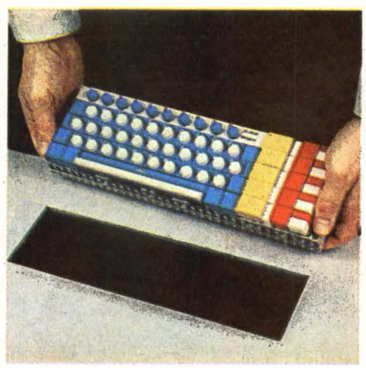

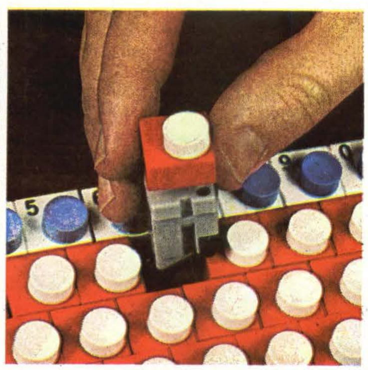

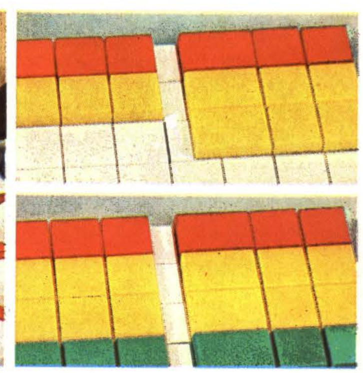

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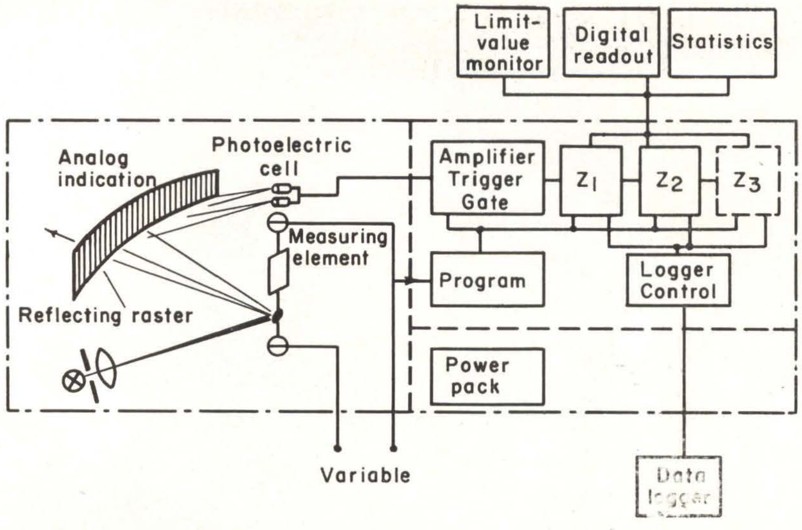

Fig. 9. Mode of operation and lay-out of the Digizet.

sequently the photocell will emit 100 voltage pulses during a full-scale deflection. The quantization error is within 0.5 per cent.

Another device, utilizing optical techniques for digitizing dynamic displacement, is also manufactured by Allied Research. This transducer system uses a transparent tape which consists of alternate, equal width, transparent and opaque sectors. The tape is fixed to the object whose motion is to be studied and the transducer is mounted on an adjacent reference surface. In the transducer head, the tape passes between a fixed illuminated gate and a photocell, resulting in alternate illumination and darkening of the photocell surface. The photocell output is a sawtooth voltage where each half cycle of voltage alternation corresponds to a motion exactly one sector in width. The standard tape has a sector width of 0.050 inch.

An inertial accelerometer has been developed by the Ford Instrument Company that uses a digital technique for detecting the rotational modulation of an unbalanced cylinder. The objective of this development was to produce a synchronous rotating-pendulum accelerometer with high-performance characteristics and a low cost, by allowing the acceleration input to influence the motion of a rotating cylinder, and computing acceleration from measurements of time. The arrangement of components that comprise the feasibility model of this synchronous rotating-pendulum accelerometer is shown in Fig. 10. The pendulum (the unbalanced inner cylinder) is made to rotate at a constant-average angular velocity by coupling it to a synchronous motor by means of a very loose spring. In the absence of any acceleration input, the instantaneous angular velocity is constant and equal to the average angular velocity. Thus, if the input acceleration is constant over a cycle of rotation, the measurements of the time required to traverse quarter cycles is sufficient to determine the acceleration components along two reference axes normal to the axis of rotation. Also, if the modulation is slight, the device behaves linearly, which indicates that both components of acceleration can be computed separately.

The unbalanced cylinder is supported on a hydrostatic gas bearing. An optical pickup generates gating pulses 180 degrees apart to start and stop a digital

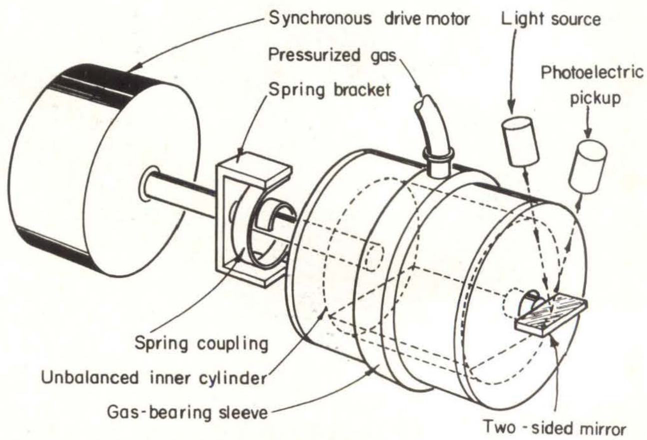

Fig. 10. A feasibility model of the synchronous rotating-pendulum accelerometer.

counter. The digital counter indicates the time required for each 180-degree rotation, and the time difference between consecutive measurements is used to measure one component of acceleration. A feasibility model of the synchronous rotating-pendulum accelerometer leads its designers to believe that it can meet the requirements of most inertial navigation and guidance systems that employ a digital computer. The technique represents a new approach to the instrumentation of inertial accelerometers with some advantages that are lacking in the conventional accelerometer.

Optical Interference Fringe Technique

An interesting technique for dividing distance intervals uses **Moiré optical interference fringes,** which provide magnification of the behavior of grating lines. Fig. 11 shows how the dark and light bands are produced at right angles to scale lines when the scale reader is tilted by a small angle with respect to the lines on the scale. The distance between the bands is determined by the degree of tilt. If the scale reader grating is moving relative to the scale in a direction at right angles to the scale grating lines, the Moiré-fringe system will move in a direction at right angles to its fringes. The relation between the two movements is such that when the grating moves a distance equal to one pitch of its line

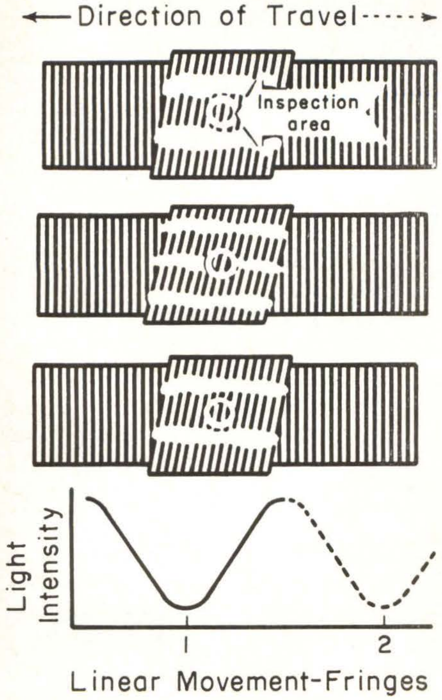

Fig. 11. Moire fringes.

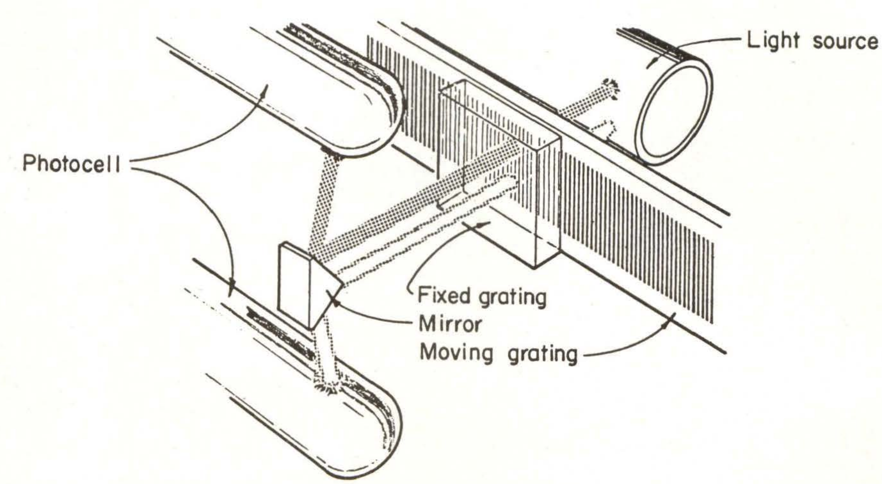

Fig. 12. Measuring displacement by Moire fringes.

structure, the Moiré-fringe system moves a distance equal to one wavelength of its fringe pattern. Its advantages for observation of relative movement by use of photocells are considerable. One of the most valuable features is that it represents an integration of relative movement between the gratings, which may be observed over hundreds or even thousands of lines so that any blemishes and local distortions or missing lines have little effect on the observed signal. Although the contrast of the fringes is slightly reduced, it is possible to separate the scale and reader gratings by five or ten thousandths of an inch, when using accurately parallel light. This spacing can be maintained without risk of contact and, therefore, provides a system that is completely free of wear. The interference technique has extremely high resolution because the wavelengths of light represent an accurate standard of measurement. A wavelength of green mercury light, as an example, is approximately ½ micron or 49 microinches. Since a moving mirror increases the optical path to twice the rate it is moving, the interference fringes in a reflection-based system would change from dark to light for 10 microinches of mirror travel.

The basic elements needed to obtain Moiré-fringe effects are a grating which is fixed to the element whose motion is to be measured, a light source that approaches coherence (without source coherency, multiple interference and diffraction of light would occur because it would consist of multiple wavelengths), and a photosensor viewing the light beam through a grating fixed to the reference point. A version of a Moiré-fringe system in which two narrow beams of light are passed through gratings, that are separated by mirrors, to the cathodes of two photomultipliers is shown in Fig. 12. The output of the photocells is in the form of two sinewaves in quadrature and the sense of direction is inherent in that the phase of one leads or lags with respect to the other. This system is used by Ferranti Ltd. With gratings of 5,000 lines per inch, for the purpose of reading with a resolution of 0.0001 inch, it is used for coordinate measurement (inspection of mechanical parts) and preparation of tapes for the control of machine tools. The Sheffield Corporation has developed a similar three-axis coordinate measurement system with an accuracy of 0.0002 inch.

Position Encoders

Position encoders can be divided into the two broad categories of continuous and quantized. In the continuous category, physical motion is transformed to a proportional electrical quantity or time interval by means of a continuous transducer, such as a precision wire-wound potentiometer, and a change to digital form is then made by a voltage or time coder. In the quantized category, physical motion is subdivided into incremental motions and transformation to digital form is accomplished by detecting the number of increments indicated by a specific motion.

The absolute shaft-position encoder manifests operational principles that ideally fit the description of a true digital transducer because it produces a digital output on demand, suitable without further conversion for direct entry to computers or data-handling systems. The absolute shaft-position encoder, in a sense, is an analog-to-digital converter, and conversion takes place as close to the physical stimulus as a measurement can be made. Digital shaft encoders are used in data processing and transmission for navigation, fire control, and target-handling systems associated with aircraft, surface vessels, and submarines. Extensive use of the encoder is made in various industrial processes. Approximately 10,000 encoders are provided annually to the military and industry, and the number of such digital systems being used is on the increase. There is a demand for

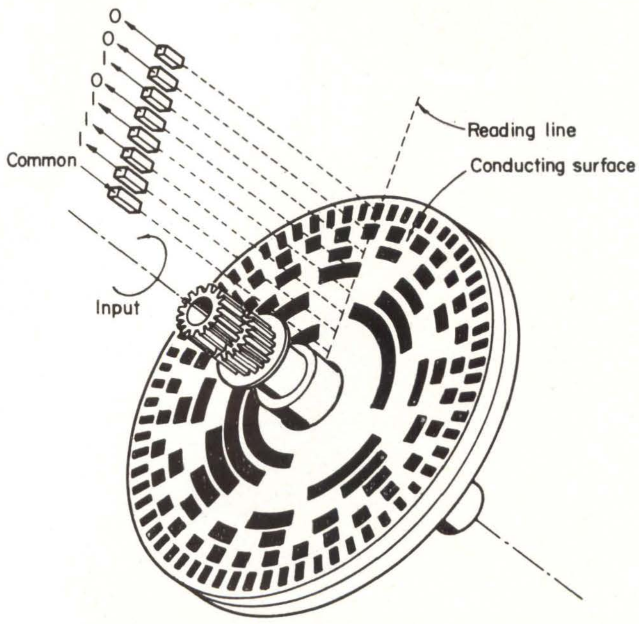

Fig. 13. Brush-type digital shaft encoder.

reliable, long-life, shaft-position encoders.

Absolute shaft-position encoders consist of two major categories — the **brush-type** and the **brushless-type** encoders. The brush type may consist of the **straight brush** or it may be designed with a **V-scan.** The brushless-type encoders fall into three basic groups: **magnetic, capacitive,** and **optical.** Regardless of the type, the encoders produce outputs to a data system in a binary-coded representation of shaft position. Encoders in most applications consist of a commutator disk attached to an input shaft and a system of sensors for extracting the position information. The disk is binary coded and consists of alternate conducting and nonconducting, magnetic or nonmagnetic, capacitive or noncapacitive, and opaque or transparent areas. (The basic principles of the circular-scale encoder have also been incorporated in a linear-scale encoder, which has the commutator scale made over a linear range, and a rectilinear position produces a corresponding coded output. The advantage of the linear encoder is that it is directly coupled to the force-summing mechanism, eliminating gearing and its associated problems.)

Most digital shaft encoders used in the Army, Navy, and Air Force today are of the brush type. This encoder consists of the disk attached to the input shaft and a set of commutator brushes. One brush is used for each of the output code wires and one for the input voltage. The disk, as shown in Fig. 13, is binary coded by arrangement of alternate conducting and nonconducting areas on the disk. The number of output brushes required depends on the resolution needed. For example, a resolution of 2.8 degrees (128 counts per revolution) would require a disk with 7 binary-coded tracks.

The brush-type encoder has physical limitations as well as limitations associated with the component reliability. The physical limitation of the disk diameter restricts the number of bits that can be included on a single disk. To increase the number of bits, it becomes necessary to add another disk, geared down from the first. For example, one dual-coded disk arrangement with a 2^{13} resolution uses a 64-to-1 gear ratio. The reliability problems of the brush-type encoder involve failures due to excessive brush and disk wear and critical brush alignment. A low operating speed (approximately 200 rpm) must be used, since high speed of rotation causes excessive brush wear, and the residue from abrasion contaminates the code wheel disk, causing loss of accuracy. High brush speed also results in brush bounce which produces extraneous pulse noise. To offset the effects of brush bounce, increased brush pressure is often practiced, however, this increases the load torque and aggravates the wear problem. The brush-type encoder is believed to have a useful life of 1 million revolutions.

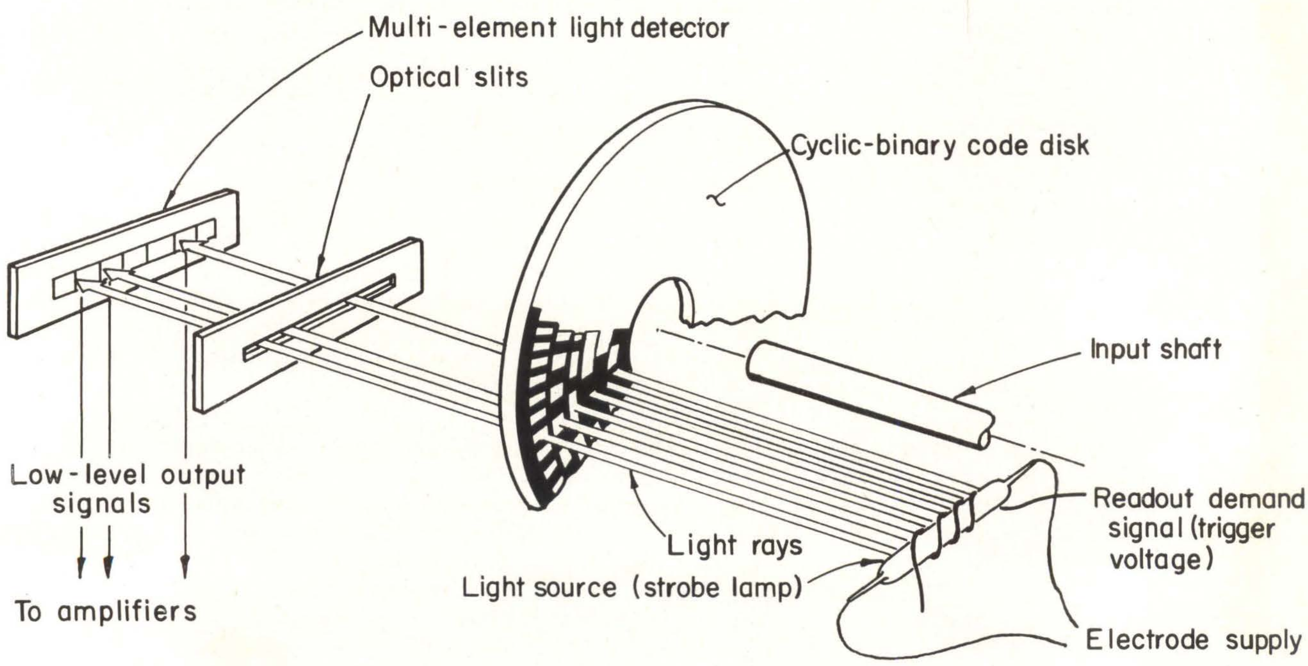

Fig. 14. Brushless-type digital shaft encoder.

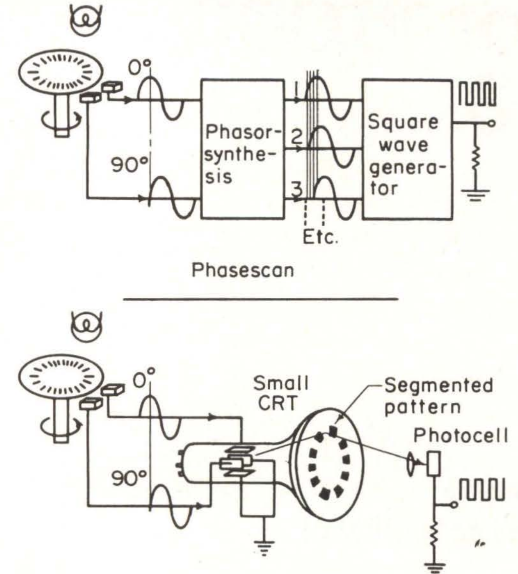

Fig. 15. Phasescan and beamscan techniques.

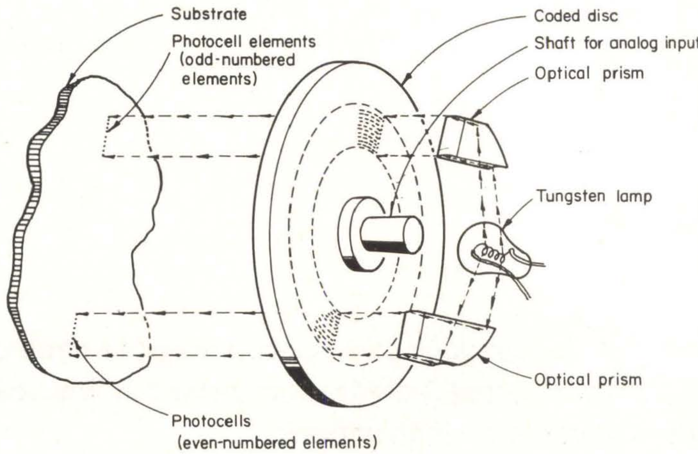

Fig. 16. Basic digital encoder system showing optical encoding scan techniques.

There is a definite limit to the resolution that can be achieved with commutator devices because brush-contact areas can only be reduced to a certain point. At the present time, a brush width of 0.004 inch is considered about minimum, and the narrowest and most useful commutator segment width is about 0.010 inch. Thus, about 256 conducting segments can be placed on a 1-inch diameter disk. Commutators are usually produced by the photoengraving process, and the total accuracy within which segment edges can be controlled is 0.004 inch; for example, segment edges in a 4-inch-diameter disk would be accurate to approximately 7 minutes of arc. However, brush-alignment problems in a commutating encoder can prevent attainment of this level of accuracy.

The three basic types of brushless encoders (optical, magnetic, and capacitive), have been developed to circumvent the disadvantages of the brush-type encoder. However, the higher cost has restricted popular use of the brushless devices: the cost of brushless encoders ranges from three to six times that of the brush type for similar applications.

Of the various basic methods of noncontacting encoding, photoelectric methods appear to be the most straight-forward, advanced, and accurate for generating digital information from shaft position. In optical-digital encoders, photocells are used to detect light energy passing from a light source through a coded disk that consists of alternately opaque and transparent segments. This is illustrated in Fig. 14. As the disk rotates, each photocell produces a binary signal, the polarity of which depends on whether a transparent or opaque disk segment is in the path of light for that photocell. The light source usually is a strobe lamp, however, there is a trend toward the use of low-voltage continuous lamps because the main disadvantages of optical-type encoders is the life expectancy of strobe lamps which is estimated to be 600 hours. The low-voltage continuous lamps have a predicted life of approximately 10,000 hours.

The resolution in reading an optical pattern is limited only by the wavelength of light. Diffraction does not become a problem until a viewing slit is made smaller than 4 microns, and then monochromatic light of very short wavelength can be used. A typical optical pattern made by photographic techniques has 65,536 opaque segments in an 8-inch diameter. The segments are approximately 0.0002 inch wide and require the use of a lens-type reading system. Greater line densities have been achieved where the resolution of optical patterns can approach 100 times that of an electrical commutator. At the present state-of-the-art, the highest obtainable accuracy of optical patterns and associated reading method is 1 part in 262,144 (5 seconds-of-arc) for an 18-bit encoder.

In magnetic-scan encoders, the code disks consist of tracks of alternate magnetic and non-magnetic areas; each magnetic track is read out by a square-loop ferrite core positioned close to the surface of the coded disk. This reading head has two windings: a primary one for interrogation or excitation and a secondary one for signal readout. The proper electronic circuitry is, as usual, required to shape the encoder output so that unambiguous, pure binary signals will result. From a reliability standpoint, the main advantage is the life span of the encoder bearings, which is generally about 100 million revolutions. The resolution of magnetic encoders does not compare favorably with the optical types, but they are capable of higher resolution and life than the brush-type device, since the index is not in contact with the patterns. Present resolution for magnetic heads is on the order of 0.0005 inch. Research into the use of Hall effect devices for magnetic reading heads has shown promise of giving an order-of-magnitude improvement in resolution for magnetic encoders.

Although there are no known encoders available that use capacitive principles, a number of proposals for the development of such a type appear to hold promise for a device with good resolution. The technique basically incorporates a method for detecting variations in capacitance between capacitively-coupled disks which electronically generate an unambiguous binary output. Capacitive sensors, like the magnetic, require excitation by high-frequency oscillators and some means of detection to resolve digital signals. Generally, this results in a more complex and, therefore, less reliable arrangement compared to photoelectric methods.

Two recent innovations have been used to advance high-accuracy readout from photoelectric encoders: Phasescan and Beamscan. Schematic layouts of these innovations are shown in Fig. 15. The Phasescan was developed to provide outputs with resolution and accuracy on the order of 1 second of arc over 360 degrees of rotation, using a single 14″ disk rotating through one turn. Phasescan uses an absolute reading disk for a coarse reading, and provides a vernier reading that allows fine data to be delivered from the least-significant digit of the absolute reading code disk. Photoelectric sensors establish an accurate 0- and 90-degree phase relation from the basic high-accuracy pattern. By composing known encoder outputs of 90-degree phase relationships it is possible to synthesize additional phasors to produce a "10 times" count from a disk having 129,600 increments (10-second-of-arc spacing). These phasors describe sinusoidal patterns as the disk is rotated and are individually fed into trigger circuits, which provide square-wave output in the time domain. These outputs are combined with the absolute-encoder data to provide a composite coded output.

The Beamscan has realized vernier outputs of up to 100 increments for each input cycle. By applying two wave forms of 90-degree phase relations to a cathode-ray tube, a circular Lissajous pattern is described each time the input waveform completes one cycle. A segmented pattern of alternate opaque and clear sectors is placed over the circular scan and the resultant light output from the CRT represents vernier data of the output. Photocells are used to digitize the light output. Using 129,600 divisions on the encoder disk and a pattern of 100 segments on the CRT, the Beamscan arrangement provides 0.10-second-of-arc increments, or one part in 12,960,000.

One of the common objections to encoders is that they, with their associated electronics, frequently occupy excessive space. There is an increasing demand for high-resolution digital transducers in small packages that can be operated with a minimum of auxiliary equipment and several developments have been initiated to develop such a compact transducer.

One developmental program produced an encoder that was housed in a single package, 1.1 inches in diameter and 2.0 inches in length, with a resolution of 8192 divisions or 13 bits for one revolution. A coded disk was mounted, as shown in Fig. 16, on an input drive shaft, and consisted of 13 concentric tracks composed of opaque and transparent segments. The relative angular positions between the segments in the various zones were such that when they were scanned with a radial index, they formed a reflected binary code representing angular positions of the fixed index with respect to the disk. The photocells used in this encoder consisted of cadmium selenide that was deposited in

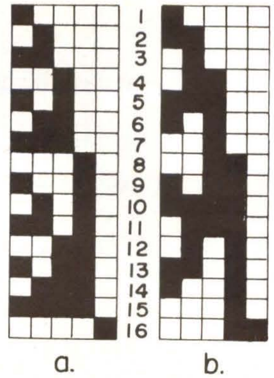

Fig. 17. Binary-coded scales.

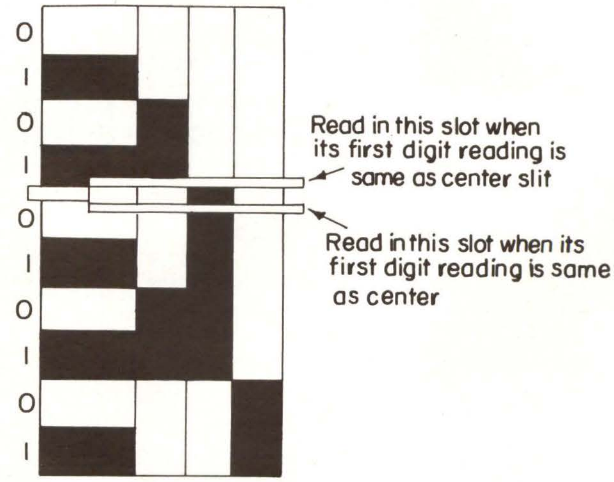

Fig. 18. Two-slit switching system.

thin-film form on a glass substrate and fabricated in a hermetically-sealed package. The photoconductive cells were sequentially interrogated by applying a positive voltage pulse, in turn, to the most significant digit photocell, then the second, and so on to the thirteenth (least-significant) photocell. The output of each cell as it occurred appeared across a common-load resistor. The sensitivity of a reference cell circuit was adjusted so that the sum of the signals from the reference and code cells was positive with respect to a selected reference level of a "1", and negative for a "0". Sequential interrogation of the photocells was accomplished by a diode matrix which consisted essentially of fourteen four-point AND-gates, controlled by a four-stage flip-flop counter. The sequential outputs of the digit photocells were amplified by three feedback-compensated amplifier stages followed by an emitter follower. All these components, plus thermostatic control, were mounted into the encoder package.

DIGITIZING CODE STRUCTURES AND SCALES

There are numerous code structures in use for producing digital encoder outputs, and reasons for selection of the proper type are important; therefore, a brief dis-

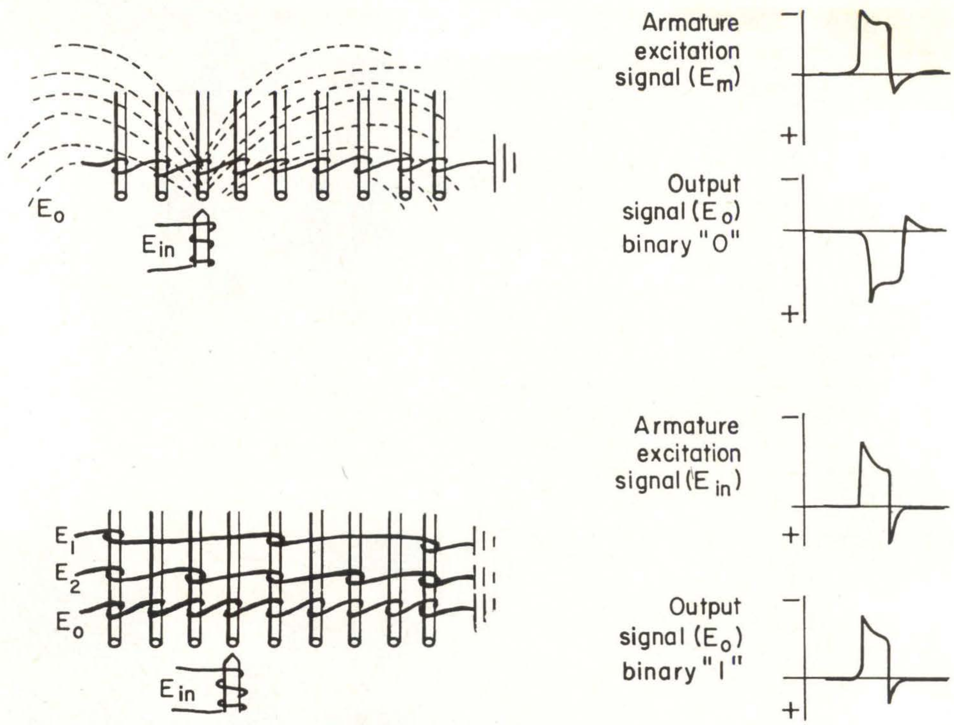

Fig. 19. Principles in the development of magnetic-reluctance digital transducer.

cussion is appropriate. The most common code structure is the familiar **natural-binary code;** it is illustrated in Fig. 17. As this scale passes through an array of optical-, magnetic-, or contacting-sensing systems, the pattern will change at each horizontal line, and changes in several tracks may occur simultaneously. Slight manufacturing imperfections can prevent these changes from actually occurring simultaneously, and this results in reading ambiguity. Simultaneous transitions are a physical impossibility in conversion devices; however, many schemes have been devised to overcome this difficulty. The most common is called the **V-scan,** which involves two readout systems for each bit, and each selection of the readout system for any given bit is based on the state of the next previous bit; the decision margin is thus one-half of the next-less-significant bit. However, this scheme eliminates ambiguity by providing two interrogating systems per bit, plus the scanning logic and circuitry. Whenever the V-scan is used, the output is in bit-serial form.

Another method of eliminating ambiguity provides all zones of the scale with **two reading slits.** One of the slits reads slightly before and one slightly after a single slit which reads on the fine scale, as shown in Fig. 18. Selection of which of the two slits to read is controlled by the crossover of the slit in the fine digit, which insures that the crossover of all the other digits occurs simultaneously. In this method, it is necessary to read through narrow slits with very slight skew tolerance.

One solution to the problem of ambiguity is the use of one of the cyclic codes; the best known is the **Gray code,** which is also shown in Fig. 17. The Gray code is a binary code having the characteristic that only one digit changes at a time. The cyclic codes permit reading with simple equipment, however, they have the disadvantage of requiring conversion to binary or other codes for the purpose of adding and subtracting, since there is no weighted relationship between bits as in the natural binary code. The Gray code has been used in digital displacement transducers because of its inherent high resolution and efficiency, and because it reduces gross errors in the readout. If a bit fails to switch at the proper time, the error will be small since consecutive binary numbers differ by only the one bit. Other codes, such as the Datex code, have also been devised to have the characteristic that only one bit changes at a time, thus eliminating the ambiguity at the bit boundaries.

DIGITAL TRANSDUCER RESEARCH

Because of the many advantages of digital transducers, many research programs have been initiated in the field. A prime objective has been the development of a digital-displacement sensor, since once a digital-displacement sensor is successfully produced, the way is open for development of transducers for measurement of pressure, temperature, velocity, altitude, strain, and acceleration. Techniques explored include magnetic reluctance, optical rulings, and ring-lasers.

Digital-Displacement Sensors

One of the early methods conceived to convert rectilinear displacement into a parallel pulse code used the **magnetic-reluctance** technique. Digital signals were generated that represented a mechanical displacement of an electromagnetic armature by successively altering

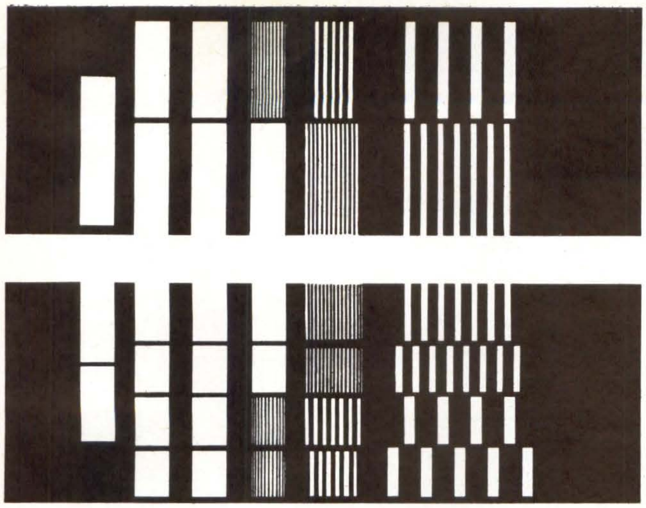

Fig. 20. Eleven-bit Gray-coded optical rulings folded against each other to form the ruling pair.

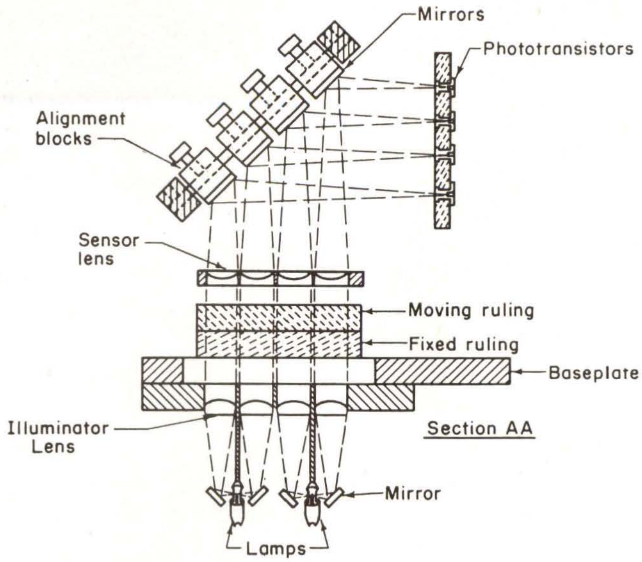

Fig. 21. Arrangement of optical parts.

the state of a matrix of magnetically-permeable wires or rods, as shown in Fig. 19. The rods and the associated sense windings form the matrix, which is positioned so that the ends of the rods are exposed to the magnetic field generated by the armature. The magnetic field is large enough to encompass the entire matrix regardless of the armature position. The sense windings are located on alternate rods and interconnected so that successive windings are opposite in polarity.

When the armature is aligned with a rod containing the sense winding, the magnetic field about the rod is increased. This results in an increased magnetic induction and a strong signal in the sense winding about the rod. Positive and negative signals that are proportional to the magnetic field are induced in the sense windings on the remaining rods. The algebraic sum of these signals results in an output signal having the polarity of the strong induced signal, which corresponds to a binary "1". When the armature is aligned with a rod that does not contain a sense winding, the increased induction in this rod is not sensed, and the algebraic sum of the remaining sense windings results in a minimum-signal output, which corresponds to a binary "0".

An **optical technique using rulings** made of sections with lines and spaces similar to a Ronchi ruling involves a pair of optical rulings that cause a transmitted light to be modulated as one ruling is moved relative to the other. Each ruling is composed of sections having lines and spaces so that the number of lines per inch from section to section varies as 2^n varies. If "n" varies from zero to ten, an eleven-bit transducer becomes feasible by using a photosensing circuit to monitor the light transmitted through each ruled section. Such a digital transducer was developed at Hughes Aircraft Company. The master ruling design was on optically-flat glass 1/4 inch thick, with a thin coating of silver deposited on one side, and the rulings were formed by shaving away silver material. The rulings used in the transducer are photographic reproductions of the master. The rulings are divided in half and the two halves folded against each other to form the ruling pair as shown in Fig. 20. Each bit consists of two sections, each with its own photocell; the lines in both sections are parallel to one another, but they differ by 180 degrees between sections, that is, the positions of lines and spaces are reversed in the second section from that of the first. Therefore, since equal lines and spaces are used in the rulings, the signals from the two photocells are 180 degrees out of phase, and a change in state is reached whenever the signals to the two photocells are equal. This method of using two photocells per bit has the advantage of being relatively insensitive to absolute light level when the two sections are illuminated from a common light source.

The transducer mechanical assembly is shown in Fig. 21. The apertures for the ruled areas are illuminated with collimated light from an array of miniature tungsten lamps. An image of the appropriate lamp filament is formed on the surface of each phototransistor sensor. Optimum alignment of the filament image on the sensor is accomplished by a block of adjustable mirrors that alter the direction of the light rays from the rulings to the photocells. When completed in prototype form, the transducer measured input position and converted this into a binary number proportional to the distance from a fixed zero reference. Test results indicated that a resolution of 50 microinches and an accuracy of 100 microinches could be maintained over the entire linear range.

Laser-Transducers

In 1963, the application of a traveling-wave ring laser for sensing rotation relative to an inertial frame of reference was demonstrated by Sperry at the conclusion of an extensive theoretical and experimental evaluation of various devices and techniques. An angular-rotation sensor was envisioned that would not use moving parts and consequently would not be subjected to accuracy changes with time; it would be applicable in maintaining precise satellite orbits, measuring trajectory changes,

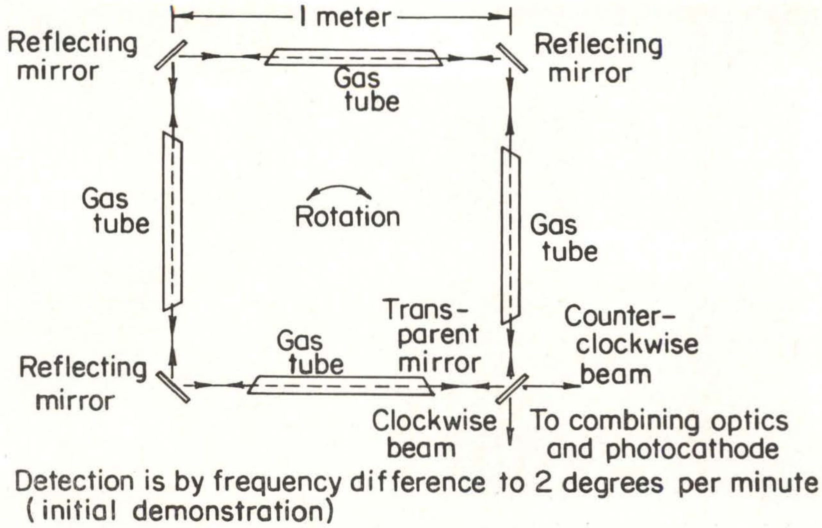

Fig. 22. Application of lasers in measurement of rotation.

space-vehicle attitude, and orientation. The principles used in the research involved classical interferometer experiments where the effects of rotation on the propagation of light were studied by a modified two-beam interferometer arrangement, as illustrated in Fig. 22, with the laser incorporated directly into the rotation sensor. Oscillation results from directing the waves around a closed optical path in opposite directions but along identical paths. The difference in frequency for the opposite-directed waves is then related to the differential phase shifts for the rotating system, therefore the beat frequency obtained by optically mixing the CW and CCW beams is related to angular velocity of the system. The principle advantage of the ring-laser over conventional interferometers is that phase changes, resulting from nonreciprocal optical-path variations, can easily be observed as a difference between resonant frequencies. As a result, a semi-digital transducer becomes feasible.

Investigations into the use of the ring-laser as a rotation sensor pointed to further application to the measurement of Fresnel drag in solid, liquid, and gaseous media. Fresnel originally postulated that light, in passing through a moving transparent medium, experienced a velocity change or a dragging effect. Experiments were conducted long ago to measure fringe shift by using flowing water and air; however, these experiments were handicapped by fringe-shift detection capabilities so that large interferometer optical circuits and dense media moving at high velocities were mandatory.

By using the Fresnel drag effect with the ring-laser to produce a frequency-mode split, it has been possible to measure flow of solids, liquids, and gases. The ring-laser used the 1.153 micron line of a He-Ne gas system in a meter-square optical resonator, with gas tubes in three legs and with the fourth leg containing the moving medium to be measured. The applicability of these experiments to many areas of study, such as mass flow, density, and refractive index measurements external to a closed system, is quite promising. This permits obstructionless flow measurements, which are important where minimum pressure drop is desired and where corrosion and cleaning problems severely limit other techniques.

Miscellaneous Digital Transducers

The manufacturers of transducers are aware of the growing demand of true digital and semi-digital transducers in all measurand categories. This recognition of user needs has contributed to many new digital systems for measuring pressure, temperature, liquid level, and displacements, designed to function according to a variety of unique principles and techniques. One digital pressure system uses a differential transformer in conjunction with a reference differential transformer and a digital counter. A similar technique is widely used for micrometric measurements; another digital micrometer uses the variable-permeance concept, with two matched impedances forming half of an inductive bridge, and the inductive balance is varied by means of the translation of a chromium-iron slug that is attached to the test specimen. All of these systems perform the measurement by servoing on a preset null position.

In one case of a digital temperature transducer, an oscillator is under the control of a quartz crystal, which has a temperature coefficient of 1000 cps per degree C, and the frequency of the oscillator is measured by a high-speed counter which, after subtraction of the zero-degree frequency, yields the absolute temperature of the crystal. A digital liquid-level system employs two capacitors as sensors, and a change in liquid level causes an unbalance in a capacitance bridge; an electronic counter then rebalances the bridge by switching into or out of the bridge the appropriate capacitance, in binary steps. When the balance is restored, the counter supplies a parallel digital output corresponding to the level. The general system performance claimed by the manufacturer lists accuracy and repeatability of 0.1 inch in 40 inches and fulfillment of the environmental requirements demanded of airborne missile instrumentation.

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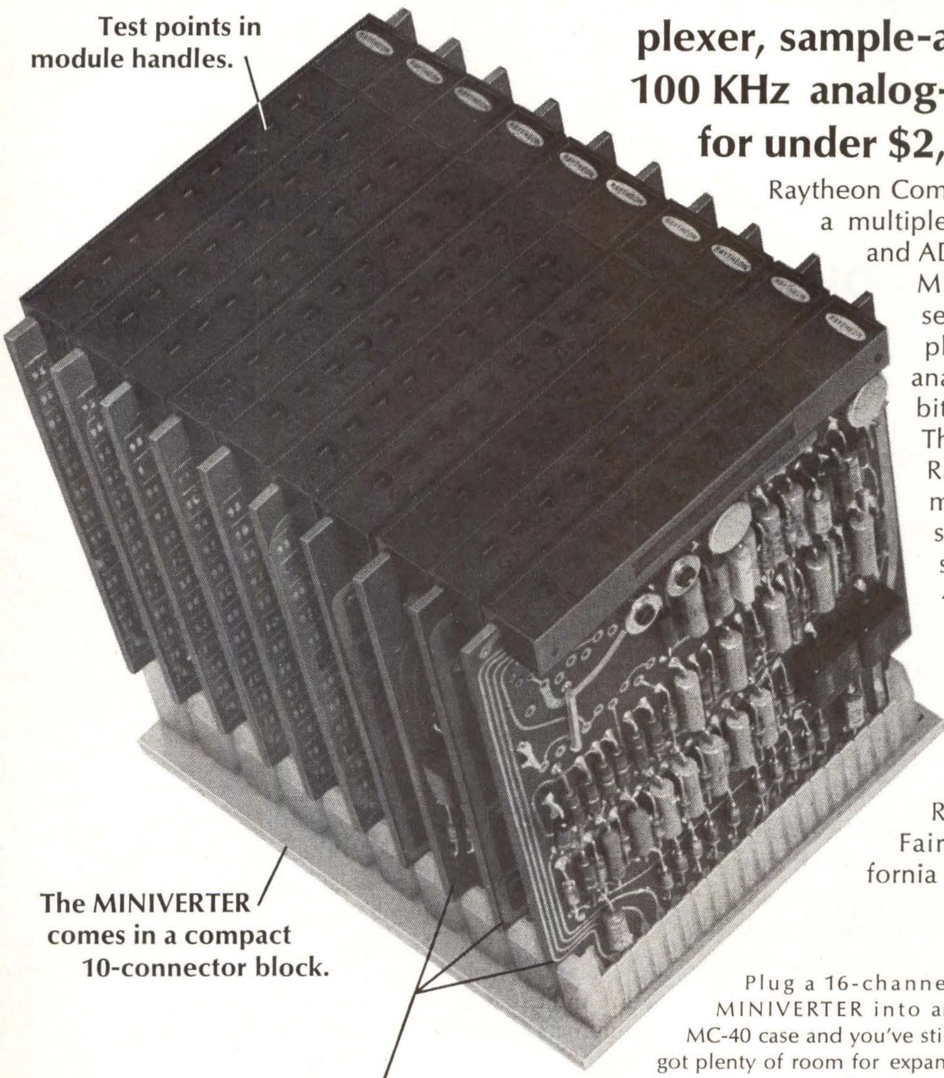
. . . You'll have a 16-channel multiplexer, sample-and-hold and 10-bit, 100 KHz analog-to-digital converter for under $2,000.



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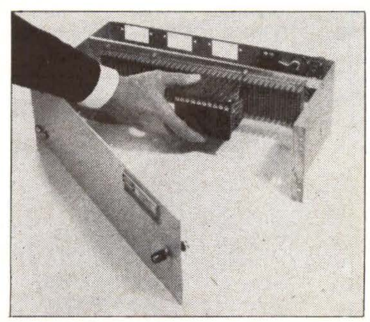


Plug a 16-channel MINIVERTER into an MC-40 case and you've still got plenty of room for expansion and logic. For fast system assembly, module connectors come in blocks of 10, 30 and 40. Power and analog and digital ground are available in module cases via laminated bus bars. And you can have automatic wire wrap if you want it.

CIRCLE NO. 29 ON INQUIRY CARD

negative radix arithmetic

M. P. deRegt

Part 5 - Division: Testing The Remainder

Editor's Note: Mr. deRegt's pioneering series on negative radix number systems began in the May issue with the introduction of basic concepts, conventions, and properties. The operations of addition, subtraction, and multiplication were covered in subsequent issues. The difficult subject of division, which was introduced in the August issue, continues to occupy Mr. deRegt's attention this month.

In part 4 of this series, we introduced the subject of negative radix division describing the procedure as far as forming the first remainder, where it was necessary to test the remainder to establish whether or not an adjustment of the estimated quotient digit is in order. The first test in normal manual division of unsigned decimal numbers, as shown in the flow chart of the previous article, is a polarity test on the remainder. If the remainder is negative, the trial quotient is too large. The next test is a magnitude test on the remainder; if the remainder (interim dividend) is larger than the divisor (weighted divisor) the final quotient digit is too small. In either case, corrective action of some kind must be taken to adjust the quotient digit and obtain a new remainder, which is again tested.

These two basic tests on the remainder are made also in manual negadecimal division. The number polarities are indicated in a different way, and the magnitude test numbers are different, but the reasoning and resulting procedural steps are the same. This being so, the execution of Step (4) of negative radix division will be explored in terms of the fundamental processes of division and illustrated in terms of decimal division. This is most easily done by considering algorithms more simple than manual, namely, a "counting" algorithm and a "mechanical" algorithm. These will be discussed in the next section.

TABLE 1

DIMINISHING OPERATION VS. OPERAND POLARITIES

Interim Dividend	Divisor	Diminishing Operation	Quotient
+	+	Subtraction	Count up
+	−	Addition	Count down
−	+	Addition	Count down
−	−	Subtraction	Count up

The Process of Division

As stated in the previous article, division as an operation may be referred to the number line, and is the process of determining how many times a given interval (the divisor) may be stepped off from the starting point (the dividend) without crossing the zero point. The only essential test for completion of division is, therefore, the polarity test, comprising a comparison of the polarities of the interim dividend and the original dividend. When these two disagree, division is complete except for a restoring operation made in the opposite direction, which results either in a final remainder of the same polarity as the original dividend, or zero. This is called "proper division" and results in a "proper" quotient and a "proper" remainder. If the restoring operation is not made, the operation is termed "improper division", resulting in an "improper" remainder (incorrect polarity) and an "improper" quotient (a magnitude too large by unity).

The arithmetic process analogous to this primitive graphical one may descriptively be called the counting algorithm, because of the way the quotient is formed. The magnitude of the dividend is diminished by repeated subtraction or addition of the divisor. The quotient formed by counting the number of times this happens, counting up from zero when the diminishing operation is subtraction (for operands of like polarity), and counting down from zero when the diminishing operation is addition (for operands of opposite polarity), forming a positive or negative quotient, respectively. The corresponding rule is given in Table 1.

The counting algorithm is illustrated in the following example, the negadecimal on the left, and the decimal on the right.

• Example 1: Divide 323 (+283) by 37 (−23) by means of the counting algorithm.
(Since the polarities of the operands are opposite, the diminishing operation will be addition, and the quotient will be formed by counting down from zero. Also, recall that in negadecimal a change in polarity is signalled by a change in the quantity of digits — an even number of digits to an odd number, or odd to even.)

Interim Dividend	Quotient	Interim Dividend	Quotient
323 37	00	+283 − 23	0
340 37	19	+260 − 23	− 1
377 37	18	+237 − 23	− 2
394 37	17	+214 − 23	− 3
211 37	16	+191 − 23	− 4
248 37	15	+168 − 23	− 5
265 37	14	+145 − 23	− 6
282 37	13	+122 − 23	− 7
119 37	12	+ 99 − 23	− 8
136 37	11	+ 76 − 23	− 9
153 37	10	+ 53 − 23	−10
170 37	29	+ 30 − 23	−11
007 37	28	+ 7 − 23	−12
24 37	Restore	− 16 − 23	Restore
07		+ 7	

Several items of interest may be observed in this example. First, although the dividend-diminishing arithmetic is most appropriately performed in the radix system of the operands, the quotient may be formed in any number system, including simple tallying. Second, since the polarity of the dividend remains unchanged up to the proper completion of division, the quantity of digits in the negadecimal interim dividend will be reduced in steps of two. Third, the change in polarity is marked by a change from an odd number of digits in the interim dividend to an even number. And fourth, although the number of digits in the interim dividend decreases in steps of two in negadecimal and steps of only one in decimal, the counting algorithm does not work twice as fast for negadecimal as decimal. By definition, exactly the same number of operations are required for all number systems, the number of operations, less two (for the polarity-changing and restoring operation), being the magnitude of the quotient. Naturally, the number of digits in the quotient will also increase in steps of two.

The complete procedure is illustrated in Fig. 1, and Example 1 illustrates that division using the counting algorithm is easy even in negative radix notation. Of course, from the point of view of machine implementation it is impractical; it is presented here to make the discussion which follows easier and clearer. The topic of that discussion is the "mechanical" algorithm, which is practical enough to be the basis for most calculating machine processes, but still markedly simpler than the manual algorithm.

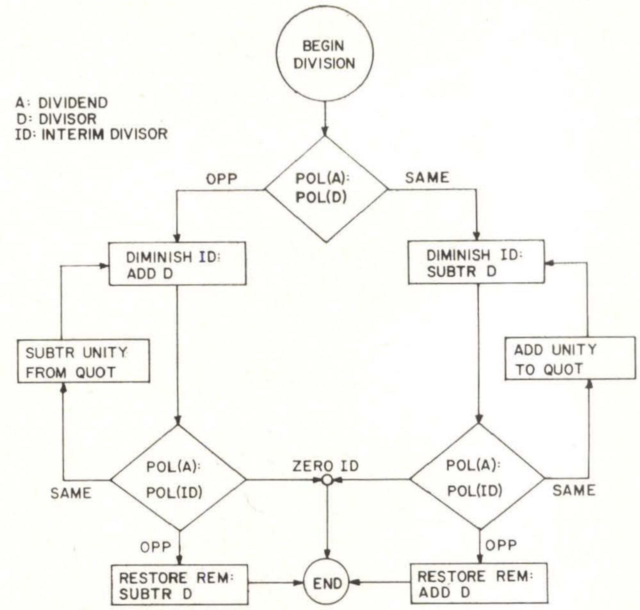


Fig. 1. Flow chart for division using the counting algorithm.

THE MECHANICAL ALGORITHM

We call this algorithm the mechanical algorithm rather than the machine algorithm because we wish to deemphasize any possible connection with a calculator or computer, and thus eliminate the resulting need for rigor. We are presenting flow charts to explain and illustrate a rather complex arithmetic operation, and not to program or design a computer. The complexity of this explanation is minimized by neglecting items intuitively obvious or conceptually unimportant.

The mechanical algorithm is one which also uses repeated subtraction or addition, but in which the magnitude of the dividend is diminished at a much faster rate than in the counting algorithm. In this procedure, a multiple of the divisor is used such as K_1D, where K_1 is a positive integer. The quotient is formed, starting at zero, by adding or subtracting K_1D (following the rules of Table 1) for each diminishing operation. However, restoring an interim dividend, after having reached a change in polarity, does not necessarily terminate division because the apparent (restored) remainder might equal or exceed the divisor in magnitude. To complete division, a smaller multiple than K_1D, such as K_2D, where $K_2 < K_1$, must be used to diminish the new interim dividend. Division is then continued by application of the rules of Table 1, assuming both K_1 and K_2 to be positive. The procedure may be repeated as often as necessary, using successively smaller integers as the weighting factor, down to unity. Again, the quotient may be formed in any base.

Although any integers could be used as weighting factors, successively smaller powers of the radix of the operands are used in practical applications, such as powers of +10 for desk calculators, and powers of +2 for binary computers. In most of these applications, the quotient is formed one digit at a time, in the same number system as the operands.

A major difference in the mechanical algorithm and the counting algorithm is that the value of the first weighting factor must be determined. If K_1 is taken too small, the algorithm tends to look more like the counting algorithm. If it is taken too large, then a lot of diminish/restore operations are executed until the right K_1 is found. For our purposes, which might be called a manual application of the mechanical algorithm, we shall determine the initial value of i in q_i (the power of the radix), in the examples, simply by lining up the high-order digits of the operands, and then avoiding special cases of examples which would call for lengthy explanations of matters of marginal value.

One complicating matter which must be dealt with is the polarity of the weighting factor. We assumed it to be positive, when no such restriction should, in general, be made. This decision is arbitrary, since the diminishing operation to be used, addition or subtraction, is determined by the polarities of the interim dividend and the **weighted** divisor. In manual decimal division, unsigned numbers are invariably used, and so subtraction is used quite automatically as the diminishing operation. In computers, which have either an adder, or a subtractor, but generally not both, the polarity of the weighted divisor is determined by the basic operation of the machine, and the polarity of the dividend. The truth table showing the relationships of the various operands and operations is given in Table 2. This algorithm is presented more graphically in the flow chart of Fig. 2, and its operation is illustrated in Example 2 for both negademical and decimal.

• Example 2: Divide 42439 (+38379) by 283 (+123) using the mechanical algorithm.

The initial value of the weighting factor is 100 for negadecimal, +100 for decimal, or an initial value of $i=2$ for

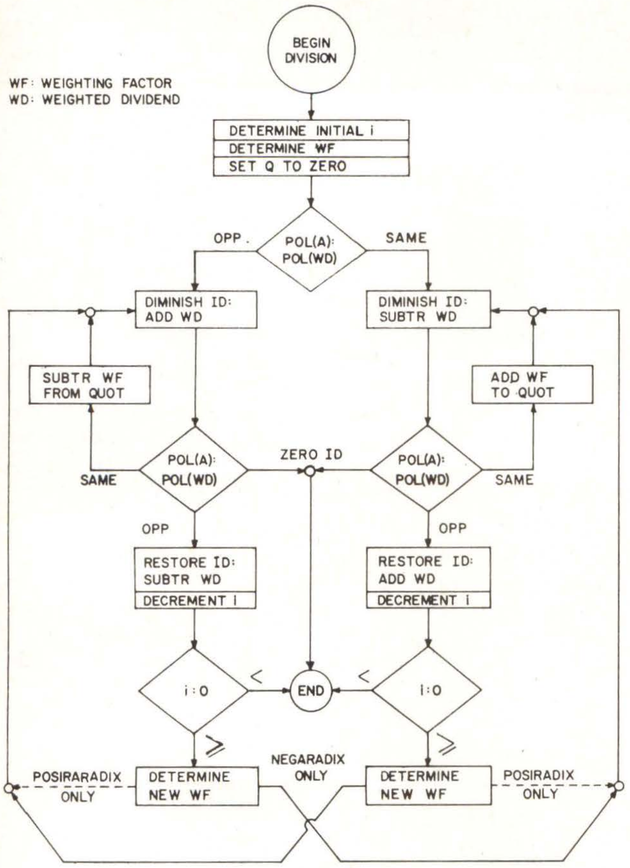


Fig. 2. Flow chart for division using the mechanical restoring algorithm. The paths designated for negaradix and posiradix systems are for constant K in weighting factor $(-1)^K (r^i)$. If the sign of (r^i) alternates, the designation of the paths would be reversed. In the general case, for any new weighting factor, each pass must begin with the first polarity test (not shown).

both systems. Referring to Table 2, which is applicable to any number system, the diminishing operation for the first pass is subtraction.

First Pass

Interim Dividend (Sub 100D)	Quotient (Add 100)	Interim Dividend (Sub +100D)	Quotient (Add +100)
42439	000	+38379	000
28300		+12300	
341	100	+260	+100
283		+123	
278	200	+137	+200
283		+123	
195	300	+ 14	+300
283		+123	
191239	Restore	−10821	Restore
28300		+12300	
19539		+ 1479	

For the second pass, the interim dividend is positive in both cases, and the weighting factor of +10 for decimal

TABLE 2

DIMINISHING OPERATION VS. OPERAND POLARITIES

Line	Interim Dividend	Divisor	Weighting Factor	Weighted Divisor	Diminishing Operation
1	+	+	+	+	Subtraction
2	+	+	−	−	Addition
3	+	−	+	−	Addition
4	+	−	−	+	Subtraction
5	−	+	+	+	Addition
6	−	+	−	−	Subtraction
7	−	−	+	−	Subtraction
8	−	−	−	+	Addition

is also positive, indicating subtraction for the diminishing operation. However, the apparently "natural" weighting factor of 10 for negadecimal, which is equal to −10, is negative, and, of course, the weighted divisor, 2830, is negative. According to Table 2, line 2, that means that addition must be used as the diminishing operation for negadecimal for the second pass.

Second Pass

Interim Dividend (Add 10D)	Quotient (Sub 10)	Interim Dividend (Sub +10D)	Quotient (Add +10)
19539	300	+1479	+300
2830		+1230	
00369	490	+ 249	+310
2830		+1230	
1199	Restore	− 981	Restore
2830		+1230	
0369		+ 249	

For the third pass, subtraction is again used in both instances, with a weighting factor of unity.

Third Pass

Interim Dividend (Sub D)	Quotient (Add 1)	Interim Dividend (Sub D)	Quotient (Add +1)
369	490	+249	+310
283		+123	
286	491	+126	+311
283		+123	
3	492	+ 3	+312
283		+123	
1920	Restore	−120	Restore
283		+123	
0003		+ 3	

This example illustrates several important properties of this algorithm. First, division is always proper, be-

negative radix arithmetic

continued

cause the restoring operation causes the polarity of the interim dividend, including the final remainder, to be always the same as the polarity of the dividend. Second, in negaradix division, the diminishing operation alternates between subtraction and addition. Third, this alteration is the only serious difference in the operation of the algorithm between negaradix and posiradix division. Note also that if we apply a weighting factor to the interim dividend instead of to the divisor (as we do when we "shift" the interim dividend in a computer), we would still find the diminishing operation to alternate. The condition would simply be that of line 5 of Table 2, instead of line 2 (neglecting columns 3 and 4).

This algorithm could be extended to a reasonably workable manual algorithm for negadecimal, but the alternating diminishing operations would be confusing, especially when we consider the variations of polarity in dividend and divisor. Also, alternating the operation is an unnatural thing to do, and such an algorithm cannot really be considered analogous to the decimal equivalent. The complexities of the algorithm are shown graphically in Fig. 2, where there are three decision blocks in sequence for each pass in negadecimal, against only two for decimal (after the first decision).

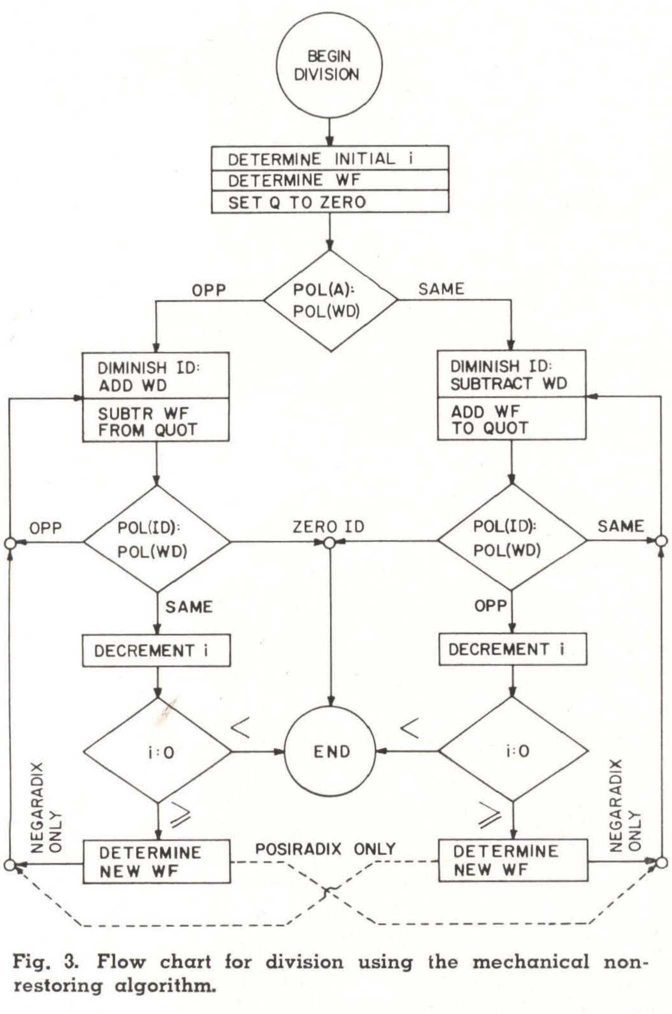


Fig. 3. Flow chart for division using the mechanical non-restoring algorithm.

Referring back to the example, if we were to insist on subtraction as the diminishing operation throughout, the rules of Table 2 would force us to use a positive weighting factor. This can be accomplished by reducing the weighting factor exponent by 2 each time, instead of by unity. For the second pass we would then have:

Interim Dividend	Quotient	Interim Dividend	Quotient
19539	300	+1479	+300
283		+ 123	
19456	301	+1356	+301
283		+ 123	
19373	302	+1233	+302
283		+ 123	
19290	303	+1110	+303
283		+ 123	
19027	304	+ 987	+304
283		+ 123	
944	305	+ 864	+305
283		+ 123	
861	306	+ 741	+306
283		+ 123	
798	307	+ 618	+307
283		+ 123	
515	308	+ 495	+308
283		+ 123	
432	309	+ 372	+309
283		+ 123	
369	490	+ 249	+310
283		+ 123	
286	491	+ 126	+311
283		+ 123	
3	492	+ 3	+312
283		+ 123	
1920	Restore	− 120	Restore
283		+ 123	
0003		+ 3	

This alternative is clearly very inefficient — theoretically, up to 101 operations might be needed. As a matter of fact, the algorithm is, in effect, a positive radix algorithm using +100 as the radix, and 100 negative-decimal-coded digit pairs as numerals, ranging in value from −90 to +9. Although each division would require about half the number of passes (since we generate two quotient digits at a pass), it would also require an average of ten times as many operations per pass. This algorithm is, therefore, hardly a sensible basis for our manual algorithm, since we would have to estimate two quotient digits at a time, and form a digit product using this digit pair. In effect, we would have to depend on a multiplication table of 10,000 elements, instead of one of 100 elements.

One other alternative for retaining subtraction in the second pass is offered by line 6 of Table 2. If we **do not restore** the interim dividend after the polarity change in the first pass, we would have the condition described by line 6. At the end of the second pass, if we again do not restore after the polarity change, we would again have the condition described by line 1. In fact, if we refrain from restoring at the end of each pass, we would alternate between the conditions of lines 1 and 6.

The algorithm corresponding to this procedure is called a "non-restoring" algorithm; in this discussion, it will be referred to as the "non-restoring mechanical algorithm," in contrast to the "restoring mechanical algorithm" which we have described earlier. The non-restoring algorithm is presented graphically in Fig. 3, and is illustrated in Example 3.

• Example 3: Divide 86315 (+74295) by 283 (+123) using the non-restoring mechanical algorithm.
The weighting factor is 100 (+100), and i is 2 for both systems for the first pass. Referring to Table 2, subtraction is the diminishing operation, applicable to both systems.

First Pass

Interim Dividend (Sub 100D)	Quotient (Add 100)	Interim Dividend (Sub +100D)	Quotient (Add +100)
86315	000	+74295	000
28300		+12300	
780	100	+619	+100
283		+123	
517	200	+496	+200
283		+123	
434	300	+373	+300
283		+123	
351	400	+250	+400
283		+123	
288	500	+127	+500
283		+123	
515	600	+00495	+600
28300		+12300	
192215	700	−11805	+700

For the second pass, the weighting factors are 10 and +10, respectively, resulting in weighted divisors of 2830 and +1230. The interim dividend is negative, and, referring to Table 2, we observe that the condition for negadecimal is described by line 6, and that for decimal by line 5. The operations are, therefore, subtraction for negadecimal, as we anticipated, but addition for decimal. This reverses the situation we found to be true for the second pass in the restoring mechanical algorithm, and what we observed there about alternating addition and subtraction for negadecimal is now applicable to decimal. This is indicated in the flow chart of Fig. 3. Note that there are six digits in the negadecimal interim dividend, one more digit than in the original dividend.

Second Pass

Interim Dividend (Sub 10D)	Quotient (Add 10)	Interim Dividend (Add +10D)	Quotient (Sub +10)
192215	700	−11805	+700
2830		+ 1230	
19158	710	−1057	+690
283		+ 123	
19075	720	− 934	+680
283		+ 123	
992	730	− 811	+670
283		+ 123	
729	740	− 688	+660
283		+ 123	
646	750	− 565	+650
283		+ 123	
563	760	− 442	+640
283		+ 123	
480	770	− 319	+630
283		+ 123	
217	780	− 196	+620
283		+ 123	
1345	790	− 735	+610
2830		+ 1230	
515	600	+ 495	+600

For the third pass, we have a weighting factor of unity, or weighted divisors of 283 and +123, respectively. The interim dividends are 515 and +495, which are both positive. According to Table 2, the diminishing operation for negadecimal is still subtraction, and that for decimal is once again subtraction.

Third Pass

Interim Dividend (Sub D)	Quotient (Add 1)	Interim Dividend (Sub D)	Quotient (Add 1)
515	600	+495	+600
283		+123	
432	601	+372	+601
283		+123	
369	602	+249	+602
283		+123	
286	603	+126	+603
283		+123	
3	604	+ 3	+604
283		+123	
1920	605	−120	+605

Of the observations that might be made about this example, two stand out. First, division is improper, that is, the final remainder is of the opposite polarity from the dividend. This will be discussed fully in the next section. Second, the second pass quite evidently did no more than reduce the first-pass (high-order) quotient digit by unity. In fact, the interim dividend opposite 600 in the first pass is identical to the interim dividend at the end of the second pass. This will be explained in more detail in the next article. It may also be observed that of all the algorithms examined so far, this one appears to be most amenable to extending to a workable manual algorithm for negadecimal division. The same diminishing operation is used throughout, and only one quotient digit at a time is generated.

The Final Remainder

In an earlier section, it was observed that the restoring algorithm is of such a nature that a proper quotient and remainder will always result, since the polarity of the interim dividend at the end of a pass is always the same as that of the dividend. In the non-restoring algorithm, however, a proper quotient and remainder will result only from an even number of passes, since an odd number will leave the remainder at a polarity opposite to that of the dividend. This is easily seen to be true simply by noting that each pass reverses the polarity of the starting interim dividend. Therefore, a proper quotient and remainder will be obtained in a non-restoring algorithm for negaradix division only if the quotient is negative (i.e., if the numerals are positive and all operands and results are considered to be integers). If the quotient has an odd number of digits (positive), an extra pass may be forced by performing a restoring operation. The possible need for adjusting the remainder is reflected in Fig. 2 by the circle, "TEST REM." There are many ways for testing whether the remainder is correct or not; one self-explanatory test is shown in the flow chart of Fig. 4.

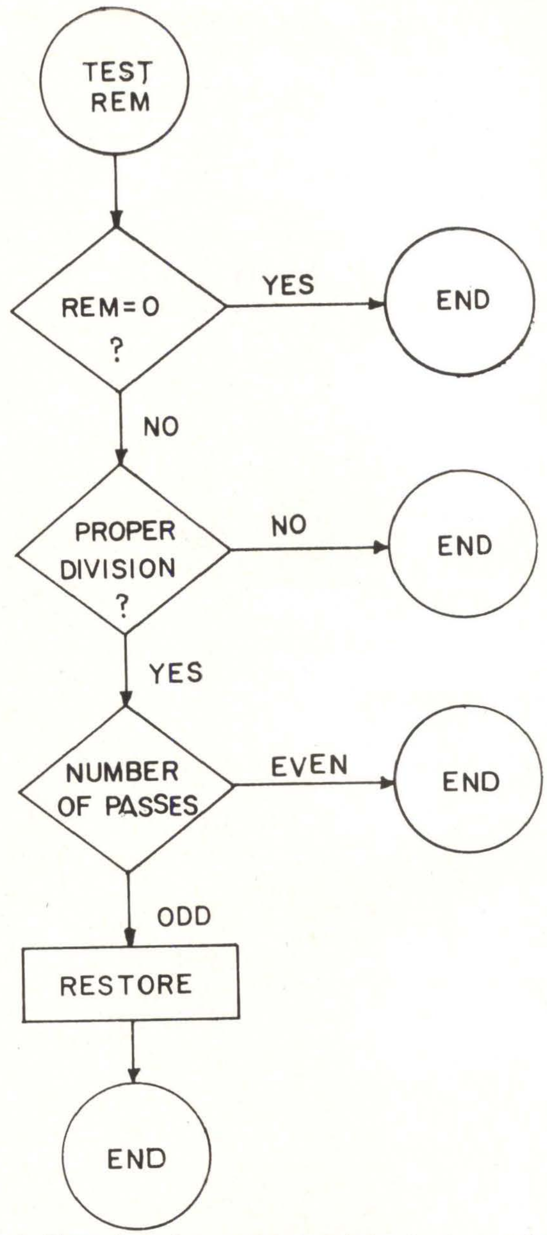
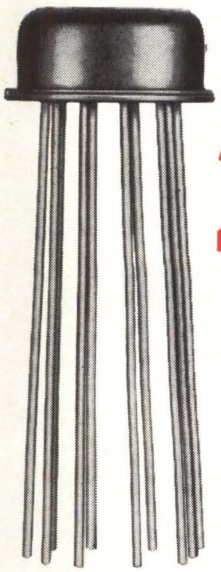


Fig. 4. Flow chart for testing remainder in the mechanical non-restoring negadecimal division algorithm.

The Magnitude Test

The non-restoring mechanical algorithm is, of itself, a completely workable algorithm for use in a digital computer. The inefficient second pass can be eliminated by a magnitude test; however, in the negabinary equivalents of this algorithm, the "inefficiency" might well be preferable, in terms of hardware, than a separate magnitude test. This is because in negabinary only two operations are required to correct the previous quotient digit instead of ten, whereas a magnitude test would require not only the magnitude operation itself, but additional hardware to implement the test.

In manual computation, however, rough magnitude tests are easy to make, even in negadecimal. In conventional decimal division, the polarity test is completely replaced by a magnitude test. For our negadecimal division algorithm, we shall develop the magnitude test in the next article.



now you can test 24 parameters of a 10-pin microcircuit in 2 minutes flat...

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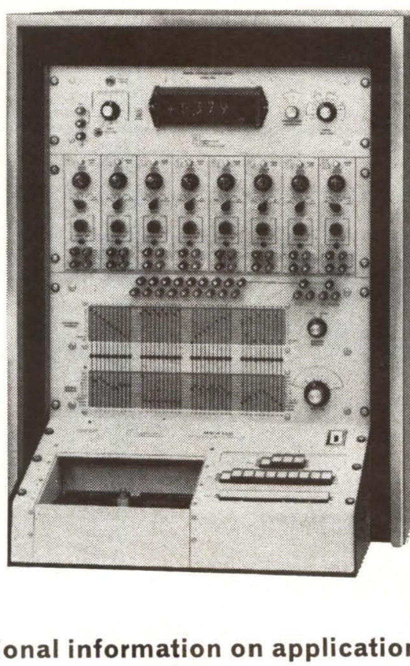


Now even a non-technical operator can speed through comprehensive DC tests on all types of IC packages with from 2 to 40 pins. Test conditions are easily set up on the programming switches of MICA-150 and pushbutton sequencing of the test from pin-to-pin of a device is simple and fast with test results indicated by direct digital readout. On a typical 10-pin, 5-input gate circuit, as many as 24 parameters of the device can be checked within two minutes without changing a single crossbar switch.

For additional information on applications of MICA-150 for DC or high frequency testing, contact W. Leo McBlain, (609) 424-2400

COMPUTER TEST CORPORATION

CHERRY HILL, NEW JERSEY

CIRCLE NO. 30 ON INQUIRY CARD

NEW PRODUCTS

85 MHz FLIP-FLOP

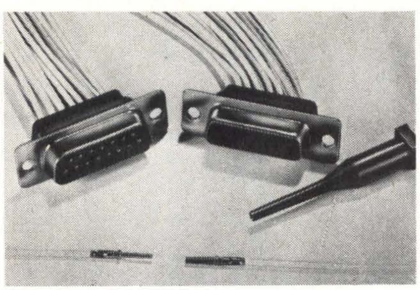
New flip-flop consists of a charge-controlled, current-mode circuit guaranteed to toggle at a frequency of at least 70 MHz and typically 85 MHz. The MC1013P Flip-Flop is the first of a "second generation" emitter-coupled logic circuit family. This new family features a nominal propagation delay of only 5 ns and is designed for an ac fan-out up to 15. Unlike the conventional J-K flip-flop, the inputs to MC1013P are the complement of J and K. This in contrast to the action of a conventional J-K in which low input states inhibit and negative going clock pulses clock the flip-flop. This approach is generally preferable from a system viewpoint since positive logic is more common than negative logic. Motorola Semiconductor Products, Inc., Phoenix, Ariz.

Circle No. 241 on Inquiry Card

STATIC CARD READER

Extending less than 2" above the panel, and weighing only six pounds, a new card reader is said to be ideally suited for portable devices. Used as a quick-change, static memory, this reader is designed for a life of over 1,000,000 operating cycles. The 540 individual switches arranged on a 12 x 45 matrix are available either normally-open or normally-closed, and both terminals of each switch appear on the back panel in the form of solder tabs. The palladium (or gold) plated contacts exhibit less than 100-milliohms resistance at 100 milliamperes and feature full wiping action. When all circuits are in use, the contacts are rated at 2 amperes. Insulation resistance is greater than 750 megohms at 500 volts. Amp Inc., Harrisburg, Pa.

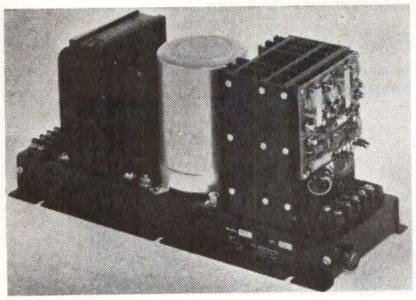
Circle No. 212 on Inquiry Card



CRIMP CONTACT CONNECTORS

Electrical connectors with crimp contacts are introduced for use in computers, business machines, plug-in module applications, cable-to-cable and cable-to-panel installations. Designated BURGUN-D (trademark), the new connectors are intermateable with present D Subminiature connector series and will operate in temperatures of up to +250°F. Since the connector series incorporates D Subminiature shell configurations, hardware, and accessories, BURGUN-D connectors can be adapted to present installations. The five shell sizes offered accommodate from 9 to 50 size 20 or 18 crimp removable electrical contacts. Other features of the BURGUN-D connector series include rear release contact retention system, closed entry socket insulators, low contact engaged and separation forces, and strip packaging of contacts. The units are available for immediate delivery. ITT Cannon Electric, Los Angeles, Cal.

Circle No. 240 on Inquiry Card



POWER SUPPLIES FOR IC'S

Two new low cost, high performance power supplies specifically designed for digital integrated circuits have been announced. Models 605 and 610 produce 5 amps and 10 amps respectively with adjustable outputs from 4.5 to 5.5 volts. Ripple is less than 1 mv peak to peak, regulation is 0.25% zero to full load, and ±0.1% for ±10% change in input. Both supplies feature a special high speed regulator which insures proper transient response. Crow bar overvoltage protection and current limited short circuit protection are built in. Construction is open frame and cooling is by convection only. Card cage mounting units are also available. Price is $125.00 for Model 605, and $139.00 for Model 610. Crow bar overvoltage protection is $18.00 additional. Delivery is stock to two weeks. RO Associates, San Carlos, Cal.

Circle No. 239 on Inquiry Card

CRT DISPLAY SYSTEM

A free standing, fully buffered, graphic CRT console was designed for man-machine dialog in "people" language. Known as Idiiom, the new system is unique in having its own programmable memory, which means that it requires no external computer for such functions as message composing and editing, light pen tracking, or display refreshing. If desired, the Idiiom can be driven from any computer but only large-scale data manipulation and storage need be done in such a central computer. Output is a bright, crisp, flicker-free presentation on a large screen, 21" rectangular CRT. Slave displays, hard copy devices, and wall-size displays can be driven from auxiliary outputs. Information Displays, Inc., Mount Vernon, N.Y.

Circle No. 246 on Inquiry Card

NEW PRODUCTS

IC MEMORY SYSTEM

An advanced state-of-the-art integrated circuit memory system offers a full-cycle time of only 500 nanoseconds and a large basic capacity of 16,384 words of 36 bits each. The large capacity, high reliability, and high speed of the 2½ D system are attributed to the use of newly-developed high-speed ferrite cores and the extensive use of integrated circuits in all but the high-current drive circuits. The ferrite cores used in the system have an exceptionally square loop and a switching speed of only 220 nanoseconds. The cores, mounted on aluminum plates which act as heat sinks, maintain uniform low temperatures to provide optimum reliability. A self-tester is an integral part of the system on display. The system is designed for a standard 19-inch rack and is only 27-inches high and 22-inches deep. RCA Memory Products Division, Needham Heights, Mass.

Circle No. 244 on Inquiry Card

DUAL-INLINE IC CARRIERS

New carriers for dual-inline integrated circuits permit manual or fully automatic handling of the devices during testing and production mounting. Base outline geometry of the new carriers is identical to company's flat-pack carriers, for complete interchangeability in automatic and semi-automatic test and handling equipment. The carriers are available in 14 or 16 lead models, constructed either of polysulfone for extended tests at temperatures ranging from −65C to 150C or of impact-resistant styrene for less critical applications. Design of the carriers is such that leads are fully protected and recessed between separators which prevent them from being deformed, yet fully expose the leads to test contacts. Lead spread or taper between rows is maintained at all times. Barnes Development Co., Lansdowne, Pa.

Circle No. 248 on Inquiry Card

DATA PRINTER

A new data printer has been designed to accept the analog signal from virtually any laboratory instrument and convert it into digital form. The compact (14″ wide, 7″ high, 13″ deep) solid state device with a non-inking printer, will present a tape printout of volts, concentration, or other units of measurement, in three digits along with the corresponding sequential sample number in two digits. Three standard models are available: 1) Model D 3 Printing Digital Voltmeter; 2) Model G 2, compatible with the Gilford Model 300 Micro Sample Spectrophotometer; 3) Model S 5, compatible with any instrument that gives a transmittance output, with log conversion done inside the printer to give printout in concentration units. Also available are optional plug-circuit boards and modules to permit peak sensing, time controlled repetitive readings, and analog multiplexing. Using analog multiplexing with peak sensing, it is possible to do repetitive sampling up to 10 variables and printout the results. Berkeley Scientific Laboratories, Berkeley, Cal.

Circle No. 217 on Inquiry Card

RESISTORS

New line of low-cost, high stability resistors are designed for computers and other industrial applications which require the stability and performance of metal film. Two types, MR 25 and MR 30, are available, with resistance values from 4.99 ohms to 301K ohms, 250 and 350 VDC. Type MR resistors consist of a ceramic core on which a resistive metal film is deposited. End caps make contact with the film, and tinned copper leads are resistance welded to the end caps. The unit is conformally coated with a protective resin. Mepco, Inc., Morristown, N. J.

Circle No. 242 on Inquiry Card

NEW PRODUCTS

ROTARY WIRE STRIPPER

Precision rotary wire stripper unit is designed for ultra-high production rates especially with teflon and PVC insulations. Unique blade design rapidly strips wires from AWG #16 - to - #26 thin or thick insulations up to 1/32″ and overall wire diameter of ¼″. Cutting blade is replaceable and constructed of carbide. Compact self-contained unit requires no installation. Techni-Tool, Inc. Philadelphia, Pa.

Circle No. 250 on Inquiry Card

DUAL-GUN OSCILLOSCOPE

New oscilloscope, priced at $1,045, couples high gain with a dual-gun CRT for simultaneous, highly reliable tests. Using two identical vertical amplifiers and a no time-sharing, dual-gun CRT, the Model 708A has a sensitivity range of 10 uV to 10 volts/cm in 19 steps of 1, 2, 5 sequence. It also features dc or ac stabilized amplifiers, 6 x 10 cm viewing area for each beam with a 5 kv high intensity CRT, and a selectable bandpass. The oscilloscope's unique electrometer-type input stage is said to give exceptional amplifier position stability. The sweep is wide range from 0.1 usec/cm to 1 minute full scale. The 708A has selectable bandpass in three switch settings (500 kc) for maximum capabilities at high sensitivities. Fairchild Instrumentation, Mountain View, Cal.

Circle No. 213 on Inquiry Card

MINIATURIZED DIGITAL PRINTER

Completely modular in construction, one basic printer design is said to accommodate a wide range of mechanical and electrical requirements. The basic unit has an 8-column capacity and prints at 12 lines-per-second or less. The complete printer system, with all operating electronics, power supply, 19″ rack-mounting ears, roll-of-action paper, sells for $1495. The printer can be supplied with as few as 4 columns or as many as 10 columns. Other options provide for print rates in excess of 40 lines per second, use of an inked ribbon or inked roller, multiple-copy printing, and ticket printing. Data input to the standard printer is BCD 8421. However, the printer electronics can be supplied to operate with BCD 4221, 2421, or mixed codes. Symbols can be changed by simply changing print-drum indexing. Physically, the printer consists of two half-rack units; one unit contains the printer mechanism, the second unit contains the power supply and electronics. The height of each unit is only 5-3/16″. The two half-rack units can be supplied in a unitized side-by-side configuration for use in a standard 19″ rack. One of the inherent features of the printer mechanism is said to be low mechanical noise-level. It has been achieved by a new suspension system for the hammers. In this system, the hammers use the air surrounding each hammer as a sound damper, as opposed to passing noise into the printer frame, which would then act as a sound amplifier. Franklin Electronics, Inc., Bridgeport, Pa.

Circle No. 201 on Inquiry Card

COLD CATHODE TRIGGER TUBE

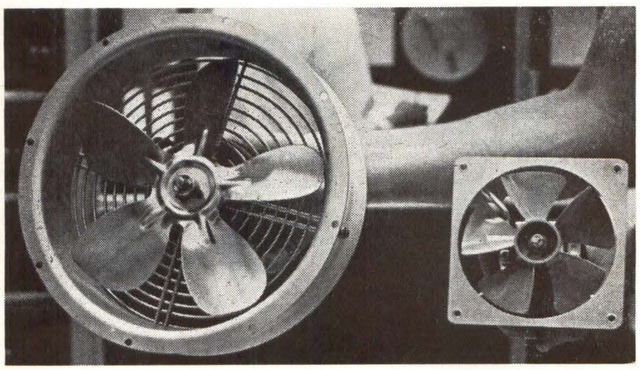
Functionally designed as a switching and indicating device, a cold cathode tube's single starter circuit makes it ideally-suited for use in shift registers for moving-text display applications. The tube features a narrow ignition voltage range due to its precisely-controlled gas content and sputtered molybdenum cathode. Compared to older and conventional neon indicator tubes, it has a high light output of approximately 0.0018 foot candles and may be seen readily from hundreds of feet under high ambient light conditions. Small in size and highly rugged, the Model ZC1031 is able to withstand electrical overloads and is negligibly affected by changes in temperature. The pure molybdenum cathode ensures stable characteristics and long life. Amperex Electronic Corp., Hicksville, N. Y.

Circle No. 230 on Inquiry Card

COMPUTER FOR COLOR MATCHING

A compact, electronic computer system, can be adapted to solve complex color comparison problems almost instantaneously. The new system features a special color-difference digital computer which is used in the production of paints and dyes. An operator enters specific instrument readings by means of the keyboard on the small display console. When several special function keys are depressed in sequence, the unit solves a set of equations and reads out numbers, on a lighted Nixie-tube display, which indicate directly the closeness of the color match obtained. Detailed calculations are controlled by a hard-wired programmer. The system consists of a processor package which measures 17″ x 8″ x 5½″ and may be connected by up to 200′ of cable to as many as four individual desk-top consoles, any one of which may be operated at a given time. The system has complete arithmetic capability and can automatically generate logarithms and anti-logs. This allows it to perform calculations with non-integer exponents. Wang Laboratories, Inc., Tewksbury, Mass.

Circle No. 229 on Inquiry Card



COMPACT COOLING FAN

A new, compact blower unit has been designed for cooling in computers and electronic systems cabinets. Able to fit in an opening less than 4¾ inches square, the new fan assemblies are rated 100 or 90 cfm at approximately 3000 rpm, and operate at 115 or 230 volts, 60 cycles. Assemblies feature a quiet shaded pole Unitized (trademark) motor with a hydrodynamic oil film lubrication system for high reliability and long life. The motor design concepts are said to provide a more electrically efficient motor with optimum alignment of bearings. In the manufacture of these motors, the air gap is present between the rotor and stator, and the motor is accurately built around the air gap dimension.

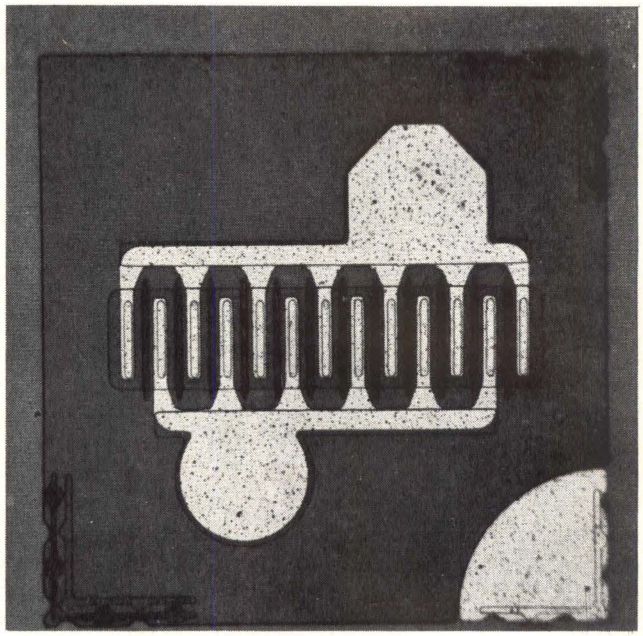
The lubrication system of the blower units creates a film of oil which allows the shaft to "float" at operating speeds, eliminating metal-to-metal contact. Motors are factory lubricated for the expected life of the motor by capillary retention. These new GE fan assemblies are designed for all-angle operation. They can be mounted in any position inside an equipment cabinet for maximum air flow over vital electronic components. General Electric Co., Fort Wayne, Ind.

Circle No. 222 on Inquiry Card

NEW PRODUCTS

SILICON TRANSISTOR

A new silicon field-effect transistor features a frequency capability twice that of such devices previously available in low-cost plastic packages. The new high-performance FET, designated TIS88, operates up to 400 megahertz, with 10 decibels minimum of power gain. Transconductance is high [Re (Y_{fs}) = 4000 μmho min. at 400 MHz], and feedback capacitance is low (C_{rss} = 1 pF max.). The ratio of the two [Re (Y_{fs}) : C_{rss}] is quite high, indicating a favorable figure-of-merit for high frequency in FETs. The N-channel epitaxial planar device is useful for a variety of consumer, industrial and military applications. It offers particular advantages in FM RM amplifiers, cascade-connected TV VHF amplifiers, and sonobouy input amplifiers. The



TIS88 is well-suited for RF amplifier and mixer applications because of its high-frequency capability, and also because of its square-law transfer characteristic which minimizes cross-modulation.

The TIS88 is available in TI's SILECT ™ plastic package with TO-18 pin circle. The drain and gate leads are separated in a D-S-G lead configuration for reduced feedback capacitance and higher maximum stable gain. The TIS88 is also available in a TO-72 (TO-18 with four leads) metal package, designated 2N4416. Other performance characteristics include a low noise figure (4 dB max at 400 MHz), and low leakage (I_{GSS} = 1 nA max). The drain-current spread is narrow (I_{DSS} = 5 to 15 mA). Evaluation quantities of both the TIS88 and the metal-case 2N4416 are immediately available from stock. Price of the TIS88 is 95¢ in 100-999 quantities. Texas Instruments Inc., Dallas, Texas.

Circle No. 209 on Inquiry Card

DATA LINE ADAPTERS

A single 9 x 7 unit provides the complete half-duplex serialize/deserialize function to interface digital data processors to serial datasets or teleprinter networks. Constructed of IC modules, the unit operates with 5 through 8 data bits. It switches from a transmitter (parallel/serial) converter to a receiver (serial/parallel) converter under single line user control. An integral clock with field changeable components covers teleprinter speeds to 10 kilobits/sec. In the transmit mode, it accepts parallel data from the user in 5, 7, or 8 bit characters. Five level units put out serial baudot code with 1 start and 1½ stop bits. Seven and 8 level units provide serial characters with 1 stop and 1 start bit for 7 level and 1 start and 2 stop bits for 8 level ASCII format. In the receive mode, the units accept incoming serial data in 5 level baudot, 7 level start-stop or 8 level ASCII. Deserialized output is presented in parallel with control signals and parity check. Western Telematic Inc., El Monte, Cal.

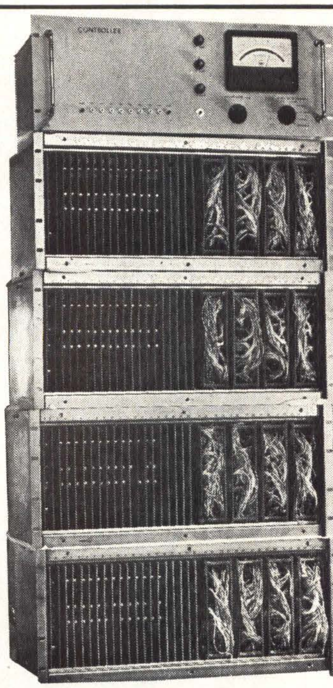
Circle No. 285 on Inquiry Card

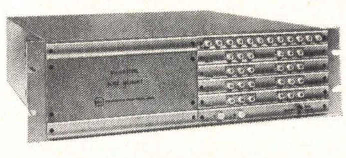
NOISE GENERATOR

A new noise generator uses computer techniques to synthesize broadband noise. As a result, it produces lower frequency noise that is more precisely defined and with higher long term power stability than previously available. Moreover, the instrument will precisely repeat noise bursts, for exact stimulus/response analysis. Gaussian noise waveforms whose power density is exactly known are generated by the new Model 3722A. Maximum amplitude is 3.16 V rms with an upper cutoff frequency selectable in 18 steps from a high of 50 kHz to a low of 0.00015 Hz. Output power remains constant regardless of bandwidth selected. Enough power, precisely known, for meaningful measurements when the noise power must be confined to a restricted frequency band can thus be obtained. Full power can be obtained with an upper bandwidth limit as low as 0.00015 Hz. Another advantage of the synthesizing technique is that noise waveforms can be repeated exactly as they occurred at an earlier time. Identical bursts may be generated. As a consequence, the exact effect of progressive alterations in the tested subject may be quickly and reliably observed. Noise generators are finding ever-increasing usage because the random characteristics of a noise waveform resemble the complex signals found in practice, thus enabling realistic tests on equipments such as those used in communications or for acoustic measurements. Also, the multi-frequency content of broadband noise enables evaluation of system performance with all frequencies present.

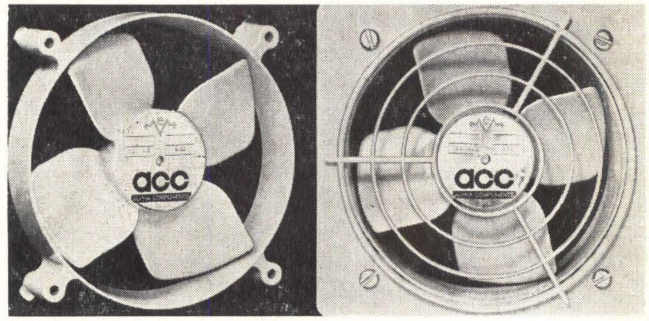
The new noise generator, because of its well-defined low frequency output, will also be useful as a forcing function for analog computers in the real-time simulation of random low frequency disturbances — earth tremors and ocean wave motion for example. In addition, it can serve as the drive stimulus for shake tables in studies of vibrations in large structures. Hewlett-Packard, Palo Alto, Cal.

Circle No. 211 on Inquiry Card





NEW PRODUCTS



AXIAL BLOWER

A new series of venturi, axial blowers for general purpose cooling or ventilation of semiconductor assemblies, electronic equipment, power supplies, business machines, computers, projectors, sound equipment, hi-fi and other heat generating equipment are available in three models with air flow ratings of 90, 130 and 150 cubic feet per minute. Measuring 5″ x 5″ x 2.75″ deep, the new blowers are said to provide greater efficiency because of the cooperation of blade and venturi shapes that produce a high volume of air against a great resistance, with a low noise level. Vibrationless, impedance protected blower motors feature two large bearings, and include an ample oil supply for long-term, maintenance free operation. Blowers are guaranteed one year. Optional features include intake or exhaust types, flush or grille mount, on-off control switch, blower grille, magnetic shield, polyurethane filters and a choice of beige or black colors. Prices start at $5.00 depending upon quantity. Alpha Components Corp., Venice, Cal.

Circle No. 228 on Inquiry Card

PUSHBUTTON SWITCH KIT

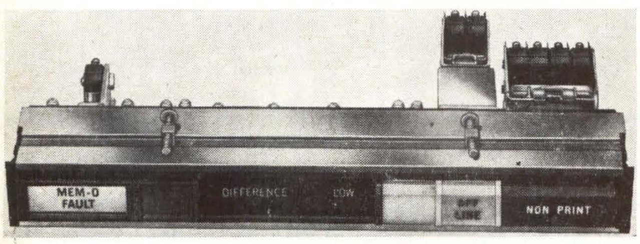
A new kit provides all necessary components for complete assembly of a line of modular pushbutton switches. The modules contained in this kit can be assembled in more than 1.5 million combinations to produce a broad range of switching devices. Included in the kit are front and rear mounting brackets, latch bars, and switch modules that will furnish interlocking, momentary, or push-push switching action. Switch brackets are provided for single units with or without mounting ears and ganged units ranging from 2 to 19 positions on 10 mm. centers, 2 to 10 positions on 15 mm. centers, and 2 to 10 positions on 20 mm. centers. Six each of thirty basic brackets are included along with sixty 2 pole double throw modules, sixty 4 pole double throw modules, forty-five 6 pole double throw modules, and twenty 8 pole double throw modules. A complete set of instructions appears in an accompanying manual. Cost of the five drawer metal kit is $150.00. Centralab, Electronics Div. of Globe-Union, Inc., Milwaukee, Wisc.

Circle No. 235 on Inquiry Card

SOLID-STATE LIGHT PEN

The new Model LP-301 solid-state light pen exhibits both high sensitivity and extremely fast response times. The new light pen is sensitive to brightness changes of 10^{-6} mw/cm^2 yet exhibits less than a 300 second response time. The acceptance area of the LP-301 is 1/8" and is defined by an illuminated solid finder circle which is projected on the CRT phosphor. To aid the operator in positioning the pen, the pen projects an illuminated solid finder circle on the CRT phosphor illuminating the exact area to be sampled by the detector. The minimum size of the acceptance area is 125 mils in diameter. The device also features a touch-sensitive actuator which, unlike the usual mechanical shutter or microswitch, has no moving parts. To enable the LP-301 to see light, the actuator switch which lies approximately where the index finger falls is simply touched. The new pen does not employ any fibre optics or photomultiplier devices. Instead, light pulses are converted to electronic pulses in the pen unit and are transmitted from the pen to the processing electronics over a light weight cable. The elimination of the fibre optics bundle and the photomultiplier tube is said to improve reliability, maintainability, and to minimize operator fatigue. Information Control Corp., El Segundo, Cal.

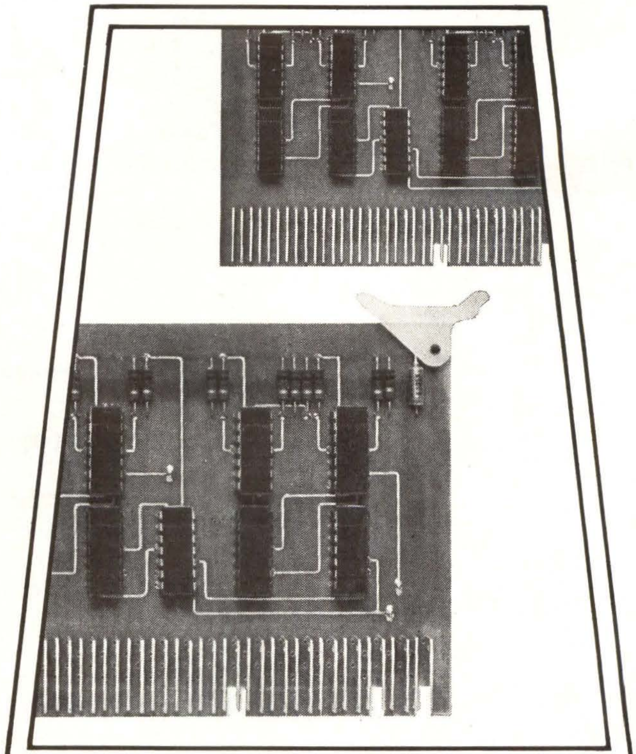
Circle No. 203 on Inquiry Card



IN-LINE MODULAR DISPLAY

Now TEC-LITE DATA-LINE display gives electronic and industrial designers a new, integrated information display and control electronic systems where console panels must be both handsome and functional, yet compatible with today's demand for compact design. Legend display areas, switches, illuminated switches and indicator elements mounted in a brushed anodized aluminum bezel present a custom designed appearance that is often difficult to achieve with individually mounted components. Display and control functions can be intermixed in any sequence — separated by colored barriers — in an extruded aluminum frame up to four feet long. The frame forms its own bezel and mounts in a single rectangular hole. A wide variety of options are provided: lens shape, length and color; legend display techniques; lamp type and voltages; and switching circuits. Curved face button lenses for indicators and switches are offered in 10 colors and can be hot stamped or engraved. Back lighted replaceable legend button lenses allow simple legend change. All button lenses snap out for front lamp replacement. Transistor Electronics Corp., Minneapolis, Minn.

Circle No. 216 on Inquiry Card



NEW PRODUCTS

INTEGRATING A/D CONVERTER

Low level 15 bit integrating A/D converter offers common mode rejection of 10 million-to-1 at dc to line frequency, and series mode rejection of more than 4000-to-1 at multiples of line frequency. Because of this it is particularly well suited for monitoring such low level transducers as strain gauges and thermocouples in high level ac environments. The converter works well with multiplexers and has an integration period which is an exact multiple of the power line frequency. Sample rates of up to 40 points/second may be selected. Standard full scale input voltage is 50 millivolts with linearity of ±0.01% and long term accuracy of ±0.05% full scale. Neither preamplification nor individual point filtering is required. La Jolla Div., Control Data Corp., La Jolla, Cal.

Circle No. 215 on Inquiry Card

DIGITAL MODULE CARDS

Two crystal clock oscillators, IXO-0271 and S-113353; a dual BCD decoder with Nixie driver, IDN-0330; and an up/down BCD counter, IFR-2278, have been added to the series of digital module cards manufactured by Engineered Electronics Company. The IXO-0271 crystal clock oscillator can be supplied to operate at a frequency from 4 kHz to 5 MHz, and the S-113353 can be supplied to operate at a frequency from 1 to 30 MHz. The S-113353 oscillator includes TTL gates and inverters. The IDN-0330 decoder and Nixie driver accepts two separate 4-line BCD inputs, converts to decimal and provides an output suitable for operating a Nixie display tube. The IFR-2278 up/down BCD counter uses 12 dual in-line DTL integrated circuits and will operate at 5 MHz. Prices range from $69.50 for the oscillator card. Delivery is stock to four weeks. Engineered Electronics Company, Santa Ana, Cal.

Circle No. 238 on Inquiry Card

J-K FLIP-FLOPS

Four new dual J-K clocked flip-flops are now available. Each dual device consists of two DTL, internally cross-coupled, J-K flip-flops in a single package. For maximum reliability, the two circuits have been incorporated onto a single passivated die which measures 56 x 56 mils, the industry standard size for a single flip-flop chip a year ago. Two DTL 945 type flip-flops and two DTL 948 flip-flops are offered in two logic configurations, one with separate clock inputs, and the other with common clock and common reset. They are also offered in two temperature ranges from −55°C to +125°C. These circuits meet the appropriate DC and dynamic specifications of the DTL 945 or the DTL 948 and are compatible with all DTL 930 series logic elements and with TTL logic elements. Their use reportedly can cut the package count in half in counters and shift registers; and, since they are already internally J-K connected, the required external wiring is said to be reduced significantly. All circuits are available in ceramic flat or dual in-line packages. The price is $10.10 in quantities of 100 to 999 and delivery can be made from stock. Stewart-Warner Microcircuits, Inc., Sunnyvale, Cal.

Circle No. 237 on Inquiry Card

LITERATURE

Rotary Stepping Switches

Bulletin CS902 describes the 42700 Series of rotary stepping switches for operation on 12VDC, 28VDC, or rectified 115 VAC, 60 Hz. The two-pager summarizes the applications of the new switches which come in standard models having 3, 4, 5, 6, 10, or 12 positions. Wiring schematics, mounting dimensions and ordering instructions are detailed in the bulletin. Also discussed is a homing circuit that self-steps the contacts forward to the number one position within one second. The A. W. Haydon Company, Culver City, Conn.

Circle No. 302 on Inquiry Card

IC Logic Cards

A new four-page publication contains information on the entire TTL and DTL functional circuit cards, power supplies, and associated packaging hardware included in the MONILOGIC line of integrated circuit cards. The MONILOGIC bulletin describes the new line of digital logic, analog, and interface card types which feature compatible TTL and DTL integrated circuits in either dual in-line or flatpack form, supplemented by discrete components where necessary. Information on various card types, drawer assemblies, and power supplies also is given. Monitor Systems, Inc., Fort Washington, Pa.

Circle No. 330 on Inquiry Card

Silicon Photocells

Featured in a 6-page brochure are discussions of the advantages of silicon photocells, the degree of performance of photovoltaic devices, definitions of modes of operation, application considerations, and diagrammatic charts illustrating the uses of the cells. Sensor Technology, Van Nuys, Cal.

Circle No. 320 on Inquiry Card

Thick Film Resistors, Capacitors

A 4-page engineering booklet describes the electrical, temperature and life characteristics of Microtek-Electronics thick film resistors and capacitors. The booklet contains design layout rules for converting conventional circuits to thick films. The booklet covers MTE thick film resistor long term stability, temperature coefficients, tracking and noise to assist designers in selecting circuit parameters. Thick film screen and fired capacitor materials are graphically portrayed allowing the designer to choose proper dielectric material for his circuit design. Layout rules answer the design questions such as conductor, resistor, capacitor spacing; resistivities available; land (pad) designs; lead spacing; and capacitor-resistor tolerances. Microtek-Electronics Inc., Cambridge, Mass.

Circle No. 301 on Inquiry Card

Subminiature Indicator Lights

Two terminal subminiature indicator lights, designed for mounting in 15/32″, ½″ and 17/32″ clearance hole are described in this twelve page catalog. Described are indicators accommodated T-1¾ incandescent bulbs with midget flanged base in a range of voltages from 1.35 to 28; and assemblies accommodating T-2 Neon glow lamps (designated as NE-2D for standard brightness and NE-2J for high brightness) for 105-125V AC-DC or 110-125V AV circuits respectively. Data, specifications, drawings and ordering information is provided for dimming and non-dimming units; assemblies with retained O-ring seal construction for water-tight feature; indicators with ½″ or ¾″ round or square plastic lens caps in a wide range of colors. Hot-stamped or engraved legend details are also provided. Dialight Corporation, Brooklyn, N. Y.

Circle No. 309 on Inquiry Card

General Instrument announces another MTOS breakthrough

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LITERATURE

Film Capacitors

A four-page catalog covering Kemet Flat-Kap parylene film capacitors explains how the ultra-thin parylene film dielectric, vacuum deposited on an aluminum foil conductor, results in a capacitor with maximum volumetric efficiency and improved stability. Presented for the first time is data on new zero temperature coefficient capacitance characteristics for precision component matching. Curves and tables give performance characteristics, and dimensioned sketches include data on the four available case sizes. A table lists capacitance values ranging from 1,000 to 100,000 picofarads. Union Carbide Corp., Greenville, S. C.

Circle No. 327 on Inquiry Card

Data Display System

Interface considerations for mating the Sanders 720 Data Display System with the IBM System/360 are included in a six-page brochure. A display communications buffer, including an I/O control, multiplexer, transmission control and synchronous modem adapter are described. The brochure depicts schematics for both remote and local connections for the model 731, Display Communications Buffer which functions as a high-speed parallel or serial interface between the IBM System/360 and the Sanders 720 Display. A complete glossary of simple source language for the file maintenance program is provided. Sanders Associates, Nashua, N. H.

Circle No. 323 on Inquiry Card

Digital Multimeters

A 10-page catalog describes what is claimed to be the industry's first complete line of digital multimeters. New units are said to feature maximum use of integrated circuits. Fairchild Instrumentation, Mountain View, Cal.

Circle No. 312 on Inquiry Card

"What ever happened to monolithic integrated circuits?" Come help us make sure we're still around when I/C's are old hat.

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LITERATURE

Integrated Circuits

A quick reference source describing the variety of dielectrically isolated integrated circuits is contained in a new, 8-page bulletin. Schematics, logic diagrams, and tables of typical characteristics are presented for three series of DTL logic circuits and operational amplifiers and for various fast recovery, medium recovery, and general purpose diode matrices. Microelectronics Div. Radiation Inc., Melbourne, Florida.

Circle No. 322 on Inquiry Card

Voltage Stabilizers

The causes of voltage variation in an apparently normal power service is concisely explained in a new catalog. In addition to covering the common problem of voltage drop by transmission, this catalog also points out the frequently occurring faults that result in excessive voltage surges which are often more damaging to equipment than undervoltage operation. The catalog will be helpful in understanding the effect of load and power factor on output voltage level as well as the effect of frequency variation and operating temperature on output voltage levels. Catalog also illustrates the various designs available in a voltage stabilizer line together with full operating characteristics. Acme Electric Corp., Cuba, N. Y.

Circle No. 317 on Inquiry Card

Thumbwheel Switches

An illustrated 4-page bulletin describes a new line of thumbwheel switches. Included are the new series of sealed Digiswitches for both industrial and military applications the miniature line of Miniswitches which are used where panel space is limited and the miniature pushbutton rotary switch which permits complete panel sealing and meets MIL-S-22710A. The Digitran Company, Pasadena, Cal.

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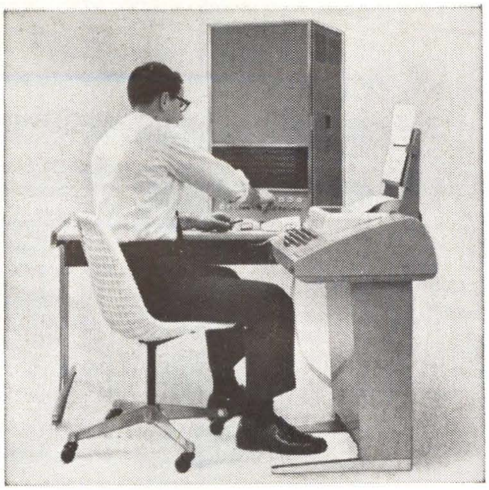

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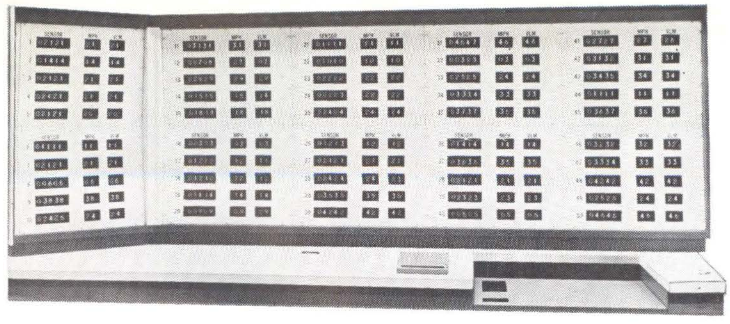

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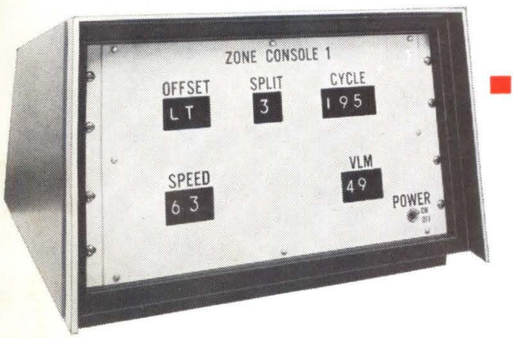

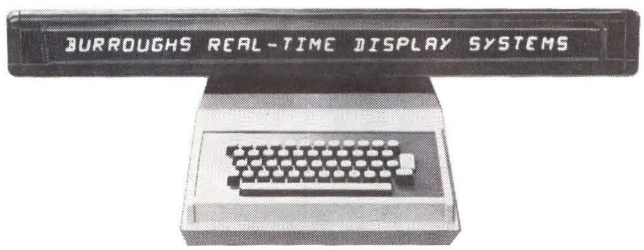

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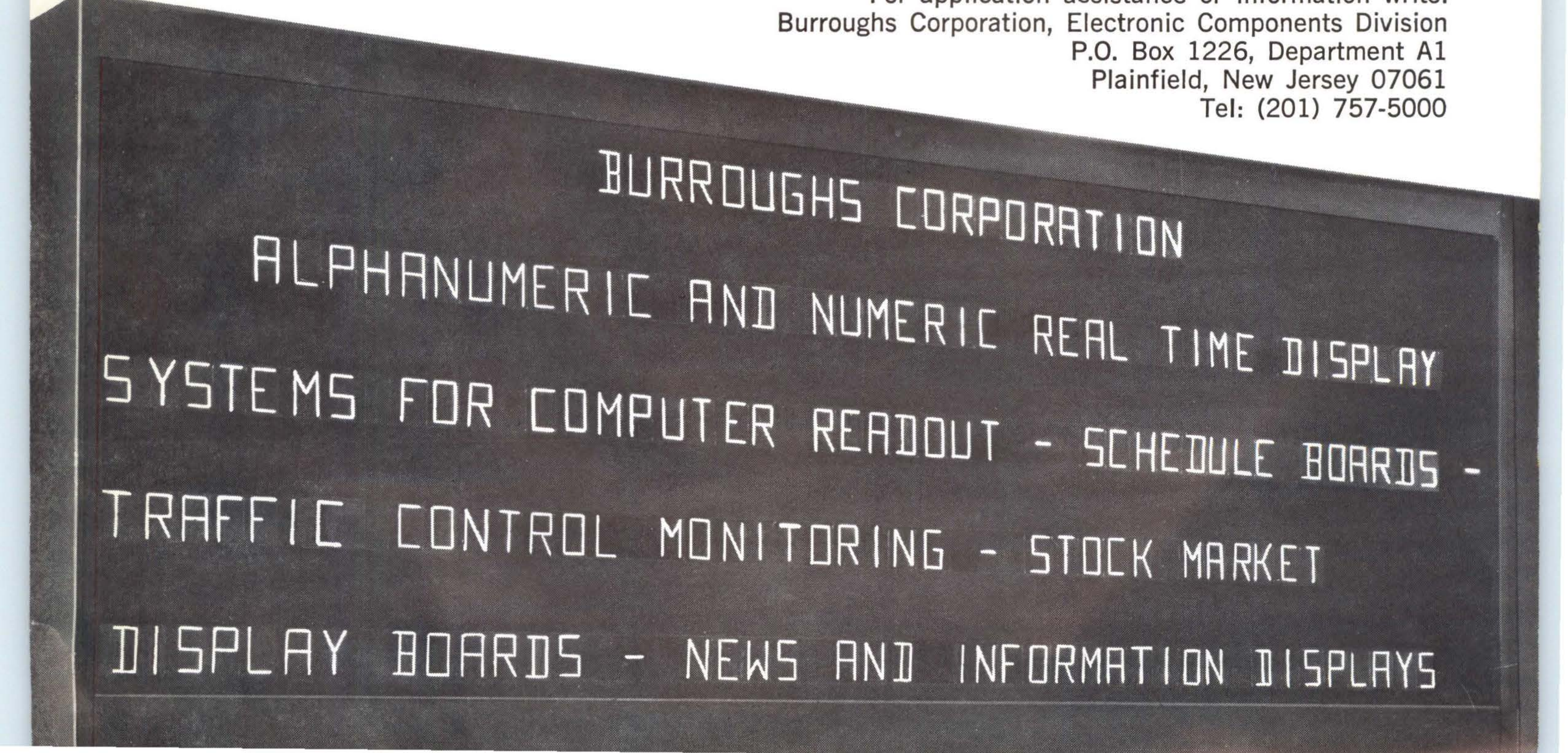

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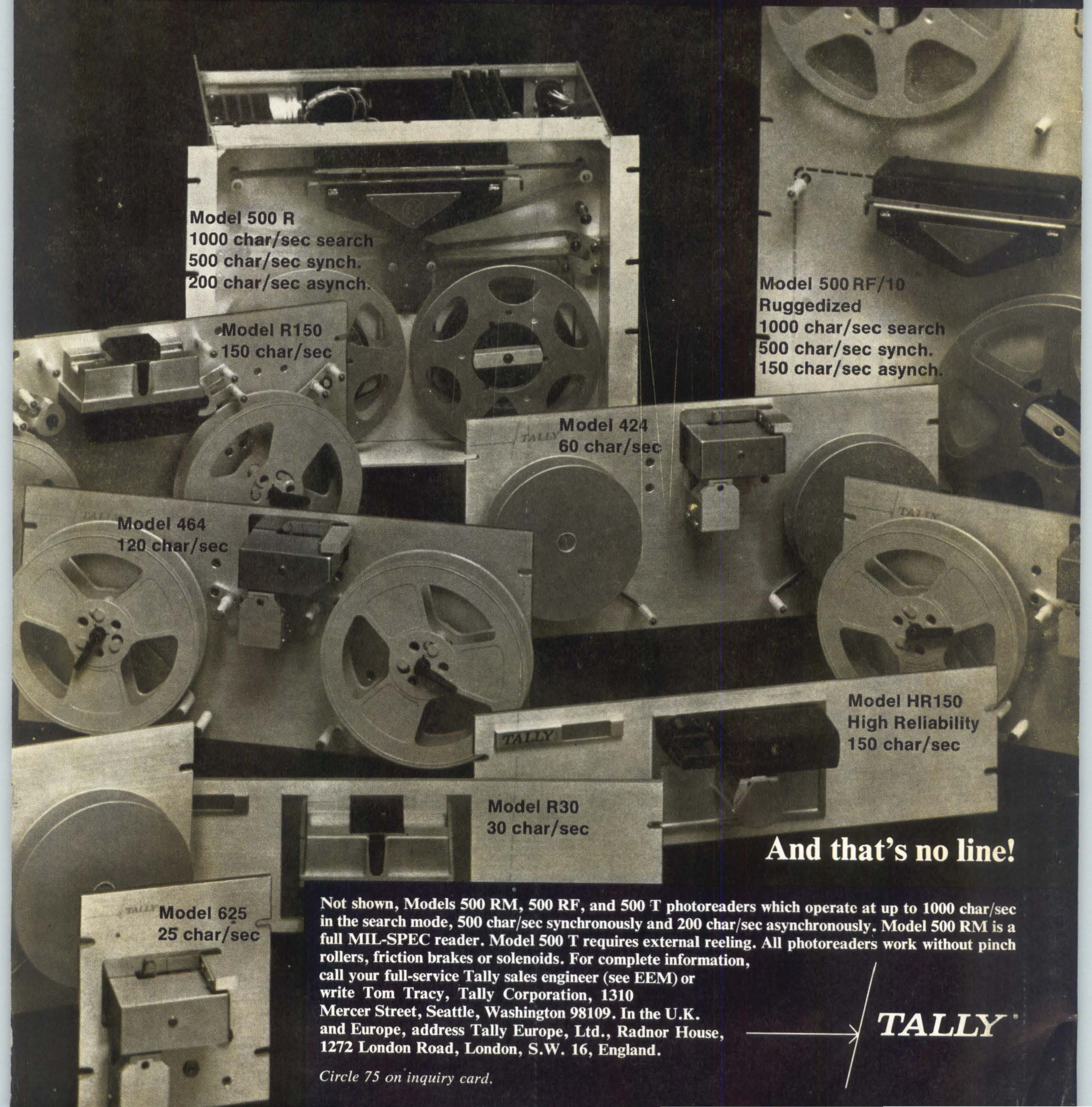

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