AMPEX

READOUT

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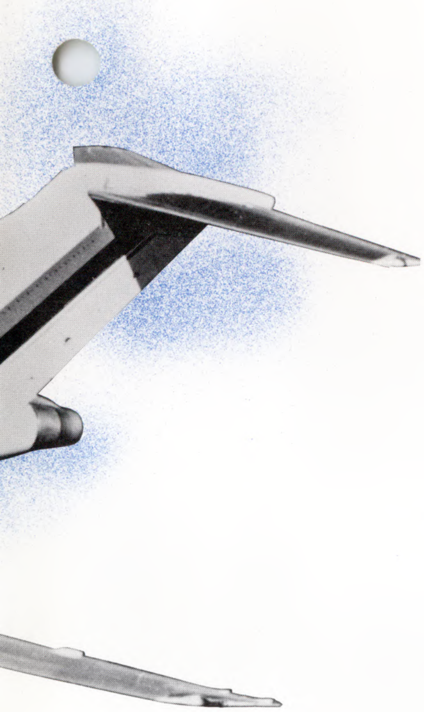
EASTERN AIRLINES

from industry's sick man to pace setter in three years

THE dynamic 40-year history of commercial aviation and the equally colorful history of Eastern Air Lines have always been closely intertwined. Following several years of pioneer mail carrying in the late 1920's, Eastern Airlines (then known as Eastern Air Transport) began its passenger service and the country's first New York to Washington service in 1930.

In those days, the principal aircraft in use was the Ford Trimotor. During the '30's, aircraft grew larger and so did Eastern Airlines. By 1959, when Captain Eddie Rickenbacker turned over the controls to a new management after 25 years of stewardship, Eastern celebrated one of its most successful years. Its routes linked every major city from New England and the Great Lakes to Florida and the Gulf coast, from the Atlantic seaboard and Puerto Rico on the east to St. Louis and mid-Texas on the west. In serving this wide area, Eastern had become the largest carrier of air passengers in the world. But, by 1963 Eastern was in serious trouble. Even the introduction of its highly popular air shuttle service between New York, Washington and Boston, failed to bring an upswing in Eastern's fortunes.



In late 1963, a new management team moved into the corporate cockpit. Operation Bootstrap was inaugurated. Every resource was concentrated on improving services. Eastern needed a new image and it set about to get one. Agressive marketing and sales promotion, a new advertising approach, a new corporate insignia and aircraft colors, and new uniforms for all personnel were inaugurated. From a net loss of nearly 20 million dollars in 1964, net profits in 1965 rose to more than 28 million dollars.

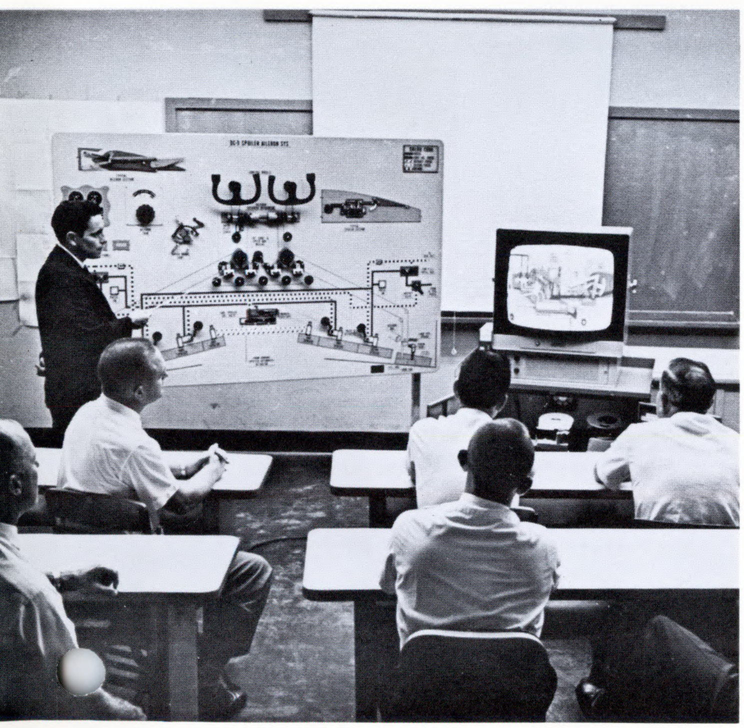
The fleet was modernized with more jet aircraft, particularly the smaller 727 and DC-9 for short range use which are particularly suited to Eastern's short and medium range concentration of flights. Radioactive isotopes were introduced for X-raying of jet engines. Computers were installed, as were wind and weather analysis equipment. Airborne computers forecast areas of possible mechanical trouble. These and many other important advances enabled Eastern to regroup and regain its reputation as a pace setter in the industry. In the area of maintenance and training, too, Eastern has become a pace setter with its extensive television training courses.

MAINTENANCE AND TRAINING: A Monumental Job

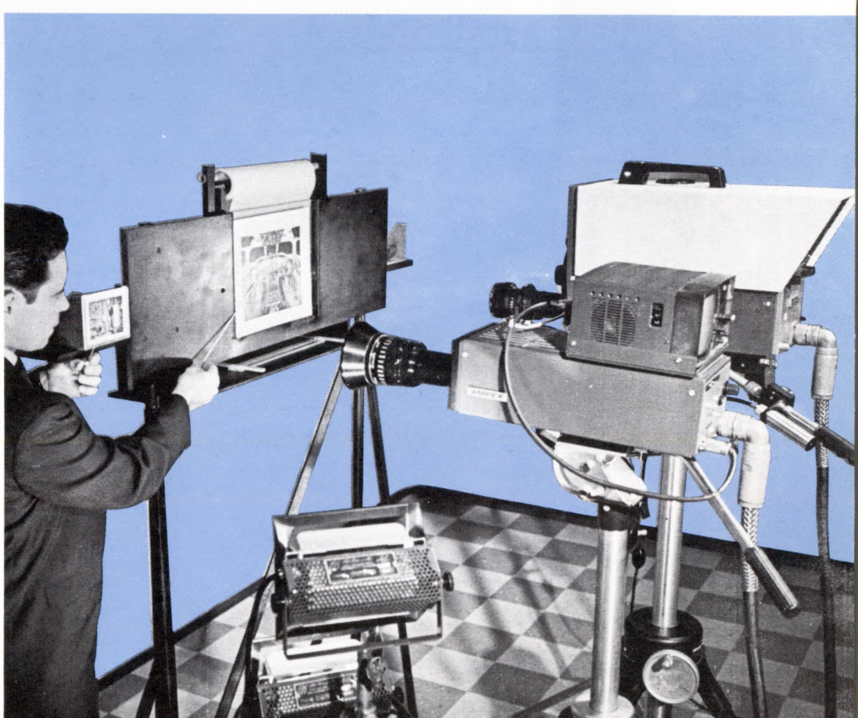
Success in the airline business depends on having a fully operational aircraft at the right station at the right time ready to take on paying passengers. To do this, the airlines use training and maintenance to an extent difficult for us to comprehend.

If you took care of your car the way the airlines take care of their airplanes, this is what you would do. Each time you drive your car, you would inspect every part by walking around it, then climbing under and on top of it. You would replace all five tires every 750 miles. You would overhaul the engine completely every 20,000 miles; you would reupholster and repaint it every 50,000 miles. And, most of this would be checked and rechecked by experts to make sure every job conformed to strict government standards.

To perform this level of maintenance and for other aspects of its operations, Eastern trains over 10,000 employees each year, including pilots, stewardesses, and ground and maintenance personnel. Further, pilots and stewardesses are constantly checked by Eastern's own experts, and all of these people—including mechanics—work under close Federal Aviation Agency surveillance.



Eastern Airlines maintenance personnel study a close-up of a specialized training aid being replayed by an Ampex VR-660 videotape recorder.



Studio setup during production of a training tape at Eastern showing how different types of specialized graphic materials are inserted into the tapes effectively extending their life and usefulness to all trainees throughout the Eastern system.

TELEVISION TRAINING:
Part of Eastern's New Look

To help in this monumental training job, television teamed up in 1966 with Eastern's pilot and maintenance training department to bring the same new look to training that corporate management was bringing to the rest of the airline. Today, televised training at Eastern has become a showplace system.

Under the direction of T. J. Tanner, the technical training section in Miami surveyed the field to find a more efficient and effective method of teaching aircraft and equipment training courses. Television was chosen over all other types of audio/visual systems for several important reasons. One of the most important is that it's easier to produce good training material on video tape than with other methods. Tanner puts it this way:

"Making video tapes is a lot easier than making film and doesn't require any special technical skills. Members of our training department write the scripts, operate the equipment, and produce finished video tapes. We found that it was easier to take our existing instructors and show them how to use a television camera and recorder than it was to train experienced film people in the complexities of aircraft electronic systems, and engine maintenance. All training tapes tie in directly with the maintenance manual for that aircraft."

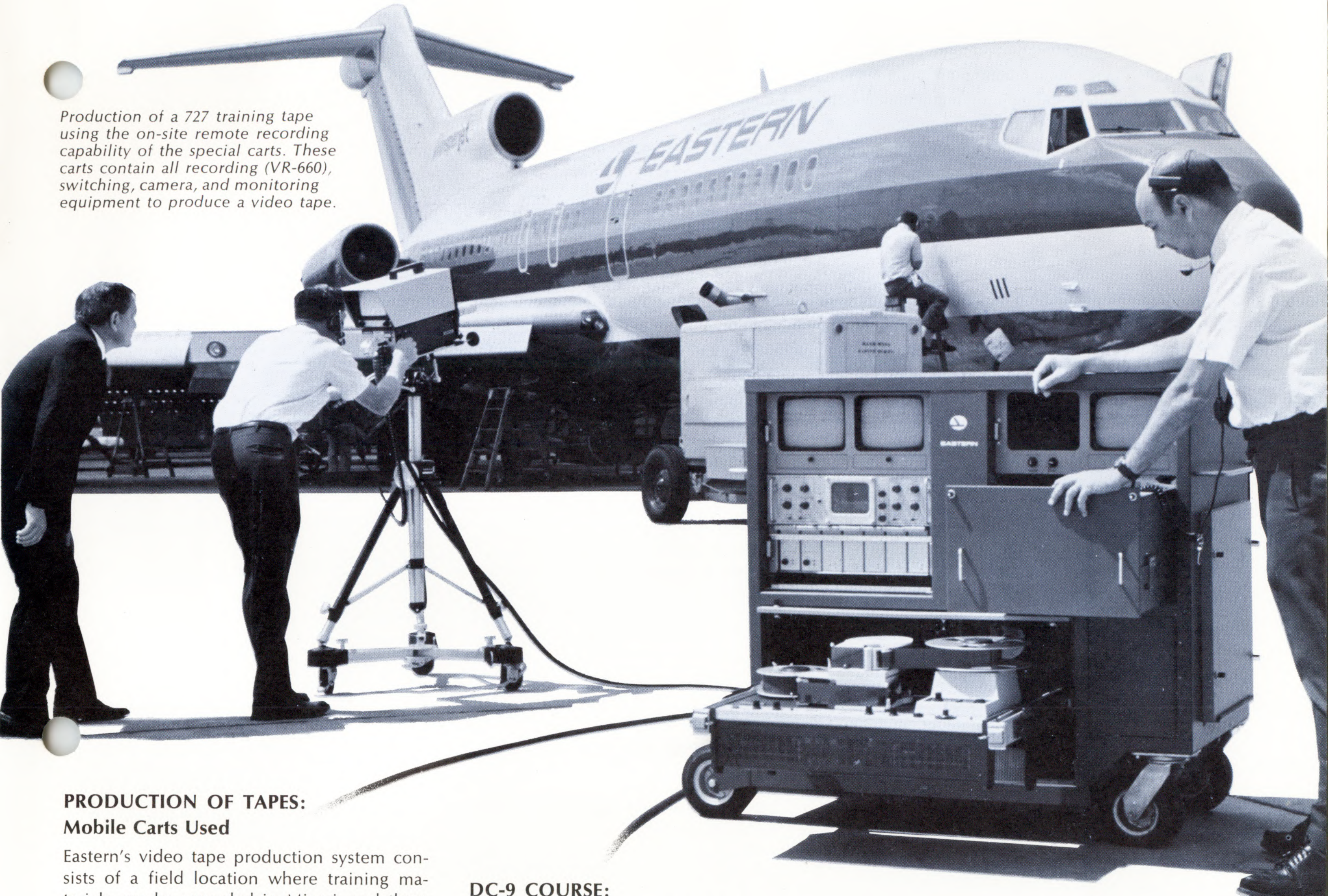
RESULTS:
Training Time Cut in Half

The results at Eastern have been impressive. Tanner estimates that it takes 50% less time to train maintenance personnel that it has in the past. Better quality with more uniformity of presentation and better retention have been achieved. Specialized training aids and mockups at any location are now shared in common at all stations by video tape. The material is always up to date because it is very easy to correct and revise a video tape when something changes.

Costs have also been significantly less. In one important area, major savings have been achieved since the training programs are carried on at each station on video tape rather than bringing personnel to Miami and taking them away from their daily jobs. Maintenance personnel have reacted very favorably toward televised instruction. Television commands interest and airline people are more familiar with electronic than film devices.

Control room at Eastern's technical training center in Miami. Ampex VR-1100 recorder at left is used to prepare master tapes for subsequent distribution to the 25 field stations.

CURTISS CONDOR



Production of a 727 training tape using the on-site remote recording capability of the special carts. These carts contain all recording (VR-660), switching, camera, and monitoring equipment to produce a video tape.

PRODUCTION OF TAPES:
Mobile Carts Used

Eastern's video tape production system consists of a field location where training materials can be recorded in Miami, and three future locations in Atlanta, New York and Boston. There is a master studio in Miami. On-location taping effectively brings the aircraft to the classroom. For on-location work, mobile carts are used. Each has a videotape recorder, camera, switching equipment and monitors for completely self-contained recording on site. These carts were designed to be operated by two men, but on occasion have been operated quite successfully by one man. Because video tape can be played back instantly for viewing without development or processing, Eastern's instructors can be certain that they have the information and presentation they're seeking during the actual recording session.

All final tapes and duplicates for field use are made in the studio in Miami. Here, Eastern has a teleproduction studio and classrooms equipped with cameras, switchers, monitors, lighting, and Ampex VR-1100 and VR-660 videotape recorders. Master tapes are first assembled on the studio quality VR-1100, then dubbed on the VR-660 helican scan recorder for field use.

DC-9 COURSE:
1000 Trainees at 25 Locations

Utilizing this system, Eastern has prepared its complete DC-9 maintenance training program on video tape. So far, more than 1,000 maintenance men have received this course. Much of the material on the DC-9 was made at the Douglas factory prior to delivery of the first DC-9 to Eastern in Miami.

At each station, two weeks before a DC-9 is received, the training begins. Tapes are replayed on the 25 Ampex VR-660 recorders located throughout the system. The trainee takes the course prior to or after his regular eight-hour work day. He receives about 30 hours of training: eleven-plus hours of video tape material, ten hours of related study and ten hours of question and answer sessions. Taped material ranges from a 15-minute introductory tape to an 80-minute presentation on the DC-9 hydraulic power system. Other video tapes deal with the plane's electric power, fuel system, pressurization, flight controls, landing gear, and auxiliary power unit. Eastern is making the DC-9 tapes available to other airlines on a rental basis.

OTHER TRAINING TAPES:
Complete Courses and Special Subjects

In addition to material for the DC-9 course, Eastern has prepared video tapes showing removal and installation techniques for components on eight major aircraft. These tapes consist of instruction on installing and removing forward passenger steps, flight recorders, power plants, wheels, brakes, and auxiliary power units.

A training course has been completed on the new, larger version of the DC-9, the DC9-30. Also, the DC81-61 and 727 Quick Change training courses are now being produced. Familiarization tapes on the DC-8, 720, and 727, describing new maintenance procedures on the most common maintenance problems have been produced.

Magneto-Optic Detection of High-Density Recordings

The various noise sources in a high density magneto-optic readout system are evaluated. It is shown that shot noise is not severe even at interrogation rates of 10^7 bit/sec and bit areas of 10^{-6} cm^2. Various techniques used to reduce the noise originating from surface imperfections are described and their effectiveness demonstrated by experimental results.

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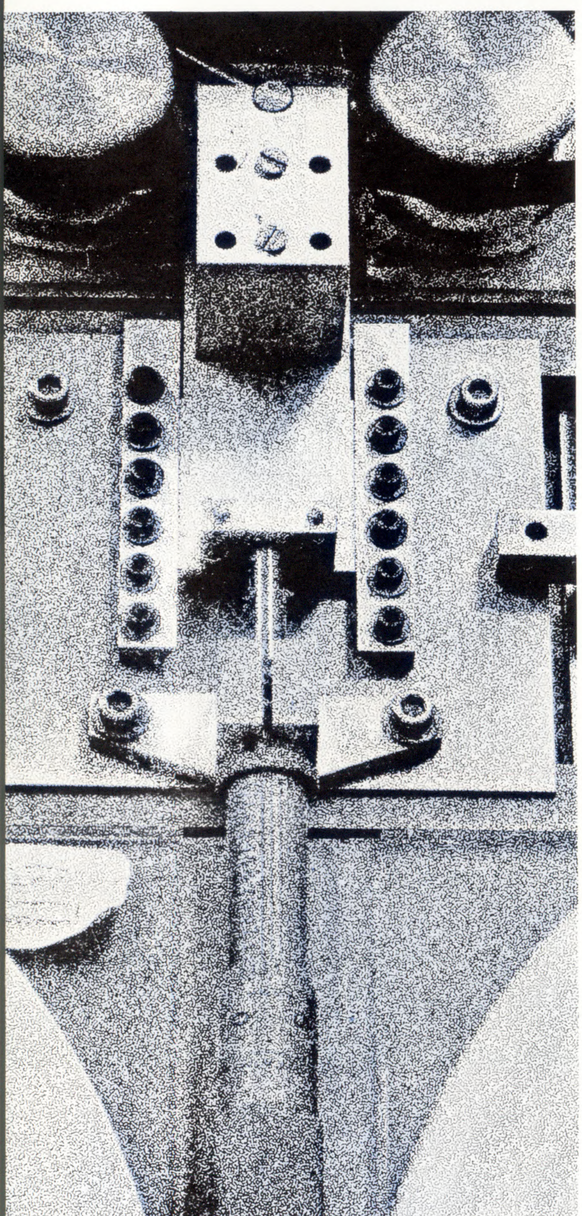


INTRODUCTION

The utilization of the magneto-optic effects for reading out information stored in magnetic media was considered in the past by several authors.[1-5]

Because of the smallness of the magneto-optic effects and because of the low power density obtainable with conventional light sources this method of information retrieval was often thought impractical.[2] The situation drastically changed with the advent of high-power c.w. lasers, and a second look was taken at the feasibility of readout of high-density recording (bit area of 10^{-5} cm^2 or less) using magneto-optic effects. In this paper the discussion is centered on the longitudinal Kerr effect; however, most of the problems and methods described are equally well suited for other magneto-optic effects.

The shot noise is evaluated taking into account the limitations due to the temperature rise in the illuminated area. With available lasers, large signal-to-noise ratios are predicted for wideband and high-density readout systems, probably making this noise source less important than the other noise sources.

After a discussion of the effects of surface imperfections on the light reflected from the magnetic medium, three techniques developed in order to reduce these effects are described. Experimental results demonstrating the effectiveness of these techniques are presented.

THE MAGNETO-OPTIC SIGNAL

It will be assumed that the information is in digital form, that is, the information is stored in bits which are magnetized to saturation in either direction. In a readout system that utilized the longitudinal Kerr effect, linearly polarized light is reflected by the magnetic medium. The magnetic information is transferred to the reflected light beam essentially as a change in direction of polarization. Let the difference of this direction for the two states of magnetization be denoted by the Kerr angle ϕ. If a polarizing crystal (the analyzer) is introduced in the path of the reflected beam, then the change in transmitted power for light reflected from two oppositely magnetized areas will be

$$\Delta W = W_0 [\sin^2(\theta+\phi)-\sin^2\theta] \qquad (1)$$

where θ is the angle of rotation of the analyzer from its position of minimum transmittance and W_0 is the light power reflected by the magnetic medium. The angle ϕ is usually very small, of the order of a few milliradians. Also, when signal and not contrast is important, one usually will set $\theta \gg \phi$. Under these conditions

$$\Delta W = W_0\phi \sin 2\theta, \qquad (2)$$

and the average light power reaching the photocathode will be

$$W = W_0 \sin^2\theta. \qquad (3)$$

NOISE

Having found the magnitude of the signal that one expects, it is now appropriate to deal with the various noise sources inherent in such a system. The three major ones are: shot noise in the photodetector due to the quantized nature of light; surface noise due to imperfections in the surface of the magnetic media, such as pinholes, dust and scratches; light level fluctuations due to arc instability, plasma noise in gas lasers, variations in reflectivity from region to region of the magnetic media, and slight changes in the alignment of the optical system during the process of readout.

Shot Noise

The shot noise current, I_n, in photodetectors is given by[2]

$$I_n = (2efPW_0)^{1/2} \sin\theta, \qquad (4)$$

and the signal current, I_s, is given by

$$I_s = PW_0\phi \sin 2\theta,$$

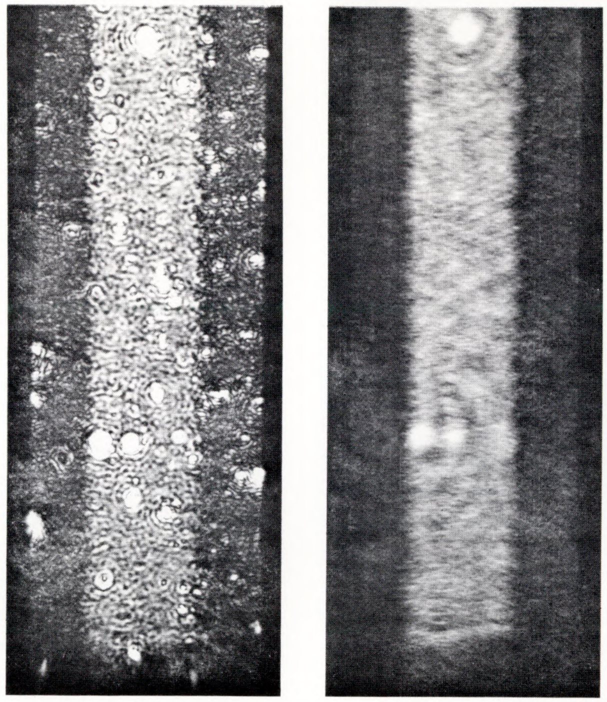
where $e=1.6\times10^{-19}$ C is the electron charge, f is the bandwidth, and P is the conversion fficient of the photocathode, a typical value of which is 3×10^{-2} A/W.

From these two equations one finds the signal-to-noise ratio

$$I_s/I_n = (2PW_0/ef)^{1/2}\phi \cos\theta. \tag{6}$$

It is interesting that this ratio is essentially independent of θ, the analyzer angle, in the whole region of interest, which rarely will exceed 10°, for reasons which will be apparent later. This ratio increases with the light power, W_0; it is therefore worthwhile at this point to compare conventional light sources to coherent sources.

For an incoherent source the maximum brightness of an illuminated spot is the brightness b of the source. The highest values obtainable for continuous illumination are in the order of $b=250$ W/cm² (PEK Lab. 107/109 mercury-arc lamp). If a light spot of area A (small compared to the source dimensions) is produced by an incoherent source, the power impinging on it will be of the order of Ab, and is thus proportional to the area of the spot. On the other hand, the total power of a coherent source can be focused on any spot larger than the diffraction-limited spot of the optical system. Therefore, comparing a 1-W coherent source with an incoherent source with $b=250$ W/cm², one finds that for spots of an area of 10^{-5} cm² the coherent source will supply optical power W_0 several orders of magnitude larger than the incoherent source, and thus will yield a considerably larger signal-to-noise ratio.



(A) (B)

Figure 1. Photograph of a 50-μ wide bit recorded on a typical film. (A) Without spatial filter. (B) With spatial filter.

From Eq. (6) it may appear that shot noise can be always eliminated as a problem simply by using a high enough power W_0. However, the temperature rise of the magnetic medium puts an upper limit to the amount of power one can use. If the amount of power is determined only by the allowed temperature rise Δt, the $f^{-1/2}$ bandwidth dependence given in Eq. (6) may change considerably. In general, at higher bandwidths each bit will remain exposed to the light beam a shorter time, allowing a higher light power for the same Δt, resulting in a slower dependence of the signal to shot noise ratio on frequency. For example, in a situation in which no heat diffusion effects occur (approximated by a thin metallic film on a good thermal insulator substrate), Δt is given by

$$\Delta t = W_a/JGC, \tag{7}$$

where G is the weight of the illuminated portion of the magnetic film, C is the specific heat and W_a is the power absorbed in the magnetic medium. Assuming that all the non-reflected power is represented by W_a, one gets

$$W_a = W_0(1-R)/R, \tag{8}$$

where R is the reflectance. Substituting (7) and (8) in (6), one finds

$$I_s/I_n = [2P\Delta tGCR/e(1-R)]^{1/2}\phi \cos\theta \tag{9}$$

which is independent of f. If heat diffusion into the substrate occurs, the heat is spread on a larger amount of material and more power, W_a, can be absorbed for the same temperature rise, Δt. Therefore, (9) describes the worst-case situation.

A better approximation to the heat-limited case is to assume a thin magnetic film deposited on a thick substrate of diffusivity, α, and thermal conductivity, k. If the linear dimensions of the illuminated spot are large compared to the heat penetration depth, heat diffusion occurs only in a direction perpendicular to the surface and the problem is one dimensional. The surface temperature rise, Δt, and the penetration depth, s, are then[6]

$$\Delta t = (\alpha T)^{1/2}\, 2q/k\pi^{1/2}, \quad s = (\alpha T)^{1/2}, \tag{10}$$

where q is the power density absorbed (assumed here to be constant over the spot), and T is the time the power is on, which is essentially the inverse of f.

Using (10) and substituting $T=f^{-1}$, $W_a= qA$ and (8) in (6), one gets

$$I_s/I_n = \left\{(P/e)\,[R/(1-R)]\,A\Delta t\pi^{1/2}\right\}^{1/2} [(k^2/\alpha)T]^{1/4}\phi \cos\theta. \tag{11}$$

It is instructive to compare the signal-to-noise ratio derived from (9) and (11) for $A = 10^{-6}$ cm², $\Delta t = 100°$C, $P = 3\times10^{-2}$ A/W, $R = 0.5$ and $\phi = 10^{-3}$ rad. For a film thickness of 10^{-5} cm, a specific heat $C = 0.5$ J/g•deg, and a specific gravity of 8 g/cm³, Eq. (9) yields $I_s/I_n \approx 30$ or 30 dB, independent of frequency. For a copper substrate with $\alpha = 1$ cm²/sec and $k = 4$ J/sec•cm•deg, Eq. (11) yields $I_s/I_n \approx 10^4 T^{1/4}$. For $T = 10^{-8}$ sec (100-MHz bandwidth) the signal-to-noise ratio is 40 dB and the penetration depth calculated from (10) is 10^{-4} cm, showing that at this frequency the one-dimensional approximation is valid. From (10) the power W_a is found to be 4 W. At 1 MHz the signal-to-noise ratio is 50 dB, $s = 10^{-3}$ cm, and $W_a = 0.4$ W. Here s is already the same as the linear dimensions of the spot, and heat will then flow also parallel to the surface. Therefore, more power can be absorbed for the same temperature rise and the value of 50 dB is an underestimation.

It is evident from (9) and (11) that enhancement of the Kerr rotation by a dielectric layer, which simultaneously increases ϕ and decreases R, may have only a limited effect on the signal-to-noise ratio. On the other hand, with the availability of high-power coherent sources, shot noise in readout of high-density information is not a severe problem and will usually be considerably smaller than other sources of noise.

Surface Noise and Light Fluctuations

While shot noise can be evaluated analytically, surface noise by its very nature is unpredictable. Observation of a large number of thin films deposited on microscope cover glass under laboratory conditions revealed always a considerable amount of surface imperfections. Figure 1(a) is a photograph of a typical film, taken with the analyzer close to extinction. The bright band in the center is a 50-μ wide bit. The bits in this and all subsequent cases were recorded on the films by contact printing from an oxide tape. On the assumption that some surface noise is inevitable even with the most careful preparation methods, several optical techniques aimed at reducing the deleterious effect of this noise were developed. It was found that the majority of the surface imperfections have dimensions, d, of less than a few microns; they scatter light roughly as if they were pinholes in the path of a plane wave, and thus the diffracted light originating from them spreads with a cone angle, β, of the order of $\beta \approx \lambda/d$ where λ is the wavelength of light. Although the incident light is linearly polarized, the light diffracted by the imperfections is essentially completely depolarized.

The first noise reduction method is based on this last property. As the diffracted light is depolarized, its fraction transmitted by the analyzer is independent of the analyzer angle θ. On the other hand, Eq. (2) shows that the signal is proportional to $\sin 2\theta$. Therefore, by increasing θ, one will increase the signal-to-noise ratio due to surface imperfections. In order to observe this effect, alternate bits of information were recorded on a film, mounted on a micrometer-driven stage so that it could be scanned. The photomultiplier output and a voltage proportional to the position of the stage were fed to an X-Y recorder. S-polarization and 30° angle of incidence were used throughout. Figure 2, which shows scans of 12.5-μ bits of information for different angles θ, clearly demonstrates the effective reduction in surface noise as θ increases. On the other hand, as θ increases, the contrast decreases, and the effect of light level fluctuations becomes more and more pronounced as seen by the fluctuation of the average light level of the top trace. Following Eq. (3), this fluctuation is proportional to $\sin^2\theta$; thus, the ratio of the signal to this kind of noise is proportional to $\cot\theta$ and decreases with increasing θ. The relative size of these two noise sources will determine the optimum angle θ for minimum total noise. This balance between noise sources is schematically shown in Fig. 3. Curves depicting noise-to-signal ratios, N/S, are used so that they can be added up in order to find the total noise to signal of the system.

The next noise reducing technique takes advantage of the diffracted nature of the light scattered by the surface imperfections and the small dimensions of the latter. If the illuminating spot is a diffraction-limited spot equal in dimensions to the bit size, D, the ratio of the cone angles in the far field region for the light diffracted by the imperfection and the main beam that carries the information is of the order of D/d. By inserting an appropriate iris in the far field, one can then stop most of the light diffracted by the imperfection, while letting through the main beam. This simple form of spatial filtering is effective only if the ratio of D/d is large. Figure 4 shows two scans of the same region of a film on which 6.25-μ bits were recorded. The top and bottom traces were taken respectively with and without the spatial filter. Note that in the filtered scan there is no loss in signal while the noise is reduced by almost two orders of magnitude. The effect of the spatial filter can be well observed photographically, as shown in Figure 1(b), which is identical to Figure 1(a) except that the filter was inserted. Most of the short-wavelength surface noise is eliminated. Figure 5 shows scans of 6.25-μ bits, taken with the spatial filter and optimum analyzer angle θ, and of 3.75-μ bits taken near extinction.

As a considerable fraction of the residual light that reaches the photodetector at extinction originates from surface imperfections, the intorduction of the spatial filter will greatly improve extinction and thus increase the contrast. Figure 6 shows short scans of 50-μ bits taken with spatial filter and at various small angles θ. The base line is obtained by completely obstructing the light beam. The lowest scans have intensity ratios for the two states of magnetization of 10. As the double Kerr angle ϕ was in this case 3.3′, the extinction ratio in the system is better than 10^{-7}, which is an exceptionally low value.

The last noise reducing method is a differential scheme based on the fact that the surface noise and the signal are carried in a different way by the beam of light; the noise is essentially an amplitude modulation, while the signal is a modulation of the direction of polarization of the light. Because of this difference, the beam can be split into two information channels in which the noise appears in common mode while the signal appears in opposite polarity so that the useful information can be added, and the noise cancelled out by feeding the two channels to a differential amplifier. The beam reflected by the magnetic medium is amplitude split by a nonpolarizing beam splitter into two beams identical in every respect except direction of propagation. Two analyzers are used for the two beams, set at angles $+\theta$ and $-\theta$ to the minimum transmittance position, respectively. This setting is made for the medium magnetized in "zero" state. The light is fed to two photomultipliers and to a difference amplifier. As the two beams reflected exactly from the same area of the medium have the same direction of polarization and angle of incidence and come from the same light source, all the fluctuations that come from surface imperfections, changes in reflectivity, and source intensity will cancel out. If the medium is now magnetized in the "one" state, one analyzer will make an angle $\theta+\phi$ and the other $-\theta+\phi$ with the minimum tranmittance position, and the difference in light power that the two photomultipliers will receive is given by Eq. (2). The advantage of this scheme with respect to that of Lentz and Miyata[1] is that here the two beams are completely symmetrical, and that there is complete freedom in the choice of θ. Figures 7 and 8 show the effectiveness of this technique. In each figure there are four traces: a baseline which is the zero light level; A and –B which are the

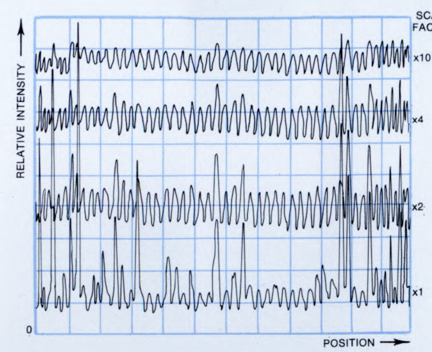


Figure 2. Scans of 12.5-μ alternate bits for different analyzer angles θ. Bottom trace: θ=5′. Top trace: θ=1.9°. Double Kerr angle φ=3.5′. Illuminating spot: 7μ X 200μ.

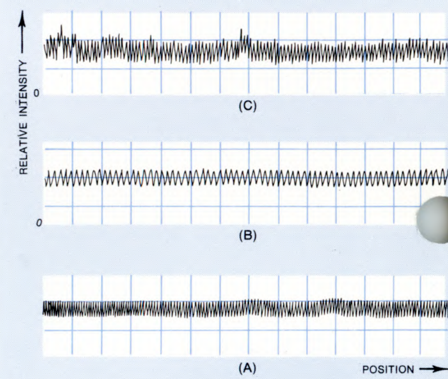


Figure 5. (A) Scans of 6.25-μ alternate bits, with spatial filter and optimum analyzer angle θ. (B) Same as (A) but on expanded scale. (C) Scans of 3.75-μ alternate bits with spatial filter and close to extinction.

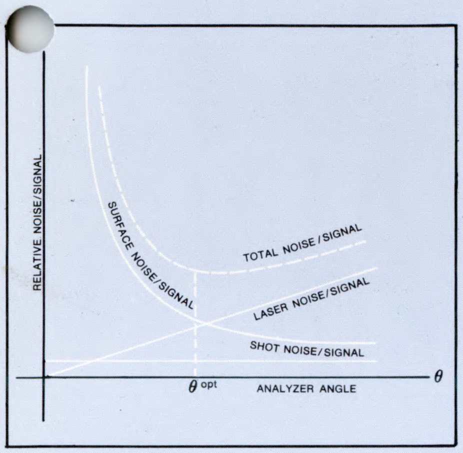


Figure 3. Schematic representation of the dependence of noise on the analyzer angle θ.

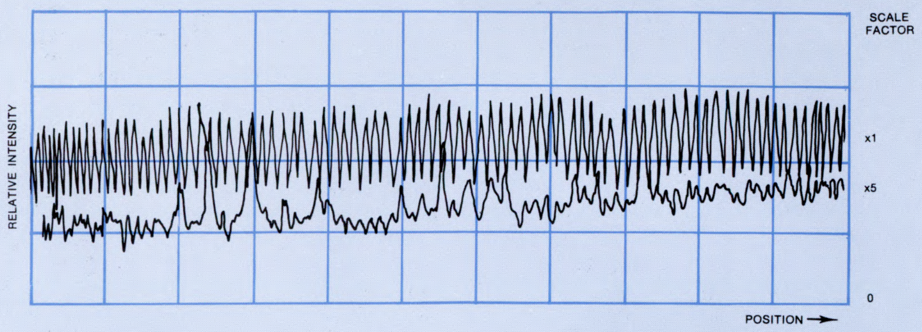


Figure 4. Scans of 6.25-μ alternate bits, close to extinction. Illuminating spot: 7 $\mu \times$ 200 μ. Top trace: with spatial filter. Bottom trace: without spatial filter and attenuated by a factor of 5.

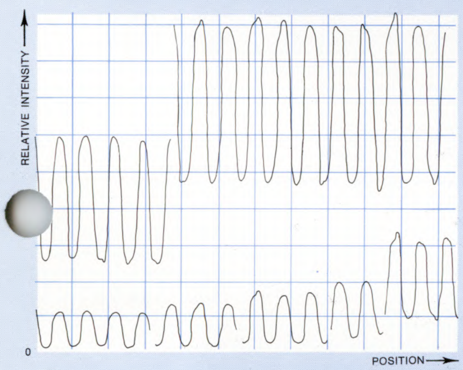


Figure 6. Short scans of 50-μ alternate bits at various small analyzer angles θ, with spatial filter. Baseline obtained by obstructing the light beam. Double Kerr angle φ=3.3′.

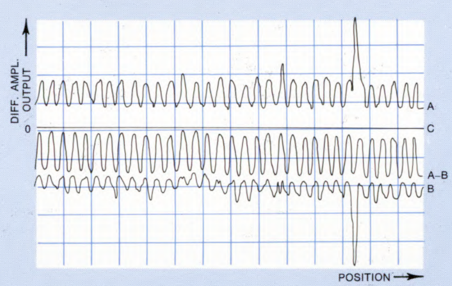


Figure 7. Scans of 25-μ alternate bits, in differential scheme. No spatial filter, and analyzer angle θ=8′. Traces A, B, and A-B are of the individual channels and their difference, respectively. Trace C is with light off.

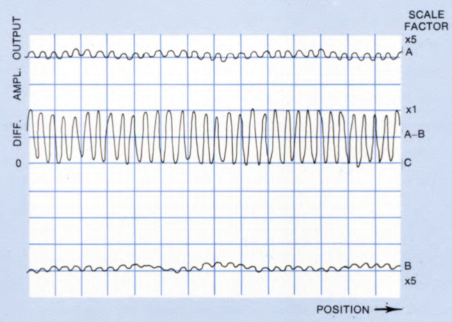


Figure 8. As Figure 7, except θ=130′

output of the individual channels (the B channel is inverted); and A—B which is their difference. In Figure 7, θ = 8′ and in Figure 8, θ = 130′. The bits are 25 μ and no spatial filter was used. Figure 7 shows the remarkable reduction in surface noise, and Figure 8 shows that light level fluctuations, which in the bottom trace are larger than the signal, are practically eliminated. The only remaining effect due to these fluctuations is a small amplitude modulation of the signal that can be observed in the A — B trace of Figure 8.

CONCLUSION

The analysis of shot noise made, taking into account the limitations due to the temperature rise in the illuminated area, indicates that bits with area of 10^{-6} cm^2 can be interrogated at a repetition rate of 10^7 bits/sec with a signal-to-noise ratio larger than 40 dB. The power of the source required is a few watts, a reasonable value for continuous gas lasers. This calculation is based on a double Kerr angle of 10^{-3} rad, which is rather conservative, and one should remember that the signal-to-noise ratio is proportional to this angle. On the basis of observations carried out on a large number of thin films prepared under laboratory conditions, it is found that, in general, the noise introduced by surface imperfection in the magnetic medium is large compared to the shot noise. However, the three methods described above, namely, the proper adjustment of analyzer angle, spatial filtering, and the differential technique are very effective in reducing the surface noise. It is felt that actually these methods, if they can be applied simultaneously, can reduce surface noise to the extent of making a magneto-optic readout system of practical value.

ACKNOWLEDGMENTS

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APPLIED TECHNOLOGY SATELLITE

Five Stationary Laboratories in the Skies

The Problem: Position a series of five scientific laboratories in fixed locations above the earth. Give them twenty major experiments each and a host of related data gathering studies. Have the satellites operate for a minimum of three years, and report a steady stream of data back to the earth.

The Solution: Applied Technology Satellites (ATS), NASA's five stationary laboratories in the skies.

THE CHARTER of the National Aeronautics and Space Administration (NASA) stated in 1958 that the policy of the United States in space should be devoted to peaceful purposes of mankind. Over the years NASA has launched, tracked and computed information from an astounding array of space vehicles including satellites, both manned and unmanned, and space probes.

Latest in its series of unmanned spacecraft is a type called Applications Technology Satellites. This program is one of the largest groups of a single type of satellite that will be space born at the same time. The operative word in the name of these satellites is applications. Already the first two are providing a wide range of data for many different technologies and wide ranging applications.

In speaking of the ATS-1, Deputy Administrator of NASA, Dr. Robert Seamans said, "This experimental satellite is built to look into some of the best means of moving ahead in a rapidly changing world. Engineering concepts will be tested on the ATS-1 and follow-on spacecraft. The man in the street will ultimately see the results in improved operational systems. He will see them in better weather forecasts, in better radio and television and in better and more flexible communications of all kinds."

Some have called the ATS a public benefactor. Others have dubbed it the busiest satellite the world has even seen. Without doubt, the applications technology satellite is busy. As a complex space laboratory it carries engineering and scientific experiments to try out new methods of spacecraft communication, meteorology, control technology, and a host of scientific observations.

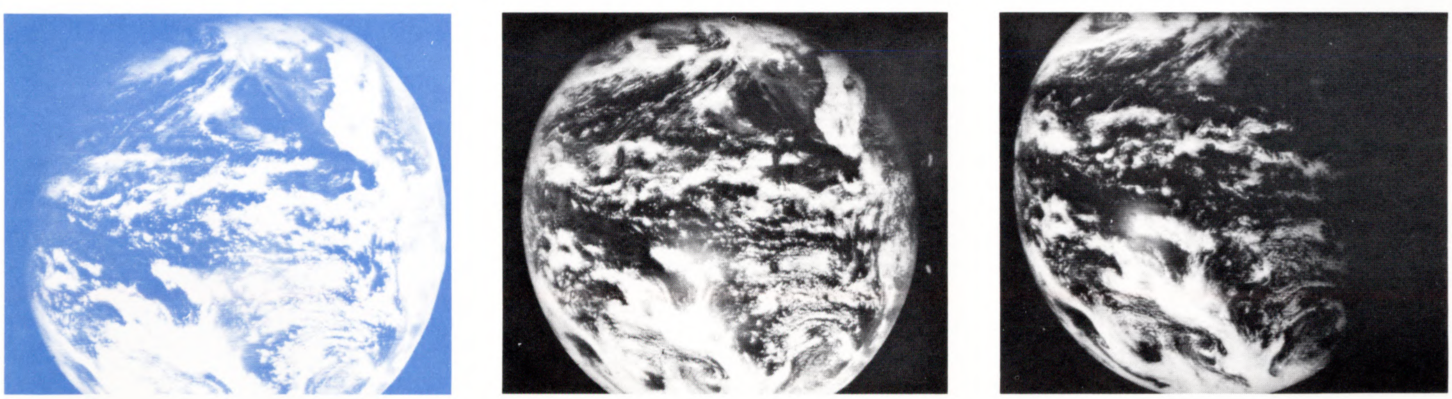
FIVE SPACECRAFTS: A through E

All five of the ATS spacecraft are basically similar in configuration. They fall into two different groups, depending on the way they are stabilized in orbit. Two will be spin stabilized at an altitude of 22,300 statute miles above the earth. The other three will use gravity gradient stabilization. Although new to man-made satellites, gravity gradient stabilization is indeed the oldest type. This is the reason the Moon presents only one face to the Earth. Billions of years ago, the Moon became our first gravity gradient satellite. Two of these latter three will be located at 22,300 miles above the earth and one was planned for 6,000 miles. Due to unexpected changes during the development phase, the launch sequence is no longer strictly alphabetical. ATS-B was the first spacecraft to be placed in orbit and is now known as ATS-1. This was followed by ATS-A, which is now known as ATS-2. These will be followed by ATS-C, D, and E, scheduled for launch in 1968 and 1969.

ATS-1: Launched December 1966

ATS-1 was successfully launched from Cape Kennedy in December 1966. The satellite is now operating in a fixed position over the Christmas Islands in the Pacific. All test objectives have been met. These included experiments in meteorology, microwave and VHF communications, weather facsimile, and environmental measurements.

WEATHER: Birth and Death of Storms. The meteorological experiment uses a spin scan cloud camera. It is providing meteorologists with their first look at the world's weather from a fixed altitude so they can watch the



THE DIFFERENCE BETWEEN NIGHT AND DAY

These photos were taken from 22,300 miles above the earth by the Applications Technology Satellite-1 on Sunday, December 11, 1966. Each photo took 20 minutes to record. Together, they show the changing cloud pattern over the world for an entire day. The Goddard Space Flight Center manages the ATS program for NASA.

birth and death of storms. Earlier weather satellites, the highly successful Tiros and Nimbus satellites, were orbital and could not provide a continuous series of pictures of one particular area or hemisphere. Staying in one location is particularly important in tracing the movement of clouds and storms from one area of the earth to another. Good picture quality of 39% of the earth continues to be received from the spin scan cloud camera about seven hours daily. Several sets have shown cloud movement from dawn until dusk. The camera has also photographed the Moon. The meteorological experiment is the responsibility of Dr. E. V. Soumi, of the University of Wisconsin.

Contributing to the success of this experiment is a special version of Ampex's 1600 series recorder, the SK-1600. This recorder allows large amounts of redundant information to be stripped out as it is recorded by means of a special rotary head synchronized to the satellite's spin.

The spin scan camera makes use of the satellite's 100-rpm spin to scan a narrow beam across the earth. This begins at about 50° north latitude (roughly the Canadian and U.S. border) and extends down to about 50° south latitude (which includes most of South America). After the camera scans across the earth, it is stepped down a small amount for the next scan so that it takes a complete picture of 2,000 lines during the course of 20 minutes. Since the longitude of the scanned area extends well beyond the limits of the earth's disc, large areas of empty space are scanned by the sensor during each revolution. This means that long gaps with no data would be recorded on tape between each earth scan on a conventional ground recorder. Typically, the earth might be in view for only 30 milliseconds of the basic 600-millisecond scan period.

The SK-1600 head is mounted in a drum that rotates about 100 rpm. Magnetic tape (½ inch width) is moved past the head at a speed of 7½ ips. This yields a relative head-to-tape speed of 120 ips. On playback, the head is locked in position, but the tape moves again at the same speed of 7½ ips. This provides a time base expansion (or slowing down) of the data by a factor of 20 to 1, allowing a steady stream of data to be played back in a conventional telemetry format.

Simultaneous with the recording on the SK-1600, a quick look at the cloud picture information is made on an electronic scanner (manufactured by Microlink Corporation) which produces a Polaroid photograph of each completed picture. A second SK-1600 is located at the University of Wisconsin where detailed data reduction is performed.

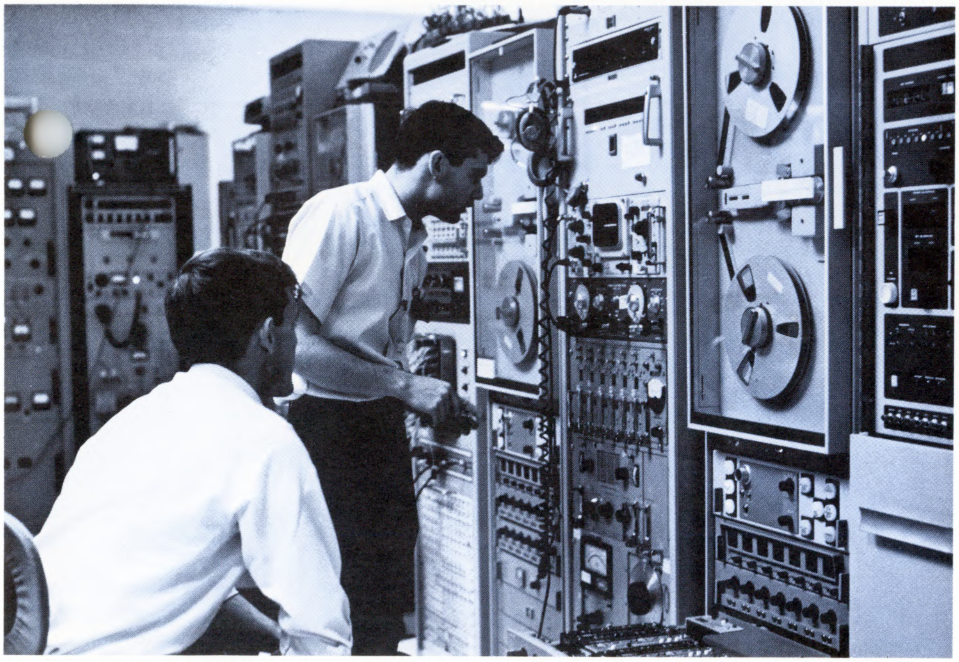
So far, the following types of information have been shown very vividly to meteorologists: diverging high pressure areas, the motion of jet streams, advance of frontal systems, easterly trade wind belts, and changes in cloud formations.

Recording spin scan camera pictures at the Mojave, California, STADAN Station. Recorder at left is an SK-1600, a special version of Ampex's 1600 series, with a 100-rpm rotary head synchonized to the ATS Satellite spin. A second SK-1600 performs detailed data reduction at the University of Wisconsin. At the right, technicians study quick-look Polaroid pictures made on a Microlonk Corporation electronic scanner.

COMMUNICATIONS EXPERIMENTS: Television Pictures. The microwave communications experiments run for about 13 hours daily. Many of the experiments have been with television, both black and white and in color. At the Mojave Tracking station in California, two Ampex VR-1100 recorders are used to record and reproduce television pictures. One recorder plays back televised material for transmission to the satellite on a 6-GHz carrier. Almost simultaneously, the satellite retransmits the television picture back to the station on a 4-GHz carrier where it is recorded on the second VR-1100 for comparison. Two television monitors show a continuous A/B presentation of the transmitted and received picture for monitoring purposes. Besides the transmission and reception at Mojave, the primary station at Rosman, North Carolina, and a further back-up station at Toowoomba, Australia, are also receiving communications data. Many of the microwave communications tests have been made in a multiple access mode which means that all the stations can participate simultaneously.

Gravity gradient experiments from ATS-2, ATS-D and ATS-E will be recorded on this Ampex FR-1800 recorder at the Mojave STADAN Station.

As part of the microwave communications experiments, television pictures are replayed on one of these two Ampex VR-1100 recorders and, after retransmission by the ATS Satellite, are recorded on the other. Twin television monitors (in next bank of racks) provide A/B comparison.



Technicians check out two of the four Ampex FR-600 recorders at Mojave STADAN Station prior to recording a run of environmental measurement data from ATS.

AIRCRAFT COMMUNICATIONS: Two-way Voice via Satellite. The VHF communications experiments permitted the first two-way voice communications between aircraft and ground via satellite. This experiment was participated in by the Federal Aviation Administration and several aircraft companies who are hoping that satellite communications can provide them with better communications, particularly over oceans and sparsely populated areas during storms and adverse conditions. Voice tests were successfully conducted between Goddard Space Flight Center and airplanes over the southwest Pacific and along the coast of the United States and the Gulf of Mexico.

Besides the possibility of using satellites for communication, the FAA hopes that the satellites might be useful in navigation for both range and range rate measurements.

SCIENTIFIC EXPERIMENTS: Environmental Data. In the scientific area, the environmental measurements experiment included seven different studies: omni-directional detector, particle telescope, electron spectrometer, solar cell damage, thermal coatings, ion detectors, and a magnetometer. The environmental experiments are of particular interest because the orbital height of ATS-1 places it in a slot between the inner and outer Van Allen electron belts. These experiments are being telemetered back to the earth in a PCM format (pulse code modulation) and recorded in the tracking stations on Ampex FR-600 recorders.

WEATHER FACSIMILE PICTURES. In addition to the tracking and data recording at the ATS stations, good quality weather facsimile pictures, maps, and charts, are being received by several of the Automatic and Picture Transmission (APT) stations in the United States and Toronto, Canada. This experiment is now scheduled for about two hours daily.

ATS-2: Launched April 1967

Launch of the ATS-2 was different in that the satellite was intended to go into a 6,900-mile circular orbit. Unfortunately, because of a valve failure in the Agena rocket, the ATS-2 failed to enter a circular orbit. Instead, it is now orbiting with a perigee of 115 miles and an apogee of 6,015 miles. However, many of the experiments are fully operational and data is being received. NASA is now evaluating the usefulness of the various types of data.

Because the satellite failed to achieve its 6,900 circular orbit, the 123-foot legs of the satellite are receiving an unexpected environmental test which may prove just how much punishment the system can stand.

NASA/INDUSTRY ATS TEAM

The ATS program is directed by NASA's Office of Space Science and Applications. Project management is under the direction of the Goddard Center. NASA's Lewis Research Center, Cleveland, is responsible for the Atlas-Agena launch vehicle. The launch operations are directed by the Kennedy Space Center, Florida. Hughes Aircraft Co., Space Systems Division, El Segundo, California, is responsible for spacecraft design, development and fabrication as well as integration of spacecraft experiments. General Electric Company, Missiles and Space Division, Valley Forge, Pennsylvania, made the gravity gradient attitude and control system. General Dynamics/Astronautics, San Diego, California, developed the Atlas rocket and Lockheed Missile and Space Corporation, Sunnyvale, California, the Agena stage.

Technical Information:
BIASING IN MAGNETIC TAPE RECORDING

By John G. McKnight, Ampex Corporation

When a magnetic field is applied to certain kinds of materials — such as the coating on a piece of tape — some of this magnetic energy is *stored* on the tape. In other words, the tape coating becomes a permanent magnet. The surface flux from this "magnet" can be detected without in any way changing the stored energy. This particular attribute of detecting without changing is what makes magnetic tape recording possible.

Why "Bias"? When we look at the relationship between the magnetizing (recording) field and the stored magnetization (Figure 1A), a defect immediately becomes obvious—there is a tremendous non-linearity. This would cause unbearable harmonic and intermodulation distortion of recorded speech or music signals.

The earliest attempts to reduce this distortion involved applying a d-c bias to the tape so that the linear portion of the curve from *A* to *B* could be used. Here only about one-third of the curve is used and the presence of the large d-c magnetization made the recording noisy, thus the signal-to-noise ratio was poor.

A better d-c biasing scheme was discovered. The tape can be magnetized to saturation in one polarity and the recording head can carry a d-c bias which *counteracts* this original saturation, bringing the magnetization back to approximately zero. When an a-c field is added, the magnetization is approximately proportional to this added a-c value and linear recording is achieved. However, it is difficult to exactly balance out the d-c and some noise is left.

A much better method is that of a-c biasing. The tape is automatically left in a demagnetized state and the full potential signal-to-noise ratio can be achieved. The principle of a-c biasing was described (but not used for magnetic recording) by Steinhaus and Gumlich in Germany in 1915. A-c biasing for magnetic recording was discovered but never used practically by Carlson and Carpenter in the USA in 1921, and again by Nagai, Sasaki, and Endo in Japan (1938). Practical utilization came with the re-discovery by Braunmuehl and Weber in Germany in 1940.

Early papers and books on magnetic recording attempted to explain the effect of a-c biasing through mathematical models, analogies with a class AB push-pull amplifier, and graphical models considering major and minor hysteresis loops of the magnetic material. These explanations are all somewhat magical and of doubtful value. A much clearer visualization of the effect of a-c biasing can be gained using the process of "ideal magnetization" (also called "anhysteretic magnetization").

For simplicity's sake, let us consider a flexible "bar magnet" made by cutting off a length of blank tape, say 4 cm long. The "bar" can be magnetized in a solenoid carrying a known amount of direct current; the resulting permanent magnetization left after the current is removed can be measured by means of a fluxmeter. When we perform this experiment, and plot the permanent magnetization resulting from various magnetizing currents, we get a curve as in Figure 1A, showing the great non-linearity.

Suppose that while the direct magnetizing current is applied we add an *alternating* magnetizing current, which we then reduce to a zero value before turning off the direct current. The resulting permanent magnetization is shown in Figure 1B for different values of the alternating current. We have clearly accomplished two things: we have greatly increased the sensitivity (the magnetization for a given d-c magnetizing current), and we have made the magnetization a linear function of the d-c magnetizing current. Thus, with this system, an undistorted recording can be made. In this experiment, the d-c represents the signal to be recorded and the a-c represents the a-c bias. There is only one major difference in an actual tape recording. In our experiment, the a-c field decreases while the d-c field remains constant. If we were to use a magnetic ring-core head on a tape recorder to magnetize a piece of tape pulled past the head, we would find that the a-c and d-c fields would die out *together.*

If we go back to our solenoid system and repeat our experiment, but now with both fields decreased simultaneously, we would find the curves of Figure 1C. Increasing the a-c up to a certain point has the same effect as before but beyond this point the magnetization decreases.

This magnetization process is exactly equivalent to what actually happens in a tape recorder at low frequencies. At high frequencies, on the other hand, the process becomes very complicated, because the d-c (signal) field is changing while a particle of tape passes across the recording gap. The 125-Hz curve of Figure 1D demonstrates the long wave output versus bias current of a tape recorder at 9.5 cm/sec (3¾ ips). Increasing bias current increases the output up to the point of maximum sensitivity (also called "peak bias"), then further increases in bias current *decrease* the output.

The choice of the "best" bias current for practical operation of a tape recorder depends on several factors, because the bias current affects not only sensitivity but also the frequency response and the distortion of the recording process.

One extremely important fact must be pointed out here: all of the relationships in biased recording depend on the relative dimensions of the tape coating thickness, the recording head gap length, and the recorded wavelength.

1. The tape-coating thickness ranges from about 5 μm (0.2 mil) for triple-play tape through 12 μm (0.5 mil) for standard tape, to about 22 μm (0.87 mil) for high-output tapes. The ratio of the thickest to the thinnest is 4 to 1.

2. The recording head gap length ranges from 1.5 μm (60 μin) for slow-speed, combination-head recorders, through 3 μm (120 μin) for normal combination-head recorders, to 25 μm (1 mil) for professional recording-only heads. The ratio of longest to shortest is 16 to 1.

3. The recorded wavelength (= tape speed in recording/frequency in recording) ranges from 4 μm (160 μin) to 500 μm (200 mils) at 4.76 cm/sec (1⅞ ips) for a frequency range from 12 kHz to 100 Hz and from 25 μm (1 mil) to 10 mm (0.4 in) at 38 cm/sec (15 ips) for a frequency range from 15 kHz to 40 Hz. Altogether the ratio of wavelengths is 2500 to 1.

In the day when recording was primarily professional—that is, 38-cm/sec (15 ips) speed, with 12-μm (0.5-mil) tape coating, and 25-μm (1-mil) recording-head gaps—one could show general relationships and draw general conclusions for optimum operation. Things are not now so simple. We shall have to be content to show specific trends for specific conditions, and simply realize that other conditions will yield different data and conclusions. The particular magnetic properties of the tape coating are also important and they affect the frequency response, distortion, and the signal-to-noise ratio that is obtained.

Effect of Bias on Frequency Response. A basic unequalized experimental recorder would use a constant recording head current *versus* frequency to produce a constant recording field *versus* recording frequency. A basic unequalized experimental reproducer would have an output proportional to the flux on the tape. For instance, by means of a loss-free, short-gap, ring-core reproducing head plus an integrating amplifier with constant flux, the head voltage rises 6 dB/octave. But the integrating amplifier response falls 6 dB/octave. Therefore, the two effects compensate and the output voltage is flux-proportional.

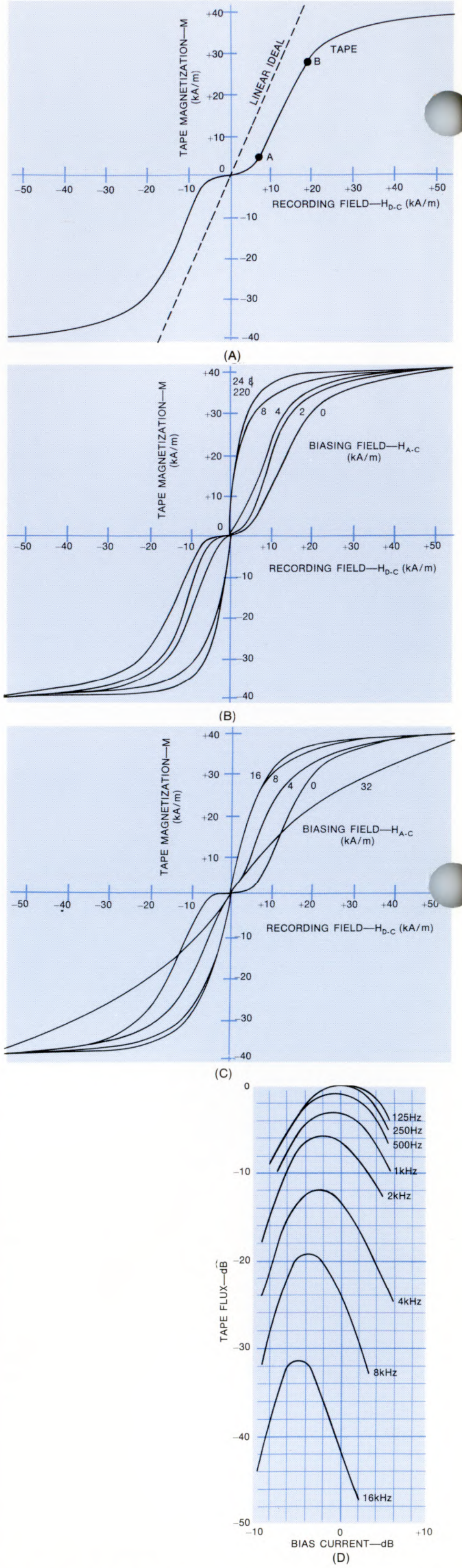


FIGURE 1. (A) An unbiased tape is inherently non-linear. (B) When a-c bias is added in various amounts to the d-c (signal), the curves are as shown. In this case, the d-c remains while the a-c decreases. (C) Same as (B) except that both d-c a a-c decrease, simulating an actual tape recorder. (D) Out rises with increasing bias to a peak then falls off. Output v bias current at a number of frequencies using unequalized (flux-sensitive) system, showing the shift required in the bias for maximum high-frequency sensitivity.

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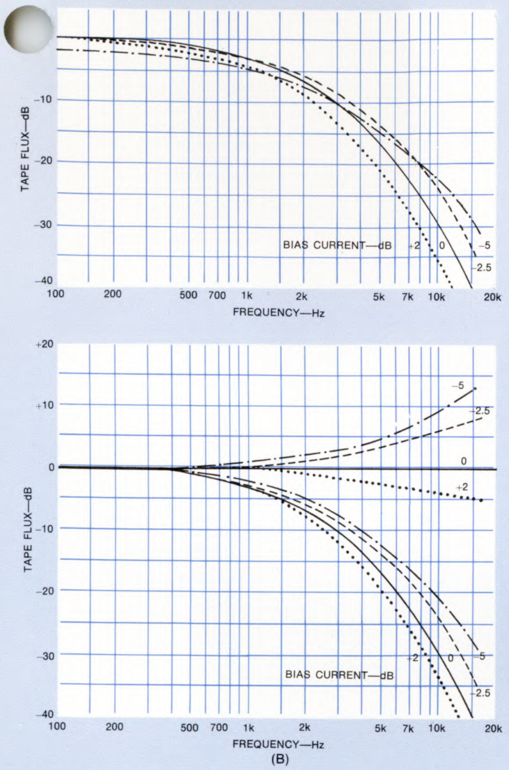

FIGURE 2. (A) Frequency response with different bias currents showing the need for equalization. (B) Same as (A) but ·th outputs at low frequencies adjusted to same level. Upper ː of curves in (B) shows the system equalized for a flat response when the bias has been adjusted to provide the maximum sensitivity at low signal frequencies.

Suppose we draw the output *versus* bias current curve at a number of frequencies, as in Figure 1D. We could see these things: 1) At all frequencies, the output rises with rising bias current, then falls off. 2) The current for maximum sensitivity is the same over a wide range of *low* frequencies (long wavelengths), then, as frequency increases (wavelength becomes shorter), the maximum sensitivity occurs at lower and lower currents.

This data can be re-plotted as a frequency response (Figure 2A). The generally drooping characteristic shows that the system must be equalized to compensate for short-wavelength losses. Figure 2B shows the relative responses if the recording field were changed to give the same tape flux at low frequencies for each bias current. We see that low bias current gives the *least* high frequency losses, and therefore would require the least amount of equalization. Therefore, from *only* a frequency-response standpoint, biasing for maximum sensitivity at the highest frequency would be best. When the system is equalized for the maximum low-frequency sensitivity bias point, changes of bias would change the equalized response as shown in Figure 2C. Lowering bias increases high-frequency response and *vice versa*.

Effect of Bias on Distortion. Figure 1B shows that at low bias the curves are non-linear and with increasing bias they become more linear. The measured harmonic distortion at low frequencies shows this effect (Figure 3A).

Harmonic distortion measurements above one-third of a recorder's bandpass are, of course, meaningless since the distortion (primarily third harmonic) is eliminated. High-frequency, non-linear distortion can be measured, however, by the CCIF intermodulation method. Two equal-amplitude high-frequency tones, say f and $f + \Delta f$, are used. If we let $\Delta f = 300$ Hz, then the frequencies could be 10,000 Hz and 10,300 Hz. In the output, we look for the second-order intermodulation frequency component at $f - \Delta f$, which would be 9700 Hz in this case. This frequency is caused by the same non-linear phenomenon which causes third-harmonic distortion, but this frequency is *inside* the system bandpass. Figure 3B shows the output for 2% IM distortion *versus* bias current, for 500-Hz, 2500-Hz, 5000-Hz signals, using a 9.5-cm/sec (3¾-ips) tape speed, standard tape, and a 5-μm (200-μin) combination recording head gap length. The 0-dB bias current is that which gives maximum sensitivity at 500 Hz.

This data shows the difficulty of improving the high-frequency response by lowering the bias current. The response at lower levels is improved (see Figure 3B), but the maximum output for a given distortion at mid-frequencies is greatly diminished. Operation at −3 dB bias, for instance, increases the 5-kHz maximum output by almost 3 dB, but decreases the 500-Hz maximum output by 4 dB, thus the mid-frequency signal-to-noise ratio is compromised in order to gain improved high-frequency performance. With separate record/reproduce heads, the problem still exists, but is not so severe.

Effects of Bias on Dropouts. When recording, a tape nodule or a dust particle causes the tape to be lifted away from the recording head, the biasing field, in effect, decreased. If the system is under-biased (say at −2 dB in Figure 1D), then a small loss of bias causes a large loss of recording sensitivity, and a large dropout of the recorded signal at all frequencies. If, on the other hand, the system were operated in the overbiased condition (say at +2dB of figure 1D), the loss of contact would decrease the biasing field, but this would result in a compensating *increase* in recording sensitivity, thus the dropout would be reduced.

Hence, we have a conflict — best response at low levels dictates low bias current. Greatest output for a given distortion dictates medium bias current. Reduction of dropouts dictates high bias current. In professional recorders (high-speed recorders with separate record/reproduce heads), there is little problem. Best operation comes from biasing at 0 to +2 dB *re* bias for maximum sensitivity at low frequencies. In home recorders (slow-speed recorders with combination record/reproduce heads) there is a real conflict and some compromise must be made. Different equipment manufacturers do this differently and extended frequency response may mean high distortion.

The Bias Frequency. The bias frequency should be as high as possible for two reasons. First, low bias frequency causes the background noise to increase. At 19 cm/sec (7½ ips) tape speed, the use of bias frequency of about 100 kHz (or more) reduces this noise to nearly the minimum amount. Second, at high recorded frequencies, the harmonic distortion which is created at high recording levels by the tape and recording amplifiers produces audible beats with the bias frequency and these beats are recorded on the tape. A frequency-response run at high levels may look like Figure 3C. The response above about 8 kHz is, in fact, a series of bias beats. This 4.75-cm/sec (1⅞-ips) recorder uses a 67-kHz bias frequency.

This problem may be especially troublesome when one attempts to make tape recordings from an FM-multiplex tuner. Both 19- and 38-kHz signals are present in the multiplex unit and may get through to the tape recorder. If these are of large magnitude, the bias beats will occur. Several solutions are possible including better filtering of the multiplex carrier in the tuner and low-pass filtering in the tape recorder input circuit. If the multiplexer is well-balanced, so that only the 38-kHz is of concern, the choice of a 95-kHz bias frequency will place the beats above the audible frequency range.

If the bias waveform has even-order harmonic distortion, a d-c signal is recorded on the tape. This has the bad effect of causing second-harmonic distortion as shown in Figure 3D. A tape noise is also added, as shown in Figure 3E. The noise consists of "cracks and pops" caused by irregularities in the tape coating; it is therefore very much a function of the tape quality.

When the bias is a-c coupled to the recording head, any *average* d-c is eliminated. Unfortunately, the *peak* bias amplitude may still be asymmetrical and this leaves a d-c flux on the tape.

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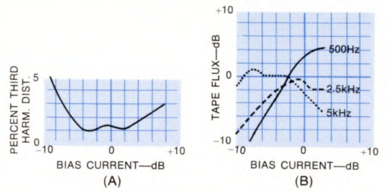
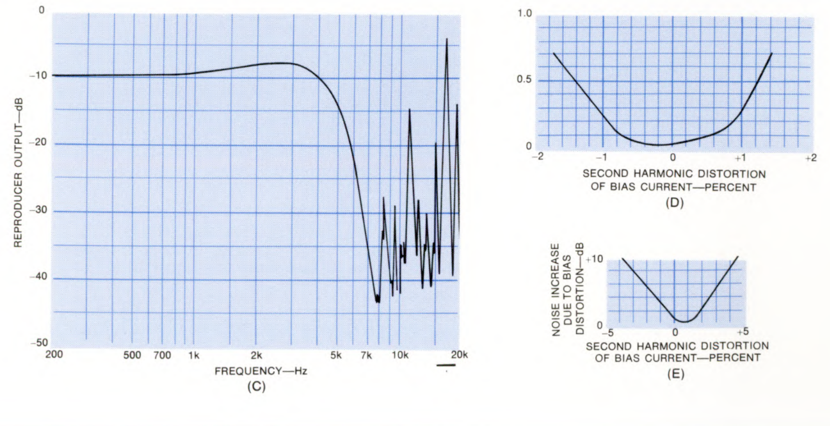
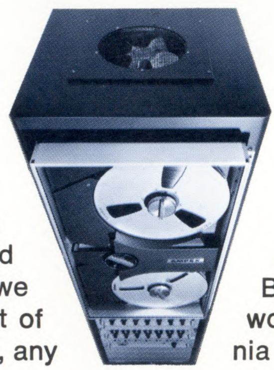


FIGURE 3. (A) Low-frequency third-harmonic distortion. (B) Maximum output for 2% second-order CCIF IM distortion. Reducing bias for improved high-frequency output results in reduced low-frequency output. (C) High-level frequency response shows "bias birdies"— spurious outputs above 8 kHz in 1⅞ ips recorder with 67-kHz bias frequency. (D) Second harmonic distortion due to bias distortion in current. (E) Noise in recording also due to bias distortion in bias current.



TYPE	FR-1600	FR-1800H	FR-1800M	FR-1800L	AR-1600	FR-1300	AR-200	CP-100	SP-300	AR-500/550	FR-900/950	FB-400 (Bin)	SP-600
General Description	Lab High Band	Lab High Band	Lab Interm. Band	Lab Interm. Band	Air/Mobile High Band	Lab/Port. Interm. Band	Air/Mobile Interm. Band	Mobile Interm. Band	Portable Interm. Band	Air/Mobile Wideband	Lab Wideband	Lab (bin) Interm. Band	Lab/Port High Band
Recording Modes	FM and DR Rec/Rep	FM, DR and FSM Rec/Rep	FM, DR and PDM Rec/Rep	FM, DR and PDM Rec/Rep	FM and DR Rec/Rep	FM, DR and PDM Rec/Rep	FM, DR, PDM and PCM Rec only	FM, DR and PDM Rec/Rep	FM and DR Rec/Rep	FM and Pre-detect Rec only	FM and Pre-detect Rec/Rep	FM, DR and FSM Rec/Rep	DR Rec/Rep
Band Widths FM/Direct	500kHz/ 2.0MHz	500kHz/ 1.5MHz	40kHz/ 500kHz	40kHz/ 300kHz	500kHz/ 2.0MHz	20kHz/ 300kHz	20kHz/ 250kHz	20kHz/ 250kHz	2.5kHz/ 40kHz	5.5MHz 5/10 MHz Carrier (PD)	5.5MHz 5/10MHz Carrier (PD)	500kHz/ 1.5MHz	1.5MHz
Channels	7 or 14	7 or 14	7 or 14	7 or 14	7 or 14	7 or 14	7 or 14	7 or 14	4 or 7	1 or 2WB w/2 aux.	1 or 2WB w/2 aux.	7 or 14	4
Tape Widths (inches)	½ or 1	½ or 1	½ or 1	½ or 1	½ or 1	½ or 1	½ or 1	½ or 1	¼ or ½	2	2	½ or 1	¼
Reel Diameters (inches)	10½, 14, 15, 16	10½, 14	10½, 14	10½, 14	10½, 14	10½	10½	10½	7, 10½	8¼	10½	Loop 5 ft.-250 ft.	10½, 12½
Tape Speeds (ips)	Discrete and Continuously Variable						1⅞-60	1⅞-60	1⅞-15	12½/25	12½/25	3¾-120	120
	3¾-240	1⅞-120	1⅞-120	1⅞-120	3¾-120	1⅞-60							
Capstan Servo	200kHz	200kHz or 60Hz	200kHz or 60Hz	200kHz or 60Hz	200kHz	60Hz	60Hz Rec only	60Hz Rec only	none	integral	integral	60Hz	integral
Record Time at Max. Bandwidth	17½ min.	12 min.	12 min.	12 min.	12 min.	12 min.	12 min.	12 min.	48 min.	50 min. (1 ch.) 25 min. (2 ch.)	60 min. (1 ch.) 30 min. (2 ch.)	Continuous Loop	19 min.
Amplifier Speed Switching Characteristics	6 spd. elec. or single spd. manual	2 or 4 spd. elec. or single spd. manual	2 or 4 spd. elec. or single spd. manual	6 spd. elec. or single spd. manual	6 spd. elec. or single spd. manual	6 spd. elec. or single spd. manual	6 spd. manual	single spd. manual	4 spd. elec.	single spd.	single spd.	electrical or manual	single spd.
Power Required	115/230V 50/60Hz	115/230V 50/60Hz	115/230V 50/60Hz	115/230V 50/60Hz	28vdc or 115/230V 50/60Hz or 115V 400Hz 3φ	115/230V 50/60Hz	28vdc or 115/230V 50/60Hz or 115V 400Hz 1φ or 3φ	28vdc or 115/230V 50/60Hz or 115V 400Hz 1φ or 3φ	115/230V 50/60Hz	115V, 400Hz 3φ	115/230V 50/60Hz	115/230V 50/60Hz	115/230V 50/60Hz

The world's dullest chart...
unless you need a recorder.



To tell you that our instrumentation recorders are made to the highest standards of quality would either be belaboring the obvious or sound like braggadocio, depending on how well you know Ampex. □ Let us just add one word that the chart omits: Whatever we make, we take care of. Service is a big part of what you buy from us. Anywhere in the world, any time of day or night that you need Ampex service, one of our engineers is close by. □ For complete information on any of our recorders or the high quality magnetic tape we make for them, write Ampex Corporation, 401 Broadway, Redwood City, California 94063.

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