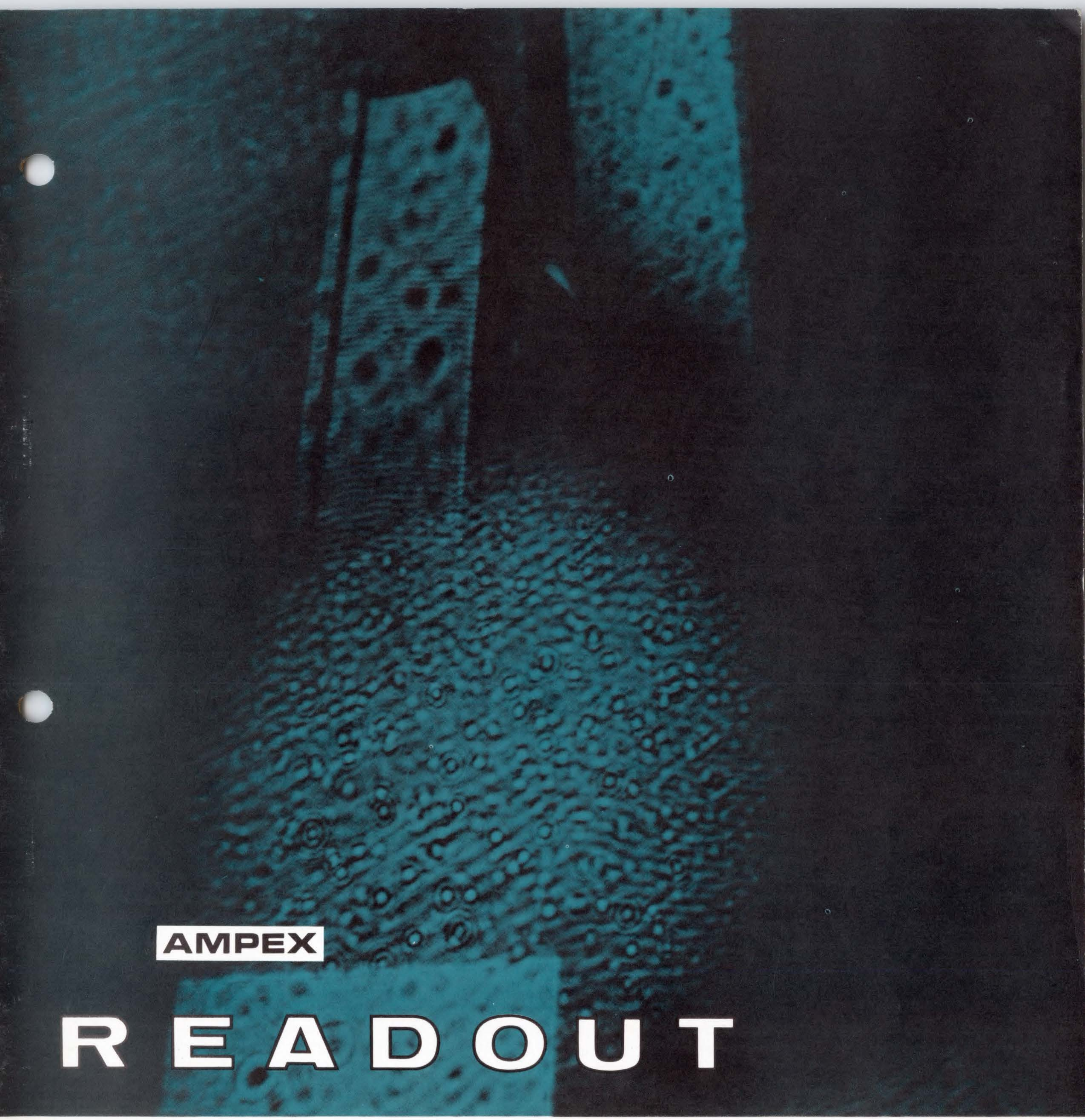

AMPEX

READOUT

In this issue:

information storage and retrieval

a state-of-the-art report

information storage and retrieval

a state-of-the-art report

By William A. Gross
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Eight years ago Ampex published a special report in READOUT on the continuing search for advanced memory techniques. This issue of READOUT updates that report. It gives an historical review of information storage and retrieval methods and discusses the state-of-the-art and exploratory work under way in 1967. Both magnetic and optical methods of recording and reproducing are examined and compared in detail.

Five years ago the Ampex motto was "Memory is our Business." Although the Corporation's technical and marketing interests have grown since then, excellence and breadth in information storage and retrieval technologies continue to be a prime objective. Future issues of READOUT will present a series of articles describing current technical efforts in Ampex research and development. This report provides a background for the series by reviewing the range of information storage techniques currently being examined. It is written for those who have some familiarity with information storage technology, and would like to update themselves in this field.

Cover: Laser Beam Patterns

A special issue of READOUT® · A magazine of Ampex Corporation · David R. McClurg, Editor ·

FOR millennia people have attempted to communicate both information and emotions. Our predecessors evolved the ability to communicate on-line through speech (real-time information) and off-line through writing (stored information). For men to progress beyond the stage of rudimentary understanding of their environment, off-line information storage was essential. For at least eight thousand years technologists have been developing mechanisms by which information could be stored. Then, as now, they provided the media by which others might communicate ideas, facts, and processes, or enjoy vicarious experiences.

The adjoining table summarizes the past and projected evolution of off-line information storage techniques. Just as a radical change in the evolution of technology and civilization followed the development of a mass printing process, so we are beginning to see a radical change in our technology and civilization as a consequence of massive data processing. Both technologies involve the storage of information for subsequent retrieval. In either case, the information may be retained, manipulated or destroyed as the user desires.

On-line information handling has evolved from voice and signals, through wireless, to satellite-relayed microwave communications. Increasingly, the technology of on-line communications is being used in information storage and handling. The technology of off-line information storage and handling is being used in communications. This interchange of technologies is becoming so common that there are unresolved legal questions regarding the distinction between communication systems and information handling and processing systems. We avoid here the examination of systems and concentrate on the techniques and devices used or proposed for storing and retrieving information.

Trade-Offs in Information Storage

There are two principal factors by which information storage devices (which otherwise appear to meet the functional requirements of size, weight, power, and environment) need to be measured: accuracy and cost. Accuracy means how well (in terms of precision) the retrieved information corresponds with that stored. Retrieval is usually more difficult and expensive than recording (about which more later). Cost means initial purchase price, operating expense, including salaries of operators and value of inventory, repair expense, and value lost due to down time.

A word more about cost before concentrating on the functional performance of different information storage technologies. Our buying sophistication tends to increase with experience. Impulse buying and ignorance of specifications are inefficient. They occasionally result in "lemons," and may lead us to buy the most expensive product hoping to increase reliability and reduce life cost. Further sophistication may enable us to assess more accurately the life cost and confidently buy products below the premium price range. Before we can do so, however, we must thoroughly understand the functional requirements and technologies involved.

Functional requirements have grown increasingly more severe. Size per stored unit, power consumed, access time, and error-rate capability have decreased (along with unit costs), as bandwidth, convenience of usage, reliability, and quality of appearance have increased.

There are substantial trade-offs possible in functional performance, some of which will be discussed later. At this point, it is useful to list some important trade-offs.

Table 1 — OFF-LINE INFORMATION STORAGE TECHNIQUES

Form of Storage	Storage Media	Date of Practical Usage
HAND STORAGE		
Engraved pictures (Chaldean Ruins, Nippur)	clay tablets	6000 BC
Engraved cuneiform (Sumerian)	stone	4000
Ink hieroglyphics (Egyptian)	stone, papyrus	4000
Ink book	papyrus	2500
Ink lettering (Greek)	papyrus, parchment	850
Ink lettering (Arabic)	papyrus, parchment	500
Ink lettering (Latin)	papyrus, parchment	300
MACHINE STORAGE		
Block printing, ink (China)	paper	50 BC
Moveable type, ink printing	paper	1455 AD
Lithography ink printing	paper	1798
Photographic print	emulsion	1802
Cylinder ink printing	paper	1811
Rotary ink printing	paper	1850
Typewriter ink printing	paper	1867
Photographic film, dry roll	silver halide	1883
Linotype ink printing	paper	1885
Motion picture film	silver halide	1896
Magnetic wire recorder	nickel iron	1938
Magnetic tape recorder	iron oxide	1944
Magnetic digital core memory	ferrite	1955
Electron beam exposure	silver halide film	1964
Magnetic digital thin film memory	thin permalloy film	1966
Laser beam exposure, reproduce	silver halide film, mag. media	1970
Laser holographic exposure	silver halide film	1971

Bit Capacity	Type	Access Time	Cost Per Bit	Remarks
10^3	Scratch pad	100 nsec	1 dollar	Active elements, thin film.
5×10^5	Main frame	1 μsec	5 cents	Core, thin film.
5×10^7	Mass core memory	3 μsec	2.5 cents	
10^9	Disc files	150 msec	1 cent	Back up for high speed memory.
10^8	On-line magnetic tape (1600 bpi)	100 sec	3×10^{-3} cents	

Technical Criteria

Three basic technical criteria may be used for evaluating storage devices for digital information: 1) packing density (i.e., bit size), 2) error rate, and 3) information rate (access and cycle time). To these are added the initial and operating cost factors, and reliability. The initial cost per bit is a major trade-off factor.

For example, a present-day large capacity computer might have memories with characteristics as shown in the above table.

The memory is backed up by a library of tape at low shelf cost (under 10^{-5} cents per bit). In fact, the reel of tape (whose ancestor was the parchment scroll) provides the lowest cost information storage media which may be updated or changed.

In recording analog information, the analogous principal criteria are: 1) the packing density (wavelength and track spacing), 2) the signal-to-noise ratio (or dynamic range; if interpreted broadly this would include time base and phase accuracy), 3) the bandwidth.

Life cost and the three technical parameters provide a wealth of trade-off possibilities for both analog and digital recording systems. New developments are almost continuously being announced for novel analog or digital storage which project huge increases in recording capability with respect to one or even two of the technical parameters. Usually ignored is the fact that the remaining parameter(s) would be so seriously degraded that the proposed system would be impractical.

Most commonly it is the fidelity of information recovery, and secondly, the speed, that are deficient in proposed schemes.When a novel storage technique is conceived, it is first applied to a very small sample. The announcements may then be made based on: 1) a scaling up (usually on a linear scale) of the recording to large quantities, and 2) an assumption of perfection in the retrieval of this information.

It is the inability to retrieve information with speed and accuracy that causes the most novel of recording schemes to be dropped. Problems may arise due to material inhomogeneity, or yield of usable storage locations. Though small samples are easily made, samples large enough to be economical may not be producible. Therefore, though bits or signals may be put into the memory system they may be lost, or rendered unusable. Problems may also arise in locating or tracking stored information where there is no direct connection to each storage location. For example, electron or laser beams may be used to deposit information on a variety of media. The limiting factor invariably seems to be the ability to retrieve the required information with acceptable accuracy. These line tracking, or beam positioning problems rise many fold as efforts are made to increase packing density.

FUNDAMENTALS

Most often, information seems to occur normally, along with noise, in analog fashion. To record this information and retain the analog character, we need a transducer which takes the information signal and deposits it on the recording medium. In a perfect system, there will be no noise in the transducer, circuits, or recording medium. Furthermore, both the transducer and medium will respond linearly to the input signal and noise. Unfortunately, every part of a system contributes some noise and some non-linearities, however small. For example, the accompanying drawing qualitatively illustrates a transfer function curve (relating the output to the input) for magnetic tape. The recorded information due to the sine wave input, without bias, is badly distorted. The non-linearity of the transfer function curve causes severe harmonic distortion. Both signal and noise are so distorted that such a technique is useable only where very poor signals are acceptable. Biasing the recording permits use of the transfer function curve only where it is nearly linear. Even so, some harmonic distortion results because we cannot obtain a perfectly linear transfer function. Clearly, the less noise inserted by the recording process, and the more linear the transfer function, the more generations of reproductions can be made without reaching an unacceptable level of signal degradation.

In digital or pulse storage, we have a different situation. If recorded magnetically on tape, the same type of transfer function curve applies. Idealized input and output signals for saturation recording are shown in drawing.

Digital storage devices operate with error rates on the order of 10^{-7} or less. In the absence of dropouts (lost bits) information can be reproduced indefinitely without signal degradation. Coding difficulties exist, though, in modulating analog signals to digital form, and in demodulation from digital to analog form. Since systems increasingly are using digital processing, users are increasingly digitizing analog data, even for storage.

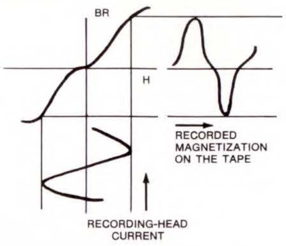
All storage techniques depend upon a transducing mechanism and a recording medium capable of changing state. Some, such as magnetic recording, involve reversible changes thereby permitting erasure and reuse. Some, like thermoplastics, involve nearly reversible changes, and the noise content therefore rises with use. Some, like photographic film involve irreversible changes and the information is therefore fixed. Since photographic film must be developed, there is a delay of ten seconds or more after recording to permit film processing.

Magnetic tape is constructed of a polyester backing such as MYLAR, which supports the oxide surface, and prevents print-through. Cigar-shaped rust (γ Fe_2O_3 iron oxide) particles, as small as 1 microinch by 10 microinches are dispersed in a binder to fit the required recording objectives.

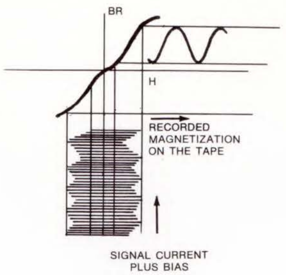
Tape manufacturers seek to obtain maximum uniformity of the particles, to bind them securely to the tape, and to maintain appropriate surface smoothness. The tape passes through a magnetic field while the binder is still soft so that the particles tend to be aligned in the direction of recording (along the direction of the tape length for longitudinal recording, and across the tape width for transverse recording).

Since a major source of signal loss is due to head-to-tape spacing, d, during record and reproduce (reproduce signal loss = 55 d/λ db), it is necessary to produce tape with ever smoother surfaces (now they're better than 5 microinches rms) as recorded wavelengths, λ, decrease. Shorter wavelengths also require thinner oxide coatings to prevent the demagnetization effects of deeper oxide layers. It is clear that considerably more care must be expended to produce satisfactory tape for high performance—short wavelength applications. (The Ampex FR-1600, for example, records and reproduces 60-microinch wavelengths at 120-ips tape speed in storing 2-MHz signals.)

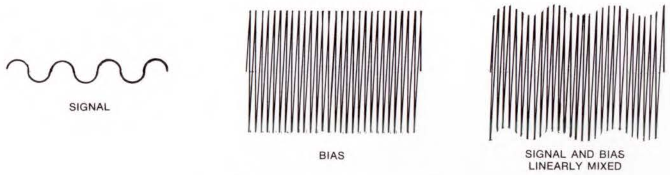
Oxide particles are small enough to be single domain (i.e., each acts as if it were a bar magnet which, under a very wide range of temperature and magnetic fields, can exist



Unbiased magnetic recording

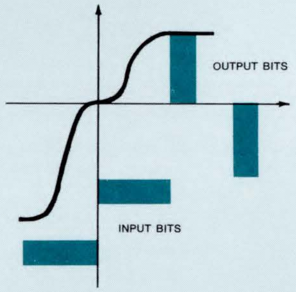


Addition of high-frequency bias to the recording signal



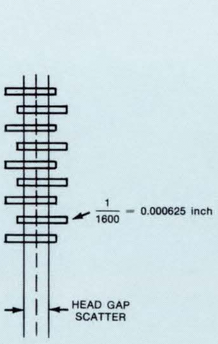
Mixture of bias and signal

RECORDING FUNDAMENTALS

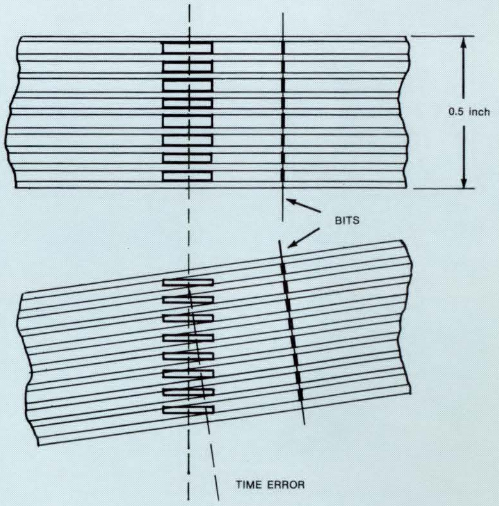


DIGITAL MAGNETIC RECORDING (Saturation Recording)

To prevent dropouts or errors in reading, this format (1600 bpi phase mode recording) requires better position control than 0.000625/0.5 = 0.00125 radian (4.3 minutes of arc).

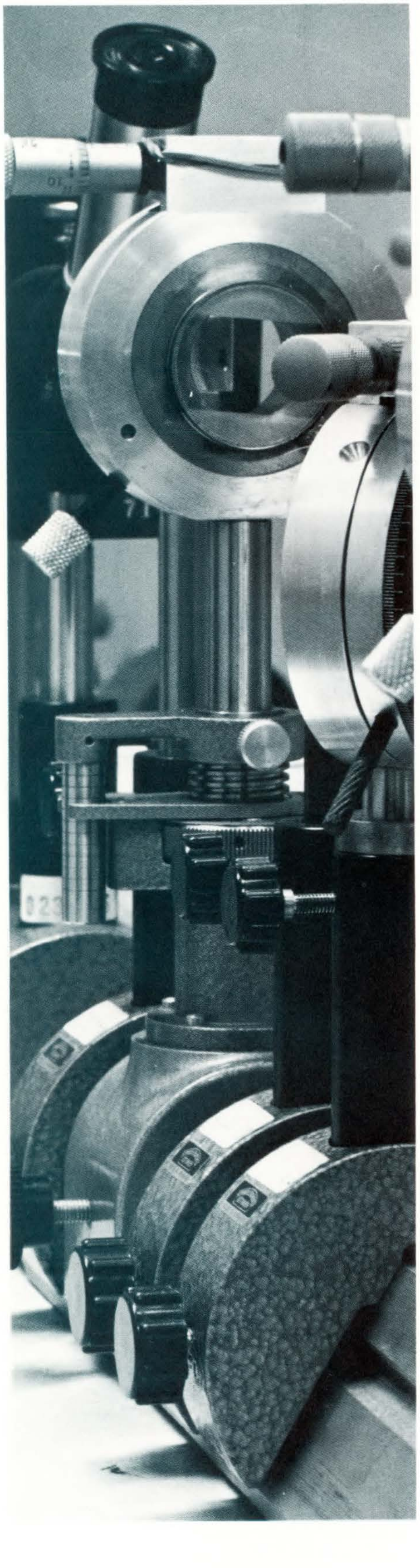


Differences between head horizontal centers cause static skew errors. Difference between the extreme right and left centers is the head gap scatter.



Exaggerated skew error caused by uneven tape travel during playback mode.

LIMITATIONS IN BIT PACKING DENSITY



in two states only, north-south, and south-north). As a single particle, not influenced by other particles, moves through the field of the recording head, it may switch polarity as many as three times. Particles, however, do interact. In fact, they tend to cluster during tape manufacturing. For example, two particles side by side form a magnetic pair, north-south, and south-north. Because of the closed flux lines, it is effectively useless.Further clustering adds to the number of ineffective particles.

The limitation in packing density of digital tape is due to the convention of recording nine bits simultaneously across ½-inch tape. The maximum bit spacing per track is 1600 bits per inch using phase mode recording. As seen in the accompanying drawing, this requires much better position control than 0.000625/0.5=0.00125 radian (4.3 minutes of arc) to prevent dropouts or errors in reading.

Digital tape transports move tape as fast as 150 ips. Tape cannot be perfectly slit. The edges are not absolutely straight and parallel, and the tape is not everywhere exactly the same width. The packing density is therefore limited by the ability of the transport to move imperfect tape so that the bits are invariably read out accurately. Tape manufacturers certify tape to be dropout-free for specific bit-per-inch recording.

Ferrite cores may be considered to be like bar magnets bent to form a toroid. Too large to be single domain, they nevertheless are frequently used in full switching (as opposed to partial switching) mode. Under these conditions, wires through the core carry current pulses during record which insure the flux will remain in one direction after the pulse is removed. During reproduce, the direction of this flux is sensed by a wire in which a current is induced by the core after it has been disturbed magnetically. At present, efforts in core memory fabrication involve developing smaller cores comprised of ferrites which withstand a wider temperature range, require lower drive currents, and are tougher physically (so they don't break during wiring).

Ferrite cores as small as 0.007-inch o.d. have been made. Continuous sheet and continuous strip ferrites have also been developed. To date, however, yield problems have prevented main frame memories from being made of continuous ferrite elements. Rather, more effort has been expended on thin film memories in which information is stored on thin (about 0.5 micrometer on wire, 0.1 micrometer on planar surface) permalloy.

As in ferrite cores, information is recorded on thin films by sending currents through wires. These are so arranged to insure that the magnetization of the film (a spot, or portion of a plane or of a coating on a rod or wire) is in a certain direction. The film is deposited so that the magnetization will rest in only two directions, north-south or south-north. The information is read out by a wire which senses changes in the magnetic field of the film. Technical problems in producing practical thin film memories revolve around producing sufficient yield for a large enough number of bits, and interconnecting them properly to electronic current drivers and sensors to minimize cost.

PRESENT DAY INFORMATION STORAGE METHODS

Table 2 lists some information storage applications for which Ampex has contributed products or technology. Checked off are the storage media being used to store this information.

Table 2 — INFORMATION STORAGE METHODS

Information Storage Applications *ANALOG*	**Silver Halide Film**	**Magnetic Tape**	**Drum, Disc**	**Ferrite Core**	**Thin Film**	**Integrated Circuit**
Audio (20 kHz)	x	x	x			
Video (to 10 MHz, FM mod.)	x	x	x			
Instrumentation (100 Hz to +100 MHz)	x	x				
DIGITAL						
Sequential	x	x				
Random sequential			x		x	x
Random				x	x	x

udio Recording

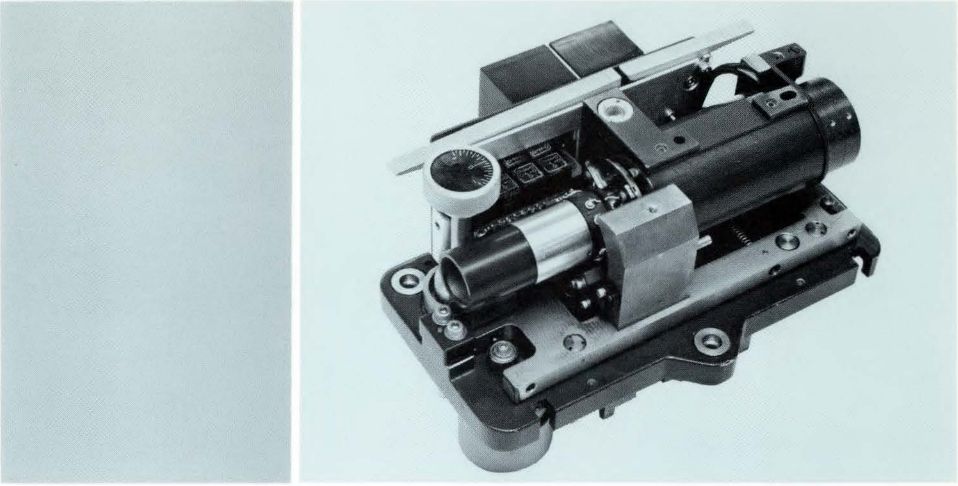
Audio information is stored on photographic films for motion pictures, and on magnetic tape or phonograph discs. Bandwidths for mono and stereo applications go to 15 or 20 kHz. Since the ear is comparatively phase-insensitive, only level amplitude response over the frequency band is important. Current technical objectives relate to providing superior performance (mostly better signal-to-noise ratio, reliability, and convenience) for the same cost, or the same performance at reduced cost. Developments are constrained by standardized tape speeds and track widths. Magnetic tape is superior to audio discs in that discs wear rapidly with use, therefore giving poorer signal-to-noise output on each play, while tape wear is usually negligible and signal-to-noise independent of number of plays. In fact, phonograph discs are commonly made from sound recorded on magnetic tape masters. Audio tracks are recorded both magnetically and optically on motion picture silver-halide film.

Picture Recording

It is estimated that the better quality motion picture films are produced with bandwidths of about 12 MHz. By comparison, the United States video standard for television use (to which video recorders must adapt) is 4.2 MHz with 3.5 MHz subcarrier for black and white, and 4.2 MHz with 3.58 MHz subcarrier for color. Ampex high-band color, for example, uses a 9.16-MHz signal. Though video recording can be extended in bandwidth to give superior resolution, it is tied to the television standard. An advantage of magnetic tape over motion picture film is its superior resistance to abrasion. Though motion picture film degrades with use (the signal-to-noise ratio of the picture decreases) the signal-to-noise ratio of broadcast standard video tape (for example) remains over 40 db with use.

Future developments in video recorders, within the broadcast standard, will result in increased flexibility and convenience (i.e., smaller size) at reduced cost. A wider range of information bandwidth is possible for non-broadcast video recorders. Though the loss in signal-to-noise ratio or resolution is unacceptable, relatively inexpensive recorders can be built if we chose to operate at bandwidths as low as 1.5 MHz. At the other extreme, bandwidths giving picture resolution comparable to the best motion picture films are possible.

Both black-and-white and color video recordings have recently been made on magnetic film plated discs. The discs, with the magnetic heads operating in contact, are used for stop, fast, slow, or normal, forward or backward motion.



FR-900 Rotary Head Assembly. Four heads spaced 90° apart on a drum record and reproduce transverse tracks on 2-inch tape. Rotary transformers remove transients when switching from each of the four heads.

Instrumentation Recording

Instrumentation recording applications range from miniature recorders for satellites and space probes, and very-long-time low bandwidth recorders for geophysical purposes, to wideband (currently 5.5 MHz; in a decade 100 MHz) recorders for predetection purposes (as in recording all signals from a rocket launching of a space probe). It appears that rotary magnetic recording can be used to bandwidths of 10 to 30 MHz, but that more exotic schemes using laser or electron beams, for example, are required for bandwidths to and beyond 100 MHz.

Digital Recording

Magnetic tape has been the repository of most digital data stored for periods longer than one second. When placed on reels (scrolls), the information is accessed and read out sequentially. When placed on strips and filed in boxes (books), individual strips can be randomly accessed and sequentially processed. Drums and discs with magnetic surfaces (usually called random access memories) are useful in digital memories because of their 100 to 200 milliseconds random access to a string of data.

Competing with these erasable memory techniques are permanent memory systems employing silver-halide film exposed by electron or laser beams. It is possible to record a higher density with beams. Readout at an acceptable error rate is the major problem. To date, no photographic read/write digital system has proved superior to magnetic tape storage with respect to any of the three critical factors mentioned earlier, or cost, even ignoring the limitation due to non-erasibility. From the cost standpoint, only magnetic tape and beam exposed media seem to be potentially practical for storing vast amounts of data (10^{11} to 10^{14} bits).

Ferrite core memories are presently the only practical means by which memories larger than 10^7 bits can be used which have cycle times under 3 microseconds and cost-per-bit under 3 cents. They also are used for most main frame memories operating at cycle times down to 1 microsecond. Some main frame memories are now made of magnetic thin films on rods, planes, or wires. Since thin magnetic films have been used as delay lines, we may also classify them as random, sequential memories.

The highest speed memories in a computer are called "scratch pad" memories. Increasingly, scratch pad memories are being designed to use integrated circuits. There is a variety of storage devices used for scratch pad memories such as sonic delay lines, thin magnetic film strips, tunnel diodes and integrated circuits. Integrated circuits (more importantly, large scale integration (LSI) which involves numerous integrated circuits tied together on the same chip) offer the best promise from the standpoint of size, reliability, and cost. Yield considerations here are important, too.

Future Storage Capabilities

To simplify comparison of the most important continuous recording processes, we compare performance on the basis of digital storage (in the accompanying chart). The first two items are available now. The remaining three are under development and will be discussed in the next section.

Table 3 — DIGITAL RECORDING COMPARISON

Technique	Packing Density 1967 (bits/inch^2)	Potential Packing Density	1967 Media Cost (\$/bit)	Data** Reliability	Recording Medium Storage Life
*1. Standard Digital Magnetic Recording (TM-12)	3×10^4	6×10^4	5×10^{-8}	1 error in 10^5 to 1 error in 10^7	Indefinite
*2. Rotary Digital Magnetic Recording (FR-950)	1×10^6	2×10^6	1.4×10^{-9}	1 error in 10^7 to 1 error in 10^9	Indefinite
3. Electron Beam Recording	1×10^6	2×10^7	4.2×10^{-8}	not known	Indefinite
4. Laser Beam Recording	1×10^6	2×10^7	4.2×10^{-8}	not known	Indefinite
5. Thermo-Magnetic Write/Magneto-Optic Read	1×10^6	1×10^8	not known	not known, probably high	Indefinite
6. Electron Beam Record, Laser Beam, Fourier Transform Reproduce	1×10^6	2×10^7	4×10^{-9}	1 error in 10^7 to 1 error in 10^9	Indefinite

*Nos. 1 and 2 are standard and available, Nos. 3 through 6 are in various stages of development.

**Raw data reliability without the use of error correcting codes.

The radical improvement in packing density made possible by rotary recording is also feasible in longitudinal recorders by recording maximum longitudinal density in nonstandard format. For example, both FR-1600 and FR-950 have comparable area packing densities of about 3×10^5 cycles per square inch. By comparison, electron beam recording is expected to have a packing density greater by an order of magnitude.

Novel Sequential Recording Methods

Electron beams have been used for recording on thermoplastic, electrostatic, or oil (Eidophor), and by machining and adding ions. The Eidophor system is successfully used for wide screen television presentations, as in theaters. Electrostatic recording has somewhat longer data life than Eidophor. Thermoplastic recording is permanent within reasonable temperature ranges, and erasures (with degradation) are possible. All three techniques have serious signal-to-noise and error rate limitations and are principally suitable for special purpose needs and display.

At first glance, machining with electron beams, or adding ions, appears to be suitable for recording digital information. However, problems in obtaining sufficient linearity in the transfer function (the dynamic range and signal-to-noise limits), and accurately positioning the electron beam for reading make it impossible to read out the potential recording density with acceptable error rates. The reduced packing density necessary for acceptable error rates cause these approaches to suffer in comparison with magnetic recording.

For recording analog information Ampex has focused efforts on silver-halide film. The transfer functions of silver-halide film are known, and processing is familiar. Furthermore, silver-halide film can be made sensitive to either electron or laser beams. The recording/reproducing bandwidth can exceed 100 MHz, signal-to-noise can exceed 60 db in a 5-kHz slot (40 db in a 20-MHz slot), and packing density is an order of magnitude greater than the most dense magnetic recording.

Electron Beam Recording

Ampex has uniquely demonstrated electron beam reproduce capability. Recorded lines have been tracked, corrections made for longitudinal and transverse stretch or compression of information tracks, and also track translation due to imperfection in the tape transport. This requires tight servo control of the electron beam.

A differential vacuum is used with the film at low pressure and the electron gun at 10^{-5} torr. Operation is now sufficiently automatic that, in about thirty seconds, recording (reproducing) can be stopped, the film chamber exposed to atmospheric pressure, resealed, pumped down, and recording (reproducing) begun again. It is like a short warmup time. Warmup is somewhat longer when a new reel is used because of outgassing of the film.

Electron beams can also be used to transduce pictorial information into electronic signals. Ampex Research built and delivered an electron beam scanner which converted five-inch transparencies to electric signals at a 20-MHz rate and 100 line pairs per millimeter resolution. This scanner uses the Ampex electron beam/scintillator/photomultiplier technique, the same as used by electron beam recorder/reproducers. The reproducing or scanning electron beam tracks, or scans, a line across the film which has been specially prepared by coating it with a thin layer of plastic scintillator. The electrons in the beam are converted to photons (light) which pass through the opacity modulated film (darkness of the line on the photograph changes with the signal) to photomultipliers which give current outputs proportional to the light they

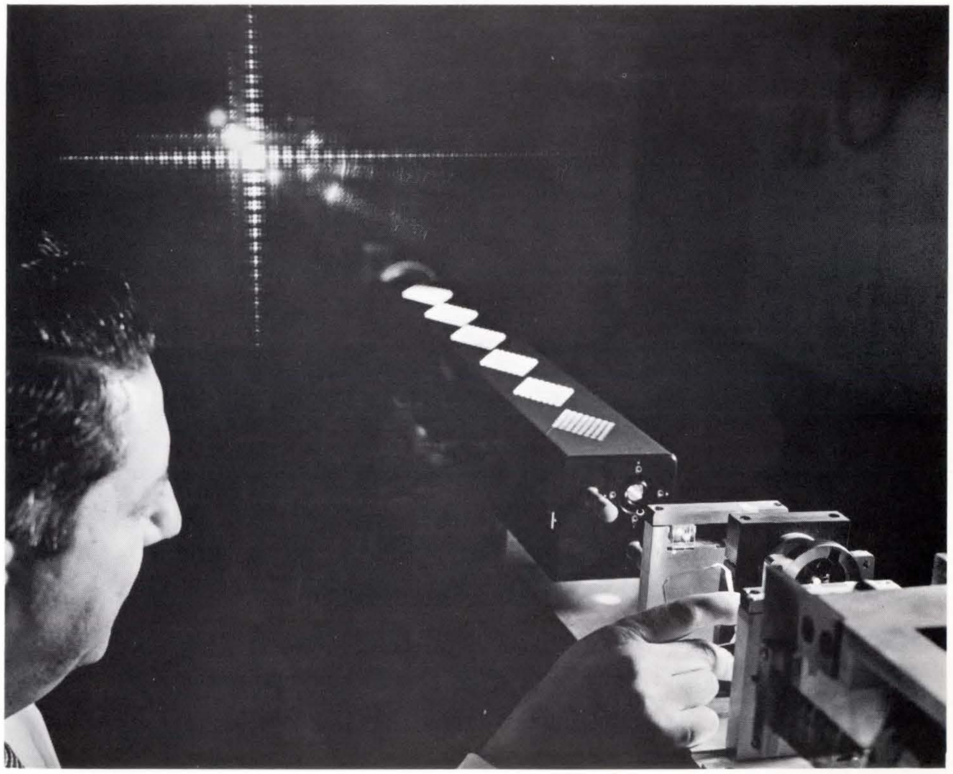
Media Operational Life	Hardware Availability	Media Processing Required	Erasability	Maximum Writing Rate (bits/sec)	Maximum Readout Rate (bits/sec)	Processing Time	Format
10^5 passes	1967	No	Yes	2×10^6	2×10^6	None	9 to 18 bit parallel
200 to 500 passes	1967	No	Yes	10^7	10^7	None	Serial
Indefinite	within five years	Yes	No	10^8	10^8	30 seconds	Serial
Indefinite	within five years	Yes	No	10^7	10^7	30 seconds	Serial
Indefinite	within ten years	No	Yes	10^7	10^8	None	Serial
Indefinite	1971	Yes	No	10^7	10^8	30 seconds	Serial or parallel

collect. These outputs are used both for the signal and for the servo control. The figure illustrates the technique used and shows a laboratory experimental electron beam gun, transport, photomultipliers, and light pipe.

Laser Beam Recording

Laser beams can be used to perform similar functions to electron beams. However, the wavelength of light is much greater than that of electrons and the signal spot size therefore must be larger. This limits the overall bandwidth. Most important, light beams are much harder to deflect than electron beams, which means the signal-to-noise ratio is not as good. There is considerable work underway in many laboratories exploring techniques for deflecting and modulating light beams. Aside from reflection from a rotating mirror, all are severely limited by the number of high resolution spot size diameters at acceptable intensity that the beam can be deflected. To date, the most practical scheme seems to be to deflect the beam lengthwise mechanically, and very small amounts at right angles nonmechanically.

Since lasers don't require vacuums, there is a significant convenience relative to electron beams. But there is a severe penalty



compared to electron beams due to problems in deflecting, modulating, and focusing. Presumably, lasers will continue to be produced in smaller, more rugged models, which are less expensive and more reliable. In time, therefore, we expect some recording/reproducing tasks to be done with laser beams.

Magneto-Optic Recording

Recent work at Ampex indicates that the Kerr magneto-optic effect is likely to be practical for reading digital information. Recording on a reflective plated tape for magneto-optic reproducing can be done by local heating with a laser or electron beam.

Magneto-optic reproducing was proposed over ten years ago to match the capability of magnetic recording heads to store information densely. The packing density limitation for magnetic tape has been the discriminating ability of the read head. If the recording/reproducing process can be developed sufficiently, including precision of readout particularly, the magneto-optic process may play an important role in digital information storage.

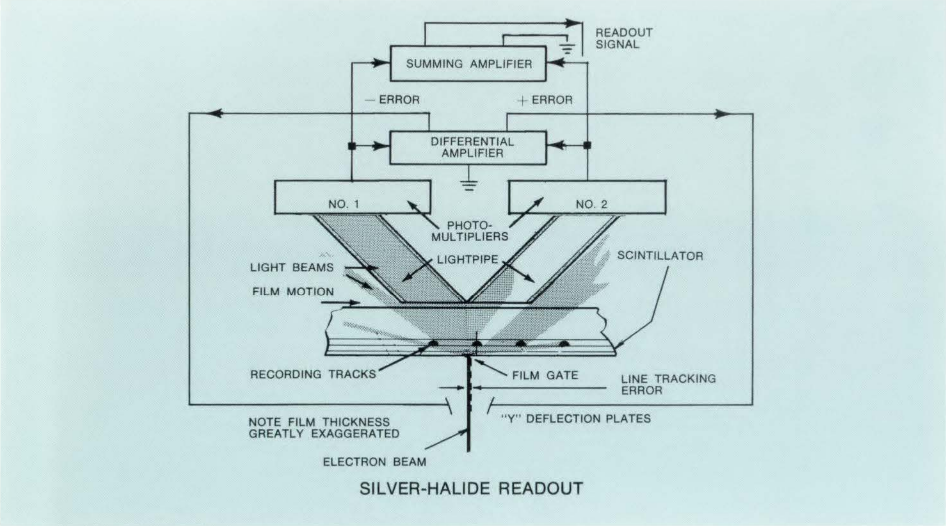
Combined Electron Beam/Laser Beam Recording

The sixth recording/reproducing technique indicated in the table, refers to a recently conceived memory which uses optical readout. Instead of recording bits as pulses, bits are recorded as frequencies.

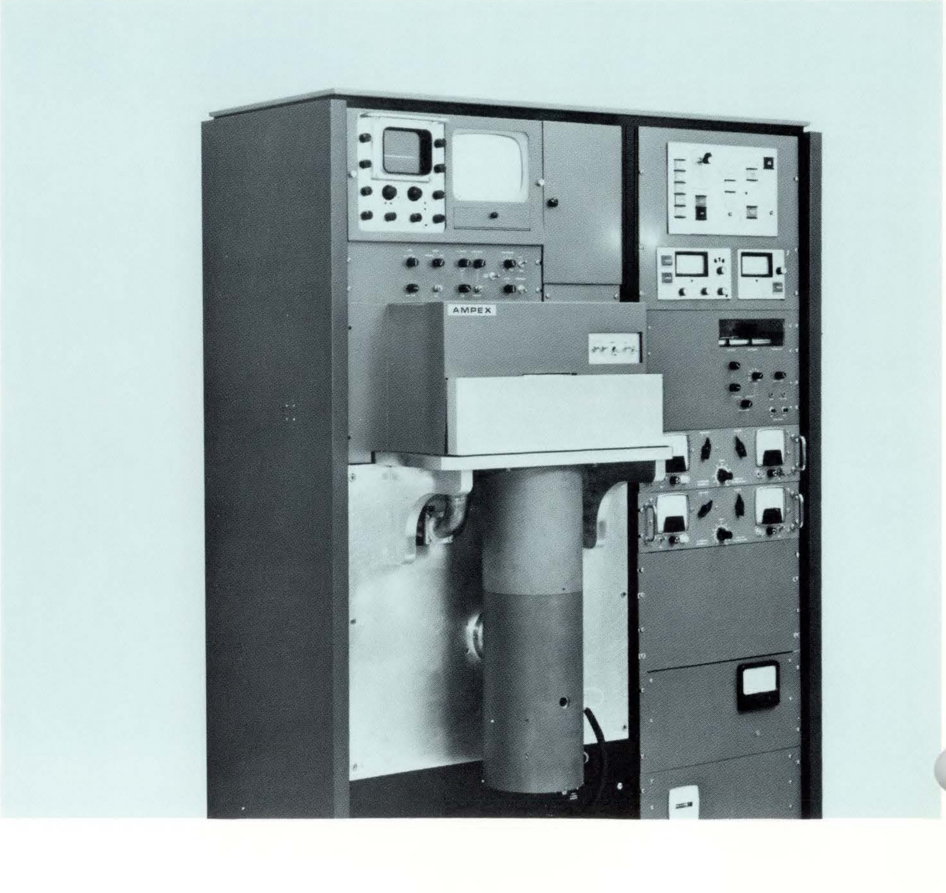
An electron beam, intensity modulated with the appropriate frequencies, strikes the electron sensitive silver-halide film moving transverse to the direction of tape motion. The existence or absence of a frequency determines the existence of a "1" or a "0." Each recorded line contains a word of as many bits as are planned.

After developing the film the information (which has been permanently recorded) is read out optically. When a laser beam is focused through a recorded line, the light and dark pattern causes the light beam to break up into a line of information spots (one for each frequency) on a display plane. The existence of a spot determines the existence of a "1."

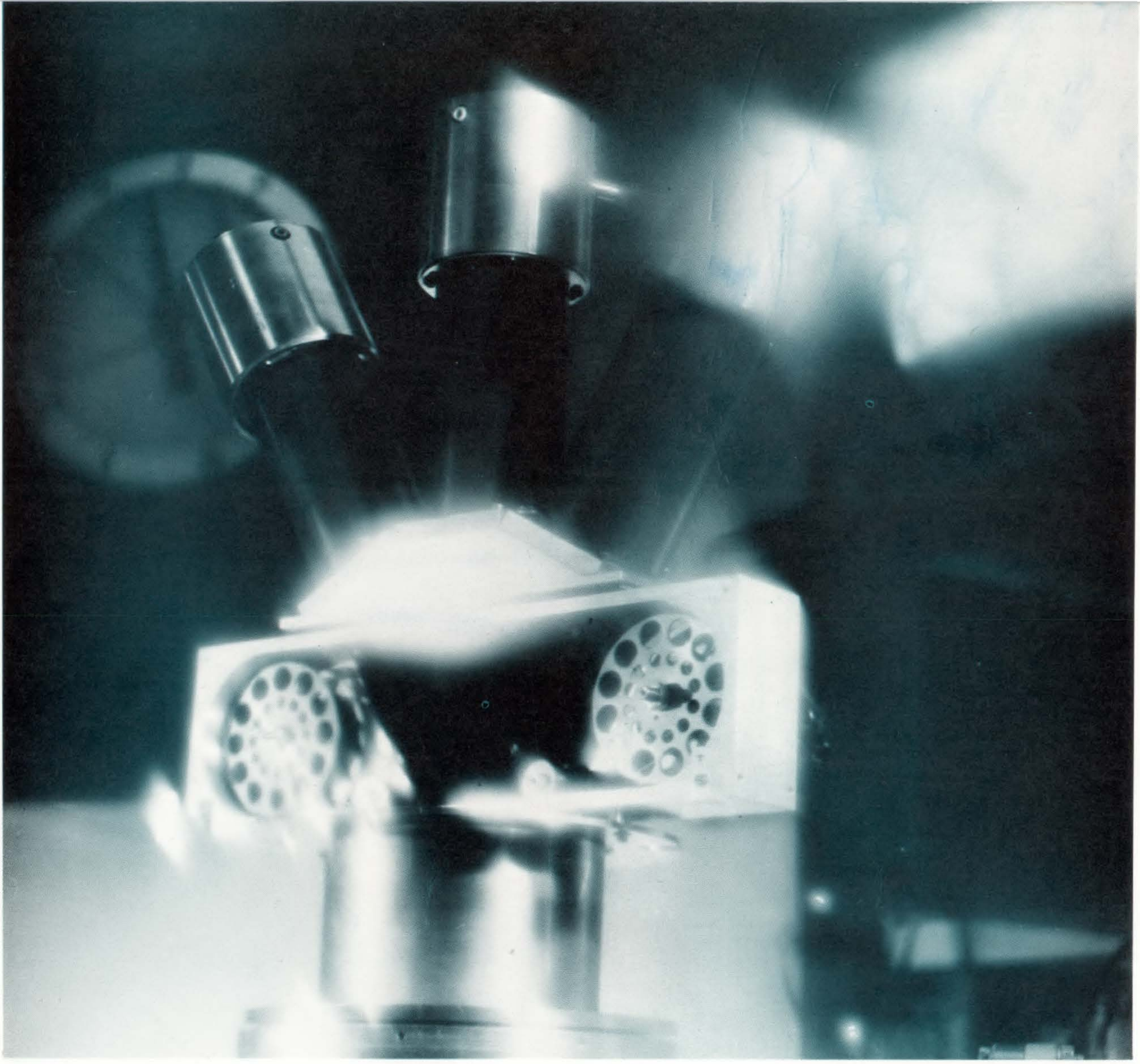
This system offers near freedom from dropouts due to scratches and surface imperfections. If many practical problems are overcome, it may be developable into a type of memory.



Silver-halide recording is read out by collecting the light produced when the electron beam strikes the scintillator material on the recorded tracks. The readout beam is centered on the recorded track by a beam-control system. The light produced when film is struck by the electron beam in the lower assembly of Ampex's facsimile scanner (photo below) is transmitted to the photomultiplier tube by the light pipe at the top of the light chamber.



The Ampex Research Department is continuing to seek excellence in information storage and retrieval. It will explore novel technologies, and develop some of these. For the forseeable future, it will continue to develop fundamental understanding of the magnetics, mechanics, and electronics of magnetic tape recording so that, when requested, it can provide consulting support for the product divisions. In the past three years for example, it has contributed to the technical evolution of the TM-9, TM-12, VR-3000, VR-6000/7000, AR-600, and Videofile/Video discs. ■



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