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The CASSETTE *Revolution*

ONE of the most fascinating speculations in the entertainment world—music and recording division—is whether the cassette will eventually replace the phonograph record. Even as recently as three months ago people were still asking "are cassettes here to stay?" But now the question has really shifted to "how long will it take before cassettes replace discs?"

Like many questions, this one is not as simple as it is usually formulated. Let's go back a little and see what the cassette revolution is all about.

In the first place, what are cassettes? A cassette is a small reel-to-reel tape system completely encased in a plastic container some 2½ inches by 4 inches in size (about the size of a pack of cigarettes). Although it uses one-seventh-inch tape, it's really a hybrid descendant of several earlier systems. It combines most of the advantages of quarter-inch open reel and cartridge reel-to-reel systems, and avoids the problems found in the very popular endless loop cartridge systems widely used today for automobile stereo.

Originally devised by the Philips organization in Holland, a good part of the success of the cassette system can be laid to the open invitation by Philips to cross license all comers. It's obvious that this policy helped to establish the compact cassette as a viable format.

Pros and Cons of Cassettes. Sound quality from a cassette is easily as good on a portable cassette recorder as the sound from a 45-rpm record on a portable record player and it's usually much better than the sound from the average transistor or home radio. Admittedly, cassette sound is not as good now as a modern stereo record played back on a high fidelity system, but it's getting better all the time.

On the durability front, cassettes are a clear cut winner, both in ruggedness during use and number of plays (thousands) before wearing out. Many people find them easier to play than records too, but it is harder to locate a selection on them than it is with the phonograph record. However, with the phonograph record this is a mixed blessing. As many of us know, it's quite easy to ruin a record by dropping the arm or skidding it across the record when selecting a band in the middle. Admittedly, it is more difficult to locate a selection precisely on a reel of tape (open reel or cassette) but the chances of damaging the tape if you don't locate it exactly are nil.

Cassettes — The Instant Tape. Probably the biggest contribution to the great success of cassettes is how easy they are to use. You just snap one into place and press a button. There is no threading of the tape, no fumbling with a tape speed selector (*all* cassettes play only at 1⅞ inches per second), no placing a needle into a groove. In short, the cassette is to tape what instant load film is to the camera.

Cassettes have other equally attractive side benefits. It is impossible to erase a pre-recorded cassette because a removable tab on the back of a cassette serves as a record interlock. Also, the track arrangement on a cassette makes it compatible for either mono or stereo without any modification. The two stereo tracks are adjacent to each other, so the mono recorder, like the many portable units, simply plays them both with a wider spaced head thereby giving us the first truly compatible mono/stereo system. But probably the most important advantage of the cassette system is that it can record as well as play back.

READOUT® Volume 9 • Number 1
A magazine of Ampex Corporation • David R. McClurg, Editor •

Multipurpose Unit with Ability to Record. What we have in the cassette recorder is essentially a multipurpose magnetic tape recorder that can play back, under a wide variety of different conditions, any one of a growing repertory of albums and still offer the ability to record either stereo or mono. In the automobile where the cartridge has an enviable ascendancy, the cassette could make a significant dent in the future. Again, the ability to record places cassettes in a unique position because you can catch up on correspondence or reports while riding in a car.

Four Types of Pre-recorded Tapes. Open reel tapes are the oldest type of pre-recorded tapes. They were first introduced in 1956 in a two-track format by Ampex and others, and in the popular four-track format in 1959. Open reel remains as the format best liked by the audiophile and the serious music listener because of its superior fidelity.

Four-track cartridge tapes came on the scene in the late 1950's and still command a large following on the West coast. We would expect that four-track cartridges will level off in favor of other systems in coming years.

Eight-track cartridges presently account for the largest number of tape albums sold. In fact, eight-track cartridge sales have yet to reach anything approaching a peak. Ninety percent of eight-track tapes are for auto use, the balance for home or portable playback.

Cassette tapes began to catch on in 1968. During 1969 cassettes will push ahead of four-track cartridges and open reel tapes and begin to give eight-track cartridges a real battle. Within about two years, we expect to see cassettes taking the lead.

Donald Hall, Ampex vice president and general manager of the Ampex Stereo Tape Division believes that the cassette will increase its share of the cartridge market for five important reasons: 1) Cassettes are only one-fourth the size of eight-track so you can store four times as much music in the same space. 2) Cartridges are more complex than cassettes because they use the endless loop principle. 3) Cassettes will become significantly cheaper to manufacture than eight-track. 4) With cassette systems you can also record, which seems to be impractical with cartridges. 5) Finally, the potential for improving the sound with cassettes is possibly much greater than with cartridges.

As of this writing, nearly all record companies are putting out an increasing part of their record libraries in cassette form. Recently ended was the holdout by the two major record companies, RCA and Columbia, with their announcement of plans for cassette introduction in the fall of 1969. In the equipment field there are now more than 70 different recorders built and marketed by companies around the world.

AMPEX STEREO TAPES

World's Largest Duplication Company. Filling the demand today for the increasingly popular cartridge and cassette is turning out to be a three-shift six-day a week proposition for Ampex Stereo Tapes. In fact, the demand for eight-track cartridges and cassettes still continues to outstrip the supply. Recently, Ampex Stereo Tapes (AST) nearly doubled the size of its facilities in Elk Grove Village, Illinois and announced plans for even greater expansion into the international market with new duplicating plants being built in Canada and Europe.

AST has a total library of 6,500 albums which it releases in the three principle formats used today: eight and four-track stereo cartridges, cassette and open reel. This library represents recordings from some 100 different labels totaling about 1,800 eight-track, 1,500 cassette, 650 four-track, and 2,700 open reel. AST releases some 100 new selections each month. To gain an even closer working relationship with the music industry, AST has now set up its own record company and is working closely with many producers of other labels. The popular music market is one where quick reaction time to changes in consumer demand as well as a fast reacting nationwide distribution system are extremely important.

AST's output totals some 4,000 miles of tape each day for a total of about 1.25 million miles of tape per year.

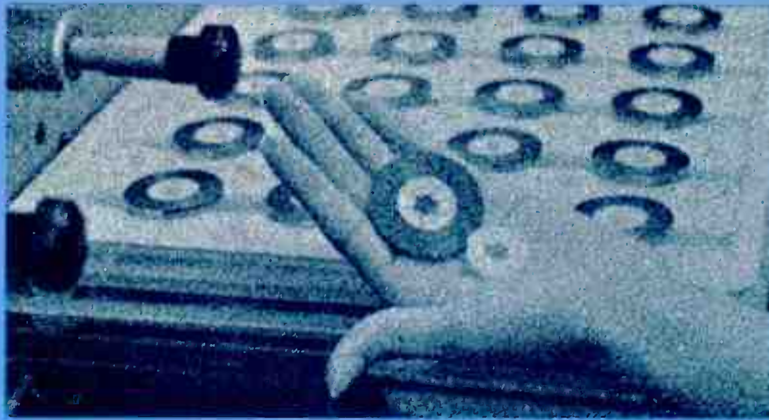
Tape Growth Outstrips Records in 1968. In 1968, the U.S. recorded music industry grew about 20%. Of this growth records accounted for about 25% and pre-recorded stereo tapes accounted for a whopping 75%. In terms of dollars discs grew by $50 million, and tape grew by $150 million. This means that 1968 was the first year that the sales growth of tape exceeded the sales growth of records in actual dollars rather than just percentages alone. In terms of totals, stereo tapes represented about 20% of the total recorded sales in 1968. As recently as 1966 stereo tapes were only about 5% of total sales. Our best guess now is that tape sales will make further gains in 1969 probably to the $400 million level. During the next three years we would expect tape to rise to command as much as a 35% to 40% share of the total recorded music business.

Four-Channel Stereo Cassette — Sound of the Future. Looking at the future for a moment there has been some discussion and experimentation in high fidelity circles in recent months with four-channel stereo. This is the technique of trying to surround the listener with sound as he would be in a concert hall. Whether this four-channel stereo will have any effect on the mass music market (cartridges and cassettes) is certainly an open question. However, within the high fidelity world of the serious audiophile, it's probable that tape would be the logical medium if systems expand to four channels.

The phonograph record as it stands is inherently a two-channel system because of mechanical limitations. It might be possible to expand to four channels using some type of multiplex scheme or alternate track arrangement with two pickup cartridges (as was originally proposed for two-channel stereo records in the middle 1950's). However, four tracks on magnetic tape is so well proven that going to a four-channel stereo system would be relatively easy. Admittedly, heads with four inline stacks rather than the two required now for two-channel stereo are going to be more expensive. This system would also cut the total playing time in half (because you'd only get one direction on the tape or cassette) which could be a problem. However, neither of these is anything like the technical problem facing the phonograph record in a possible conversion to four-channel stereo. ■

Cassette Duplication

Cassette duplicator line being loaded with blank tape for the next run.



In this tailoring step, large tape pancakes are cut into album lengths and wound onto the tiny cassette reels.

Skilled hands assemble the reels into plastic cassette housings.

DUPLICATING STEREO TAPES AT AMPEX

a unique marriage of mass production with quality control

Cartridge Duplication

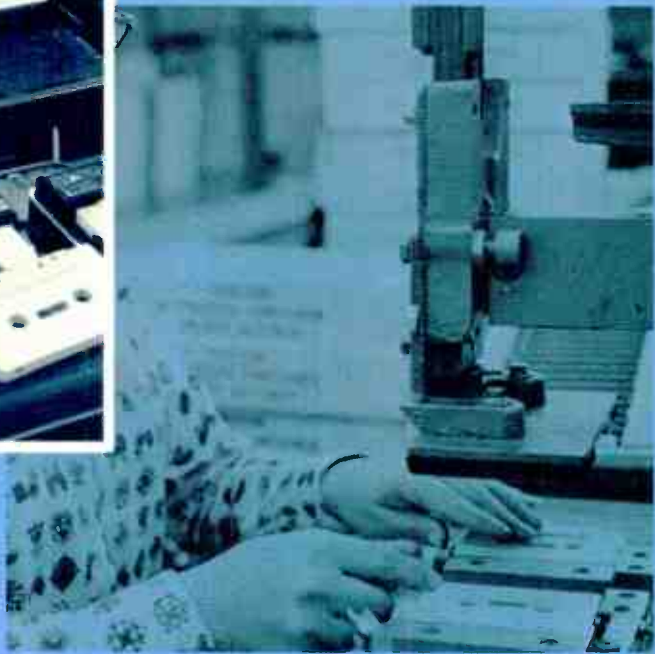
Pancake of blank tape is mounted on cartridge slave.

Ampex bin loop reproducer (BLM-200) drives ten cartridge slaves.

Tape is fed directly onto album length reels in this side-winding assembly.

Quality control operator checks cassettes
for mechanical functioning. At the
next station, a sound check is made.

The two halves of the cassettes
are sealed together by this
ultrasonic bonding machine.



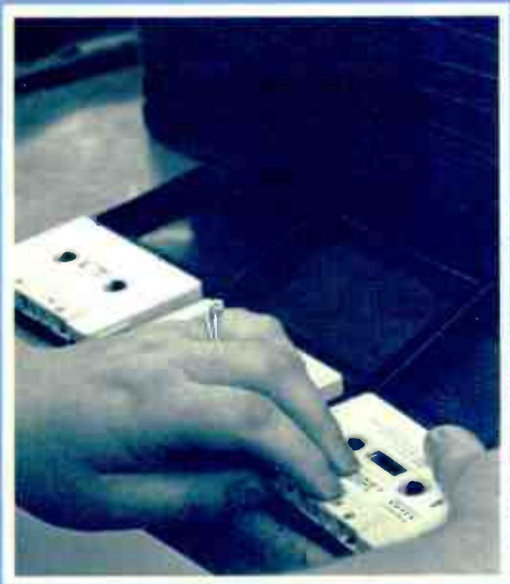
Labels identifying each selection are
pressed onto both sides of cassette.

Album length reels are removed from the
slaves for insertion into cartridges.

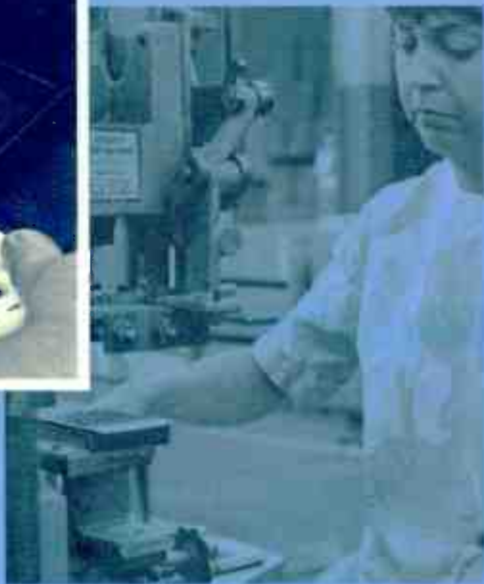
Moving belt, one of many used in the AST
assembly lines, carries assembled
cartridges to the next station for sealing.

The ends of the tape are brought together
and spliced to form a continuous loop.

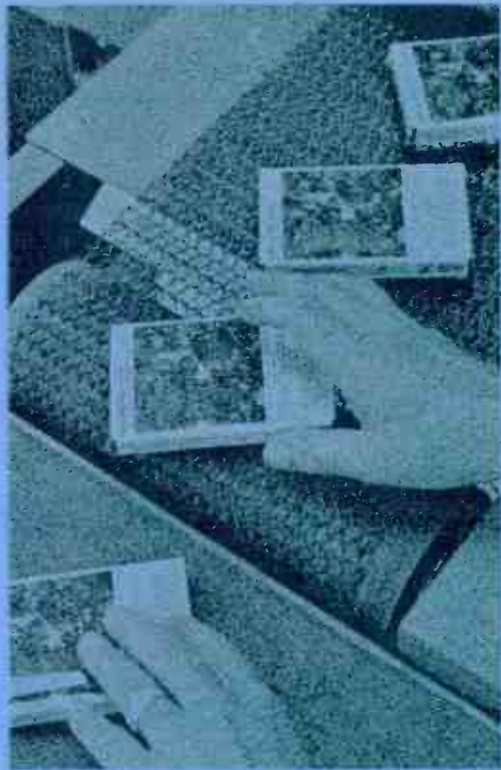
Cassette Duplication



Inserting the cassette
into its outer plastic box.



Colorful outer label is applied to the box.

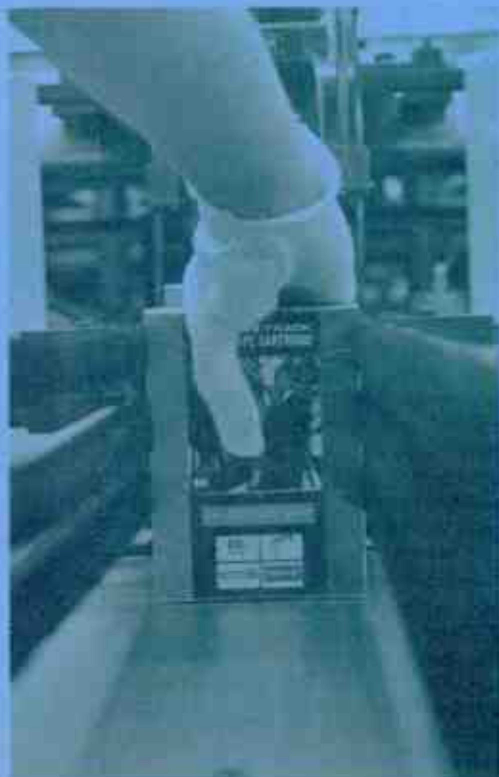


After wrapping in see-through plastic,
cassettes are boxed for shipment

Cartridge Duplication

Following a stringent mechanical
check, another quality control
station makes a listening test.

Next, the cartridges are labeled,
then inserted into an outer sleeve.



Packer removes plastic wrapped cartridges
from conveyor for boxing and shipment.

Multichannel Aids Creativity

...at MARQUEE STUDIOS, London

At Marquee Studios, London, a group of musicians record the backing for a new disc by John and Anne Ryder, on a multichannel MM-1000 Master Recorder.

MARQUEE RECORDING STUDIOS is located at the top of an L-shaped mews off Dean Street, Soho-centre of London's thriving show business. It is one of the biggest and busiest recording studios in the capital.

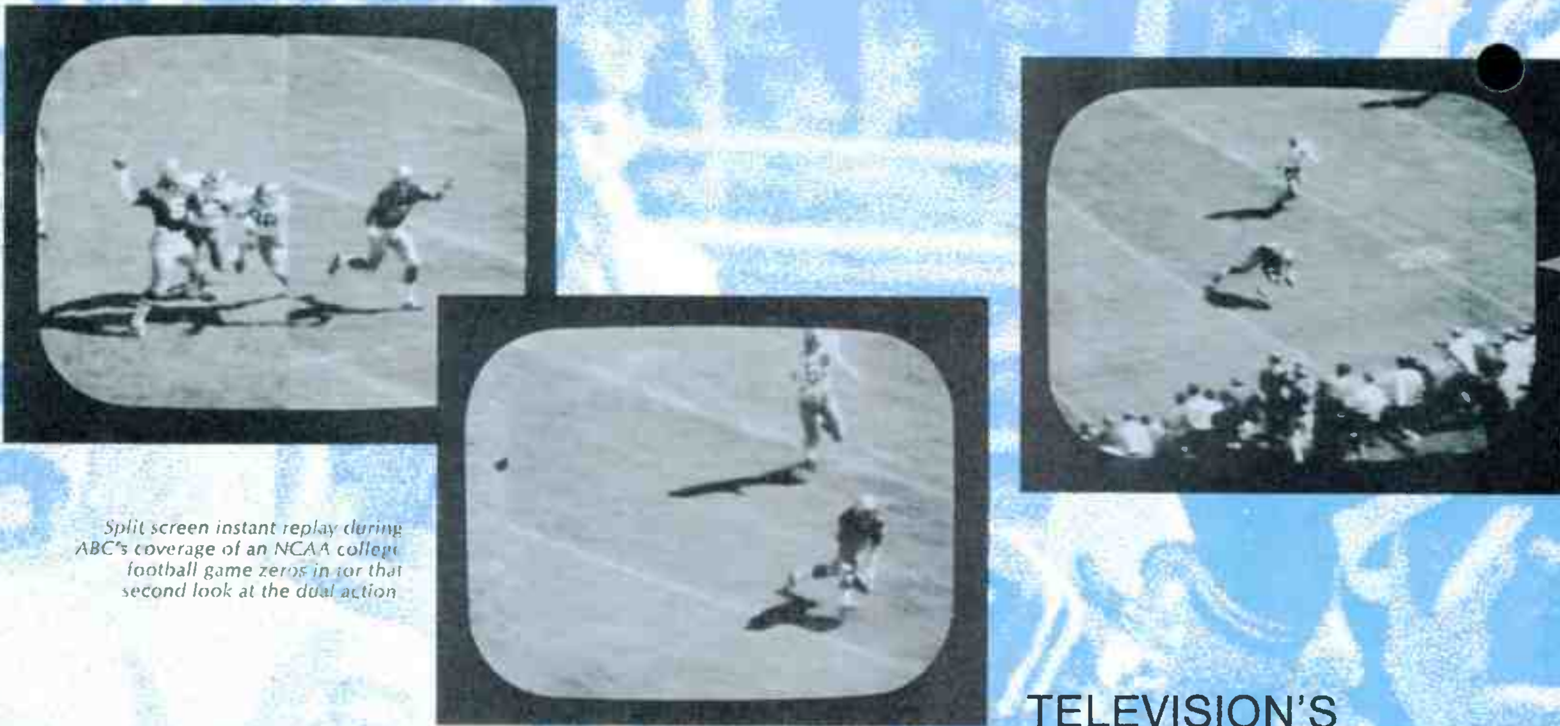
Before 1964 when the present premises were taken over by the Marquee Group, the site was occupied by a raincoat factory. Marquee Studios comprise offices, a spacious studio and a well-equipped control room.

Marquee's high reputation attracts such star names as Blossom Dearie, Manfred Mann, Paul McCartney, The Moody Blues and the New Seekers.

Much of the original taping is now being done on an Ampex MM-1000 multi-track recorder. Its versatile multi-channel capability allows more flexibility than was previously possible: "For example, the quality on the Sel Sync is so good," states Gerry Collins, Marquee Studio Director, "one can really mix down tracks previously recorded onto a remaining clear track, allowing the original tracks to be recorded over."

In addition to its new MM-1000, Marquee have several other Ampex recorders including a Model 351 which has already given five years good service.

Producer Mark Edwards, left, and Marquee's Studio Director, Gerry Collins, collaborate to create a new hit. MM-1000 master recorder, latest in the range of Ampex recorders at the studios, is matched to the multi-input board giving Collins complete control during recording and editing.



Split screen instant replay during ABC's coverage of an NCAA college football game zeros in for that second look at the dual action

TELEVISION'S

INSTANT.

How every armchair fan becomes a Monday Morning Quarterback on Saturday afternoon

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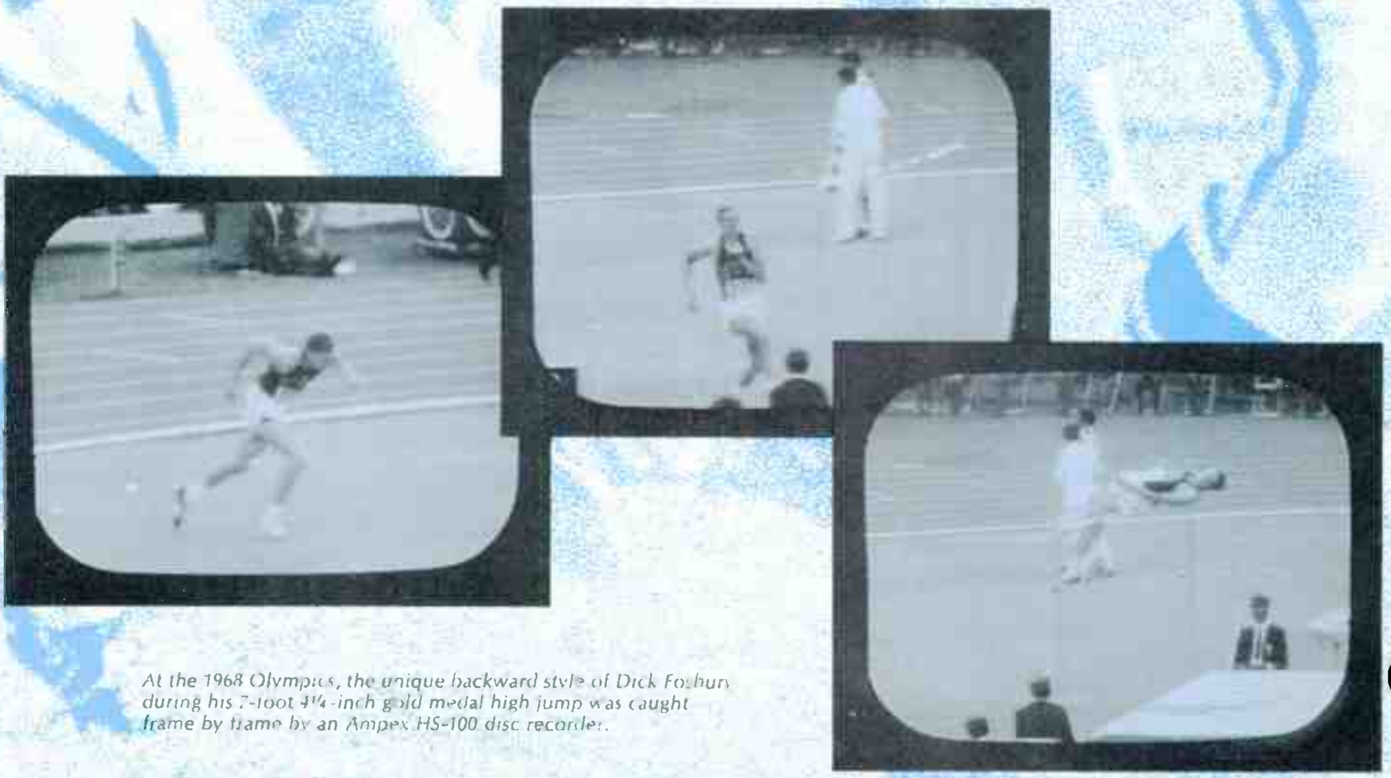
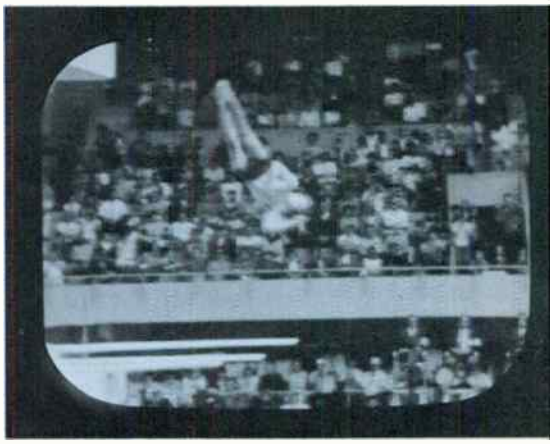
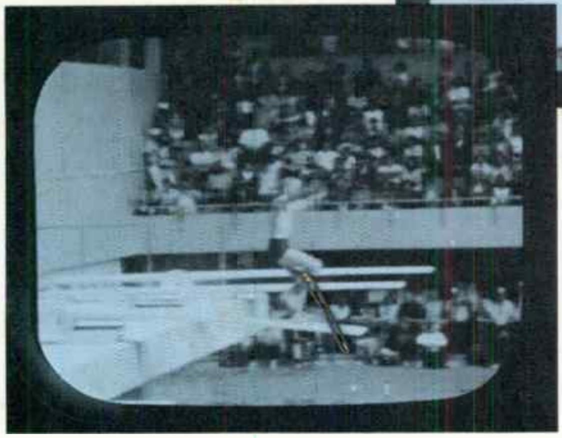


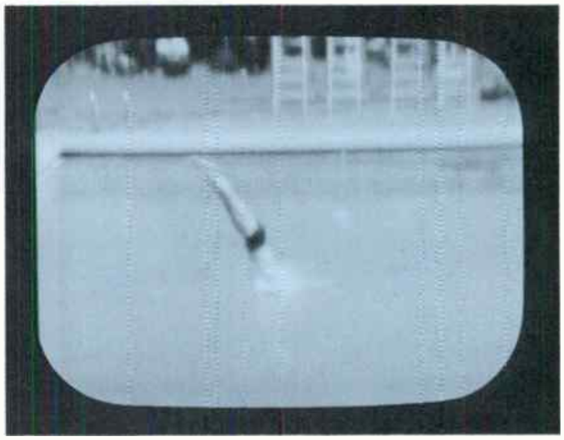
At the 1968 Olympics, the unique backward style of Dick Fosbury during his 7-foot 4¼-inch gold medal high jump was caught frame by frame by an Ampex HS-100 disc recorder.



Undoubtedly some of the most dramatic examples of slow and stop motion during ABC's exclusive coverage of the 1968 Olympics were the diving and swimming events.



REPLAY



IN THESE PAGES, we have often characterized the videotape recorder as a kind of miraculous time machine. Every evening, as if by magic, it manages to suspend the restrictions imposed by those irregular lines that divide the North American Continent into time zones. It does this by recording programs for delay with no loss in liveness or picture fidelity and rebroadcasting them at the proper time in each geographic area. When this was first done some 12 years ago, we were proud to announce that the days of kinescope squint were over. The first practical videotape recorder (the Ampex VR-1000) had been introduced.

Recently, another technological breakthrough was brought out by Ampex. This is an electronic cousin of the videotape recorder, the magnetic disc recorder, which has become a kind of time machine in itself. It allows us all to second guess the professionals and become Monday morning quarterbacks while still watching the game on Saturday afternoon.

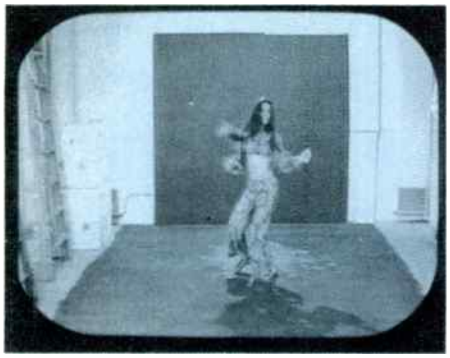
In the related areas of teleproduction the disc recorder is playing an important role too. It allows a new level of creativity and special effects not hitherto available with such ease and flexibility when producing programs and commercials on video tape.

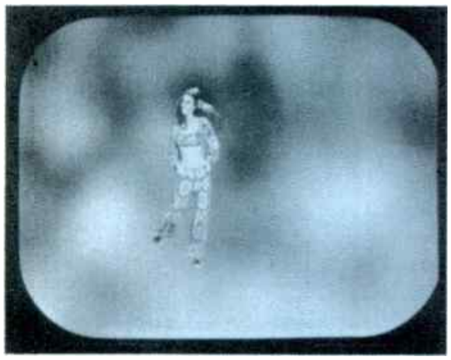
Disc Recorders—A new kind of time machine. The phrase "let's see that again on instant replay" is now familiar to all of us. Originally used primarily for football and baseball, instant replay in normal, fast, or slow speed with color quality equal to that of video tape is now being used in nearly all sports. These include most of winter and summer events at the 1968 Olympics in Grenoble and Mexico City, plus golf, ping pong, tennis, soccer, rugby, hockey, bowling, boxing, motor racing, and a host of others.

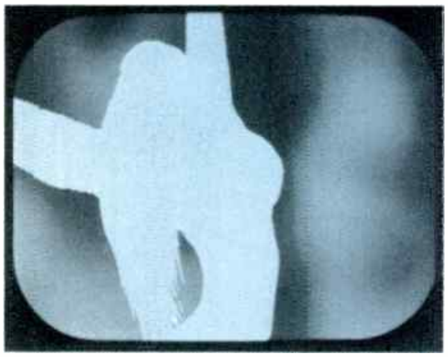
Over a period of just a few years, instant replay has developed from an essentially hit or miss gimmick of the early 1960's into a precise electronic function. Today, Ampex magnetic disc recorders specifically designed for sports have brought color fidelity and high resolution in instant replay to a level not possible with earlier equipment. A disc recorder like the Ampex HS-100 records a full 30 seconds of material in color, which has proved more than enough for just about any type of sports action. Replay is made in forward or reverse at normal speed, double speed, slow motion at any speed, or stop motion. When in the stop mode, the picture can be advanced or reversed frame by frame to really pin point action.

Even with this advanced technology in the hands of the expert sportscasters who call the coverage, a little bit of luck is still needed to capture the proper action for instant replay.

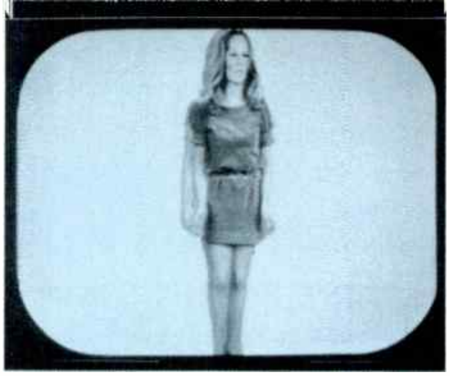
Sports Team — 35 Men Strong for Football. Covering any sport is a complicated business today. To televise football, for example, the usual crew taken by ABC to a college game or CBS to a National Football League game totals about 35 people. Twenty of these will be technical men, the other fifteen production. A minimum of four (and more commonly five to seven) color cameras are used, depending on the importance of the game. As you would expect, pre-game preparations are in keeping with this level of activity. Well before the game, several planning conferences are held, frequently on-site at the college campus or practice field, to decide strategy for covering the game. Most sportscasters today are former players themselves. They rely on their inside knowledge not only to make the sportscasting interesting but to be sure that the various cameras are following the right play and to anticipate plays that might come up. Despite this pre-planning and expertise, it's often necessary for the crew to change its coverage more than once during the game depending on the score and shifts in strategy as the play progresses.







Color demonstration tape made by Technicolor in Hollywood shows the many teleproduction effects possible with the HS-200. Here, successive images are sequentially preprogrammed by the computerized HS-200 in a combination of chroma keying with positive and negative images.



One dancer repeated four times is one of many special effects made easy by the Ampex HS-200, teleproduction version of the HS-100 slow and stop motion disc recorder.

Pre-game Set Up. Several days prior to the game, the crew places the cameras around the stadium, makes the long cable runs to the van that serves as a mobile control room, and completely checks out the entire system. Two or three cameras are positioned high in the stands flanking the 50 yard line. One is placed at the sidelines on a mobile dolly. Another camera covers the end zone from high on the rim of the stadium or sometimes even on a crane. (At the Mexican Olympics, ABC's camera in the sky was 225 feet up atop a tempo-ray construction crane, manned by an apparently nerveless cameraman.) A smaller camera is frequently used in the announce booth for interviews during halftime and diagrams of the action. Two or more cameras may be placed at other strategic locations depending on the importance of the game or the physical structure of the stadium.

To get the close-up bone crushing action at field level, ABC also regularly uses a hand-held Ampex BC-100 camera on the sidelines. This is connected by microwave (sometimes by a small cable) to the mobile control room located in a van outside the stadium. It was also this hand-held camera that brought action directly from the ski slopes and the floor of the stadium at the Olympic Games.

Instant Replay. For the instant replay action, the director assigns one of the cameras to zero in on where he anticipates the action will take place. This camera may key on a flanker, a running back, or a pass receiver going down field. Frequently, the director must second guess the quarterback and anticipate the type of play to be called. In many important games, two instant replay machines are used: two HS-100 slow motion disc recorders or one HS-100 and a videotape recorder like the VR-2000 or VR-1200 (which plays back at normal speed as in a regular replay). In this type of situation, disc recorders are preferred because in addition to the different playback modes, they can be cued up more quickly than a reel to reel machine.

New Viewing Habits. We have all become so used to instant replay in sports that our viewing habits are actually changing. It's not unusual to see a group of people crowding around a television receiver with much greater interest in the instant replay than in the original play itself. This is because the instant replay camera will frequently have zeroed in on the action while the primary camera may have only caught it from a distance. Even at the stadium, amidst the noise and color of a live game, many a fan will remark wistfully "I'd sure like to see that again on instant replay!" Occasionally, the television crew covering the game will miss a key play, but success is frequent enough to make instant replay an exciting part of sports coverage throughout the world.

Special Effects in Teleproduction. The added dimension given by instant replay to televised sports is a logical extension of the ability of all magnetic recording to replay programming immediately without processing. In the area of production, disc recorders have gone even one step further than the variable speed forward and reverse playback possible with the HS-100. The teleproduction version of this widely used machine, the HS-200, is programmed by a small built-in computer. It allows many special effetcs to be set up automatically such as a freeze frame, instant frame access, variable frame animation, automatic dissolves of variable length, and sequential pre-programming.

The advanced technology of disc and tape teleproduction is bringing a new breed of television commercials with creativity derived from the electronic medium itself. Immediacy and liveness of magnetic recording combine with its speed and special effetcs to give an added dimension to production of television commercials and programs. ■

A 100-MHz Electron Beam Recorder/Reproducer With Subnanosecond Timebase Stability

J. Diermann, *Ampex Corporation*

INTRODUCTION

This paper is concerned with recent advances in electron beam recording. Most of the work presented was performed in 1968 and 1969 under contract F 30602-68-C-0248, ARPA order No. 796 sponsored by the Advanced Research Projects Agency and Rome Air Development Center. The objective of the program centers on the design and construction of an experimental electron beam recorder/reproducer for analog signals with significant spectral content up to 100 MHz. Playback of the recorded signals occurs at the full recording bandwidth without change of timebase. Fidelity of the signal on playback with respect to amplitude, noise, nonlinear distortion and spurious sidebands is held at practical levels.

Figure 1 gives an overall view of the electron beam recorder/reproducer system. It is a laboratory model in the sense that its operational complexity still requires highly skilled operating personnel. In many ways, however, the system bears the marks of an engineering prototype. Some of its present features, such as the automatic vacuum system operated by a small computer, are the results of previous work and field experience with electron beam systems. Future machine generations will bring about simplified operating procedures and reduced maintenance. They will be subject to refinements in many areas but not to redesign of basic components.

The electron beam recording technique used in the program is based on the interaction of an electron beam and special silver-halide film for recording, and a plastic scintillator coating for readout. This method has been used by Ampex for a number of years in an unchanged form.

The main section of the paper will present a discussion of the signal flow from the record-input to the playback-output connector. The recorder/reproducer is shown as a system of cascaded black boxes with differing transmission characteristics. Individual boxes have varying effects on the record-to-playback signal transfer. Their influence and their limitations with respect to frequency response, distortion, signal-to-noise ratio and spurious sideband content are presented.

PRINCIPLES OF RECORDING AND PLAYBACK

A high-resolution, **direct positive,** electron sensitive film, developed by Eastman Kodak Company, provides the recording medium. The electron beam is intensity-modulated by the signal and scans back and forth across the film causing electron exposure (Fig. 2). Adjacent lines are connected by an extremely fast transition (1 nanosec) of the beam, so that the spurious energy due to the line discontinuity will be negligible.

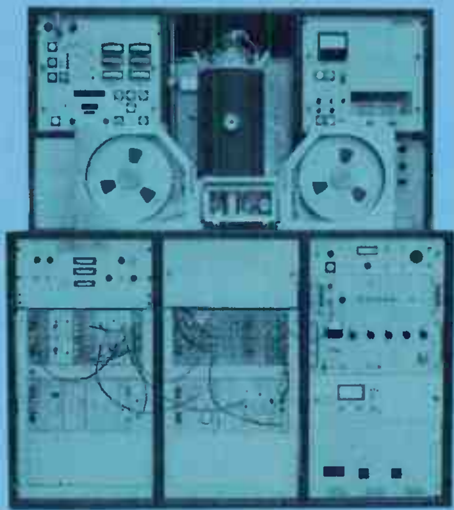


FIGURE 1
Overall view of 100-MHz Electron Beam Recorder/Reproducer

Following chemical development of the film, the recording consists of lines of varying light transmittance on a high-density background. Over the operating range, the film maintains a linear relationship between electron exposure and light transmittance.

On playback, a plastic scintillator coating, which is part of the film package, acts as a light source with a very fast response (Fig. 3). A constant-current beam travels on the recorded lines causing scintillator light emission. The light transmitted through the film carries the signal modulation and is reconverted into an electrical signal by a photomultiplier.

PERFORMANCE DATA

The following record-to-playback performance has been achieved to date:

Frequency Response: Low frequency recording limit: 500 kHz; −8 dB at 100 MHz with respect to response at 3 MHz

Wideband SNR: (peak-peak/rms): 26 dB at 3 MHz; 20 dB at 100 MHz

Nonlinear Distortion: −27 dB

Spurious AM-Sidebands: −35 dB at 3 MHz −18 dB at 100 MHz

Timebase Error: Less than 1 nanosec rms

Recording Time: 10 minutes

RECORD-TO-PLAYBACK SIGNAL FLOW

Frequency Response

Figure 4 shows the system block diagram and the frequency response of the transmission blocks plotted in columns below their respective symbols. Both record and playback amplifiers are capable of operation well above 200 MHz and have no noticeable effect on the record-to-playback rolloff. Gain for the beam modulation is provided by a distributed amplifier supplying a high output level to drive the electron gun. The gain variations remain within ±1.5 dB throughout the frequency range of interest. The playback amplifier is a low-level RC-coupled unit with excellent gain flatness. A similarly flat response is exhibited by the photomultiplier. Its response is within 1 dB from DC to 150 MHz and reaches −3 dB at 200 MHz.

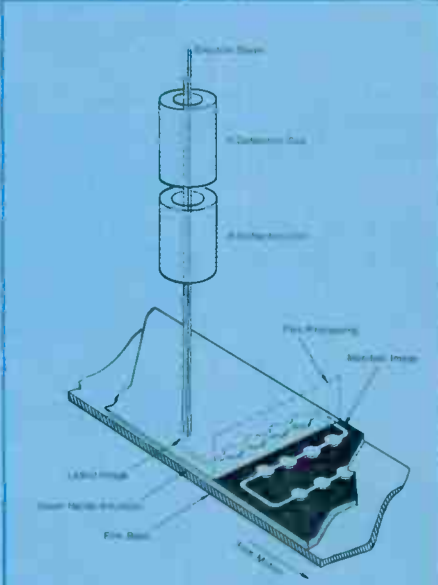


FIGURE 2 Basic Recording Process

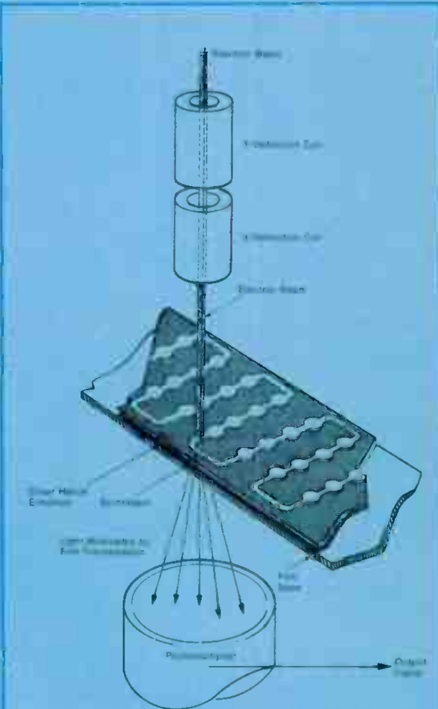


FIGURE 3 Basic Reproduce Process

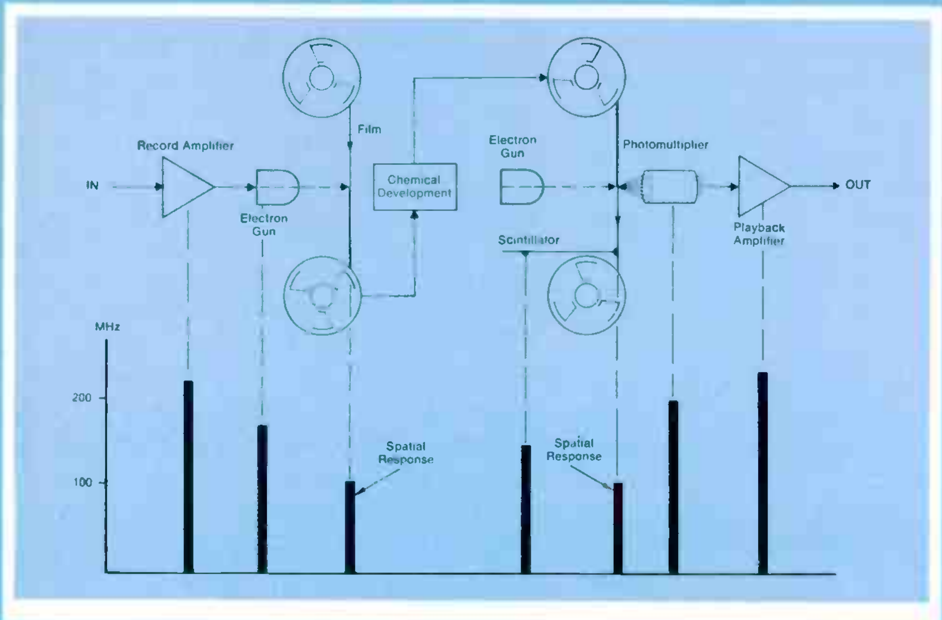


FIGURE 4 Frequency Response of Individual System Components

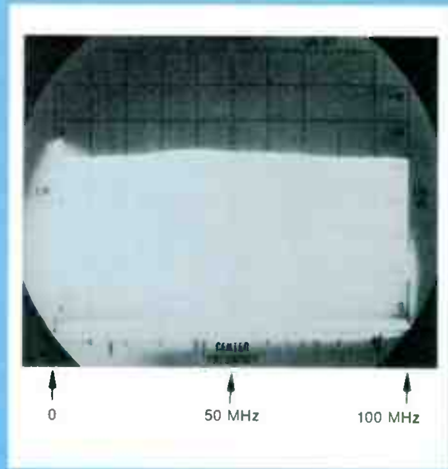


FIGURE 5. Electronic Throughput Frequency Response Exclusive of Spatial Rolloff (Logarithmic Scale)

A slightly lower frequency response in the chain is displayed by the plastic scintillator that generates a flying light spot for the readout process. Its decay time of 1.9 nanosec corresponds to a -3 dB point of approximately 150 to 175 MHz in the frequency domain.

The rolloff of the complete record/reproduce chain is dominated by the spatial responses of the record and playback processes, i.e. the ratio of spatial wavelength to electron spot diameter. This ratio is analogous to the ratio of spatial wavelength to gapwidth in magnetic recording.

Figure 5 shows the measured electronic throughput response including all transmission elements except the spatial effects. To arrive at this response, a constant-level signal generator is used as a signal source. The frequency is varied manually at a slow rate. Instead of a recorded film, a clear film carrying only the scintillator coating is used so that beam modulation is transferred directly into light modulation. This light modulation is recovered through the playback channel and displayed on a spectrum analyzer with a storage screen. There is no noticeable rolloff at high frequencies.

The display in Fig. 6 presents playback of the same constant level signal, this time **including** the spatial elements. The result is a 6 to 8 dB drop of the response near 100 MHz.

Nonlinear Distortion

Nonlinear distortion products include harmonic generation, intermodulation and crossmodulation effects. With respect to distortion, transmission blocks operating at high levels are usually more offensive than those at low levels. Record amplifier and electron gun, both operating at high levels, dominate the total distortion of the system. The amplifier generates nonlinear products mainly in its output stage. In the electron gun, the signal passes through the beam current/grid voltage characteristic of a triode with a large voltage swing. The result is a nonlinear distortion level of approximately -27 to -30 dB.

Figure 7 shows playback of a 30-MHz signal recorded in addition to the usual pilot frequencies needed for timebase stabilization. The analyzer reveals several nonlinear products, all of which are at least 29 dB below the level of the 30-MHz payload signal.

Signal-to-Noise Ratio

We will assume that the signal to be recorded carries very little noise, i.e. the signal-to-noise ratio at the recorder input is high; say 80 dB. Since the signal arrives at the recorder at a level of approximately 0 dBm, the noise contribution of the modulation amplifier will be negligible, even if its noise figure is poor. The electron gun, however, contributes significant, but not dominating noise to the signal. The beam's shot noise contribution is proportional to the square root of the average beam current. This beam current in turn is the result of a compromise between the film sensititvity and electron gun characteristics. Recording beam current is between 0.5 and 1.0 μA, resulting in a signal-to-shot noise ratio of 52 to 55 dB over a bandwidth of 100 MHz. Due to the large ratio of electron spot to grain size the electron sensitive emulsion does not contribute measurable grain noise. Thus, the SNR of the recording actually placed on the film is mainly a function of the recording beam current.

In the playback process, the signal encounters additional noise. The playback beam shot noise of a 1.0 μA beam is added to the signal causing a 3-dB deterioration of the SNR. Although the conversion by the scintillator of 18 KeV electrons into blue photons is associated with an effective quantum gain of 3 shot noise, reduced by the quantum gain, is added to the signal. Due to the statistical nature of the quantum conversion itself, excess noise is generated in addition to the shot noise that is governed by the number of information-carrying quanta. The SNR deterioration due to playback beam noise, scintillator noise and due to the conversion process is approximately 6 dB.

With an average film transmittance of 10%, the average number of photons is reduced by a factor of 10 causing a further SNR decrease of 10 dB, before the signal reaches the photocathode. Finally, the signal is subjected to the quantum loss of the photocathode (0.1 to 0.2) resulting in a noise increase of 7 to 10 dB. The ultimate signal-to-noise ratio of 20 to 25 dB (depending on frequency), is not significantly affected by the subsequent current multiplication process or the playback amplifier noise.

It is obvious, that all playback stages associated with a quantum loss require particular attention in the design of the system. Future improvements of the signal-to-noise ratio can be expected from small reductions of each of the various quantum losses, rather than from a drastic change of any single one.

Spurious Signals

Spurious signals are undesirable spectral additions to the reproduced payload signal. They may have an AM or FM character, and their frequency difference relative to the payload signal is usually a multiple of the scanning rate. Spurious AM is quite common in all types of recorders, including the magnetic rotary head and helical types. In the EBR system, spurious AM is almost nonexistent at low frequencies but becomes quite noticeable at the high end of the band. We measure an AM level of −35 dB or better at the low end and −20 dB at the high end of the frequency range. The causes of these types of spurious signals are mainly spot shape changes along the recording line and light transmission variations of the medium and of other optical playback links.

Spurious FM signals are generated by timebase errors, i.e. by deviations of the playback scan from the scan of the original recording beam. Extremely small deviations will lead to substantial FM sidebands at the higher frequencies. A difference in scan length of only 3 spot diameters (20 μm) out of 30 mm (30,000 μm) would add FM to a 100-MHz carrier with a deviation of approximately 100 kHz and a modulation index of 3. At this FM level, the sidebands would no longer be spurious but would exceed the payload signal level and thus render the system unusable for any transmission scheme that carries information in its phase. Figure 8 shows playback of a 99.75-MHz signal with the timebase system both operating and not operating.

The theory of timebase errors and the electronic means for their reduction are most complex and exceed the scope of this paper. A more detailed treatment is presented in a paper by R. Ravizza and R. Markevitch, "The Significance of Tracking and Timebase Correction in Electron Beam Playback."

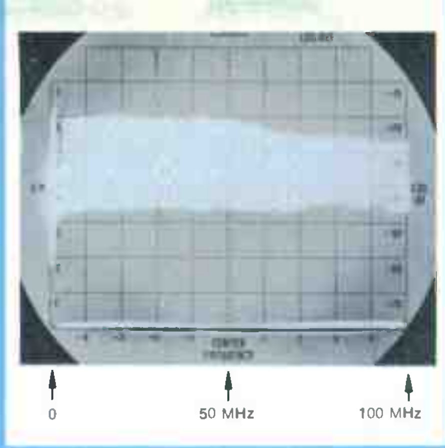


FIGURE 6 Total Record-to-Playback Frequency Response Inclusive of Spatial Rolloff (Logarithmic Scale)

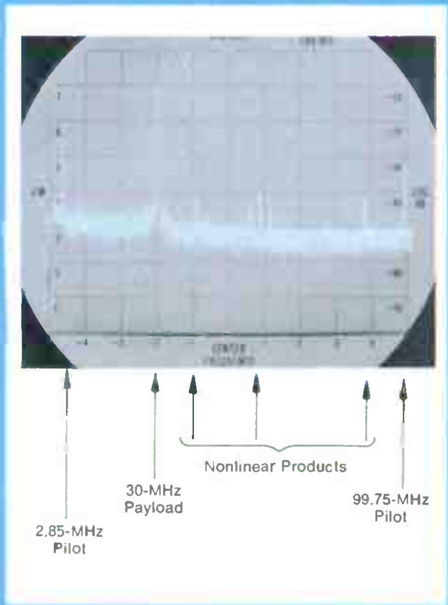
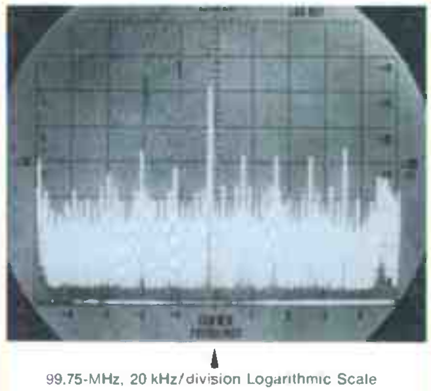
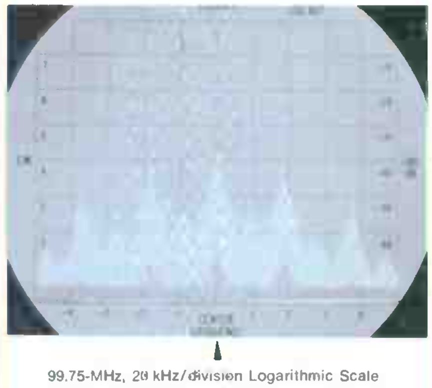


FIGURE 7 Playback of 30 MHz Signal and Pilot Frequencies (Logarithmic Scale) Spectrum Analyzer Scan, 10 MHz division, IF Bandwidth, 300 kHz Video Bandwidth 10 kHz



Spectrum of 99.75 MHz Signal on Playback with Timebase Stabilizing Loops Operating. Spurious Sidebands 48 dB below 99.75 MHz Signal



Spectrum of 99.75 MHz Signal on Playback with Timebase Stabilizing Loops Not Operating. Spurious Sidebands about equal to the 99.75 MHz Signal

FIGURE 8 Playback of 99.75 MHz Signal. Effect of Timebase Stabilizing Loop on Spectral Distribution

Technical Article: BASIC ELECTRONICS: a non-technical guide

BASIC CONCEPTS AND ELEMENTS

Many of us have a need to know about electronics for use in our work, but may not have had much formal training in the subject (and what we had may have been several years ago). If you fall into this category, treat this series of articles as an intelligent layman's familiarization trip through a complex subject that increasingly commands attention in our work and in the world around us. All we assume is that you want to learn about electronics and are willing to build understanding from basic concepts and building blocks.

The series will extend from the electron to the electronic computer, and along the way touch on electricity, radio, hi-fi, television, and magnetic recording. Whenever possible, we will try to explain things so they can be visualized, but we will try to avoid pointless analogies and oversimplified drawings. The technical level will be to the "block diagram" depth. This means that technical explanations will go just so far to insure basic understanding of concepts and building blocks. Beyond that point, the reader will have to accept the theories and detailed operations on faith. Indeed, faith is an important ingredient in trying to grasp any complex subject.

By this we mean that man will probably never know why (in the Aristotelian sense) that certain phenomena occur. For example, the ultimate facts that tie electricity to magnetism (and both of them to gravity) are probably no better understood now than they were by the Greek philosophers of the third to sixth century B.C. Modern physics (beginning with the controlled experiments of Galileo) structures itself to explain how things relate, not why.

The question of how most phenomena in electronics really work can be quite well explained within the context of 20th century quantum electrodynamics. But these theories are well beyond the scope of this article. For our purposes we'll bring them into the discussion only to the level necessary for understanding and ask you to take the rest in faith.

WHAT IS ELECTRONICS

Most books about electronics start out by saying that electronics is the study of moving electrons. More specifically, it's the study of how moving electrons operate in thermionic or solid state devices. But we'd like to go one step beyond that and ask the question why are we talking about electrons at all. Why are we concerned with these tiny indivisible particles or units of energy that are too small to see and almost impossible to imagine?

The best answer that we know is that when you want to hear, see, transmit or compute something it can be done much more easily if you first convert it into electrons or electricity (more exactly, into an electrical signal). In other words, by first converting sounds, pictures, numbers, or scientific data into an electrical signal, we can then work many wonders on them and cause them to do many things impossible in their original condition.

We stumbled on the word signal a moment ago. It's a fundamental concept in electronics because it turns out that signals are what carry intelligence and meaning. An excellent way to describe a signal is to think of how smoke relates to a smoke signal. If you build a fire up on top of a high hill and simply allow the smoke to drift up into the sky, there is no intelligence or message being sent out (other than the presence of smoke, and hence a fire). If however, you cover the fire with a blanket and cause puffs of smoke to leave the fire in some kind of pattern or code, then you're trans-

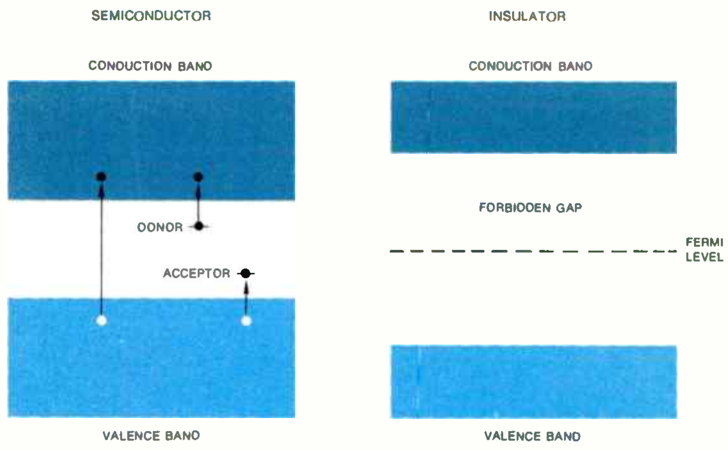


FIGURE 1. Energy-band structures of a semiconductor and an insulator. Electrons can exist only in certain allowed energy bands, separated by forbidden energy gaps. The highest energy occupied by the electrons is called the Fermi energy. In a pure semiconductor at absolute zero the valence band is completely full and the conduction band is completely empty. An input of energy to the semiconductor in the form of light or heat can raise a valence electron into the conduction band. Carriers can also be supplied to the semiconductor by impurity atoms with energy levels in the forbidden gap. Donor impurities contribute electrons to the conduction band. Acceptor impurities contribute electron holes to the valence band. The forbidden gap in an insulator is too large to be bridged thermally short of melting the crystal.

mitting a signal. Another way to say this is that information, data, or intelligence is being transmitted. Ultimately, what we are discussing here is how intelligence can be conveyed by means of electronics.

Origin of the Term. Electronics as a word didn't even come into common use until after World War II, although it apparently was coined in Britain in about 1930. The word is based on the earlier word electronic which itself came into currency around the turn of the century. Electronics was originally defined as a branch of science which deals with the study, application, and control of electricity in a vacuum, or in gas, liquid, semiconductor, conducting, and superconducting materials. In contrast, electricity deals with the flow of electrons through solid conductors, like copper wire.

The present day definition is shorter as well as considerably broader: "Electronics is that field of science and engineering which deals with electronic devices and their uses."

In any of these definitions, the related study of magnetics is implicit if not stated, because of the equal role it plays in generators, transformers, and the entire area of electro-magnetic (radio) waves.

What Is An Electron? An electron is one of the many particles that make up the atom. Besides the electron, a host of others have been discovered or postulated: the proton, meson, positron, neutron, neutrino, anti-proton and anti-neutron, not to mention lambda particles, alpha rays, beta particles, and gamma rays. The atom is usually conceived as a positively charged nucleus made up mainly of protons and neutrons with electrons circling about in cloud-like formations. The one we're interested in is the electron which is seen as being a fundamental particle of nature (that is indivisible, indistinguishable from any other electron, and perfect in form and function) with a known mass, and a negative charge in relation to the positively charged proton in the nucleus. It weighs 1/2000 as much as a proton.

It is also spinning about its axis in either direction, which gives it magnetism. The entire atom becomes magnetic if more of its electrons are spinning in one direction than in the other.

Dual Roles of the Electron. Part of the confusion in electron theory comes from the two dual natures of the electron. In the first of its dual roles it's a particle, but it's also a wave. (Someone once proposed it be called a waveicle.) In point of fact, it's apparently both. This is not just taking the easy way out because there are sound reasons why it's both. Einstein's theory of relativity tells us that when matter reaches the speed of light it sheds its mass and becomes energy (although we understand someone disputed one aspect of this the other day).

So an electron is a particle when we consider it as a part of the atom. But when we consider it in motion, it becomes energy that moves as a wave. If you think this recent paradox is a problem for the electron, remember that arguments about the wave/particle aspect of light have been going on for centuries.

Electric Current—Billiard Ball or Wave. The second dual role of our busy electron is that it serves as a fundamental part of every atom and is also a carrier of electricity. In its role as a fundamental (indivisible) particle of every atom, we can measure (or infer) its mass, assign a polarity to it (negative) and tell that it is spinning on its axis (which is what causes magnetism). We can visualize it as a micro-microscopic billiard ball (but without any actual spatial extensions) that hops back and forth between cloud-like energy states (called levels or bands) within the atom. But in electronics, we are more concerned with electrons in motion, the ones that move from atom to atom. Here the subject is about as cloudy as it must be inside the atom with all those billiard balls flying around like so many lethal hail stones. The one thing we are sure of is that electrons move and serve as carriers of electricity (agents of conduction).

Loose Electrons — Conductors and Insulators. It seems that electrons in the outer band of atoms (valence electrons) of some materials like metal are not as tightly bound as those closer to the nucleus. This means they are loose or free to move to the next atom. (Materials without loose electrons are insulators.)

Now just how these electrons move in conducting, semiconducting, or insulating materials is beyond the scope of this article. One thing we can say: the old billiard ball analogy (with one electron knocking or nudging the next one) and the visualization of electrons as orbiting the nucleus, have been completely discredited by 20th century quantum electrodynamics.

Suffice it to say, that when electrons move, you should forget that they're particles and imagine them as waves. Then, when they get where they're going think of them as particles again. To have electrical conduction, the first requirement is a supply of carriers that can move freely through the material. Electrons can move freely in metals and some crystals (under the influence of thermal agitation) because the atoms in these materials are arranged regularly. But their net movement in any direction is zero, until an external electrical, thermal, light, or magnetic field is imposed on the material. Then, their motion (current) is proportional to the strength of the field and the inherent resistivity of the material itself.

Holes, Transistors and Positive Current. Those of you familiar at all with electronics have probably noticed that we have avoided the subject of holes and hole current. This is because the concept of holes can be a little hard to follow without some buildup (and a modicum of faith).

You'll remember we mentioned discrete energy levels in the atom swirling around like clouds above the nucleus. Well, the gist of this hole theory (without getting into Planck's constant, Pauli's exclusion principle, and other equally arcane matters) is that it's easier for electrons to move between these energy levels in conductors like metal than in nonconductors (insulators) like rubber, wood, or plastic.

This is true in all atoms, but in the atoms of some crystals there are some important differences. First, when atoms solidify to form a crystalline solid, they arrange themselves in a regular (crystal) pattern (each pattern being unique to that material). The electrons in such a solid are free to move throughout the entire crystal, not being tied any more to any one atom. Also, in the atoms of crystals, the discrete enegy levels of isolated atoms become bands of energy levels rather than single levels as the atoms become closely packed into a crystal lattice.

A pure crystal such as germanium or silicon is basically an insulator at low temperatures. It is made into a semiconductor by addition of a tiny amount (one part per million) of impurity. The impurities can add or take away electrons from the outer (or highest occupied) energy level, depending on whether they are n (negative) type or p (positive) type.

In the resulting p type semiconductor (and here comes the paradox) the current is not carried by electrons but by *positive* carriers called *holes*. The p impurity is short one electron in its valence structure so when it is deposited in the pure germanium, an electron from the germanium fills the hole, leaving a hole in the original atom. Thus, besides electron motion, the holes left at vacated sites can also become mobile electric carriers that move (under the influence of external fields) like positive particles in a direction opposite electrons.

A hole is mathematically equivalent to a positron and represents a vacant energy level where an electron used to be. In the same semiconductor we find both electrons and holes each moving and producing current. However, regardless of whether it's electron or hole current in a given type of semiconductor the overall effect is the same in terms of the job being done.

Remember, this positive flow is only inside the material of the solid state device. On either side of this component we return to electron flow again, moving from a negative potential toward a positive potential.

MAGNETISM

With electricity, magnetism is the other twin phenomenon that makes up electronics. Although the properties of magnetic materials have been known since about the sixth century B.C., even today the exact relationship to electricity is not fully understood. Magnetism was put to practical use in compasses by the Chinese and Arabians before the year 1000.

Modern theories of magnetism began with Gilbert who in about 1600 postulated the earth's magnetic fields to explain how the compass works. The density of the magnetic field lines of earth's field is very small. It measures only about one-half gauss. Whereas, the magnetism in a dime store magnet has about one hundred gauss. Gilbert conducted many basic experiments and laid down some of the first laws of magnetism.

Throughout the centuries, it has been characteristic of magnetism that our use of it in practical applications has far outstripped our theoretical knowledge. Every day in the United States alone magnetism helps to generate billions of kilowatt hours of electric power. The transformer, which is used to distribute this electric power efficiently, also depends for its operation on magnetism, as does the electric motor. Magnetism allows us to reproduce sound, pictures and data on magnetic tape, to store vast quantities of information on cores in computers, and even to operate speedometers in automobiles.

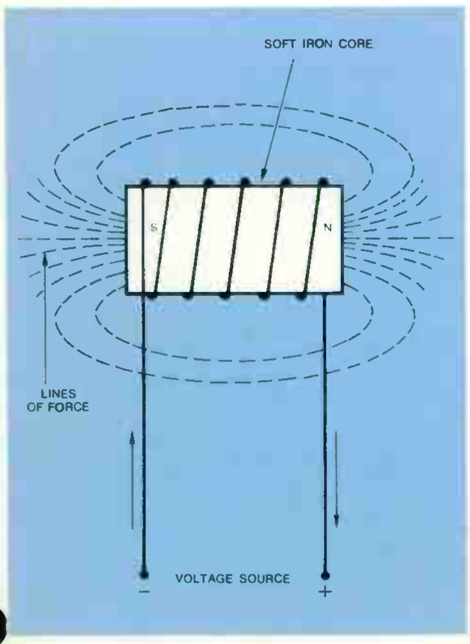


FIGURE 2. Magnetic lines of force surrounding an electromagnet. Lines would be identical with a bar or permanent magnet. Iron ore of electromagnet increases overall magnetic force because of magnetic currents set up in the core by the electric current flowing through the coil. Total magnetic force is limited in an electromagnet when the core reaches a point called saturation.

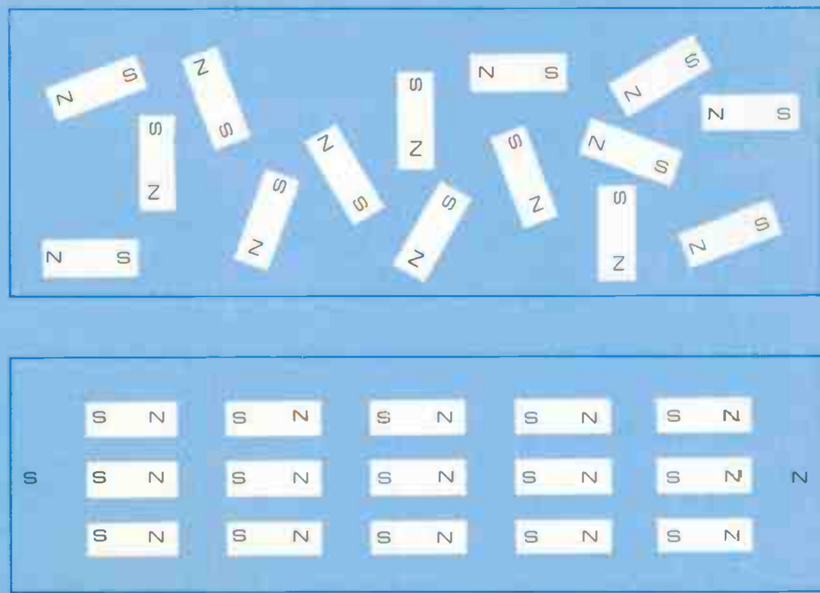


FIGURE 3. Top drawing shows random arrangement of individual magnetic domains in an unmagnetized material. By subjecting the material to an electric or magnetic field, the domains are oriented as in the bottom drawing, thus making the material magnetic. How long the material will retain the magnetism after the field is removed (retentivity) depends on the material and the strength of the activating field.

However, until about 40 years ago no one knew why certain materials were magnetic. Even today there are more questions about magnetism than there are answers.

Basic Laws. Gilbert showed that any magnet has two poles, which he designated north and south and that like poles oppose each other and unlike poles attract. Lines of magnetic force radiate from both ends of a magnet, then curve back and meet the lines from the other end. The area in which the magnet attracts is called the field of force or magnetic field. By bending a bar magnet in two, to make it into horse shoe shape, its strength is increased. The two poles are now closer together, so that the lines of force are shorter and crowded into a smaller area. This gives them a stronger effect, just as many wires in a cable are stronger than a few wires.

Most of these properties of magnetism were quite well known before the 19th century, when several scientists began experimenting with electricity and magnetism (Coulomb, Gauss, Oersted, Henry, Maxwell, and Faraday). Maxwell in particular derived some of the basic equations of electromagnetic fields that stand with the equations of Newton and Einstein as pivotal generalizations of physics.

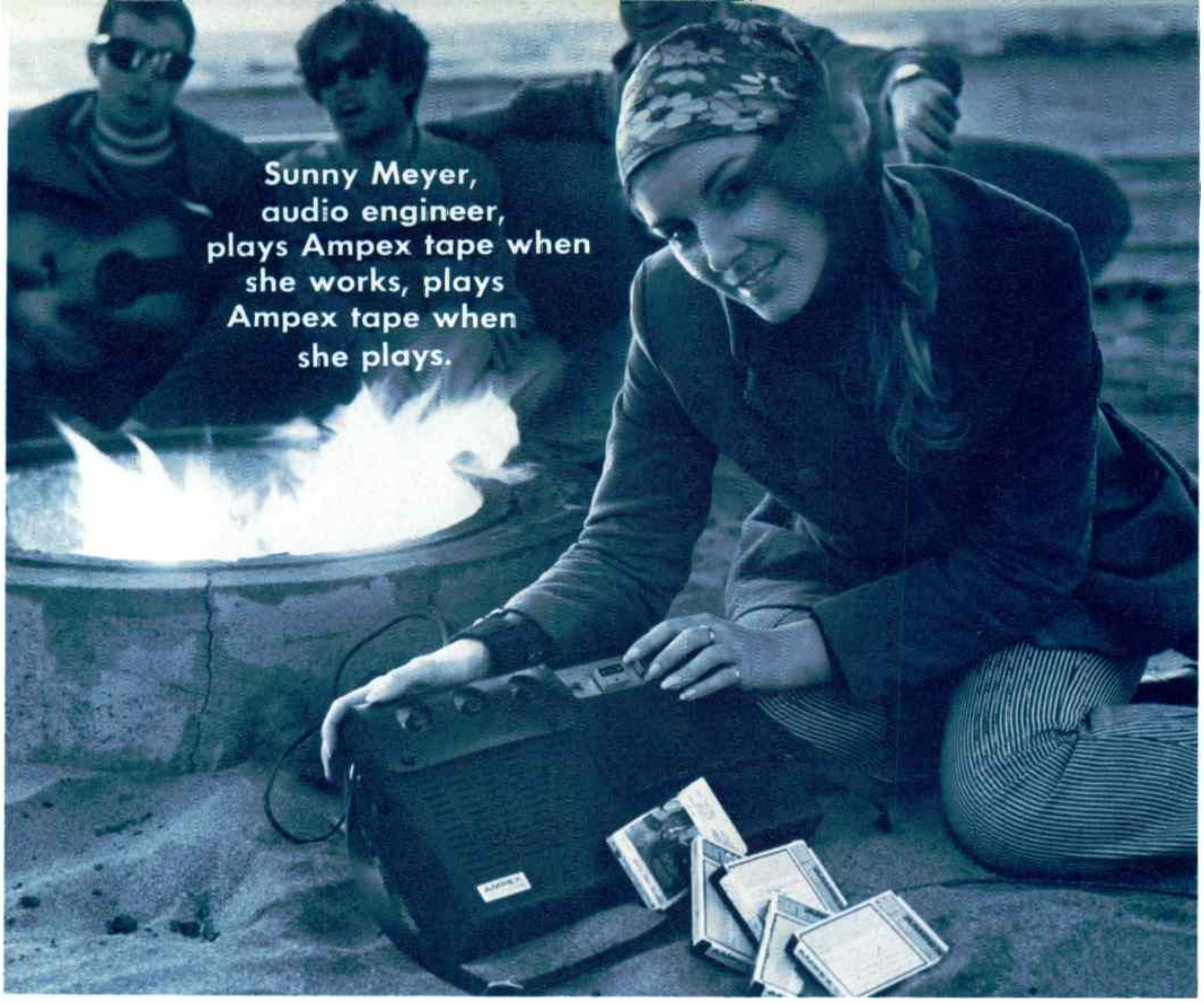
An early discovery in magnetics was the electromagnet. It was found that current flowing through a wire creates a magnetic field around it. By arranging this wire into the shape of a coil, the magnetic field can be increased. Furthermore, by wrapping the coil around an iron core the magnetism can be increased even more (up to a point called saturation), because of the interaction of the magnetic currents with the iron. This discovery of the electromagnet led to the telegraph, the telephone, the electric motor and electric generator.

Just as a magnetic field is created when an electric current flows through a wire, so it is that the opposite is true. When a coil is moved through a magnetic field an electric current is generated within the coil. This was discovered by Faraday in the 1830's and was called a dynamo or generator. The electric motor is a corollary to this in that it has a coil positioned between the poles of a magnet. By introducing current into the coil it can be made to rotate.

Magnetic Domains. Just how magnetism works was first explained by a French physicist, Pierre Weiss in the early years of this century. He surmised that magnets are made up of small permanently magnetized regions, called domains. Total magnetic strength he defined as simply the sum of the magentic strengths of each of the domains. If the domains are aligned or they can be aligned by the application of an external magnetic or electrical field, the domains will line up much like weather vanes and greatly increase the total magnetism. If however, the magnetic axes of the various domains happen to point in many directions, the total magnetism of that material will be very small or even zero. Depending on the strength of the exetrnal magnetizing force, a material may either become temporarily or permanently magnetized.

Weiss was not able to explain why these domains existed but his inductive reasoning was astonishingly accurate. His theory has been now supported by the electron theory in which magnetism is seen as coming from two kinds of motion. One is the angular momentum (acceleration) of the electron's spin and the other is the angular momentum of the electron's motion around the nucleus. An electron possesses a magnetic moment from this spin. It is in fact a tiny magnetic dipole with a north and south pole. Magnetic materials apparently maintain the magnetic moments of many atoms parallel to each other just as postulated by Weiss. We now have direct evidence (from electron microscopes) that magnetic domains really exist. They are usually between 0.1 and 0.01 centimeters across. Compared with the dimensions of atoms, electrons, and molecules, these domains are enormous.

—Continued in the next issue—



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