Digital Magnetic Tape Recording:
Principles and Computer Applications

Digital Magnetic Tape Recording: Principles and Computer Applications

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Dedicated to my children
Harry and Sharon
who are a source of enjoyment
and inspiration

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PREFACE

This book is a comprehensive coverage of digital magnetic tape recording in terms of basic mechanical, magnetic, and electronic techniques, including computer applications. The difficult task of unifying all aspects of this unique application of magnetic recording has been accomplished, hopefully, without sacrificing detail. The basic principles of digital magnetic recording and the characteristics of the tape medium and the tape transport, which are detailed here, should be of value in different ways to numerous readers.

To compete more successfully with other methods and devices, digital magnetic tape recording must become a better organized discipline. The attention given this category in a few, special symposiums and its inclusion in such a general category as input/output equipment are no longer sufficient. Within a year of this publication, gross sales from this vital and fast-growing segment of the electronics industry will exceed one billion dollars. This will not go unnoticed.

In many respects, this book is an idea symposium that will enable hardware people to accomplish basic operations without monotonous digital module circuit explanations. It does this by supplying system aspects for proposal and cost estimating, indicating avenues for further research, and detailing computer applications. For the reader with no technical background, few mathematical terms and equations are used. Standard practices are cited for those readers involved in the specification, purchase, and use of digital magnetic tape equipment.

This wide audience appeal is reflected in the topic formulation and content of the chapters, each of which is a self-contained unit that concentrates on a particular subject.

Chapter 1 summarizes the overall magnetic recording field. From a design point of view, the salient features of both analog and digital recording are tabulated for quick reference.

In Chapter 2, the digital magnetic tape transport is examined in terms of mechanical operations. Practical information on tape reservoir and tape length sensing, tape and reel drives and brakes, and tape guiding and tape deck layout is given. The chapter ends by comparing current digital tape transports in these areas.

Chapter 3 is devoted to selection, fabrication, and assembly of the magnetic head. Field orientation, core material, coil winding configurations, gap geometry, and gap effects are examined in terms of mechanical design for digital requirements.

Chapter 4 covers the digital recording and recovery processes. The theory of magnetic writing and reading is analyzed and equivalent head circuitry is detailed for both operations. Hysteresis and eddy currents are considered in terms of digital recording.

Chapter 5 gives a comprehensive coverage of digital tape recording encoding techniques for binary 1's and 0's. A deliberate attempt has been made to evaluate each technique with an appreciation of the problems associated with the medium, pulse crowding, electronic signal recovery, and ultimate computer coding and applications. A concise tabulation summarizes the attributes of all methods in terms of effective signal strength, frequency response, signal direction, and waveform and information accessibility.

Chapter 6 considers magnetic tape specification (or the lack of it). This medium is the most elusive component in the digital magnetic recording system.

Organization of data on magnetic tape is treated in Chapter 7. If a single method were to be selected to define a tape recording system, the organization of data might qualify. Before a specification can be written, such system details as buffering, speed, synchronization, number coding, word length, instructions, transfer methods, and interlocks must be resolved and are reflected in the organization of data on tape. The basic principles are presented here.

Chapter 8 briefly reviews and summarizes all information presented in the preceding chapters by developing a digital module representation of tape recording. From here, comprehensive write and read logic detail and system operations are delineated. Forward, reverse, and stop operations are logically presented, along with buffering arrangements, to complete the integration of a digital magnetic recording operation into a computer installation.

Chapter 9 shows the complexity of interfacing a digital magnetic recording device within a system by developing the essential units of a tape control unit. This entails data transfer formats, input/output communications and programming instructions, and word and block transfer operations. A multiple computer facility is developed by modular representation of computers integrated by a versatile tape control unit module. Much of the material is applicable in any computer system and has never before been presented as a design tool for logic engineers in one easy reference.

The last chapter demonstrates how heavily invested research in all areas should result in many innovations in the next few years. To those who feel that magnetic recording may be displaced (or replaced) by new state-of-the-art breakthroughs, the fact that industry is so enthusiastic and liberal in R and D funds should indicate that this discipline will become more deeply entrenched in the electronic developments of our time.

I would like to record my sincere appreciation for the assistance rendered by the many individuals and organizations who have been so generous in furnishing information and material for publication. It would be difficult to list all the individuals I am indebted to for making this book possible, but I would be remiss for not citing one. Sol Baybick read and constructively criticized the technical contents of the complete draft and contributed considerably in the topic selections of the last few chapters.

I am extremely grateful to my wife, Lillian, who has gracefully accepted my hibernation for the duration of this project. Finally, a debt of gratitude is owed to the alert and untiring efforts of the stenographic force, Mrs. Joann Bakota and Mrs. Jane Singer, and to my daughter, Sharon Jae Bycer, for painstaking clerical and filing assistance.

Philadelphia BERNARD B. BYCER

Contents

1

Magnetic Tape Recording

Magnetic recording has become an invaluable aid in modern digital computing systems. The use of magnetic tape for sound recording is well known, but the use of magnetic tape recording for experimentation, instrumentation, and simulation purposes is less widely known. Although analog magnetic recording may be used for some of these applications, it is the digital form of magnetic tape recording that has expanded the application of magnetic recording so considerably, especially in automatically operated digital systems. In this book, the subject of digital magnetic tape recording will be examined in detail. Although a voluminous amount of information on digital magnetic tape recording is available in various publications, this is the first attempt to consolidate and present the information in a coherent manner.

The invention of magnetic recording is attributed to a Dane named Valdemar Poulsen, who filed his first patent application on December 1, 1898 in Denmark, under the title "Magnetic Recording and Reproducing Sounds or Signals." The technique of magnetic recording was entirely new, it was not a modification or improvement of an existing idea. In fact, it is not known how Poulsen came upon the idea of using residual magnetism to preserve sound. However, the desire of retaining or storing information and the convenience of recalling it appear to have been his prime concerns. Basically, Poulsen considered his machine, the Telegraphone, to have the following possible uses: (1) the recording of telephone messages; (2) the delayed transmission of telephone messages; (3) recording telephone calls in the absence of the telephone user.

As narrow as these applications may appear to be now the common denominator, data preservation and the recall of such data at the user's convenience, led others, including Marconi, Carlson, Carpenter, Blattner, and Camras, to perfect and implement magnetic recording techniques for use with radio and telegraph, motion pictures, and other commercial devices.

The use of magnetic tape for data processing began in the early 1940's. Until then, documentation and data tabulation were performed manually, which was a time-consuming operation. Of the many methods investigated for reducing the time required for these laborious operations, magnetic tape recording of data in analog form appeared to be the solution. As more complex requirements were imposed and greater detail and data precision became necessary, the use of digital formats solved many problems involved in processing data into usable form and simplifying its distribution. Although magnetic tape recording was fully developed first, there is no doubt that the tremendous growth of and need for the digital computer gave important impetus to developments in the magnetic tape recording field. In return, however, magnetic tape greatly extended the usefulness of the digital computer in many areas, especially in those dealing with nonarithmetic operations and where large storage systems were required.

Analog Recording

Analog recording is generally associated with the identical reproduction of a recorded signal, a familiar process used in the audio recording of speech and music. An extension of this process is used to record instrumentation data and modifications of the process have led to digital recording. The three basic processes used in analog recording are (1) direct recording; (2) frequency modulation (FM) recording; and (3) pulse-duration modulation (PDM) recording.

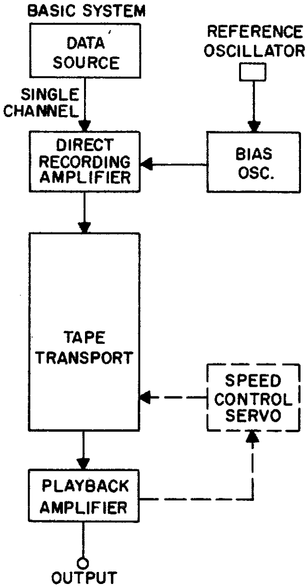

Fig. 1-1. *The direct recording process.*

Direct Recording

The direct recording process (Fig. 1-1) is, by far, the most familiar, since it is the method used in audio recording. The signal to be recorded is conditioned to activate a recording head through its coil-wound core (Fig. 1-2), recording a signal on tape that, essentially, is a direct, unmodified reproduction of the original signal. When a high degree of signal fidelity is required, high-frequency bias is linearly mixed with the signal prior to recording (Fig. 1-3). With this scheme, the recorded signal falls on the linear portion of the transfer

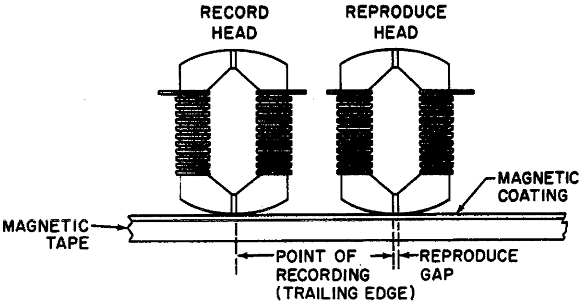

Fig. 1-2. *Magnetic recording and reproducing.*

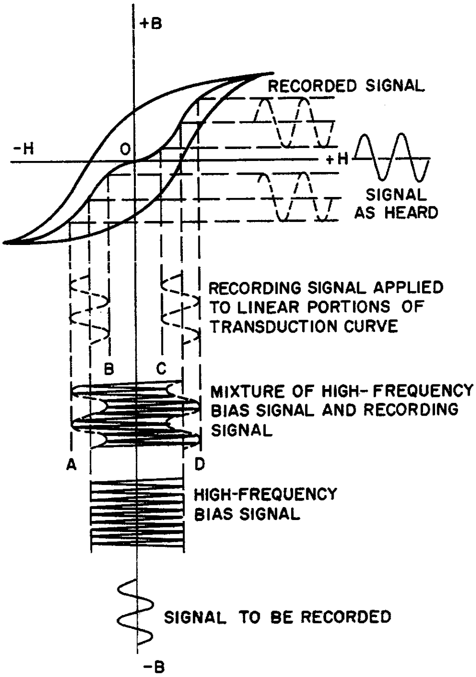

Fig. 1-3. *Linear mixing for direct recording.*

curve, as shown in the figure. The amplitude of the bias signal is several times that of the desired signal. The linear signal-mixing of the two is achieved without introducing new sum and difference frequencies; thus, amplitude-modulation is avoided. Because the bias frequency is usually three to five times the highest frequency to be recorded, the bandwidth capability of the circuitry and the head response characteristics of both the record and playback operations remove the auxiliary signal. The actual value of the bias signal amplitude is critical, the frequency is not.

The first requirement of a recording system is that it be capable of recording and reproducing the original signal (intelligence) with a high degree of accuracy in frequency, phase, and amplitude. Good high frequency response is an outstanding advantage of direct recording. Figure 1-4 shows frequency response of the direct recording process for various tape speeds. At 60 inches per second (ips), the effective frequency range within the 3-db points is 50 cps to 100 kc. The frequency range can be extended proportionally by increasing tape speed or by other means such as rotating heads.

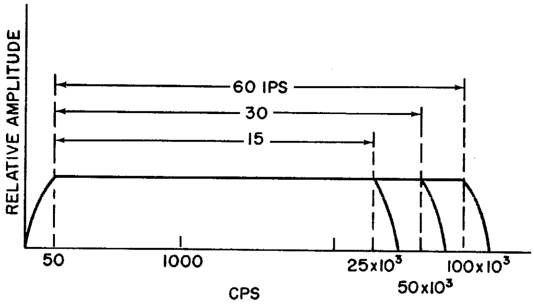

Fig. 1-4. *Direct recording frequency response at various tape speeds.*

The major disadvantage of the direct recording process is its poor low-frequency response, especially below 30 cps. The low-frequency range could be extended, but only by making the system much more complex. A simpler but a more efficient solution is to use frequency modulation techniques when good low-frequency response is required.

Frequency Modulation (FM) Recording

Direct recording is generally associated with the recording of one signal per recording track. In many cases, however, a wide frequency range may be more efficiently utilized by multiplexing several signals on a number of individual carrier frequencies, each modulated by a separate signal (Fig. 1-5). Using a separate subcarrier oscillator, low-frequency signals down to dc modulate each carrier and are then mixed linearly together. The output of the mixer contains the composite signal that is fed into the direct recording system. Here, the full bandwidth and linearity of the direct recording method is

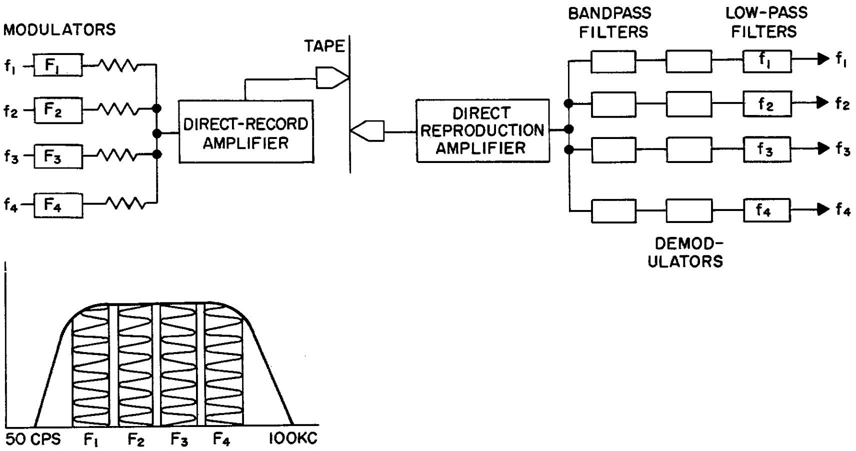

Fig. 1-5. *Basic frequency-division multiplexing of a narrow deviation FM system.*

utilized to permit a simultaneous recording of a number of signals on a single tape track. The reverse process (de-multiplexing) is performed during playback and the original signal is recovered. This modified form of FM recording is known as frequency-division multiplex. In frequency modulation (FM) recording (Fig. 1-6), a set of carrier frequencies are chosen with specific allocated sidebands. Each carrier and the amount it may deviate are chosen

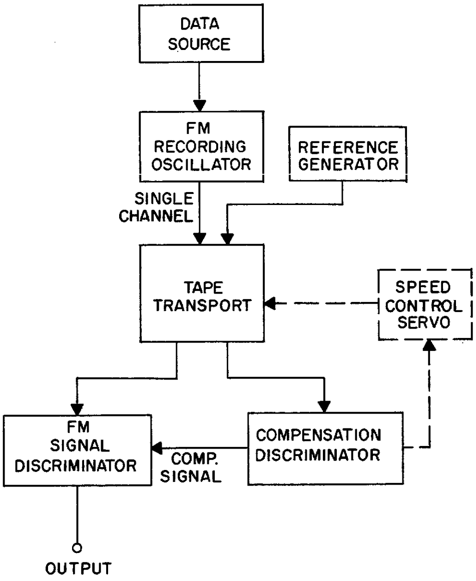

Fig. 1-6. *The FM carrier system.*

so that no overlapping of sidebands occurs. The output of the modulator is FM. This composite signal can be used to frequency modulate a center frequency at the midpoint of the direct recording process response. This method, whereby each subcarrier is frequency modulated and the master carrier is frequency modulated, is called *FM/FM.*

Consider the final FM operation. One signal (composite) is used for wide deviation of a center carrier. For actual values at 60 ips, a center frequency of 54 kc width ±40% deviation has an information capacity of 20 kc (Fig. 1-7). Since bandwidth is proportional to tape speed, instead of 20-kc capacity, a 10-kc bandwidth intelligence for 60 cps can be produced with reduced tape speeds, as shown in Fig. 1-8A. Slower tape speeds will alter bandwidth as shown in Figs. 1-8B - F. Examination of the bandwidth response discloses a large vacant area at the lower end. A method of recording that utilizes the lower band will be discussed under *Pulse-Duration Modulation Recording (PDM).*

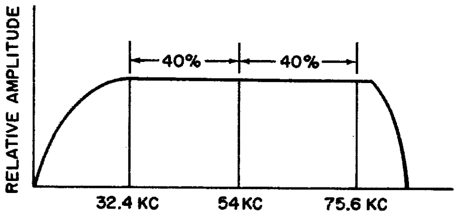

Fig. 1-7. *A wide deviation FM carrier bandwidth at 60 ips.*

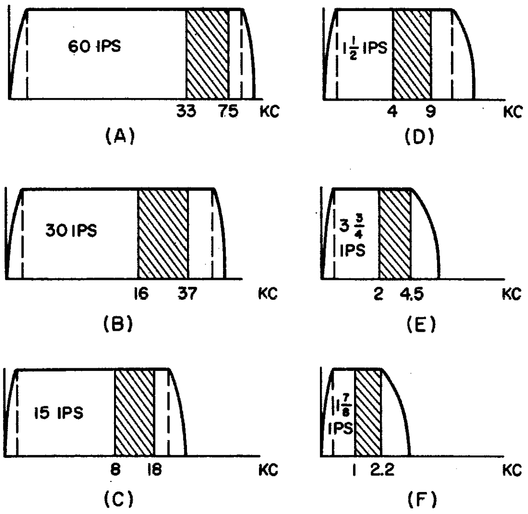

Fig. 1-8. *FM carrier and modulation bandwidth at various tape speeds: (A) dc to 10 kc/s; (B) dc to 5 kc/s; (C) dc to 25 kc/s; (D) dc to 12 kc/s; (E) dc to 600 cps; (F) dc to 300 cps.*

FM recording overcomes two basic limitations associated with the direct recording process: (1) inability to record low frequencies and (2) amplitude compression. The amplitude characteristics of magnetic tape are only fairly linear. Generally, analog precision is one part in a thousand or 0.1%. The dynamic range of the direct recording process and the amount of amplitude and signal distortion are shown in Fig. 1-9. A high degree of precision is obtainable with the FM process, as FM recording is insensitive to amplitude variation as long as a good signal-to-noise ratio is maintained. In cases where reduction in signal level is attributed to irregularities of the tape surface, FM recording is more able to cope with this type of amplitude instability than is the direct recording method.

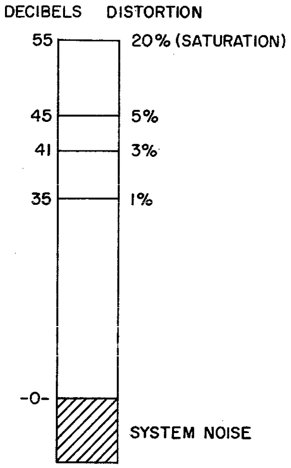

Fig. 1-9. *Direct recording process amplitude tape range.*

The use of FM techniques results in certain disadvantages. First, FM recording is sensitive to speed variations. Any speed variation introduced into the tape during recording and playback processes will cause unwanted modulation of the carrier frequency and result in distortion (noise). This is the limiting factor of the FM method. Secondly, FM places stringent requirements upon the tape transport and requires more complex electronic circuitry than the direct recording process. Finally, using FM recording techniques results in reduced information bandwidth relative to the direct recording method.

Pulse-Duration Modulation Recording

The third analog recording technique is pulse-duration modulation (PDM), or pulse-width modulation (PWM), illustrated in Fig. 1-10. The analog-information amplitude content exists in the pulse width and the rate of change of the leading edges of the pulses contains the frequency content. Where FM is a frequency division multiplexing technique for compiling a

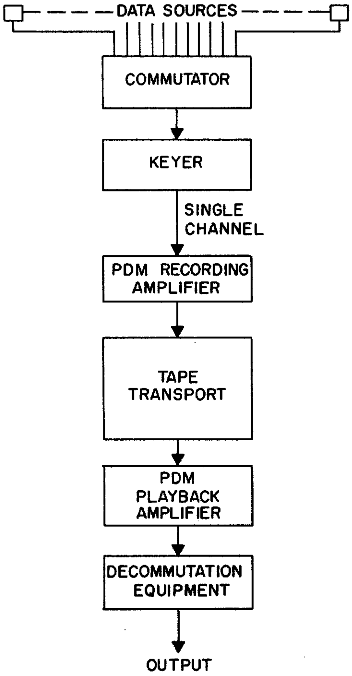

Fig. 1-10. *The pulse duration modulation process.*

number of signals onto a single tape channel, PDM accomplishes the same thing by assigning fixed time slots for the same purpose. This latter technique is called time division multiplexing and requires a fixed sampling rate of a number of signal channels on a sequential basis.

PDM recording is based on the fact that the frequency and amplitude of any sine wave can be accurately expressed from information obtained by sampling or measuring the amplitude at fixed time intervals. If the information obtained is to be meaningful, a sufficient number of samples must be taken from one cycle so that reconstruction of the wave is possible with minimal distortion. Sampling theory states that, at minimum, two samples per cycle of the highest frequency component of a complex wave are required. Therefore, the more complex the waveform, or the better the desired reproduction of the serrated signal, the greater must be the sampling rate. Because of this, the number of signals that can be multiplexed onto one recording tract increases as the frequency content of the signals decreases and the recording bandwidth increases. Figures 1-11 and 1-12 show the signal sampling (chopping) and a time scale of combining three signals sequentially.

In practice, each signal source is fed to one pole of a multipole rotary switch. A mechanical switch is frequently employed, but today a number of systems use electronic switching. A system diagram of a mechanical com-

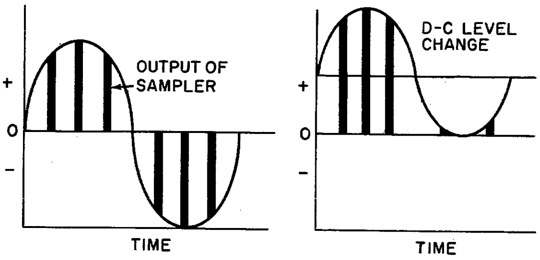

Fig. 1-11. *PDM signal sampling.*

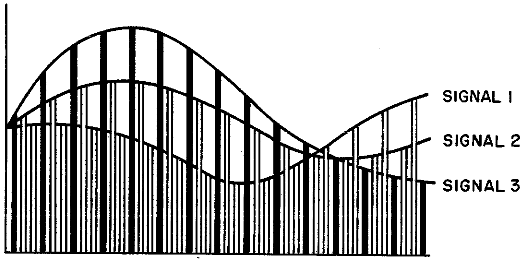

Fig. 1-12. *Time-division multiplexing of sampled signals.*

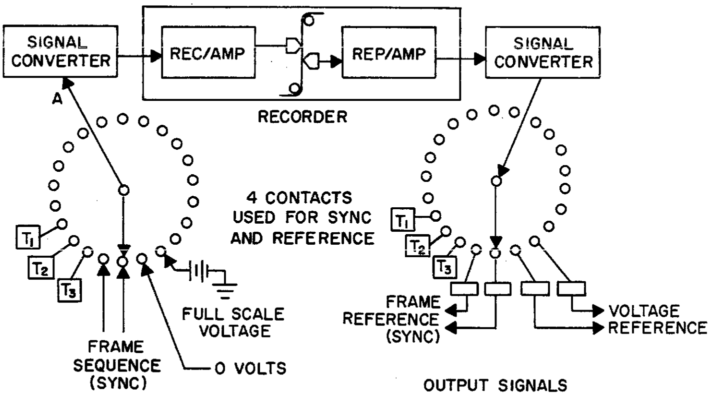

Fig. 1-13. *The PDM multiplexing recording system.*

mutator for PDM recording is shown in Fig. 1-13, and the signals at various points of the system are shown in Fig. 1-14. As the switch rotates, each input contact is sampled and fed to the recording system. Since the information is in analog form, two contacts are set aside for calibration purposes: one for zero voltage and one for maximum amplitude. In addition, two contacts are set aside for identification and control purposes. It is necessary to synchronize the two switches to identify the various signals on playback. For signal recov-

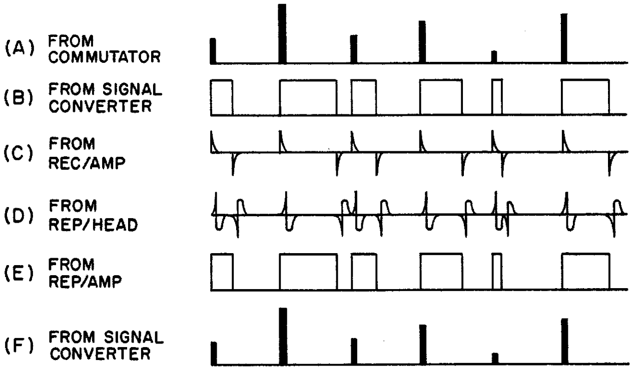

Fig. 1-14. *Signal shapes at various points in the PDM recording system of Fig. 1-13.*

ery, the output of the tape is applied to a similar switching system and synchronization is achieved by means of the timing signals already recorded. The outputs from the various contacts are fed through suitable low-pass filters that reconstruct, or sine-wave restore, the playback signals. Any final corrections are accomplished by decommutating calibration signals of known voltages and applying the necessary corrections.

The PDM method requires the conversion of amplitude to pulse width. For zero voltage, a minimum pulse duration is assigned and correspondingly, for full signal input, a maximum pulse duration is determined. Any intermediate signal voltage between zero and full-scale would be represented by a pulse duration somewhere between these two boundary values. Since the record signal amplitude is constant, PDM is superior to the direct recording process. On the other hand, PDM is sensitive to tape speed variations, but not as much as is FM. Any instantaneous speed variations are integrated over the duration of the pulse.

A variation of the PDM is Pulse Code Modulation (PCM). The recorded signal of a PDM process has an infinite number of pulse durations between zero signal input and full-scale input. If, during the commutation process, the serrated signal is fed to analog-to-digital converter equipment, a number can be determined and assigned for each signal amplitude. Using a binary code decimal (BCD) numbering system each decimal column has its own binary representation. Each four-bit weighted column has four discrete pulse durations. Three sets of BCD characters are necessary to read three decimal digits. Here, only four discrete pulse widths have to be encoded and decoded. With PCM tape, speed variations are a minor problem.

The chief advantage of the PDM recording process is its ability to multiplex a large number of signals onto one information line. Other advantages are its high accuracy, using a self-calibrating method, and good signal-to-noise ratio, resulting from the narrow bandwidth requirements. The PDM process has some serious limitations. It is the most inefficient of the three method processes presented so far, and requires very complex electronic equipment.

Digital Recording

Digital recording (Fig. 1-15) may be considered an extension of or a variation of analog recording. A magnetic tape transport handling digital information on an intermittent basis (stop and go) is constructed in a different fashion than a tape transport handling analog information. The digital tape transport requires some type of tape reservoir to absorb speed differences of the tape reel drive and the tape drive when rapid operational changes occur. Although both recording processes utilize similar signal waveforms and several recording channels, the arrangement of information on tape in each system is not the same. In analog recording, the information to be recorded is generally restricted to a single channel and is referred to as *single track* or *serial recording*. In digital recording, the equivalent information is recorded on multiple tape tracks and is referred to as *parallel recording*.

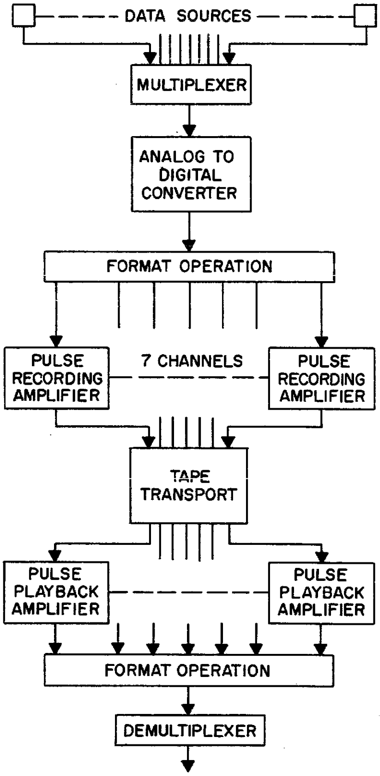

Fig. 1-15. *The digital recording system.*

The field of information storage and retrieval that is concerned with data gathering and preparation, classification, documentation, filing, and retrieval of information, offers extensive opportunities for digital magnetic recording.

In many systems magnetic tapes are considered to be the only input/output method of communication with high-speed computers. For this reason, input information is translated from many other data forms and subsequently reduced to magnetic tape. Likewise, computer output data is frequently recorded on magnetic tape and later transcribed to the desired final form. In addition to normal applications of digital tapes (tabulations, documentation, plotting boards, strip charts, etc.), extensive duplication of data and reports is often required and magnetic tape is a means of making this possible in a convenient package. A number of versatile tape-to-tape converters are available for this purpose. Not only do they translate one computer language into another but can convert from any 5, 6, 7, or 8 level punched paper tape and punched cards into any computer language and vice versa.

Many measureable quantities are continuous and the particular device sensing them is compatible with analog methods. In most cases of closed-loop operation where analog precision is sufficient, it may be preferable to avoid the additional expense for hardware to perform analog-to-digital conversion and the reverse process. Maintenance and spare parts may also be a problem. However, in cases when a system contains many units, or where the units are physically separated from one another, problems often arise in intercommunication, time correlation, standardization, and system integration. Digital recording techniques and operations offer the best solution to these problems.

Figure 1-16 is a representation of analog data recording covering a variety of possible transformations and conversions that are likely to be encountered in handling analog signals until the measured quantity is digitized. The area of nonarithmetic operations and nonmeasureable quantities is excluded. A parameter, P, is to be measured and recorded for further analysis and data reduction. In addition to other identification nomenclature, time is used to qualify the occurrence of measurement. A transducer or sensor supplies the information in electrical form. Some reference is initially used when absolute recordings are required. Each amplification introduces some degradation of the signal. To ensure a given degree of accuracy, it is necessary to monitor the references, standards, temperature, power supply drift, and other conditions that are likely to affect this measurement. Finally, after playback, the analog signal is digitized to satisfy the following equation:

$$C = me + b$$

where C is the computation value for sensor output e to be reduced. By proper adjustment of the parameters, m and b, a variation in the analog e can be made to give a linear variation of C that exactly corresponds to the value represented by e. Under ideal conditions, the only sources of error are the references (stability and precision). Values of m and b are inserted in the collator to achieve a symmetrical distribution defining the parameter with equal plus and minus tolerance values. The data handling of C can be processed by supplying e and the values of m and b in terms of a set of calibration values (strip charts, tabulation, etc.) or a set of correction values for

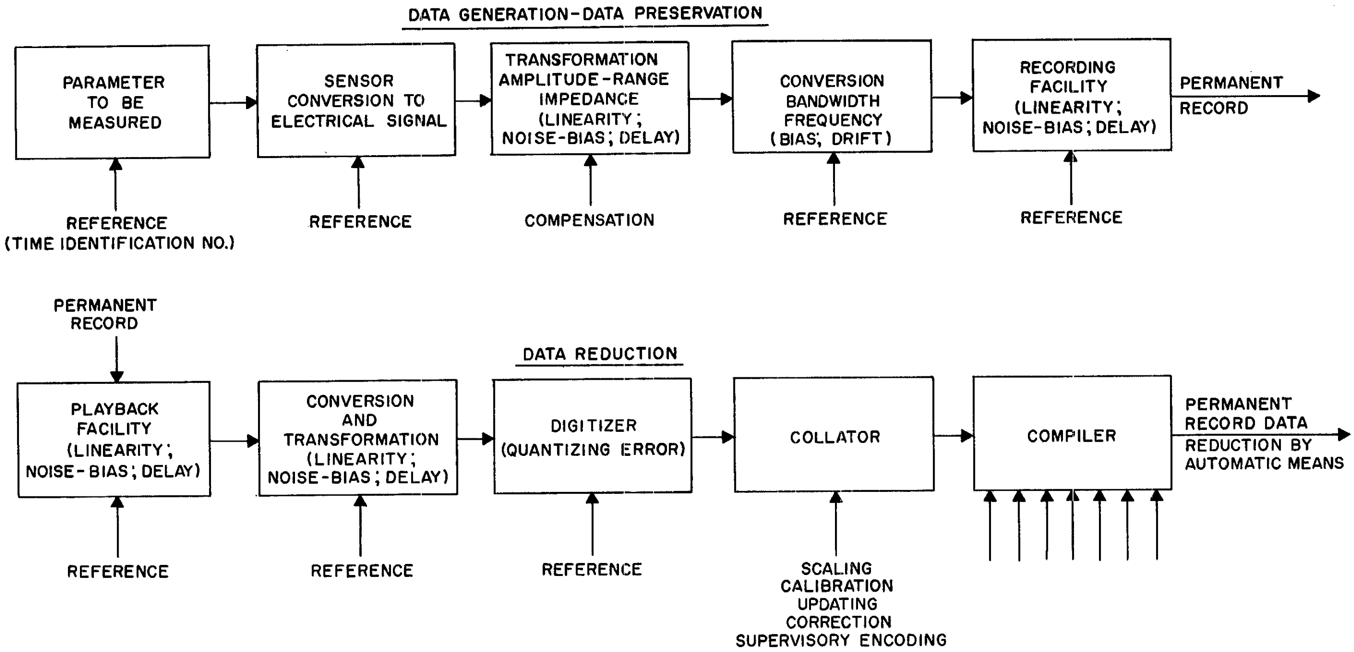

Fig. 1-16. *Analog data flow.*

the parameter. Without adding further complexity to the disposition of parameter P, a test setup requires a number of these measurements simultaneously and many are interrelated. Simplicity is achieved when the sensor output is in digital form or when a digitizer is placed adjacent to the sensor output. After the initial errors of analog-to-digital conversion have been incurred, subsequent data handling operations do not change the data in any way.

Comparison of Analog and Digital Recording

A better understanding of both analog and digital magnetic tape recording methods is obtained when a comparison is made. While both methods are similar, their differences can be used effectively to illustrate the merits of both techniques. For comparison, a parallel recording of eight channels and 1000 bits (or cycles) to the inch will be used.

The figure of 1000 cycles (1 kc) to the inch for analog recording was standard practice over a decade ago. Today, this figure is close to 2000 cycles per inch. Consequently, a 100-kc signal is recorded at a tape speed of slightly more than 50 ips. For digital recording, 1000 bits to the inch is obtainable, but it is not common at this time.

The precision of amplitude measurement for an analog signal here will be limited to seven bits in binary notation or 1% accuracy (Fig. 1-9). Also assume a sampling rate of two data samples per sine wave (or highest frequency component) of the signal to be recorded. Using these ground rules (1000 bits to the inch, 1% accuracy, 8 parallel tracks and 1-kc data signal), the analog signal is continuous while digitally the data is discrete and discontinuous.

The basic arrangements of analog and digital magnetic tape recording are compared in Fig. 1-17. The analog signals (1-kc sine wave phenomena) are applied directly to the analog tape transport for recording. The digital equivalent of the same data is quite different in many respects. Intially, all eight data lines are interrogated simultaneously and stored (analog). Then each analog-stored data line is sequentially converted into a numerical value and digitally stored. The final process takes the digits and places each numerical data value in sequential order on tape. The data sample and analog-to-digital conversion processes for each recorded track are performed at twice the highest frequency component (2000 samples per second). Obviously, the analog signal of one complete sine wave occupies 1/1000 of an inch of tape. The digital equivalent occupies 16 times (16/1000) as much tape as its analog counterpart and requires additional conversion hardware and switches.

This simplified illustration of analog and digital magnetic tape recording would imply that analog techniques are far more efficient and, possibly, preferable to the digital method. Actually this is only partially true. In essence, many analog restrictions are not self-evident and need clarification. The parallel recording of analog data requires stringent tape transport speed control

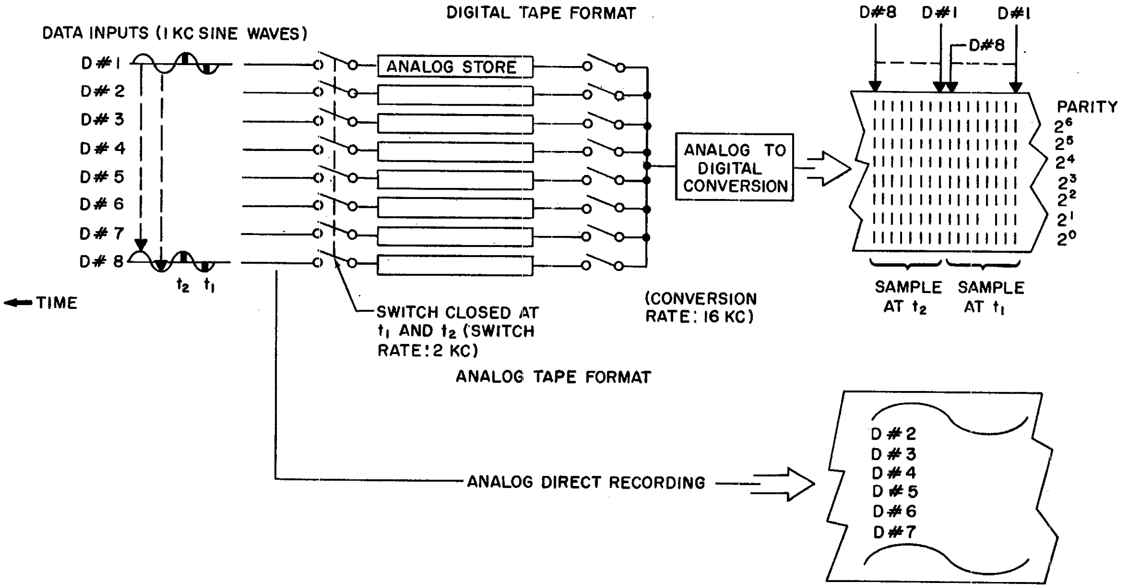

Fig. 1-17. *Analog and digital magnetic tape formats.*

and stringent playback amplifier design. For high-quality instrumentation analog recording, each data channel has a carrier, or reference, signal superimposed on the information signal. During playback, this carrier signal provides the amplitude and frequency correction of each recorded track signal for the overall response (record and playback). Also, one of the carrier signals (or a separate reference track) is used in the speed servo control loop to maintain a constant tape velocity.

Information content is contained in the signal amplitude. Analog recording is sensitive to tape dynamic range (see Fig. 1-9), speed variation, spacing between head and tape, and tape surface smoothness. The reference signal

TABLE 1-1. Comparison of Analog and Digital Magnetic Tape Recording

Type	*Advantages*	*Disadvantages*
Analog (Direct) 60 ips	High frequency limit, 100 kc Usually one signal per track Simplest method	Low frequency limit, 50 cps 1% tape speed variation results in 1% error Drop-out effect is serious Stringent tape speed control required
Analog (FM) 60 ips	Low frequency limit, 0 cps Relatively insensitive to tape drop-out One signal for wide deviation or up to 18 inputs (narrow deviation) for one track	High frequency limit, 10 kc 1% tape speed variation results in 2.5% error Complex circuitry High tape transport quality required
Analog (PDM)	Low frequency, 0 cps Multiplex up to 86 signals on one track Less sensitive to speed variation than FM (1% error for 1% speed change)	Limited high-frequency response Complex equipment required Low tape utilization
Digital	Low frequency, 0 cps High data accuracy Insensitive to amplitude and speed variations Compatible with computer operations Start/stop capability Extremely versatile	Limited high frequency (150 kc) Data must be digitized Sensitive to drop-ins and drop-outs Requires computer quality tape Low tape utilization

amplitude provides compensation, within limits, for all sources of amplitude degradation. Also, any phase and frequency distortion is minimized with good tape speed control.

A few less obvious analog limitations are worth noting in this magnetic tape comparison (see Fig. 1-17). In general, the data is limited to one reel of tape because of the continuous signal characteristics. Also, the frequency response is quite wide for the analog method while the digital is fixed frequency. The low-frequency limit is in the vicinity of 50 cps (FM and PDM have a low-frequency limit of 0). Any additional data inputs require additional hardware on a per-track basis. High-quality linear magnetic tape characteristics with controlled amplitude compression for equalization are required. Table 1-1 summarizes the advantages and disadvantages of analog and digital recording methods.

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2

The Digital Magnetic Tape Transport

Principles of Operation

The function of the tape transport is to move a strip of magnetic tape at constant speed past a magnetic head. Typical elements of a tape transport are listed in Table 2-1. The type of element used depends upon the tape transport application; e.g., the tape reservoir in one application might be a tension-arm type while in another application it might be a vacuum-loop type. No single element is far superior or unquestionably more efficient than another. All of the different types of elements listed in Table 2-1 can be found in equipments presently on the market.

The operational elements of a basic tape transport are shown in Fig. 2-1. These elements will be treated in detail in this chapter. Although the magnetic tape has very little inertia, obtaining controlled motion in conjunction with

TABLE 2-1. Elements of a Tape Transport

Element	*Tape Reservoir*	*Tape Sensor*	*Tape Drive*	*Tape Brake*	*Reel Drive*	*Reel Brake*
Types of Element	Tension arm Vacuum loop	Mechanical Photo-electric Electronic Pressure	Mechanical Air Pressure vacuum	Mechanical Pneumatic	Servo motor Squirrel-cage Induction motor Synchronous & induction motor	Mechanical Magnetic

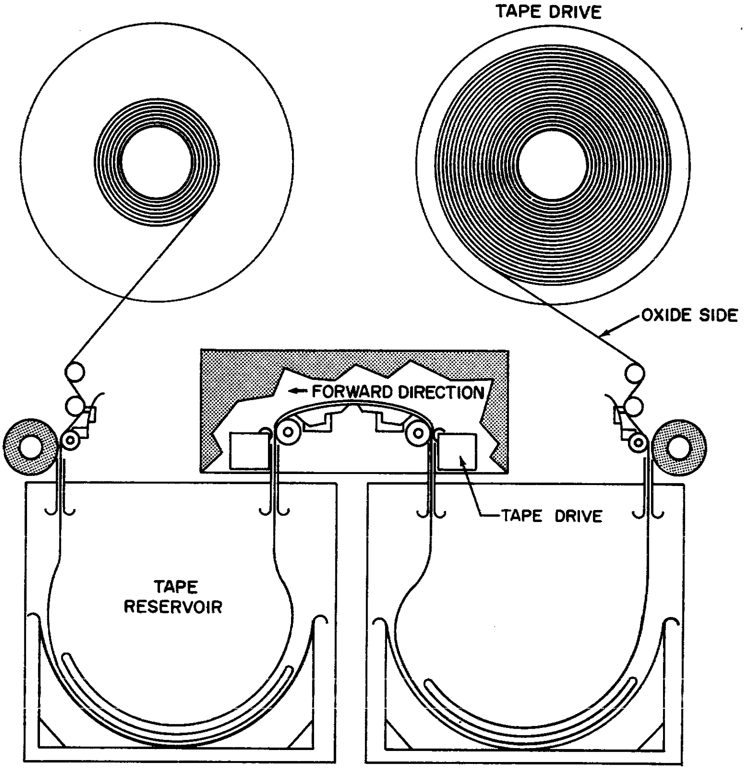

Fig. 2-1. *A digital transport tape-handling mechanism.*

delicate mechanical handling presents a difficult problem in fast start and fast stop operations. To move the tape past the magnetic head, the tape is trapped against a rotating capstan by mechanical or vacuum pressure. Because of the initial high acceleration of the tape, a period of time must elapse before the tape speed settles down within permissible speed variations. Various methods, such as pressure pads or vacuum hold-down, are used to ensure intimate contact between the tape and the magnetic head during both the transient starting period and steady running.

Since there is a reaction time delay between the motion of tape and its feed from the reel, a tape reservoir is used to supply the tape initially. The reservoir must hold a large enough supply to prevent tape breakage. Before the tape supply is exhausted in the reservoir, the feed reel must be up to speed to supply the tape for continuous tape motion. A complementary operation is performed by a second tape reservoir in conjunction with the take-up reel. This reservoir must be able to absorb the tape spent from the first reservoir, without overloading, until the take-up reel reaches the proper speed. The tape reservoir provides a supply of unreeled tape during acceleration periods to minimize any stress on the tape and to allow the supply and take-up tape reels sufficient time to overcome their initial inertia. The tape reservoir functions in the same fashion during the braking operation.

Three separate motor drives are needed for these three areas: tape drive, feed drive, and take-up drive. All three motor drives must be controlled by a system of clutches and brakes that facilitate rapid changes in tape speed and direction and provide sufficient tension to avoid tape slack, slippage, and tape breakage.

Other transducers are required to ensure proper tape handling and mechanical operation. The tape reservoir supplies signals to the servo control to regulate the speed of the supply and take-up reels. Tape tension must be monitored and transmitted as input signals to the supply and take-up reel servo system for accelerating the tape from a stationary position and for the detection of tape breakage. The tape supply is monitored, also, to supply stop signals to the servo system at each extremity of the tape. In addition, for digital application, the remaining recording time is displayed locally at the tape station control panel or at a remote control console.

In digital recording, the need for fast start-stop operations is paramount, while all other mechanical requirements are secondary. The analog tape recorder is generally used only on a continuous basis while a digital tape transport is operated either on an intermittent or a continuous basis. The analog tape recorder preserves the electrical signals in a linear fashion on magnetic tape and is concerned with the accurate representation and reproduction of the original electrical signal. Tape speed and amplification associated with each process (record and playback) must be identical or compensatory. This is achieved by uniform motion between the heads and the medium. The degree of speed uniformity influences the cost of the equipment and errors due to timing and flutter or wow must be reduced or eliminated, if possible.

For digital applications, problems associated with analog tape recording are present, but are minimized for several reasons. If the digital tape recorder is operated on an intermittent basis, tape speed variations of ±5% from nominal are generally acceptable. Hence, tape speed need not be exactly the same for record and playback operations. The problems associated with flutter or wow are not too important in digital recording unless the playback signal is below the threshold of the playback amplifiers. Amplitude variations and synchronization are treated differently in digital applications and these factors do not have a counterpart in analog recording. The construction and operation of a digital tape transport are very complex.

The Tape Reservoir and Tape Length Sensing

Fast start-stop digital operations can snap or break the magnetic tape medium unless care is taken to hold the stress or strain within recommended values. In practice, the tape must either be brought up to speed over the heads from rest or reduced from nominal operating speeds to a complete stop in a few milliseconds.

The tape reservoir relaxes mechanical tape handling requirements by acting as a shock absorber and a tape storage bin that supplies or absorbs (starts or stops, respectively) tape while maintaining correct tape tension over the heads. The tape reservoir acts as a speed converter while the massive tape reels attain the correct speed or continue to coast momentarily after a stop command has been given. Because the inertia associated with the tape in the reservoir is very small, acceleration and deceleration at a high rate are possible. Obviously, more efficient and versatile tape reservoir design reduces or prevents excessive winding tension on the tape. This in turn decreases tape slippage on the reel under fast start and stop operations. By storing sufficient tape in the reservoir, the power and reaction times of the initial torque requirements and brake actuators are considerably reduced. (The reel drive power requirements may be simply stated by $P \alpha \frac{V^3}{S}$. See Appendix 1.)

The design and sophistication of the reservoir system vary greatly with tape speed, tape reel mass, and start-stop operations. A simple tape reservoir consists of a mechanical storage arm with rollers. The elements of such a system are shown in Fig. 2-2. In this system, the tape guide support holds

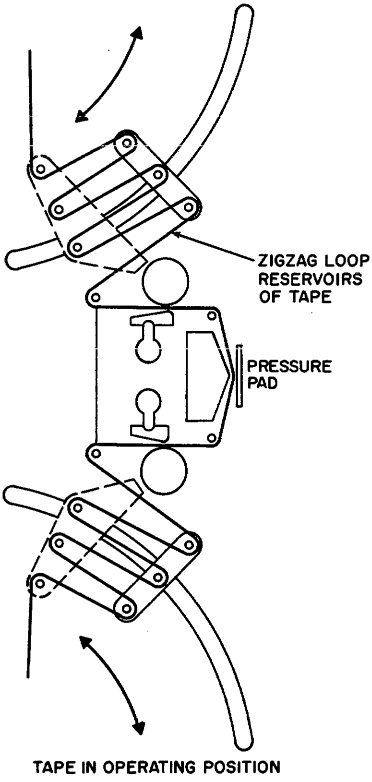

Fig. 2-2. *A tension-arm tape reservoir.*

low-inertia idlers and the movable pulley arm is flexed in a zig-zag manner over a curved path. The rollers of the pulley system have precision ball bearings and some contain shoulders to guide the tape. A suitable servo system keeps an adequate amount of tape within the reservoir between maximum and minimum limits.

Basically, the problem of controlling the tape in the reservoir is one of measuring the amount of tape in it so that a departure from some mean or null produces an error signal. This signal can be used to control the speed of rotation of the supply and take-up reels with which the reservoir is associated. The resultant acceleration or deceleration of the tape reel will then alter the amount of tape in the reservoir, returning it to the desired or equilibrium position.

Tension-Arm Tape Reservoir

Various methods have been employed to sense the amount of tape in the reservoir. The method used in any system depends largely on the design and configuration of the reservoir. In the system shown in Fig. 2-2, tape length is monitored by observing the position of the movable tension arm. Many transport schemes use a linear system that measures tension-arm position by synchro transmitters or variable resistances. Others measure tape lengths in discrete steps or with go, no-go indicators by attaching an element to the position arm that moves over a series of electrical contacts. All applications of this reservoir system incorporate limit switches. When activated, the limit switches actuate brakes that stop the tape reels and inhibit any further operation of the tape transport until remedial action has been taken.

An expanded view of the tension-arm operation is shown in Fig. 2-3, which illustrates three possible types of sensors for tape supply monitoring. The arm position can control a sliding arm contact on a potentiometer (A). Speed direction and the distributed resistance will supply error signals to the motor drive system. A continuous analog signal is available that is linear or proportional to the arm movement. The dash pot contact method (B) supplies discrete steps that are related to the tension arm translation. The operation of the contacts is equivalent to step-function signals. The number of contacts need not necessarily be balanced about a null point. It may be preferable to have more contacts on one side of the null, or quiescent, position than on the other, or the equivalent by a distributed weighing function per contact. This arrangement prevents the rollers on the movable arm from lining up on a straight line with the fixed rollers. When a high start signal supplies tape in a burst fashion, the tension arm moves in the opposite direction after the initial start to take up the slack tape. As the tension arm reverses direction, there are varying contact closure error signals to ensure that the tension arm always has an ample supply of tape. If rotation error signals are desired, a synchro transmitter may be attached to the take-up arm shaft (C). A high-speed, low-inertia synchro system is now available. The rotation scheme is adaptable to digital read-out techniques. Here, a digital servo system may be implemented instead of an analog one.

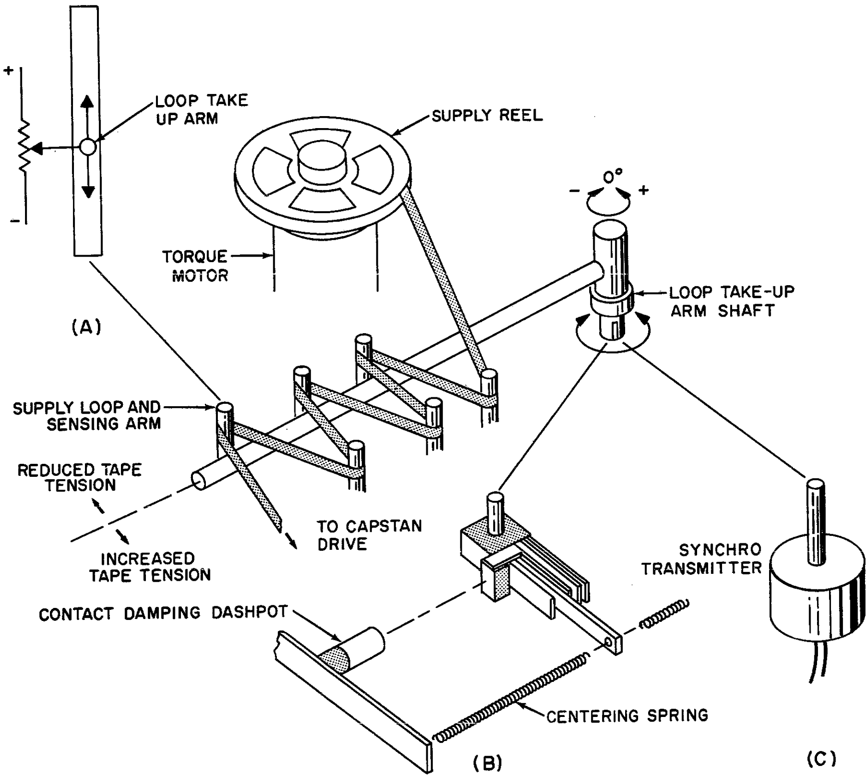

Fig. 2-3. *Tension-arm take-off sensors: (A) potentiometer; (B) dash pot; (C) synchro transmitter.*

The Cook Electric Company's Model 59 digital magnetic tape transport is shown in Fig. 2-4. The dust cover or door is open and the tape deck and elements are clearly shown. Following the tape path from lower reel to upper reel, the following components are shown: dancer arm with precision bearing rollers (provides correction tension, tape storage, and tension error sensor drive); vacuum chamber (provides minor tape storage and tape cleaning station); reverse capstan and actuator; tape brake; plug-in head assembly; tape brake; forward capstan and actuator; vacuum chamber; dancer arm; and upper precision reel. The tension arm position is sensed by a synchro. The reel servo system is a proportional system and does not employ relays or other mechanical switching devices. Vacuum buffer pads are used to damp mechanical transients developed in the tape while cycling (FWD, STOP, FWD).

Vacuum-Loop Tape Reservoir

Although the pulley tension arm is widely used, there are several other tape reservoir configurations on the market. The vacuum loop or chamber and storage bin systems are quite popular. The vacuum type tape reservoir

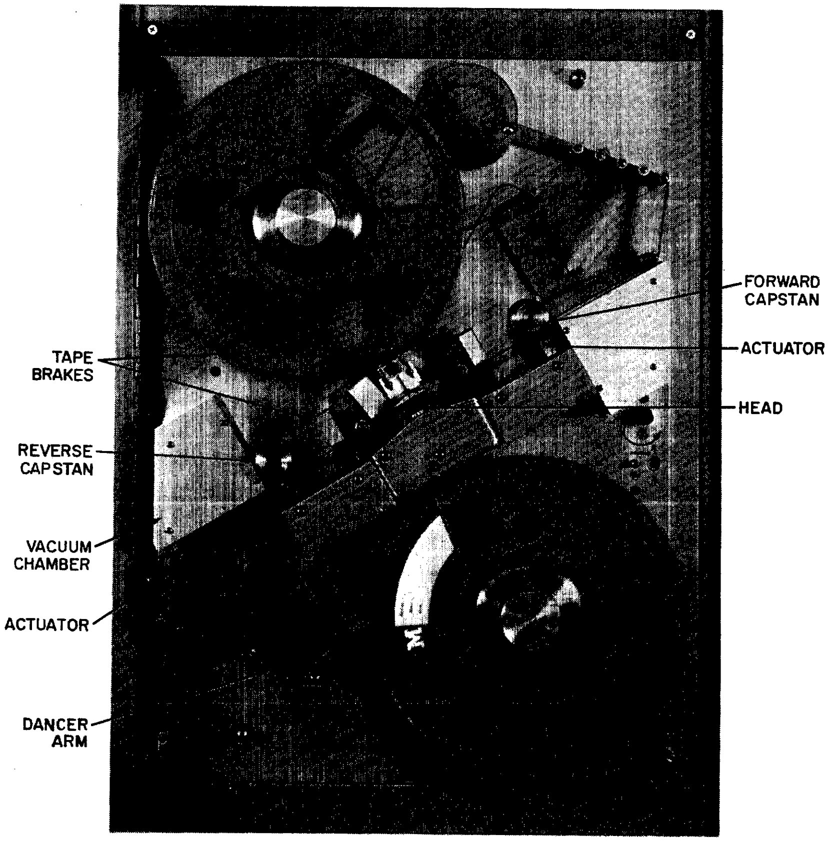

Fig. 2-4. *The Cook tape transport, Model 59 (Cook Electric Company).*

may be a single or double loop configuration. The single loop, shown in Fig. 2-5, permits the tape loop to expand and contract in two directions. Tape length measurement is achieved by an integrated pressure value, an effective capacitance, or a photoelectric indicator. Tape is drawn into the reservoir and the loop shaping is done by differential pressure. The output signals of transducers located along the chamber column are used to control the reel servo motors which, in turn, drive tape into, or remove tape from, the reservoir according to the direction in which the tape is being driven by the capstans.

This system is a good illustration of the principles involved in the design of a reservoir and its associated servo control system. The shape of the tape loop approximates an ellipse bounded by the retainer walls, chamber base, and plate glass cover. Air is evacuated from the chamber at its extremities and tape shape is maintained by the pressure difference between the inside and outside of the loop. The pressure difference can be increased by a slightly positive pressure within the loop. The first effect of this pressure difference

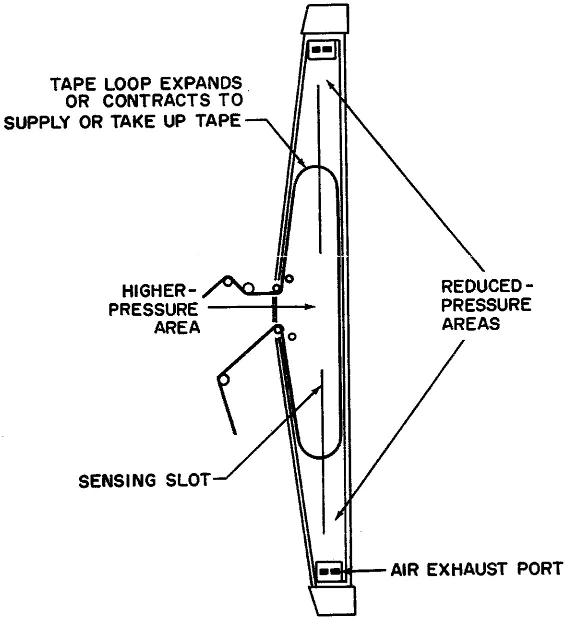

Fig. 2-5. *A vacuum reservoir with a variable tape loop.*

is to maintain the tape taut within the chamber at a loop size dependent on the amount of tape available. If more tape is removed from the chamber at one end than is supplied at the other, the loop is reduced. If more tape is supplied at one end than is removed at the other, the loop will be increased. Narrow sensing slots near the base of the chamber are connected by tubing to a pressure-sensitive transducer in a sealed compartment. The expansion or contraction of the tape loop induces changes in the moving element of the transducer. The pressure sensitive element generates a corresponding electrical signal that is proportional to the rate of change of the loop size. This signal is converted into a form suitable to activate the drive motor of the tape reel associated with the vacuum chamber. The null-seeking servo system attempts to maintain an optimum loop length in the chamber.

The front view of the Ampex Model TM-2 digital tape handler is shown in Fig. 2-6. This model illustrates how the vacuum storage column gently holds the tape supply and take-up loops. Notice the vent holes within the loop and the evacuating ducts at each extremity of the chamber. Long and short sensing in the vacuum chamber is available. The vacuum columns instantly supply or take up tape until the reels have accelerated to proper speed. The packer arm prevents cinching by pressing out inter-layer air during fast modes, thereby maintaining a firm tape pack. The tape handling area is maintained with filtered air at higher than atmospheric pressure to keep the area clean.

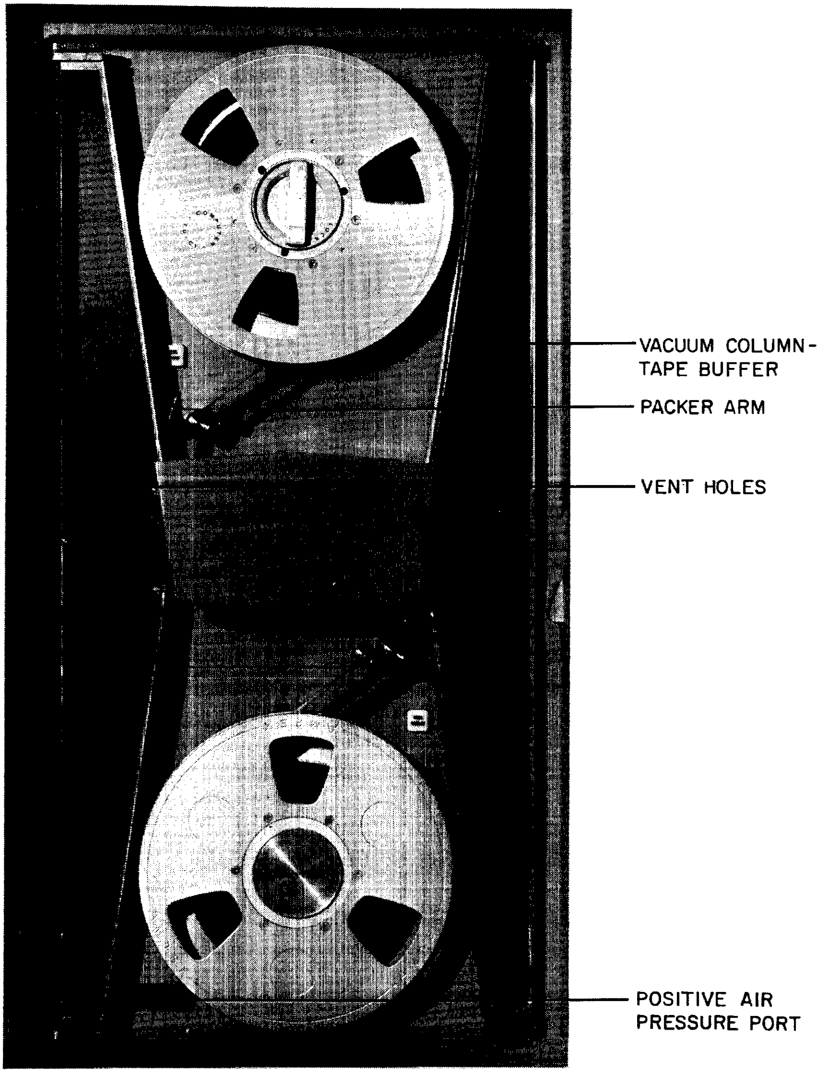

Fig. 2-6. *A front view of the Ampex TM-2 tape unit (Ampex Corporation).*

Storage Bin Tape Reservoir

Of the three tape reservoir configurations (tension arm, vacuum loop or chamber, and storage bin), the storage bin employs the longest tape length and, therefore, the drive motors of the lowest power (Figs. 2-7 and 2-8).

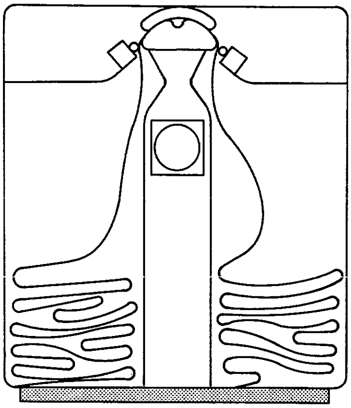

Fig. 2-7. *A tape bin reservoir.*

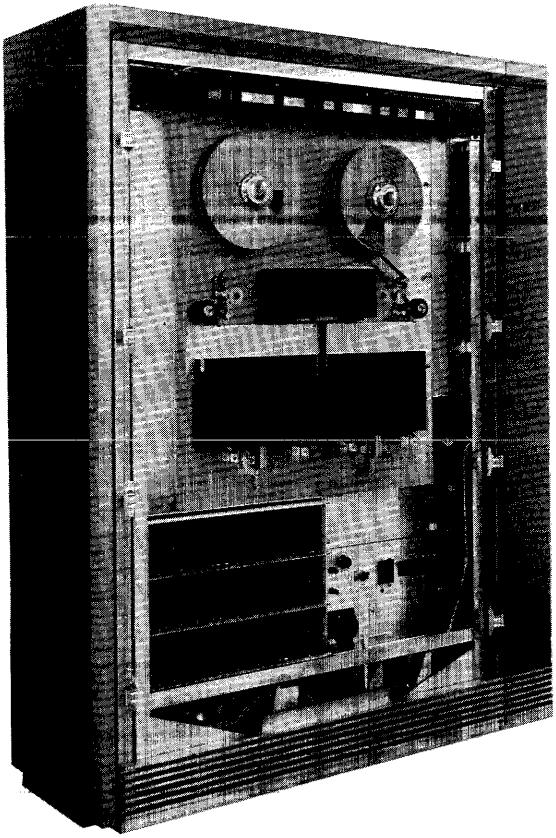

Fig. 2-8. *The RCA tape bin unit for the RCA 581 Tape Station.*

A number of methods for measuring the length of loosely-folded tape in the bin can be used. The tape can be accurately weighed, measured by photosensitive elements, or its length can be sensed by the capacitance method. In the latter method, an air-dielectric capacitor is formed by two plates of the storage bin. This is accomplished by evaporating a metallic film on the plate surface that is thin enough to leave the plate transparent for observations. A change in capacitance is caused by the dielectric properties of the tape lying between the two plates of the air-dielectric capacitor. The change of capacitance is very small and the sensing circuit can be made sufficiently drift free by selected components that are temperature-compensated.

Tape Drives

The prime requirement of a digital transport is that it perform in accordance with issued commands from an automatic controller, such as a computer or similar device. The mechanism should follow any combination of commands in random order and impose a minimum of restrictions upon its controller. The capstan will move the tape at a constant linear velocity past the head in accordance with the issued command.

The most important part of the digital transport is the magnetic tape. Therefore, the tape drive must be designed around the magnetic tape's physical properties. Any area of contact or possible tape wear must be diminished or eliminated. The tape accelerating forces should be distributed uniformly over a large area to lessen skew effects and minimize any transverse vibrations (Fig. 2-9).

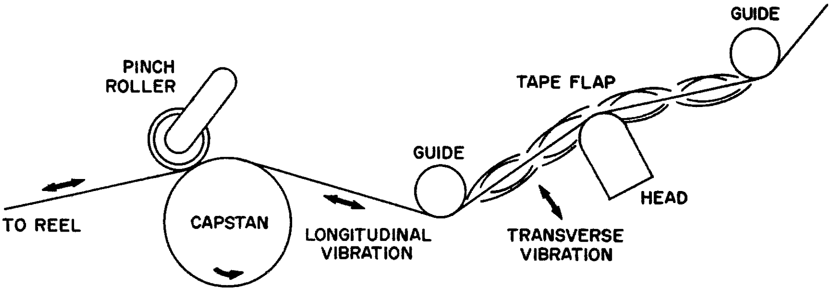

Fig. 2-9. *Tape vibration: longitudinal and transverse (Midwestern Instruments).*

Pinch Roller Drives

The most common tape drive is pinch roller, shown in Fig. 2-10. In most designs the pinch roller is rubber covered and is driven by friction from the capstan. To drive the tape, an electromagnetic actuator moves the pinch roller

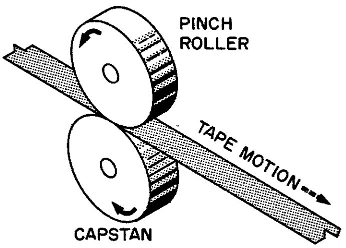

Fig. 2-10. *A pinch roller drive mechanism.*

down to the capstan and pinches the tape between them. The pinch roller compresses slightly and imparts drive to the tape. Since start-stop times and distances depend largely upon pinch roller clamp performance, actuators require large forces to shift the mass of the pinch roller from one position to another in the shortest possible time. Thus, the tape is trapped and held in position between the pinch roller and capstan while both are continuously moving. To get the tape up to speed quickly, energy is imparted to the length of tape in the tape reservoir, not that on the reel, thus exerting very little force on the capstan drive.

Pinch roller drive must be designed carefully to minimize tape damage and distortion. Assuming that the pair of rollers are absolutely parallel and the tape is perpendicular to the roller axis, tape thickness variation may cause the driving roller to produce skew and permanent tape deformation, as illustrated in Fig. 2-11. The hammer blow of the pinch roller upon the capstan may emboss wear particles or other foreign matter into the oxide of the tape. This action may create ridges of loose oxide that can accumulate on the magnetic head, thereby reducing the life of the tape and the magnetic head. These problems and others do not invalidate the use of the pinch roller. The clamp pressure is not very high and the tape medium thickness is fairly uniform and has sufficient resilience. Most tape transports extract dust and dirt and purify the air to ensure good performance and prevent contamination of the tape.

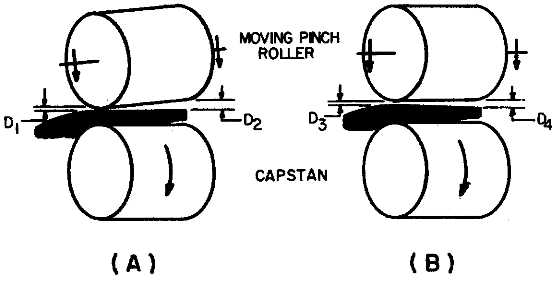

Fig. 2-11. *Skew considerations for pinch rollers: (A) out-of-line pinch rollers; (B) tape thickness variation (Minneapolis-Honeywell).*

Vacuum Drives

Although pinch rollers perform well, the demand is increasing for more sophisticated tape transports that will permit more gentle tape handling, higher tape speeds and packing densities, and more reliable operation. One tape drive method that overcomes some shortcomings of the pinch roller drive is the vacuum drive. The vacuum drive utilizes a pneumatic capstan which is a hollow rotating drum with slots or holes on its periphery (Fig. 2-12A). The reservoir within the capstan is connected to a valving arrangement that permits either evacuation or pressurization. As the tape passes over the drum it is in contact with over 90° of the drum's surface. Under normal conditions, the friction between the vacuum capstan and the tape is insufficient to cause the tape to move. When the capstan reservoir is evacuated, however, atmospheric pressure forces the tape into intimate contact with the drum, greatly increasing the frictional forces. As a result, the tape is propelled in the direction of motion of the capstan. The tape can be released by increasing the pressures within the capstan above normal atmospheric pressure. The tape then will float above the drum surface on a film of air.

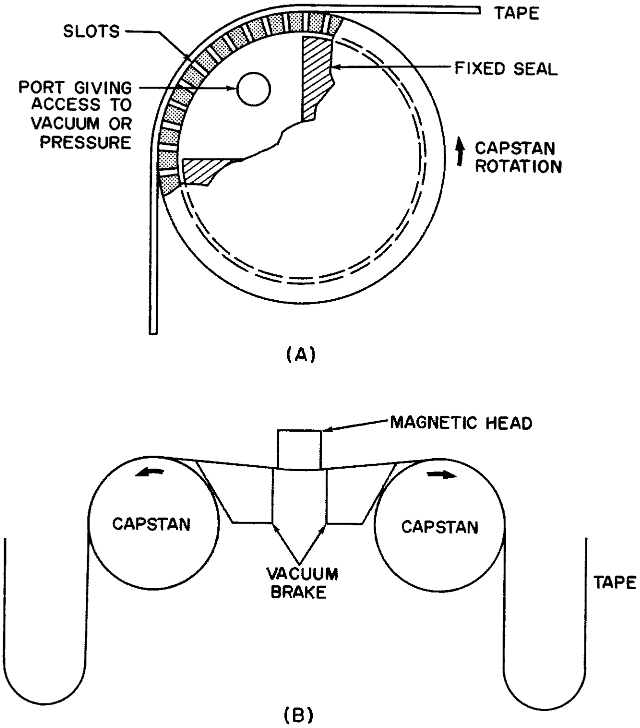

Fig. 2-12. *Vacuum drive and vacuum brake.*

The digital transport using this concept is made of two counter-rotating capstans connected to a regulated pressure supply (Fig. 2-12B). To drive the tape forward, one capstan is evacuated and the other is pressurized. To drive in reverse, the above operation is reversed.

Tape life is longer with vacuum drive than with the pinch roller drive. However, there are particular problems associated with vacuum drive. Although tape acceleration is more gentle, it is limited by the pressure differential between atmospheric pressure and absolute vacuum. Also, the switching arrangement is complicated by the fact that the capstan pressure variation must be changed from above atmospheric pressure to below atmospheric pressure, requiring a source of positive pressure as well as a source of high vacuum. The pneumatic logic operations involved are relatively new and subject to constant product improvement.

One of the most recent tape transports incorporating the vacuum capstan drive is the Minneapolis-Honeywell Type 804 magnetic tape mechanism. Figure 2-13A shows a close-up of the capstan area and the magnetic head. The centrally-located, three-inch diameter billet houses the magnetic head assembly, which contacts the oxide surface of the uppermost tape side. The tape lies horizontally over a two-piece horizontal vacuum brake and makes a 90° turn downward into the vacuum loop chambers. Each capstan, when not actively engaged in moving the tape, is provided with a positive pressure of 2 psi that floats the tape above the capstan. Figure 2-13B shows the capstan and head area with the head pivoted away from the tape oxide surface. This head motion is automatically controlled and on fast winds and rewinds there is no tape-to-head contact. (This feature also simplifies the tape changing operation.) A view of the disassembled capstans, brake, and actuators is shown in Fig. 2-14. The capstans (only one is shown) are mounted directly to shafts with very little runout and taper. Tight tolerances are held on the machine parts to achieve good tape tracking.

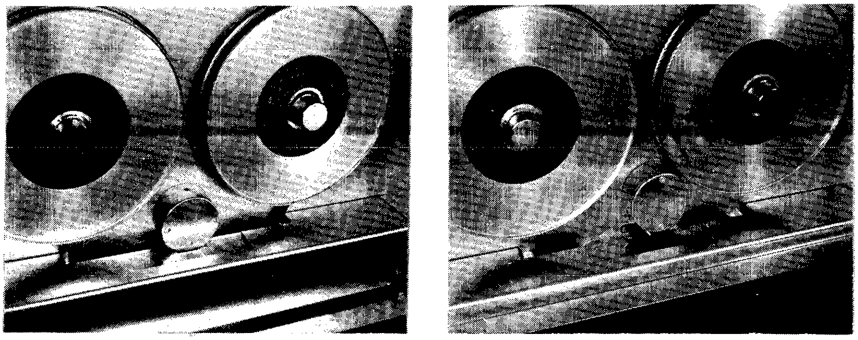
(A) (B)

Fig. 2-13. *Head area detail: (A) in tape operation position; (B) with head pivoted away from tape (Honeywell Type 804).*

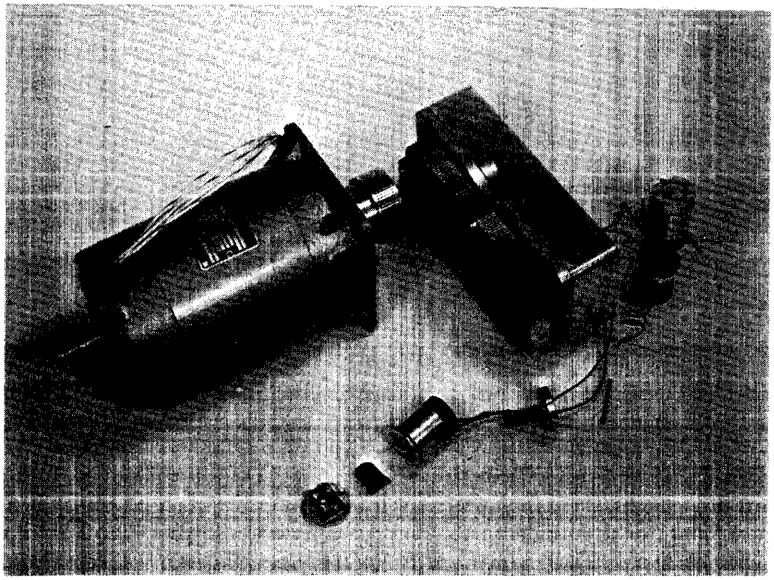

Fig. 2-14. *Close-up of vacuum capstans, brake, and actuators (Honeywell Type 804).*

Pressure Drives

Another method of tape acceleration is the positive pressure drive. This is a pneumatic system using only positive pressure that offers the advantages of vacuum drive and is not limited by the pressure differential between atmospheric pressure and absolute vacuum. As this system operates in an atmos-

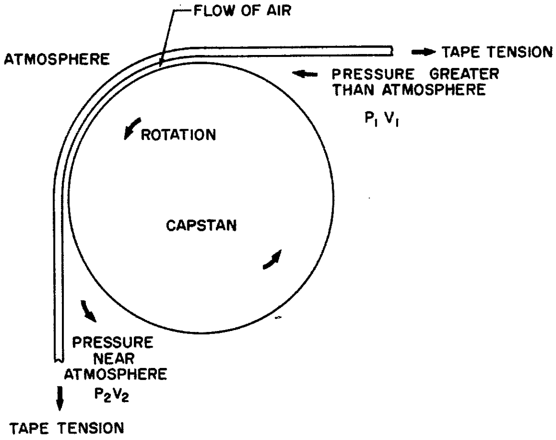

Fig. 2-15. *Pneumatic drive system: Bernouilli Principle (Midwestern Instruments).*

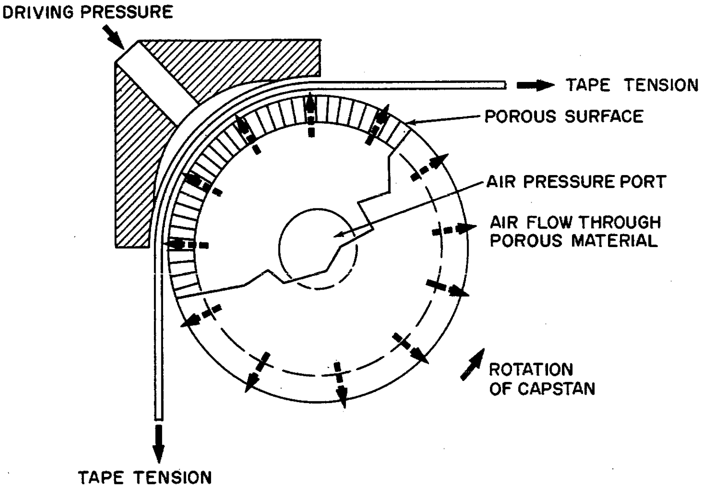

Fig. 2-16. *Pneumatic drive system: positive air pressure (Midwestern Instruments).*

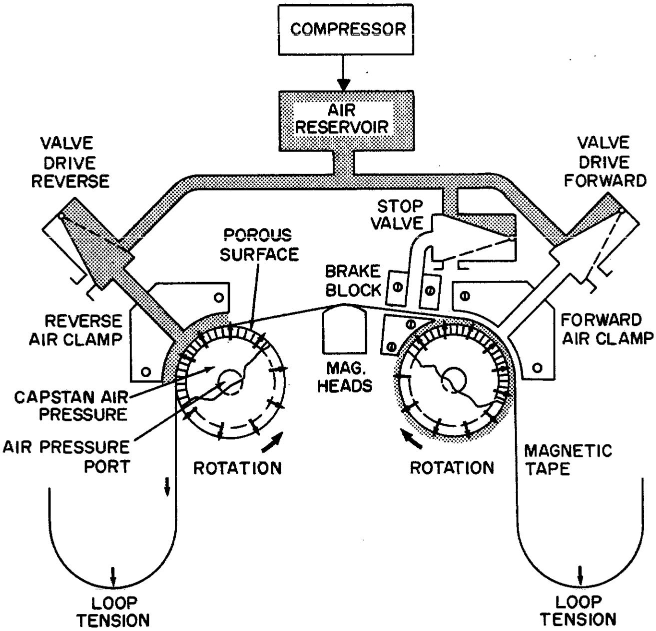

Fig. 2-17. *The pneumatic drive assembly, showing the tape driven in reverse (Midwestern Instruments).*

phere, a pressure greater than atmosphere applied between the tape and the capstan will float the tape. If a pressure greater than the floating pressure is applied on the outside of the tape, the tape will then compress against the capstan and will be accelerated by a force equal to the difference between the driving force and the floating force times the dynamic coefficient of friction. The floating air pressure needed for this drive can be achieved in two ways: (1) by applying the Bernoulli principle (Fig. 2-15); or (2) by using a constantly pressurized capstan having a homogeneously porous surface (Fig. 2-16). The latter method has been more successful for the following reasons: (1) the floating pressure can be regulated and is independent of the

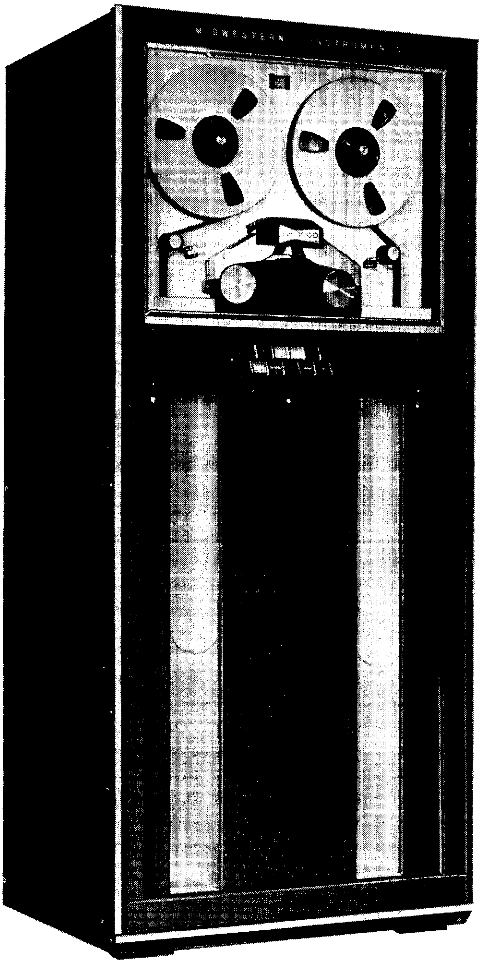

Fig. 2-18. *Midwestern tape transport Model 300 (Midwestern Instruments).*

capstan velocity; (2) when the capstan is under compression, the floating air molecules are pushed back through the pores, thereby eliminating the time-consuming operation of discharging the air bearing; (3) the tape accelerating time can be regulated by the driving pressure.

This method of positive pressure drive is equally applicable to tape braking by expelling air to force the tape against a braking surface.

The Midwestern Instruments' Model M3000 shown in Figs. 2-18 and 2-19 employs positive pressure capstan drive. In normal operation, clamps A1 and A2 assume the positions shown in Fig. 2-19. The capstans rotate at a constant speed and in opposite directions. Air is forced through the porous capstans at enough pressure to effect tape flotation (less than 3 psi). In standby, the capstans are rotating but the tape is held motionless. In this mode, air is directed to the brake orifice, which holds the tape against the lower surface of clamp A2, while air bleeding from the capstan provides a complete disengagement of the tape from the capstan. Upon receipt of a command (e.g., forward), the reeds in the valve open capstan orifice CO2 to a pressure of 15 psi while disengaging the brake. The pressure differential created is sufficient to produce viscous coupling between tape and capstan surfaces, thus effecting forward drive.

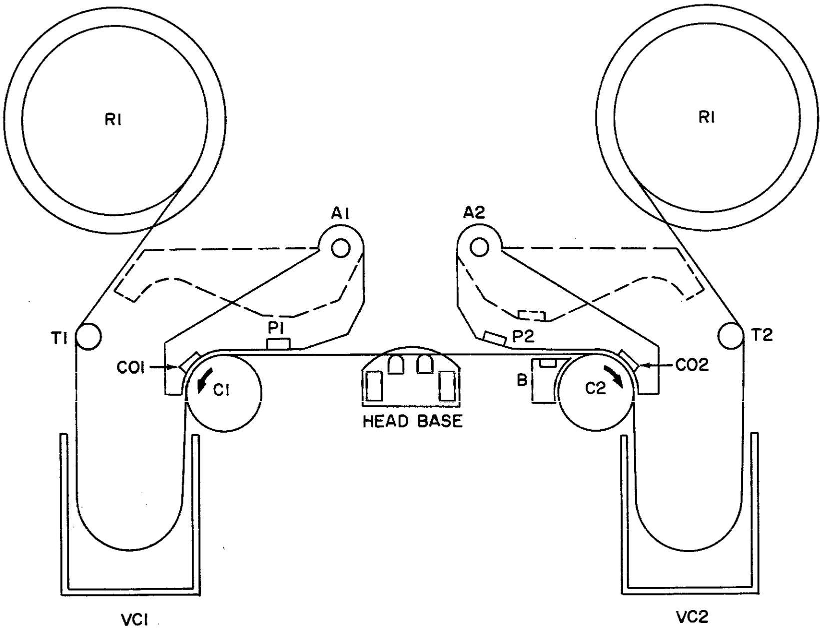

Fig. 2-19. *Positive air pressure drive system (Midwestern Instruments).*

Table 2-2 and Fig. 2-20 compare the characteristics of the three types of tape drives discussed in this section.

TABLE 2-2. Comparison of Tape Drives*

	Pinch Roller Drive	*Vacuum Drive (Optimum)*	*Pressure Drive (Optimum)*
Time from command signal to the beginning of accelerations	.5 ms	1 ms	1 ms
Time of acceleration from 0 to full velocity	100 μsec	2 ms	1 ms
Time required from full velocity to fully regulated tolerance ±5%	5 ms	0	0
Total accelerating time from command signal	5.6 ms	3 ms	2 ms
Starting distance to reach ±5% of final velocity	.600″	.120″	.060″
Average accelerating force on 1″ wide tape	10.5 lbs	.5 lbs	1 lbs
Average tensile stress during acceleration on the tape	5650 psi	525 psi	792 psi
Stretch proportion	10.75	1	1.51
Time from command signal to the beginning of deceleration	1 ms	1 ms	1 ms
Deceleration time	.5 ms	2.5 ms	1 ms
Total decelerating time	1.5 ms	3.5 ms	2 ms
Average decelerating force	1.25 lbs	.416 lb	1 lb
Stopping distance	.150″	.270″	.180″
Total stop-start time	7.1 ms	6.5 ms	4 ms
Total stop-start distance	.750″	.390″	.240″

Tape Brakes

An efficient braking system in conjunction with a fast starting tape drive system will minimize the vacant space on tape, thereby saving time and tape. The braking time and stopping distance are less than their acceleration counterpart (Fig. 2-20). In the pinch roller drive, the tape brake consists of two rubber pads mounted above the tape guide block, one on each side of the head. When the tape has to be stopped, the tape brake actuator is energized and the pads press the tape against the brake blocks. The tape is clamped at these points and cannot move. Any further motion of the tape reels is accounted for by an addition or deletion from the supply of tape in the tape reservoir.

The vacuum brake is similar in operation to the mechanical brake used in the pinch roller drive. Portholes are located on each side of the brake

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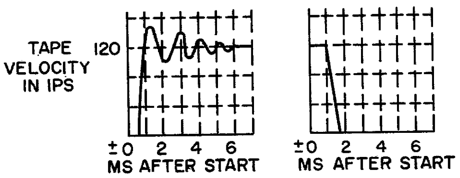
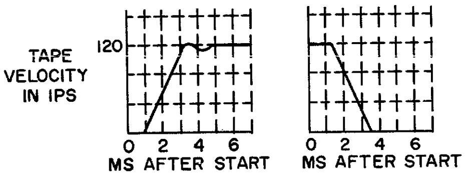
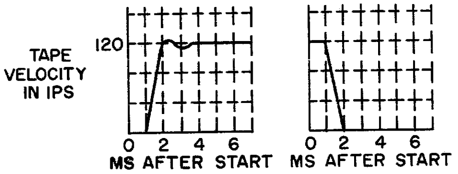


(A) PINCH ROLLER TYPE ACCELERATION & DECELERATION



(B) VACUUM DRIVE ACCELERATION & DECELERATION



(C) PRESSURE DRIVE ACCELERATION & DECELERATION

Fig. 2-20. *Acceleration and deceleration graphs for tape drive systems: (A) pinch roller; (B) vacuum drive: (C) pressure drive (Midwestern Instruments).*

head. During tape motion, the tape may by floated or the portholes may be evacuated. The latter method is somewhat similar to "driving with the brakes on," which is possible because the driving capstan area is greater than the braking area. The braking time and stopping distance are greater than in the pinch roller method. The stopping action is achieved in a two-step process. First, the air source for tape flotation is removed and then the chamber is evacuated to bring the tape in contact with the brake surface. This can be aided by directing a positive pressure against the tape above the brake portholes.

Driving Systems

During recording and playback, the reel motor drives must provide, as far as possible, steady tension on the tape, both in fast forward and reverse running directions. An ideal supply reel should feed tape out smoothly and the take-up reel must change its rotational speed to compensate for the slowly-increasing winding diameter. Whatever the speed or direction of rotation, each motor or drive exerts torque in the same direction.

Because variation in tape speed and tape tension across the head or heads is undesirable, tension-sensing devices have been incorporated that provide an input to the servo control of the reel drive. Each reel drive is associated with a separate tape reservoir that automatically produces the desired tape tension by allowing for the disparity in the speeds of the feed motor drive, tape take-up motor drive, and capstan drive.

The driving system may be comprised of one, two, or three motor systems. A single motor system would require complex linkages to perform a multiplicity of functions. For maximum simplicity of design involving a minimum number of mechanical linkages, three motors are used and, generally, two speeds. Digital applications require a constant speed for recording and playback, consistent with the compatibility of the electronic circuitry and other related devices. A fast rewind is used to reduce the rewind time interval at a speed that is usually at least double the tape operational speed. The three motor systems easily furnish the required power for tape wind, capstan drive, and rewind. The design becomes complicated because of the two-speed automatic changing, with each motor drive considered as being operated with its own set of semi-independent controls. For example, each tape reel, depending on the tape direction, has its own tape reservoir to regulate its speed and turn-on, turn-off time. The reel drives must accommodate a wide variety of start-stop operations, the continually varying duration of each operation and, at the same time, handle the tape gently. The reel motor is actuated by the buffer loop sensing devices and is independent of the capstan drive. The tape sensors associated with the tape reservoir ensure that constant or nominal tape length is achieved via the reel servo system.

There are start-stop operations where the reel drives and capstan drives are not on at the same time. The capstan drive and the brakes are interrelated. The capstan is a constant speed device and generally a single-speed operation. Its primary purpose is to move the tape during a record or playback operation. If the tape operation is in one direction, the capstan drive is in one direction. During a fast wind or rewind, the capstan is disengaged from the tape to prevent wear. The tape brake is only used during a record and playback operation. The brake drives are activated to halt the tape until further tape operations are required. During fast wind and rewind operations, the brakes are disengaged and the reel drive system not only moves the tape but is provided with sensors to monitor the tape and control the application of braking power to the reel drive shafts. In this manner, with appropriate controls, the tape is stopped gently from a high speed and is positioned to begin operations again.

Tape and Head Contacts

It is important that the tape, in its movement past the head, remain in continuous, intimate contact with the head across the head gap. Proper tension on the tape could be obtained if associated mechanical parts and the tape

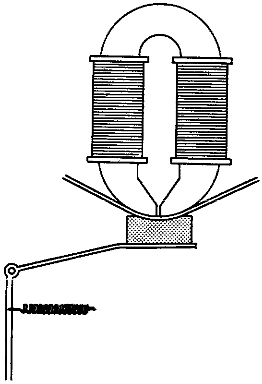


Fig. 2-21. *Pressure pad operation.*

medium were perfect. This is impossible, however, and measures must be taken to ensure head-to-tape contact during recording and playback operations. From a mechanical viewpoint, it is common practice to provide some positive pressure against the tape in the direction of the head. The most common device is a spring-loaded lever with a small felt pad attached at the free end (Fig. 2-21). The pad presses the tape against the head when it passes the head gap and holds the tape firmly in close contact with the head. On fast rewind operation in either direction, the pads are positioned away from the head. Use of a pressure pad should be avoided.

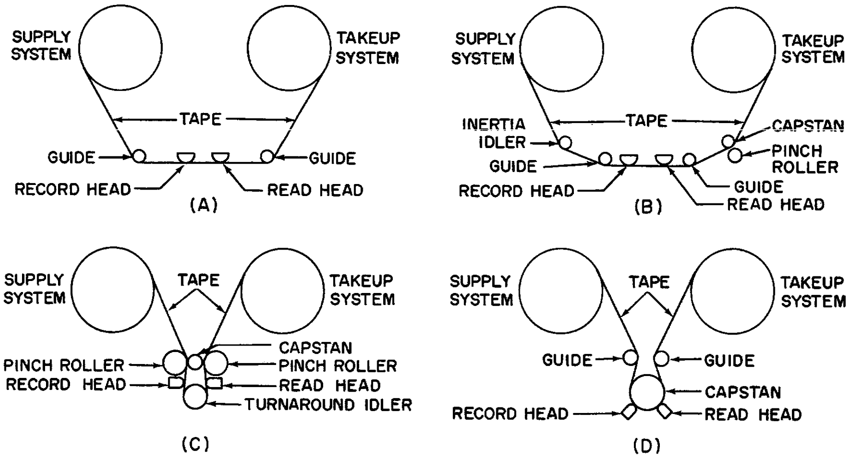


Fig. 2-22. *Tape, head, and capstan drive geometry: (A) basic tape transport; (B) open-loop tape drive; (C) closed-loop tape drive; (D) zero-loop tape drive.*

Another contact method positions the head into the tape with sufficient tension on each side. Generally, the tape is in contact with a larger head surface, depending on the geometric configuration of the head block. For fast rewind operations, the head is pivoted away from the tape or the tape is raised away from the head. When vacuum drives are used, contact is maintained by use of the brake portholes located on the head block. The brakes are always applied (air is evacuated) and the tape is held firmly in contact with the head. For fast rewind operation, the brake portholes are pressurized and the tape is literally "blown upwards" away from the head block, freeing it from all contact with the head. With either method, tape preservation is ensured by prohibiting any contact whatsoever between the tape medium and any surface on the tape deck for all operations other than record or playback.

There are numerous head-to-tape configurations. Depending on the selection and location of other tape transport elements, a wide variety of geometrical relationships between tape, head, and capstan drive are available (Fig. 2-22).

Tape Guiding

Tape should be under guidance control at all times. At each reel the tape should be carefully handled to prevent any scraping of the edges. Any tape contact with the reel will eventually destroy the tape edges and cause other serious problems. For example, such contact loosens material from the tape which may subsequently accumulate upon the heads, necessitating their replacement. In extreme conditions in vacuum systems, such material is liable to clog the system. Uneven tape feeding or tape winding may intermittently retard the tape speed. Obviously, precision reels driven by low eccentricity run-out of the reel shaft perform the initial tape guiding as the tape winds and unwinds. Tape guide rollers should be free running at predetermined points to ensure consistent tape alignment throughout its length between the two reels. If the rollers are provided with shoulders or grooves just wide enough to permit the tape to pass around them without pinching or snatching, small alignment corrections are obtained. Eccentricities in these rotating elements must be carefully controlled to avoid tape cinching and tape speed variation.

To avoid tape snake dancing over the head, a separate guide is mounted on each side or part of the head. Thus, final alignment corrections are made and maintained as the tape passes on the head. This does not mean that all tape guiding corrections can be accomplished at the last minute prior to passing over the head; it means that nominal guiding corrections are accomplished. In fact, head alignment procedures associated with head replacement are eliminated.

The most advanced tape guiding takes advantage of the precision cutting of the tape medium. One edge of the tape is used as a reference line that is

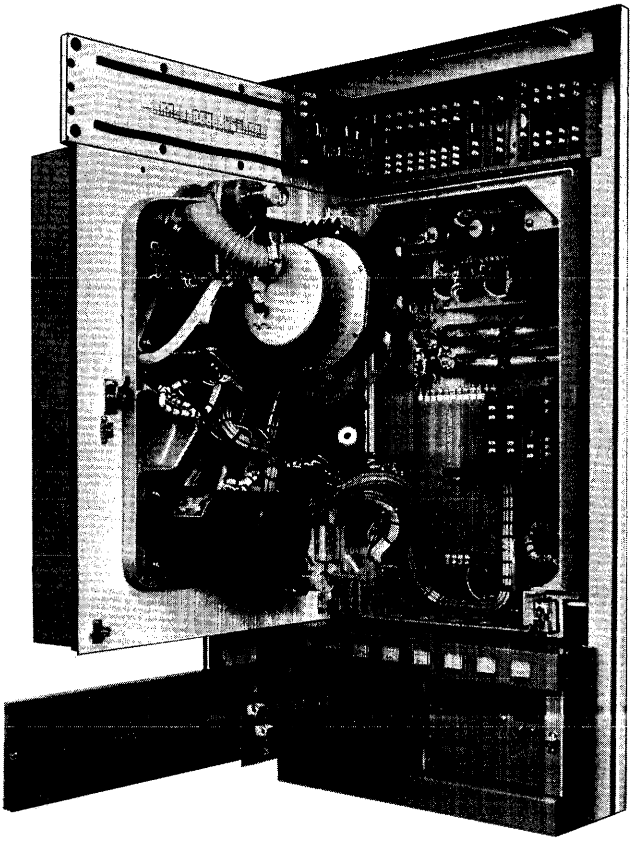


Fig. 2-23. *Rear view of the Cook Model 59 tape transport.*

on a common surface with the two tape reels and parallel to the tape deck. The tape is guided by this back edge and the front edge is free to account for the tolerance of the tape. Continuous guiding affords better guidance control than periodically-spaced flanged rollers. Snaking can be reduced to the extent that other areas make a more prominent contribution to skew problems. Today, tape slitting can be held to a tolerance of +.000 and −.001 inch, but the standard manufacturing tolerances are +.000 and −.003 inch.

Tape Deck Layout

The tape deck layout and construction must be adequate to withstand constant start-stop operations. Invariably, this type of short-duration, high-shock vibration can set up mechanical oscillations throughout the tape deck and affect all mounted components. To avoid any mechanical failure, mechanical

TABLE 2-3. Characteristics of Commercially-Available Tape Transports

Manufacturer	*Model No.*	*Tape Reservoir*	*Reservoir Sensor*	*Reservoir Tape Length*	*Reel Drive*	*Reel Brake*	*Reel Drive Power*	*Tape Drive*	*Tape Brake*
AMPEX	TM-4	Tension arm plus vacuum chamber							
BURROUGHS	BC 422	Vacuum loop	Photoelectric 5 step		D-C servo	Mechanical (emergency)		Mechanical	Vacuum
CDC	603	Vacuum loop	Photoelectric	114 in.	D-C servo	Magnetic	60 in. lb. torque	Pneumatic	Vacuum
	606	Vacuum loop	Photoelectric	114 in.	D-C servo	Magnetic	60 in. lb. torque	Pneumatic	Vacuum
	607	Vacuum loop	Photoelectric	114 in.	D-C servo	Magnetic	60 in. lb. torque	Pneumatic	Vacuum
CEC	DR 2700	Tension arm plus vacuum chamber	Precision potentiometer	96 in.	A-C motor	Mechanical (emergency)	1/7 h.p.	Mechanical	Mechanical
COOK	59	Tension arm plus vacuum chamber	Synchro	92 in.	D-C servo	Mechanical	400 in. oz. torque	Mechanical	Mechanical
	750-7300	Tension arm	Synchro	73 in.	D-C servo	Gear loading	1/5 h.p.	Mechanical	Mechanical
DATAMAC	D2020	Vacuum loop	Pressure switch	50 in.	D-C servo	Mechanical	200 in. oz. torque		Mechanical
HONEYWELL	804	Vacuum loop	Electro-pneumatic switch	98 in.	D-C servo	Mechanical	1/4 h.p.	Vacuum	Vacuum

TABLE 2-3. (Cont.)

Manufacturer	*Model No.*	*Tape Reservoir*	*Reservoir Sensor*	*Reservoir Tape Length*	*Reel Drive*	*Reel Brake*	*Reel Drive Power*	*Tape Drive*	*Tape Brake*
IBM	Hypertape 7340-7640	Vacuum loop	Capacitive	60 in.	D-C servo	Mechanical		Mechanical	Mechanical
	729 II-IV	Vacuum loop	Pressure	12-15 ft.	Induction motor	Magnetic	1/3 h.p.	Mechanical	Mechanical
MIDWESTERN	M 3000	Vacuum loop	Vacuum	10 ft.	D-C servo	Mechanical	1/8 h.p.	Pneumatic	Pneumatic
POTTER	906 II-2	Tension arm plus vacuum chamber	Precision potentiometer	60 in.	D-C servo	Mechanical	1/4 h.p.	Mechanical	Mechanical
RCA	582	Tape bin	Differential transformer	50 ft.	Induction motor	None	160 in. oz. torque	Mechanical	Mechanical
	581	Tape bin	Differential transformer	40 ft.	Induction motor	None	90 in. oz. torque	Mechanical	Mechanical
	382	Tension arm plus vacuum chamber	Differential transformer	88 in.	Induction motor	Mechanical	65 in. oz. torque	Mechanical	None
	381	Tension arm	Differential transformer	68 in.	Induction motor	Mechanical	35 in. oz. torque	Mechanical	Electro-mechanical
UNIVAC	III A	Vacuum loop	Pressure	12 ft.	Induction motor	Mechanical	240 in. oz. torque	Clutched capstan, vacuum assisted	Braked capstan, vacuum assisted
	III C	Vacuum loop	Pressure	12 ft.	Induction motor	Mechanical	240 in. oz. torque	Clutched capstan, vacuum assisted	Braked capstan, vacuum assisted

TABLE 2-4. Speed Characteristics

Manufacturer	*Model No.*	*Start Time (milliseconds)*	*Stop Time (milliseconds)*	*Start Distance (inches)*	*Stop Distance (inches)*	*Rewind Speed (ips)*	*Start/Stop Rates (per second)*	*Tape Reversal (per second)*	*Read/Write Speed (ips)*
AMPEX	TM-4	3.3	1.8	.182 ± .020	.065 ± .035	160	120		75
BURROUGHS	BC 422	3	3	.130	.340	375			90/120
CDC	603	2.5	2.5	0.07	0.15	320	90	90	75
	606	3	2	0.2	0.225	320	100	100	150
	607	3	2	0.2	0.225	320	100	100	150
CEC	DR 2700	3.5	2	0.38 ± 0.02	0.15 ± 0.02	200	200	200	150
COOK	59	3	1.2	.210	.150	225	100	100	112.5
DATAMEC	D2020	5	1.5	.080	.045	160	200	100	45.0
HONEYWELL	804	3	3	0.1	0.3	360	250	200	120
IBM	Hypertape	7 (II)				225			112.5
	729 II-IV	5 (IV)		.28	.17	500	125	20	75–112.5
MIDWESTERN	M 3000	4	4	.130	.360	460	100	100	
POTTER	906 II	3	2	.210	.150	240	200	200	100
RCA	582	2.5	2.5	.075 ± .050	.150 ± .035	150			100
	581	2.5	2.5	.075 ± .050	.150 ± .035	100			100
	382	4.3	1.4	.129	.042	120	50		60
	381	7.0	4.0	.105	.06	90	75		30
UNIVAC	III A	3.0	3.0	.12	.15	360	100		100
	III C	3.0	3.0	.13	.20	360	100		112.5

resonances must lie outside the band of the start-stop operations. The most difficult problems are usually encountered in the band up to 1 cps. This varies with each manufacturer; some are able to offer their products with no programming restrictions. A rugged casting is used to mount all the heavy components on the back of the tape deck. In general, heavy components (reel servo motors and capstan motor) are installed symmetrically about the deck for good weight distribution. Large cutout areas and material removal from the tape deck should be avoided. A rear view of the Cook Model 59 tape unit is shown in Fig. 2-23. The simplicity of the front view (Fig. 2-4) belies the existence of such a complex layout as is shown in this photograph.

Characteristics of Modern Tape Transports

Table 2-3 lists characteristics of typical, commercially-available tape transports. Characteristics of their start-stop operations are given in Table 2-4.

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3

Digital Magnetic Heads

The object of magnetic recording is to produce a remanent magnetic state (proportional to the energizing force) at arbitrary points in the tape medium. The magnetic head, as a transducer, functions as an energy converter by converting electrical energy to magnetic energy or magnetic energy to electrical energy. (Magnetic heads have both mechanical and electrical properties. In this chapter the magnetic head is considered in terms of its mechanical construction and geometric configuration. Electronic characteristics are covered along with magnetic recording principles in later chapters. Electrical properties are introduced in this chapter only where it is necessary to establish their need and relation to the head configuration and selection of core material.)

Of the three functions performed by magnetic heads, *recording* (writing new magnetic impressions), *playback* (detecting the magnetic imprints), and *erasing* (obliterating all previously-stored intelligence), the requirements for playback operation are probably the most exacting. When the mechanical construction and assembly of the heads fit the playback requirements, they can very likely be used for the recording and erasing functions with only slight electronic modifications. In fact, a single magnetic head may perform all three operations, although this generally is not done. Sometimes two heads are used and, in some cases, the three operations are performed by three separate heads.

For recording operations, the head is basically a flux-gathering core with at least one coil wound on it. A typical head is shown in Fig. 3-1. A gap separation is used to direct, or focus, a magnetic field in the direction of the tape, which collects the field by reducing the reluctance path between the pole faces of the gap. The core and coils are shielded to prevent pick-up from stray magnetic fields and to prevent magnetic coupling between heads in a multihead configuration.

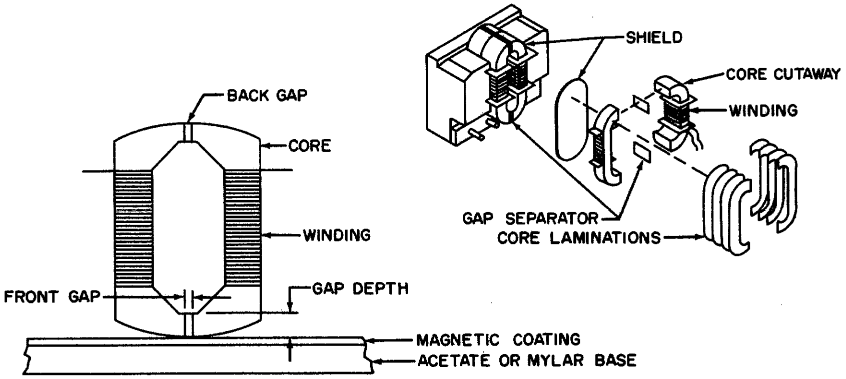

Fig. 3-1. *Magnetic head components.*

Magnetic Field Orientation

Before a magnetic head type can be selected, the magnetic field orientation must be determined. Head configuration and the magnetic remanent state configuration should not be treated independently; considering the magnetic field direction and head location in combination permits a variety of solutions for various problems. However, before an acceptable arrangement is decided upon, factors concerning head construction, fabrication, reproducibility, and cost must be investigated. In addition, the complete processes of recording, playback, and erasing must be made compatible with final head structure and field orientation. Lastly, the applications for digital recording must be considered because they place specific requirements on magnetic field arrangements which are independent of field directions.

The definition and direction of magnetization are closely related to the geometry of the head. The major directions of magnetization of a tape medium, as shown in Fig. 3-2, are *longitudinal, perpendicular,* and *transverse* recording. If the magnetic field is applied in the direction of tape motion, the remanent magnetic field assumes a corresponding direction and the process is called longitudinal recording. Perpendicular recording results when the magnetic field is directed into the tape, registering a field from head surface to head surface. The field direction in transverse recording is perpendicular to that of the previous two methods; the alignment of the magnetic field is from one edge of the tape to the other.

Longitudinal, Perpendicular, and Transverse Recording

Two methods of generating a longitudinal field are shown in Fig. 3-3: by ring-head and by double pole-piece. The two magnetic field patterns show the longitudinal (solid line) and perpendicular (dotted line) components of

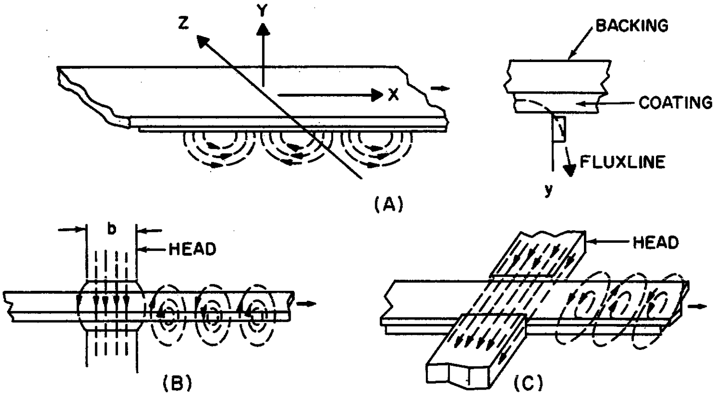

Fig. 3-2. *Major directions of magnetization: (A) longitudinal; (B) perpendicular; (C) transverse.*

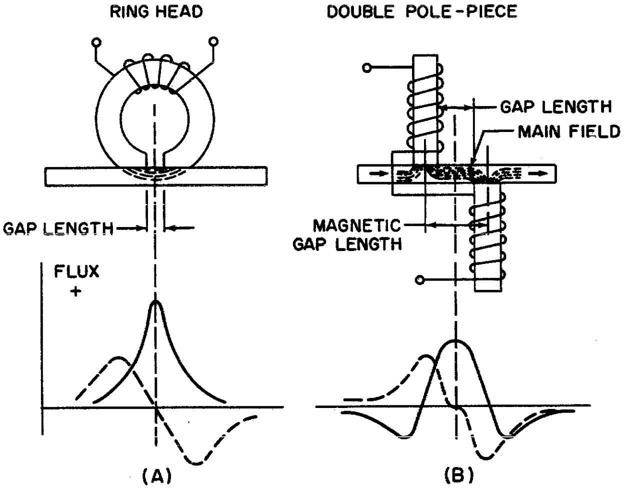

Fig. 3-3. *Longitudinal recording head configurations: (A) ring head; (B) double pole.*

the magnetizing field relative to the head geometry and the tape medium. The coils mounted on the core are energized to generate a magnetic field that is directed to the magnetically-hard recording medium by the pole faces. In both cases the magnetic field leaves and enters the pole faces in a perpendicular orientation. In the presence of tape, the magnetic field is shunted from one pole face through the tape to the other pole face. The gap length determines the recording field length; the magnetic remanent field on the tape is always larger than the physical gap dimensions. The two field directions illustrate the useful flux field (the longitudinal) and the auxiliary field or energy loss field (the perpendicular). In the ring head configuration, however, not all of the perpendicular field is a total loss. Some of it is gathered at the head-to-tape contact surface area and loops the pickup coils during the playback operation. Actually, it is the stray or leakage field across the gap that is useful in longitudinal recording. (The gap shape and pole profile will be examined in detail later.)

The double pole-piece head (Figs. 3-3B and 3-4) is shown as a second method of longitudinal and perpendicular recording, but numerous shortcomings prevent it from being seriously considered in either orientation: it is difficult to fabricate and align while maintaning tight tolerances; a narrow gap length is difficult to machine and maintain; the feeding or initial tape loading for this configuration is very difficult. Such problems are only a few of the reasons why the double-pole structure is not preferred. A closer look at the fringe fields shown in Figs. 3-3B and 3-4B will substantiate that the two-pole structure has little to offer.

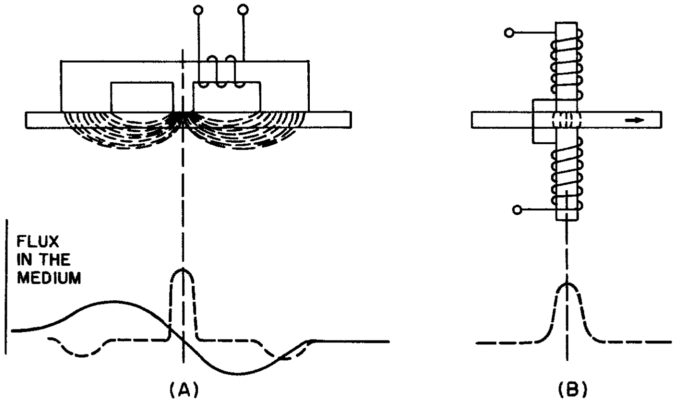

Fig. 3-4. *Perpendicular recording head configurations.*

The other method of perpendicular recording places the head on one side of the tape (Fig. 3-4A). The field is concentrated in the perpendicular direction by the center leg of the E-shaped laminated core. The flux field is divided equally in both directions, with opposite fields on each side of the center leg. The field is concentrated in the perpendicular direction and its magnitude is sufficient to magnetize the medium at that point. This method has been used successfully in magnetic disc recording but not in magnetic tape recording.

Transverse recording (Fig. 3-5) can be achieved by scanning (multiheads on a single recording track) or by using a long air gap. In any event, this method of magnetic recording, like perpendicular recording, has little to offer in the digital recording field and is seldom used.

Longitudinal recording, therefore is generally employed for conventional recording purposes and especially for digital purposes. Magnetic focusing is achieved by the absence (air gap) or the presence of material (core leg). Invariably, it is less difficult to define and maintain an air gap of 500 microinches than a laminated pole face or single-wire turn head of the same dimension.

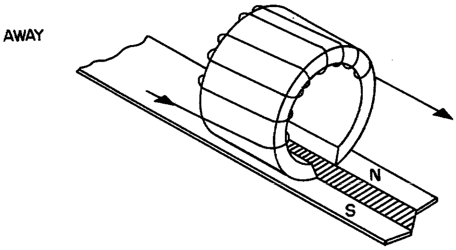

Fig. 3-5. *Transverse recording.*

The Magnetic Core

A ring-core head structure is generally used because it is easier to fabricate and because numerous core materials are acceptable. The arrangement lends itself to symmetrical construction of two exact legs with front and rear gap arrangements. This core configuration is preferable because hum pickup from stray fields is lower and because leakage is minimized during recording and playback. The effect of external fields is considerably reduced by arranging the windings so that they have an equal number of turns and by placing them on parallel legs on each side of the air gap. The coil winding arrangement may have a two-, three-, or four-lead arrangement. The current-carrying capacity of the windings is determined to satisfy the head operation (record, playback, or erase), and is generally far in excess of values required to saturate the tape.

A number of winding arrangements are shown in Fig. 3-6. A separate coil is shown on each leg and three wiring arrangements are delineated. The magnetic head may be required to perform more than one operation and, therefore, a multitap or multicoil winding arrangement may be used.

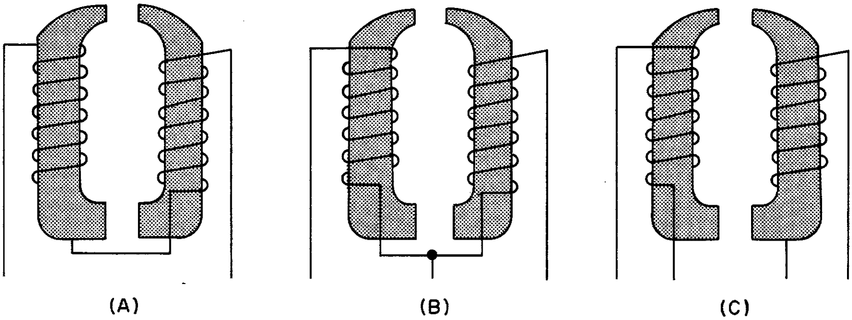

Fig. 3-6. *Coil winding arrangements for a ring head: (A) typical 2-lead arrangement; (B) centertapped winding (3-lead); (C) separate winding (4-lead).*

Core Materials

In digital recording, the magnetic core material must be immune to high-current saturation. Fidelity of the leading and trailing edges of the signal pulse is very important. Quick recovery from high-current signals is essential. Therefore, high frequency response, low losses, and no hysteresis effects are desirable electrical properties of the core material. Also, the core material must lend itself to precise geometric configurations and simplified manufacture. It must be durable and yet not abrasive to the tape medium. It must be capable of accepting a highly polished surface and of retaining it for thousands of hours of use.

Fundamentally, the magnetic head is composed of two identical core halves built of thin laminations of a material of high magnetic permeability. In Fig. 3-7 the dimensions *d* and *c* are controlled by a lamination stamping tool and *t* is the lamination stacking factor. All dimensions remain constant, but *d* is reduced by final grinding and lapping of the working face of the head to achieve a clean and polished head face and a sharp, well-defined gap (Fig. 3-7B). The core cross section ($c \times t$) is controlled in the process of head construction and, consequently, affects the sensitivity of the head performance by less than 1 db. For a *d* dimension of 0.025 inches, a tolerance of ±0.0025 and ±0.0001 inches gives a sensitivity change of ±1 db and ±5 db, respectively. In accordance with good transformer practice, each lamination must be insulated on each side from adjacent laminations. Modern techniques allow depositing an insulating film on each side. For final clamping of the two half-cores nonmagnetic separators are used at the front and rear sections. Standard gap dimensions of 500 microinches are used with tolerances of ±100 microinches.

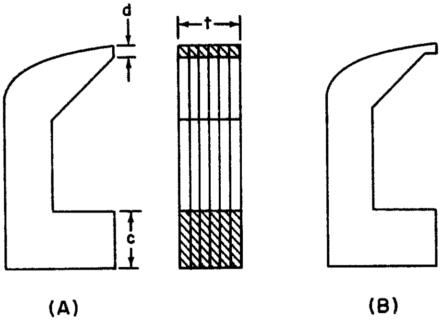

Fig. 3-7. *A magnetic head lamination stack.*

Mu-metal or permalloy laminations are used for head-core construction. Rho-metal may be substituted for erasing operations to reduce iron losses. Eddy currents are major core losses. These currents are proportional to the square of the lamination thickness. Therefore, the thinner the lamination, the lower the iron losses and, in the case of the playback head, the better the high-frequency response. The thinnest gauge in general use today is about 5000 microinches. The trend is toward the thinnest possible laminations, and 1000 to 500 microinches are thicknesses obtainable for use in special applications.

Laminated core construction has disadvantages. Foremost among these is that it would be simpler to cast or form a ring head core in its final geometric form without all the sequential processes associated with the laminated cores.

Among the promising new materials for head cores are ferrites. Ferrites are manufactured by pressing a suitably-mixed oxide into a die of a final shape configuration. Since the head dimensions must be precise, and the ferrite material cannot be machined by ordinary means, surfaces have to be carefully ground and lapped by using abrasive cutting tools. Electronically, ferrites exhibit constant permeability up to 4 mc, and eddy current losses are lower than the corresponding laminated heads at the same frequency. In addition, ferrites are nearly twice as hard as mu-metal and 20 percent harder than the magnetic tape oxide surface. However, ferrites are very brittle and are susceptible to wear due to the head contact with the motion of tape. Eventually, softer tape surfaces and superior head cores may eliminate the head wear problem.

Coil Windings

Electrically, the magnetic head is an extremely simple device, consisting of two coils wound on bobbins that are initially mounted on the core leg, or wound on bobbins and slipped over the core into position. As shown earlier, the coils may be connected in series or brought out separately.

The Recording Head

For a recording head, a strong magnetic field must penetrate the tape thoroughly; yet a sharp and well-defined field must remain. The current-carrying capacity of the record head winding is determined by the wire size, and the number of turns must give sufficient ampere turns to saturate the tape for effective digital recording. High-frequency head losses and circuit losses reduce the maximum permissible turns. Therefore, the required ampere turns are obtained by increasing the magnetizing current through the head coils. As a result, the record head has fewer turns of heavy wire (relative to the playback head) and is a low impedance source. The small number of turns and low distributed winding capacity permit a high self-resonant frequency for the head. Good high-frequency response can only be achieved if the core material has low eddy current and hysteresis losses.

The Playback Head

In contrast, the playback head is not an active element in the true sense; the current flow is produced by a moving magnetic field. Since high current is. not present, the playback head does not experience such power losses as eddy currents and hysteresis. For the same required frequency response, it is advisable to use as many turns as possible to loop the flux in the core in order to obtain a high signal output. Since allowable space is at a premium, the smallest diameter wire consistent with power-handling requirements should be used.

Since the playback head is required to operate with small magnetic fields, the gap and head geometry must literally "soak it all up." As stated earlier, the requirements for the playback head construction and operation are more stringent than for the recording and erasing heads. For example, the relative magnitude of signals for recording and erasing is always greater than any external field that might be present, but the magnetic field available on the tape medium is small and external fields tend to reduce the signal-to-noise ratio during the playback operation. Hum, for example, always exists where motors, power transformers, and the like are found. Proper orientation of the components and hum-bucking construction in the head helps to reduce its interference. In multihead structures and simultaneous record and playback operations, hum-bucking construction helps but, in addition, magnetic and electrostatic shielding is required to reduce the levels of the unwanted fields. Finally, the output leads from the playback, when coupled to an amplifier, should be shielded and kept short to minimize any further signal degradation.

The Erasing Head

The usual form for an erasing head is similar to the recording head. For erasing, high currents produce strong fields. These fields will require the use of core material that can sustain high flux densities without saturation. When alternating current is used, low circuit losses and thin laminations are required to avoid eddy-current losses. The erasing field is concentrated to penetrate the medium by making the air gap cross-section small and the gap length long. Generally, a good electrical conductor is inserted into the air gap to produce a high counter magnetomotive force, thus directing the erasing field into the tape. The heat dissipation of the conductor in the gap is often the limiting factor in the design and performance of an erase head.

Air Gap Geometry

The air gap of a ring-head configuration is the prime means of focusing or directing the magnetic field into the tape medium for recording purposes. For playback, the air gap acts as an absorber and literally "soaks up" all of the magnetic field within the vicinity of the air gap. The gap dimension and pole profile must stay fixed. This latter requirement is not easily met. The permalloy laminated head core is harder than the tape medium. At first, the tape medium acts as a fine abrasive substance, polishing the head surface in contact with the tape, and then it slowly wears down the material at the air gap. The rate of head wear is dependent upon the pressure exerted on the tape by mechanical tension or pressure pad, the tape speed, the tape surface smoothness, and the contact area.

To concentrate the maximum flux at the point of contact with the tape, the air gap is shaped to divert, and finally to obstruct, the direction of the flux path except at the point of contact. Four generalized forms of basic air gaps are illustrated in Fig. 3-8. The triangular gap (A) initially produces the desired flux field pattern. At the point of contact between air gap and tape a minimum reluctance path exists. From there, the air gap widens in a linear fashion, proportional to the distance from the contact reference line. In this fashion, the flux field is concentrated at the pole tips and the tape medium offers the path of least reluctance for the flux field to circumvent the air gap.

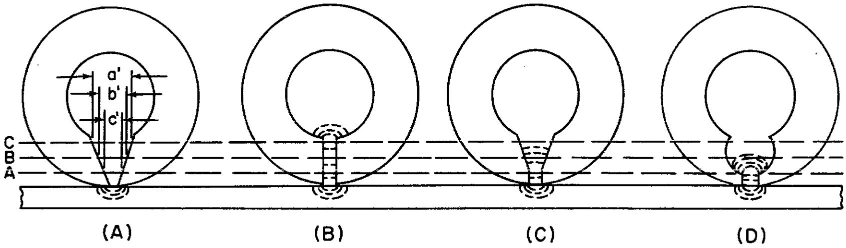

Fig. 3-8. *Basic contours of head air gaps: (A) triangular; (B) parallel; (C) trapezoidal; (D) circular.*

The triangular gap profile is not durable. The gap dimensions, cross section, and length change with head wear. Not only are the physical changes that affect the head performance apparent (Fig. 3-8A) but the corresponding inductance changes affect circuit response and matching networks. If the head is used for recording, power transfer is affected, and gap length changes alter the recording characteristics. If the head is used for playback, its resolution capability is seriously impaired, resulting in a marked decrease in high-frequency response.

To overcome the limitations of the triangular gap, the gap length is held constant throughout the pole-face cross section by aligning the pole faces in parallel (Fig. 3-8B). Thus, the gap length will remain fixed under any conditions of head wear. The major objection to this arrangement is that the recording flux field cannot be concentrated at the leading edge in contact with the tape medium. A close-up representation of the field distribution around the parallel gap is shown in Fig. 3-9. All of the flux field is concentrated in the center of the cross section. With no tape medium present, the

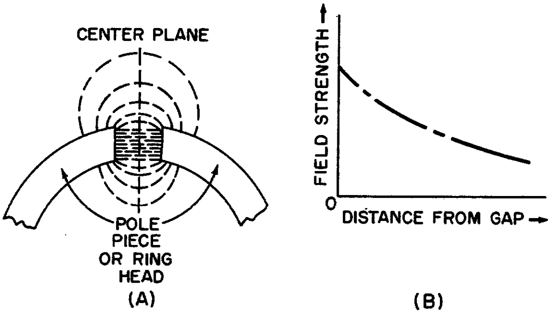

Fig. 3-9. *(A) Field strength distribution around the parallel air gap. (B) Decay of field strength in the center plane away from the gap.*

fringe fields or leakage in the front and rear parts of the air gap are approximately equal. This magnitude of inefficiency (approximately 50 percent of the available field) produces the need for higher than normal recording currents with additional losses incurred by hysteresis and eddy currents. These additional losses further augment the need for higher recording currents. If an equivalent gap geometry is used for playback operations, the deep parallel walls of the air gap shunt the minute flux field picked off the tape. The flux field enters the head on one side of the air gap, goes across the gap, and down into the tape. If the gap geometry were similar to the triangular one, the flux field would enter one side of the air gap, go around the core looping the pick-up coils, and enter the tape on the other side of the air gap. In this manner a more efficient operation would be achieved and higher voltage pick up would be obtained during playback.

A combination of the two types of gap contours is illustrated in Fig. 3-8C. Here, the parallel length is just enough to withstand head wear before replacement. This means that as the parallel length is decreased, the head-to-surface contact area is increased. If head wear were permitted to continue beyond a certain limit, the tape would become defective. Therefore, the parallel length is just sufficient to be compatible with the life expectancy of the head. Beyond this point, the contour becomes triangular, a profile whose merits have been discussed.

A slight variation of Fig. 3-8C is shown in Fig. 3-8D. Instead of a triangular shape, an arc of a circle is substituted. Since the flux field enters and leaves the surfaces at right angles, the field travels a longer path in air space.

Head Gap Losses

Problems arise and losses are incurred regardless of the infinitesimal length of the air gap. No matter how small the gap dimension is, it is finite and of sufficient magnitude to cause losses and present problems of head alignment. Of the three losses associated with the head gap and examined here, two are intrinsically related to the ring-head configuration and the third is a by-product of gap dimension and affects the time displacement of a multihead play-back operation. The three losses mentioned here are caused by field intensity as a function of distance from the gap center, gap effect, and orientation of the head gap to the tape track.

Field Intensity Losses

The fringing field of the head gap is shown in Fig. 3-9. The gap size must be chosen to produce a recording field sufficient to saturate the surface-layer cross section immediately underneath the head gap. With reduced gap length, a lower limit exists below which high energizing currents and a microscopic fringe field are insufficient to saturate the tape. The flux intensity as a function of distance from the pole tips may be approximated by the following formula:

$$\text{Spacing loss in db} = K\frac{d}{\lambda} = K\frac{df}{v} \qquad \text{(Eq. 3-1)}$$

$$\lambda = \frac{v}{f} \qquad \text{(Eq. 3-2)}$$

for digital applications:

$$\text{bits per inch} = \frac{f}{v} \qquad \text{(Eq. 3-3)}$$

Therefore, wavelength and bits per inch are related in the following manner:

$$\text{bits per inch} = \frac{1}{\lambda} \qquad \text{(Eq. 3-4)}$$

where d = distance from the pole tips in inches
λ = wavelength in inches
f = frequency in cycles per second
v = tape speed in inches per second
K = 55 (preferred, although other publications have used values from 54 to 57, inclusive)

In subsequent formulas, wavelength (λ) is used as an expression of the highest frequency performance of the head. For digital applications, Eq. 3-4 is used to convert terms of wavelength into digital nomenclature when applying the formulas used in this chapter and throughout the book.

Gap Effect

The air gap effect is present during playback operations and results from the finite length of the air gap and the recorded wavelengths of the same order of magnitude. Recovery of the recorded signal on tape is directly related to the effective playback head gap length and the length of the magnetized spot on the tape. Ignoring all other independent losses, the basic problem of resolution will still cause the playback output to fall to a minimum when the recorded wavelength and the air gap length are approximately equal.

In digital recording, the magnetized spots or isolated magnetic poles can be considered to form a chain of magnets of equal strength. Regardless of the digital magnetic recording techniques used, the flux field pattern comprises a series of end-to-end magnets or a series comprised of alternating spaces and magnets of equal strength. In the former arrangement, the recorded digital information occupies the full area (or cell) allocated for one bit of information and the flux field is reversed during the transition from one binary state to another. In the latter arrangement, the head is energized for only a portion of the cell area and, therefore, the remaining area is a space or unmagnetized tape area; however, the current in the head is reversed in a shorter interval of time. This is an oversimplication of digital recording but it should suffice for demonstrating how magnets are created on tape. A more thorough explanation will be given in Chapter 4.

For illustrative purposes, digital recording may be pictured as a series of magnets of equal strength that are set end-to-end with like poles facing each other. The gap-length effect is examined in terms of equal length magnets. When two magnetic reversals occur in sequential order, they approximate a sine-wave magnetizing field (Fig. 3-10A). If the gap length of the playback head is equal to the total length of both magnets, no flux lines will flow through the core and the pick-up coils will produce no output. If this pattern

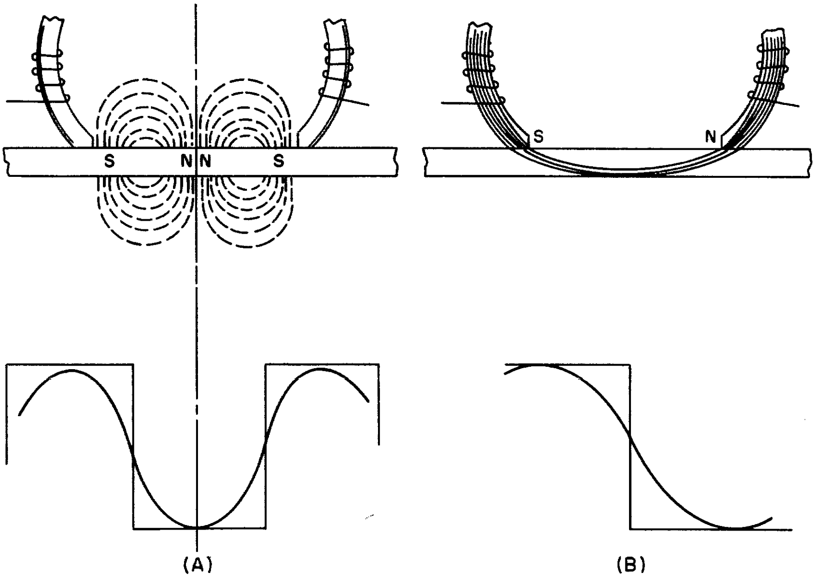

Fig. 3-10. *The gap effect of a ring head: (A) full wavelength; (B) half wavelength.*

is repeated and extended longitudinally along the tape, no signal will be induced in the pick-up coils of the core structure. It becomes apparent that when the gap length approaches the recorded wavelength, the voltage output of the playback channels approaches zero. On the other hand, when the gap length approaches one-half the recorded wavelength (Fig. 3-10B), maximum signal energy is induced in the pick-up coils. Obviously, a pronounced null effect is produced when the gap length is an even multiple of recorded wavelengths, and a maximum output is produced when the gap length is an odd multiple of half wavelengths. The relative loss in output signal can be expressed in the vernacular of digital techniques by using the substitution of wavelength in Eq. 3-4.

$$\text{gap effect loss in db} = 20 \log \frac{\sin \pi lp}{\pi lp} \qquad \text{(Eq. 3-5)}$$

where l = effective gap length
p = bits per inch-packing density

For this reason, the smallest length for a bar magnet created on tape in digital recording should be larger than the gap length. The number of magnetized spots to the inch (magnets per unit length) in digital recording can be considered a constant, or the transition from one magnetic state to another is a constant. Therefore, digital recording is a fixed- or single-frequency operation where the highest frequency is selected for efficient use of tape. In actual practice gap lengths are made even smaller than one-half the highest recorded frequency in order to reduce the problems of time displacement between the two outermost tracks of a multitrack tape recording.

Head Gap Orientation

Incorrect alignment of the air gaps of playback heads with respect to the direction of tape motion is another cause of loss at the high-frequency end. Unless the gaps of the recording and playback heads are at exactly the same angle with the direction of tape travel, a loss of high-frequency response will result. This is caused by misalignment of the head in three dimensions and also by poor head construction at the air gap.

In Fig. 3-11 a possible misalignment is shown when a recording is made in the proper manner and the same tape is played back with the gap rotated at an angle θ with the perpendicular direction of tape travel. (For illustrative purposes, a large track width and the shortest wavelength are examined.) This situation could arise where both heads (record and playback) are misaligned and the total azimuth displacement is one half wavelength of the recorded signal. The playback head can be considered as a number of parallel heads, each of which is energized by the magnetic field in the immediate vicinity of the air gap. The sum of these head elements is the playback head width. Since each of the head elements are at different points across the track width, each element will be activated by the field strength at the immediate pole tip,

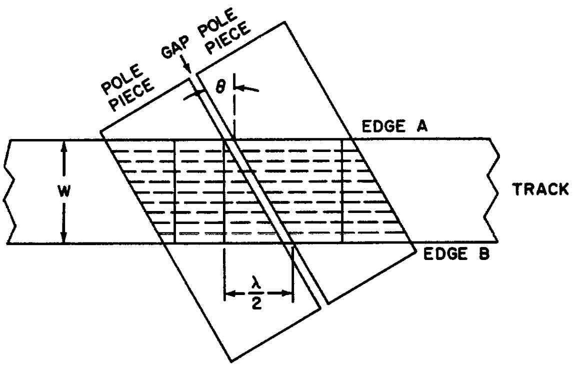

Fig. 3-11. *Gap track alignment.*

and the total flux will be integrated in the core and sensed by the pick-up coil. When properly aligned, each head element will be positioned exactly at the same point of a sine wave, and the flux through the core will be maximum.

For the conditions shown in Fig. 3-11, the flux field would be in one direction at edge *A*, and in exactly the opposite direction at edge *B*. In the situation shown, the field across the gap from edge *A* to the center would attempt to pass around the core of the head in one direction, while the field across the gap from edge *B* to the center would attempt to pass the same number of lines around the core in the opposite direction. The result would be an approximate cancellation of all lines and the voltage output would approach zero.

The following general formula may be used to determine the loss in output caused by misalignment in the azimuth direction at an angle θ:

$$\text{Loss in decibels} = 20 \log \frac{\sin (\pi w \tan \theta/\lambda)}{(\pi w \tan \theta/\lambda)} \qquad \text{(Eq. 3-6)}$$

where w = track width
θ = azimuth angle
λ = wavelength

Instead of considering the playback head as a number of elements, it can be considered as a set of individual heads over a multitrack recording. Each track comprises a series of bar magnets, and the air gap is rotated an angle θ (Fig. 3-12). All tracks are recorded in the same manner at one frequency. Therefore the bar magnet density (highest number of magnetized spots to the inch) of each track is identical. No error is introduced if the air gap does not cover an adjacent bar magnet. As shown in Fig. 3-10A, the half-wave track position would be across two like poles of two bar magnets. Between the half wavelength and full wavelength the field direction is reversed. In digital recording any misalignment less than a half wavelength between the outermost tracks would be acceptable, from edge *A* to edge *B*. However, the output signal is a function cos θ and must exceed the threshold limit of the playback amplifier. If the gap is between edge *A* and edge *B* and the displacement exceeds the half wavelength but is less than one wavelength, the field is reversed and the signal output is reversed; a change in binary states that would incur an error in digital operations. Since digital recording techniques vary, azimuth misalignment may be expressed in degree of phase displacement between one edge and another or by the time displacement as a function of tape speed.

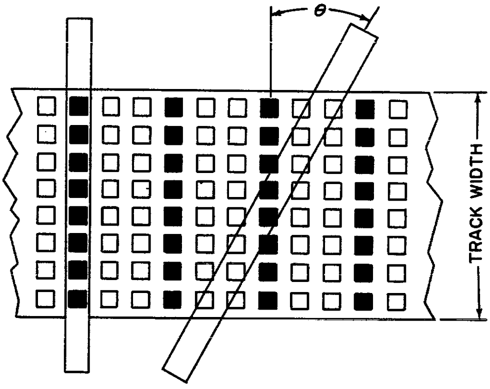

Fig. 3-12. *Playback head tilted at an angle θ.*

$$\text{Phase error} = \frac{w \tan \theta}{\lambda} \times 360 \qquad \text{(Eq. 3-7)}$$

$$\text{Time displacement} = \frac{w \tan \theta}{v} \qquad \text{(Eq. 3-8)}$$

where θ = azimuth angle
w = tape width
λ = wavelength
v = tape speed

Intertrack time displacement is a primary factor in determining an upper limit on the number of bits to the inch which can be recovered during playback operations without resorting to electronic skew correcting circuits (Fig. 3-12). The magnetic head (record and playback) is designed to have a minimum amount of gap scatter in construction and tilt in assembly on a head mounting base. There are a number of checking procedures to evaluate the digital requirements further aggravate these problems. In addition to the methods incorporate the following procedure. A measurement is made by recording simultaneously on all tracks and noting the time displacement of the retrieved signal from each track referenced to any one track selected for comparison.

Multitrack Magnetic Heads

The mechanical construction and tolerances so far enumerated apply to a single-track tape recording. However, when digital information is written (recorded), the coding system employed requires a number of parallel tracks. Multitrack recording imposes severe tolerances on head construction, and digital requirements further aggravate these problems. In addition to the problems of head construction discussed previously, the designer now has to contend with the alignment of gaps within the stack (gap scatter), head alignment (gap perpendicularity to tape motion), and cross-talk.

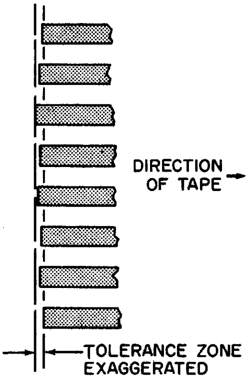

Fig. 3-13. *Gap scatter (exaggerated).*

Gap Scatter

Gap scatter (Fig. 3-13) denotes alignment of the gap centerline of each track within the stack to a reference centerline perpendicular to a reference surface. The total excursion about the reference centerline is the head gap scatter. Deviation from this reference centerline can be held to less than 100 microinches in accurately-made heads. The head misalignment gap azimuth is the angular rotation of the head centerline from the true reference perpendicular line to the reference surface (Fig. 3-14). Azimuth displacement can be held to within one minute of arc of angular rotation. Cross-talk, or pickup, is the coupling of flux between the individual heads. Cross-talk is present when intertrack shielding is ineffective and there is pickup of fringe fields at pole-face tips, especially when the tape is not in contact with the head.

Field Intensity Losses

When more than two tracks are recorded simultaneously, the technique is classified as multitrack recording. As stated earlier, standards have not been formalized to any extent in defining track width and track spacing. Since

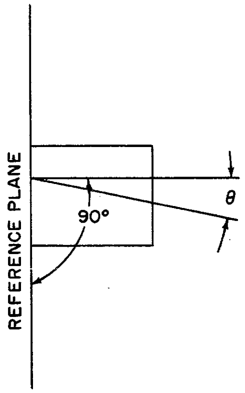

Fig. 3-14. *Multihead azimuth alignment.*

there is really no fixed relationship between track width and track spacing, a varied number of tracks per tape width are available. Obviously as the number of tracks are increased for a given tape width, the relative track-width dimensions must be reduced. This, in turn, reduces the gap cross-sectional area.

The magnetizing force and the available signal output for playback have a linear relationship to the head width. Therefore, the power loss may be expressed in the following manner as a function of track width:

$$\text{loss in db} = 10 \log \frac{w_1}{w_2} \quad w_1 < w_2$$

The construction of the head core, selection of material, and the space allocation for the winding coils are further complicated with reduced track dimensions. Sufficient core cross section must exist to prevent core saturation and other losses. Smaller diameter wire and tighter winding tension may cause poor electrical performance. These problems call for careful winding procedures.

The blank spaces between the tracks must be reduced to achieve greater head densities. More space must be allocated for interhead shielding to prevent cross-coupling in proximity of adjacent coils due to insufficient core material and fringe field effects at the pole tips.

Furthermore, for efficient manufacturing and for ease of interchanging of tapes between tape machines, it is desirable that the physical head dimensions in multitrack recording do not prohibit the interchangeability of magnetic tapes.

There are a number of ways of achieving multitrack recording. The *in-line* method (Fig. 3-15) is the arrangement of all gaps on the same axis of the tape. Ideally, the gaps are all perfectly in line in both azimuth and lateral positions. Track densities are of the order of 20 per inch, corresponding to head widths of 7 to 100 mils. The term *interlaced tracks* (Fig. 3-16) implies

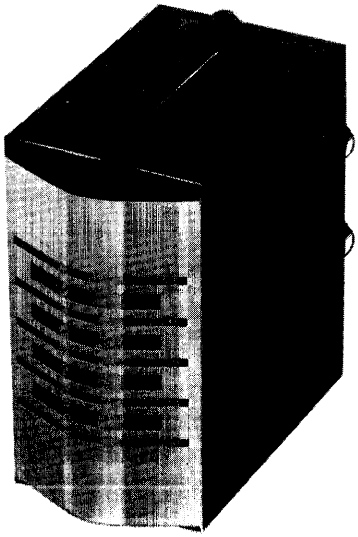

Fig. 3-15. *The Clevite In-line, 4000 Series (Brush Instruments).*

in-line heads displaced longitudinally and laterally on tape. Arrangement of the maximum number of tracks per lateral inch without incurring insurmountable problems is accomplished by the parallel alignment of two adjacent tracks with sufficient guard space between them. Among the critical dimensions demanding tightest control are the alignment between the gap centerlines of the two interlaced stacks, gap scatter, and azimuth of each stack. The *staggered* gap arrangement is accomplished by displacing two or more gaps along the longitudinal axis of the tape. This arrangement may be satisfactory for

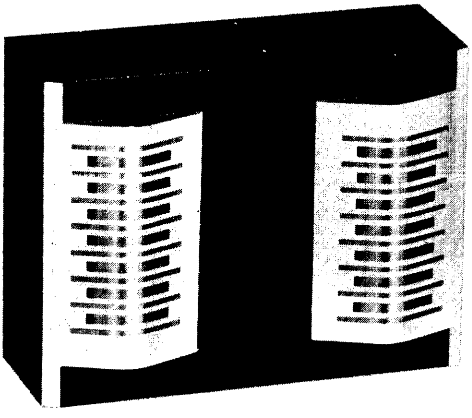

Fig. 3-16. *The Clevite Integral-Interlace, 2000 Series (Brush Instruments).*

multiplexing pulse information on a common track but has very little application in the digital field.

The multihead stack demands identical mechanical and electrical characteristics of each head within the stack and close control of the sensitivity associated with each gap. Of the three dimensions associated with the air gap (depth, length, and width), the depth is most critical. Fortunately, present-day grinding and lapping processes for finishing the head face permit the attainment of depth-dimension to ±0.0002 inch over a length of 1 inch.

Skew Problems

Of the major criteria for evaluating a digital magnetic tape transport, packing density is the best guide. Skewing of tape as it moves past the gap of the magnetic heads is a major limiting factor in the achievement of higher packing densities.

Tape is guided across the head block by using one edge as a reference side. Skew refers to the angle between the head gap centerline and its normal alignment to a tape edge when the tape is passing across the head block.

Incorrect alignment of the head gaps with respect to the direction of tape travel and uniformity of head construction have been discussed previously, and may be classified as sources of *static* skew conditions. The most critical tolerances of the head stack are gap scatter and azimuth alignment. The head block has guide posts to ensure proper tape guiding in the region of the magnetic heads. Thus, the tape is made to "seat itself" and to follow the same path across the head during recording and playback operations. The skew effects are compounded by the requirement that the tape transport be able to accept recorded tape reels from other tape stations and also from removed tape reels of the same tape station. Obviously, the problems of static skew can be minimized if one gap is used for recording and playback operations and the tape reel is not removed from the tape station and subsequently returned to be used for playback operations.

In describing the basic formation of multitracks on tape, it was stated that the tape tracks and the head gap are perpendicular to one another. The tolerances of head components and their assembly alignment reduce this achievement in perpendicularity to within a few minutes of arc. Static skew is further complicated by the dynamic motion of tape and other contributing sources.

Dynamic skew can be attributed to the mechanical tape guiding across the head, to tape tolerances and dimensional stability, and to random tape vibrations caused by high speed start-stop operations. Another major source of dynamic skew is the electronic circuitry, with its inherent time delays, jitter, and circuit instability. Extensive signal conditioning during the playback operations is required along with associated data processing and checking procedures for reliable tape operations.

No matter how small the disturbances created by reel wobble and variations of tape tension, mechanical oscillations can be initiated and sustained during tape motion, and these cause serious skewing. Pressure pads and pressure rollers contribute to dynamic skew when misaligned. Some tape transport manufacturers have incorporated small vacuum-damping loops on each side of the head to reduce, or eliminate, tape vibrations in the immediate vicinity of the gap.

While the problem of skew was discussed in terms of playback operation, an analogous problem exists during the recording operation. Since skew exists during both record and playback processes, the skew effect of recording and reproducing misalignment may be cumulative. To illustrate, a tape transport is evaluated in terms of packing density using assumed values for head tolerances and for dynamic and static skew capabilities. Assume the following values:

Gap scatter = ±75 microinches
Head azimuth = ±75 microinches
Static skew = 300 microinches (2 way)
Dynamic skew = 2 microseconds at 150 ips (1 way)
Tape width = ½ inch

With all tolerances normalized to the same speed (150 ips) the two-way addition of error in microinches is:

300.00 (static skew)
600.00 (dynamic skew)
600.00 (electronic circuitry total 4 microseconds)
1500.00 microinches

Packing density capability of tape transport (ignoring speed variation) is:

$$\frac{1}{1500 \times 10^{-6}} = 666.67 \text{ bits per inch}$$

The values for this computation were selected to stress a particular point. The gap scatter and head azimuth are combined and considered to be the total static skew. In practice, the magnetic head is assembled on a precision block and is then attached to the tape transport. Unless diligent care is maintained in head assembly and mounting, the precision of head construction becomes meaningless. The head is assembled on the precision block using a precise reference surface for the express purpose of this operation. Optical means are used to obtain a high degree of accuracy and the tape guiding posts are part of the head mounting block. Therefore, the total static skew comprises the final composite dimensions attributed to the head construction details.

Multitrack-Multi-operation Magnetic Heads

If three individual heads were used for magnetic recording, they would be arranged in the following order: erase, record, and playback (Fig. 3-17).

Assuming the record gap length to be of one dimension, the erasure head gap would be larger than the record gap and the playback gap would be smaller. Similarly, considering the record head width as a reference dimension, the erase head width would be larger, and the read head width would be smaller. Although it is quite possible to construct a single head to perform all operations, compromises peculiar to each function often result in unsatisfactory performance for each specific operation. The multi-operation head can have any combination of a one-, two-, or three-gap construction.

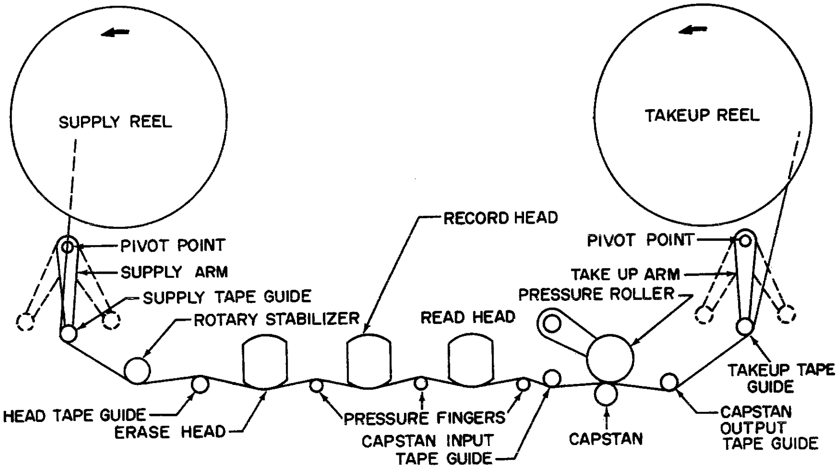

Fig. 3-17. *A typical tape-handling mechanism with all "above panel" elements.*

To ensure the validity of a correct recording in digital applications, it is desirable to play back the recorded signals immediately. Two advantages are gained by including this capability within the system: (1) Once played back correctly, a correct tape recording can be assumed to have taken place. (2) Any detected errors indicate some malfunction of the recording and playback operation and may disclose the location of the failure.

A combination head having record and playback capabilities is shown in Fig. 3-18. The combination head shown has a dual gap sharing the center leg for continuous flux lines for both record and playback operations. Erasing has not been emphasized because in digital recording the recording process

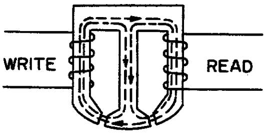

Fig. 3-18. *A diagram illustrating the principles of a combined record/playback head.*

TABLE 3-1. Digital Magnetic Head Characteristics

Manufacturer	*Model No.*	*Gap Length Write/Read (microinches)*		*Dual Gap Distance (inches)*	*Static Skew*	*Dynamic Skew*	*Speed (ips)*	*Write Current (milliamperes)*	*Read Voltage (millivolts)*	*Head Replacement*
AMPEX	TM-4	—	—	—	—	6.0 microseconds	75	—	—	—
BURROUGHS	BC 422	—	—	.15	225 microinches	100 microseconds	—	40	35	Without alignment
CDC	603	1000	250	.30	1.0	2.0 microseconds	75	65	25	With alignment
	606	1000	250	.30	0.5	1.0 microseconds	150	65	30	With alignment
	607	1000	250	.30	0.5	1.0 microseconds	150	65	30	With alignment
CEC	DR 2700	1000	250	.30 or .39	—	8 microseconds (1″)	—	—	—	Without alignment
COOK	59	—	250	—	Total Skew	5.3 microseconds	112.5	—	—	—
DATAMEC	D2020	—	—	.30	10 microseconds	8 microseconds	45.0	100	20	Without alignment
HONEYWELL	804	500	—	—	—	4 microseconds	120	120	10	Without alignment
IBM	Hyper Tape	—	—	.15	—	—	—	—	—	With alignment

TABLE 3-1. (Cont.)

Manufacturer	*Model No.*	*Gap Length Write/Read (microinches)*		*Dual Gap Distance (inches)*	*Static Skew*	*Dynamic Skew*	*Speed (ips)*	*Write Current (milliamperes)*	*Read Voltage (millivolts)*	*Head Replacement*
	729 II-IV	—	—	.30	—	—	—	75	—	With alignment
MIDWESTERN	M 3000	500	—	.30	3.50 microseconds	7.5 microseconds	—	120	3.25	Without alignment
POTTER	906 II	—	—	—	3.5 microseconds	—	100	30	9-18	With alignment
RCA	582	—	250	.20	—	2 microseconds	100	50	8	Without alignment
	581	—	250	—	200 microinches	4 microseconds	100	50	6	With alignment
	382	—	500	.30	100 microseconds	5 microseconds	60	80	9-13	—
	381	—	500	—	—	10 microseconds	30	38	5-7	Without alignment
UNIVAC	III A	200	200	.250	1 microinch	5 microseconds	100	8	6	Without alignment
	III C	500	200	.250	—	2 microseconds	112.5	105	28	Without alignment

automatically erases the previously recorded information. (This function will be discussed further when magnetic digital recording techniques are examined.) Therefore, a two-gap head construction requires very few compromises to perform both functions. However, the ever-present problem of cross-talk and stray field pickup determines how close the two gaps may be placed within a single stack; one-half inch apart and less are standard manufacturing values. The Clevite Corporation has two identical head stacks mounted in a single structure with closely-spaced gap lines. Two separate head stacks perform the record and playback operations with a minimum of interaction.

On the other hand, narrow gap spacing between record/playback operations permits wide flexibility in the selection of tape formats and inter-record spacing. These areas will be covered in the organization of data on tape (Chapter 7), but they are brought up here because they involve the mechanical construction of the head. In the Burroughs 422 Magnetic Tape Unit, the dual-gap head used for read/write operations has a gap spacing of only 0.15 inches. A closeup view of the head mounting block, including the head and tape guiding features, is shown in Fig. 3-19.

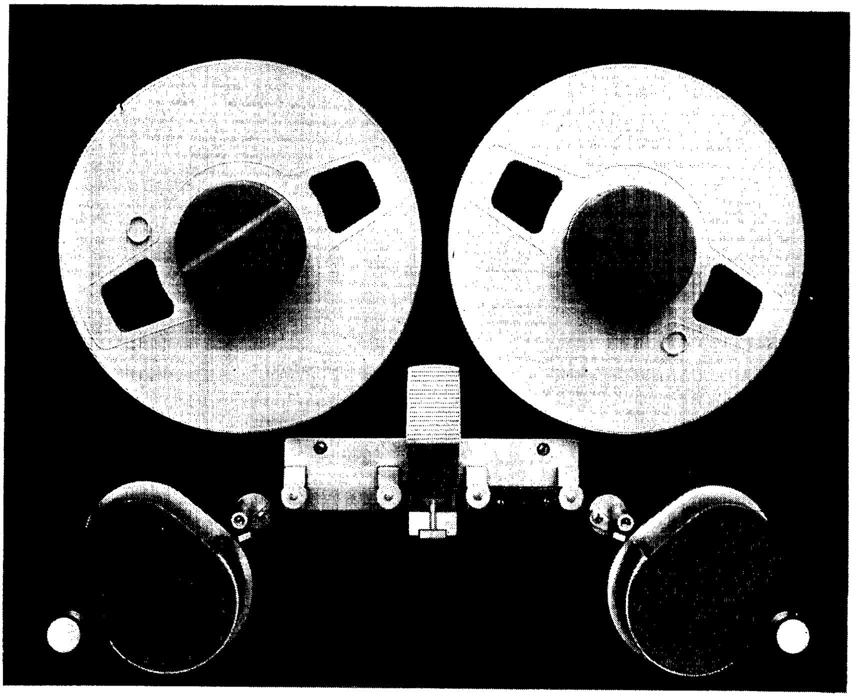

Fig. 3-19. *The Burroughs BC422 Magnetic Tape Unit (Burroughs Corporation).*

Table 3-1 lists the characteristics of various commercially available digital magnetic heads.

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4

Principles of Digital Magnetic Recording

In Chapter 3 the magnetic head was examined in terms of mechanical considerations. In this chapter, it is examined in terms of its electrical performance associated with pulse recording.

Digital magnetic recording involves writing information on a suitable tape medium and reading back the identical information "error free." In writing, the magnetic head is energized by means of coils and a signal current, providing sufficient magnetic flux to produce a concentrated localized magnetic field that is directed into the tape medium. Thus, in the immediate vicinity of the head gap, a definite magnetic state is established in the tape medium with a polarization and magnitude that are attributed to the energizing source. The interruption or sudden reversal of current flow in the head coils establishes a definite pattern on the magnetic tape as it passes by the magnetic head. (For purposes of discussion, the magnetic tape properties are considered to be permanently altered, thereby maintaining a permanent magnetic imprint.) The retention characteristic or memory capability of the tape surface is due to the magnetic remanence produced by the tape's ferromagnetic composition. Because the tape is in motion during the recording process, the recorded pattern along the tape surface is related to the time variation of head current. The spatial relationships of data and time are established by the tape speed.

Once information is permanently established on tape, an external magnetic field exists along its surface that can be magnetically coupled with a reading head. Passing the tape across a reading head will develop an output voltage across the pick-up coils on the head core because of the time variation of the flux lines.

A functional block diagram of the digital magnetic recording and recovery processes is shown in Fig. 4-1. Note that every time a function or process is performed, some corresponding loss occurs. In Block 1 the writing head current establishes a concentrated magnetic field that is directed into the tape medium. The partition of the flux lines into two groups, one into the tape

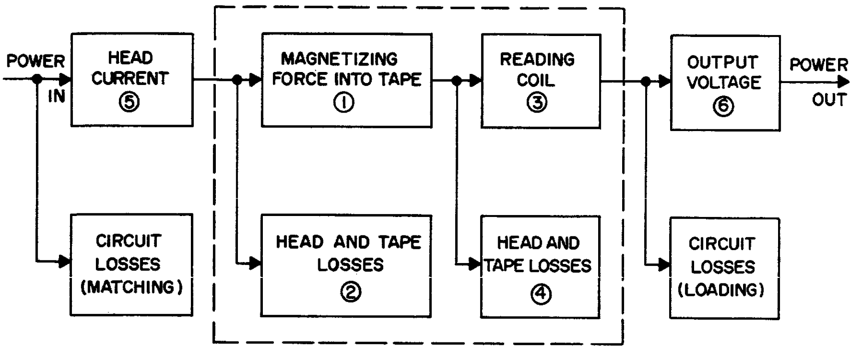


Fig. 4-1. *Digital magnetic recording and recovery processes. The dashed line encircles the functions associated with recording and playback.*

and the other across the pole faces, accounts for Blocks 1 and 2. Once on tape, the magnetic dipoles experience a demagnetizing effect. In addition, the orientation of the magnetic dipoles on the tape relative to the playback head gap determines the recoverable useful flux. Again, the partition of the flux lines into two groups, one into the head-core leg looping the reading coils and the other across the pole faces, accounts for Blocks 3 and 4. The recorded magnetic dipole is identified by the X parameter defining its spatial relationship on tape and its field orientation relative to the magnetic head. The recoverable flux is the average flux per turn of the read coil. Blocks 5 and 6 detail the writing and reading of digital information. Since the output voltage need not be an exact replica of the writing head current, a number of methods are available for implementing these two boxes. It is only necessary that the stored information (zero or one) be retrieved without any error. With this concept, it is worthwhile to describe in detail the head operations delineated in Fig. 4-1.

Magnetic Head Operation

Figure 4-2 shows a cross-sectional view through the tape and the recording head in the vicinity of the air gap. The dashed lines indicate the path of the flux produced when the write head coils are energized. Only a portion of the flux flowing through the core cross section enters the tape medium. Generally, the core permeability is much higher than that of tape, so the leakage flux across the head gap is restricted to a small portion of tape. It is possible that the permeability of the core material can be lowered if the flux density exceeds the gap cross-section capacity or the core deteriorates during the grinding and polishing of the pole tips. When these conditions exist, flux concentrations created by high bursts of head current can increase the magnetic flux fields about the head gap and augment the amount of flux entering the tape, a phenomenon that should be avoided. These fringe fields are un-

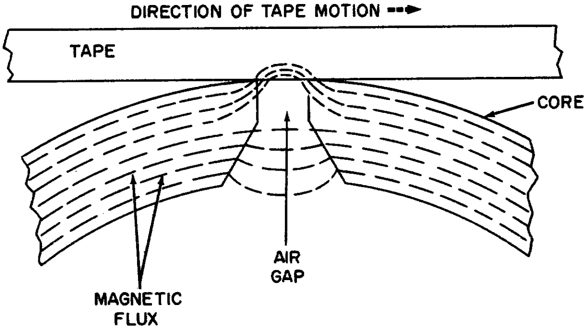


Fig. 4-2. *Magnetization of tape by leakage flux across the head gap.*

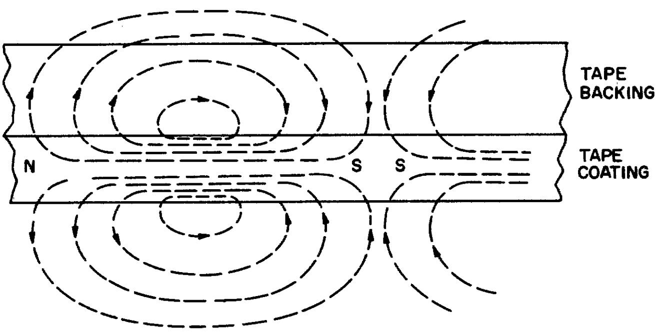


Fig. 4-3. *Flux lines inside and outside the recorded tape.*

predictable and may not contribute to the overall useful flux during the playback operation. The lower permeability brought about by these conditions increases power losses, contributes to a distorted magnetic field pattern, and reduces the response of the recording system. Information recorded under these conditions sets up flux fields both inside and outside the tape, as shown in Fig. 4-3.

In the read operation, the magnetic flux emanating from the magnetized portions of the tape enters the high-permeability read core on one side of the air gap, passes through the ring core linking the head windings, and leaves the core on the other side of the air gap. In this manner, a large portion of the flux follows the low reluctance path through the playback head core, while a small portion is shunted across the air gap. The division of flux between the two paths, of course, is determined by the relative ease with which an unbroken magnetic path is created.

When the air gap is located in the center of the magnetized region, as shown in Fig. 4-4, a part of the total flux present in the tape completes a magnetic path by going across the air gap and does not link the head windings. Another portion of the magnetic energy stored on the tape is not intercepted by the read head at all. These flux lines of the magnetic dipole are completed

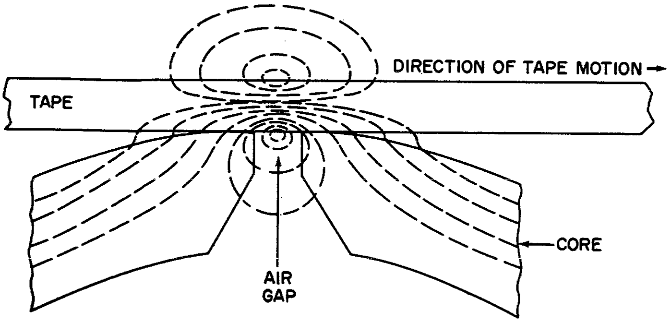


Fig. 4-4. *Playback with the air gap at the center of the magnetized region.*

by following a path through the tape backing around to the other side of the recorded magnetic dipole. When the air gap is slightly displaced from the center of the recorded magnetic dipole, as in Fig. 4-5, an attempt is made to maintain the established initial flux line path of Fig. 4-4. However, the motion of tape continuously brings forth a new magnetic dipole, establishing a given field pattern. The removal of the dipole from the air gap vicinity collapses the field. Similarly, a recorded magnetic dipole entering the gap experiences the same phenomena trying to establish and close a flux link path about the magnetic dipole. This build up and collapse of the flux pattern not only affects the read-coil output but also causes uncertainty as to the precise time occurrence of field reversal for digital recording. The problem of associating the unique time of field reversal on a single track is quite difficult; for multitrack digital recording the problem is even more difficult.

When the reading process is considered in the same manner, the problem is cumulative and the read head aggravates it. During playback, the magnetic fields are distorted to maintain and retain a given field pattern. During the recording process, it is necessary for the magnetic field to be established in

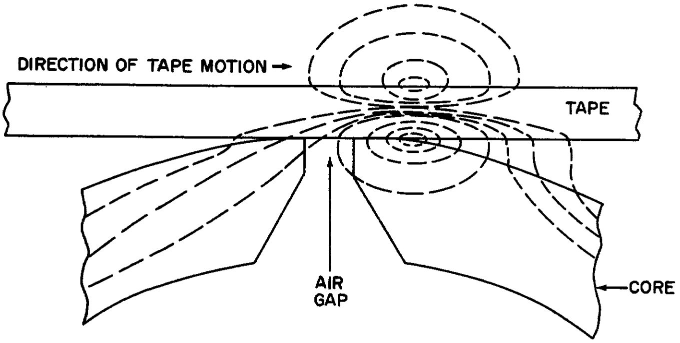


Fig. 4-5. *Playback with the air gap displaced from the center of the magnetized region.*

the magnetic recording head and removed before the next pulse of current arrives at the head winding. This is somewhat impeded by the established recorded field in the vicinity of the air gap, which attempts to maintain a low-reluctance path about the recorded magnetic dipole. This may include the retention of flux lines around the head-ring core. In effect, the residual field counteracts the next pulse current for field reversal or diminishes the incremental change of a like flux field. Therefore, in the initial recording process, the achievement of ideal recording conditions are next to impossible and the playback process can only function on the basis of the remanent field pattern on the tape surface.

Equivalent Circuit for Recording Head

For the most efficient tape utilization, the highest packing density is desirable. Such densities are acquired with a format of coded digital pulses that occupies a minimum of tape length. Obviously, a minimum length of tape will be achieved in the magnetizing process if the tape is stationary and the head air-gap length is extremely small. This might work well for an isolated magnetic pole, but for the applications involved, it is not practical to obtain any volume of data by this method. Since this is impractical, there are two conditions that have to be met prior to utilizing any digital magnetic recording methods: (1) It is necessary to initiate a magnetomotive force (MMF) of very short duration. (2) It is necessary to magnetize the tape as it moves a very short distance. Under these conditions the MMF developed across the air gap must rise rapidly to a maximum, remain constant for a short duration, and then collapse immediately. The tape speed, the physical air-gap length, and the duration of MMF all participate in achieving a minimum recorded dipole on magnetic tape. The first two factors have been treated in earlier chapters.

To develop a rectangular flux waveform, a square-wave voltage pulse is necessary. For simplicity, the actual configuration of a recording operation and its equivalent circuit are shown in Fig. 4-6. The schematic shows a recording head as a direct load to a transistor amplifier. The actual circuit (part A) shows three sources of capacity: the amplifier output capacity (C_o), the wiring and cable capacity (C_w), and the stray capacity associated with the internal wiring of the head (C_s). The capacity associated between each turn of the head coil is assumed to be negligible and is not considered. However, the capacity between each wire turn and the head core is additive and shunts the output and wiring capacity. The total capacity of the equivalent circuit (part B) is denoted by C_T. The resistance of the amplifier is denoted by R and the inductive effects associated with the core and leakage about the air gap are labeled L_C and L_l, respectively.

The following assumptions are made in this section: (1) A rectangular pulse supplies a constant MMF across the air gap for the duration of the pulse. (2) The surface magnetic induction is constant for this time interval. (3) Losses such as hysteresis, eddy currents, and copper losses are ignored.

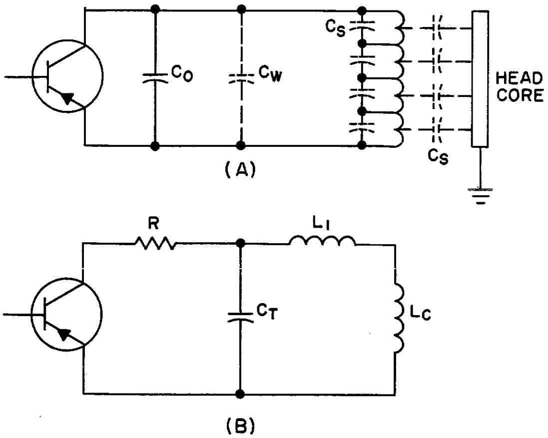


Fig. 4-6. *Recording process configuration.*

A single-transistor amplifier can be replaced either by a voltage generator or by a constant current source, both of which are shown in Fig. 4-7. The two circuits are equivalent in detail, but it is the voltage generator that will be examined more closely because it is more familiar than the current generator configuration.

From the classic transient analysis of the RLC circuit, it is evident that a rectangular voltage pulse applied to the circuitry shown in Fig. 4-7 has three possible waveform solutions. The one permitting the fastest rise time and fall time is the desirable solution. The ideal response will supply the proper flux waveform through the core across the air gap and a well-defined dipole will be formed on the tape medium as a result of the MMF.

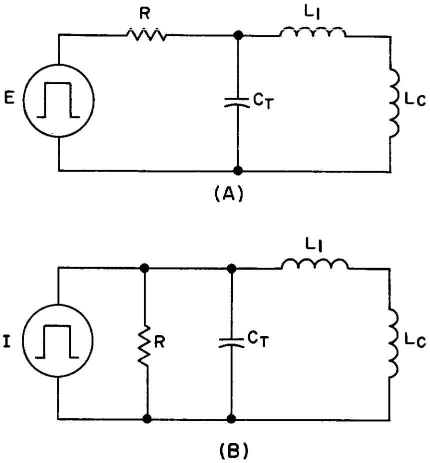


Fig. 4-7. *Recording head equivalent circuit.*

The critically-damped solution for the differential equation of the equivalent head circuit has R equal to $\frac{1}{2}\sqrt{L_T/C_T}$ (where $L_T = L_C + L_l$). If R is permitted to have a value less than this critical value, a longer time interval would be required to reach a maximum level, and a corresponding time interval would be required to minimize the field in the head core. On the other hand, if R exceeds the critical value, the flux field will build up and pass the steady-state maximum level, oscillate about this value, and finally settle down to the steady-state value at a rate determined by the time constant of the circuits. From a circuit point of view, the optimum value for the record equivalent circuit is the critical-value solution. With the critical resistance value ($R = \frac{1}{2}\sqrt{L_T/C_T}$), the rise time and fall time is equal to L_TC_T. By reducing the product of L_TC_T, the flux field duration across the air gap is reduced, with a correspondingly smaller dipole formed on the tape medium.

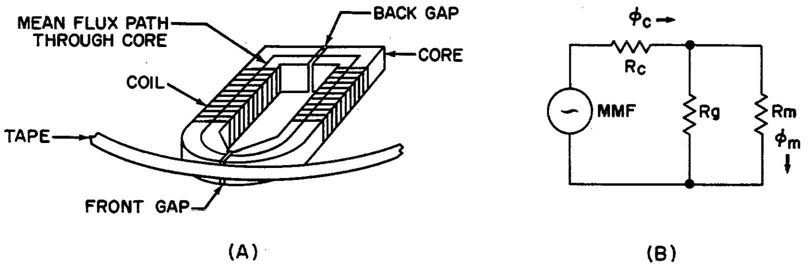
There is a magnetic circuit that complements the preceding electrical circuit. In the magnetic circuit, an MMF developed by the current of the head coil sets up a flux field (Φ) through the core, establishing a reluctance (R) path defined in the following manner:

$$R = \frac{l}{\mu A} \qquad \text{(Eq. 4-1)}$$

where R = reluctance = MMF/Φ
MMF = magnetomotive force
Φ = total flux
l = flux path length
μ = permeability = B/H
B = flux density
H = magnetizing force
A = cross-sectional area perpendicular to the flux path

A representation of the magnetic circuit of the recording head is shown in Fig. 4-8. Part A of the figure shows a conventional ring-type recording head. Assuming that flux flow through the core has no leakage, no external fields are introduced by the butt joint of the back gap, nor is there any leakage at the back area of the front gap. Under these conditions, the recording flux is proportional to the ratio of the reluctance of the tape plus the area of the tape in contact with the recording head to the front gap reluctance of the total flux through the core. All of the flux field is confined to the pole tips and the magnetic tape and divides into two parallel paths according to the reluctance of each path.

Only a small portion of the flux field in the core is effective in magnetizing the tape. Decreasing the air-gap depth dimension may saturate the pole tips and require head replacement more often. Increasing the cross-sectional area of the core may imply more recording flux in the tape without possible saturation of the pole tips, but it does mean a greater total flux in the head, with



$$\phi_m = \left[\frac{MMF}{R_c + \frac{R_g \cdot R_m}{R_g + R_m}}\right]\left[\frac{R_g \cdot R_m}{R_g + R_m} \cdot \frac{1}{R_m}\right]$$

$$\phi_m = \frac{MMF\ R_g}{R_c(R_g + R_m) + R_g \cdot R_m}$$

Fig. 4-8. *Equivalent magnetic circuit for recording: (A) head construction; (B)* R_c *is the core reluctance including the back gap;* R_g *is the front air gap reluctance;* R_m *is the tape reluctance.*

a corresponding increased inductance. Generally, a core of small cross section with a few coil turns would effect a low-inductance value and permit a fast rise and fall time, requiring a high recording-head current. Low shunt capacity as a result of fewer wire turns would improve the pulse recording response.

Equivalent Circuit for Playback Head

The main consideration for playback operation is that existing magnetic fields in the tape be recovered and diverted through the head-core material. Initially, the pole tips are used to shape and focus the immediate field into a well-defined field pattern. For maximization, material of high permeability is used to divert the recorded flux lines through the core with minimum leakage. Finally, the head coil converts the magnetic energy into electrical energy by flux lines linking the head windings; the output voltage of the playback head is proportional to the rate of change of flux linking the head coil turns and must be of sufficient amplitude to provide a good signal-to-noise ratio. The voltage so produced requires large amplification with sharp and well-defined leading and trailing edges, and yet it must be insensitive to residual noise of the tape and threshold noise of the amplifier circuitry.

A playback configuration and its equivalent circuit are shown in Fig. 4-9. In the equivalent circuit (part B), the head coil, L_P, acts as an ideal coil source of voltage e that is a function of tape speed in which a given number of flux lines cut a fixed number of wire turns of the playback head. Again, it is assumed that there are no leakage losses in the front and rear gaps and that simple head-to-circuitry coupling is used. The total capacity is lumped together in the equivalent circuit and labeled C_T. The series and shunt stray capacity of the head are added together with the cable capacity of the amplifying circuits, including the input capacity of these circuits. The input load resistance is defined by R_i. For digital applications, the inductance, and posibly the d-c resistance, of the head coils has to be considered when defining an equivalent circuit. As before, the desired solution is the critically-damped one in which R_i equals $\frac{1}{2}\sqrt{L_P/C_T}$ and the rise time of the generated voltage e is $\sqrt{L_PC_T}$ for a pulse response.

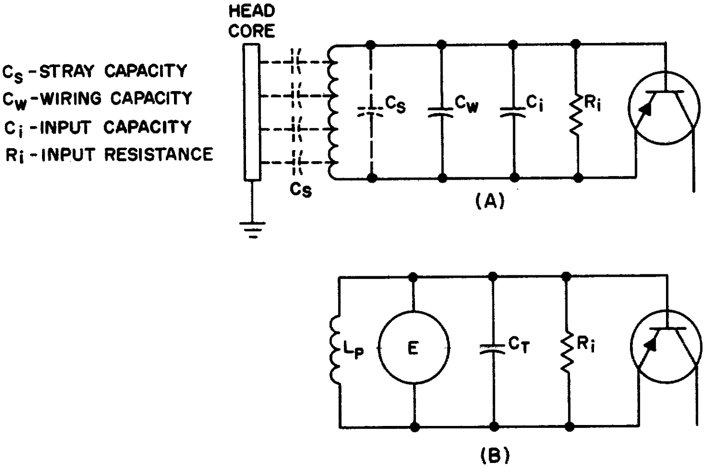


Fig. 4-9. *Playback head equivalent circuit; (A) actual circuit — C_s is stray capacity; C_w is wiring capacity; C_i is input capacity; R_i is input resistance; (B) equivalent circuit.*

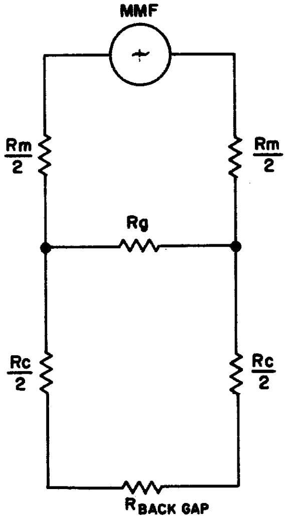


Fig. 4-10. *Equivalent magnetic circuit for playback operations.*

The design of the playback head circuit is a compromise with regard to circuit parameters, core size, head coil turns, and head structural details. As usual, conflicts develop when such a wide range of factors are balanced. For example, for a high output level a large number of turns with no d-c resistance is required to link the flux lines through the core. The lower the reluctance path of the head core the greater the number of flux lines linking the coils. On the other hand, this approach results in a very high inductance value that reduces the circuit response for digital applications and lowers the output level by increasing the voltage drop across L_P. A higher resistance value for R_i may be permissible to maintain critical damping, but the head-coil winding resistance will alter this value. More coil turns and wire surface area adjacent to the head core increase the total capacity, C_T, thereby inhibiting fast circuit response.

Compromises are also necessary when considering the equivalent magnetic playback circuit (Fig. 4-10). The equivalent magnetic circuit for playback is identical to the record magnetic circuit except for the location of the energy source. For playback, the magnetic tape supplies the MMF in series with the magnetic reluctance of the medium and the magnetic reluctances encountered in contact or lack of contact between the head and the tape medium. This total reluctance path is designated as R_m. R_g represents the magnetic reluctance path across the air gap. R_c is the total reluctance path of the core travel length, including the rear gap value, if one exists in the head.

In Fig. 4-10 the pole face is considered as two terminal points, each with a reluctance path in series with the MMF. The core leg is broken into two equal reluctance paths with a back gap that is considered to be part of the circuit. Since the head wear, tape medium, and head-to-tape surface contacts are nonuniform and unsymmetrical, Fig. 4-10 permits the assignment of two different values to R_m by using subscripts if necessary. The inclusion of a back gap in the core leg serves to isolate each section of the core structure. In this manner, various magnetic field patterns that bypass the head coils present losses for recovery of the recorded signal.

The magnetic circuit arrangement has the effect of the front gap circumventing the flux lines that would normally link the head coils when going around the low reluctance path of the core. At the pole tips, the flux lines divide into two parallel paths relative to their ratio of reluctance across the pole tip terminals. Making R_g large will reduce the direct losses of useful signal from the output coils. This can be done by reducing the depth and increasing the length of the air gap. Increasing the length of the air gap is contrary to the requirement that a short-length gap is needed for digital recording. However, this can be done provided that it does not interfere with high-frequency response.

In general, the head core may be an assembly of two sections, creating an unwanted rear air gap. This second gap not only is a source of leakage flux, but it tends to increase the reluctance path around the core, diminishing the linkage flux through the output coil on the head. The head impedance for both record and playback operations is very low. A common device used for impedance matching is transformer coupling. This type of coupling does not invalidate the equivalent circuitry. In fact, it may prove beneficial in many respects, since generally digital recording is a single-frequency or narrow-bandwidth operation.

Demagnetization

Before the process of writing information on tape is completed, forces are present that tend to reduce the magnitude of surface induction on tape. These demagnetization forces begin to act the moment the tape leaves the vicinity of the air gap and their initial effects are completed once the tape has been removed from the recording head. Once information is written on tape, the position of stored magnetic dipoles is random, and many tape sections are physically in contact with each other. The initial effect is a continued reduction in signal output during subsequent playback operations until a stabilized or limited surface induction is obtained. Every time the information is removed and replaced by new digital data, the same phenomenon is experienced.

Examination of its hysteresis loop indicates that a hard ferromagnetic material is more likely to be left in one of two possible remanent magnetic states. Yet the facility of being able to effect complete demagnetization is essential in magnetic tape recording. Almost complete demagnetization can be achieved by subjecting the material to a series of diminishing, alternating magnetizing forces. If the magnetizing force is very slowly reduced from

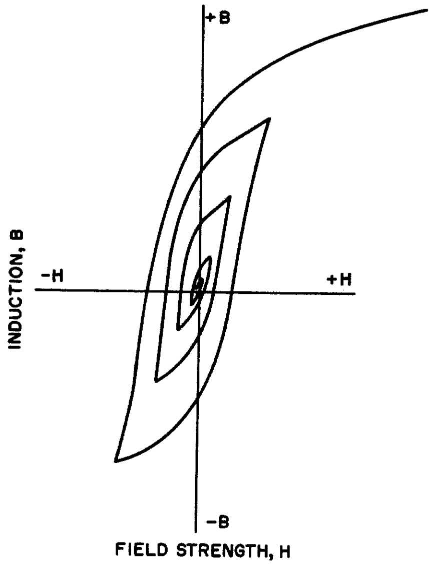


Fig. 4-11. *The change of a B-H curve developed by a gradually decreasing cyclical magnetic field.*

the maximum value to zero, the remanent induction will correspondingly cycle through a reducing B-H curve until a near zero value is obtained (Fig. 4-11).

In digital magnetic recording, complete demagnetization or erasure that leaves the medium in a neutral state is not always required for tape re-use. All that is necessary is the substitution of new information for old information or the complete removal of the previous information. This will be considered in greater detail in the next chapter when digital magnetic recording techniques are discussed.

Ferromagnetic materials can be classified as being either soft or hard. Soft materials have low values of coercivity, high flux densities at saturation, high values of permeability, and no magnetic retention qualities; i.e., no appreciable signs of magnetization after the removal of the magnetizing force. Soft materials are used where their properties prove advantageous, such as in magnetic heads for recording and playback operations. For writing digital information on tape, high flux densities with low magnetizing currents and low losses are required. In addition, no residual fields should exist after removal of the magnetizing force.

Hard ferromagnetic materials are characterized by high coercivity values, low flux densities at saturation, low permeability values, and a high remanent state. These properties are essential for the establishment of a series of permanent magnets along a recorded length of tape. On the basis of these characteristics, materials in this category are selected for magnetic-tape coating material. (This topic will be covered in more detail when digital magnetic tapes are evaluated.)

Three generalized B-H curves are shown in Fig. 4-12. For soft material, the curve of Fig. 4-12A shows a high flux density characteristic requiring a low magnetizing force. At the same time, the total B-H curve area is small, showing that only a small amount of energy is required to trace the path of the B-H curve. The B-H curve shown in Fig. 4-12C indicates high coercivity and high retentivity. The former characteristic is desirable in magnetic tape

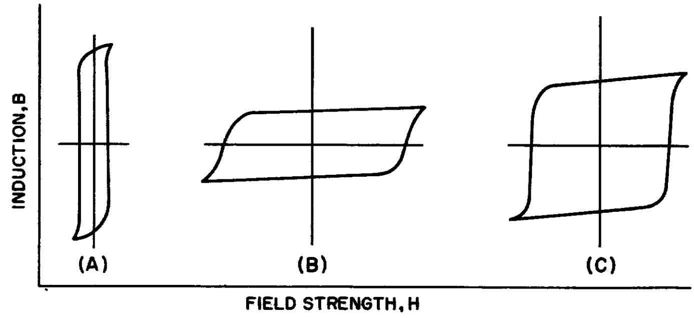


Fig. 4-12. *A comparison of hysteresis loop shapes: (A) low coercivity with high retentivity; (B) high coercivity with low retentivity; (C) high coercivity and high retentivity.*

to resist demagnetization and the latter characteristic is a must for high signal outputs. Obviously, the B-H curve area may be large, denoting that a substantial amount of energy is necessary to switch from one remanent state to another.

Gap Effect in a Magnetic Circuit of Soft Ferromagnetic Material

Use of a solenoid is the simplest way of producing a magnetic field of known strength and direction. Figure 4-13 shows a solenoid and diagrams equipotential lines of force within the center area. If both the equipotential lines of force for each unit length within the coil and the cross-sectional area are constants, the flux density (θ/A) will be a constant. On the other hand, if a plane perpendicular to the solenoid axis cuts the lines of force at various distances from the solenoid's center point, a diminishing value of flux density will be measured. If the useful magnetic field is defined at the center point, there are two sources that contribute to major losses: losses incurred to obtain useful energy and intrinsic losses of the system. As the air path length to complete a magnetic line of force is made greater, so, too, must the energizing source be increased to obtain a given field strength within the coil. As long as the magnetic field is maintained within the solenoid, the energizing source constantly supplies these losses. Intrinsic losses include the lines of force radiated at each extremity of the coil, which never return to the other side to form a closed path. The intrinsic losses, however, are not recoverable and are inherent losses of the selective geometric configuration of the device.

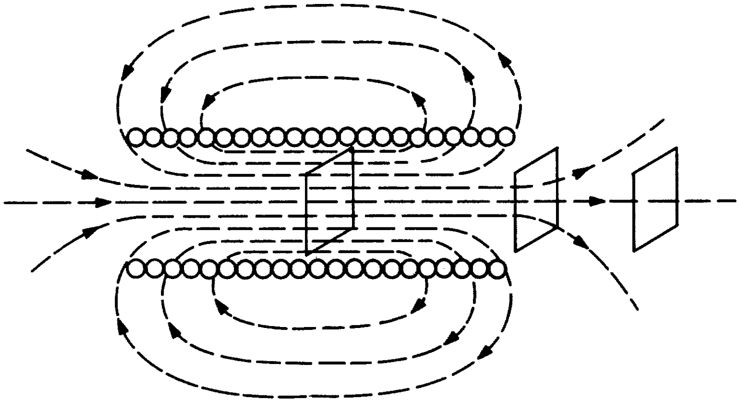


Fig. 4-13. *Field distribution within a solenoid.*

All magnetizing curves shown so far are representative of an open magnetic circuit and, therefore, a variable set of permeability values with changing cross-sectional areas. In a closed magnetic circuit, losses considered above become virtually nil.

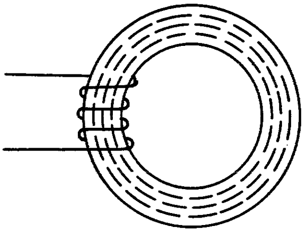


Fig. 4-14. *A closed magnetic circuit.*

A closed magnetic circuit is represented as a wire-wound toroid core in Fig. 4-14. Omitting the ohmic losses of the coil for the moment, all lines of force are confined within the core material. There is an appreciable increase in the flux density for a given cross-sectional area of the toroid in comparison with the solenoid. The increase is due to the reduction or elimination of all the power-consuming losses such as the nonrecoverable lines at the solenoid extremity and the reorientation of the air path lines into the core (Fig. 4-13). At the same time, however, going from an air core to an iron core will introduce new sources of power losses. If the iron is a soft material with a high magnetic permeability value (Fig. 4-12A), the low coercivity parameter means that very little energy is consumed in establishing a magnetic field throughout the toroid. Under these conditions, a minimum of power is necessary to establish a magnetic flow and the maintenance of magnetic lines is considerably reduced because of the high permeability. If a perfect B-H curve could be obtained it would approximate a letter S of zero thickness.

With a ring-type head, consider the case when the closed circuit is broken by an air gap, even a gap as short as 0.001 inch, for recording purposes. Since the permeability of air is unity and the remaining portion of the magnetic path is of the order of several thousand, the effective permeability of the previously closed circuit will be lowered considerably. If, as in Fig. 4-15, a small air gap is introduced into an otherwise closed magnetic path, the application of a magnetizing force will give rise to a flux of reduced magnitude passing through both iron and air. It is difficult to ascertain the altered values of flux

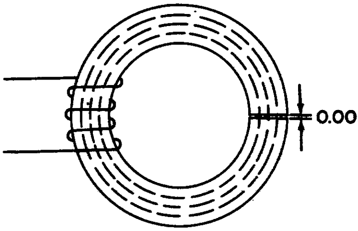


Fig. 4-15. *An open magnetic circuit.*

and flux density and the shape of the modified magnetizing curve. This is due, in part, to the fact that lines of flux spread in the gap according to the principle of least resistance and are perpendicular to the emitting and receiving surfaces. The determination of the exact cross-sectional areas and exact lengths of the travel paths of the magnetic lines are far beyond the scope of this book. Only approximations are given when attempting to analyze the demagnetization effect of an air gap inserted in a closed magnetic circuit. (See Appendix 2.)

The earlier description of equivalent magnetic circuitry for recording and playback operations did not stress the relative magnitudes of these losses. Instead, the front-gap and back-gap losses appeared nonexistent since they were absorbed, respectively, in the reluctance paths of the recording gap and core path. Actually, the magnitudes of the magnetizing force and the flux density within the magnetic head are very large. The recording core cross-sectional area, in many instances, is inadequate, and high losses are sustained in leakage in the immediate area and heating losses in the magnetic shields. These losses also cause cross-talk or pickup in adjacent coils. In the vicinity of the air gap, the concentrated flux lines cause heating at the pole tips and distortion of the magnetic paths. In addition, there is the normal gap leakage associated with open magnetic circuits. Since the magnetic field beyond the core (in air) is unpredictable under these conditions, it is rather difficult to define the useful signal content, distortion, and other losses. Although power input is costly, signal distortion, partial erasure of adjacent information, and extensive signal processing for recovery of information increase the complexity of digital application in an otherwise simple magnetic recording system.

Gap Effect in a Magnetic Circuit of Hard Ferromagnetic Material (PM)

The demagnetization effect of air gaps in hard ferromagnetic materials is entirely different from that in soft magnetic materials. In the latter case, it is important to create a concentrated localized magnetic field as a source of MMF for a short time duration. During this time interval, control is exercised in directing and maintaining the desired field orientation with a minimum of power consumption. In the case of permanent magnetization, however, higher values of remanence and coercivity are present, and the time duration is of much concern. Preservation of the data or permanent magnetization without deterioration for an indefinite period of time is paramount with hard ferromagnetic material. The demagnetization losses associated with soft iron can be supplied in sufficient quantity to counteract the gap effect. This cannot be done with permanent magnets, but using a shorting bar across the air gap can reduce the demagnetization effects.

The geometric shape of permanent magnets on tape is of finite width and depth, but the length can be as small as one data bit or as long as the length of tape. The dimensions of a bar magnet of extremely long length present no problems, but the demagnetization effect of a short bar magnet is pronounced and detrimental to ultra-reliable digital magnetic tape recording.

Therefore, it is necessary to establish a strong type of permanent magnetism in the tape so that it is less susceptible to deterioration and immune to any influences that might alter or even establish a new set of unordered magnetic conditions.

Consider the case of a bar of hard ferromagnetic material with a coil embracing it. When current is passed through the coil to saturate completely the iron and is then removed, the bar becomes magnetized and establishes a magnetic pole at each end as point sources of magnetic intensity. If the iron bar is small, the poles are comparatively close and have a demagnetizing effect on each other because of polarity and proximity. The demagnetizing force for the short bar is far greater than that of a longer bar. In the ideal case of the closed ring magnet, no specific poles exist because a complete closed path is present. Consequently, no force is present to reduce or react against the established permanent field within the iron core. In the case of the bar magnet, the effective magnetizing force is $H - H_d$ where H is the applied magnetizing force and H_d is the demagnetizing force. For any particular permanent magnet, H_d is proportional to the intensity of magnetization:

$$H_d \; \alpha \; NJ$$

$$N \; \alpha \; \frac{A}{l}$$

where N = demagnetizing factor and a function of core geometry

J = intensity of magnetization

A = cross-sectional area perpendicular to l

l = mean length between poles

For the toroid, N is equal to zero. A short, thick magnet is subject to a much greater demagnetizing force than a long thin one, as shown qualitatively with the above formulas.

A permanent magnetic field in a circular core with an air gap present is established in the following manner (Fig. 4-16). The core is magnetized and saturated at some maximum flux density, B_m. The magnetizing force would be removed and the core left in a remanent state of B_r if there were no air gaps present in the core. For the case at hand, the B-H curve is traced along

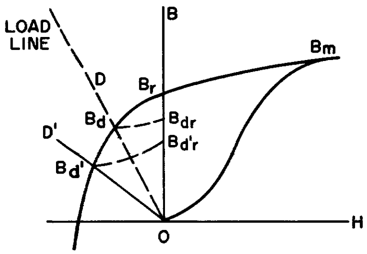


Fig. 4-16. *Gap effect in a permanent magnet.*

the curve from B_m to B and then to B_d. As a result of the air gap, the flux density is reduced to B_d with a demagnetizing force of H_d at the pole tips. If a line is drawn between B_d and the origin, O, the line DO is expressed as a load line or shearing line (Appendix 2) where the slope is determined by the geometry of the magnet and air gap dimensions. If the gap is made longer, H_d is increased and the flux density will be reduced still further along the curve to position B_d'. If the demagnetizing effect is removed, a path will be traced that will join the load line to the *B* axis (dashed line in Fig. 4-16). This can be accomplished by placing a piece of iron of high permeability across the air gap.

This method of reducing the demagnetizing effect of a permanent iron core is performed with every playback operation. The shorting strap is operated by sliding it on and off in a nonuniform manner, disturbing the permanent magnet field orientation.

Demagnetization in Tape

Magnetic tape is comprised of a film of numerous ferromagnetic particles distributed more or less evenly on a sheet of material that supports the film. Some of the particles and agglomerates touch one another, while others are isolated by the binding material. Present techniques make possible a higher composition percentage of magnetic material to binder material. A finer dispersion of homogeneous coating deposited on backing material permits higher tape data densities and ultra-smooth oxide surfaces.

The process of writing information on tape produces bar magnets of random lengths, depending on the digital techniques. As described earlier, the process of recording digital information causes a series of bar magnets with like poles of adjacent magnets facing each other. In some cases the magnets are practically in contact with each other while other digital recording techniques may create isolated bar magnets relatively distant from each other. This effect of opposite polarity alone will give rise to demagnetization. When the recording density is 1000 bits to the inch, the bar length is 1 mil (.001 inch) and demagnetization is aggravated.

When the structure of the tape coating is considered as a particle composition instead of a solid material, the demagnetization effect becomes complicated. A long bar magnet may actually be comprised of a large number of smaller magnets that may be further subdivided down to the dispersion particle itself. The characteristics of the individual particles differ widely in geometric shape, permeability, and pattern of magnetic-field orientation.

Losses Associated with Magnetic Recording

Since some of the losses associated with magnetic recording are due to the head alone, some to the tape alone, and some to the association of the two, there is no particular advantage in attempting to segregate each loss. Instead, the fact that losses exist, and that they are dependent on either wavelength or frequency is of considerable importance. Major losses associated with wavelength are due to: (1) gap and head alignment; (2) head and tape separation; (3) tape losses; and (4) demagnetization (head and tape). Major losses associated with frequency are due to: (1) hysteresis losses (head and tape); and (2) eddy current losses (head and tape).

Gap and Head Alignment

Under ideal conditions, the motion or tape during playback and record operations is perpendicular to a plane parallel to the centerline of the air gap. This means that the edges of the playback head gap must be parallel to the trailing edges of the recording gap. In actual practice, the most common air-gap losses can be attributed to the air-gap construction and the alignment of the head. Losses are incurred when the flux field is not properly recorded due to imprecise head construction and alignment; e.g., the effective gap length might be exceptionally large and scatter the useful field over a wide area, with a field pattern that is improperly orientated. Under these conditions, because the losses are incurred in the initial recording, signal recovery is not always possible.

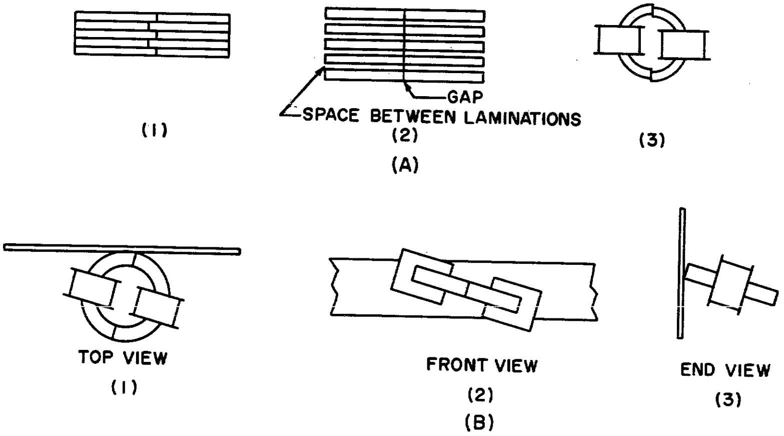


Fig. 4-17. *(A) Gap misalignment: (1) longitudinal; (2) lateral; (3) transverse. (B) Head misalignment: (1) longitudinal; (2) lateral; (3) transverse.*

Figure 4-17 illustrates two of the most common causes of gap loss: improper alignment of the gap edges and improper alignment of the gap. A third common cause of gap loss is incorrect alignment of the recording and playback heads as a unit system.

If the head is improperly constructed, a sharp and well-defined focusing slit is not available for recording purposes. As indicated in the previous chapter a wide air gap creates a null point (zero output), which restricts the minimum wavelength for recording. If the air gap edges are not parallel, the magnetic field at the edges will be scattered and distorted and the complete system of magnetic recording will be degraded. The departure of the recording slit from a straight line is similarly detrimental for tape recording interchange. Even on the same transport, lateral tape motion may present problems for recording and playback operation.

Misalignment of the magnetic head reduces the sensitivity of the pickup coils on the playback head. As the head is aligned in three axes, any deviation from the perpendicularity of any axis with the recorded field orientation will reduce the signal output during playback. The losses associated with these mechanical problems were covered in the preceding chapter. They are fixed and unalterable. They set an upper limit on the high-frequency response and resolution capability of the recording system.

Head-to-Tape Separation Losses

Thus far it has been assumed that the surface of the head and tape are in intimate contact at the gap line. However, if they are separated by a distance d, the playback loss due to separation between tape and head is expressed in the following manner:

$$\text{Playback loss in decibels} = 55\,\frac{\text{separation}}{\text{recorded wavelength}}$$

There is a corresponding loss associated with the recording operation that is at least as great, so that the total loss for both operations (record-playback) is the decibel sum:

$$\text{Overall loss in decibels} = 110\,\frac{\text{separation}}{\text{wavelength}}$$

An unintentional separation of 0.001 inch can be prevented, but a separation of 0.0001 inch is very likely to occur. Such possibilities as tape curl, roughness of coating surface, and hardening of the head surface through grinding are always present. After repeated use, a tape may pick up dust and dirt or lose some particles of oxide, even under the best operating conditions. At high data packing densities, the slightest foreign matter, if only a fraction of a micron in size, can incur erratic operating conditions. Table 4-1 lists standard speeds and recording densities with their corresponding separation losses for recording or playback operations.

At present speeds of 150 ips and higher, air can collect about the head and tape area and form an air film. This phenomenon is observed only at high tape speeds. Air is trapped between the head and tape and builds up enough pressure to hold the tape away from the head. The tape assumes an average space pressure at speeds where its mass and springiness prevent exact conformity to the head contour.

In the case where head-to-tape separation is unintentional, an opposing force must be created to counteract the pressure and bring the tape into con-

TABLE 4-1.

Frequency (cps)	*Speed (ips)*	*Density*	*Separation Loss per mil (db)*
15 kc	75	200	1.1
75 kc	150	500	2.75
200 kc	200	1000	5.5

tact with the head. This may be accomplished by controlling the head-to-tape tension, thereby arriving at a tape tension that performs well for various speeds and tape qualities. To do this without impairing the head or tape is difficult. On the other hand, the air-formation separation can be accepted as a desirable condition that minimizes head and tape wear. If bounce and tape fluctuation can be prevented, the recording and playback circuitry may be modified to use a higher write current with a more sensitive playback amplifier.

The preceding losses are introduced, in part, into a diminishing magnetic field as a function of distance from the magnetic source. For a fixed-head assembly, the further the tape is from the head, the weaker the recorded field will be.

Tape Losses

Separation losses, which reach such high values at short wavelengths, have been shown to be due to shorter excursions of flux lines from the head into the tape. Tape coating is of a finite thickness and it is reasonable to expect that for short wavelengths a decreasing proportion of flux lines actually penetrate the tape coating under the oxide surface. It may be possible to reduce the coating thickness without affecting the recorded level. This would result in less tape weight or more playing time for a given spool diameter.

In digital recording, short wavelengths and nonlinear recording produce a nonuniform magnetic field distribution within the tape. The tape characteristics for digital recording have two remanent magnetization states. Consequently, a diminishing magnetic field will either saturate the tape or not. Energy, then, is expanded and, in many cases, does not prove useful. (An explanation of energy content for a B-H curve is given under *Hysteresis Losses* later in this chapter.) For the moment, it is enough to state that the flux density is insufficient to move past the knee of the curve, and the magnetic state of the tape reverts back to its starting remanent state. This reversible change is brought about by an inadequate magnetizing force and the B-H squareness to switch the tape from one remanent state to the other. Furthermore, it is possible that the magnetic state of the tape as a function of tape depth may assume numerous magnetic values between the two maximum remanent states ($\pm B_r$ and $-B_r$). For tape operations, this reduces the signal output and, at the same time, raises the noise level. Both conditions are objectionable.

Nevertheless, the variation of magnetization with any one recorded wavelength will be in discrete steps, the magnitude of which depend upon the uniformity of the tape. The uniformity of particle size and the distribution, orientation, and proximity of adjacent particles make it difficult to define an accurate field distribution. The size of a single particle imposes an ultimate limit on short wavelength recording. The discreteness of the data and the finite particle dimension with the presence of the binding agent set a practical upper-limit capability on present day digital magnetic recording tapes. (Chapter 6 is devoted to magnetic tapes. These problems will be examined in detail there along with other tape characteristics relevant to digital recording.)

Self-Demagnetization

In general, losses to self-demagnetization may be expected to occur in several ways during the recording and playback processes. A loss may be introduced during the recording process as the tape leaves the vicinity of the head. This demagnetizing force is introduced by the length of tape that is already recorded. A further loss may occur when the tape leaves the recording air gap. The air path of a permanent magnet does not assume the flux density corresponding to a magnetizing force of zero, but is something less on the B-H curve for a minus H. Obviously, the recording field does not fall to zero but will fall through zero to a negative value equal to the demagnetizing force. While in the area of the head but past the air gap, the core will tend to reduce this effect, but the demagnetization that occurs will eventually reach a stabilizing value when the tape leaves the head altogether.

In practice, the tape will not be uniformly magnetized through its entire depth, but the demagnetization should be small when $\lambda >> d$ (λ = recorded wavelength and d = tape thickness). Again, the losses do not continue to increase indefinitely with diminishing wavelength, but tend towards a limiting value. Under these conditions, the thicker the tape, the sooner the self-demagnetization reaches its limiting values. The analysis of self-demagnetization losses previously given is only approximate. However, it throws some light upon the interaction of dimensional and magnetic properties of head and tape. It also emphasizes the important fact that the tape losses cannot increase indefinitely with decreased recorded wavelength and that a limiting value exists for a given set of conditions.

Losses Associated with Frequency

In magnetic devices operating with a steady-state flux field, no heating losses occur in the material. If, on the other hand, the current is cyclical or varying, the magnetic field will build up to a maximum every half cycle and fall through zero to the reverse direction on the alternate half cycle. A slowly varying d-c current experiences very little resistance to flux changes, while a frequently changing d-c current will cause the circuit to resist the varying field and energy losses will be present. Therefore iron-core losses occurring in the material arise from the following causes: (1) the tendency of the material to oppose a change in magnetic state (magnetic hysteresis); and (2) the tendency of an electric field to appear in the medium as a result of the time variation of the flux field (Faraday's Law of Induction). The first loss is commonly known as *hysteresis loss* and the second as *eddy current loss.* The total iron-core losses of a material are the sum of hysteresis and eddy current losses.

Hysteresis Losses

If a plot of flux density versus magnetizing force followed a curve that retraced the same path for positive H and negative H, as in the ideal hysteresis loop shown in Fig. 4-18, no losses would occur, nor would it be possible to store any magnetic energy in the core material. At zero magnetizing force, no flux would exist in the material. Fortunately, the forward trace and the reverse trace follow two different paths and the iron material can store magnetic energy. A distinction is made here between hysteresis and hysteresis losses. The phenomenon known as hysteresis is the capability of the material to retain magnetism or resist a change in an established magnetic state. The loss associated with hysteresis is the heat generated during the process of cyclical variation of the magnetic state of the material.

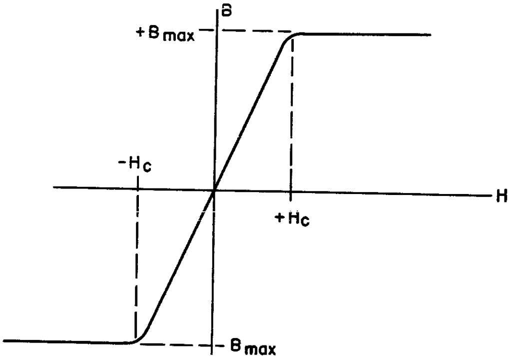


Fig. 4-18. *An ideal hysteresis loop.*

The conversion of electrical energy into magnetic energy can be demonstrated by the circuit configurations of Fig. 4-19, where a composite hysteresis loop and a magnetization curve are shown. (A complete plot of a typical hysteresis loop is shown in Fig. 4-20.) Using the plotting circuit of Fig. 4-19B, the measurement starts from a demagnetized state and traces the curve of OB_{max} (Fig. 4-20). Further increase in the magnetizing force produces only a slight increase in magnetism of the material. At the point of $+B_{max}$, $+H_{max}$,

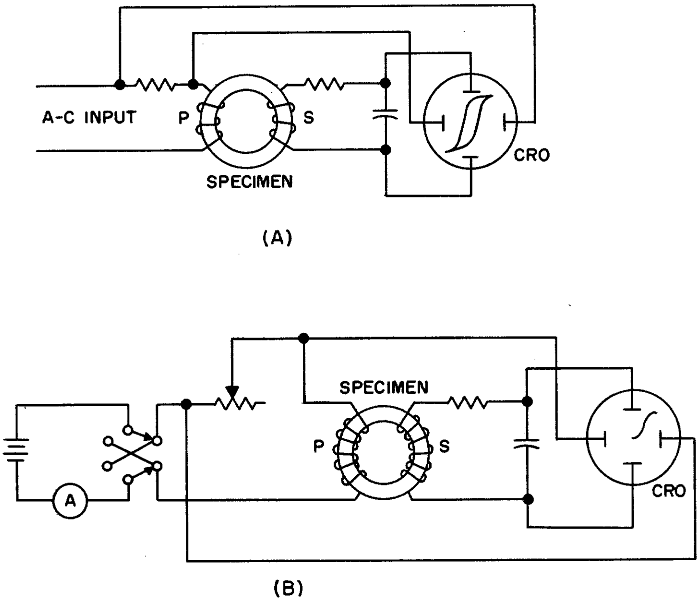


Fig. 4-19. *Hysteresis loop and magnetization curve.*

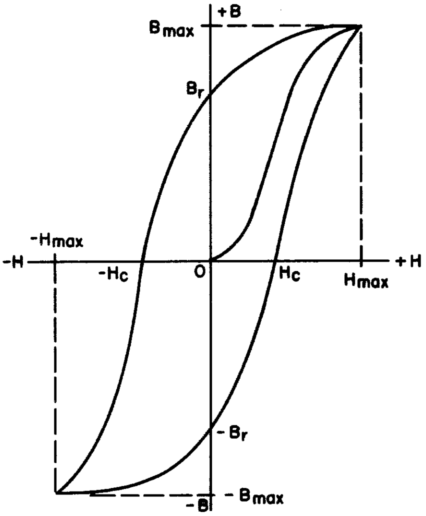


Fig. 4-20. *A typical hysteresis loop.*

the material is considered saturated for a maximum magnetizing force H_{max}. Starting from $+B_{max}$, $+H_{max}$, the magnetizing force is reduced from $+H_{max}$ to O, but the curve follows the path $+B_{max}$ to $+B_r$ and not $+B_{max}$ to O. A given amount of induced magnetism is returned by the material and this is represented by the intersection of the return path from $+B_{max}$ with the B axis at $+B_r$. The value of $+B_r$ represents the residual flux density when no demagnetizing force is present. From this point, the magnetizing force is changed by reversing the battery polarity and increasing the magnetizing current in the opposite direction. A path from $+B_r$ is traced until the demagnetizing current reduces the flux density to zero. At this point ($B = 0$, $H = -H_c$), H_c is commonly called the coercive force and is indicative of the retentive force of the material. If the magnetizing current is further increased, a curve will be described by $-H_{max}$ to $-B_{max}$. Reducing the magnetizing current again and reversing its polarity will describe the remaining portion of the B-H loop from $-B_{max}$ to $+B_{max}$.

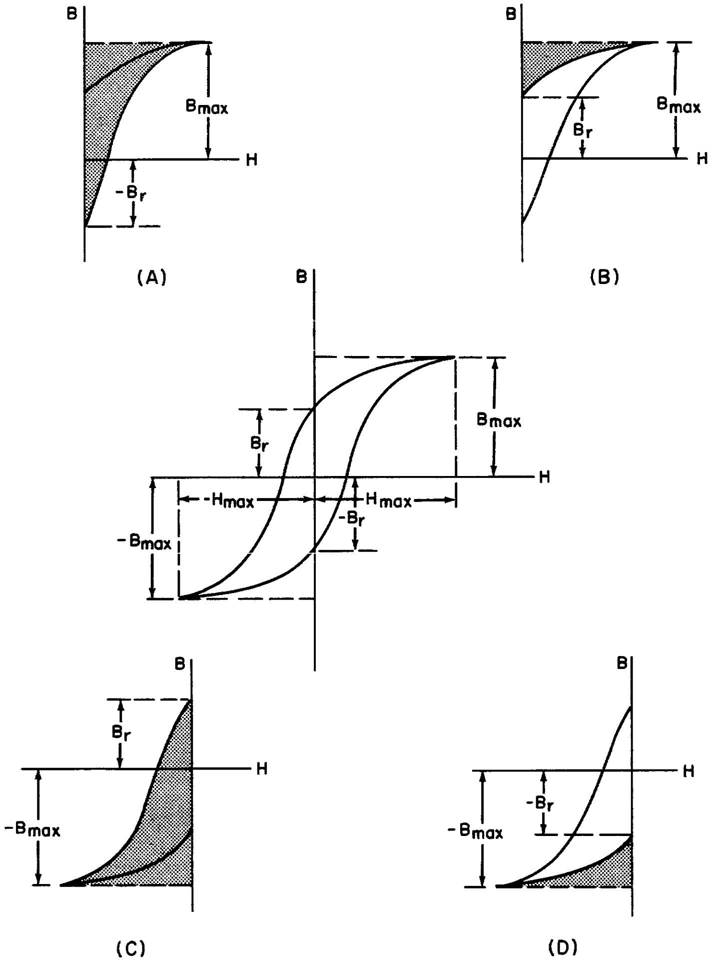


Fig. 4-21. *The energy content of a hysteresis loop: the shaded areas in (A) and (C) show energy absorbed; in (B) and (D), energy returned.*

A qualitative representation of the previous hysteresis loop is shown in Fig. 4-21. Energy is expended in tracing out a closed loop. In Fig. 4-21A, energy is stored in the material from $-B_r$ to $+B_{max}$. With the removal of the energy source, the B-H curve follows the path of $+B_{max}$ to $+B_r$. The shaded area is the energy returned to the electric circuit (Fig. 4-21B). For the reverse change of magnetic state, the B-H curve is traced along the path from $+B_r$ to $-B_{max}$ (Fig. 4-21C). The energy stored in the material going from $+B_r$ to $-B_{max}$ is shown in Fig. 4-21C. With the removal of the energy source, the B-H curve follows the path of $-B_{max}$ to $-B_r$. The shaded area is the energy returned to the electric circuit (Fig. 4-21D).

The conversion of electrical energy into magnetic energy requires a storage medium to hold the flux. If energy is stored, obviously it is recoverable. The tracing of a hysteresis loop discloses the return of some of the energy to the electric circuit; the rest is converted into heat as a result of the work done on the material when it responds to magnetization. Therefore, the energizing current (i) in the coil produces a flux (ϕ) that is defined in the following equations:

$$E = N \frac{\Delta\phi}{\Delta t} \qquad \text{(Eq. 4-2)}$$

$$\text{Power } Ei = Ni \frac{\Delta\phi}{\Delta t} \qquad \text{(Eq. 4-3)}$$

Where
$\Delta\phi$ = change of flux
Δt = time interval associated with flux change
$\phi = BA$
$H = \frac{4\pi Ni}{l}$

and

$$\frac{\text{energy}}{\text{unit volume}} = \frac{\text{power} \times \text{time}}{\text{unit volume}} = \frac{1}{4\pi} HB \qquad \text{(Eq. 4-4)}$$

Equation (4-4) shows that the energy is independent of the length of time it takes to trace out the area of a hysteresis loop; that is, the energy depends only on the amount of change of B and not on the rate at which the change takes place. Therefore, the hysteresis loss is equal to the area HB. If the current changes f cycles per second, then the hysteresis losses are linearily related to frequency by the following equation:

$$\text{Hysteresis loss} = f \times \text{area of the BH loop} \qquad \text{(Eq. 4-5)}$$

Eddy Current Losses

The eddy currents that flow in magnetic material are caused by an electromotive force (emf) created by the varying flux field. These currents assume a direction perpendicular to the direction of the magnetic field. In Fig. 4-22A,

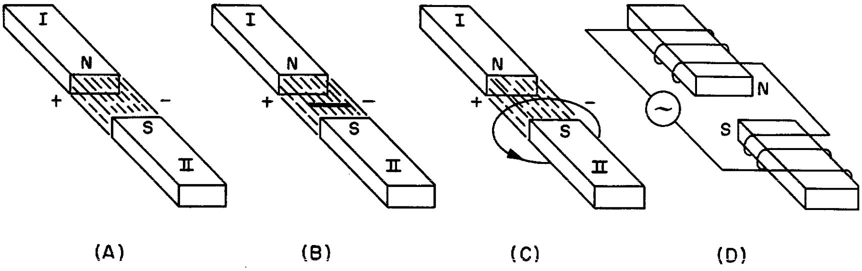


Fig. 4-22. *EMF produced by a changing flux field.*

two magnets are shown with a magnetic field between them. If the magnets are moved toward and away from each other, the magnetic field will tend to increase and decrease. The changing flux field induces an emf across the conductor midway between the two magnets with the polarity designated. If the ends of the conductor in Fig. 4-22 are connected by a wire external to the magnetic field, a current will flow in the closed circuit as the field is changing and an emf will be generated. Instead of moving the magnets to create a changing field, a bar wrap-around coil can be substituted for each magnet. The flux field would then change at the rate of the a-c source (Fig. 4-22D). For the permanent magnets, the flux field would change in the gap between the magnets. The a-c method would not only have the field changing in the air gap, but the field within the iron bars would also vary. Since the iron bar can simulate a closed loop electrical path around the flux field, an equivalent shorted turn effect becomes apparent. The electromagnetic bar is a solid material and it would be impossible to pick out each single closed loop turn and count the total across the bar. High-order mathematics permits the summation of these turns on a per-unit-length basis. Therefore, each turn would have a current flow through its closed circuit. These currents are called eddy currents. They remove energy from the source in proportion to RI^2; the energy is dissipated in the form of heat. The eddy current power loss can be expressed in the following manner:

$$P_e = (K_e f^2 t^2 B^2_{max})/P \qquad \text{(Eq. 4-6)}$$

Where K_e = constant
f = frequency
t = thickness of lamination
B = flux density
P = volume resistivity

Accordingly, the circuit of Fig. 4-22D is quite similar to the recording process when eddy current losses are considered. The emf is set up, as previously indicated, throughout the whole circuit (iron and air) and its direction reverses

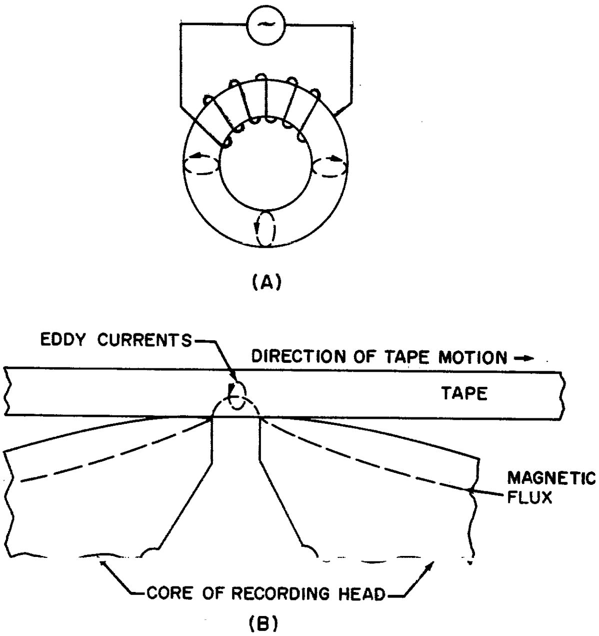


Fig. 4-23. *Eddy currents: (A) iron core; (B) magnetic tape.*

in a cyclical manner as the flux reverses. Figure 4-23 illustrates the formation of eddy currents in an iron core and a low permeability path of magnetic tape. In the case of the iron core (Fig. 4-23A) subject to an a-c magnetizing force, the flux in the core is continually changing and causing eddy currents to flow. The magnetic tape (Fig. 4-23B) shunts the head pole tips and reduces the reluctance path to complete the magnetic circuit. Most magnetic materials are of low resistivity and, accordingly, would give rise to substantial eddy current losses. Unfortunately during recording, high flux densities exist in the head and the tape is subjected to a magnetizing force to saturate it up to, and possibly past, the B_{max} point of the B-H curve. High packing densities on tape mean frequent flux reversals that tend to increase the eddy losses in core and the tape.

In the case of the magnetic heads, eddy current losses are minimized by maintaining a high-permeability path for the flux path and restricting the circulatory current path. This is accomplished by constructing the head of thin laminations that are insulated from each other. A two-fold effect is achieved in reducing the eddy currents. The eddy current equations disclose that the losses are proportional to t^2 and to $1/P$. The laminations are extremely thin, with an insulating layer on each laminated side. The insulation breaks up the eddy current path and reduces the losses. In the tape, the magnetic coating consists of ferromagnetic particles that offer a high resistance to eddy currents and increase the reluctance value for the flux path of the recording signal. These losses must occur at the expense of the source of energy, as they are always present. Under these circumstances, they are also present in the playback process.

The eddy current losses are proportional to f^2 and, therefore, always increase with frequency. Unless corrective measures are taken, even a low frequency source can cause eddy currents to circulate sufficiently to raise the core temperature to a red heat. Using the circuits of Fig. 4-19, a static hysteresis loop and two dynamic hysteresis loops are shown in Fig. 4-24. The static method (d-c) produces a very narrow hysteresis loop with a minimum of iron core losses. An a-c magnetizing force requires higher field strengths to obtain the same induced flux density. This shows that greater losses occur with higher frequencies that increase the B-H loop area. As the frequency is raised, the B-H area becomes wider and the losses increase still further. The variations in lamination thickness will also affect core losses, and thinner laminations reduce circulating eddy currents by reducing the area of the hysteresis loop (Fig. 4-25).

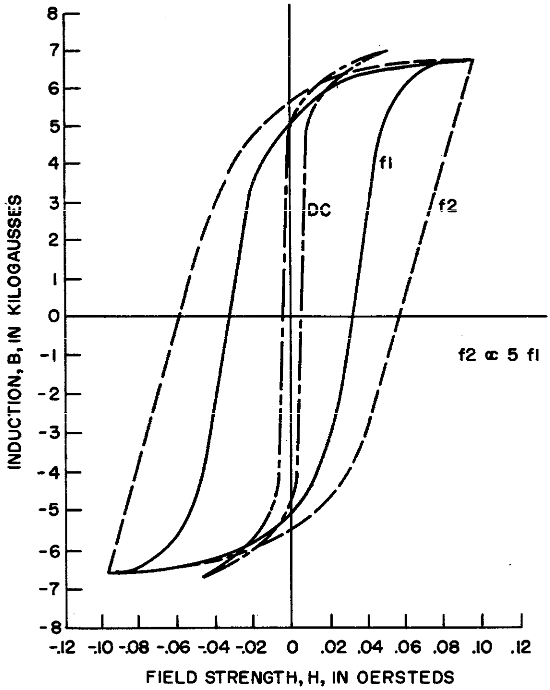


Fig. 4-24. *Hysteresis loop variation as a function of frequency.*

Within the tape the circulating eddy current creates magnetic fields that combine vectorially with the recording fields to cause distortion, as shown in Fig. 4-26. Here, a counter MMF is created within the tape that is parallel

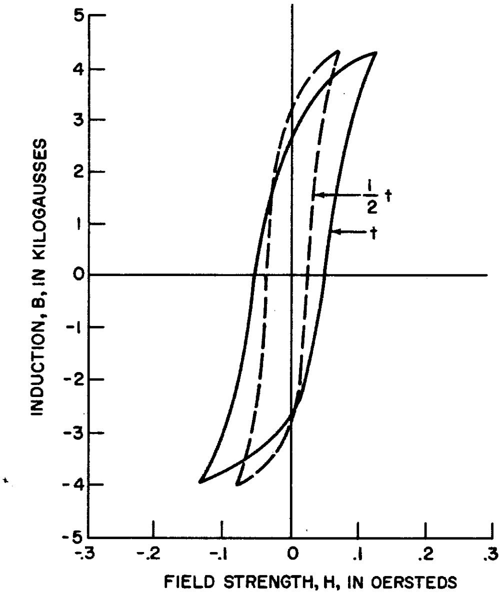


Fig. 4-25. *Hysteresis loop variation as a function of lamination thickness.*

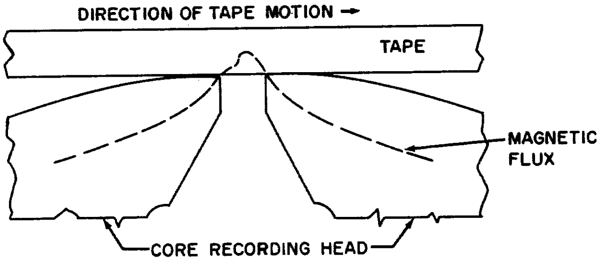


Fig. 4-26. *Eddy current distortion in tape.*

with the tape and in the direction of tape motion. The counter MMF opposes the field in the vicinity of the air gap. Since the flux field is greatest in this area, the effect is most pronounced in spreading the magnetization and decreasing the field strength. Poorer high frequency response is noted with diminishing output signals during playback.

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5

Coding Digital Magnetic Tape

Writing digital information on magnetic tape is accomplished by current switching through the record head windings between different, predetermined levels. In this manner, the tape area immediately below the head is magnetized and holds a flux field pattern indicative of this process. In general, the tape is in motion and a sequence of magnetic poles forms a single recording channel. The channel width is determined by the head width and the digital information is bounded by a pair of hypothetical or imaginary lines, forming a magnetic field zone called a *cell*. For illustrative purposes, a multichannel recording is shown in Fig. 5-1 where the write head current is turned on and off to generate a tape magnetic pattern designating a series of decimal numbers in binary notation. The fundamental unit in a binary numbering system is the bit, and the cell length as shown is one bit length. The absolute bit length

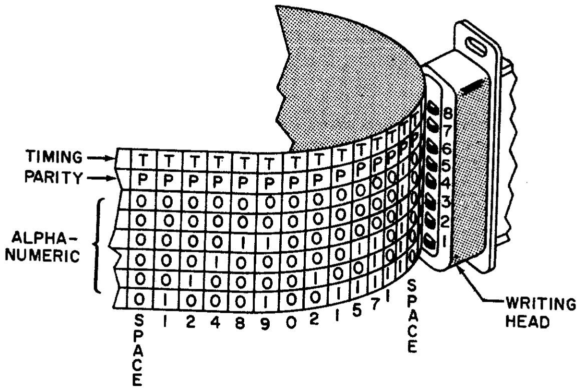


Fig. 5-1. *A multichannel recording.*

is of no consequence as long as the written information can be recovered without error. This requirement of error-free recording, along with the high density demands of digital data systems, has presented major problems for recording and reading digital information on tape. In most cases, the deciphering of this information is primarily dependent upon distinguishing the cell boundaries. Therefore, the transition from one cell to another and the corresponding magnetic state of adjacent cells determine the end of one bit and the start of the other.

Cell length is determined by tape speed, gap length, pole tip profile, fringe fields, and the duration of the magnetizing current. Also, the quality and performance of the tape cannot be neglected in discussing cell density for digital recording, which makes the cell length an elusive dimension. One possible circumvention of this problem is to assign a predetermined cell length with sufficient guard space to achieve the reliability of the system. Under these conditions, the cell area may be fully or partly occupied (magnetized).

Magnetic tape is a natural storage medium for a two-state data system; it can be magnetized to indicate two states by field orientation (north-south or south-north). Digital tape recording utilizes this principle of polarity direction. On the tape, however, during the transition from one direction to another, there is an intermediate area of uncertainty as to the demarcation point for each field direction. As indicated in the description of cell occupation, there can be areas of nonmagnetic fields. The nonmagnetic area may be deliberate or unintentional (poor tape quality). Again, cell boundaries are difficult to determine, so cell centers are used to decipher the written information. Hence, digital information is located on a positional or transitional basis, or both.

Although the process of writing binary information on tape may appear straightforward, considerable research has gone into both the development of the coded patterns used to represent 1's and 0's and the decoding techniques. In writing information on tape the digital information is supplied to recording circuitry for encoding into a form that is most compatible with this method of recording. The complementary process of decoding this information is fully determined by the coding technique used. However, since the tape station is just another component within a major system, its integration cannot be arbitrarily defined in terms of the recording process. Therefore, in selecting a particular magnetic recording coding method, compatibility with the data and control equipments must be considered. In the following paragraphs, a number of available magnetic tape coding techniques are presented, following a brief explanation of the writing and reading of magnetic fields in terms of digital nomenclature.

Recording Processes

Digital information may be expressed in pulse-type and level-type signals. Both signal types are used for magnetic recording. A pulse-signal waveform momentarily changes from one d-c level to another and then returns to the original d-c level. Ideally, the transition for each d-c level change is accomplished in zero time. However, the time interval of the intermediate level is of finite duration.

A typical waveform description of a pulse is shown in Fig. 5-2. Generally each change requires a sufficient amount of time to approach and attain its final level. The 90% points of a given direction are considered a d-c level change completion. The 10% to 90% points bound the time interval for this change. The 50% points are used to compute the energy of a pulse signal. One input signal is needed to initiate a pulse for digital operation. A pulse can be generated by such devices as a one-shot (monostable) multivibrator or a blocking oscillator.

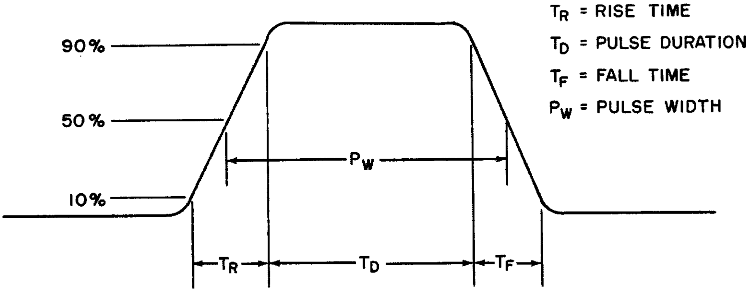


Fig. 5-2. *Pulse parameters.*

Pulse-signal type recording is similar to return-to-zero (RZ) recording. It can be compared to either a turn on (zero to saturation) or a turn off (saturation to zero). Since tape can be saturated in either direction, pulse recording may have three signal levels.

The other signal type is indicated with a level change. A single input signal is used to cause a permanent level change from one level to another. Since there is only one level change per input, an additional signal input is needed to reverse the level change and establish the initial d-c level condition. Two independent signal inputs in sequential order are necessary to perform the equivalent of a pulse change using d-c levels. However, the duration at each level can be as short as a pulse or infinitely long. Therefore, level signals have memory or storage capabilities. The advantages this signal type offers are simplicity, flexibility, and minimum constraints on certain types of interconnections. Power consumption is rather high when compared to pulse signals. A typical waveform description of a d-c level signal in digital language is shown in Fig. 5-3.

Generally, the d-c level signal is associated with non-return-to-zero (NRZ) tape recording. In using two different levels, the NRZ recording is a change between the saturation levels of opposite polarities. There will be a flux

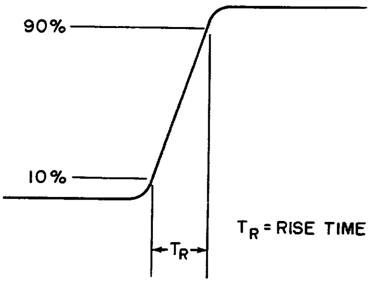


Fig. 5-3. *Level parameters.*

field change for each d-c level change. It would be appropriate here to redefine saturation and its concept in terms of the types of signals just described.

Tape Saturation

Tape saturation is a matter of degree or a relative state of magnetic condition. Saturation is reached when a further increase in recording current through the head can not appreciably increase the output signal on playback. Consequently, this concept introduces two similar terms, *oversaturation* and *undersaturation.* By *oversaturation* we mean that a magnetic field is larger that that required to saturate the tape. Another term used synonymously with oversaturation is *overwrite.* Again, oversaturation is a matter of degree. It is an overwrite condition when original information is still retained or exists when new information is written on the same segment of tape. By *undersaturation* we mean a magnetic field insufficient to saturate the tape. Other terms used to describe this magnetic state are *nonsaturation, below saturation,* and *linear recording.*

Digital Writing

The simplest way to understand writing on tape is to assume that a constant current is energizing the record coil windings. The magnetic field generated has a field distribution in air as shown in Fig. 5-4. The magnetic field is a vector, and a three-axis system is required to fully describe the field distribution. For the sake of clarity, the Z-axis is assumed to be constant and the view shown in Fig. 5-4 is the x-y plane. Under these conditions, the magnetic field within the gap is assigned the value of unity (or 100%).

The field strength diminishes with distance from the gap in the vertical direction (Y axis). Note that lines of constant field are circular arcs intersecting the gap vertices. The field strength is maximum at the gap centerline and decreases symmetrically with distance along the X dimension. In the vertical direction at one unit gap length away, the maximum field tangential to a surface would be approximately 28 percent of the field strength across

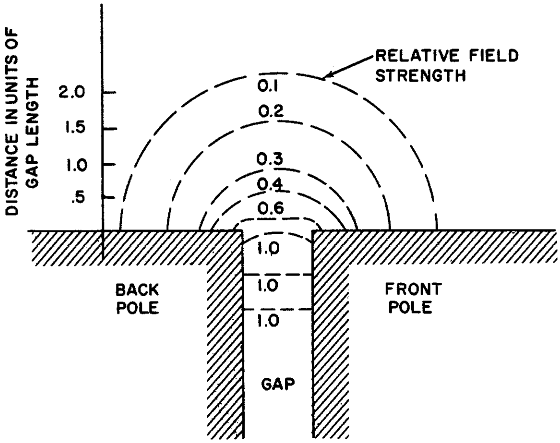


Fig. 5-4. *Magnetic field distribution in air (Bryant Computer Products Division).*

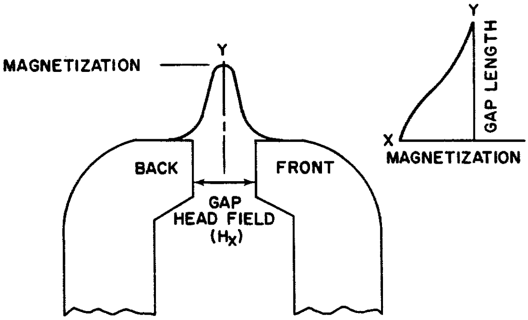


Fig. 5-5. *Field distribution within recorded tape.*

the gap. If the lines of constant field are traced until they intersect the gap vertices, the width along the *X* dimension would be four times the gap length. If a tape of one gap thickness were placed in contact with the head shown in Fig. 5-4, the field strength on the outside surface of the tape would be 72 percent less than that on the front surface, and the lines of constant force would indicate that a magnetic zone of at least four times the head gap length on the tape would exist on the front surface. A typical field distribution within the tape is shown in Fig. 5-5. The field strength in the *Y* direction is a copy of the vertical scale of Fig. 5-4.

Now consider the condition of a current level change through the head coil winding as the tape moves across the gap. A number of general forms of level switching in the positive direction are illustrated in Fig. 5-6. It should be noted that the transition time from one level to another is assumed to be instantaneous (zero time). The relative levels as shown are not current but

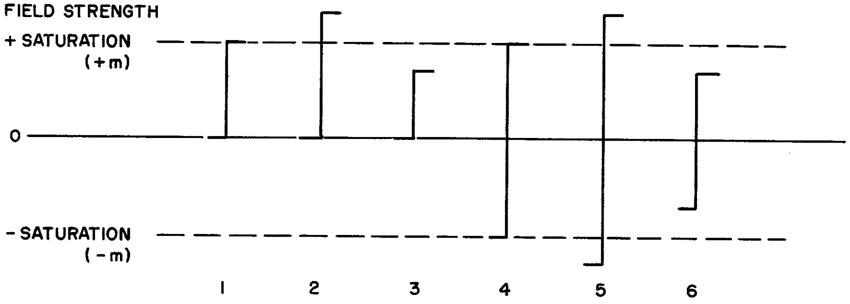


Fig. 5-6. *General forms of level switching.*

are magnetic field strengths in terms of tape characteristics (which are explained in Chapter 6). The return-to-zero (RZ) signal type is level-switching waveform 1. Its corresponding oversaturation and nonsaturation level switchings are 2 and 3, respectively. The nonreturn-to-zero (NRZ) signal type is depicted as level-switching waveform 4, and its oversaturation and nonsaturation level switchings are 5 and 6, respectively. Obviously, there is a reverse direction switching (plus to minus) possible for each level, as illustrated. The RZ has three possible magnetic levels (+M, zero, and −M).

For illustrative purposes, switching between two levels is expanded in detail in Fig. 5-7 for a signal input that is approximately equal to waveform 1 in Fig. 5-6. For convenience, the tape has no magnetic history (virgin tape) and is assumed to be moving from left to right. With a field change from zero to saturation the front pole face begins to magnetize a portion of the tape that

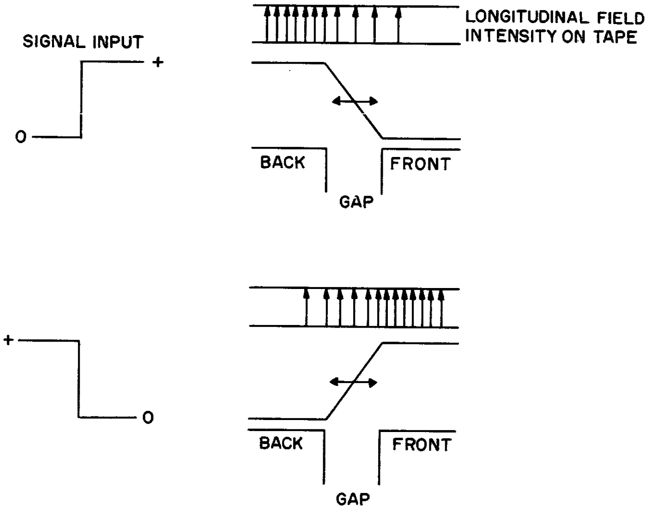


Fig. 5-7. *Zero-to-saturation and saturation-to-zero level switching.*

immediately leaves the magnetic field; the tape to the left experiences the same field strength but continues in the direction of increasing field strength to the maximum at the gap centerline. From here the tape continues to the right and experiences a diminishing field strength at it leaves the gap vertices. The front edge of the field is fixed on the tape and moves with the tape while the trailing edge is fixed relative to the gap and remains stationary as the tape continues on. The tape has a net gain in field strength.

If the tape continues, we can reverse the process by going from saturation to zero. Here the tape is continuously being magnetized along its entire length until a change in level occurs. The second level switch (saturation to zero) removes the magnetic field by causing the field to collapse within the gap vertices. Some of the tape to the right of the front pole tip retains its magnetic state, while succeeding tape segments experience a diminishing field. In practice, the field cutoff is determined by the edge of the back pole tip. Here, when two separate level changes are initiated, there are different time displacements for each change. Also, the waveform for each is different. If the circuitry, tape, and head core are considered for full current (zero to saturation) and no current (saturation to zero) characteristics, the ideal response of a symmetrical pulse waveform during readback is seldom achieved.

Writing a pulse signal using d-c level signals requires that the two level switching operations occur in rapid sequential order. If the signal is switched from zero to saturation and from saturation to zero, a small area would be magnetized and have the general waveform of Fig. 5-8. On the other hand, if a saturation-to-zero input is immediately followed by a zero-to-saturation input, the last level change could erase the first transition and no detected signal would result.

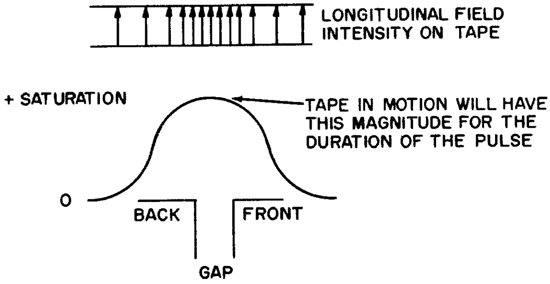


Fig. 5-8. *Pulse recording field.*

Signal variations on readback are often obtained; e.g., a symmetrical pulse or the leading edge could be shorter than the trailing edge or the trailing edge shorter than the leading edge. In addition, the crossover for each field direction may vary about a mean, as could the pulse width and pulse location. Finally, the amplitude on playback can vary from a maximum to zero.

Playback Process

The playback head is a transducer that converts magnetic energy to electrical energy. The output voltage is the time derivative of the magnetic flux the head detects from the tape. In other words, the output voltage is a function of the rate of change of flux for a given time interval rather than magnitude of field strength. Neglecting the sign convention, the playback voltage may be expressed as follows:

$$e = KN \frac{d\phi_x}{dt} \qquad \text{(Eq. 5-1)}$$

where K = constant of proportionality

N = number of coil turns

$\frac{d\phi_x}{dt}$ = flux change per unit time

(Equation 5-1 is the same as the equation illustrated in Fig. 4-9 and is of the same form as Fig. 4-2.) Once the information is recorded, it is the change in flux along the tape (in the *x* direction) as a function of distance that becomes the source for magnetic pickup during the playback process. The readback signal output is dependent upon the space derivative or the slope of the tape magnetization per unit length. Equation 5-1 can be rewritten in the following manner:

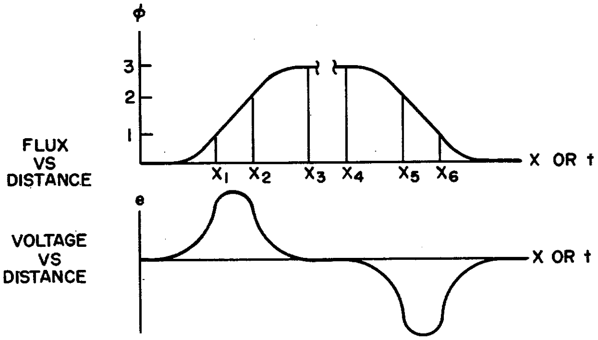
$$e = KN \frac{d\phi_x}{dx} \bullet \frac{dx}{dt} = KNv \frac{d\phi_x}{dx} \qquad \text{(Eq. 5-2)}$$

where v = tape velocity in inches per second

$\frac{d\phi_x}{dx}$ = longitudinal flux distribution along the X axis

Here the readback voltage is directly proportional to the tape velocity and the space derivative of the flux transitions of the waveforms shown in this chapter under the recording process. The flux field wavefronts were emphasized during the level switching of the recording process. It is further emphasized that the readback signal varies in time and amplitude as a function of the net magnetization of the writing process.

A typical flux distribution along the tape for a pulse- or level-type signal is shown in Fig. 5-9, along with the corresponding readback signal. As shown, a magnetic spot on the tape will be detected on playback as a double pulse output. The derivatives of three points on the curve of the flux distribution are given for a positive- and negative-going output signal and for a zero output. For a symmetrical wavefront, the double-pulse outputs will be identical to, and a displaced mirror image of, each other. However, a nonsymmetrical magnetization wavefront requires complex mathematics for explanation. The only concern here is that the flux-vs-distance of Fig. 5-9 can assume a number of



OPERATOR $\frac{\Delta\phi}{\Delta X} = \frac{\phi_{i+1}-\phi_i}{X_{i+1}-X_i}$

1 $\frac{\phi_2-\phi_1}{X_2-X_1}$ = POSITIVE VALUE OR INCREMENT $\phi_2 > \phi_1$

2 $\frac{\phi_4-\phi_3}{X_4-X_3}$ = ZERO, NO VOLTAGE OUTPUT $\phi_4 = \phi_3$

3 $\frac{\phi_6-\phi_5}{X_6-X_5} = \frac{\phi_1-\phi_2}{X_6-X_5}$ = NEGATIVE VALUE OR DECREMENT $\phi_2 > \phi_1$

AND $X_2-X_1 = X_4-X_3 = X_6-X_5$ = ONE UNIT DISTANCE

$$\left|\frac{\phi_2-\phi_1}{X_2-X_1}\right| = \left|\frac{\phi_6-\phi_5}{X_2-X_1}\right|$$

Fig. 5-9. *Flux vs. distance (space derivative) and playback waveform (voltage vs. distance).*

distributions, as shown in Fig. 5-10. Rather than analyze the causes for these deviations from a symmetrical response, we are interested in how the information is recovered under these conditions.

Although a constant maximum magnetization is assumed for simplicity, Fig. 5-10 shows that the readback signal will vary in amplitude and time displacement of the double pulse. This is summarized in Fig. 5-11, which shows amplitude and time variations of the detected signal. A sequence of processing steps to eliminate or reduce the wide amplitude variations is shown. After rectification and signal slicing, the uncertainty of the lead edge of the signal is unresolved. The pulse width can be formed by any combination of two lines in Fig. 5-11C.

Signal Detection

The problem of detecting the readback signal will now be considered. There are a number of methods that permit the extraction of digital information

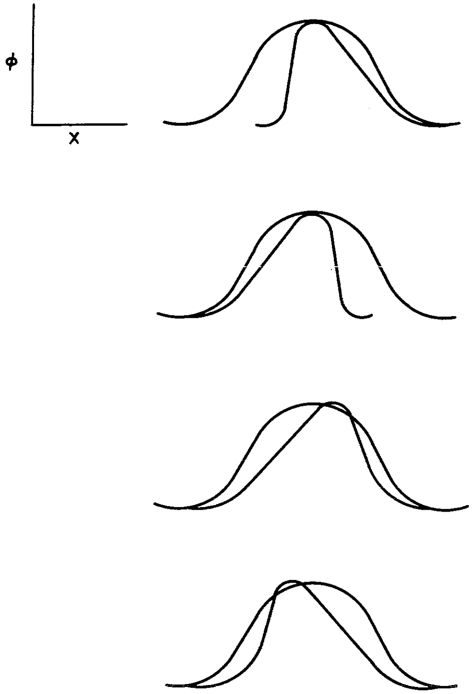


Fig. 5-10. *Flux vs. distance: symmetrical and nonsymmetrical waveforms.*

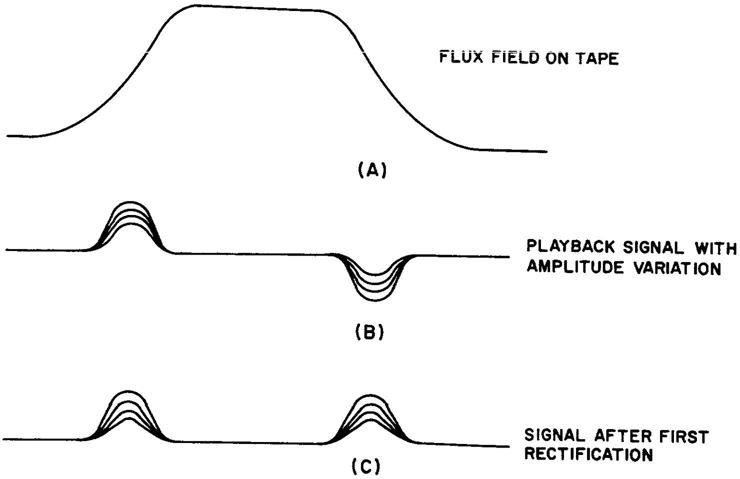


Fig. 5-11. *Amplitude and time variations of readback signals.*

from the read signal output. These methods are independent of the method used to code the data prior to recording. This means that the "raw signal" is amplified, frequency and phase corrected as required, shaped, and finally applied to digital logic circuits for decision making to extract the binary information (1's and 0's). Most of the methods for signal detection can be classified as either *amplitude detection* or *peak detection.*

A number of sequential steps are necessary to condition the read signal prior to its utilization. For example, the pulse signal may undergo amplitude correction and special attention may be paid to its phase characteristics. The effect of pulse correction is shown in Fig. 5-12. Not only is the pulse made more symmetrical, but a reduction in pulse width from 2 to 1 is incurred. Detection methods benefit by circuits performing integration, delay, and differentiation.

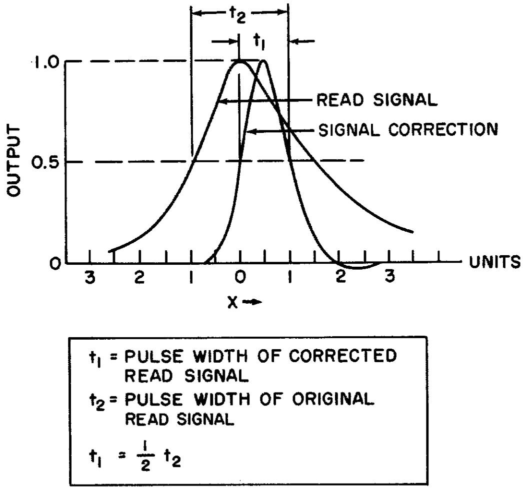


Fig. 5-12. *Pulse correction.*

Amplitude Detection

Amplitude detection is straightforward and ultilizes the direct read-out signal. Amplitude sensing detects the presence of a pulse for a binary 1; the absence of a pulse is assumed to be 0 information.

Limits are assigned that qualify the acceptance of a 1 and the rejection of other signal amplitudes for a 0 in the following manner. For a given linear bit density of operation, the lowest-amplitude 1 signal is obtained, while a high threshold limit is made equal to the maximum system noise. Here, two independent limits are set: one for 1's and the other for 0's. Some tape systems use a single limit where a signal exceeding this value is denoted as a 1 and anything below it is automatically called a 0. This detection method is inherently insensitive to base-line noise. With increased packing densities, the high-speed factor extends the use of amplitude detection in this region, although deterioration of the signal waveform and increased noise are apparent. There is a net signal-to-noise gain with increasing speed. The read signal amplitude increases linearly with speed while the noise amplitude increases with the square root of the speed. The signal adds vectorially (arithmetically) in phase, while noise has no phase characteristics. Noise is a random phenomenon and is statistically computed. At low speeds, a good signal-to-noise ratio can be maintained with good circuit design, and stray noise and low-level hum are removed by threshold circuits.

A typical amplitude detection method is depicted in Fig. 5-13A. The signal is clipped and a square-wave pulse is available for gating operations. A more detailed amplitude detection scheme is illustrated in Fig. 5-14. A read signal (part B) is linearly amplified, reproducing the positive-going and negative-going flux transitions of part A. Rectification inverts the negative-going pulse, resulting in the waveform of part C. A slicing circuit samples a portion of the rectified signal, producing a series of trapezoidal waves having relatively sharp leading and trailing edges as shown in part D. The slicing level for a single-speed operation is generally chosen at 20 to 30 percent down from peak amplitude to exclude base-line noise.

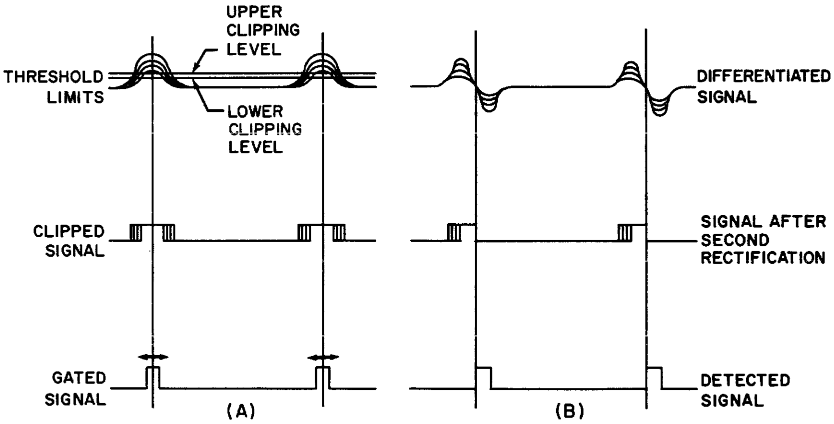


Fig. 5-13. *(A) Amplitude detection. (B) Peak detection.*

Leading edge detection is accomplished by differentiation of the Fig. 5-14D waveform and clamping the negative pulse. The remaining positive-going trigger pulse is used to operate subsequent digital circuits. The read signal is resynchronized by strobing the signal with a clock pulse. Several resynchronizing alternatives are presented in the lower portion of Fig. 5-14, but all accomplish the same purpose. For a given bit, only one pulse output from the detection circuits is necessary to denote the presence of digital information. The signal polarity (positive or negative) is incidental, since an inverting logic amplifier or transformer will complement the binary state.

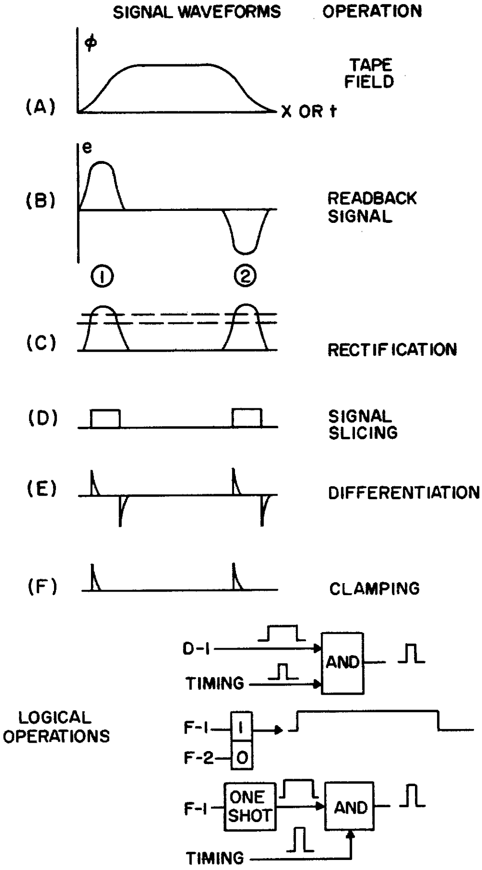


Fig. 5-14. *Amplitude detection of readback signal.*

Leading edge detection has been successfully used for playback speeds as low as 1 ips to as high as 150 ips. For single-speed operation below 60 ips, the differential jitter is tolerable. Generally the time variation is 3 to 5 percent of nominal pulse repetition rate up to 200 bits to the inch on tape. At the upper speed limit, higher gain accentuates noise, and greater bandwidth reduction than necessary counteracts this problem. The effect of narrower bandwidth on the desired pulse signals tends to stretch the readback pulses. Therefore, varying d-c levels will occur and will affect the base-line level. As a consequence, signal jittering is augmented.

Peak Detection

With peak detection, the recovery problems are somewhat different. Although flux field patterns may vary considerably on tape, this method is most effective when the head has the most control over the medium when the information is written. The slope of the field for a change in polarity (zero crossover point) has the largest readback signal. After a field transition has occurred, the flux field peak is noted by a corresponding zero in the read signal output. These two identification points (maximum signal and zero crossover) are illustrated in Fig. 5-13B. Although there is uncertainty as to the leading edge because of amplitude variation, the peak signal location is well defined. Peak detection is superior with coding systems that write transitions at the cell boundaries, whether the cell contains a 1 or 0 because maximum signal output occurs there and defines the cell boundaries. In this way adjacent bits are separated by one cell length. Peak detection is not without problems. Although differentiation augments small signal variations at high writing densities, the signal-to-noise ratio is impaired by accentuating noise peaks and base-line ripple. Some form of filtering based on frequency or energy discrimination is necessary to minimize noise peaks.

A more detailed peak-detector description is shown in Fig. 5-15. The field pattern and differentiation readback signal are shown in parts A and B.

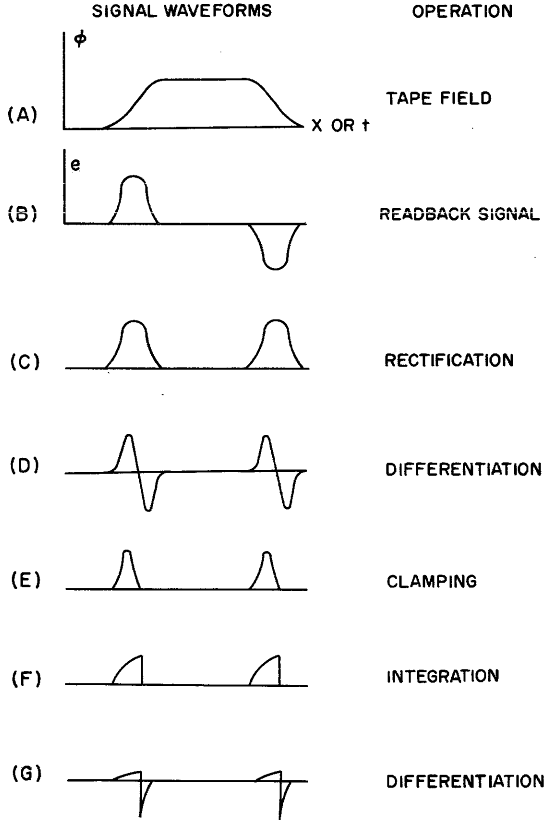


Fig. 5-15. *Peak detection of readback signal.*

After amplification, the signal is rectified as shown in part C. A differentiating circuit transforms the waveform of part C into the double pulse of part D. From here, the positive portion is passed and the negative part is removed (part E). The signal is fed into an integrating circuit, which converts the signal into the form shown in part F. The RC network accumulates all the energy under the pulse and suddenly drops to zero at the end of the signal. Any impulse noise present at this point of the processing stage is insignificant to the total energy content of the signal in part F. The sharp trailing edge of the signal coincides with the peak input signal to the detector and is 50% up on the magnetic field pattern, as shown. The process of integration locates the peak of the input signal and is insensitive to base-line fluctuations. An asset of integration is the removal of the short duration noise peaks that could cause false triggering. An additional stage of differentiation sharply defines the trigger pulse to drive a multivibrator with an adjustable pulse width, or the output signal can be a d-c level. The time jitter of peak detection is of the order of one microsecond or less, and is insensitive to the most common problem of readback — amplitude variation.

Other Detection Methods

There are two other methods that are extensively used for detection of the readback signal. Both are a form of differentiation, and differ only in the manner in which two signals are combined to construct an output.

The first method is called *differencing* or *canceling*. In Fig. 5-9, if the denominator is normalized to a value of one, the fraction reduces to a difference of two signals. The signals are from the same source but are displaced in time. The readback signal is delayed and combined with the original readback signal in a differential amplifier. The difference between both signals (original and delayed) will be positive or negative according to whether the readback signal is increasing or decreasing.

In this method of detection (Fig. 5-16), the readback signal is delayed by an amount equivalent to one half the cell period, and this delayed signal (or readback) is subtracted from its original signal (or delayed signal). This is accomplished by feeding the two inputs, E_1 and E_1 (DELAYED), to a differential amplifier. The difference of the two signal waveforms is shown in Fig. 5-15C. The subtraction process can be accomplished by inverting the delayed signal to attach a minus sign to it and adding this signal to the original signal. This method adds both signals algebraically. Like voltages have a zero output and the difference between the two (E_1 and inverted E_1 DELAYED) is accentuated.

The other method of reading information stored on magnetic tape, which offers advantages over the canceling method, is shown in Fig. 5-17, which shows signal correlation for both positive and negative signal processing. This scheme provides accurately timed output pulses that are not sensitive to the amplitude of the signal. This method yields gating areas that are sharply

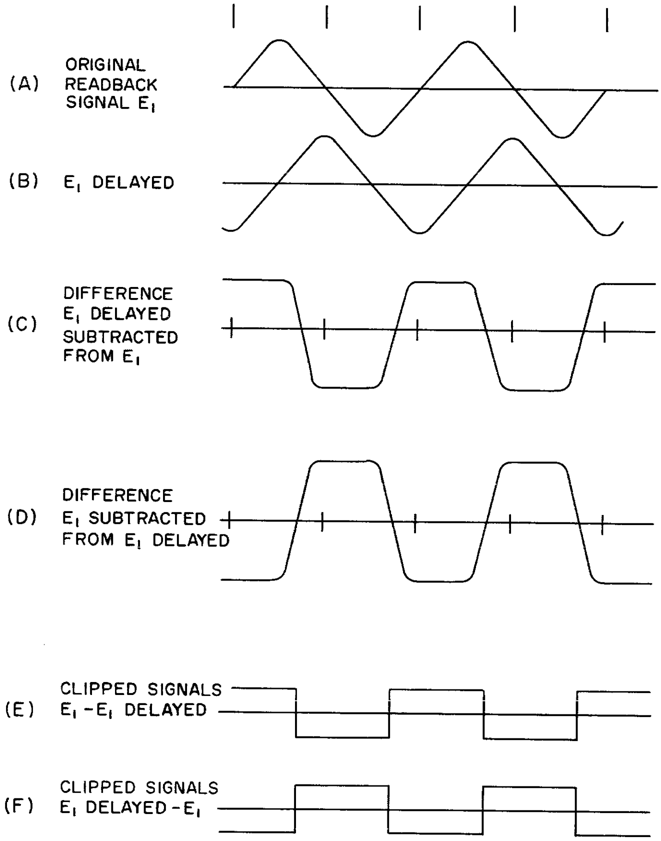


Fig. 5-16. *Differencing detection.*

defined and precisely located, as does the differentiation method, with improved signal-to-noise performance. The latter method (differentiation) accentuates the signal noise and requires additional amplification to compensate for losses resulting from differentiation. The write current waveform is the return-to-bias method shown in Figs. 5-24 and 5-25. With this technique, a constant head current is maintained and the tape is magnetized in one direction. Whenever a 1 is to be written on tape, the current is reversed and returned to its initial level. In this manner only 1's are recorded.

The output of the AND gates is dependent on the slope of the signal rather than its amplitude. The magnitude of delay of the circuit is not critical. The greater the delay, the larger the gated area. It is desirable that the delay element be optimized to avoid the inclusion of the signal peaks. In this manner amplitude and pulse position variations are minimized.

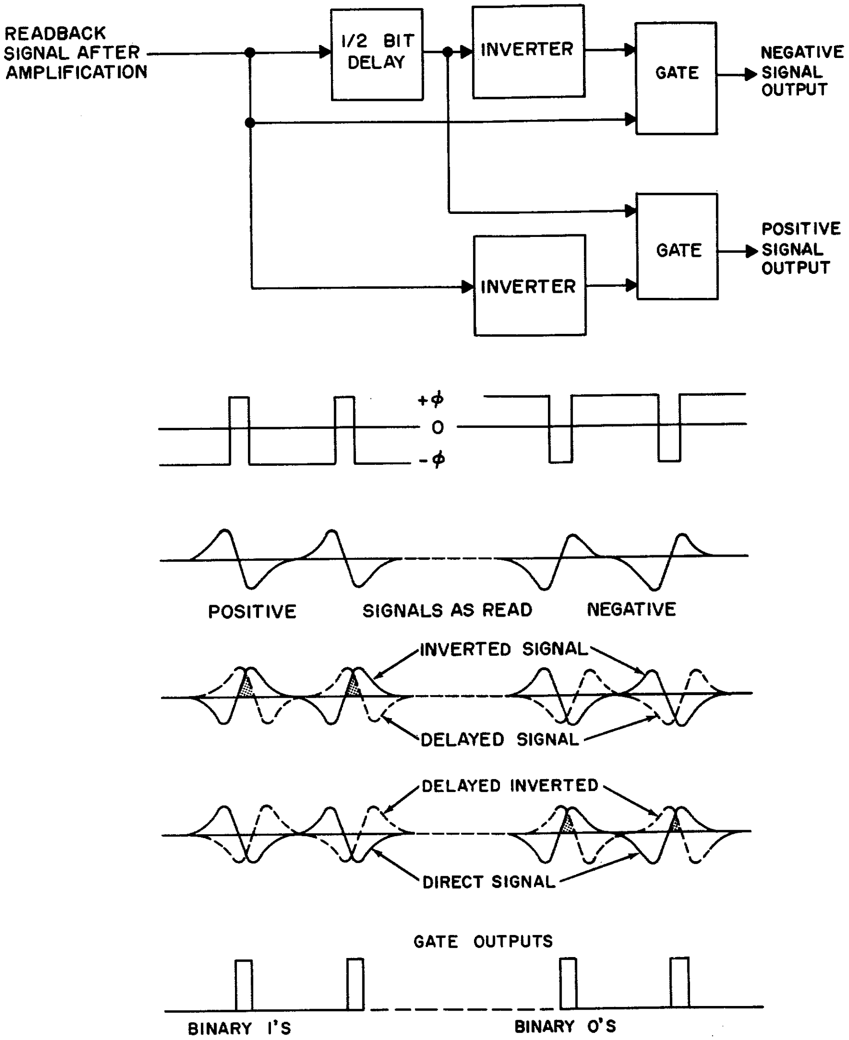


Fig. 5-17. *Correlation method of detection.*

Coding Methods

In digital recording, the information is in, or is converted to, binary notation prior to code translation for recording. Recording on a single channel is called *serial digital recording* and is the easiest process to understand. However, simultaneous recording on a number of channels (or tracks) is necessary to represent a number, alphabetic letter, mark, or symbol. This is *parallel* *recording*. By combining these two methods a continuous flow of recorded information is obtained. Each number read from tape is completely defined instantaneously and continuous numbers are available consecutively along a length of tape.

The complex nature of magnetic recording and the probabilities of an inadmissable error of one bit in a billion are cause enough for scrutinizing coding methods. At high recording densities, better signal recognition by certain coding methods may result when extensive processing is provided. The various detection methods, edit and control information of the coding method, and checking capabilities should be considered in evaluating each method of digital tape recording. Writing with automatic erasing is preferable but not mandatory, and reliability is paramount. The amount of circuitry required to extract the data during readback might reduce the overall system reliability. In the following paragraphs, the various coding techniques are examined and their limitations and attributes are evaluated in terms of the digital requirements listed above.

Return-to-Zero (Polarized Dipole)

The return-to-zero (RZ) method is the least complex operation in implementing digital data magnetic tape recording. The tape is initially in an unmagnetized state. Binary 1 and 0 are assigned opposite magnetic states and the direction of magnetization is used to differentiate between 1's and 0's. The tape is magnetized by head current pulses that create small dipoles oriented on the tape according to whether a 1 or 0 is to be recorded. With this system it is necessary that the flux produced by the head build up and collapse in less than one cell length (pulse period). Obviously, some portion of the allocated space or cell assigned to a single bit is left unmagnetized. As the head current is bidirectional, circuitry must be compatible to accept current through the coil windings in both directions for read/write operations. This method requires that a blank time interval exist between each pulse.

RZ recording is illustrated in Fig. 5-18. The binary information occupies the top line and the writing current is shown below. Note that the writing head current returns to a zero state after each bit that is recorded. The pulse duration or cell occupation is one-third cell length. This method of digital recording is also called the *polarized dipole method.* The polarized classification comes about from the orientation of the magnetic dipole on tape.

Conventional pulse techniques are employed to retrieve the data once it is recorded on tape. It should be noted that each information bit (1 or 0) is not dependent on the state of an adjacent cell. For each bit recorded, two current or field excursions are present, and a timing signal can be constructed from the information content. Since three levels of magnetization are present, selective erasure and writing over a previously recorded spot are quite difficult, if not impossible. The timing accuracy necessary for selective erasure is approximately one part in 100 million. This number is computed in the following manner:

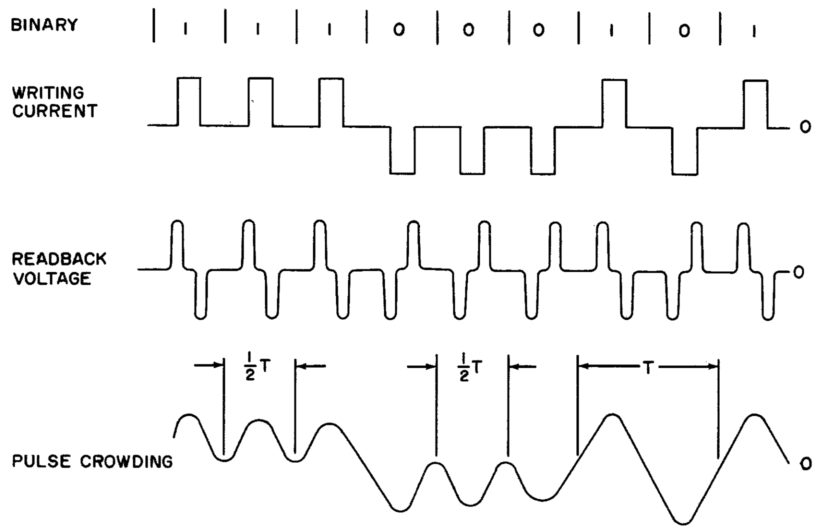


Fig. 5-18. *Return to zero (RZ) recording.*

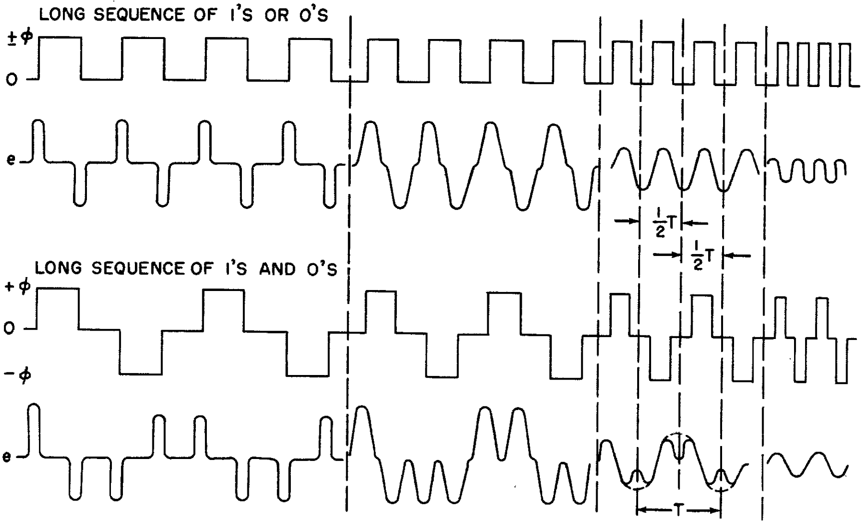


Fig. 5-19. *Frequency response of RZ recording.*

pulse width = 1/3 cell length

bit (cell) density = 1000 bits per inch

tape reel length = 2400 ft

$1/3 \times 1/1000 \times 1/2400 \times 1/12 = 1/86{,}400{,}000$

With a guard space on each side of the pulse that is equivalent in length to the pulse width, writing a 1 over a 0, or vice versa, is not practicable. Therefore, the normal erase procedure requires a complete erasure that leaves the tape in a neutral or nonmagnetic state before re-recording.

The frequency response of RZ coding is shown in Fig. 5-19. The upper portion shows a long sequence of successive 1's and 0's as they appear as readback signals; as the bit density is increased, the double-pulse output blends into a sine-wave output, at which point the signal amplitude tends to diminish. At this point the high-frequency response of the overall write/read process is integrated by the system parameters, and it is here that cell interaction occurs.

As stated earlier, the flux must build up and collapse within the allotted cell length. After a sequence of identical digits, the first flux change between two dissimilar digits is the greatest differential change. When going from a 1 to a 0, or vice versa, the field change is the complete excursion from one saturation level to the other within the time interval of one cell length. However, if the sequence of like digits is long, the field tends to stabilize about a mean, and the readback voltage decreases to a minimum to reflect the slight field variations. This condition exists because the flux field does not collapse to zero before the next dipole is written or read. Head core retentivity, core and circuit losses, fringe field effects, or any combination of these contribute to this condition. Finally, the pulse-like nature of the information deteriorates into a sine wave, and only the changes of state associated with 1's and 0's are decipherable.

Signal degradation at high density recording is also illustrated in Fig. 5-19. A sequence of 1's or 0's and a sequence of alternate 1's and 0's are shown. At the point where the double-pulse readback signals begins to blend together, the frequency response of like digits is twice the pulse rate of alternate 1's and 0's. This is noted in the segment where the alternate 1's and 0's take two cell lengths to complete one sine wave. This pattern illustrates the effects of close cell spacing and adjacent cell interaction. Fundamentally, no d-c component exists and the bandwidth requirements are limited to accurate reproduction of the pulse write currents.

More serious problems are encountered when attempts are made to reduce the absolute cell length to a point where there is slight interaction between adjacent bits. Under these conditions, the exact nature of the flux pattern is not determined by analytical means. A pictorial representation of progressively increased bit density is shown in Fig. 5-20, illustrating a sequence of 1's and 0's and one set of dissimilar digits. After the like digits have been written, the magnetic flux arrows from one cell join the tails of the adjacent cell. The resulting flux lines combine and the net result is a reduced number of flux lines around the core legs to activate the read coils. If the density is increased still further, the sequence of like bits is irretrievable. In this case, there is practically no means of identifying adjacent like digits, the cell is saturated throughout its length at one polarity. It would appear that the tape surface was being saturated by a direct current.

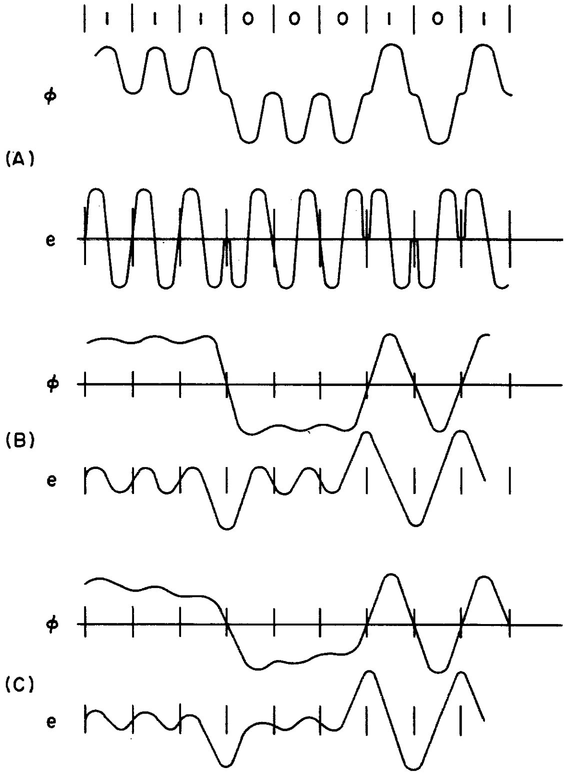


Fig. 5-20. *High-density RZ recording.*

However, the output of adjacent 1's and 0's, and vice versa, is at a maximum and the greatest field differential exists between adjacent dissimilar digits. As the written dipoles on tape have like magnetic poles adjacent to one another, producing a repulsion force that appears to force the flux lines into the immediate area above the tape surface, the readback signal of alternate 1's and 0's is maintained under these adverse conditions.

At higher densities (Fig. 5-20), the characteristic pulse shape is lost and some of the digits are indistinguishable by ordinary methods. Yet, information can still be extracted from the readback waveform by knowing the coding characteristics. Note the polarity reversals associated with dissimilar adjacent digits. At the highest density in Fig. 5-20C and at any cell where a 1 is present, output voltage is negative in the second half of the cell and is negative-going throughout the cell length. The opposite is true for a written 0. For a written 1, the negative-going signal is examined in terms that the absolute magnitude is plus in the first half and minus in the second half. This sequence of plus and minus and a negative direction identifies the existence of a stored 1. Using this coding information, it is necessary to store the first half of the cell period and combine it with the second half of the cell period. Conversely, a minus and plus and a positive direction identify a stored 0.

One way of recovering the information stored on tape by high density RZ recording, the differencing method, is shown in Fig. 5-21. The voltage waveform of Fig. 5-20C is delayed on half cell time and is shown with the original readback signal in Fig. 5-20A. The readback signal and the inverted delayed signal are combined to give the waveform of Fig. 5-21B. This *difference signal* is amplified and clipped to present a level change for each set occurrence of dissimilar digits. The positive (or upper) level in the figure denotes a 1 direction and the negative (or lower) level denotes a 0 direction. The binary information is extracted by strobing this signal with timing pulses occurring in the second half of each cell period. (Waveform E indicates the presence of 1's.) The timing pulses necessary to extract this information are supplied externally. They cannot be constructed from the single recorded track normally associated with RZ coding.

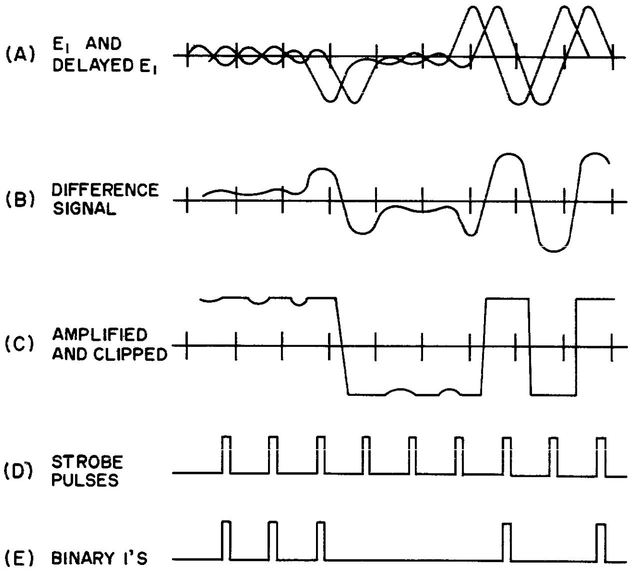


Fig. 5-21. *Difference detection for high-density RZ coding.*

There are other coding methods available to create timing pulses (clock or sprocket). The output is not limited only to 1's; the waveform of Fig. 5-21C can be inverted and strobed to supply pulses for the presence of 0's. In a two-wire digit system, both methods can be combined simultaneously to have two output lines, one designated as 1's and the other as 0's. Furthermore, the two outputs could be mixed in an OR circuit to provide the required timing pulses, provided they are compatible with the simultaneous readback of other parallel recorded tracks. This method of coding and recovery has functioned well above 800 bpi recording densities.

As stated earlier, differencing is another form of differentiation. The differentiation detection method for RZ coding is shown in Fig. 5-22. Instead of the usual half cell delay, the delay is decreased considerably and true differentiation is approached. The differentiated signal of the readback output shown in Fig. 5-22B is smaller in amplitude and more susceptible to noise. Nevertheless, this form of detection method has some merit. The information is available much sooner than it would be by differencing. Note that the waveform of Fig. 5-21C is created by amplifying and clipping the waveform of Fig. 5-21B. The readback signal is small; further degradation by differentiation may substantially reduce the reliability of this detection method.

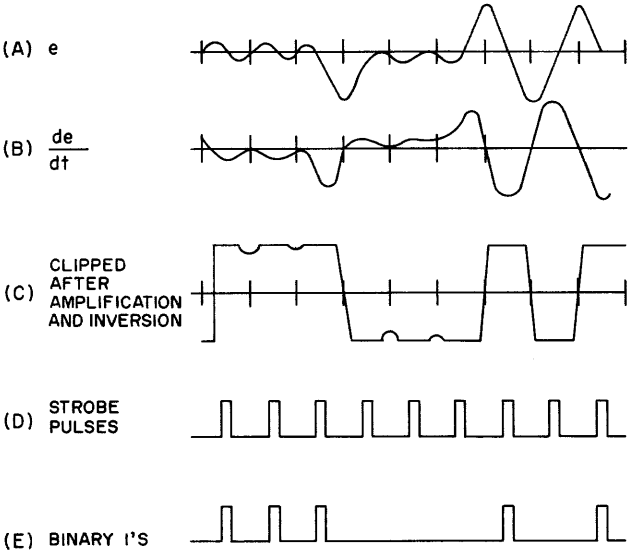


Fig. 5-22. *Differentiation of high-density RZ coding.*

Dipole or Pulse Recording

Binary information requires only two states: 1 or 0, yes or no, on or off, present or absent, etc. For digital applications, a 1 or 0 is assigned a reference state or position and all other values are assigned to the other state. Therefore the three levels of magnetization available by the polarized dipole (RZ) method contain superfluous information, and two-state devices can ignore the unaltered, or third state, or one of the saturation levels, as a source of information.

When dipoles are recorded on tape to represent 1's, the absence of 1's or no recording during a time interval implies the presence of 0's. As in the case of polarized dipole recording, the writing current returns to zero after each pulse; hence, this method is another form of return-to-zero digital recording. However, in the presence of 0 binary information, longer tape lengths are left in an unaltered or nonmagnetic state.

A representation of dipole or pulse recording is shown in Fig. 5-23. The writing current is from zero to either direction for saturation of the magnetic tape. The magnitude of flux field strength is the same for RZ coding and the readback output signal is the same for the binary information. Again, a burst of 1's is the highest frequency bandwidth requirement and no d-c component is present.

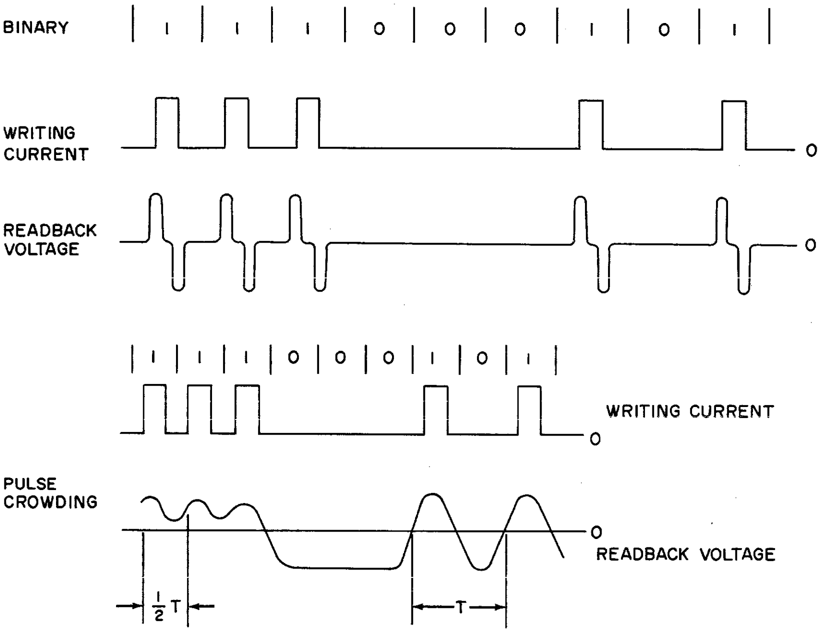


Fig. 5-23. *Dipole or pulse recording method.*

Normally, the RZ method can supply a pulse train for timing and counting purposes if required. At high densities, however, self-clocking capability is somewhat diminished. The dipole coding method appears to be similar in waveform to the RZ method, but the self-clocking characteristic of RZ is non-existent with the dipole method.

Fundamentally, this method requires erasure of tape prior to reuse, and the demagnetization must be complete. If the tape is not in a neutral state or is improperly erased, subsequent tape use may result in false readings of 1's and the reel of recorded tape will be worthless. To offset this problem the tape could be magnetized in one direction (biased) during erasure and saturated in the opposite direction to record 1's on the tape. Zero binary signals produce no writing current and would have no effect on the tape. Therefore, the tape is left magnetized in the 0 or bias magnetic state. After the writing of each 1 pulse, the signal will return to a no-write current and the tape will remain in the previous erasure saturation state. This arrangement simplifies tape erasing and a larger readout signal is available. With a larger writing current required, a written 1 saturates the tape of opposite polarity and a full excursion from one saturation level to another is the total readout signal. This is twice the amplitude of an RZ method of recording a 1. This arrangement requires external means or a separate operation for erasing. A combination of this method of writing with self-erasing is called *return to bias.*

Return-to-Bias (RB)

A modified version of the dipole or pulse method is shown in Fig. 5-24. This approach eliminates the need for erasure prior to reuse of a tape reel. A d-c bias current is maintained at all times during the writing operation. The tape is saturated in one magnetic state. For each recorded 1, a momentary net change of d-c current takes place and head current reverts back to the direction of the bias current. As in the RZ and dipole methods, the RB method is a pulse-shape recording. Transformer coupling can be used with d-c current flow in the secondary to maintain a bias current in the head winding at all times during the recording operations.

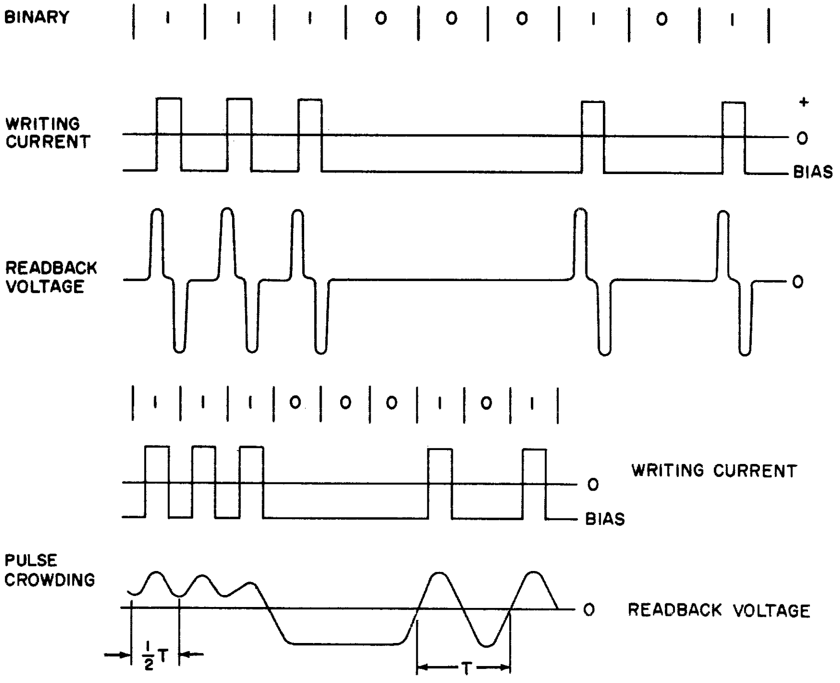


Fig. 5-24. *Modified dipole or return-to-bias (RB) recording logic.*

The voltage waveforms obtained by the dipole and RB methods are similar to those obtained with the RZ method. Even the waveforms of a series of 1's followed by a 0 are identical to the polarized dipole method except that no signal is available to indicate the presence of a 0. Therefore, to detect a 0, a synchronizing signal is required to identify respective periods associated wth binary 0's.

The RZ method and its variations, from a circuit standpoint, are illustrated in Fig. 5-25. Transformer coupling is used to emphasize the non-existence of a d-c component. The true RZ requires a bidirectional current source, while the alternate methods do not. Only the return-to-bias method has the self-erasing feature. The RZ coding demagnetization is the most stringent of the three methods.

Non-Return-to-Zero (Modified Dipole)

The non-return-to-zero (NRZ) method of recording uses a positive current flow for the duration of writing 1's and a negative current flow for the dura-

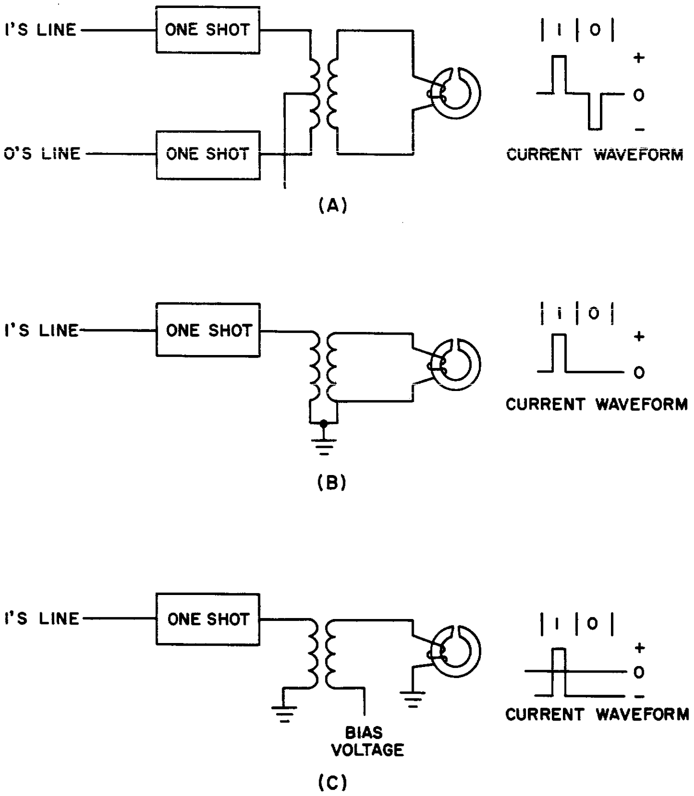


Fig. 5-25. *Logic circuitry comparison of RZ recording: (A) return-to-zero; (B) dipole or pulse method; (C) modified dipole or return-to-bias.*

tion of writing 0's for digital recording. When a 1 is to be recorded, the entire cell of the writing tract is magnetized to plus saturation. If there is a series of 1's, the entire length of the the tract is magnetized to plus saturation. The first 1 initiates the d-c level change and the subsequent 1's maintain a constant write current. When a 0 appears in the code, the respective cells are magnetized to a minus saturation. A series of 0's is represented by a corresponding length of tract uniformly magnetized to minus saturation. The tape surface is continuously saturated at one polarity or the other. A long series of like digits imprints a long single magnet on tape. Polarity reversal only occurs when a 1 follows a 0 or when a 0 follows a 1.

Associating signal type with coding method, we may consider NRZ coding to be level-type and the RZ method to be pulse-type. A sequence of like digits requires memory, and level signals have this capability. Therefore, a digit being written is dependent on its predecessor. If the present and previous digits are alike, no polarity change occurs. If two adjacent digits are dissimilar, a polarity change occurs in the established direction of the most recent binary information. Obviously, there is no output from the read head except when two adjacent bits are not alike, and the directional change is indicative of the most recent information change. The storage cell is fully magnetized throughout its length.

NRZ coding is summarized in Fig. 5-26. The NRZ has an output whenever there is a change in the sequence of 1's and 0's. The highest frequency

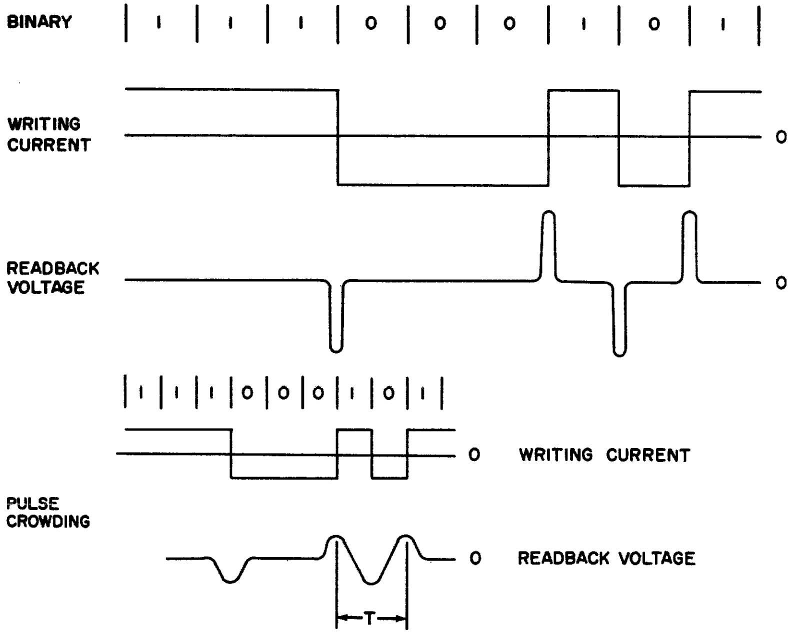


Fig. 5-26. *Non-return-to-zero (NRZ) digit recording.*

bandwidth must accommodate a pulse train of alternate 1's and 0's. At the low end of the frequency response curve, direct current is necessary to write a series of like digits. The bandwidth requirements for this coding method may prove objectionable. In addition to the wide bandwidth requirement, complex circuitry is necessary for resolving written digits during readback, with external timing pulses supplied to construct the readout information. Furthermore, the power requirements of the current source for writing are two or three times greater than those for pulse signals. At high-density recording and compact head construction, core heating and additional head losses are most likely to occur with this coding technique.

The NRZ method offers a means of obtaining higher information densities and higher operating frequencies than the RZ system with essentially the same recording head parameters and limitations. Since a maximum flux reversal occurs for a string of alternate 0's and 1's, there is only one polarity change per bit. The frequency of this sequence of digits is the same as for the RZ coding. However, a series of 1's for RZ is 2f (f equals frequency), as great as alternate 0's and 1's (see Fig. 5-19). Therefore, with NRZ coding, it is possible to record twice the amount of information compared to RZ coding when ordinary detection techniques are used for digit recovery.

The non-return-to-zero coding is examined in terms of high density in Fig. 5-27. Normally, the polarity of the readout signal designates a 1 or 0. For a long series of like digits, the first field change supplies a signal output and defines the digit. This information is stored in level form and strobed by a clock pulse to supply digital information.

At high densities where cell interaction is present, data recovery becomes a problem. The waveform of Fig. 5-27 can be recovered by employing the same delay and differencing techniques that were employed for the RZ coding. Since it takes a full cell length to determine the existence of a field change, the bit delay associated with the differencing detection method must be increased to one bit delay. If the delayed signal is subtracted from the readback signal, the resultant signal can be used directly by a pulse strobe at the end of each cell time. The coding rules remain the same. The first strobe output of a positive-going signal after a negative output indicates a field transition from 0 to 1. The same holds true for deciphering the field transition from 1's to 0's, but the directions and voltages are the opposite.

Modified Non-Return-to-Zero

There are a number of modified NRZ coding methods. A major objection to the NRZ method is the inability to construct or generate clock-pulses for synchronization and control purposes. A variation of the NRZ method alleviates this problem. This variation differs from the NRZ in that the magnetization direction is changed each time the data sequence contains a 1. This method is known by several names. It may be called NRZ-1 because every time a 1 is present a change in state occurs or the 1 is inverted; it may be

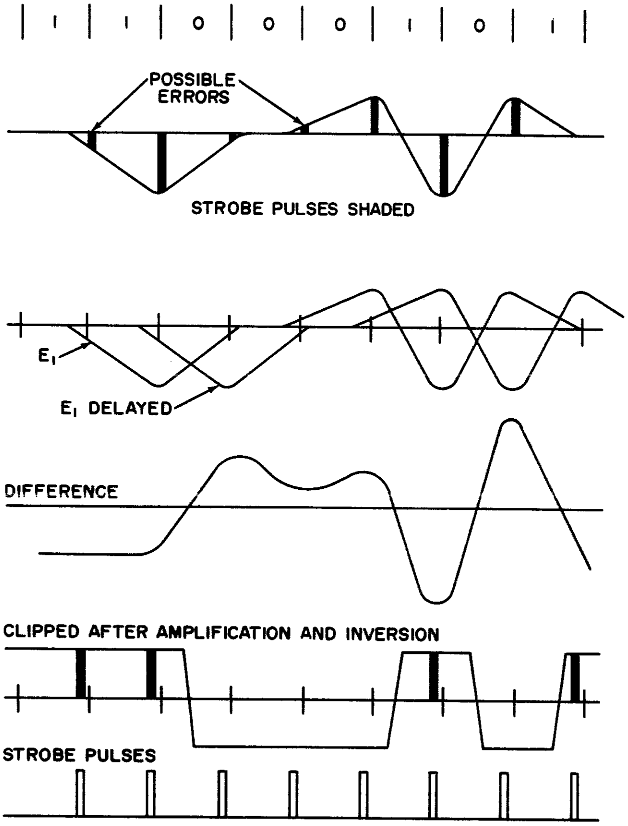


Fig. 5-27. *Non-return-to-zero recovery method.*

called NRZ-M to mean non-return-to-zero mark. When a complementing flip-flop is used as a current source for writing and reading, this method is called NRZ-Module 2. International Business Machines has used NRZ-Module 2 so extensively that it has often been referred to as the IBM method.

The modified NRZ coding method is shown in Fig. 5-28. By choosing a unique code to represent digits (Fig. 5-1), a tape format representation of decimal numbers has at least one 1 written for each row across the tape width. With this approach, at least one transition or readout pulse is available to locate a row of storage cells. (The conventional NRZ method does not have this capability.) Under these conditions, all readout pulses are rectified and each pulse signifies a binary 1. Whereas the conventional NRZ indicated the presence of a binary 1 or 0 by the polarity of the read-back signal, polarity direction has no significance in the modified NRZ coding method. Although the modified NRZ has lost an essential coding characteristic, the bandwidth characteristics are the same as for NRZ. The highest frequency is determined by a burst of 1's. Automatic erasing when writing is characteristic with this coding scheme. At present, a practical upper limit is 800 bpi.

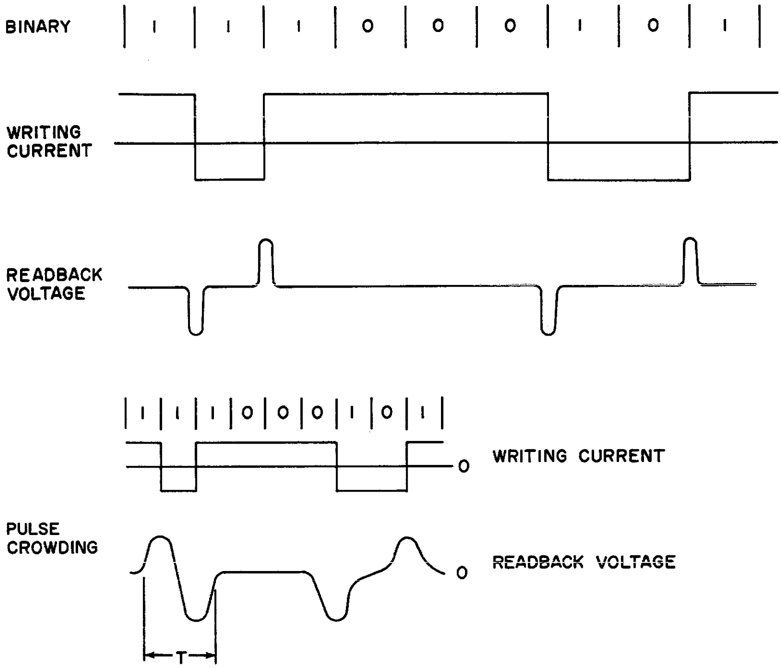


Fig. 5-28. *Modified NRZ coding.*

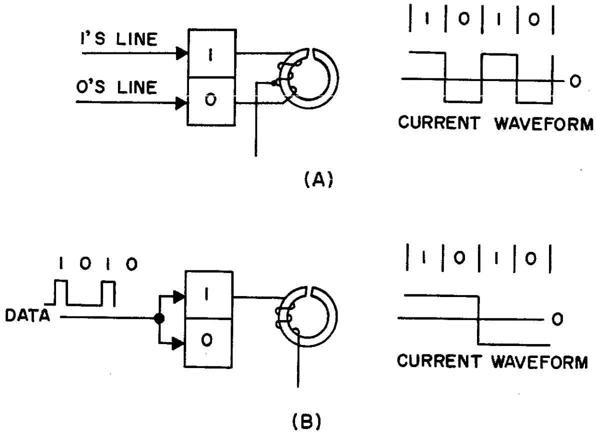


Fig. 5-29. *Logic circuitry of non-return-to-zero recording methods.*

The logic circuitry needed to write and read the NRZ and modified NRZ coding methods is shown in Fig. 5-29. The current sources are direct-coupled to the coil winding of the head coil, emphasizing zero frequency response. A bidirectional current source is required with this coding method.

Double-Pulse Recording

Present digital magnetic tape systems have achieved lower costs and higher operational speeds through high-density recording. High-density recording provides more information per tape reel and less time is required to read this information. Fewer tape stations, smaller tape libraries, and such intangibles as reduced manual operations, labor force, office space, etc., are a direct by-product of high density recording.

Sophisticated techniques have made it possible to pack data on tape in excess of 1000 bpi without undue complexity. At the same time, some of the problems previously cited are minimized or eliminated. Actually, the writing current waveforms are pulse or RZ type and level or NRZ type. The d-c levels are of short duration and require two inputs for two field changes. Each field change may be substituted for a pulse signal.

Double-pulse recording is used to achieve higher recording densities and high reliability of information extraction during the detection process. This is accomplished by utilizing the complete information content that is available. Inherently, this coding method defines the centers and boundaries of a storage cell, supplies self-clock capabilities, maximum amplitude signals, polarity identification, and checking features, and has a natural immunity to low-frequency noise.

The two field transitions per cell ensure a maximum signal output for each saturation level change. Since there is at least one field change per cell regardless of information content, the double-pulse method automatically marks the cell boundary locations and features self-clocking. A double pulse within a cell period supplies maximum (peak) and zero (crossover) output signals. Time or phase and polarity or polarity sequence have sufficient redundancy for self-checking, so that more than 50 percent loss of signal content per cell does not invalidate information retrieval. Since two field changes occur per cell period and one is the reverse of the other, the average writing current per cell storage is nil.

The bandwidth frequency response for the double-pulse coding is limited to one octave. This means that the major frequency components are f and 2f. Such limited bandwidth and close cell spacing creates a sharp and well-defined magnetic wave front (slope) to obtain a high readback signal output. Field spreading and fringe field effects are reduced, permitting reliable, high-density recording. The double-pulse coding magnetic field does not penetrate the tape depth as do the long wavelengths associated with NRZ. Obviously, thinner-coated recording tapes are permissible, meaning longer tape lengths per reel. Since the net weight is the same, the reel drive motors are unaffected, but information content per reel is increased still further. A comparison of low-density and high-density recording clearly illustrates the economics afforded by high-density recording. The small additional cost required for the initial equipment is more than compensated for by the reduction in tape stations and tape storage reels.

LOW DENSITY	HIGH DENSITY
200 bits to the inch	1200 bits to the inch
2400 feet tape length	3600 feet tape length
Tape reel weight is W	Tape reel weight is W

$$\frac{1200}{200} = 6, \frac{3600}{2400} = \frac{3}{2}; \frac{\text{High Density}}{\text{Low Density}} = 6 \times \frac{3}{2} = 9.0$$

Phase Modulation (Manchester Method)

A long sequence of like digits using the RZ coding deteriorates into an NRZ waveform. To avoid this, phase modulation may be employed using the RZ polarity characteristics in terms of phase information. With this system, a 1 is written by generating a positive field direction for the first half of a cell period and reversing the field for the second half. To write 0's, the first half has a negative field direction and is followed by a field reversal during the second half of the cell period.

The phase modulation coding method is shown in Fig. 5-30. A pulse writing current is shown first; the first half of each cell contains the same polarity content as the RZ coding method. Figure 5-30B shows the approximate saturation waveform for the high-density pulse signal type. The writing level current and field saturation are shown in Fig. 5-30C, still maintaining field direction information. At the high densities depicted here, the difference in readback signal between RZ and NRZ is negligible. The RZ method does not reduce the power requirements very much because of a lower duty cycle. At these high frequencies, head core and circuit losses overcome any savings. The level-type signal (NRZ) occupies 100 percent of the cell length and is more effective in erasing previously written information. The readback signal (Fig. 5-30D) has a peak at the center of each half cell. This is positive or negative whether a 1 or 0, respectively, has been written. At high bit densities the amplitude peaks of alternate 1's and 0's are somewhat greater and are one half the frequency of a series of like digits. Note that the readback signals for a series of 1's and 0's are alike except that they are displaced by one half cell length.

Amplitude detection may be used to recover the information. The readback signal is amplified, clipped, and strobed by a clock pulse (Fig. 5-30E). By sampling at approximately the cell center, positive or negative pulses (or both) are obtained for 1's and 0's, respectively.

The phase-modulation coding method lends itself equally well to differencing and time correlation methods of data detection. In the former method, the readback signal is delayed one half cell period and subtracted from the original readback signal. The readback signal (Fig. 5-30D) and its delayed counterpart are shown in Fig. 5-30F, and their difference is shown in Fig. 5-30G. If the

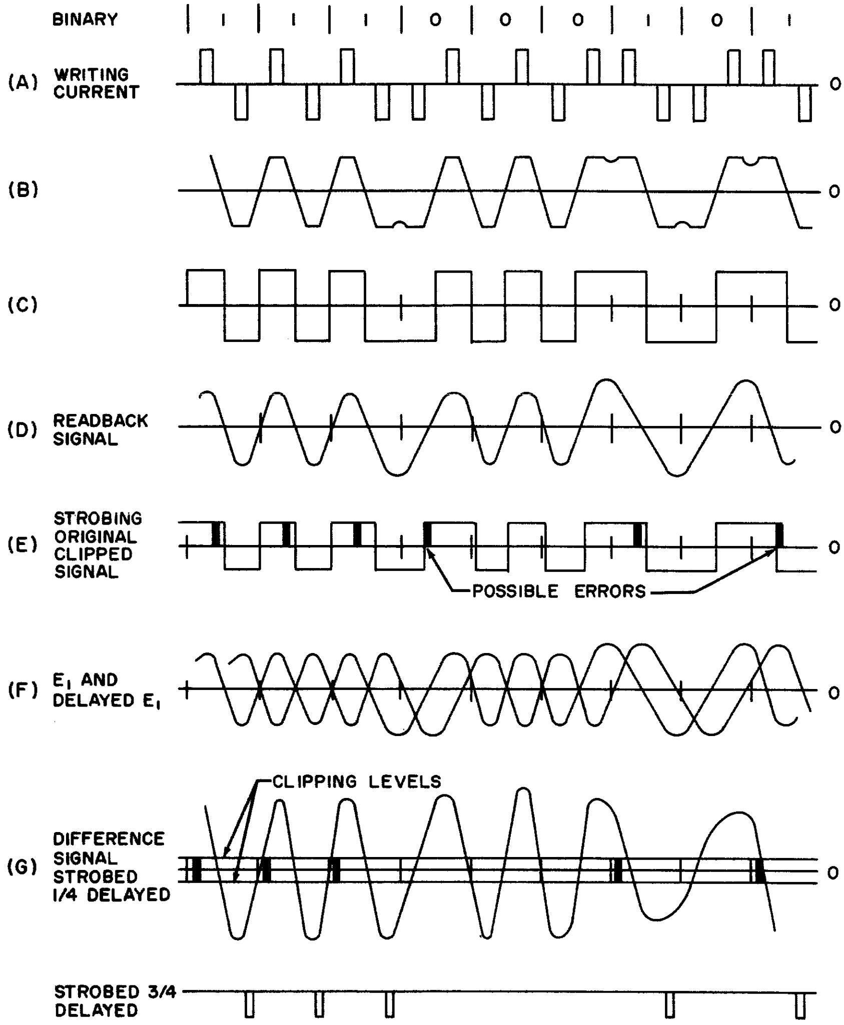


Fig. 5-30. *Phase modulation digital recording method.*

difference signal is shaped and sampled at the three-quarter cell period, positive and negative outputs are 0's and 1's, respectively. In the first half, the positive- and negative-going slopes of the waveforms are 1's and 0's. If the waveform of Fig. 5-30G is differentiated, the positive and negative spikes are interpreted as 1's and 0's, respectively.

The last method of readback detection is the time correlation method. Alternate crossings can be sensed by this method. At half cell time there is always a field reversal by coding characteristics. To find the positive-going crossovers, the difference signal is inverted and delayed. The two signals are combined in an AND circuit, which is responsive only when there is coincidence between the inverted and delayed signals. An output signal is available at each positive-axis crossing. Negative-axis crossing output signals are combined in a similar manner. Both signal outputs for this detection scheme are illustrated in Fig. 5-17.

A logical method of writing in phase modulation coding is shown in Fig. 5-31. A two-phase clock is required and the binary input information must be able to designate the 1's and 0's. The binary information is written at Clock A time; the 1's and 0's are still retained for polarity indication. Since a two-phase clock is used, the output signal polarity is complemented at each half cell time. Therefore, at each half cell time, a field reversal occurs and maximum signal output denotes this time event. The field direction of each half cell time or sequence for each cell period contains the written binary information.

Frequency Modulation (Harvard System)

In the previous code, phase or time indicated information content. The frequency spectrum was limited to f and 2f. The frequency-modulation (Harvard System) technique has the same frequency response. This method uses two pulses per bit. Binary 1 is written as two pulses in the same saturation

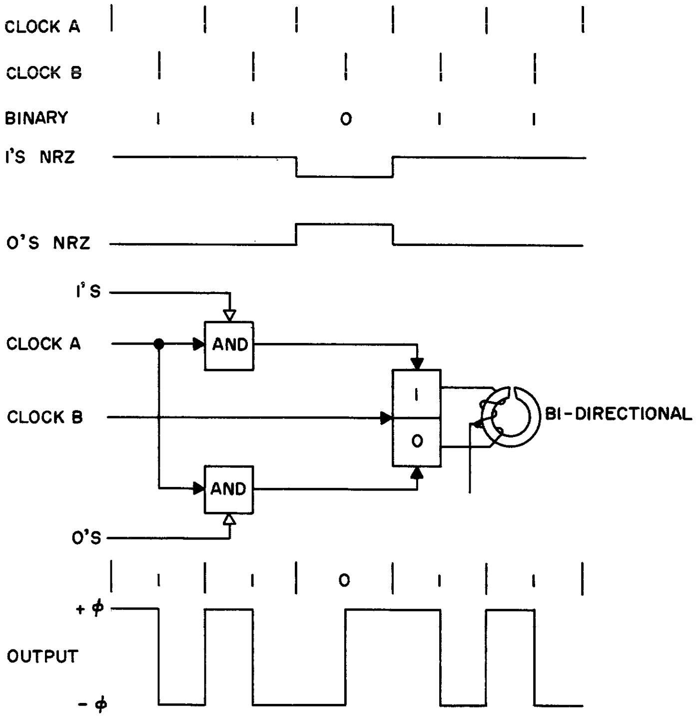


Fig. 5-31. *Phase modulation digital recording method logic circuitry.*

TABLE 5-1. Digital Magnetic Tape Coding Methods

Digital Coding	*Effective Signal (RZ-1)*	*Automatic Erasing During Writing*	*Timing on a Per Track Basis*	*Frequency (f = 1 for RZ)*	*Pulse Pattern for Frequency Response*	*Head Current Polarity*	*Information Signal Type*	*Information Accessibility*
Return to Zero (RZ)	1	No	Yes	f ½ f	series of 0's or 1's series of alternate 1's and 0's	Bipolar	Pulse	¼ digit period in advance or retard.
Dipole or Pulse Recording	1	No	No	f ½ f	(1) series of 1's series of alternate 1's and 0's	Polarized	Pulse	¼ digit period in advance or in retard.
Return to Bias (RB)	2	Yes	No	f ½ f	(1) series of 1's series of alternate 1's and 0's	Polarized	Pulse (3)	¼ digit period in advance or retard.
Non-Return to Zero (NRZ)	2	Yes	No	½ f f = 0	series of alternate 1's and 0's series of 1's or 0's	Bipolar	Level	Predicated on preceding digit.
Modified Non-Return to Zero	2	Yes	No	½ f f = 0	series of 1's series of 0's	Bipolar	Level	Predicated on preceding digit.
Phase Modulation	2	Yes	Yes	2 f f	series of 1's or 0's series of alternate 1's and 0's	Bipolar	Pulse or level	½ digit period later.
Frequency Modulation	2	Yes	Yes	2 f f	(2) series of 0's (or 1's) series of 1's (or 0's)	Bipolar	Pulse or level	1 digit period later.

(1) Series of 0's, f = 0.
(2) Frequency for a series of alternate 1's and 0's is between f and 2f.
(3) Pulse superimposed on a steady d-c current.

TABLE 5-2. Digital Data Recording

Manufacturer	*Model No.*	*Packing Density (bits per inch)*	*Head to Tape Method*	*Recording Method*	*Tracks*	*Tape Width (inches)*
AMPEX	TM-4	556	Contact	NRZ	7	½
BURROUGHS	BC 422	555.5	Contact	NRZ	7	½
CDC	603	200 or 556	Contact	NRZ-I	7	½
	606	200 or 556	Contact	NRZ-I	7	½
	607	200, 556, or 800	Contact	NRZ-I	7	½
CEC	DR 2700	556	Contact	RZ, NRZ, NRZ-I	7 or 8 14 or 16	½ 1
COOK	59	556	Contact	RZ, NRZ, NRZ-I	7	½
DATAMEC	D2020	800	Contact	NRZ	7	½
HONEYWELL	804	556	No Contact	NRZ-I	10	¾
IBM	Hyper Tape	1511	Contact	IBM PHASE ENCODING	10	1
	729 II-IV	200, 566, or 800	Contact	NRZ-I	7	½
MIDWESTERN	M 3000	556	Contact	NRZ	7 or 16	½ or 1
POTTER	906 II	800	Contact	NRZ-I	7 or 8	½
RCA	582	667	Contact	NRZ	16	¾
	581	333	Contact	RB	16	¾
	382	333	Contact	NRZ	7	½
	381	333	Contact	NRZ	7	½
UNIVAC	III A	1000	Contact	Phase Modulation	9	½
	III C	556	Contact	Modified NRZ	7	½

direction for one cell period. A binary 0 is written as two pulses for one cell period but of alternate directions. Since a series of 1's may appear as dipole or pulse recording, a field reversal occurs at each cell boundary regardless of the preceding cell's information state. As is the case with modified NRZ, field direction has no significance in the frequency-modulation coding method.

Writing current waveforms are shown in Fig. 5-32. Again, the pulse and d-c level waveforms are represented. Two pulses within a storage cell spread out and appear as one broad pulse at high-density recording. Therefore, a 1 is denoted as f and a 0 is denoted as 2f. Information recovery can be on a frequency selective basis. A phase reversal within a cell period is considered a 0 and its counterpart of no field change during a cell period is denoted by a binary 1. With this method of recording, the readback signal must be delayed one half cell time and combined with the original signal in a differential amplifier. The difference output between two half cell periods for a 1 will be zero voltage, while voltage doubling will occur for a stored 0. The final voltage may be sampled at the end of a cell period to determine the 0 digits.

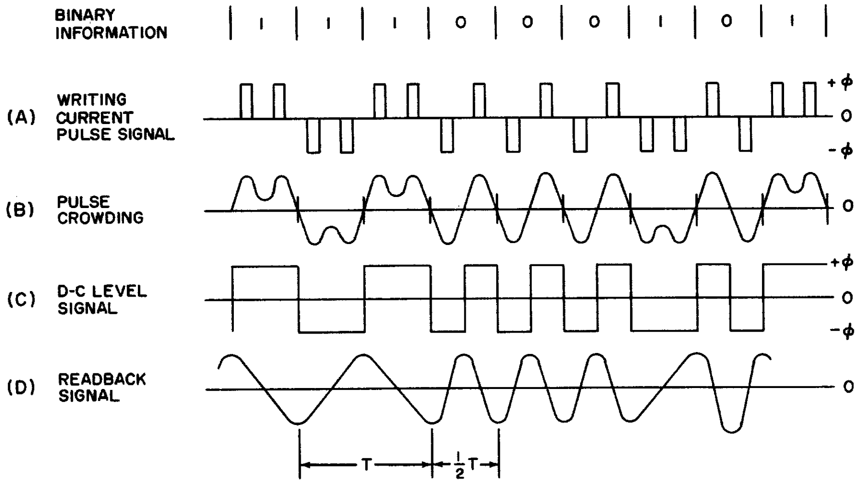


Fig. 5-32. *Frequency modulation digital recording method.*

The presence of 1's can be obtained by interchanging frequency coding, such as f denotes a 0 and 2f denotes a 1. The frequency-modulation coding technique is as effective in high-density recording as the phase-modulation method and performs reliably above 1000 bpi.

The logic configuration for frequency modulation is shown in Fig. 5-33. Again, a two-phase clock is required. In phase modulation, Clock B always complements or reverses the existing condition of the flip-flop. In frequency modulation, Clock A always complements the flip-flop and, therefore, determines the cell boundaries. Clock B always inserts an additional polarity re-

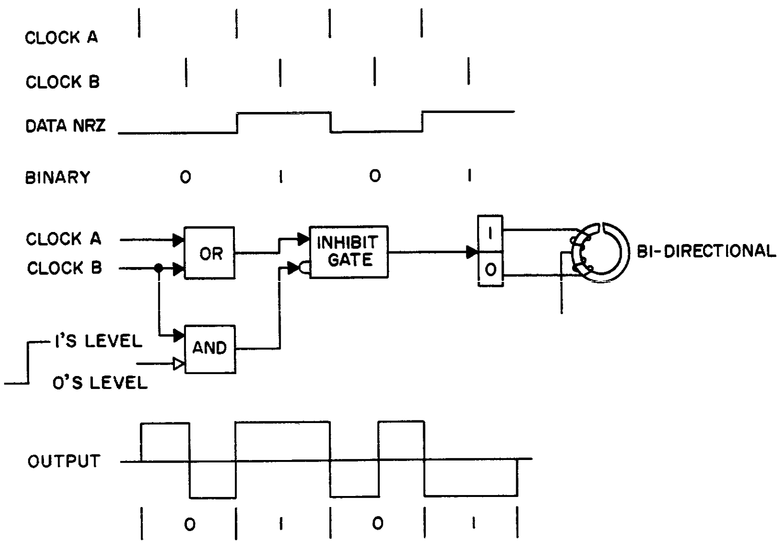


Fig. 5-33. *Frequency modulation digital recording method logic circuitry.*

versal every time a 0 is to be written. The AND gate and INHIBIT gate ensure that no polarity reversal occurs for a written 1. With this logic arrangement, there is always a field reversal at the beginning of each cell period and an additional field reversal during a cell period when a 0 is to be written.

Summary

Various ways of recording digits on magnetic tape are summarized in Table 5-1. Current digital recording methods used by leading tape transport and computer manufacturers are summarized in Table 5-2.

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6

Digital Magnetic Tape

In this chapter, digital magnetic tape specifications are analyzed on the basis of recording requirements and the availability of related commercial products. All magnetic and physical characteristics are interdependent and must be considered when evaluating tape performance. Magnetic, chemical, and tape configuration properties are firmly established during manufacture, but tape usage, storage, and manual handling tend to modify them. Constant usage, finally, will degrade and distort the tape characteristics to the extent that the tape becomes useless. The reliability and longevity of magnetic tape depend primarily on two factors: (1) tape selection and quality manufacturing; and (2) careful tape usage and storage. Once the tape has been processed, tested, and selected for operational purposes, it should be treated as a perishable item that needs constant care and vigilance to prolong its use.

Tape Specifications

At the present time, there is no set of established standards or test procedures for evaluating magnetic tapes. The major properties of magnetic tape that must be considered are listed below:

A. *Physical Properties*
   1. Width and width tolerance
   2. Coating — base thickness and tolerance
   3. Reel length

B. *Mechanical Properties*
   1. Stiffness of tape — cup and curl
   2. Edge smoothness and tolerance
   3. Surface smoothness
   4. Tensile strength — breakage and elongation

C. *Environmental Properties*
    1. Temperature characteristics — tensile strength flexibility, friction, dimensional stability, etc.
    2. Humidity characteristics — dimensional stability, flaking, etc.
    3. Blocking

D. *Magnetic Properties*
    1. Sensitivity — coercivity and remanence
    2. Squareness

E. *Electromagnetic Properties*
    1. Signal output — sensitivity
    2. Noise and signal-to-noise ratio
    3. Tape errors and tape flaws

F. *Performance*
    1. Number of passes across a fixed tape length
    2. Friction and squeal
    3. Storing and handling
    4. Combustibility
    5. Effects of nuclear radiation

A majority of these items are specified by tape manufacturers in defining the characteristics of their tape. However, the test methods or application of tape specifications, to a design engineer, are usually inadequate or not applicable. Most of the mechanical tests do not require the use of a digital tape transport, and the electromagnetic tests nearly always require the use of the digital recording device. Overall operation with respect to reliability, maintenance, and down time (digital tape system out of operation) is a major consideration to the system designer in selecting a device and to the tape user once the device has been incorporated into the system. Intangibles such as these, which specifications most often fail to include, are the cause of high system costs attributed to standby equipment, redundancy recording, error detecting and error correcting equipment, and processing equipment for storing and decision making.

Typical digital computer tape specifications are summarized in Table 6-1. Manufacturers specify magnetic tapes in terms of physical properties of the base material (acetate and polyester) and magnetic properties of the oxide coating. Some manufacturers specify percentage of errors or possible magnitude of errors per tape reel in terms of bit densities (200 bpi) of NRZ coding. Very few provide tape performance figures at 800 bpi. Some tape manufacturers supply such tape performance characteristics as wearability, skew, service range, and tape uniformity within and among tape reels.

Physical Properties

Magnetic tape is basically a ribbon of two layers: a base film and a coating of fine oxide particles held in a binder. There are several variations of this basic configuration. Digital tape recording mediums are available in the

TABLE 6-1. Digital Computer Magnetic Tape Specifications

	Base Material		
Physical Properties	*Polyester*		*Acetate*
Base thickness (mils)	1.5	1.0	1.5
Coating thickness (mils)		0.1 to 0.4	
Width tolerance (inches)		+.000 − .004	
Mechanical Properties			
Tensile strength (room temp.)			
Pounds*	9	7	6
PSI	25,000	25,000	14,000
Residual elongation (%)	.1 to .5	.1 to .5	
Environmental Properties			
Coefficient of expansion $\times 10^{-6}$			
Thermal inches/in./°F, 70° 120°F	15	15	30
Humidity inches/in./%RH 20-90%RH	11	11	150
Magnetic Properties			
Instrinsic coercivity, H_c (oersted)		230–275	
Saturation flux, ϕ_s (lines) *		0.35–1.60	
Remanent flux, ϕ_r (lines) *		0.25–1.1	
Retentivity, $B_r = \phi_r/A$ (gauss)		800–1200	
Erasing field (oersted)		800–1200	
B/H loop squareness		.75–.82	
Electromagnetic Properties			
Uniformity at 15 mil wavelength (%)			
Within reel		±2.5 to ±5	
Reel to reel		±5 to ±15	
Error count (as specified by tape mfg.)		1 or less than reel	
Performance			
Relative wearability	10	10	1
Coefficient of friction		.05 − .33	
Recommend service range		−50° to +175°F	

Remarks

Magnetic properties are evaluated with a 60 cps B/H loop tester at 1000 oersteds.

Generally analog tapes are tested to conform to MIL-T-21029 specifications.

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* ¼-inch tape width although later specifications are given in ½-inch widths.

** Standard Widths of ½, ¾ and 1 inch Tape Lengths of 800, 1200, 1800, 2400 and 3600 ft. per reel.

following forms: powder-coated; magnetic metallic tape; nonmagnetic metallic tape; metallic-coated plastic tape. The present-day nonmagnetic base (acetate or polyester) provides the necessary mechanical strength and the coating provides the magnetic properties.

Metallic magnetic tapes are made by rolling a magnetic metal into thin strips. Some of the most common metal tapes are made from stainless steel, cunife, or vicalloy. However, mechanical properties of metallic tapes, such as brittleness or lack of ductility, preclude their general use. Another metal-tape approach is the use of magnetic-plated surfaces; nonmagnetic conductive material (phosphor bronze, brass, etc.) at a thickness of one mil with a plating of 0.2 mil or more. Although not commercially available, Sperry Rand Co. has been successful in manufacturing and utilizing this recording medium in its tape transports. This type of tape is believed (by the manufacturer) to permit a greater length of service. A half-mil plastic tape is moved slowly between the high-speed metallic plated tape and the magnetic head during tape operation.

In a more recent development, metallic magnetic coatings are vacuum-deposited on a nonmetallic surface, which offers desirable advantages over powder-dispersion tape. The mechanical properties of this new magnetic medium enable it to supply a much harder and less abrasive surface that permits intimate head contact and conformity to head profile. Presently a thin plate of cobalt, nickel, or alloy of both (.00005 inch and less) serves as a metallic magnetic coating.

Magnetic tape is specified in terms of the physical properties of the base material and the magnetic properties of the oxide coating, which form two independent sets of parameters. The thickness of the base material is standardized at 1 and 1.5 mils for both acetate and polyester tapes and at 0.65 mil for prestretched or tempered polyester. The standard tape width, or slitting, tolerance is +000 and −.004 inch for all standard widths of 0.5, 1.0, and 2.0 inch tape (Fig. 6-1).

Tape Slitting

It is virtually impossible to secure a sufficiently clean edge when slitting tape from a continuous coated sheet. One cause of this is the frequent regrinding of the knife edges, since the oxide in the coating is still a powerful abrasive that wears down the knives. Although the dimensional tolerance specified for magnetic tape is tight, it still remains inadequate for high-density recording.

In Fig. 6-1, where a number of possible tape width contours are shown, the most preferable arrangement is the upper-most configuration. If a perfect reference edge is obtainable, the opposite side is free to vary without any undesirable effects. Actually, one edge becomes the working side. A possible width specification may contain this information, if a reference plane is used, to specify a magnetic head mounting block. This requirement can be super-

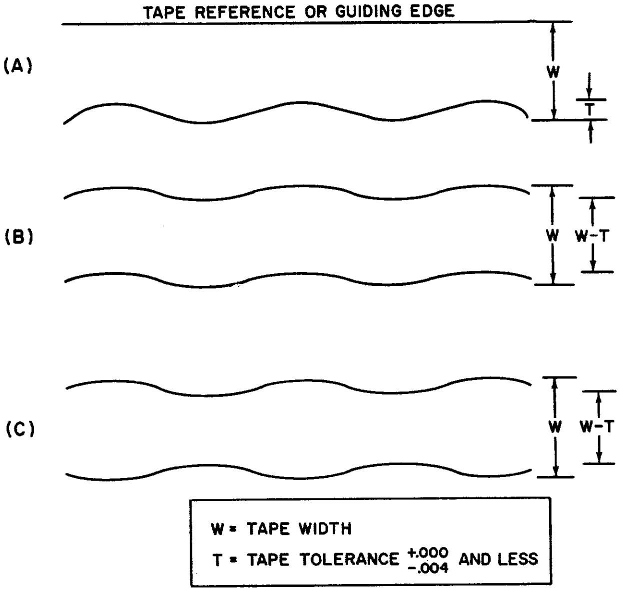


Fig. 6-1. *Tape width geometry.*

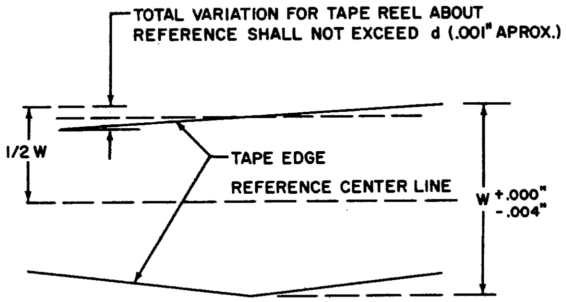


Fig. 6-2. *Tape width specification.*

imposed on an existing specification (Fig. 6-2). One side is selected and carefully regulated during a cutting or tape refinishing process. The other edge is permitted to have a wide tolerance as long as the precision reel used is unaffected during the winding process. The reference edge is used to guide the tape up on the reel. One possible precision reel for this proposed tape width specification is shown in Fig. 6-3. A solid plate and hub permit the winding of tape. The front plate merely serves to load the hub symmetrically and to supply structural strength to complete the reel.

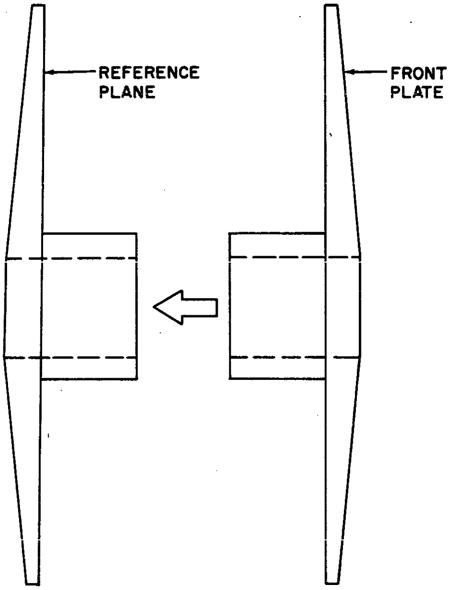


Fig. 6-3. *Tape reel using tape reference edge.*

Mechanical Properties

Thickness and Width

The stiffness of the base layer decreases very rapidly as its thickness is reduced and, therefore, thin base magnetic tapes are considerably more flexible than those of standard thickness. In fact, a considerable improvement in digital recording has been obtained by using thin base tapes. A thick tape base may not conform to surface deviations, especially a sharp change, in a smooth contour of the head, guide post, or capstan drive. Loss of contact within the head gap vicinity causes complete loss of high-density recording. This effect may be sporadic, depending on the magnitude of the tape tension at the magnetic head and throughout the tape handling mechanism. Since good head conformity is now obtainable, the tape tension across the head gap may be reduced without sacrifice of performance.

While the increased flexibility of thin base tapes improves head-to-tape contact conformity and permits more tape length per reel without weight increase, it also presents problems in tape guiding and winding. The usual method for lateral positioning of the tape is to pass and direct it by closely-spaced guides or rollers with shoulders. Pressure is applied to the tape edges to direct its path motion. The increased flexibility of thin tapes makes them more prone to fold or crease when edge-guided.

Thin base tapes are more subject to damage by edge guiding when positioning the tape to minimize skew. For tape preservation, present tape transport design minimizes physical contact between the tape and any other surface. In pneumatic systems, tape is guided on and off tape reels and controlled at the immediate vicinity of the magnetic head. Very little, if any, contact exists between the tape and any surface once it leaves a reel until it comes in contact with the head, all lateral correction (or skew) is accomplished using guide posts on the head block. A view of tape guiding is shown in Fig. 6-4, where the magnetic head is behind the reader and the tape is coming toward it. The thin base tape is pressed toward the reference edge permitting the variations to occur to the right side. Possible tape flexing is shown in the *YZ* plane. The tension stress is applied by guide posts in the *XY* plane. At fast writing speeds, any protruding tape edges on the guiding side are easily damaged and a perfectly acceptable tape may be creased, curled, or cupped on either edge. In fast rewinds, the tape is floated above the heads, but poorly-wound reels will crush the tape edges to the extent of completely destroying the tape.

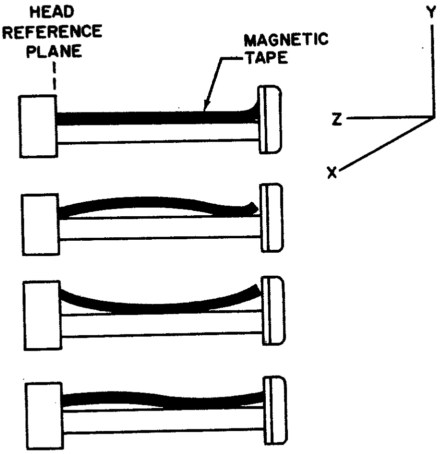


Fig. 6-4. *Edge wear due to tape guiding.*

Cupping

Cupping is a transverse curvature of the tape, and usually results from contraction of the coated dispersion during the tape drying process. Occasionally, cupping may be due to a differential absorption of moisture by base and coating, to improper tape usage, or to adverse environmental storage conditions.

Cupping leads to poor tape winding and tends to impose unequal tension over the tape width. The elastic forces causing the cupping action oppose the compressive effect of the winding tension. The end result is a tape reel of variable radial stress, which will buckle and separate the tape pile. For acetate base tapes, cupping is quite large, with the oxide layer on the concave side. The cupping is much less for Mylar base tapes, and the oxide layer is on the convex side.

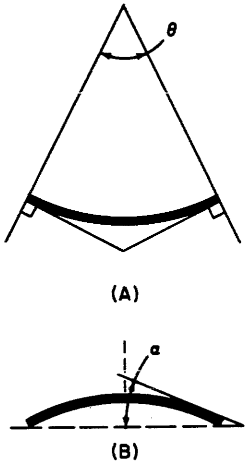


Fig. 6-5. *Tape cupping measurement.*

The degree of cupping may be measured in terms of the angle θ, between the junction of two lines that are tangential to the tape edges (Fig. 6-5A). The degree of cupping can also be measured in terms of the angle α, which is the angle at which the arc of the curved section intersects the chordal plane (Fig. 6-5B). Using the first method, θ can be measured with a vernier caliper calibrated in degrees, or with a piece of tape on an etched scale. The cross section of the cupped tape is considered in the first method. The second method is subjected to considerable human error when a correct position for the point of tangency is being determined.

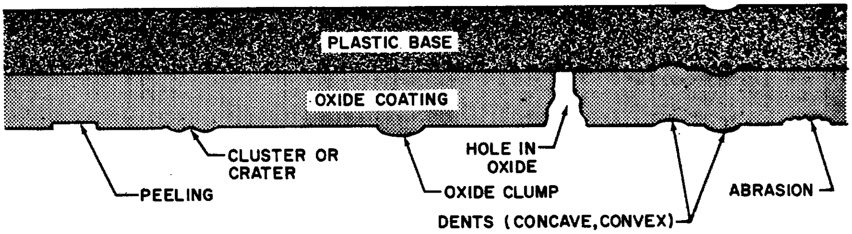


Fig. 6-6. *Magnetic tape surface defects.*

Curl

A length of tape laid flat on a smooth surface should be in contact with the surface along its entire length. If it is not, the tape is curled. Curling can result from careless tracking during the slitting operation, but more often it is the result of variations in thickness across the tape.

A curled tape will never wind or rewind satisfactorily; it will rock and twist from side to side while spooling, and will do a "snake dance" across the head gap. A fast wind and rewind operation before using a tape is a quick way to uncover tape defects such as cup and curl.

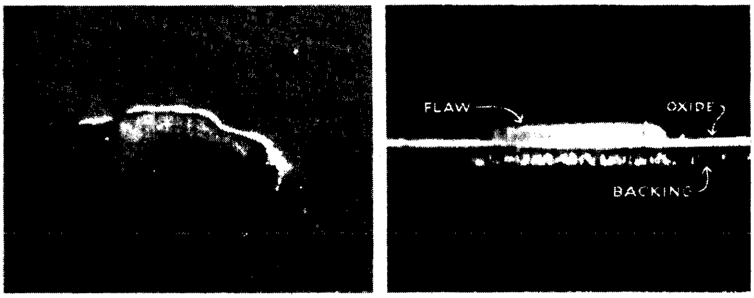
Edge Smoothness

The importance of a smooth tape edge was emphasized earlier. Edge quality can easily be determined by observing the edge through a microscope. A poor edge will be jagged or nicked. Constant wear will aggrevate this condition and poor base material will eventually tear. Even with a well-defined edge, the coating will show dislodged or flaked oxide at the edges. Small fragments will become further detached upon tape usage and will embed themselves in the coating or clog up the head gap and any moving parts that guide the tape. Nothing can be done to the tape to cure this particular problem.

Surface Smoothness

Proper coating surface smoothness is the sum of good initial base and coating smoothness, fine oxide granularity, and proper drying, aging, or curing of the oxide layer when anchoring both layers (coating and base) together.

Various faults and tape blemishes that cause tape rejection are listed below. Some of them are shown in Figs. 6-6 and 6-7.



(A) (B)

Fig. 6-7. *Photo micrograph of an oxide flake embedded in the tape coating: (A) front view; (B) cross-section.*

1. Foreign particles embedded in either layer.
2. Droplets of magnetic material adhering to the oxide recording surface.
3. Air bubbles or collapsed bubbles formed during the coating process.
4. "Clumps" on the coating surface.
5. Foreign matter, contamination, and improper oxide and solvent mixer combination.
6. Dents and surface abrasions.
7. Large oxide magnetic particles perpendicularly aligned.
8. Poor adhesion of coating to base and base layer imperfection.

Generally speaking, most of these faults have been eliminated or greatly minimized by quality manufacturing, surface conditioning and polishing, and tape length selection. However, the accumulation of dust, dirt, and foreign particles entrapped within the tape deck transport after tape acceptance is a major cause of frequent tape replacement. A "clean" environment in the immediate vicinity of tape operation, frequent cleaning of head and tape guides and dust removal during tape operation greatly extend the life of a reel of tape.

It is generally accepted that a tape of proven performance is preferable to the questionable operation of a virgin reel of tape. Quite often, as the tape is broken in, there is a tendency for the oxide surface to become further polished, and improved performance results. From this time, the tape is at its peak performance until signs of wear become noticeable. Under normal operating conditions, 25,000 passes for a reel of tape is common and can be expected.

Tensile Strength

Magnetic tape is subjected to both constant steady-state tension and peak, or shock, conditions. Both are detrimental to the tape. Probably the most apparent source of constant tension forces acting on tape is a loaded tape reel. Generally, the tape reel is wound under constant tension or constant torque methods. Thus, ordinary winding methods cause the inner portions of the tape pile near the hub to be stored under less tension than the portions near the reel edge. The pressure gradient is toward the hub, with the greatest differential occurring at a point one quarter to one third of the distance from the hub to the outside diameter of the reel. Here the tension forces undergo a negative to positive transition that tends to produce disruption of the tape pile. Since the tape is subject to plastic flow, these forces will slowly dissipate themselves after winding. The outermost tape becomes stretched to relieve the tension. Inside, the tape compresses toward the negative tension of the initially-wound tape. The net effect is to reduce the interlayer pressure gradient. When the forces stabilize, the roll tends to develop a void at or near the transition diameter. Tape layers on each side of this area collapse to fill the void in a wrinkled condition (Fig. 6-17). Under environmental variations (temperature and relative humidity) and vibrations, the tape will undergo permanent mechanical distortion, and very little can be done to salvage the entire reel. Employment of winding tension patterns as a function of spooling diameter and proper storing and shipping procedures will prevent this condition on precision tape reels (Fig. 6-18).

Another condition of constant tension occurs in high speed winds (searching) and rewinds. Here, improper tape handling mechanisms and accumulation of static charge can cause tape elongation and, in extreme cases, tape breakage. The latter problem, static pull or drag, can cause reel servo motor damage before the polyester tape completely ruptures.

Start-stop operations subject tape to high shock forces. In the past, paper-base tape could not survive this treatment and metal-base tapes afforded the only solution. Today with improved tape handling mechanisms and high tensile strength tape, the effects of shock are nil in properly operating tape transports. In the start mode, the brake is released before the capstan drive is engaged. The reverse is true for the stop mode; the capstan drive is disengaged before the brakes are applied. Normally, only when the equipment is malfunctioning can tape breakage occur. Some possible tape break conditions are failure of the tape brakes to operate or slow in operation, failure of the servo motor to operate or slow in operation, static attraction in a vacuum loop buffering system, jammed or sluggish tape take-up arms, and worn tape guide posts.

Tape breakage prevention should be considered in the early design stages of the equipment and in the selection of high-quality digital tape. In a good mechanical tape handling design, tape buffer storage and reel servo motor design should ensure that the peak tape tension stress is below 5 oz for standard magnetic tape and that the normal operating tension is less than one-half this value. A high derating tension value will prevent tape breakage.

Splicing digital tape is not recommended at any time. Should the tape break, splicing should only be used to transfer the data onto a good reel. If the tape is mechanically damaged beyond repair, a new reel must be prepared from other records or sources.

Tape tensile strength can be evaluated in a number of ways; two methods are suggested here. Since temperature and relative humidity affect the performance of tape, they are always specified for any tape tensile testing. Tape testing can be performed in a tensile testing machine. A length of tape is anchored at two points which are separated gradually, and the applied stress is indicated as the separation takes place. Breakage is the complete rupture of the tape. Tearing or breakages at the clamping points are ignored. Abnormally low tape tensile strength is generally associated with excessive drying out, poor slitting, or nicked edges.

Impact testing is stated in terms of energy of shock absorption. A recommended form of testing is anchoring the tape between two points and subjecting the middle point to a free-falling object of known weight.

Another measurement used for stress measurement is tape elongation. A specified length of tape is subjected to a constant force for a specified interval of time. The weight is then removed and the tape length is measured after some time interval. The difference between the initial tape length and final tape length is specified in percentage change.

Environmental Properties

Moisture and temperature affect dimensional stability, tensile strength and toughness of the base layer, and the cohesion and adhesion of the binder and magnetic material. Detrimental physical and magnetic effects occur when generally-accepted limits are exceeded.

Humidity

Of the two environmental elements, moisture and temperature, the effects of high relative humidity are less serious in many respects. First, if a polyester base is assumed, the moisture absorption rate is nil. (This is not so for an acetate base. Cellulose acetate has a tendency to swell. A commercial magnetic tape cleaner uses plain water as the cleaning fluid with some detergent as required on polyester magnetic tapes. Acetate bases would never survive this operation.) Some binder formulations are insensitive to moisture. Humidity seldom causes permanent tape damage (unless the tape is under tension), especially when the tape is conditioned prior to utilization in a controlled environment of 50° to 75° F and 50% to 55% relative humidity for several hours.

Temperature

Temperature affects three main areas:

1. The base layer or substrate that supports the oxide coating.
2. The binder composition and content.
3. The magnetic properties of the coating layer.

Safe operation is generally specified from −40° to 200° F. Below −60° F, the coating becomes brittle and chips. This can be tested by wrapping a piece of tape around a narrow diameter mandrel and flexing it. Above 150° F, temperature-sensitive degradation of the base layer reduces the tensile strength, the oxide-binder mixer cohesion and adhesion properties deteriorate, and a tendency to peel develops. Contrary to expectation, acetate-base tapes tend to shrink rather than expand with increasing temperature. With decreasing moisture content and increasing temperature, shrinkage is caused by dehydration. The plasticizer in acetate base film becomes brittle, impairing its ability to withstand the suddenly-applied forces encountered in normal digital tape operations.

Over the same temperature range, Mylar shrinkage takes place in the first ten minutes of high-temperature exposure. The total permanent deformation of Mylar tape is less than 5 percent at 300° F. Furthermore, once the Mylar film has been cycled through the high temperature zone, no more shrinkage is to be expected for subsequent operations.

Binders combine flexibility with toughness and produce a coating having high cohesive and adhesive properties. The range of operation of magnetic tapes is quite low compared to the base film properties and suggest that binder degradation sets an upper limit in the range of 200°-250° F.

Of the numerous components, the plasticizer and thermoplastic resins are most sensitive to high temperatures. Most thermoplastic resins require a plasticizer to make them pliable enough for tape operation. Generally, the plasticizer has a low melting point and the binder is vulnerable to permanent destruction by heat. Frequently, both cohesive and adhesive properties of the coating disintegrate with the plasticizer and the tape becomes worthless. The oxide particles can withstand temperature up to the Curie point (750° F).

The safe temperature limits specified for both acetate and polyester tapes are approximately the same and are set by the oxide coating rather than the particular base material. The safe temperature limits are −40 to +150° F (50% R.H.), while the recommended storage conditions are 70 to 75° F (40-60% R.H.).

Blocking (Layer-to-Layer Adhesion)

Layer-to-layer adhesion is the tendency of adjacent layers to stick together on a roll during an unwinding operation. When this happens, the tension required to unreel a tape is increased and oscillating tape motion is created. Even with mild blocking, unwinding occurs in a jerking or snapping operation that increases the pull of the unwinding mechanism. For digital operations, the tension variations caused by erratic unwinding affect the writing and reading operations. The instantaneous tape speed variation may also modulate the recorded signal and affect particular coding methods.

When layer-to-layer adhesion becomes severe, the tape coating may be stripped away entirely during the unwinding process. The problem becomes more severe during temperature and humidity cycling and with improper reel winding tension. The latter effect usually causes adhesion to occur near the hub.

Adhesion occurs in both acetate and Mylar tapes. Blocking can usually be traced to the plasticizer, to excess resin in the binder, or both. It is more severe in acetate base because a plasticizer is present, while a plasticizer is not required in Mylar.

A simple way to evaluate blocking is as follows. Wind a tape specimen on a mandrel of fixed tension and subject it to a temperature-humidity cycle one or more times. (A recommended cycle is 16 to 18 hours at 125° F and 85% R.H.) This should be followed by a drying-out process of 4 hours at the same temperature. Adhesion or blocking is readily apparent if the tape end is loosened and the tape fails to unwind with the mandrel turned to assist the unwinding. Several turns of tape may be peeled off and the process attempted again. The degree of unwinding is indicative of the magnitude of tape blocking.

Magnetic Properties

Magnetic properties of oxide coating can be tailored to specific digital requirements. B-H curves were discussed in Chapter 4 and the plotting of the hysteresis loop was explained step-by-step. The hysteresis loop shows the relationship between the H field and the flux density (B) and not the rate of change of the flux density as a function of the magnetizing current. As stated earlier, the hysteresis loop can be modified so that two magnetic materials may appear to be quite similar and have the same H_c and B_r values. Yet one of the two may be unacceptable for digital recording purposes.

Hysteresis Sensitivity and Squareness

Three hysteresis curves are illustrated in Fig. 6-8 to show the ideal square loop, normal digital characteristics, and a general hysteresis curve for analog

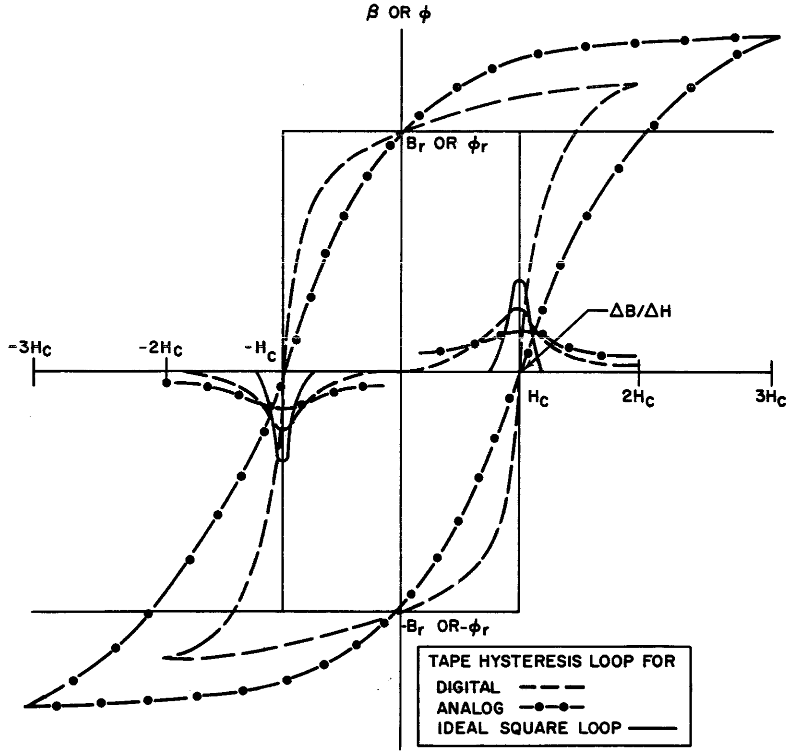


Fig. 6-8. *Hysteresis loop for different magnetic materials.*

recording. The digital and analog curves have the same H_c and B_r values but possess different magnetic properties. Normally, the hysteresis loop characteristics presented on an oscilloscope are obtained by integrating the flux density between two limits over the H field (magnetizing current.) Actually, the measurement is in terms of flux lines, but the scale can be marked in terms of flux density by normalizing the measurement in terms of coating thickness. If the rate change of B is plotted, the waveshape of the derivative curve may reveal differences not apparent in the hysteresis loop. In this respect, the derivative curve (Fig. 6-9) is more sensitive to slight variations than is the magnitude of the measurement; this is important in evaluating a digital tape.

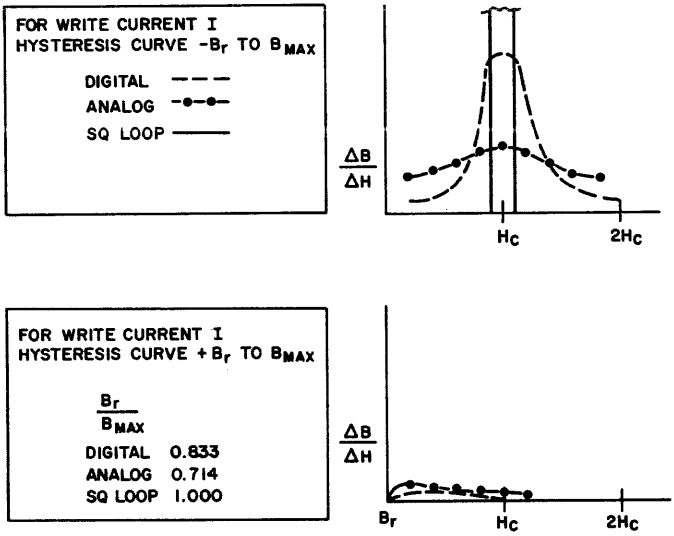


Fig. 6-9. *Derivative curves for tapes of Fig. 6-8.*

Normally, the scope presentation of a hysteresis loop is traced out over the frequency range of 60 cps to approximately 1 kc. Care should be taken to obtain a B-H characteristic curve that is free from the effects of external magnetic fields and test equipment frequency response and distortion. A more revealing test is one that discloses infinitesimal changes along the curve that are pertinent to digital recording. The rate of change of flux lines the readback coil encounters indicates tape sensitivity. The readback signal output must be obtained without increasing the noise component, or a net gain does not exist.

In a normal hysteresis loop the greatest slope change occurs at H_c (Fig. 6-8). Accordingly, the distances on the *B* axis are divided by unit distances along the *H* axis and the resultant is plotted as a function of the H field. The derivatives are expanded two to one and are shown in Fig. 6-9 to illustrate the sensitivity for the two curves. The slope of the curves at $+H_c$ and $-H_c$, and, correspondingly, the magnitude of the peaks of the derivative curve, are useful indicators of tape sensitivity. Similarly, the linear portions of the hysteresis curves show a flatness of peaks in the derivative curve. Obviously, any distortion is accentuated and will show different magnetic properties.

As expected, the magnetic material with the squarest hysteresis loop will have the highest peaks in the derivative curve, giving the highest sensitivity and the maximum undistorted pulse output. For pulse recording, as for coincident ferrite cores, an instant change of magnetic state is desirable since the pick up coil is a derivative type of transducer.

Normally, hysteresis curves do not check the switching characteristics from one magnetic saturation state to another. Fundamentally, a magnetic threshold exists in terms of time delay or energy consumed. In Fig. 6-10, the switching characteristics are examined in terms of pulse waveforms. Consider a pulse with a vertical rise time of short duration. If the pulse is too narrow, the tape begins to follow the curve from $-B_r$ up to the knee below the value of H_c and then returns to $-B_r$. Insufficient time permits only a temporary alignment of the magnetic moments and the magnetic state of the tape reverts back to its initial state with the sum magnetization unaltered. If the magnetizing current is increased while maintaining the same pulse duration, the magnetic state may remain unchanged. By increasing the pulse duration, the field generated causes all of the magnetic moments to align themselves in the direction of the field and the tape saturates at B_{max}. When the magnetizing current is removed, the flux in the tape decreases to $+B_r$ since some of the original alignment was only temporary. Now, if the field is reversed and applied to the tape, the magnetic moments will align themselves in the field direction

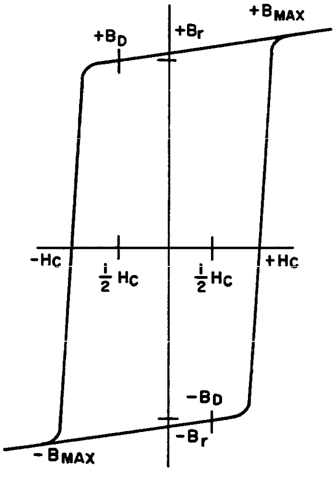


Fig. 6-10. *A square hysteresis loop (B vs. H).*

and trace the negative path and saturate at $-B_{max}$. Removing the field decreases the flux to $-B_r$. Since as much flux as possible should remain after removal of the magnetizing field, a high remanent state is desired.

A minimum allowable time is required for initial magnetic alignments for core losses and frequency losses. During this time interval, no permanent energy is stored in the tape. A slower pulse rise time will supply the initial energy requirements while reducing other losses. The net result is approximately the same as a sharp vertical energy pulse with less input energy.

A third pulse waveform is an S-shaped curve (Fig. 6-11). This waveform supplies the initial energy to align the field within the tape while minimizing core and high-frequency losses. Once the magnetic field is aligned within the tape, the straight portion of the wavefront is fully utilized to switch the tape magnetic state from one saturation level to the other ($-B_r$ to $+B_{max}$). The upper portion of the S-shaped wavefront abruptly flattens out and the tape experiences no rate of change of flux lines. This wavefront supplies a maximum output with minimum losses and noise generation.

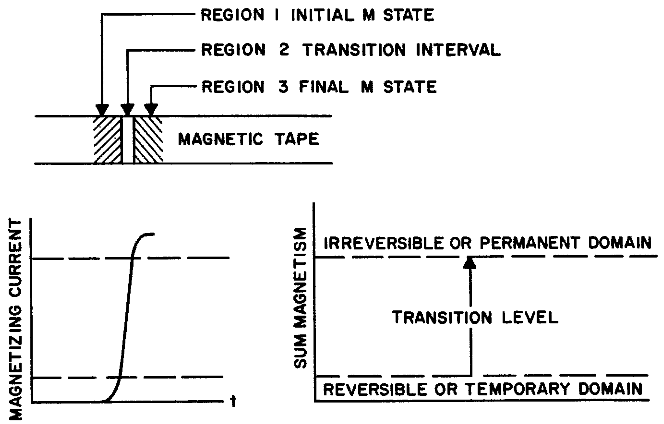


Fig. 6-11. *S-shaped rise time and corresponding flux field.*

Evaluating Hysteresis Squareness

The squareness ratio is not normally included in published tape data, although tape manufacturers use it as a measure of magnetic efficiency. A square loop indicates that the tape retains its saturation level after the magnetizing field is removed. The more nearly square the loop, the greater the signal output during a readback operation.

There are a number of ways of defining the squareness factor. The squareness of the B-H loop is defined by most tape manufacturers as the ratio of the remanent flux to the saturation flux.

$$\text{Squareness factor} = \frac{\phi_r}{\phi_{max}} \text{ or } \frac{B_r}{B_{max}} \qquad \text{(Eq. 6-1)}$$

However, suggestions have been made to consider the demagnetization properties of the tape (see Chapter 4).

$$\text{Squareness factor} = \frac{B_d}{B_{max}} \qquad \text{(Eq. 6-2)}$$

where B_d = flux density at H_d (Fig. 6-10)
H_c = magnetizing force (H) required to reduce B to zero

With either method, the limit approaches one for the ideal square hysteresis loop.

The efficiency or squareness can be computed in another manner:

$$\text{Squareness ratio} = \frac{B_{max} - B_r}{B_{max}} = 1 - \frac{B_r}{B_{max}} \qquad \text{(Eq. 6-3)}$$

$$= \frac{B_{max} - B_r}{B_r} = \frac{B_{max}}{B_r} - 1 \qquad \text{(Eq. 6-4)}$$

Equations 6-3 and 6-4 indicate that the lower the squareness ratio, the more preferable the tape. Any method used will suffice to indicate the preferable tape selection. The only difference will be the spread of numbers to give a sharp peak distribution or a broad peak to pass marginal tapes.

Laboratory means are available to evaluate squareness using the coincident current ferrite core method of checking a square hysteresis loop. Using the square loop of Fig. 6-10 and a pulse code pattern, maximum and worst-case signal outputs can be checked. Not only is the squareness observed by these measurements, but axis assymmetry and loop assymmetry can be evaluated. For coincident core magnetic memory operations, the X and Y drivers have one-half unit current values. When added, the two half currents have a magnitude of one unit equal to H_c to switch the core. A half current ($\frac{1}{2}$ H_c) disturbs the core in the direction of the field.

The above method will now be used to evaluate the worst-case conditions of signal output. The signal readout is indicated at the appropriate time and the corresponding flux values are shown in Fig. 6-12. A set of expressions are tabulated to satisfy Eqs. 6-1 and 6-2 and signal-to-noise ratio in terms of magnetic core nomenclature. The coincident current ferrite core material was included here because of the similar magnetic properties and readout methods. Magnetic ferrite core methods are well established and much knowledge has been accumulated in evaluating ferrite magnetic properties. The waveform variation previously discussed applies very readily to memory core testing. The S-shaped curve can be simulated by delaying one of the two half-current drivers.

In regard to efficiency, the more nearly square the loop, the less the H field required for erasure. However, to ensure complete erasure under all conditions or to write a 1 or 0, the magnetizing current value H_c should be exceeded at the head gap vicinity.

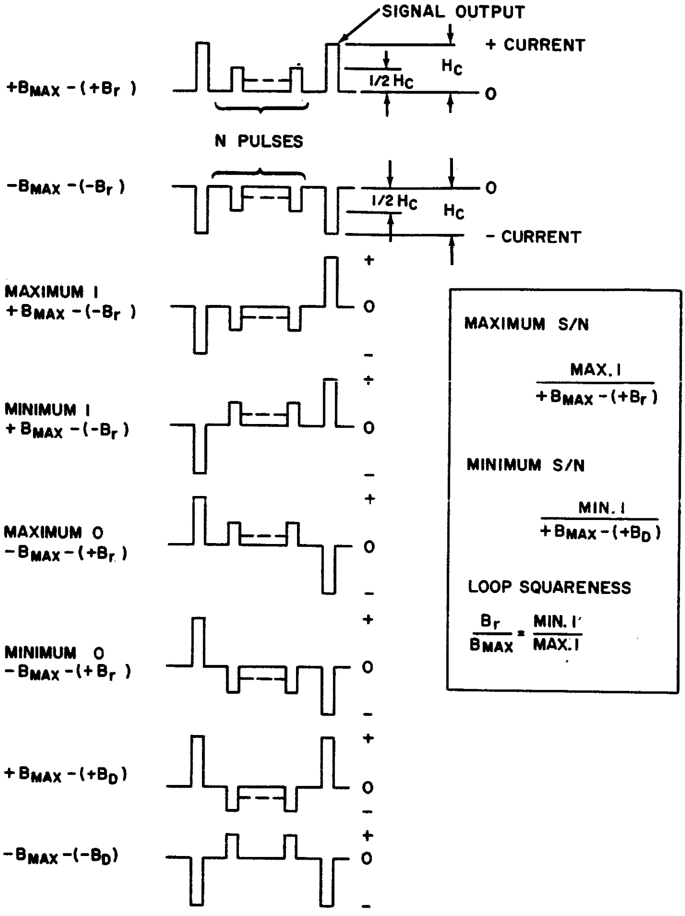


Fig. 6-12. *Pulse code pattern for square loop testing.*

Electromagnetic Properties

Signal Output

In some tape specifications, the terms *output* and *sensitivity* are expressed in several ways. These properties are based on standards established by the tape manufacturer and depend on wavelength measurements or relative signal comparisons. Generally, sensitivity is expressed in units of decibels (db) or in percentage (%) comparison of one signal with another. Conditions for measurement are specified in terms of head type, track width, tape speed, and other factors. To cite a few examples, the tape sensitivity specifications of several tape manufacturers measurements are reviewed.

Ampex lists computer tapes of the 800 series as having a relative output of 600 bpi in terms of 200 bpi at zero reference. Resolution capability is defined in terms of comparison for these two pulse densities. Audio Devices Inc. doesn't specify output as such in their extra precision audiotape for use on electronic computers, but, rather they specify maximum percentage variation from average peak output of test tape. Also, Computron Inc. defines peak output as percentage within a reel and from reel to reel. MacPanel Company lists computer tape sensitivity in db for 15 mil and 1 mil wavelengths. Uniformity at 15-mil wavelength is given in percentage within a reel and from reel to reel. Memorex Corp. lists computer tape average pulse output in percentage within a reel and from reel to reel. Peak noise and relative noise are stated in relative units. Minnesota Mining and Manufacturing Company lists thin coat high-resolution tape (591 and 592) sensitivity in db for 15 mil, 1 mil, and 0.5 mil wavelengths referenced to No. 408 standard instrumentation tape, along with uniformity within a reel and from reel to reel. Reeves Soundcraft specifies their computer tape in terms of wavelengths and the ratio of 556 bits to 200 bits.

Generally, any comprehensive evaluation of tape performance is so complex that it is usually preferable to consult the tape manufacturer for detailed tape specifications and his methods of tape testing.

Noise and Signal-to-Noise Ratio

The concepts of noise and signal-to-noise ratio in digital recording are not the same as those in analog recording. Noise, by definition, is the residue of the signal content when the information (or intelligence) has been subtracted. Noise in digital recording may arise from removal of the data, such as dropouts, or from the insertion of noise that is equivalent in every respect to the desired data. The signal magnitude may be diminished by a number of factors, and extraneous signal energy may be added. The signal-to-noise ratio becomes a relative measurement of acceptable performance determined by the user, using his facilities. Since an established set of standards is not available, tape evaluation for this parameter is only conjectural.

The signal-to-noise ratio can be altered by lowering or removing the information content and increasing the extraneous signal component or both. When measuring the signal-to-noise ratio of tape, the magnetic properties of the tape are modified by tape handling mechanisms, magnetic head performance, erasing procedures, coding methods, and electronic circuitry. Furthermore, noise may arise from induced pickup from input transformers, magnetic heads, and magnetic actuators and from motor electrical disturbances and mechanical vibration. Friction between the tape and heads and guides during high tape speeds (especially in the rewind operation) may produce electrostatic charge. Static charge thus accumulated can acquire voltage value sufficiently high to cause arcing, which affects the readback operation and, in extreme cases, causes skew by static pull or drag. Also, any temperature change will modify the magnetic characteristics of tape.

In practice, all the noise sources are always present with the exception of pickup and static charge, which can be reduced or eliminated if sufficient care is taken of the tape. Tape may be tested by any means but, unless dynamically evaluated under laboratory conditions, the signal-to-noise figure has no meaning. For illustrative purposes, background noise associated with tape will now be examined.

Background noise determines the lower limit of good operation. The noise is attributed to nonhomogeneity of the tape due to nonuniform distribution of the oxide-binder material, variations in coating thickness and surface smoothness, and variation in contact between tape and magnetic head due to tape mass, tape stability, flaking, or tape erosion. Both the physical dimensions and magnetic remanence will vary along any recorded channel. In general, these variations will be statistical in nature, and the average of both, taken over a sufficient length, must be assigned a value of tape acceptance.

Tape Errors

It is difficult to manufacture tape without flaws. These flaws result in dropouts or dropins which, in turn, result in signal errors. If any tape specification was to be selected as the basis for digital tape selection, it would be error count.

The loss of information (dropouts) and introduction of noise (dropins) are serious problems in digital tape recording. A dropout is defined as any signal reduction greater than 50 percent of nominal signal output. This constitutes a signal error or a bit loss of information and indicates a signal-to-noise ratio of 2 to 1. Some tape systems require a greater margin of safety and a value of 3 to 1 might be necessary. A dropin, or the existance of an extraneous 1, is a spurious noise pulse greater than 10 percent of nominal signal output and is assumed to be a bit of information. Both dropouts and dropins are traceable to discontinuities in magnetic tape coating.

The read signal is the function of the tape remanent state and space variations between head to tape. The space variations are, in turn, a function of tape smoothness. A few types of tape surface flaws were illustrated in Fig. 6-6. One of the accepted methods of evaluating surface smoothness as a possible source of tape errors is pulse recording similar to return-to-zero (RZ) coding. A series of 1's are written and read back at a stipulated bit density per channel and tape speed. For the moment, any mechanical errors in such areas as tape guiding, head parameters and alignment, and other possible factors that may alter these measurements are ignored. If a series of 1's are written on tape, any cause that prevents the tape from maintaining contact with the head will reduce the recording field strength, as defined in the following equation:

$$\text{Separation loss} = 55\,\frac{d}{\lambda} \qquad \text{(Eq. 6-5)}$$

where d is the space displacement and λ is the record wavelength. Similarly, the same effect is present during readback. In passing across the head, any bumps present on the tape push the tape away from the head and cause a drop in signal level. If the upraised surface is a concentration of oxide, it is possible that the signal output will increase slightly. If the bump contains no oxide material a drop in signal occurs immediately. Also, if the tape is stiff, the tape tension slight, and the recording density high, the bump will maintain a separation between head and tape after it passes the air gap. Therefore, one or more pulses will be affected by one single bump. Obviously, a series of bumps can disqualify a lengthy area of tape. This condition is illustrated in Fig. 6-13. Any discontinuity in surface smoothness or a lack of oxide material will diminish or prevent the writing and reading of such imperfect tape areas. Tape testing for drop-out errors must be able to sense a signal drop below the specified maximum value. Regardless of the method of locating and recording errors, those tapes marked for rework must have their surfaces scrubbed and polished to remove defects.

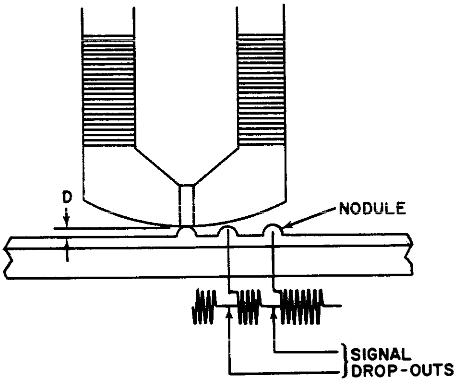


Fig. 6-13. *Tape operation affected by surface defects.*

Other causes of dropouts, not directly attributed to surface smoothness but often uncovered in tape testing, are dust, flake particles, or any contaminant accumulated during the manufacturing process. Thus, besides surface refinishing, tape cleaning is often necessary. For easily removable particles and foreign matter, plain buffing or wiping with a lint-free cloth or soft brush is satisfactory. For more difficult contamination, a cloth moistened with Freon TF can be used. Freon TF is nontoxic and nonflammable. There are other possible cleaning agents, but care must be exercised in using them. Tape manufacturers recommend avoiding carbon tetrachloride, ethyl alcohol, trichloroethylene, or any cleaning agents of unknown composition because they may soften the oxide, deform the backing, or both.

A defect too small to be seen by optical means can be detected by electronic methods. The approach presented here concerns only a single track. Tape flaws can be detected between adjacent tracks of a multitrack recording. If a bump exists at the edge or center portion of a wide track, amplitude change is very little. If the track width is small, so the whole track is affected, a complete dropout will occur. Generally, a tiny bump is more troublesome than a tiny pinhole. The tiny hole is not removable, but it does not affect any adjacent areas.

Fortunately, the sources of dropins, holes and sharp surface irregularities, occur infrequently. The severity of noise or signal interference attributed to holes and sharp surface irregularities is generally less than 10 percent of the total tape defects. Metallic particles usually cause noise signals rather than dropouts. Particles located on the surface can be removed by previously-mentioned methods. Particles deeply embedded in the oxide coating cannot be removed.

Dropins, or noise pulses, are located by saturating the tape at one polarity. The field seen by the read head under this condition of constant magnetization would be essentially zero for an acceptable tape, even though small variations and leakage flux from particle to particle of the oxide will cause a noise background output. However, if a discontinuity in the coating occurs, such as a pinhole or particle that distorts or interferes with the written field pattern, an incremental field change will be formed on each edge noting this field distribution and will produce a signal output. Noise pulses of 10 percent and greater are counted. As a rule, these tape defects are below the surface and attempts to correct them usually result in damage to the tape.

From the user standpoint, if perfect magnetic tape is demanded the price of the tape may become prohibitive. If the equipment can accept an error count, the amount of error correction must be determined to reduce the error magnitude or error rate to an acceptable value. While a manufacturer may classify tape as error-free, the tape might still not be satisfactory in certain user applications. Signal detection methods operate from 70 percent and higher of nominal readback signals. Tape tests conducted by manufacturers are at 50 percent of nominal output. Dropins are checked at 10 percent of nominal readback signals. Many conservative tape users have a threshold for a 1 at 70 percent and a noise threshold of 5-8 percent. The user's circuitry is fast and sensitive to narrow spikes. The tape manufacturer's circuitry has a different threshold operating level and is sensitive to pulse durations in terms of his test procedures.

Tape Performance

At the present time, it is difficult, if not impossible, to define and isolate those factors that truly evaluate the tape from those that are distorted by the test equipment. Some say high-density recording is limited by the quality of tape, while others contend that the recording device is the limitation.

While noncontact recording methods appear very promising, the majority of present day applications employ contact recording. Thus, friction wear continues to be the most important factor in determining the useful lifetime of a tape.

At present, the hot spot due to friction is focused on the head-to-tape contact surface. Present high-density tapes require high input writing currents at high tape speeds. This causes the temperature to rise to 250° F or more at the head-to-tape contact surface. Excessive friction due to tension, tape flaking or shedding, foreign particles, and blocking contributes to this temperature rise and causes thermal distortion of the air gap line. Heat attacks the resin or plasticizer in the coating and sticking occurs even though a lubricant may be included in the coating formulation. The net result is transient shedding and welding of coating material to the head surfaces, especially in the air gap vicinity.

The input energy loss in the form of heat is proportionate to energy-per-writing bit. When the bit rate (frequency) is increased from 15,000 bits per second to 90-125 kilobits per second, the heat losses increase eight fold. Losses dependent upon frequency increase to the second power. Eddy currents become 64 times greater. The amount of heat generated is directly proportional to tape speed and therefore the heat generated during high-density recording (200 ips) is approximately three times as great as it is during low-density recording (75 ips). Also, ensuring intimate head-to-tape contact may result in added tape tension causing a twofold increase in heat. When these figures are summed, the heat losses are increased approximately 80 times over the low-density recording methods. Thus, present digital magnetic tapes become pitted and, finally, will destroy the magnetic head.

There are a number of methods to measure the coefficient of friction and tape tension. Test setups can be made to determine the one in terms of the other. One method of determining the coefficient of friction is to hang a length of tape over a mandrel and attach weights at each tape end. Additional weights are then added to one end of the tape until friction is overcome and the effect of the imbalance keeps the tape slipping. The coefficient of friction is given by:

$$\mu = \frac{1}{\alpha} \ln \left[\frac{F_2}{F_1} \right] \qquad \text{(Eq. 6-6)}$$

where α = angle of wrap around the mandrel in radians

F_2 = large weight (total)

F_1 = small weight

(Starting friction is higher than moving friction)

The same brake-hand formula can be rearranged in terms of tape tension.

$$\frac{T_1}{T_2} = \epsilon^{\alpha\mu} \qquad \text{(Eq. 6-7)}$$

A pictorial representation of both measurements is shown in Fig. 6-14.

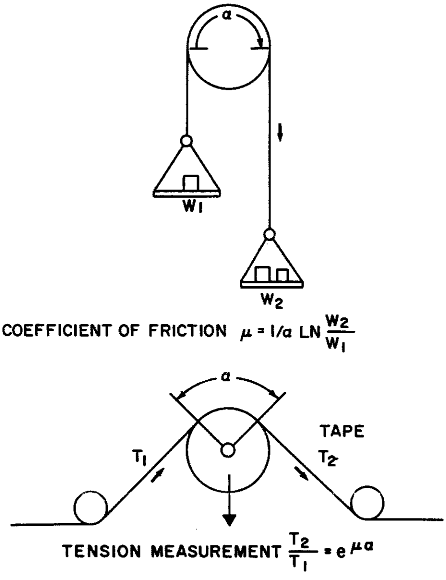


Fig. 6-14. *Tape friction measurement procedures.*

A dynamic friction test on tape is more realistic. This may be accomplished with a tape loop arrangement having two opposing capstan drive motors. Initially, one capstan drive moves the tape. The second is activated and its power is increased until the tape is brought to a stop by the opposing capstan drive motor. Both power inputs to the capstan drive motors are noted. This setup permits the operation of tape for a specified time and increased friction values are obtained as a function of tape operation. Although the measurement is not absolute, reproducible results and comparisons make this test setup a valuable aid in evaluating digital tapes.

Another tape property that is critical with respect to tape durability is storability. Tapes, when not in use, should be placed on precision tape reels at a correct winding tension that is a function of winding diameter. The best way to protect the tape is to place the reel in a sealed container and store it on end in a storage bin equipped with partitions between each reel. Rewinding the tape once or twice a year during storage is advisable because it releases expansion-contraction stresses and reduces the possibility of blocking. Temperature extremes or rapid changes in temperature and humidity should be avoided. The recommended storage conditions for acetate and polyester base tapes are: humidity, 40-60% R.H.; temperature, 60-80° F.

If extreme temperature and relative humidity are encountered (shipment in winter months at temperatures as low as −20° F), tape must be brought up to normal operating temperature before it is used. Assuming, for instance, that tape has experienced subzero temperature, it should be returned to normal operating temperature in not less than 24 hours, otherwise condensation may form and mechanical vibration due to heat may move or flex the tape and damage it. Very little information concerning prolonged exposure to low temperatures combined with transportation vibration is available. Excessive heat (discussed earlier) should be avoided. Flame temperatures for magnetic tapes range from 500° F for acetate to 700°F for polyester, and self-ignition temperatures (without direct contact with a flame) are 700° F for acetate and 1000° F for polyester. Fireproof boxes can maintain safe temperatures for several hours permitting the rescue of reels of tape from a burning facility.

Auxiliary Tape Equipment and Accessories

Tape Cleaning

Tape errors or even shutdowns can be caused by dirt, lint, fingerprints, loose oxide, and tape base chips that collect on the tape. Regular preventive maintenance service, operation under controlled environmental conditions, frequent room cleaning, and dust prevention all improve tape performance and extend tape life.

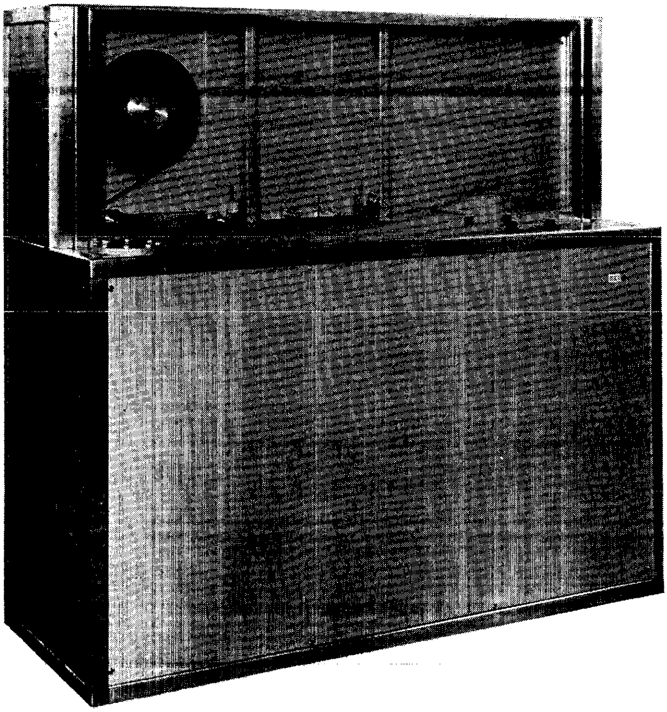


Fig. 6-15. *A magnetic tape cleaner (General Kinetics, Inc.).*

There are a number of suppliers for magnetic tape cleaners. General Kinetics Incorporated's Model CT-2 Kinesonic tape cleaner is shown in Fig. 6-15. This cleaner will remove dust or other foreign particles without affecting the data stored on the tape.

Tape Winding

There are many suppliers of tape winding apparatus. An important asset of off-line tape winding is the attention paid to producing stable tape reels by programming the required winding tension for any combination of tape and reel size. The graphs shown in Fig. 6-16 illustrate winding patterns for constant tension, constant torque, and program tension.

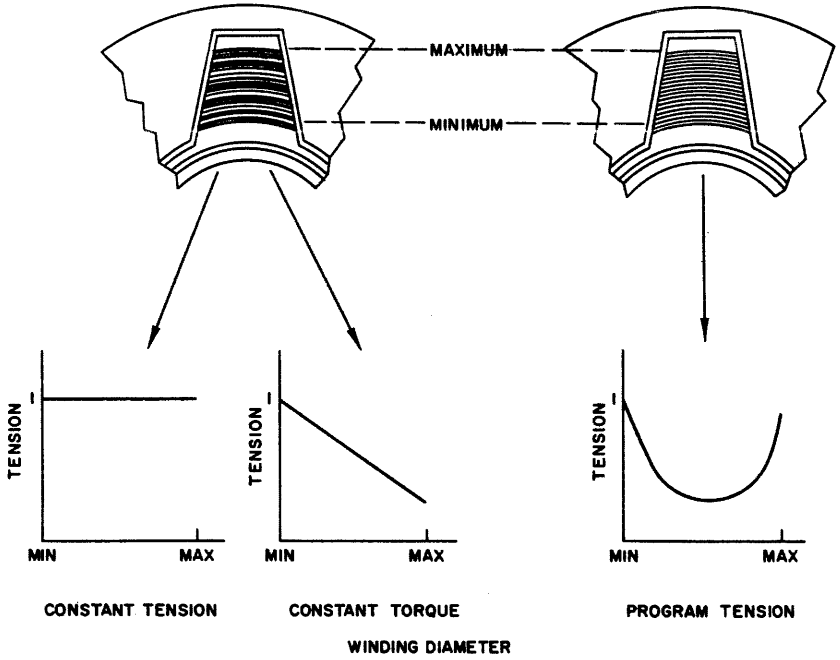


Fig. 6-16. *Tape winding patterns.*

Ordinary winding methods cause the inner portion of the roll to be stored under extreme inward pressures, while the outer portion of the roll enters storage with much lower inward pressures and positive tension. In Fig. 6-17 at a point one quarter to one third of the distance from the hub to the outside diameter, the plastic flow of the inner and outer portions occurs in opposing directions, resulting in the breakup of the pile.

When tape rolls break at the stored-tension transition region, additional problems occur when the rolls are put into service. Even under the best condition, these rolls can cinch and produce folds and abrasions due to a inertial reaction of the loosened outer portion. Such action, of course, will

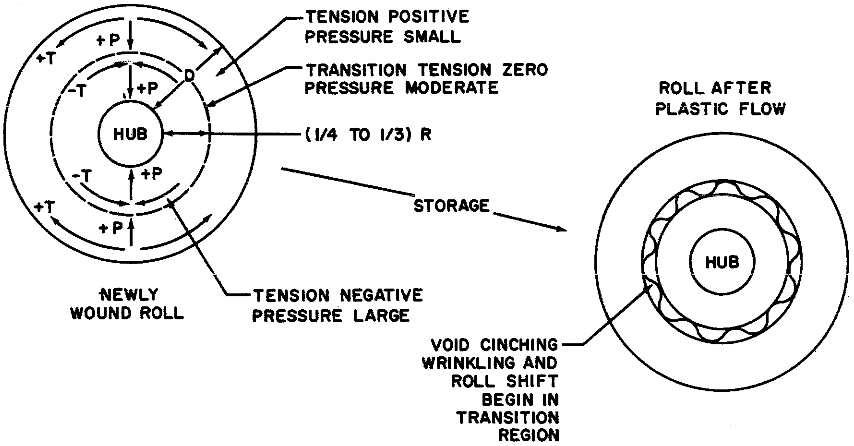


Fig. 6-17. *Constant tension forces acting on a tape roll.*

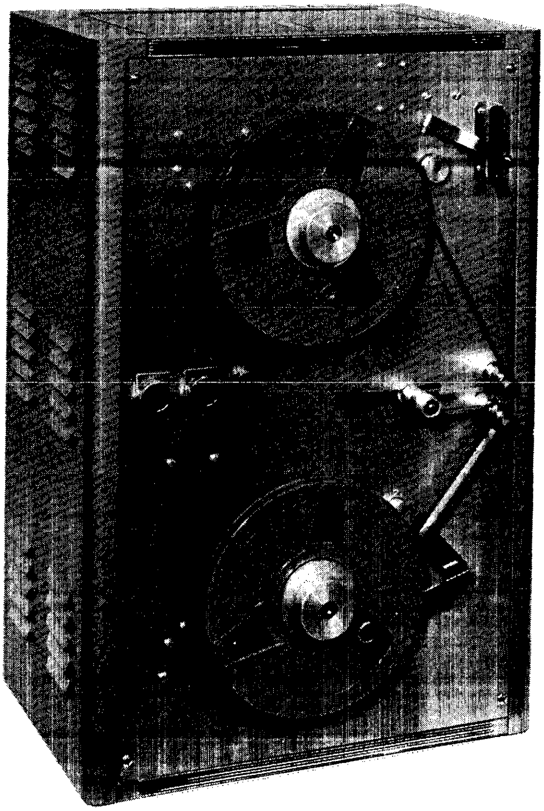


Fig. 6-18. *A programmed tension tape winder (General Kinetics Inc.).*

produce dropouts. In addition, axial slippage of a tape roll, which often occurs spontaneously as the pile is disrupted, produces a skewed length of tape and attendant time displacement errors.

General Kinetics Incorporated's programmed tension winder Model WT-183 (Fig. 6-18) minimizes or eliminates tension transition regions. The winder is basically a tape transport that winds magnetic tapes on standard reels according to a theoretically-derived and experimentally-proven pattern of tape holdback tension. During the winding process, the diameter of the wound reel is measured continuously by a balanced follower arm resting lightly on the tape pile. The instantaneous position of the arm is transmitted mechanically to a cam system that continuously varies the winding tension according to the calculated program. Tape reels, as they come from the winder, are

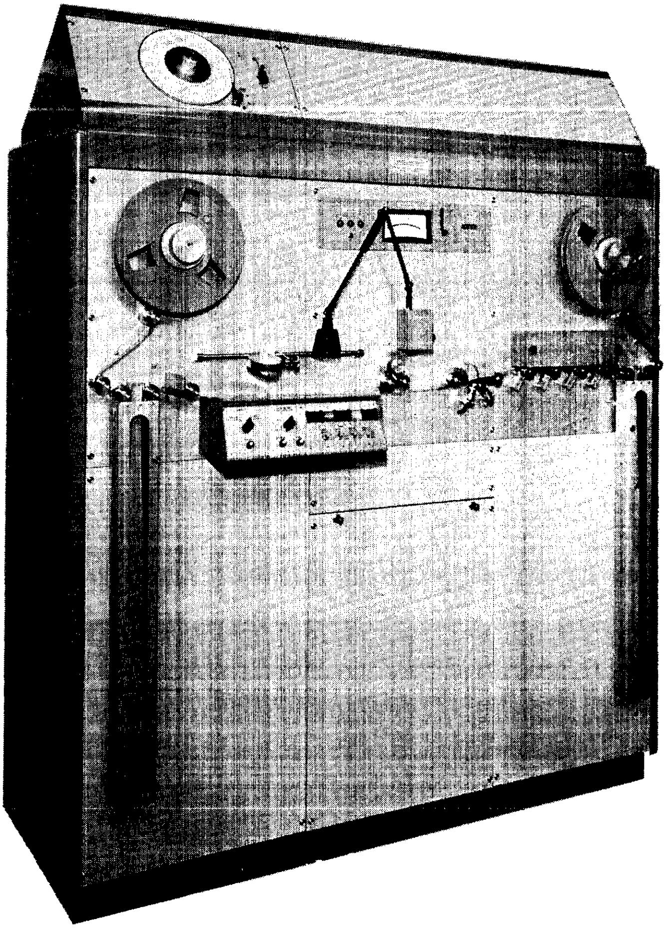


Fig. 6-19. *A tape tester (General Kinetics Inc.).*

smooth, compact, and stable and will remain so for extended periods, even under wide variations of temperature and humidity.

Tape Testing

Every tape manufacturer has a tape testing setup to check tape flaws associated with dropins and dropouts. But most computer manufacturers also have tape testing centers for the express purpose of retesting tape. Digital magnetic tapes are completely checked for dropouts or errors and repairs are made by burnishing or polishing the oxide-coated surface. In some cases, tape flaws remaining after cleaning and conditioning are not removable. Some can be removed with a scalpel or a special polishing material. If this fails, the tape length can be shortened a few percent, salvaging the remaining tape. IBM has found that a customer submitting 100 used tapes for retest would have returned the equivalent of 89 standard-length tapes. Compared to the initial investment of purchasing an equivalent number of new tapes, this service amounts to a saving of 30 percent, according to an analysis of tape salvage statistics by IBM's Retest Service.

Tape testing requires a very complex setup. A thorough cleaning of the tape throughout its entire length is performed prior to tape testing. Exact locations of tape errors are determined and manual or automatic methods are used for remedial purposes. If the tape flaw, such as a loose foreign particle, is corrected or removed, the same area is tested again to guarantee that the tape is perfect.

Figure 6-19 shows the General Kinetics Model 7 Tape Tester, which is designed especially for preventive maintenance of magnetic tape. The tester, in one pass, can determine error-free surface areas and tape defects due to dropouts; time-displacement errors and noise pulses are detected and recorded in ink on a circular graphic chart. The operator may select a mode of operation that will allow the tape to stop at a repair station or the test may run continuously, marking error regions on the tape and visually on the graphic record. At the end of the test run when all error locations are known, the operator decides whether to accept the tape, shorten it, or rewind and stop at each error mark to attempt to make a repair. Thus, tapes are tested and repaired and a permanent record of results can be retained with the tape.

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7

The Organization of Data on Magnetic Tape

The basic tape transport operation, head design, digital coding methods, and magnetic tape performance influence to some degree the minimum requirements in specifying a tape format. The remaining tape format requirements are generally in terms of such system requirements as operation control, instruction coding, transfer operations, and checking features.

Many new words that may appear foreign to the reader will be used in the following paragraphs. Although these words, individually and collectively, may exist in a dictionary, their usage here implies an entirely new meaning or concept. For convenience, these terms are defined in a glossary at the end of this chapter.

Tape Format Fundamentals

Lateral Structure

Data on tape is stored in rectangular magnetic zones called cells. The width of each cell across the tape and the spacing of adjacent cells are determined, to a major extent, by the physical dimensions of the magnetic head. Generally, mechanical construction, shielding, interchannel crosstalk, power capacity of the head core material, coil winding space, and insulation coating have required cell compactness to be in the range of one sixteenth of an inch per magnetic head. (No doubt special heads are built.with smaller width dimensions.)

The accepted standard of ½- and 1-inch tape widths results in 7 or 8 tracks per ½-inch tape and 14 or 16 tracks per 1-inch tape. The total number of tracks across the tape is limited by density requirements and reel tape weight. High-density recording limits the total amount of skew permitted. This limits either the tape width or total recording tracks to a specified intertrack time displacement that is the total skew of mechanical and electrical time delays. Tape weight for a fixed reel length is a function of tape width. When tape widths are greater than ½ inch, programming restrictions, such as start-stop time, are increased by the tape transport manufacturer and poorer tape utilization results.

Reliability and performance of high-speed recording are improved by the use of narrow tapes. One-half inch and one-inch tapes that permit 8 and 16 parallel tracks have been found to be a good compromise of operation and information storage capacity. The cell width and space factor for 7 and 8 track parallel recording are shown in Fig. 7-1.

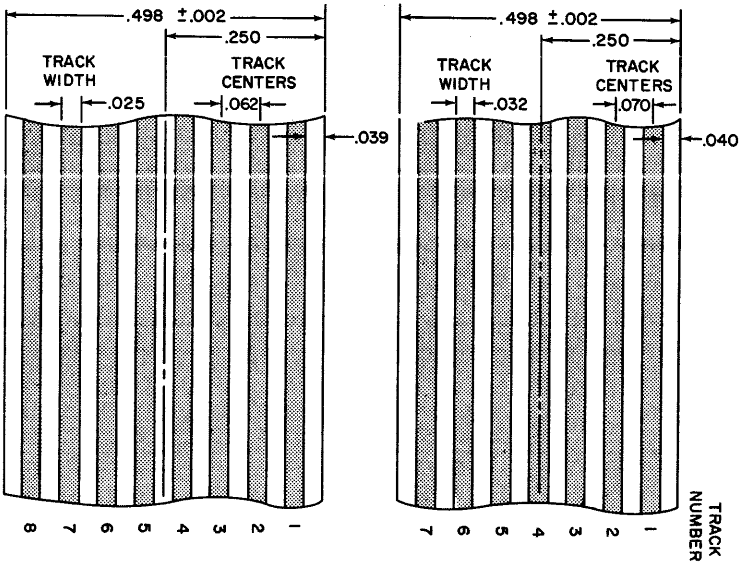

Fig. 7-1. *7 and 8 standard track configuration.*

Longitudinal Structure

The cell length is limited to the resolving power capability of the magnetic system of recording. Earlier, the resolving power was presented in dimensions of gap length, gap scatter, and head azimuth alignment. All these factors present a limitation, but not a major one. Tape surface smoothness, edge tolerance, particle size, dimensional stability, and tape quality in general are a hindrance to achieving the full potential of magnetic recording. Greater mechanical precision in heads and guide systems with logical electronic operations has reduced the cell length dimensions to .001 inch (1000 bits to the inch). As soon as tape quality improves, mechanical precision will be the most severe limitation. The longitudinal structure of a single track of digital recording is shown in Fig. 7-2.

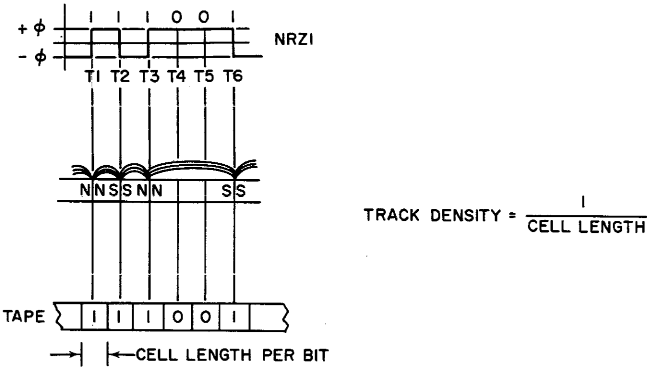

Fig. 7-2. *Longitudinal data structure on tape.*

Tape Markers

Two essential markers for control purposes are the beginning of tape (BOT) and the end of tape (EOT) identification signals. Tape must be prepared to identify each end. Many tape manufacturers prefer to perform this service to ensure prevention of tape damage. If the tape does not come with markers, they may be manually applied. The mechanization of tape markers is fairly well accepted, although variations exist in the particular location of the marker in conformity with the tape transport. Markers are physically attached to the tape to ensure against loss of information and prevent tape breakage and must be compatible with the tape transport tape handling mechanism. The markers are used to activate tape stoppage in sufficient time. In some cases they perform a control function. The EOT signal may automatically start another tape transport or rewind automatically, with the BOT signal stopping the tape and releasing the tape transport from remote control.

Generally, vaporized aluminum or any other good electrical conductor with reflective properties may serve as a tape marker. The markers are attached to the base (uncoated) side and placed parallel to the tape edge. One marker is located on one edge for one tape end and another is located on the other edge for the other tape end, and each is designated properly to signify the BOT and EOT locations.

Optical and electrical methods are used to sense the presence of the tape markers. A typical configuration for the optical method is shown in Fig. 7-3. Each photocell output is mechanized to indicate the tape reel status (beginning or end). Since the optical sensors are already available, an additional lamp and mirror are used to sense tape breakage. Signal output from both cells indicates that the tape is broken.

The same tape markers may be sensed in another manner; an insulated sensing post is required (Fig. 7-4). The sense post has three conductive rings

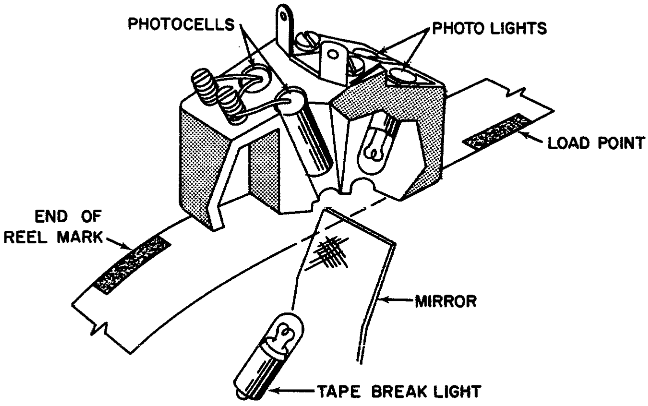

Fig. 7-3. *Sensing tape markers by optical means.*

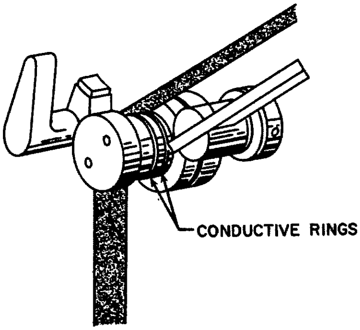

Fig. 7-4. *Sensing tape markers by electronic means.*

that are insulated from each other. All three rings are used to perform the same system function as the optical method. The inner ring is normally at ground and serves as a common return for either circuit. The tape marker completes the circuit to ground to identify the proper tape end. This arrangement can use two separate posts of only two insulated rings to perform the same operation. However, the capability of recognizing tape breakage is not present. This function can be accomplished by optical means or by loss of tension sensed by the tape reservoir (tape take-up arms). The tape markers are essential in that they are specified in the initial purchase of the tape or become a part of the tape format. By no means are tape markers standardized on any tape reel. They are a necessary requirement and vary with every computer installation and every digital magnetic tape system.

Generally the BOT marker serves as a reference point to load the tape. Data is written on tape after the reflective spot has passed the head. With the tape moving in the forward direction toward the take-up reel, a write delay is initiated to ensure that the tape marker has passed the write head. From the rewind direction, the tape is stopped leaving a sufficient tape length for starting and reading the first written data. The location of the start of data with respect to the BOT marker is somewhat critical.

The requirement for the EOT marker is not critical. Here the signal output is used to forewarn the approach of the end of tape. Sufficient tape length exists to complete the longest anticipated data to be written. As a rule, if the tape format contains a code for an end of message, it is written just after the data has been completed.

Information Representation

With each new form of data processing, a coding system adapted to its needs and modified somewhat in accordance with its external environment is required. For example, a specialized system of digital coding has been evolved for each of the punched-card business machines of IBM, Sperry-Rand, etc. Because of the universality of their application, these specialized codes have become fairly standardized and widely recognized.

In Chapter 5 the coding methods to represent 1's and 0's for a two-state storage medium such as tape were discussed. The coding of information, although restricted to 1's and 0's and limited to the number of recording channels, permits a variety of ways to represent information. Two different computers very seldom use the same code, let alone the same format arrangement on tape. Within the computer complex, itself, different information-bearing codes are used. We most often use the decimal system of number representation, the tape is compatible with a two-state numbering method, and the computer has a language of its own. Since each component has its own language it is necessary to seek a common denominator to communicate among all three. Obviously, compromises are to be expected. At present, no solution has been offered as a standard that is approved by all interested parties, so three basic numbering systems are used, each with a number of variations. (It is not our purpose here to detail number theory of representation. It is impossible to expect an individual to be fully acquainted with every computer code. A basic understanding of coding principles is sufficient to comprehend and appreciate the problem.)

Number Notation

Man's written language is comprised of numbers, letter symbols, ideographic symbols, marks, and other notations. This language is represented on magnetic tape in the form of digits and an ordered code is sufficient to store and retrieve this type of information. Generally, the digital magnetic tape system is responsive to its control unit. As stated earlier, the minimum requirements of a tape format are determined by the recording method while the information content and coding are determined by the control unit (remote or local).

Additive and Positional Notation

A good numbering system requires a minimal variety of symbols and column positions to code any information. Two of the fundamental numbering methods are the additive and the positional. The Roman symbols are representative of an additive system:

Symbol	I	V	X	L	C	D	M	X	C	M
Number	1	5	10	50	100	500	1,000	10,000	100,000	1,000,000

It is fairly easy to perform simple arithmetic operations in the additive systems. For multiplication and division, however, the great variety of symbols required considerably complicates operations.

A number in a positional system is expressed as:

$$A_N \; A_{N-1} \; A_{N-2} \ldots A_1 A_0$$

and is evaluated by the following means:

$$N = A_N B^N + A_{N-1} \, B^{N-1} + A_{N-2} \, B^{N-2} + \ldots + A_1 \, B^1 + A_0 \, B^0$$

where B represents the base or radix and A is any of the digits used with that base (A equals 0, 1, . . ., B−2, B−1, but not B). If the base is 10, then A may be any of the ten digits from 0 to 9 and the weight of each column is ten times the weight of the column to its right. If the base is binary (2), then A is 0 or 1 and the weight of each column is two times the weight of the column to its right.

The radix point may be located anywhere without affecting the column weight rules. The general method of calling attention to radix location is as follows: the base power is zero to the left of the radix point and a minus 1 to the right; the column weight rules are still in force.

Whole number: $A_1 \; A_0$

$$N = A_N \; B^N + \ldots + A_1 \; B^1 + A_0 \; B^0$$

Whole number and fraction: $A_1 \; A^0 \bullet A_{-1} \; A_{-2}$

$$N = A_N \; B^N + \ldots + A_1 \; B^1 + A_0 \; B^0 + A_{-1} \; B^{-1} + A_{-2} \; B^{-2}$$

Fraction only: $.\; A_{-1} \; A_{-2} + \ldots + A_{-N}$

$$N = A_{-1} \; B^{-1} + A_{-2} \; B^{-2} + \ldots + A_{-N} \; B^{-N}$$

The substitution of 1 for B in the whole number equation above yields a system with base 1, the unitary system. In this system, numbers are represented by the amounts of 1 digits recorded. Without the digit 0, however, there is no way of indicating position for arithmetical operations. As this system is useful, a few modifications of it will be described.

A biquinary representation uses a unitary-coded decimal system. In this system, shown in Table 7-1, 7 bits with weight 5, 0, 4, 3, 2, 1, 0 are used for each decimal character and are combined in two groups: one group of 2 bits and one of 5 (hence *biquinary*). The first group (under *Bi* in Table 7-1) indicates when the digit is equal to or greater than 5 by having a 1 in the more significant place, and less than 5 by having a 1 in the other place. The

TABLE 7-1. Biquinary Representation

Decimal	Bi	Quinary
0	01	00001
1	01	00010
2	01	00100
3	01	01000
4	01	10000
5	10	00001
6	10	00010
7	10	00100
8	10	01000
9	10	10000

second group shows the digit by the position of the 1 in the five possible locations. This arrangement has self-checking features that are desirable in transferring or executing operations.

The unitary system is used in punch-card machines. The IBM punch card requires a wide variety of symbols in addition to digits 0 to 9. The card has 80 columns and 10 rows (0–9) called the sector area plus two more rows (X, Y) called the zone area. Numerals are recorded by a single punch in one of the digit positions. For the alphabet the columns are double-punched, one hole in the zone area, and the other in the sector area.

The unitary is the simplest numbering system in use. Its rotation is restricted to the presence or absence of a mark (one). The storage of 1 signifies the presence of data or the initiation of an operation. The absence of a 1 is ignored and nothing is done.

Positional coding has a weight value associated with each column (position) and those weight values are ordered. The number notation is formed according to a specific rule. If the rule is known, you can find the weight value for any position in any system. Any number may be written to any base and interpreted as a decimal number. The accepted method of base designation is indicated in the following subscription notation.

1010_{10} (Base 10): $1 \times 10^3 + 0 \times 10^2 + 1 \times 10^1 + 0 \times 10^0 = 1010$
1010_8 (Base 8): $1 \times 8^3 + 0 \times 8^2 + 1 \times 8^1 + 0 \times 8^0 = 520$
1010_2 (Base 2): $1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 0 \times 2^0 = 10$

Any number may be written in terms of another base notation.

Binary Coded Decimal (BCD) and Binary Coded Octal (BCO)

The Binary Coded Decimal (BCD) notation is a method of expressing decimal numbers in binary form (0's and 1's), but not according to the numbering rules just presented. BCD is not a numbering system, it is a form or method of representing a decimal number in arbitrarily weighted codes. The biquinary notation is a form of BCD. A binary coded decimal can be expressed in any binary sequence of any length. Rather than list a portion of such codes, the regularly weighted code of 8421 will be used.

TABLE 7-2. Binary Coded Decimal System

Decimal Digit		*Binary Coded Decimal Digits*			
	WEIGHT	8	4	2	1
0		0	0	0	0
1		0	0	0	1
2		0	0	1	0
3		0	0	1	1
4		0	1	0	0
5		0	1	0	1
6		0	1	1	0
7		0	1	1	1
8		1	0	0	0
9		1	0	0	1
SUPERFLUOUS CODES		1	0	1	0
		1	0	1	1
		1	1	0	0
		1	1	0	1
		1	1	1	0
		1	1	1	1

To accommodate decimal notation in terms of two-state devices, a four-bit code in binary notation provides a simple arrangement, although not necessarily the best. If the decimal number has several digits, the following BCD method is used.

Decimal	5	1	1_{10}	5	1	2_{10}	
BCD	0101	0001	0001	0101	0001	0010	
Binary	111	111	111_2	1	000	000	000_2
Octal	7	7	7_8	1	0	0	0_8

The octal notation is shown to illustrate its derivation from the binary notation. The octal notation can easily be converted into binary, and it reduces the lengthy sequence of numbers. The merit of binary coded octal is illustrated in Table 7-3. Only three bits are required per coded digit and no superfluous codes exist. The octal code possesses all the technical advantages of binary notation, plus the advantage of writing in binary notation with a minimum of digits. A serious disadvantage of the octal method is that a readout will not be in decimal number or notation. Although it appears that octal coding has many serious limitations and would rarely be used, this code is often used as a shorthand notation in designing digital equipment. Programmers find it an aid in writing their computer programs, while some display readouts use octal numbers to reduce equipment costs.

TABLE 7-3. Binary Coded Octal System

Octal Digit		*Binary Coded Octal Digit*		
	WEIGHT	4	2	1
0		0	0	0
1		0	0	1
2		0	1	0
3		0	1	1
4		1	0	0
5		1	0	1
6		1	1	0
7		1	1	1

Alphanumeric (Character Code)

Although digits are used to construct a number, they can be used in a code to represent any symbol or mark. Therefore, if numbers requiring 10 different symbols and the alphabet (26 symbols) are to be represented, a minimum binary code for the 36 different symbols would be a six-bit code:

$$2^6 = 64 \text{ unambiguous codes}$$

The 28 superflous codes ($64 - 36 = 28$) are used for other symbols.

The cross index of alphanumeric characters and binary representation has not been standardized. As shown with BCD conversion, a simple matrix arrangement can be constructed to convert various binary combinations into alphanumeric characters. Weighted coding becomes meaningless. Note that some of the binary codes represent any symbol (letter or number); no rules are available that permit the decoding of this arrangement without using a conversion chart. Part of RCA's 301 alphanumeric code is shown in Table 7-4.

At this point, it is sufficient to know that alphanumeric coding is used to communicate between man and machine. In fact, all communications between man and machine, whether numbers, letters, symbols, instructions, or special symbols, are accomplished in this manner. No alphanumeric system exists that would exhaust a digital representation of it.

Layout of Information

In previous sections, it was tacitly assumed that the written information would be read correctly and that no major restrictions existed. Actually, this is not so. Magnetic coding requires some method of obtaining sampling pulses for the readback operation. Error-free tape is nonexistent in the true sense of the word. Therefore, a clocking or sampling pulse must be present on a tape track or its equivalent must be derived to supply the necessary control to reject errors or false information.

TABLE 7-4. The RCA 301 Code

Character Description	Printed Symbol	MACHINE CODE							TAPE CODE							CARD CODE											
		P	ZONE		NUMERIC				P	ZONE		NUMERIC				PUNCHED ROWS											
		2^6	2^5	2^4	2^3	2^2	2^1	2^0	2^6	2^5	2^4	2^3	2^2	2^1	2^0	Y	X	0	1	2	3	4	5	6	7	8	9
Zero	0	1	0	0	0	0	0	0	0	1	1	1	1	1	1			1									
One	1	0	0	0	0	0	0	1	1	1	1	1	1	1	0				1								
Two	2	0	0	0	0	0	1	0	1	1	1	1	1	0	1					1							
Three	3	1	0	0	0	0	1	1	0	1	1	1	1	0	0						1						
Four	4	0	0	0	0	1	0	0	1	1	1	1	0	1	1							1					
Five	5	1	0	0	0	1	0	1	0	1	1	1	0	1	0								1				
Six	6	1	0	0	0	1	1	0	0	1	1	1	0	0	1									1			
Seven	7	0	0	0	0	1	1	1	1	1	1	1	0	0	0										1		
Eight	8	0	0	0	1	0	0	0	1	1	1	0	1	1	1											1	
Nine	9	1	0	0	1	0	0	1	0	1	1	0	1	1	0												1
Space		1	0	0	1	0	1	0	0	1	1	0	1	0	1												
Number	#	0	0	0	1	0	1	1	1	1	1	0	1	0	0						1					1	
At the rate of	@	1	0	0	1	1	0	0	0	1	1	0	0	1	1							1				1	
Open Parenthesis	(	0	0	0	1	1	0	1	1	1	1	0	0	1	0								1			1	
Close Parenthesis	)	0	0	0	1	1	1	0	1	1	1	0	0	0	1									1		1	
		1	0	0	1	1	1	1	0	1	1	0	0	0	0	Not Used											
Ampersand	&	0	0	1	0	0	0	0	1	1	0	1	1	1	1	1											
A	A	1	0	1	0	0	0	1	0	1	0	1	1	1	0	1			1								
B	B	1	0	1	0	0	1	0	0	1	0	1	1	0	1	1				1							
C	C	0	0	1	0	0	1	1	1	1	0	1	1	0	0	1					1						
D	D	1	0	1	0	1	0	0	0	1	0	1	0	1	1	1						1					
E	E	0	0	1	0	1	0	1	1	1	0	1	0	1	0	1							1				
F	F	0	0	1	0	1	1	0	1	1	0	1	0	0	1	1								1			
G	G	1	0	1	0	1	1	1	0	1	0	1	0	0	0	1									1		
H	H	1	0	1	1	0	0	0	0	1	0	0	1	1	1	1										1	
I	I	0	0	1	1	0	0	1	1	1	0	0	1	1	0	1											1
Plus	+	0	0	1	1	0	1	0	1	1	0	0	1	0	1	1				1						1	
Period	.	1	0	1	1	0	1	1	0	1	0	0	1	0	0	1					1					1	
Semicolon	;	0	0	1	1	1	0	0	1	1	0	0	0	1	1	1						1				1	
Colon	:	1	0	1	1	1	0	1	0	1	0	0	0	1	0	1							1			1	
Apostrophe	'	1	0	1	1	1	1	0	0	1	0	0	0	0	1	1								1		1	
		0	0	1	1	1	1	1	1	1	0	0	0	0	0	Not Used											

Timing Track

Magnetic tape coding methods described earlier not only permit high-density capabilities but also provide self-clocking and self-checking features. One technique of ensuring correct spatial placement of information on tape is the use of a clock track. A clock pulse gates the information into the proper cell locations and is simultaneously written (Fig. 7-5). A similar procedure is followed during the reading process. The clock pulses, which

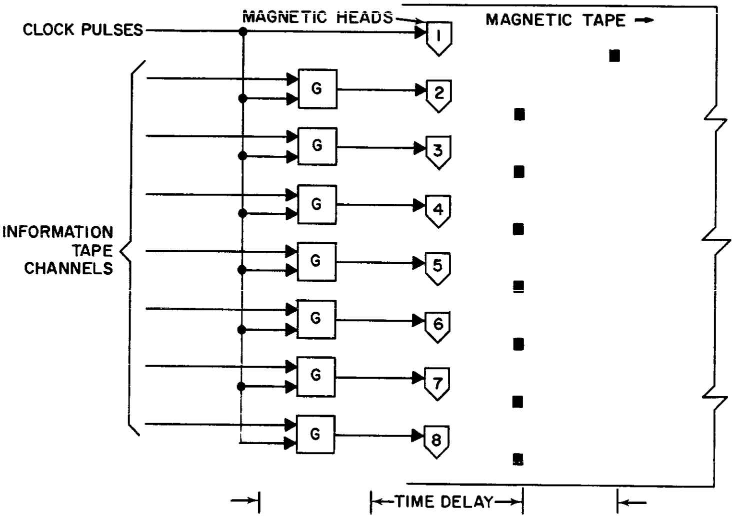

Fig. 7-5. *Gating logic to write a clock track.*

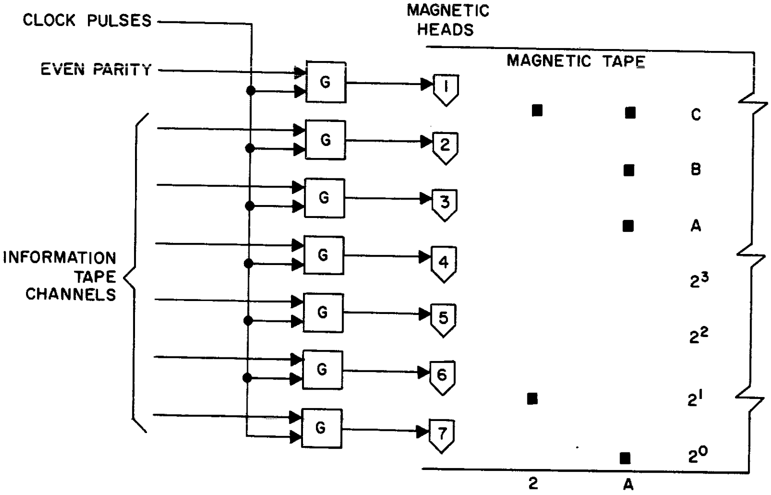

Fig. 7-6. *One 1 in BCD and alphanumeric codes.*

were initially written on tape with fewer circuit delays, are slightly in advance of the written information. If no degradation occurs, the read information is preceded by the clock pulse that performs the control operation.

Another method of obtaining clock pulses without using a separate track is superfluous coding. As shown earlier, the 4-bit BCD and 6-bit alphanumeric codings have sufficient surplus codes to ensure at least one 1 for each symbol (number or letter). Therefore, any symbol written in binary form must have a 1 in its code. This is shown in Fig. 7-6, in which a 4-bit BCD and a 6-bit alphanumeric code are used. A simple OR circuit is used to construct a clock pulse. The first 1 to arrive is used as the clock pulse and the cell length is sufficiently long to include all the information of one tape line (simultaneous output of all tape tracks). This procedure is adequate in obtaining a derived pulse train for control purposes.

Parity Checking

A problem arises when compact coding is required, surplus codes are not available, and the sequence of 1's and 0's is random. In this case, an additional track is necessary for the express purpose of obtaining a clock track if the magnetic tape coding doesn't supply clock pulses (e.g., NRZ). One way of solving this is to combine the pulse train generation and error detection. This method is called *parity*. For the case when no 1's are present in a tape line, a 1 is inserted in the additional track. When a 1 is present, there is no need to write a 1 in this additional track. This arrangement permits a method of detecting errors. If a 1 is not present in the coded information, a 1 is written in the additional track. If an even number of 1's is present in the coded information, a 1 is still written in the additional track. This arrangement is called *odd parity*.

Many tape formats make a distinction between a BCD and alphanumeric character coding and a pure number notation (a pure binary code is the binary code of a number based upon positional number coding). Using the same tape channels, 7 being a minimum for numbering and coded characters, an *even parity* method is used. As stated earlier, a coded character by design has one 1 in the code. With even parity, an additional 1 is written in the additional track. Therefore, the pulse train is assured of two pulses per code to create a clock train. These arrangements are illustrated in Fig. 7-7.

Basically, a coded character, such as a number in BCD and letters and numbers in alphanumeric, is adequately accommodated across the width of the tape with 7 or 8 tracks. When a number or symbol exceeds the available tracks across the tape, some procedure of digit disassembly of 1's and 0's is necessary. This type of information will be examined later.

It should be remembered that the double pulsing methods always have at least one flux field transition per cell on a tape track. With this tape coding arrangement, each track has a self clock to synchronize and indicate each magnetized spot independently of the other parallel tracks. This autonomous synchronization is used very effectively in high density recording in de-skew buffers.

TOTAL BITS PER COLUMN		2	2	2	2	2	
CHECK BITS			■		■	■	7
							6
							5
8							4
4	■	■	■				3
2	■			■	■		2
1		■		■		■	1
BCD	6	5	4	3	2	1	

TOTAL BITS PER COLUMN	4	4	4	4	4	
C		■		■	■	7
B	■	■	■	■	■	6
A	■	■	■	■	■	5
8						4
4	■	■				3
2			■		■	2
1	■		■	■		1
ALPHANUMERIC	E	D	C	B	A	

TOTAL BITS PER COLUMN	3	3	3	3	
	■	■		■	7
	■			■	6
					5
					4
	■	■	■		3
			■		2
		■	■	■	1
RANDOM DIGITS					

Fig. 7-7. *Even and odd parity.*

Tape Word

Just as an English word is composed of letters, a tape word is composed of 1's and 0's. Tape word and tape line are used synonymously here. A tape word is a fixed length determined by the maximum parallel readout across the width of the tape. Up to this point, a tape word has been considered as having 7 or 8 bits. This bit length can be increased by using more tracks across a wider tape or it can be defined in another manner by the tape user.

The need for a 6-level coding to accommodate an alphanumeric character has been established. The seventh track (Fig. 7-8A) serves a dual purpose of timing and parity. The IBM format of 7 channels does not contain a clock track, but one is created during readback (lateral odd parity) for binary tapes.

The 8-track format (Fig. 7-8B) has 6 tracks for information and one parity track, as before. The eighth track is used for timing. This arrangement permits the grouping of 7 adjacent channels to generate a timing signal (as a check and standby) while the eighth track is primarily a timing signal. The 7

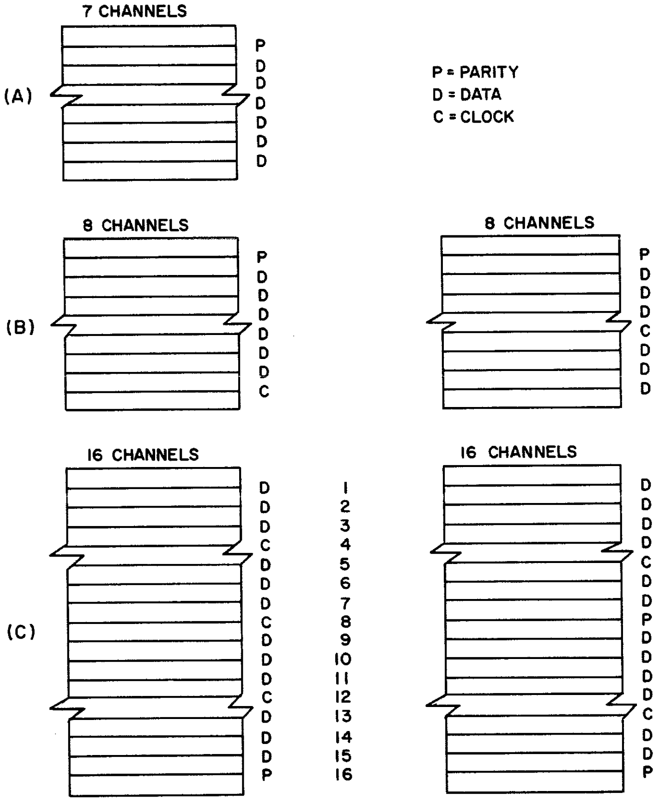

Fig. 7-8. *7,- 8- and 16-channel tape formats.*

channels are initially aligned with the clock signal from the eighth track. A timing track (whether in the tape center or edge) makes the readback operation independent of tape speed. A clock track simplifies the NRZ recording of information in binary form. If the magnetic tape edges become worn or present a problem, it is conceivable that the data can be retrieved with the timing and the parity tracks as the two outermost tracks.

Generally, analog data is handled in digital form. The conversion equipment supplies the data in 12-bit word lengths. This type of word is easily handled as two tape words or as a single word by increasing the number of lateral tracks.

Another format arrangement worth consideration is a one-inch, 16-channel tape. With this arrangement, there is only one parity channel, the 16th channel, and three clock tracks are used (Fig. 7-8C). The three clock tracks are located in positions 4, 8, and 12. Since the bits in a tape line must be accurately aligned in time before the information can be decoded, alignment procedures are accomplished in two steps. During preliminary alignment, data from tracks 1, 2, 3, 5, 6, and 7 are aligned with a clock signal from track

4. In a similar manner, data from tracks 9, 10, 11, 13, 14, and 15 are aligned with a clock signal from track 12. During secondary alignment the two groups are aligned with a clock signal from track 8. (Parity is aligned with clock track 12.) This method of alignment allows any error that is proportional to distance across the tape to be nearly twice as great as would be allowable without the preliminary alignment.

Computer Word

There are two factors to be considered in deciding the word length of a computer. The first is the instruction-word structure. The instruction word must provide, at a minimum, room for memory address, order code, and index register selection, if one is present. The second factor that determines the word length is the data or information. The size of a computer word may be fixed or variable. When the word length is fixed, the computer is said to be a fixed word-length computer and when it is variable, the computer is said to be a variable word-length computer. Both machines are in use and tape formats accomodate both. Each method has merit; the fixed word-length arrangement is simple, while high speed and better tape utilization are associated with variable-length methods.

Regardless of computer word length, the number of digits generally exceeds 6 bits. Therefore the recording of a computer word always involves the disassembly of the machine word into tape words for writing on tape and the reverse procedure of bit assembly when the tape storage is called upon to supply the data.

Block Length

It is desirable to utilize the tape in the most efficient manner with continuous data from the beginning to the end of a tape reel. The alternative would be the insertion of a space for stopping from full speed and reaching full speed again (start-stop distance). The frequency and purpose of such gaps, however, are somewhat of a problem.

The computer dispatches data in various block lengths determined by its requirements. Magnetic tape operations require large blocks of continuous data for efficient tape utilization and minimum reel changing operations. For speed and computer economy, many computer systems operate peripheral equipment such as a page printer (120 column), data communication links, plotting boards, numerical control machines, newspaper type-setting machines, and many other devices via a tape station. One thing which all such devices have in common is that they are slow in data acceptance of tape data delivery. A speed converter in the form of buffer storage is necessary to mate two different speed devices. If the data blocks on tape are large, the buffer storage is correspondingly large, costly, and complex.

The block length is determined by the needs of the complete system. A block of data may comprise any fixed or variable length on tape. A customer record in a department store application may contain the customer's name, address, account number, quantity rate, and balance outstanding. For an insurance policy holder, a block of data can be much more extensive. A data acquisition facility such as a radar installation may require an entirely different tape format arrangement to accommodate the data source, system requirements, and equipment arrangement for the highest reliability for real time recording.

For illustrative purposes, a printing format computation is given in Table 7-5. Here, the peripheral equipment is a 120-column, high-speed page printer. The block of data on tape would contain the necessary instructions and control information in addition to one line of printing. One line would require 120 alphanumeric codes for a total of 720 bits (6 × 120). The block length is 120 tape lines plus instructions. A typical format using a 7-channel track is shown in Fig.7-9. The data conveyance from tape to printer using a buffer as an intermediary typifies the type of coding and tape format arrangement.

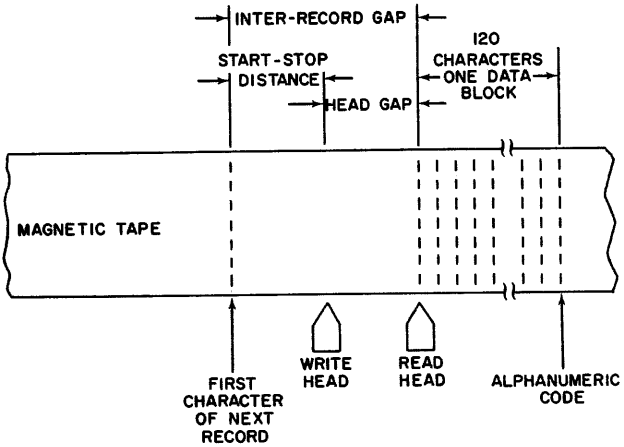

Fig. 7-9. *Tape format for printing.*

In Table 7-5, tape efficiency is computed and shows the earlier arrangement to be more efficient. Actually this is not so. The earlier tape transports used more tape for data but did not use it more efficiently. Present models compress more data per linear inch of tape with a slight reduction in unrecorded tape. Present digital tape systems require a smaller tape length for start-stop operations. The absolute tape length of unrecorded tape per reel is much less with present digital recording systems. Table 7-6 proves that start-stop operations for line-at-a-time print is time consuming and poor tape utilization. This has introduced auxiliary off-line peripheral equipment subsystems where the computer has been relieved of this chore, and the complete printout is transferred to the tape station.

TABLE 7-5. Tape Utilization for a Printing Operation

Assumptions

1. No delays incurred for circuit and mechanical components.
2. Tape acceleration is linear.
3. Two 36-bit instruction words are necessary.
4. Page printer is 120-column printer.

	Early Tape Transport	*Current Tape Transport*
1. Start Time	3 milliseconds	2.0 milliseconds
2. Stop Time	3 milliseconds	1.5 milliseconds
3. Read/Write Gap Distance	0.5 inch	0.3 inch
4. Tape Speed	75 ips	150 ips
5. Tape Density	200 bpi	800 bpi
6. Tape Lines	120 + 2 × 6	120 + 2 × 6
7. Start Distance V/2 × t	.1125 inch	.15 inch
8. Stop Distance V/2 × t	.1125 inch	.1125 inch
9. Data Length Tape Lines/Tape Density	0.66 inch	0.165 inch
10. Block Tape Length Start/Stop Distance + Gap Length + Data Length	1.385 inch	0.7275 inch
11. Tape Utilization Efficiency (%) Data Length/Block Length	48	22.7
12. Interblock Length Efficiency (%) Unused Tape/Block Length	52	77

Word Format Structure

So far, the reference units used have been in progressive order from a character to a computer word to a data block. Many systems for recording information and processing time that have high storage requirements find these tape format units inadequate. A unit sequence of increasing order is illustrated below:

n bits	*n* characters	*n* words	*n* blocks	*n* records
make a	make a	make a	make a	make a
CHARACTER	*WORD*	*BLOCK*	*RECORD*	*FILE*

This sequence is arbitrary; the method of assigning values to *n* for each rank is complex and determined by a multiplicity of requirements. Since fixed word lengths have been mentioned, each rank generally is fixed by the equipment specification. Once this is done, it is difficult to alter the initial values of *n*. This rigidity is not objectionable. The simplification of hardware and programming gained by establishing fixed magnitudes for *n* more than compensates for it.

Control and Edit Information

Tape Code

It is essential that the beginning of data be recognized to initiate a reading operation. Either a start message symbol or the first clock pulse after an unrecorded tape length serves as the beginning of the reading process. Obviously, an unambiguous code ensures the detection of the beginning of a data block and prevents any false starts. A start message symbol serves a dual purpose. In addition to recognizing the beginning of data, all the 1's are used to line up the tape and head for a minimum of skew. If all 1's are followed by 0's, the dynamic pulse response of writing and reading can be evaluated.

Likewise, in continuous data recording, special codes for identification are necessary to fully process the written data. During the writing process, control is supplied locally or remotely. After this, the reading process must supply all the control information as well as the data. Besides the data and timing, instructions are obtained during the reading process from the tape to reconstruct fully the data and properly distribute it.

The tape system normally handles data in a fixed manner, by design. In this way, fixed routines and fixed counting operations simplify the reading process. Generally, the start pulse or sync clears and initiates the beginning of a reading process. The reading process is a simple fixed built-in program to reconstruct the data. Any deviation must be initially written or implied in order to be interpreted properly during a reading process. When data on tape are not restricted to fixed character, word, or data block lengths, as much information as is needed can be included in a compact form.

A block of data or blocks of data can be separated on tape by a fixed length of unused tape. The data block is fixed and can be repeated continuously without interruption. An unused tape length indicates an interruption of data that designates the termination of a series of continuous data blocks and permits the stoppage of tape on an unused portion. Here, any wastage of data space is the "fill" inserted to complete the last data block. If a fixed record length is used, then the "fill" (or dummy blocks) can be more than one data block. There are cases where the word or the characters that comprise a word are variable, adding considerable complexity to a data block. It becomes difficult to determine if the variable length of continuous data is due to record, block, or word length, since the smallest tape unit is a single tape line.

Tape Records

The versatility of any tape system is measured by its ability to process any number of variables in any form and any sequence, efficiently identifying, controlling, and distributing data. The tape system must work optimally with the following operating conditions: (1) random and synchronized inputs; (2) variable word length and nonstandard groupings; (3) serial-parallel and multiplex operation; (4) coding, word structure, and format assembly; and (5) fixed versus changeable control.

Variable word length and nonstandard grouping (variable block lengths) are interdependent and are of major concern in a tape recording system. The variable word length and variable block length, along with controls that recognize and execute the necessary operations, should maintain uniformity during a merging, sorting, or collating process.

A radar data tape format is shown in Fig. 7-10. This radar system is very complex, embodying many principles generally not found in the normal business and scientific applications of digital tape recording systems.

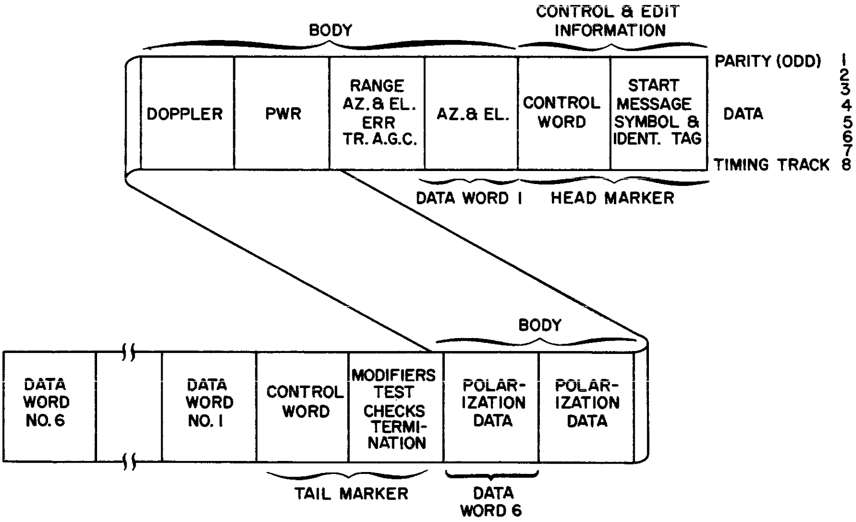

Fig. 7-10. *Radar data tape format.*

Variably-Sized Records

Variably-sized records have a definite place in data processing. Their use is limited by their disadvantages, but their advantages more than compensate for these disadvantages when they are properly used. The system designer and the programmer must use discretion in employing this valuable tool. No doubt some programs have already been developed for the manipulation of variably-sized records, while other programs are under development or contemplated for high-speed data processing.

Variably-sized records are a means by which information can be stored in time occurrence and yet be processed efficiently and economically. The headers and other additional information that make up the variably-sized record eliminate the wasteful fill caused by former machine limitations. Variably-sized items, permit less storage space, less cost, and easy expansion.

Variably-sized record layouts should be made with care. A balance of factors must be examined and weighed many times so that the most efficient method is chosen. Programming and hardware considerations are most important and must be included in the format of the record. Only through the proper design and use of variably-sized records can the benefits of greater speed and lower costs be obtained.

Head Markers

There are many methods of coding available for identifying digital data and distributing it within a computer and among its associated terminal equipment. The selection of a code is dictated, to a considerable extent, by the requirements of the system. The method of labeling the variables, from an implementation standpoint, imposes some restrictions and requires a control word or head marker compatible with this identification scheme. The marker defines, in terms of block transfer, the total variables of a sample period and therefore, supplies sufficient information to process the variables on a block basis.

This type of control word permits handling more than one word transfer. The normal computer programs requiring extensive instructions (on a per-word transfer) are eliminated by handling groups of words in nonmathematical operations. During this process, the prime concern is the classification, addressing, and distribution of large quantities of data within the system, whether it be for data processing or computation. The control word description is based on labeling and distribution. No distinction is made between the stage at which the data is being handled and the coding structure of the computer. However, emphasis is placed on moving the data (data handling) within the equipment and keeping track of the process by the location of control registers at effective junction points.

The arrangement of information within a head marker is important. Headers of variably-sized records generally conform to specified procedures entailing field examination and their execution. Fields should be arranged, if possible, with program techniques in mind. Fields should be lined up to facilitate pattern extraction of data.

Tail Markers

The tail marker does not contain data, but, in conjunction with the control words in the header, it carries all of the information needed to describe a particular addition to a basic tape record or data frame. In cases where the amount of information and data occurrence vary widely, the tail marker may be variable in length. The header requirements are applicable to the tail marker. The tail marker must contain designators or codes that describe its use so that it may be found and its size must be noted so that chain operation may be accomplished. Tail markers need not contain information that would duplicate that found in the header, such as keys.

The same considerations of efficient programming methods should be followed in constructing tail markers as were employed in designing headers. The tail marker size and designators should be particularly well placed so that the desired information may be found easily and efficiently.

The format structure and information content (data, and edit and control) illustrated have great possibilities. Exceptions, modifications, and additions (no deletions) in generating a tape record can be handled by this record format system. The no deletion aspect should be emphasized to show that a block of data may be rearranged or additions may be "tacked on."

Coding for Tape Flaws

Before leaving the subject of control during a tape operation, a few less obvious operations should be mentioned. Tape is not flawless. Therefore, some means of control is necessary to ensure that tape imperfections are not present during a writing process. Just as coding is required for an "end of data," a "cancel the last block," and "end of record or file," some method of coding is necessary to prevent the use of poor surface areas on tape. Several methods have been developed to do this. Some tape users punch holes into tape and, by optical means, skip the portions of tape between holes containing one or more defects. This method has been abandoned for obvious reasons. Others have proposed cutting out defective sections and splicing error-free sections to make a new tape roll. This is not practical with high-speed tape systems.

In the initial evaluation of virgin tapes, defects are exposed. When a timing track is used, the writing and reading processes may disclose tape imperfections. When a completely examined tape is supplied, the timing remains to indicate the cell locations of error-free writing. (With no timing track present, sampling pulses are not available for writing; an arrangement that is independent of tape speed.) As the tape is continuously used, additional timing pulses are removed or the tape is reclocked during a testing and cleaning procedure. In this way the clock channel is always present, and writing is made on tape lines indicated by the spatial location of the clock pulses on tape.

Tapes with a few imperfections that are not pinpointed may be used when a dual read/write capability exists and time is available for many checking operations. Consider the procedure for creating a file tape. When a record that has been correctly written is not successfully read on the first attempt, further rereads will probably result in a valid or invalid writing operation.

Therefore, a roll-back program step is initiated and several attempts are made to reread the same tape area. If these subsequent steps read successfully, the programmer may or may not elect to accept this portion of tape. In any event, if a decision is made not to use a specific tape area, a skip instruction is issued and, hopefully, this advances the tape sufficiently beyond the defective area. An erasure operation is then necessary to remove any signal from this skipped area that could create a noise pulse at the read head that would be interpreted as valid data. With a worst-case condition of several imperfect tape lines, the reassembly of tape lines into a computer word would automatically expose this problem and treat this error as a noise record or system noise. The skip tape operation makes possible a blanking section of tape and the relocation of a written record when a defective tape section has been sensed. Again, the outline of the tape defect can be marked by special coding, and an unused tape length prevents any writing over a defective area in the first pass.

In some cases, special operations are incorporated in a tape station facility. In Table 7-4, the tape code is the complement of the machine code. For the RCA 301 operation, the computer may complement prior to readout or in the disassembly of the machine word into tape words.

Checking Systems

It is difficult to decide just how much checking should be built into the tape system. As built-in checking circuits are added, the cost and complexity of the subsystem increases, and system reliability is more difficult to maintain. Magnetic tape is prone to errors in recording or playback from time to time (transient error), but this should not be considered an indication that the system is faulty and requires maintenance.

Parity Coding

A parity check bit can be used with each tape line to verify a valid recording. Each tape line is read and the lateral parity (odd) is checked for any errors. When the errors accumulated over a given time interval exceed an established error rate, the immediate tape station is disqualified and the next tape station (standby) is automatically switched in on the next data group.

A double error is undetectable in some cases. Generally a tape defect can spread and include two adjacent tape tracks. If more lateral tracks are available, one checking track performs a parity check on even rows while the other performs a parity check on odd rows (Fig. 7-11). Other tape users may write the same information twice to increase the reliability of recording, as is done in the RCA 501 tape format (Fig. 7-19).

The lateral parity serves to check one dimension of a tape surface. A longitudinal parity check can be used to verify a valid recording track. Each track is read for longitudinal parity (even) and checked for errors. Lateral and longitudinal parity checking supply the X-Y location of a single bit error for corrective purposes (Fig. 7-12). Again, a double error can go undetected using the above longitudinal parity scheme. A check-sum method will prevent this.

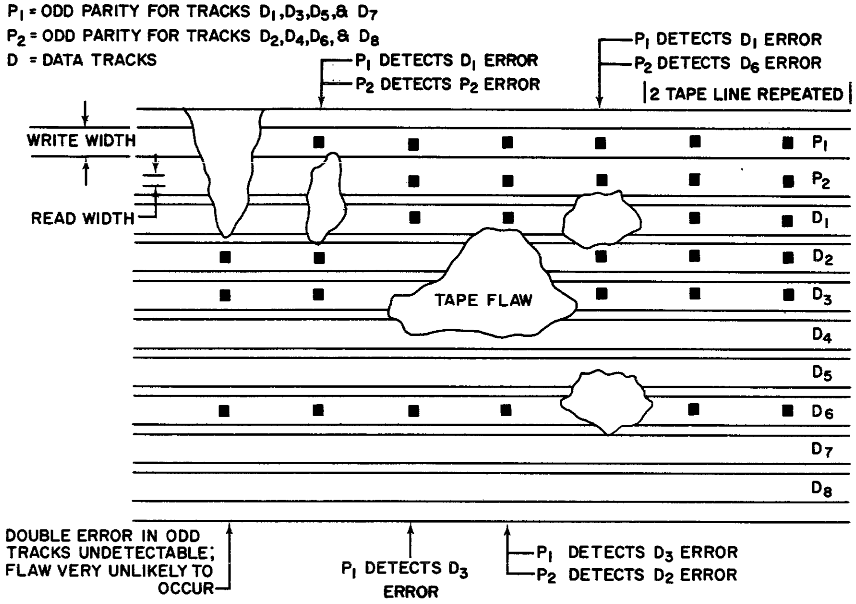

Fig. 7-11. *Odd and even check tracks for parity checking.*

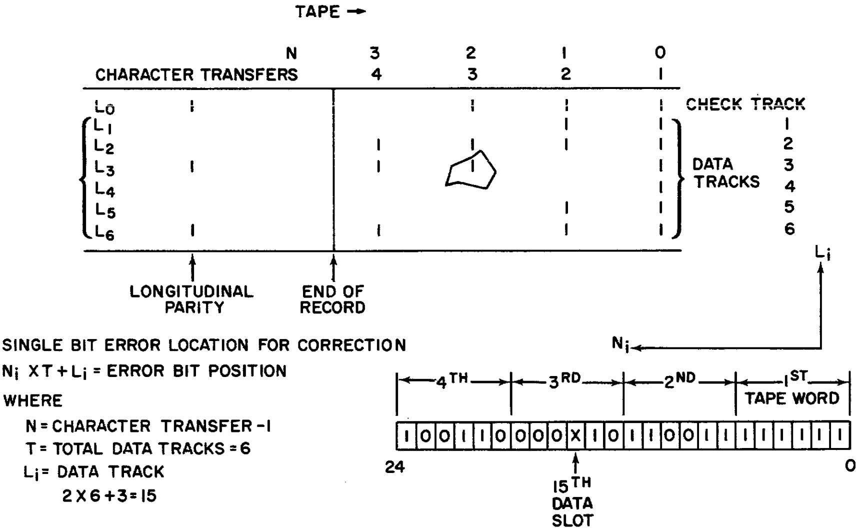

Fig. 7-12. *Lateral and longitudinal parity checking error correction.*

Check Sums

Check sums can be performed at the time of recording and checked during playback. As each tape line is written on tape, it is added in the check-sum tape register. Two errors can cause a compensating error on a parity system, but not on a check-sum tape system. A check-sum can be performed on the word transfer, the positional coding, and the actual number of computer words.

Another form of error, which is not detectable by the check-sum tape system, is error due to distortion of tape, improper tape guidance, or misalignment of heads. This can be checked with a gate that establishes a short interval of time between two consecutive clock pulses. One complete line of data will be present during this gate if the line is properly positioned. If the line is skewed, part of the data will occur outside the gate and will be lost. Thus, the amount of tolerable skew is determined and the gate length set accordingly, after which any excess skew will be detected by a parity check.

Reliability and Built-In Checks

Tape markers, tape breakage, and specific remedial measures for tape surface imperfections were discussed earlier.

A tape verifier operation (writing and concurrent reading) is recommended to summarize the operability of the tape recording station and to assist in the maintenance of this system. It is generally true that if a magnetic tape has been written and read successfully once, subsequent reading operations can be assured.

Finally, the tape format control can insert additional tape lines and record the status of selected operations of the system. This can serve to keep a statistical record of the equipment operation.

A summary of the information given in this section is tabulated in Table 7-6.

TABLE 7-6. Summary of Tape Formats and Information

Description	*Advantages*	*Disadvantages*
1. Data arrangement per sample	Efficient tape utilization; real-time operating conditions.	Requires more time for computer entry (non-real time).
2. Data arrangement per target or per record	Fast entry into the computer.	Poor tape utilization.
3. Intermessage gap per data frame	Real-time operating conditions; simplifies buffering costs; compatible with wide variety of peripheral equipment.	Poor tape utilization; requires more time for computer entry.
4. Intermessage gap per multiple data frame or per multiple blocks	Compatible with computer speed.	Buffering complex and costly.

TABLE 7-6. (Cont.)

Description	*Advantages*	*Disadvantages*
5. ½" tape, 7 channel	Preponderant in the field (IBM); wider tape tracks.	Poor packing density; sensitive to tape speed variations.
6. ½" tape, 8 channel	Good compromise between reliability of narrow tape and storage capability of wide tapes.	Requires non-IBM tape drives.
7. 1" tape, 16 channel (1000 bpi and 150 ips)	Same as item 6. Permits real-time recording.	New in the field; lower start and stop acceleration rates.
8. Write and playback concurrent capability (dual magnetic heads)	Monitoring feature; versatile system.	Determines intermessage gap length; requires additional equipment.
9. Write or playback at one time only (single head)	Less equipment.	Magnetic head is a compromise for both operations.
10. NRZ recording	Self-clocking by coding; insensitive to pulse width and shape; higher information density and operating frequencies than RZ; automatic erasing.	Higher power requirements; sensitive to dropins.
11. RZ recording	Self-clocking; lower power requirements.	Requires better tape quality; sensitive to dropouts.
12. Double pulsing (frequency modulation, phase modulation)	Self-clocking; redundancy. High density recording.	Very complex; stringent tape transport spec; high quality tapes.
13. Fixed data blocks	Simplifies programming; simplifies debugging.	Poor tape utilization; time consuming in data handling.
14. Variable data blocks	Efficient tape utilization; preserves real-time operating conditions.	Sorting is not recommended; not extensively used because comparable programming not available.
15. Alphanumeric and straight binary interchangeable on one tape reel	Good versatility.	Complex data structure and programming.
16. Separate tape reels for each alphanumeric and straight binary data	Simplicity; used extensively in the computer field.	Special-purpose tapes.

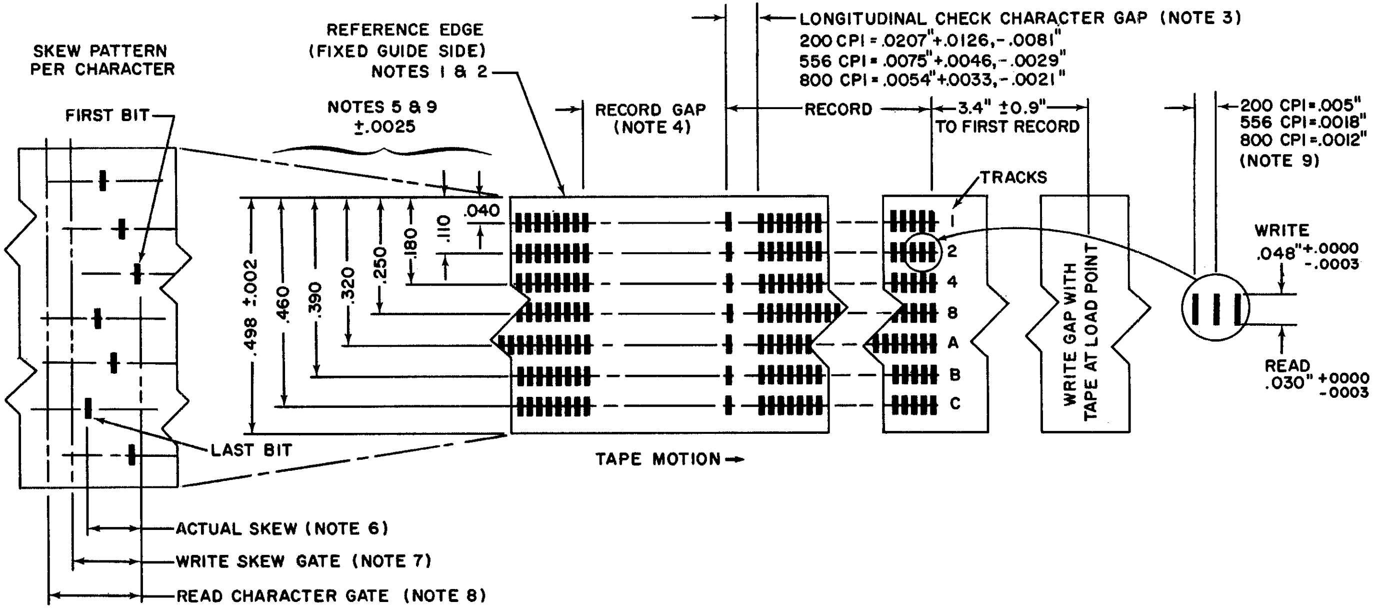

Fig. 7-13. *Typical IBM 7-channel tape format. (See notes on page 199.)*

Computer System Tape Formats

Current tape formats can generally be designed by using or modifying one or more of the existing coding techniques. Logically, some of the tape format structures are repeated in different systems because of the common recording device: magnetic tape recording. Other similarities between tape format structures are due to common control units (computers) and similar applications (communication, data acquisition, file and retrieval systems, printers, etc.).

IBM Tape Formats

Data is grouped on tape in an organized manner to form records. A computer word is disassembled into as many tape words as necessary to completely store the required information. Since digital tape is becoming more

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NOTES:

1. Tape is shown with oxide side up, Read/Write head on same side as oxide.
2. Tape shown representing 1 bits in all tracks, NRZI recording; 1 bit produced by reversal of flux polarity, tape fully saturated in each direction.
3. Variation permitted in the location of the Check Character assuming nominal values for tape speed and all oscillator timings in the Tape Control. No longitudinal check bit is written if longitudinal count in the track is even.
4. Mylar Tape: 3/4″, +5/32″, −1/16″. Acetate Tape: 3/4″, +5/32″, −1/8″. Zero backward creep. Forward creep less than 0.2″ per cycle.
5. Dimensions of tape measured at 50% relative humidity and 70°F. Tape thickness (Mylar or IBM HD) is 0.0022″, +.0003″, −.0004″.
6. To insure complete interchangeability, skew of each tape unit is adjusted to 0.25 usec or less at the read bus of the tape unit when reading-while-writing continuous 1 bits. Maximum skew for any reel of tape, read by any tape unit connected to any tape control, must be equal to or less than the read character gate for the bit density and tape speed at which the tape was written.
7. Write Skew Gate, ±5%

	Time from First Bit	
7. Write Skew Gate, ±5%	Rise	Fall
729 II or V, 556 CPI	6.3 usec	16.1 usec
729 II or V, 200 CPI	16.9 usec	44.0 usec
729 IV or VI, 556 CPI	4.3 usec	10.8 usec
729 IV or VI, 200 CPI	11.4 usec	29.5 usec
729 V, 800 CPI	6.3 usec	10.4 usec
729 VI, 800 CPI	4.0 usec	6.8 usec

When reading, while writing coded information, all bits within a character must be received before the rise of the write skew gate.

8. Read or Write Character Gate, ±5%

729 II or IV, 556 CPI	10.5 usec	729 IV or VI, 200 CPI	21.0 usec
729 II or V, 200 CPI	29.2 usec	729 V, 800 CPI	7.9 usec
729 IV or VI, 556 CPI	7.5 usec	729 VI, 800 CPI	5.4 usec

9. Time Between Characters: Writing — shall not be less than fall of the skew gate timing plus 1 usec, including variations due to tape speed, skew and bit configuration. Reading — shall not be less than read character gate timing plus 1 usec, including variations due to tape speed, skew, and bit configuration.
10. Tape purchased to IBM Engineering Specifications: 512459 for Mylar, 351527 for IBM HD.

and more useful in high-speed data processing systems, it is necessary to have available a variety of methods that fit present and anticipated needs. IBM has a variety of tape formats, tape codes, tape densities, and tape speeds for ½-inch and 1-inch tapes. A typical IBM 7-channel tape format is shown and described in Fig. 7-13. Figure 7-14 illustrates a BCD tape coding. The tape tracks are referred to as 1, 2, 4, 8, A, B, and C, with the track designated as 1 adjacent to the reference edge. The C track contains a check bit for characters based on the tape coding: odd parity for binary tapes and even parity for the alphanumeric (BCD) tapes. The enlargement in Fig. 7-14 shows that the shaded areas occur for each magnetic state transition (modified NRZ).

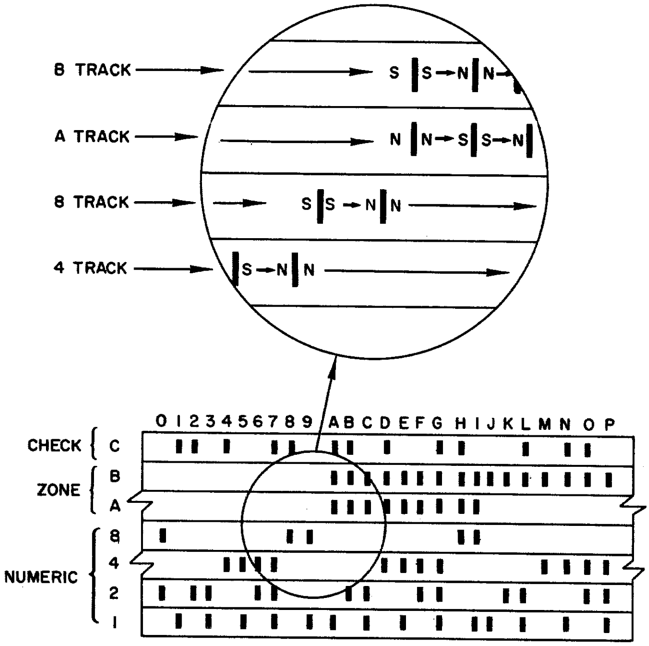

Fig. 7-14. *IBM BCD 7-channel tape format.*

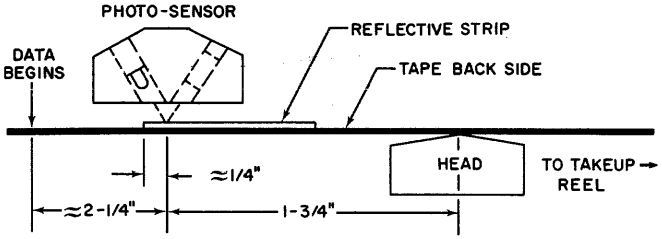

Fig. 7-15. *IBM-type reflective spot sensing of tape load point.*

IBM end-of-tape markers are used to signify the beginning of a file (load point) and end of a reel. The load point specification for an IBM 7-channel system is shown in Fig. 7-15.

The IBM information recorded on magnetic tape has the following format structure. A 7-channel track is used to record a 36-bit word; six tracks carry information and the seventh carries an error check bit. The next division of tape layout, the tape record, is a series of characters (6-bit data groupings) separated by an end-of-record (EOR) gap. The record may be of any length, from a minimum of six characters (one IBM word) to a maximum of the full reel of tape. An EOR gap is a ¾-inch length of unused tape. A single record or block of records is defined or noted by an inter-record gap (IRG) before and after the data (Fig. 7-16).

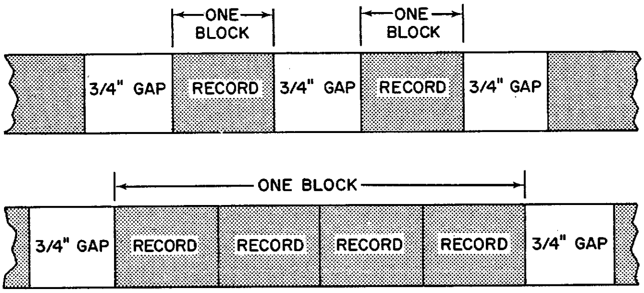

Fig. 7-16. *IBM single and multiple tape record formats.*

Each record also contains an error-checking character called a longitudinal redundancy check character (LRCC). The LRCC is written after all information of each record is recorded. Therefore, the LRCC is an integral part of the record. A record written by the 709 or 7090, with machine words of 36 bits, will always contain an even multiple of six characters and the LRCC. However, tape records prepared on a serial type of machine may contain any number of characters. The largest tape division in the IBM language, the file, is defined as a series of records separated by an end-of-file (EOF) tape mark. An inter-record gap, followed by a special single character, 0001111, in the end-of-file gap, terminates the file length. This special character is automatically generated and written on the tape following the last record of the file. Some IBM systems recognize the end of file as an elongated gap, about 3¾ inches in tape length. Files need not be limited by tape length; one file may comprise several tape reels. Under these conditions, the tape mark would not only indicate the end of a file but also the end of a number of tape reels of a computer program (Fig. 7-17).

Recently, IBM has introduced a new concept in magnetic tape devices. The 7340 Hypertape Drive uses ten parallel tracks using an 8-bit character code and two tracks for check bits to perform error correction and complete error detection. Two BCD characters are compressed into one 8-bit tape

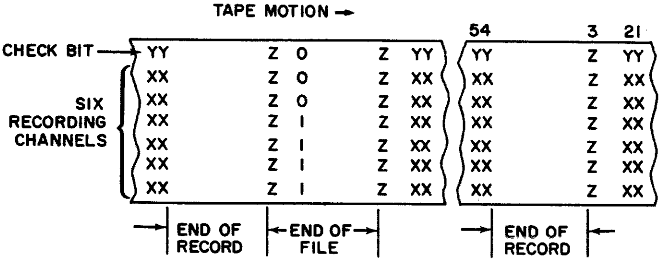

Fig. 7-17. *IBM EOF tape marking.*

word, thus doubling the density for numeric data. Although the 7340 reel of tape is small in length (1800 feet), higher data capacity per reel is obtained by increased recording density, shorter inter-record gaps, and data compression. The recording density is 1511 bpi, with an inter-record gap of .45 inch (nominal).

The Hypertape track layout is shown in Fig. 7-18. The tracks designated C_0 and C_1 perform a dual odd-parity check. Single bit errors and most double bit errors, including all double bit errors in adjacent tracks, are detectable and generally correctable by assigning specific information tracks to each of the check bits.

RCA Tape Formats

Two RCA tape formats are illustrated in Fig. 7-19. The 7-channel tape for the RCA 301 computer (Fig. 7-19A) is quite similar to numerous other 7-channel tape formats using alphanumeric characters having even parity.

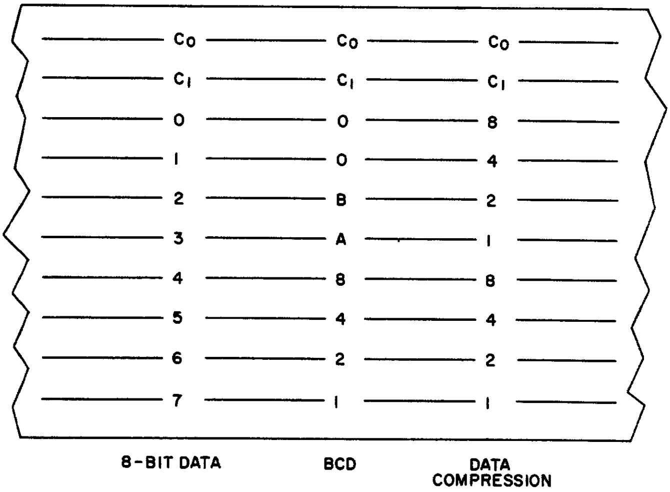

Fig. 7-18. *IBM Hypertape track layout.*

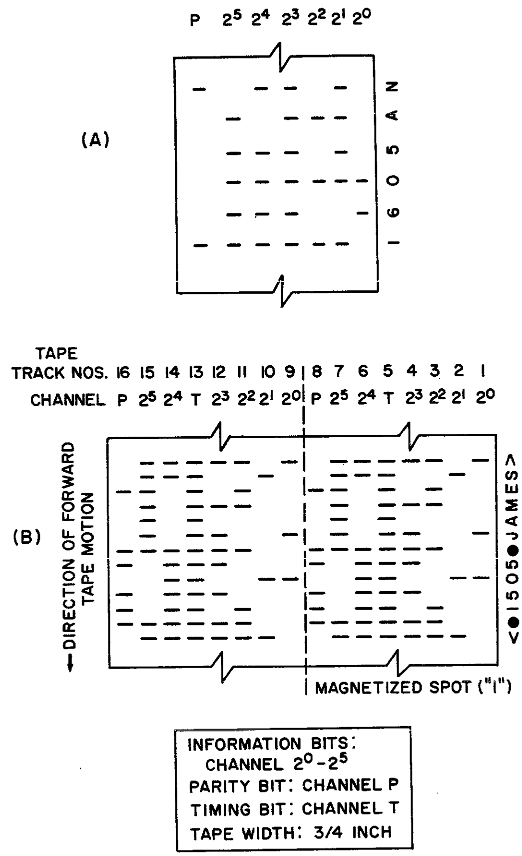

Fig. 7-19. *Tape formats for RCA 301 (A) and RCA 501 (B).*

The tape format used for the RCA 501 and RCA 601 computer systems (Fig. 7-19B) has certain system attributes worth mentioning. A redundant recording of eight channels is accomplished on a ¾-inch tape, using two magnetic head coils in series with one driver amplifier. During a readback operation, the tape format permits each set of eight channels to be utilized independently or in combination. (This will be explained in further detail.)

In the RCA 501 computer configuration, the tape density is 660 bpi and the tape speed is 100 ips. During the readback operation, each bit position of each set (e.g., 2^0 of Set One and 2^0 of Set Two) is combined at the input of one readback amplifier (a total of eight readback amplifiers). In this fashion, the loss of signal from one section of tape will not invalidate the reading process. The parity checking error operation becomes activated when the combination of both signals on a per data read channel falls below the preset threshold voltage level.

In the RCA 601 computer configuration, which uses the same 16-channel tape format, the tape density is 800 bpi and the tape speed is 150 ips. One set of eight tape tracks is arbitrarily assigned as the primary data source and the other set of eight tape tracks operates on a standby or replacement status. Normally, only one section of the tape is used during a readback operation at any one time. For any cause of poor tape quality or loss of data bits during the reading process, the standby eight-channel set is automatically switched in without any apparent indication of the alternate data channel source selection. In the event both sections of tape are sequentially selected and each indicates parity errors on a per channel set basis, both sets are combined on a per bit basis and are checked for any parity errors. As a result of this system's operational procedure of redundant recording and a three-way procedure of readback, RCA has been able to obtain ultrareliable operation in their high-density tape operations. Since magnetic tape imperfections may be a major source of intermittent or random errors, the RCA 601 tape format and checking procedure permit readback frequencies of 120 kc with an average per tape reel of one error or less.

UNIVAC Tape Formats

It is interesting to note the different machine codes and track layout assignments used in the Univac computer systems (a division of the Sperry Rand Corporation).

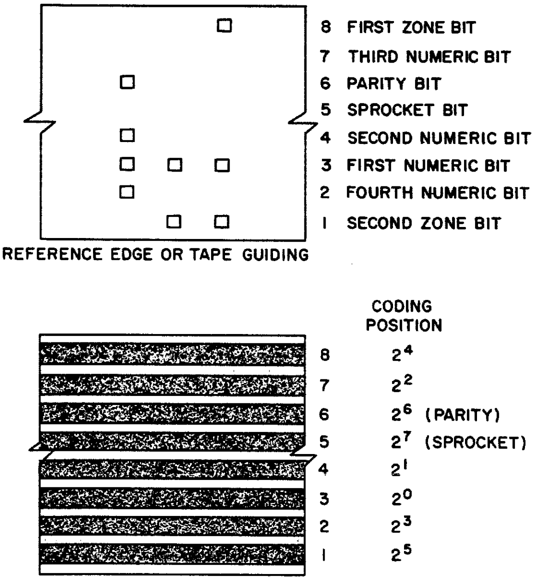

Fig. 7-20. *Tape formats for Univac computers.*

An earlier Univac magnetic tape unit, Uniservo, is an 8-channel recording. The tape formats for the Univac File Computer and Univac II, shown in Fig. 7-20, have the timing track (sprocket bit) and the parity bit occupying tracks designated 5 and 6, respectively.

A more recent and advanced magnetic tape unit is the Uniservo III A and C. The Universo III A subsystem has eight data channels and one parity channel for each tape word (or frame) on magnetic tape and provides various tape format options. In the Univac 1107 Thin-Film Memory Computer, the 36-bit computer words are normally disassembled into five 8-bit frames with 0 fill, as needed (see Fig. 7-21A). A second tape format arrangement is shown in Fig. 7-21B. In it, the same computer word is expanded into 6 frames of 6 bits of information requiring additional zero fill in. The relationship between the computer word and disposition of bits on tape for the Univac 490 Real-Time System are shown in Fig. 7-22. There are many reasons for two data arrangements per computer system; the most fundamental is that no single track layout or single code language can ever be optimum for all intended computer applications.

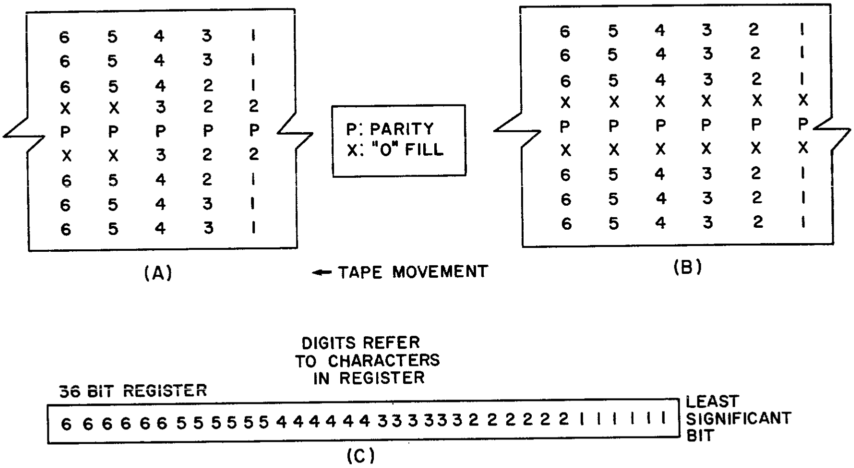

Fig. 7-21. *Univac 1107 thin-film memory computer.*

Glossary

Some of these terms are widely used to describe the organization of data on magnetic tape. The definitions presented here apply to the text material of this chapter.

Binary Coded Decimal (BCD). A unique and unambiguous code in which binary digits represent decimal numbers 0 through 9 (4 binary digits are a minimum BCD code).

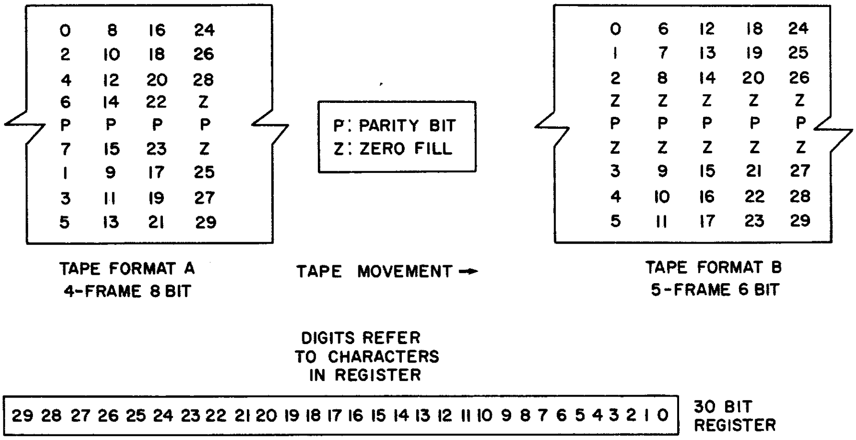

Fig. 7-22. *Univac 490 real-time system.*

Block Length. A group of words (machine or tape) recorded serially on magnetic tape.

Character. A unique and unambiguous code of binary digits that represents a symbol, mark, or unit of information. Generally, a character comprising 6 bits is adequate to represent alphabetic and numeric symbols and other special marks.

Control Word. A coded word supplying command, instruction, and execution of an operation.

Head Marker (Heading, Label, Leader, Prefix, etc.). A descriptive code (sentinel, key, or initial word) which essentially identifies and defines a group of related information.

Inter-record Gap (IRG) — Interblock Space. The absence of recorded data between two records; hence inter-record space. In read-after-write operations (dual gap head), the IRG is limited to the dual gap dimension. The unused tape permits start-stop operations without any loss of recorded data.

Packing Density (Bit Density). The number of magnetic spots (or cells) per linear inch of tape of a single track by a single head.

Parity. A means of verifying or checking the accuracy or authenticity of the recorded information.

Tail Marker (Trailer, Suffix, etc.). A descriptive code which essentially identifies and defines a group of related information. A sentinel is used for continuance or termination of data or operation.

Tape Code. A bit configuration across the width of the tape and serially along the tape length. Coding must be adequate to disassemble information into a series of tape words and to reconstruct them into their original form. (See Tape Format.)

Tape Format. The organization of binary digits on tape in a predetermined manner to permit information recovery from tape and the reconstruction of the data into its original form.

Tape Marker. Physical (and visual) identifiers on tape to denote each tape extremity: beginning of tape (BOT) and end of tape (EOT).

Tape Word (Frame or Line). A group of parallel bits across the width of tape. The bits may be unrelated or comprise a code or character.

Track Density. The number of parallel recording channels across the width of the tape. (The number of magnetic heads per unit length for in-line head construction.)

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8

The Digital Tape Station

Because digital magnetic tape is basically a storage medium, it is frequently classified with input/output devices. Actually, magnetic tape is much more flexible than this; it can be employed as a medium-access memory in a slow-speed computer complex. Magnetic tape has several distinct advantages as an input/output medium or internal memory. It can store large amounts of information and can be moved about from one machine to another in bulk. In this manner, very large computer programs (software) or extremely large blocks of data are available for data processing regardless of their origin. Thus, a reel of tape on a drive unit is a major component that makes valuable data, documents, or voluminous files of information accessible.

The process of adapting or integrating digital data for recording is covered in this chapter. To do so it is first necessary to relate the tape recording device to its associated equipment complex. A typical block diagram of the tape transport, its interface (tape adapter, tape control unit, data synchronizer, etc.), and one possible data source are shown in Fig. 8-1. In this system, the input/output buffer serves as a data source for writing information on tape and as a receiver of data during a reading operation. The tape control unit performs the following operations:

1. It accepts data from an external source.
2. It transmits data to an external source.
3. It executes the commands of the data source.
4. It transmits the current status of the operation.
5. It encodes and decodes data in terms of tape recording requirements.
6. It monitors the overall tape station operation.

Obviously, the magnetic tape transport as a black box is inoperable as a recording device. Without the tape control unit, which encodes any type data into a magnetic tape recording format, the tape transport has very little value. Because the design of the tape control unit normalizes the data in terms of

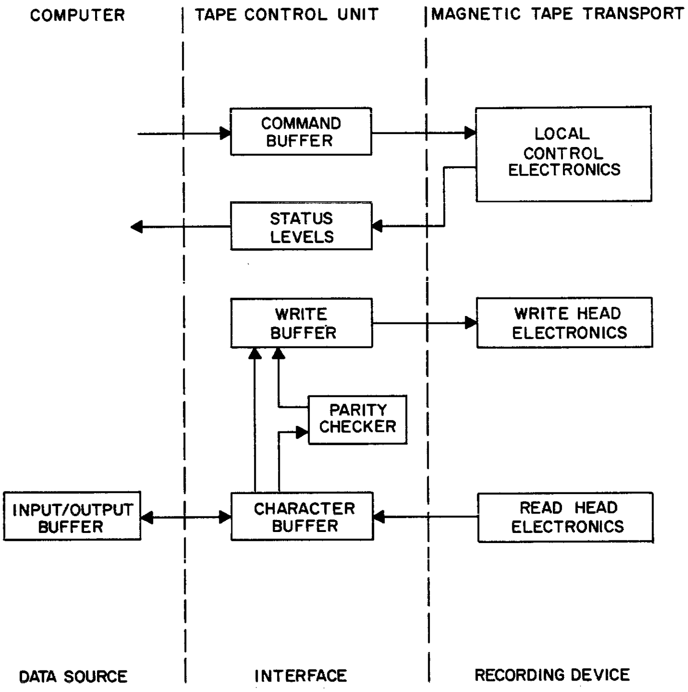


Fig. 8-1. *Magnetic tape station information flow.*

the recording device, the tape transport can be standardized and treated as a digital building block. The tape control unit may assume different configurations to fulfill the various system requirements, permitting the use of a standard digital tape transport.

The tape control unit integrates the tape recording device with the data source (generally a digital computer) via data channels commonly referred to as the *input/output data bus.* Incoming data and the particular format are momentarily stored in a buffer register. Here, any speed discrepancies (data rate) between the data source and the tape recording device are accommodated. During this temporary storage period, code translation, word or block formulation, editing, or any other data processing that may be required prior to recording is performed. The control unit performs these operations. Although the data source may supply the major portion of command control, some local autonomous control is required and is an integral part of the tape interface equipment. Therefore, the interface equipment primarily supplies the input/output lines, buffering, and control as required by the system. Each subunit of the tape control provides the matching between the tape transport and its data source, permitting the tape transport black box the versatility and flexibility necessary for numerous applications. Only the basic operations of the tape control unit are illustrated in Fig. 8-1. Many possible variations are illustrated in the next chapter where several tape recording systems are detailed.

Tape Operations

The tape transport consists basically of the tape supply (supply reel, take-up reel, and associated servos), the tape drive system, and write and read electronics. Generally, the tape supply operation, including the operation of the sensors associated with the tape reservoir, is a closed-loop servo system. This means that this system is not an integral part of the tape transport and is not subject to either local (operator) or remote (computer) control. The tape drive system, however, is an integral part of the tape transport. Tape drive commands may be supplied locally for operating, testing, and maintenance procedures and remotely via the tape control unit for external operation. The write and read electronics are shared by both the tape transport and the tape control unit. The write and read electronics of the tape transport comprise the write current head drivers and the readback head voltage amplifiers. All the coding, control, editing, and error information, in addition to the input data, are processed prior to any writing operation in the tape control unit. Likewise, after reading, all inserted information must be "stripped" from the read data so that only the data are transmitted. The writing and reading data processing is accomplished in the tape control unit.

All of these operations are necessary to complete a digital magnetic tape recording operation. Therefore, these basic functions, control, coding and formating, and write/read operations, will be examined in detail.

Electromechanical System Outline

The elements of an efficient high-speed tape handling operation are illustrated in Fig. 8-2. At the left side of the figure are tape reels A and B, which supply and take up tape. A mechanical arm, the tape reel supply indicator, monitors the tape supply of each reel. The closed servo loop is illustrated by the mechanical connection of the reel and reel motor with the servo input control signal obtained from the tape reservoir optical sensor. The reservoir type shown here is often called a vacuum servo control. The optical sensor supplies the start and stop signals to the reel drive motor. The complete tape supplying operation for either direction and maintainence of an adequate supply of tape in the reservoir are accomplished independently of the tape drive capstans. Generally, the servo control system is a variable speed system.

The capstan motor is the prime source of tape drive. In Fig. 8-2 it is connected to the upper and lower capstans by means of a belt pulley drive arrangement. Digital data processing is an orderly procedure defined in fixed terms of system operation. Therefore, tape speeds are fixed. By utilizing

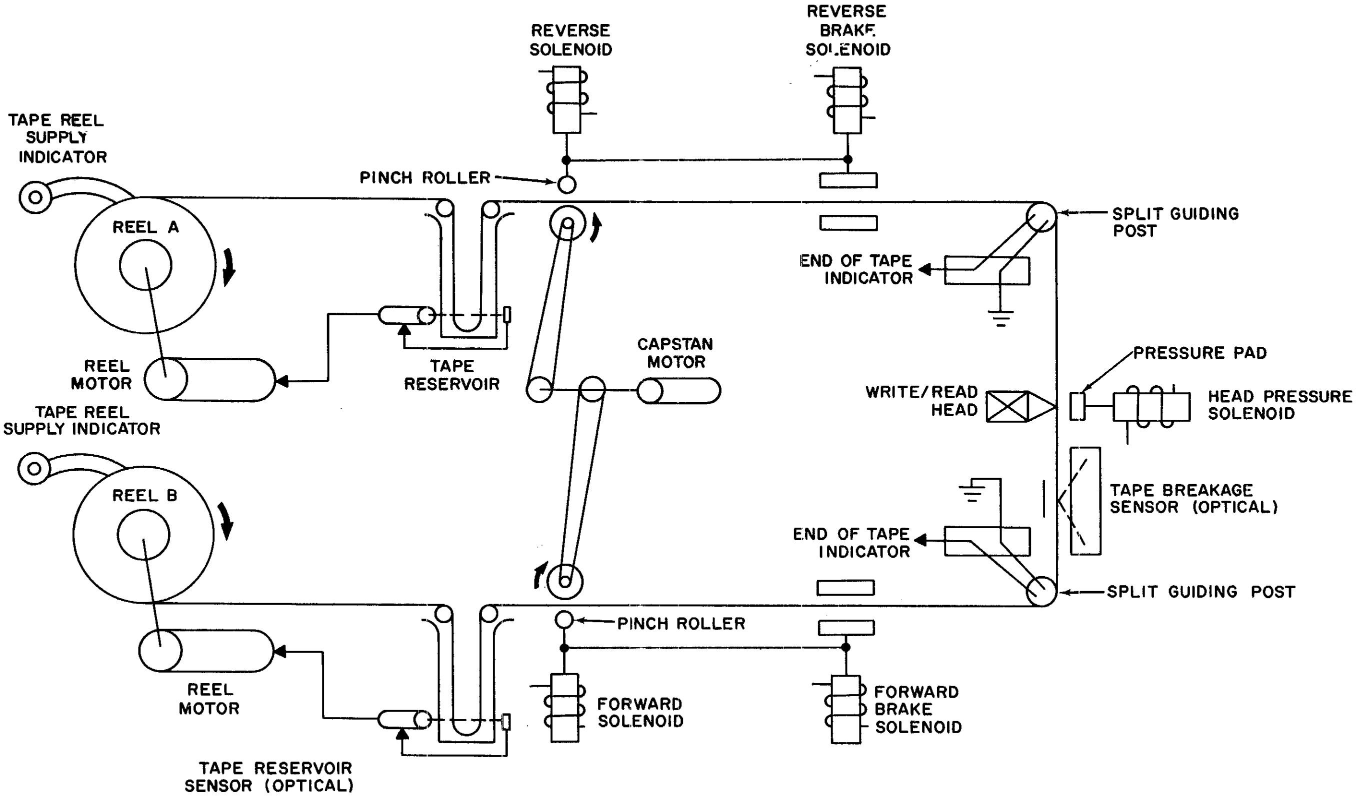


Fig. 8-2. *An electro-mechanical representation of a magnetic tape station.*

dual-speed capstan motors in conjunction with belt and pulley configurations, various tape speed combinations are obtained. Nevertheless, discrete tape speeds are used and are generally limited to operational speed (read/write) and fast forward and rewind operations. Unlike the start-stop operation of the reel drive motors, the capstans are in continuous motion during a tape station operation.

Tape is accelerated by the solenoid-actuated pinch rollers shown in Fig. 8-2. A mechanical or electrical connection between the forward (or reverse) solenoid and the forward (or reverse) brake ensures fail-safe tape operations by preventing the simultaneous operation of both solenoids (pinch roller and brake).

The end-of-tape indicators are shown at the top and bottom of the figure. Each one senses the tape extremity and completes a ground circuit.

A head pressure solenoid is also shown. Depending on the head-capstan configuration, tape and head contact is maintained by tension or by a spring-loaded pad. During a high-speed forward or rewind, this may cause excessive tape and head wear. Some manufacturers move or release the head pressure pad, while others move the head or pneumatically float the tape above the head. Generally, all tape-breakage sensing is accomplished by photocells, which offer the advantages of simplicity and small packaging.

Write and read operations are fixed and determined by coding techniques described in Chapter 5. All other operations shown in Fig. 8-2, such as reel motor drive, end-of-tape sensing, and tape breakage, are an integral part of the tape transport.

Tape Drive Operation

The tape drive operations are performed by the tape supply (reel and reservoir) and the capstan drives and brakes. All digital tape transports have much in common. A certain amount of interchangeability of tape reels is possible in large installations where several different tape transports are present. Each manufacturer accomplishes the same basic functions previously enumerated but not necessarily in an identical fashion.

Vacuum Servo Control

A vacuum servo control system is shown in Fig. 8-3. Air is evacuated through vent holes located at the bottom of the pressurized enclosed reservoir column. With reduced pressure below the tape and positive pressure (atmospheric pressure) above it, any tape slack is directed into the enclosed column. This tape is removed whenever the pinch roller is actuated and engages the continuously-operated capstan and is replenished by reel A. This procedure is reversed when the reel and capstan drive interchange functions. Then, the capstan drive supplies tape and reel A takes up or removes the tape.

In Fig. 8-3 two lamps are spaced on one side of the column directly opposite two photocells. A light path exists between each lamp and its photo-

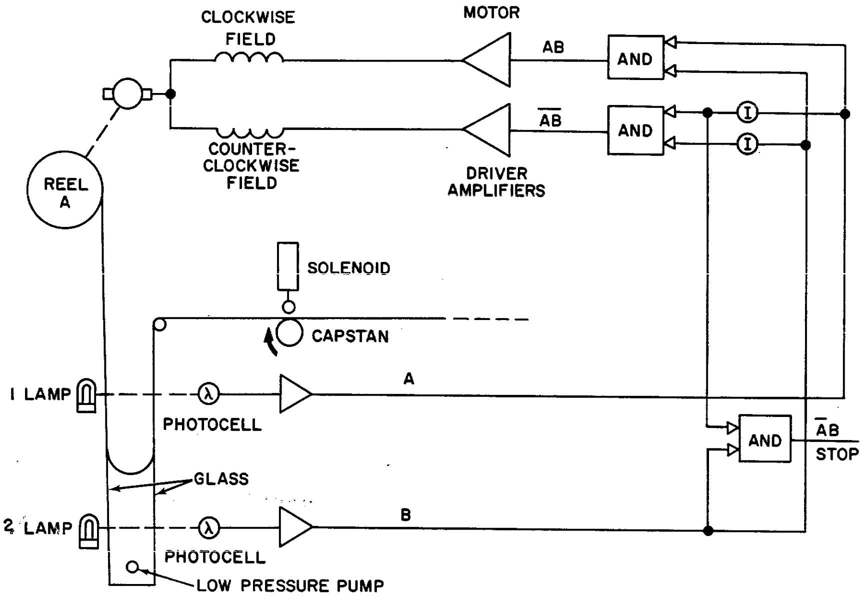


Fig. 8-3. *Vacuum servo control of a digital tape transport.*

cell unless the tape obstructs the path of the light. The two lamp locations are dictated by the operating tape speed and acceleration and deceleration of the two tape reels. Lamp 1 is located in the upper column to signal the reel drive motor when tape should be supplied before it is exhausted from the column. Lamp 2 is located below Lamp 1 and above the column bottom to signal for the removal of tape before the tape folds and piles at the bottom. The two lamps are spaced so that the tape being supplied will pass Lamp 1 and come to a stop before Lamp 2 becomes obstructed. For example, if enough tape is extracted from the column to cause a signal output from Lamp 1, both lamps will be energizing both photocells and the reel motor will rotate clockwise to refill the tape reservoir. Similarly, when tape is being supplied and more than an adequate supply is present, both photocells do not supply any signal output and the reel motor rotates in the counterclockwise direction, removing tape from the column. This closed servo system is sometimes referred to as a *bang-bang servo*. The motors are either operated at their maximum or fixed speed or they are off.

Other vacuum columns may use a series of lamps in a proportional servo system, such as the vacuum reservoir shown in Fig. 8-4. Here, the signal is proportional to the tape supply and is not on a go and no-go basis. The continuously-variable speed of the servo motors supplies tape to the reservoir in proportion to tape entering or leaving the low-pressure air column.

Photocells are not the only type of sensor used to monitor the tape supply and complete the servo loop. Other sensors such as pressure transducers or capacitive pickups may be used to control the tape supply in the reservoir.

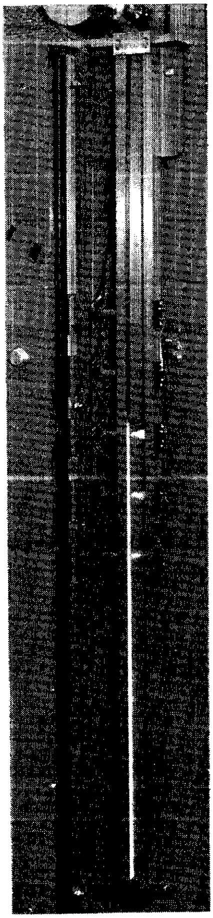


Fig. 8-4. *The vacuum reservoir of the Burroughs BC422.*

Mechanical Servo Control

A mechanical servo control system was shown in Fig. 2-3. The tape reservoir consists of a moveable arm holding a number of ballbearing rollers. A corresponding set of rollers is mounted on the main front plate tape deck. As the tape is supplied to the control arms, the tape tension is reduced and the arm will move outward and away from the fixed rollers; as the tape is removed from the control arms, the tape tension is increased and the arms will move inward and toward the fixed rollers.

All of the methods available for tape-supply sensing using this type of tape reservoir utilize angular displacement. The angular displacement of the arm is translated into electrical signals by means of a servo potentiometer or a synchro transmitter linked on a common shaft. Since servo amplifiers may provide power in proportion to the amplitude of the signal inputs, the tape reel speed is a function of the angular magnitude displacement from the null (or center) position. The direction of the offset from the null position is mechanized in the polarity of the signal to control the direction (clockwise or counterclockwise) of the servo motor rotor.

This control system can be proportional, or a bang-bang servo operation incorporating contact closures and a dashpot can be used. Also, angular displacement sensing could be replaced by translation motion of a sliding contact.

The synchro transmitter sensing system for this type of tape reservoir is worth examining, since it affords less mechanical wear and is fast acting. A good illustration of this type of proportional closed-loop servo system is the one used in the Model 59 Tape Transport manufactured by Cook Electric Company (Fig. 8-5). Each servo system controls the rotation of its associated reel in such a way that an adequate tape supply is always maintained at the operating tape speed. The synchro transmitter output is an a-c signal corresponding to the control arm position. The oscillator circuit provides a 5 kc signal (A) to the synchro rotor. The demodulator converts the a-c signal from the synchro to a d-c signal (E) that contains the angular displacement and offset direction of the control arm. The d-c amplifier compensates for the mechanical lag of the control arm. The ramp generator is synchronized to each half cycle of the line frequency (120 cycles per second) and the slope of the ramp signals (G and H) contains the d-c analog of the control arm position. Trigger signals (K and L) are obtained from the ramp signal and provide the control pulses to the motor drive circuits. Since the trigger circuits fire at a fixed level, the time relationship of the control pulses to the synchronizing waveforms is dependent upon the slope of the ramp signal. The trigger pulses are used to turn on silicon control rectifiers to provide pulsed d-c current (M and N) to the series-field, d-c reel drive motor. During the time duration of these current pulses, input power is supplied for motor rotation. The control rectifiers cease to conduct when the anode voltage drops to zero 120 times a second on the trailing edge of each half cycle of the line waveform.

The servo reel drive is a series-field, d-c type motor with forward and reverse fields. The circuit description is duplicated for each motor field (forward and reverse) beginning with a demodulated d-c signal to handle the two directions of motor rotation. When the control arm is approximately in the null position, the d-c excitation for both motor fields is equal and opposite, field cancellation occurs, and no motor rotation is possible.

Capstan Brake Control

Once a tape transport has been activated and put into operation, the capstans rotate constantly. Provisions are necessary to ensure that tape breakage is prevented. This breakage can occur when the tape drive pinch rollers

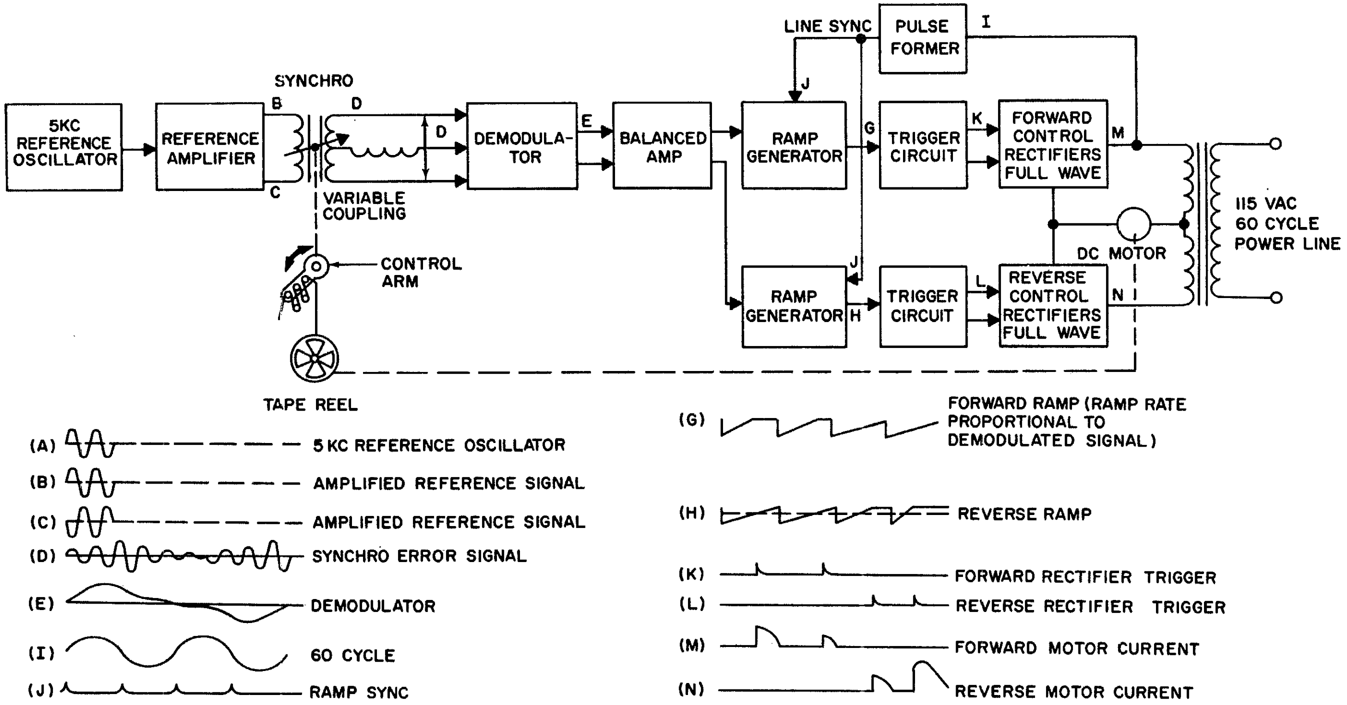


Fig. 8-5. *The synchro method of tape supply sensing used in the Cook Electric Company Model 59 tape transport (Cook Electric Company).*

and the mechanical brakes are activated simultaneously. In Fig. 8-2 a link is drawn between the tape drive actuator (forward or reverse) and its associated brake. A more positive and reliable method in practice is a mechanical interlock arrangement, in which the linkage prevents the simultaneous application of tape drive and tape brake.

Figure 8-6 depicts the overall tape drive and brake arrangement and Fig. 8-7 shows the three operating positions (stop, go, and neutral) for the right drive assembly. Whenever tape is put into motion, one drive arm must be down to engage the rotating capstan and the other drive arm must be in a neutral position. The status of the drive arms for various tape operations is as follows:

Tape Status	*Drive Arm Status*	
	Left	*Right*
Forward Stop	Stop	Neutral
Forward Go	Neutral	Go
Reverse Stop	Neutral	Stop
Reverse Go	Go	Neutral

To provide forward tape motion (left to right), the left drive arm is released before the right drive arm is engaged. The tape is stopped by applying force at the side of the supply source, from the left side in this case. In each case of tape motion, the tape supply source with the adjacent drive arm is placed in a neutral position before the opposite drive arm engages the rotating capstan. The same drive arm in neutral is used to stop the tape only after the opposite drive arm has ceased to move the tape. This time sequence is summarized below:

Time	*Drive Arm Status*	
	Left	*Right*
Time 1	Neutral	—
Time 2	Neutral	Go
Time 3 (Tape in motion)		
Time 4	Neutral	Neutral
Time 5	Stop	Neutral
Time 6 (Tape not in motion)		

If the tape is being moved from right to left (reverse direction), the preceding description remains the same, except that left and right are interchanged.

This mechanical configuration prevents the simultaneous application of driving and braking power with one drive arm. Also, it is not possible to command go and stop sequentially (or the reverse) without going through a neutral position. This is important when simultaneous tape commands for opposing tape directions are given.

Another approach to the tape breakage problem is the elimination of all brakes. In this manner, the tape is put into motion by the drive circuits.

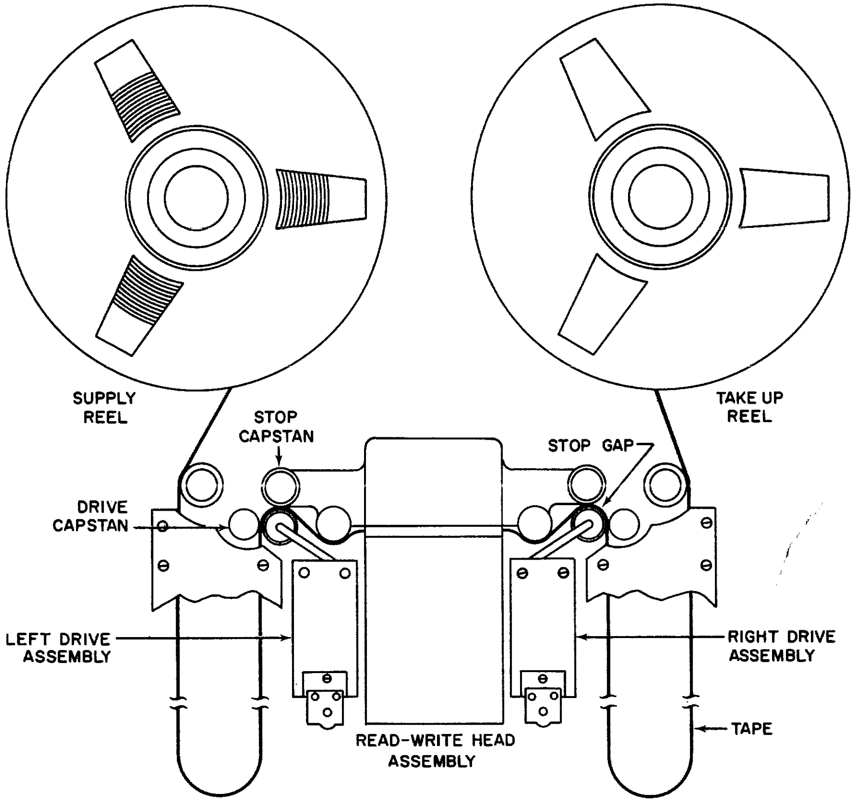


Fig. 8-6. *IBM tape drive and brake arrangement (IBM).*

As soon as the tape driving power is released, only the tape's momentum can continue its motion. Tension or frictional forces will oppose the tape motion and prevent any appreciable magnitude of tape travel depending on tape speed.

There are system requirements where it is desirable to control the amount of unused tape either for more efficient tape utilization or tape recording synchronization, or both. This is accomplished by mechanically applying brakes and clamping the tape, sometimes at two points. Another method in practice, where pneumatics are the prime means of tape drive, is the application of tape driving power with the brakes on. With air capstan drives and air suction brakes, the peripheral surface of the capstan far exceeds the braking surface, so that the applied force of the capstan will move the tape while the brakes hold it in intimate contact with the head. When the tape driving power is removed, the brakes have sufficient frictional force to oppose the tape's momentum.

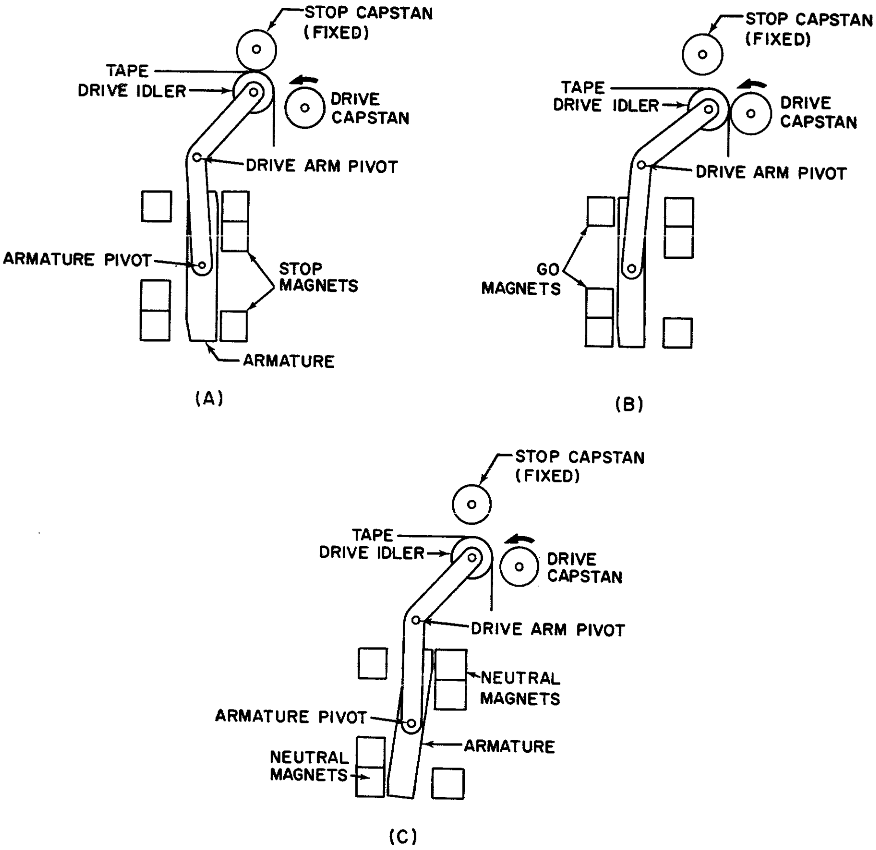


Fig. 8-7. *Three operating drive arm positions: (A) STOP; (B) GO; and (C) NEUTRAL (IBM).*

Capstan Drive Control

Generally, tape transport construction or circuit logic is used to prevent the simultaneous application of tape drive and tape brakes. Command control for tape operation is generally initiated at a local control panel or remotely for external control. . Two possible conditions are likely to occur that may cause tape breakage when the two drive commands, forward and reverse, are issued: the simultaneous issuance of opposite commands and rapid sequential commands for opposite tape drive operations. Generally, it is not always practical to interlock the forward and reverse driving units, as it was with their associated brakes (Fig. 8-7). Locally, the pushbuttons for forward and reverse can be constructed to prevent the simultaneous issue of both commands. The second cause of breakage can be averted by enforcing a safe-time interval for the turn-around condition that will prevent snapping the tape or possible damage to the capstan drive surfaces and pinch rollers. This is accomplished by incorporating logic in the tape control unit or local tape transport electronics that will control the sequence of commands. Whenever a tape drive command is issued, or the two opposite drive commands (forward and reverse) are issued, the first command arriving takes precedence, and a delay is generated to prevent a subsequent command from aborting the execution of the first command. Once this logic has been implemented, the second command may be stored and honored when the first command has been completed, or it may be completely ignored and have to be reissued.

In practice, methods of preventing the issuing of simultaneous tape drive commands of opposite directions are built into the equipment or incorporated into the programming instructions for tape operations.

Tape Motion

There are two basic drive functions (reel drive and tape drive), requiring three separate motors and three independent operations. Figure 8-9 is a basic logic diagram in which the forward, reverse, and stop operations of the capstan drive are consolidated. These three functions are accessible at junction points in the hardware and are available on the control panel of the equipment.

A remote-local pushbutton switch-indicator is used on the control panel to place the tape operation under local or remote control (Fig. 8-8). For simplicity at the remote selection, two input wires designated Remote Forward

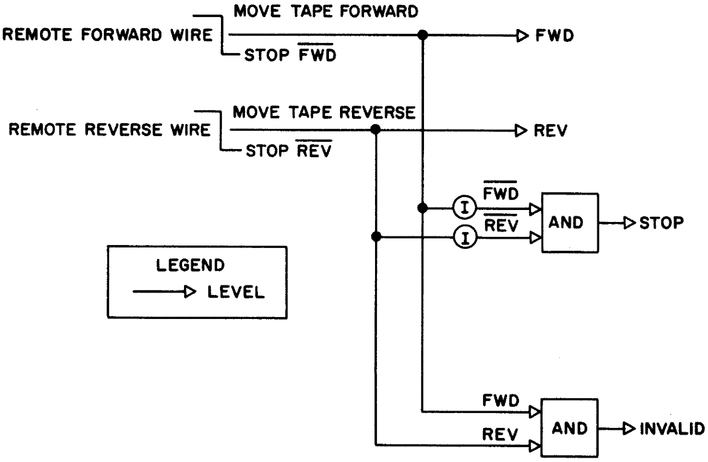


Fig. 8-8. *Remote logical operation of forward, reverse, and stop.*

and Remote Reverse are adequate. The absence of an input on both lines constitutes a remote stop mode. If both inputs are present simultaneously, an invalid condition exists. This invalid condition can be mechanized in a number of ways: a lamp may be turned on to register it; the signal may inhibit any tape motion; or it can be used to control the stop tape operation.

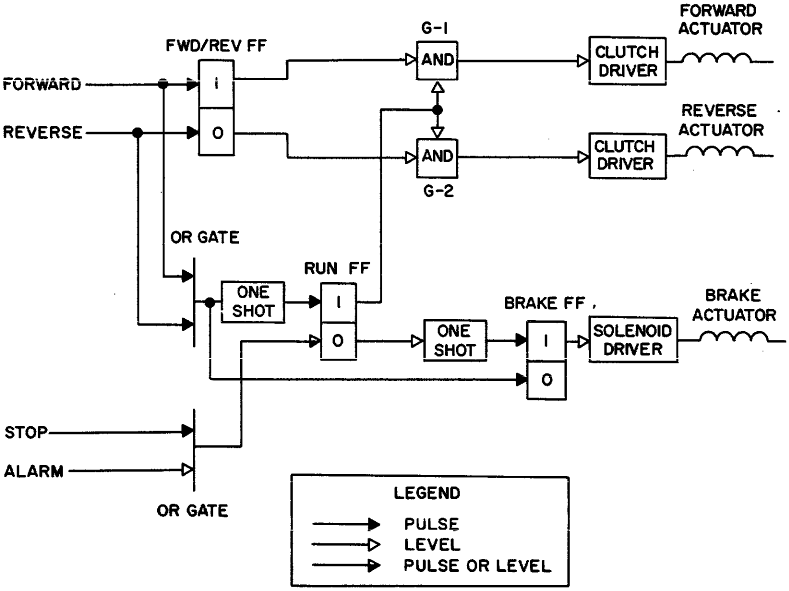


Fig. 8-9. *Forward, Reverse, and Stop operations.*

In Fig. 8-9, a local selection has control of the tape transport. Mechanically, the Stop control button takes precedence over the Forward and Reverse control buttons. If the Stop control is held depressed, both the Forward and Reverse controls are rendered inoperative. Pressing the Stop control will de-energize the hold operation (FWD/REV) of the previously-actuated tape direction control at AND gates G-1 and G-2. At a later time interval, brakes are applied to stop the tape when the Brake FF is energized. The Forward and Reverse control buttons are electrically interlocked in such a way that if one is depressed when the other is already actuated, the latter will de-energize and remove that control from operation. If the tape is put into motion, two conditions are required: Go and Direction. A forward or reverse tape drive command is used to move the tape. However, this command is used first to release the brake via the Brake FF and set up the Go condition via the Run FF. The actual tape command directions are delayed prior to selecting the state of the Run FF. Mechanical and electrical interlocks are used to ensure that only one out of the three possible operations are ever selected and any rapid sequential selection is delayed to accommodate mechanical operation of the tape drive and tape brakes.

Tape Rewind

The normal read/write speed of the capstan is too slow for a rewind operation. The rewind times of 2400-foot and 3600-foot tapes are tabulated below:

Tape Speed		*Tape Reel Length*	
		2400 feet	*3600 feet*
Read/Write	100 ips	4.8 minutes	7.2 minutes
	150 ips	3.2 minutes	4.8 minutes
High-Speed Rewind	200 ips	2.4 minutes	3.6 minutes
	300 ips	1.6 minutes	2.4 minutes
	500 ips	.96 minutes	1.44 minutes

Since high-speed operations are usually desired, and costs are related to computer time, 4 or 5 minutes is an infinitely long time when other operations are measured in nanoseconds. This problem can be solved by using one of the following methods: (1) rewind off-line or on another machine; (2) rewind at the read/write speeds; (3) rewind at a higher speed than read/write.

In method 1 maximum time is saved by removing the tape reel and rewinding it on another tape station. This poses no problem in tape transport design but could require additional tape facilities. As stated in Chapter 6, a programmed tension winder could be used to rewind the tape smoothly in a tension pattern designed to prolong the tape life.

Method 2 poses no design problem. The tape transport is operated normally and is always under programmed control using the logical operations of Fig. 8-9.

Method 3 creates a variety of problems that must be considered in the design of the transport and in its operation. The first problem involves the effect of high-speed rewind on tape. At 500 ips, the tape is traveling 30 miles per hour. If the head configuration has the tape wrap around to ensure intimate head-to-tape contact, as shown in Fig. 8-10, a high rewind mode would be objectionable. Too much tape-to-metal contact will exist and friction heat would be excessive. Therefore, the head must be programmed to move or retract at rewind to eliminate this problem. Also, if head pressure pads are used, they must be moved out of the way. Furthermore, any tape reservoir system that requires extensive tape-to-surface contact cannot be used. Obviously, the most desirable configuration for a high-speed rewind is no tape-surface contact. Where tape must be guided around posts, positive air pressure can be used to prevent any tape-to-metal contact.

A dual-speed capstan tape drive is one solution for obtaining a high-speed rewind as well as a high-speed forward wind. Standard tape transports use a ratio of 2 to 1 for high speed wind to operating speed. The reel servo motor

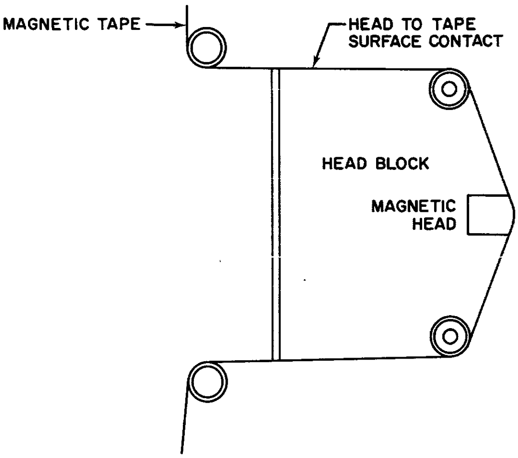


Fig. 8-10. *Tape wrap-around head configuration.*

control system sees an incremental speed change of one unit from start to operating speed and one unit incremental speed change from operating speed to high speed. The servo motor control is always in operation (with its sensor inputs) and the two-speed sequence is necessary from start to high speed or the reverse. No major problems are encountered with the dual-speed capstan method.

In the servo control tape motion from high speed to normal speed, the capstan motors take about one half second to return to operating speed. Therefore, on a high-speed rewind, a delay must be inserted after the BOT signal to ensure an adequate time interval before the next operation.

An exceptionally high speed to operating speed ratio presents another problem: determining a method of going up to a very high speed and than returning to a normal speed without damaging the tape. The servo motor can supply tape faster than the capstan drive can remove the tape from the tape reservoir. The servo motor is d-c operated and the reel motor speed is related to signal input. If the high d-c input to the reel servo motor is used, the normally operated closed loop control must be opened up and a new control system used to protect the tape. As the rewind approaches completion, an advance warning is necessary to reduce the tape speed and switch back to normal operating conditions. The advance warning can be obtained by monitoring the tape capacity on the take-up reel. Figure 8-11 indicates how an optical sensor is used to obtain this information. The packer arm in Fig. 8-2 could perform the same function.

Tape Threading (Loading and Unloading)

The following tape threading procedure is used by such manufacturers as Ampex, Cook Electric, and Potter Instruments to load a tape transport using a tension-arm reservoir:

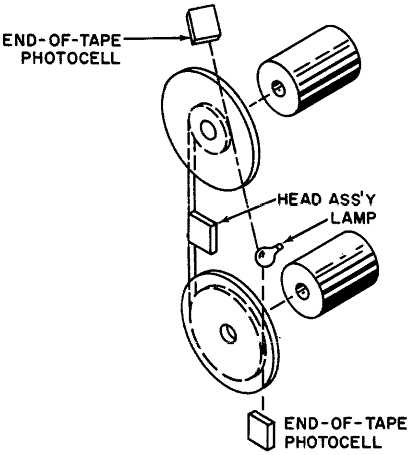


Fig. 8-11. *End of tape advance warning.*

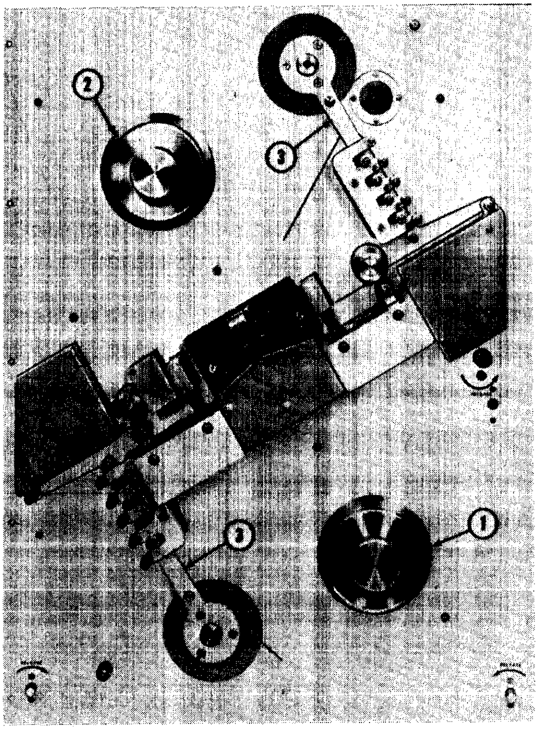


Fig. 8-12. *Tape loading: tension arms in inner detent position (Cook Electric Company).*

1. Open the tape transport dust cover. The cover interlock removes all power from the tape transport in the event the power has not been turned off.

2. Move the tension arms (generally by a control knob) inward until they can be engaged in a detent position past the fixed arms. Figure 8-12 shows the moveable arms (3) in the proper position for loading; the tape reel hubs are numbered 1 and 2.

3. Install the full reel (or supply reel) and the empty reel (or take-up reel) in their proper locations and lock them into position by turning the hold-down knob for each reel hub.

4. If a head cover plate is used, move it to expose the head assembly for tape loading.

5. Unwind a sufficient amount of tape from the supply tape reel and feed it onto the take-up reel. Pay particular attention to routing the tape through the tension arms and guide rollers (1 and 2 of Fig. 8-13), past the drive capstans, and between the pressure pad (if one exists) and the head (5 and 6 of Fig. 8-13). The dull (oxide) side of tape should be against the head.

6. Wind the tape on the take-up reel in the following manner: Hold the

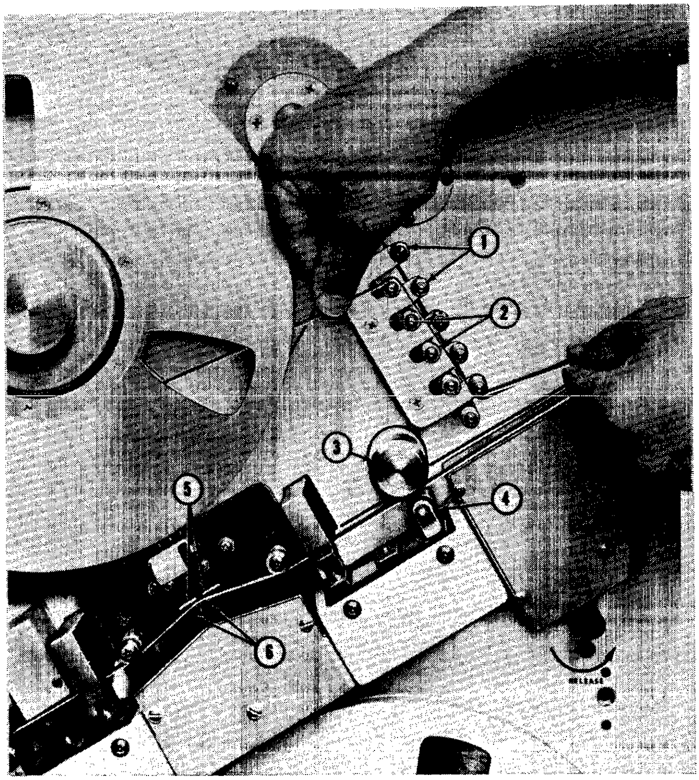


Fig. 8-13. *Tape loading: tape threading (Cook Electric Company).*

free end of the tape against the core of the empty reel with the finger pressed against the tape in contact with the core of the reel. Manually turn the empty reel until the slack has been taken up and a few turns are firmly anchored to the take-up reel. Then add a few additional turns of tape to the take-up reel by rotating the supply reel to play out the tape to be wound on the take-up reel. These additional turns will ensure that the tape is securely wrapped on the take-up reel and any improper tape guiding can be observed. When the tape threading is completed, the tension arms are released (manually or automatically) and move outward until the remaining slack in the tape is taken up (Fig. 8-14).

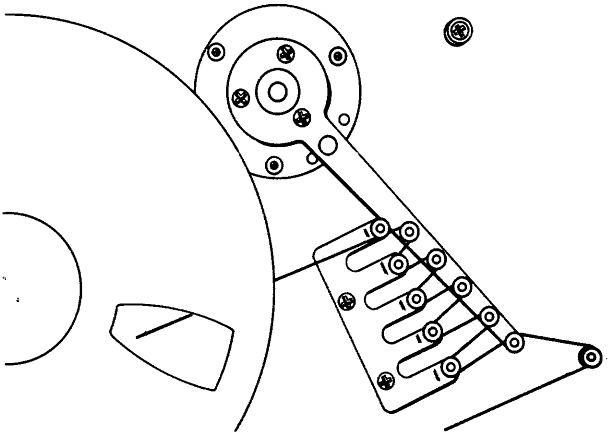


Fig. 8-14. *Tape loading: arms released (Cook Electric Company).*

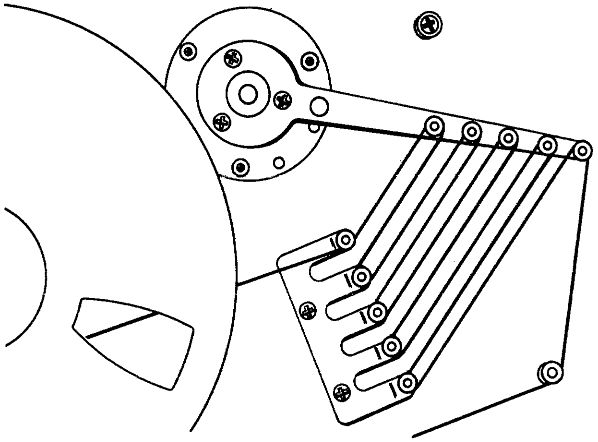


Fig. 8-15. *Tape loading: arms at null (Cook Electric Company).*

7. Manually position the tension arms to a null position by rotating the reels in the proper direction until the arms assume the position shown in Fig. 8-15.
8. Return the head cover plate to its operating position and inspect the tape once more to see if it is properly positioned within all guide rollers and the head block guide posts.
9. Close the dust cover door. To prevent excessive dust and dirt from entering the equipment, it is important that the cover door be closed except when a loading or unloading operation is in progress.

This loading procedure may be further simplified. Some manufacturers have incorporated auxiliary features in their equipment such as pressure pad motion in conjunction with the head plate cover. The tape anchoring procedure may be eliminated by leaving a long leader on the tape take-up reel and threading the tape through the driving system from the supply reel. The beginning tape of the full reel has a corresponding mating leader spliced to it (Fig. 8-16). The two leader ends are manually connected together and the empty reel is turned a few revolutions.

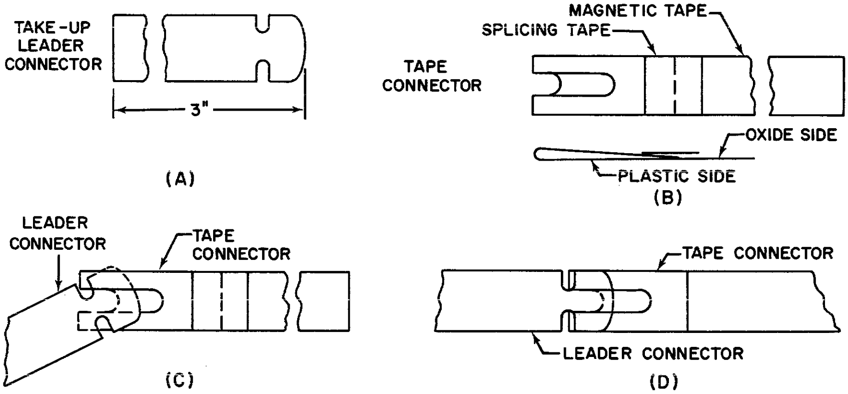
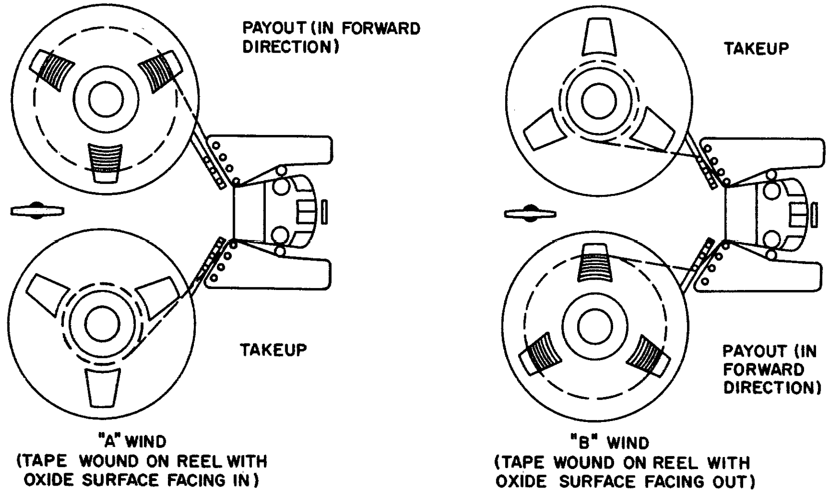


Fig. 8-16. *Tape-to-leader connection (RCA).*

Digital tape transports with other types of reservoirs have simplified tape loading procedures. The procedure for tape loading is quite similar to the previous description given for the tension arm reservoir. The tape is unwound from the supply reel and threaded through the head and capstan drive area and anchored to the take-up reel. Once the tape has been anchored to the take-up reel from the supply reel, the threading operation is completed. The dust cover door is then closed and the load button (locally) operated. Power is supplied to the closed loop servo system and tape is loaded into the tape reservoir (vacuum column, basket, or bin) until operating tape capacity is available.

A tape reel can be installed to accommodate either winding direction and oxide surface direction. In Fig. 8-17, the tape reel can be installed and operated with the oxide coating facing in or out.



"A" WIND (TAPE WOUND ON REEL WITH OXIDE SURFACE FACING IN)

"B" WIND (TAPE WOUND ON REEL WITH OXIDE SURFACE FACING OUT)

Fig. 8-17. *Tape threading with the oxide coating facing in or out (Potter Instruments Company, Inc.).*

Electronic Operations

The simplified logic diagram shown in Fig. 8-18 presents the digital tape transport as a digital building block. This illustration is neither typical nor representative of a digital magnetic tape transport. It is presented to simplify and clarify basic tape operations. Such a representation permits detailing digital operations without continual reference to the tape transport machines. This shorthand notation eliminates any need to include areas of tape operation that are not pertinent to the subject at hand.

The read and write amplifiers are shown at the top of Fig. 8-18. In addition, clocking and gating are shown to indicate the interrelationship of writing and reading with tape drive commands. For versatility, the output of the 1 side of the Run FF primes AND G-1 and G-2. Reading and writing can be accomplished in the forward and reverse direction. On the other hand, if AND G-1 and G-2 were primed from the 1 side of the FDW/REV FF, the same reading and writing operations could be performed only when the tape is moving in the forward direction. A single wire, the clock, terminates at the write amplifier, indicating that all parallel heads are energized simultaneously. The letter N inserted in the read and write wires denotes a multiple wire conductor of N wires. The AND gates are generally located in the tape control unit.

The section below the read/write operation containing forward, reverse, and stop operations is a simplified version of Fig. 8-9. It is sufficient to say that tape drive controls are provided and the exercise of the three controls will not cause or augment a tape drive malfunction.

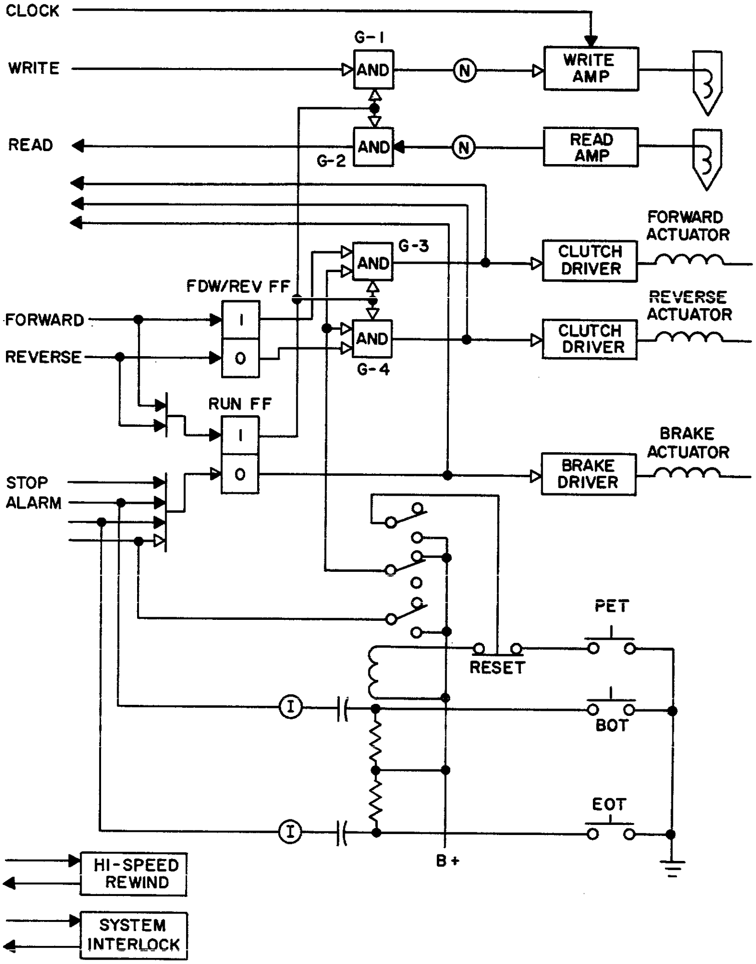


Fig. 8-18. *A digital module representation of a digital tape transport.*

Similarly, the closed-loop servo control system is not detailed. It is not subject to external control of the tape transport and is not represented in the tape logic diagram. However, this information is implied because it contributes to the system operation and may impose some programming restrictions. The high-speed rewind is shown for the same reason. Certainly, a high-speed wind command wire is necessary for mechanization and its termination pulse, but beyond this, the tape control unit must provide adequate programming control to ensure fail-safe operation. The built-in alarm function of the tape transport will be operated if improper tape applications ever occur. When in doubt, always make sure at the time of tape transport purchase how many fail-safe interlocks are included. After this, any additional safety is built into the tape control unit.

Some of the more obvious safety interlocks shown in the lower-right portion of Fig. 8-18 are related to tape. The beginning of tape (BOT) and the end of tape (EOT) are activated by the tape markers attached to the tape. The tape markers are used to supply a ground connection and generate a pulse that causes the Run FF to turn off the driving power and apply the tape brake. In the case of the physical end of tape (PET), a level is fed to the Run FF and the tape drive is permanently disabled until the malfunction is corrected.

There are other standard safety devices. Because writing automatically erases any previous recording on tape, a no-write lockout is required to prevent accidental erasure. A plunger-type contact switch is used to inhibit any writing operations when the contacts are open. To do this, a plastic protection ring must be placed in a circular groove molded in the back of the tape reel (Fig. 8-19). When the reel is mounted on the supply hub, the ring depresses the plunger shaft protruding from the tape deck front plate, closing the switch, and allowing current to flow in the write heads. After writing is completed, the protection ring is removed. In some cases, where valuable tape reels must be protected, the tape is rewound off-line onto a reel that does not have any protection ring mounting. It is impossible to engage the plunger switch contact when this tape reel is installed. When the protection ring is on the reel in the groove, the plunge shaft rides freely and the switch contacts are always closed. The same write protection may be obtained using an orifice in the same location instead of a plunger switch contact. In this setup, a vacuum switch is activated when the protection ring covers the orifice opening. When the protection ring is not on, the vacuum cannot be generated, the switch remains open, and no writing will occur.

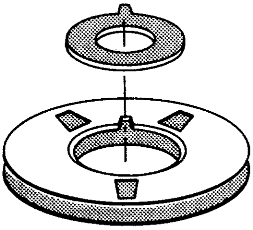


Fig. 8-19. *The write interlock protection ring.*

Write (Record) Logic System

Start-Stop Control

A start-stop control logic diagram is shown in Fig. 8-20. Basically, the tape must run for a short period of time before any writing or reading can

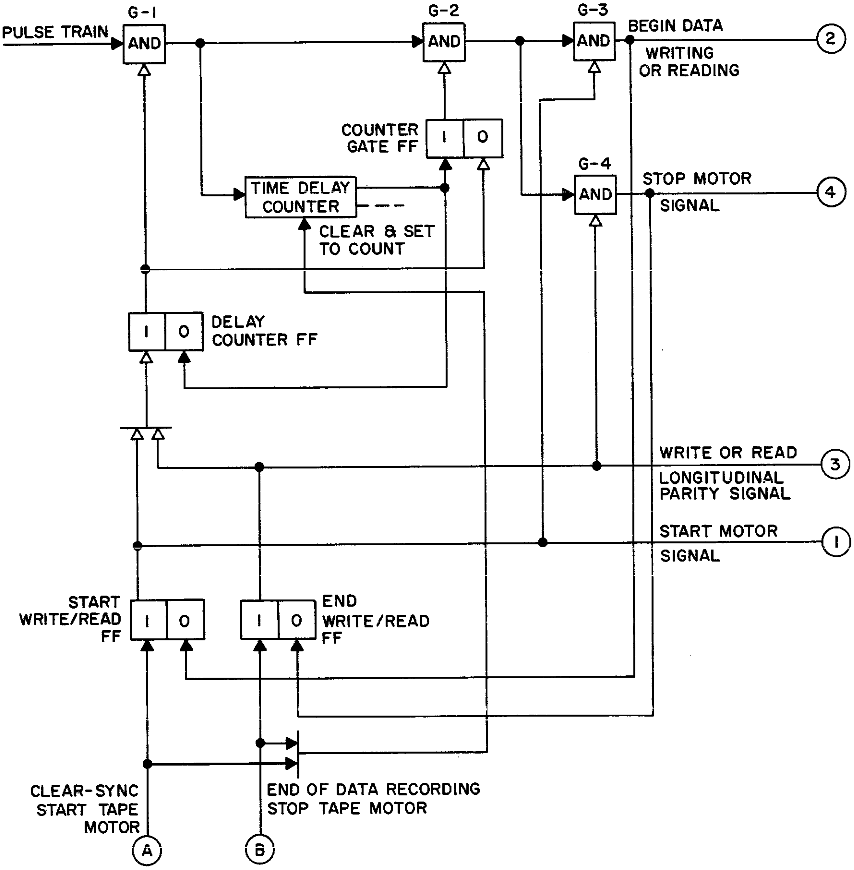


Fig. 8-20. *Start-stop control.*

begin. Similarly, all writing and reading must be completed before the brakes are applied to stop the tape. A typical programmed sequence of writing would be as follows. A writing command is given at terminal A and stored in the Start Write/Read FF. Then a time delay is initiated at AND gate G-1 via the Delay Counter FF. Simultaneously, a tape drive command is given at output terminal 1 (Start Motor signal). After a specified time delay, the Counter Gate FF is set, a pulse passes through AND Gates G-2 and G-3, and a Begin Data Writing signal at output terminal 2 is sent to start the writing on tape.

When the data to be written has been completed, additional time may be required to write additional digits for control and checking purposes. The end of data signal to initiate the stopping of tape is sent to input terminal B. The time delay initiated by the End Write/Read FF signal permits the counting process to begin via the Delay Counter FF. Simultaneously, on output terminal 3, the Longitudinal Parity signal is used to write any digits prior to the application of the tape brakes on output terminal 4. After a prescribed time interval, a pulse passes through AND gates G-2 and G-4 and out through terminal 4 to turn on the tape brakes. For simplicity, the delay time to start the tape motion and to stop the tape is identical. Generally, the start delay is in the vicinity of 2 to 3 milliseconds and the stop delay is defined in terms of the gap distance of a write/read head. In the figure, a separate dashed line is used from the counter to indicate a separate time delay to stop the tape. The time delay counter is always cleared prior to initiating a counting operation. The output sequence of operation is the sequence of numbers 1 to 4.

The sequence and circuitry for the read operation are similar. It takes the same amount of time to start the tape whether a write or read command is in force. During the read operation, the end data must be read prior to the application of brakes.

A simplified logic diagram of the time delay is shown in Fig. 8-21. For this application, the writing operation is completed when the longitudinal parity is written after the data have been recorded (see Chapter 7, *Organization of Data on Tape*).

Word Disassembly

As indicated in Fig. 8-1, a character buffer is required to store data momentarily so that several operations in the preparation of the writing process may be performed. A single character register of one tape line is shown in Fig.

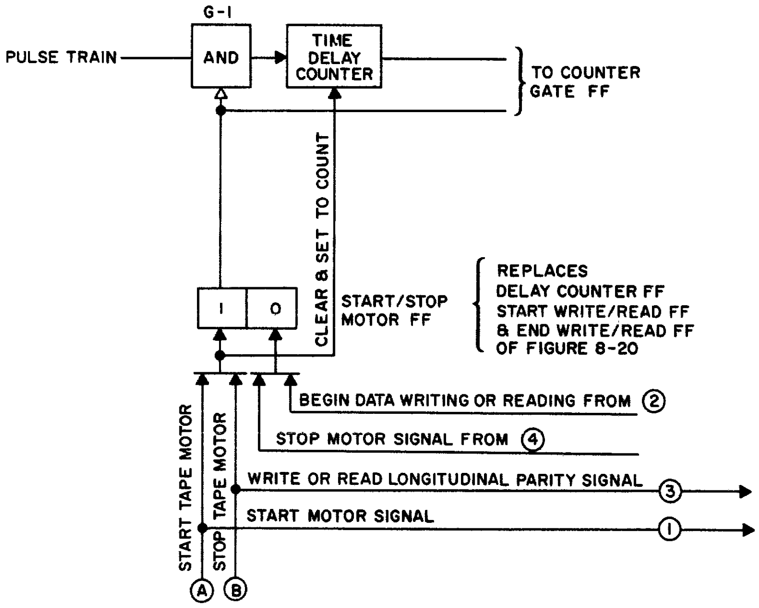


Fig. 8-21. *Simplified diagram of Fig. 8-20.*

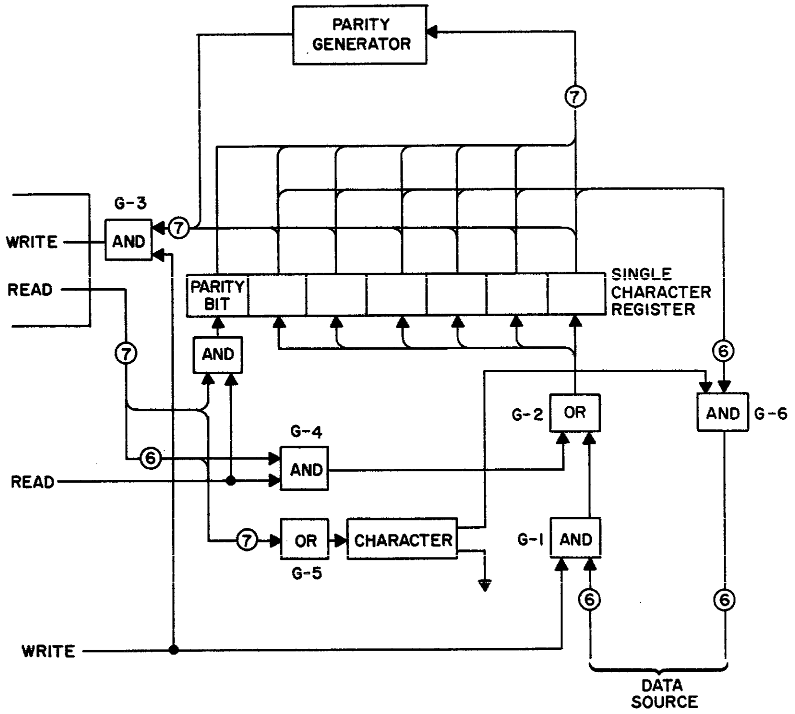
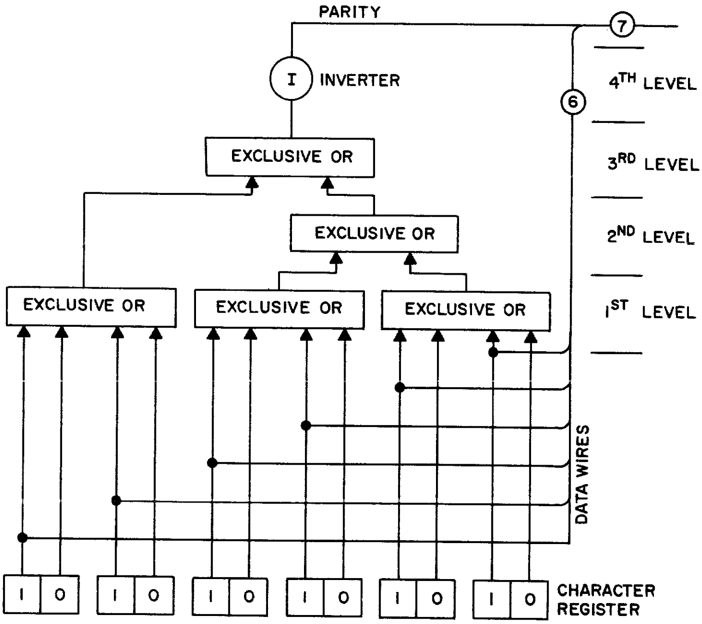


Fig. 8-22. *Single character buffer logic for read/write operations.*

8-22. A six-bit character contains the data to be written and one-bit parity must be generated for each tape line. The logic diagram shows a write and read operation in a sequential manner. This means that either a write operation or a read operation is in progress, but not both simultaneously.

To write, information is disassembled into sizes of one tape line and stored in the character buffer through AND Gate G-1 and OR Gate G-2. Additional controls are supplied to gate the data and the parity through AND gate G-3 and the information is written on tape by the write amplifiers. A seven-channel recording is shown (6 data bits and 1 parity bit).

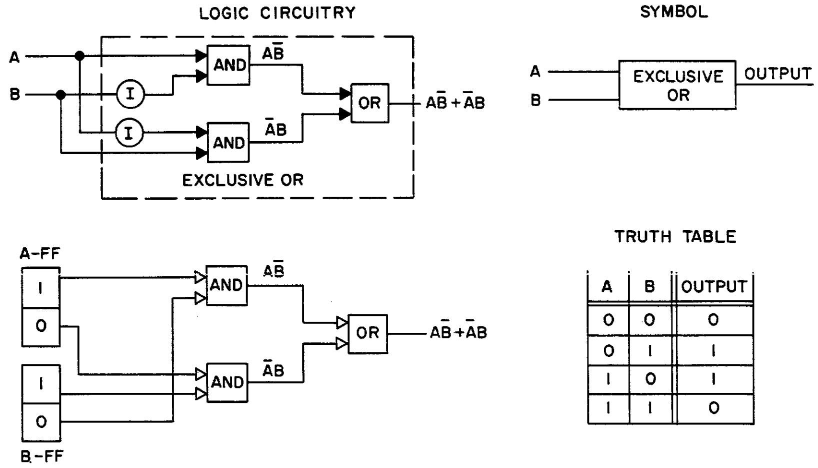
A parity generator operates concurrently with the single-character register. Once the data has been established in the character register, a parity check is performed. Before AND gate G-3 is enabled to write the data on tape, a check is made to see if the total of 1's in the register is odd or even. Depending on the particular parity used (odd or even), the contents of the character register and the parity are written on tape via AND gate G-3. A parity generator is shown in Fig. 8-23. The character register supplies the hold-down signals (d-c levels) for the gates to perform their logic operation. Tracing through the five Exclusive OR Gates, the output is representative of the character register content of 1's.



BIT POSITIONS AND VALUE						TOTAL 1'S	PARITY BIT	
1	2	3	4	5	6		ODD	EVEN
0	0	0	0	0	0	0	1	0
0	0	0	0	0	1	1	0	1
0	0	0	0	1	0	1	0	1
0	0	0	0	1	1	2	1	0
0	0	0	1	0	0	1	0	1
0	0	0	1	0	1	2	1	0
0	0	0	1	1	1	3	0	1
0	0	1	0	0	0	1	0	1

Fig. 8-23. *A parity generator.*

An odd parity will be illustrated. A truth table of an Exclusive OR is shown in Fig. 8-24. The output of an Exclusive OR is a 1 when either one of two inputs is a 1. If both inputs are the same (0's or 1's), there is no signal output. Therefore, an output exists if the two inputs to the circuit are different. A few possible binary digits are illustrated in Fig. 8-23 and the equivalent parity output is given. The value of the parity is 1 when the total sum of the 1's is even (odd parity). If the Exclusive OR's are attached to the 1's of the flip-flops, there would be a 1 output at the third level. Then, a parity 1 would be recorded along with an odd number of 1's (from the data bits). This would be logic error. Instead, the third level output is inverted and a 0 is written in the parity track. When the total number of 1's of the character register are even, the output of the third level of the Exclusive OR's is a 0, the inversion of which is a 1.



TRUTH TABLE

A	B	OUTPUT
0	0	0
0	1	1
1	0	1
1	1	0

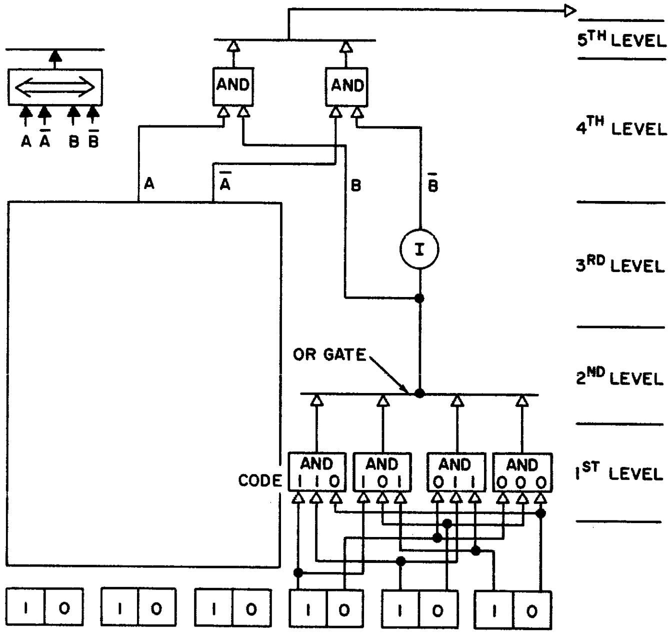
Fig. 8-24. *Exclusive OR operation.*

A five-level system using a matrix decoder and an equivalence symbol are shown in Fig. 8-25. Here, if each section (3-bit decoder) output is even, the equivalence circuit will have an output to give an odd parity. If either section is odd, the equivalence circuit will be 0 and the total seven bits will have an odd number of 1's.

It is possible to misinterpret logic diagrams. Following the initial ground rules of only positive logic and noninverting AND and OR Gates, the parity generator shown in Fig. 8-23 comprised of Exclusive OR gates might be preferable to the matrix decoder shown in Fig. 8-25. This Exclusive OR has only four levels (or two paired delays) and the matrix method has five levels (or two and a half paired delays). It would appear that the time delay through the matrix operation would be longer. Assuming that any gate module (AND, OR, and Inverter) costs approximately the same as any other and has approximately the same delays, each Exclusive OR has a minimum of two levels and three gates (Fig. 8-24).

Parity Generator

	Exclusive OR	*Matrix*
AND gates	10	10
OR gates	5	2
Inverters	1	2
Total Modules	16	14
Levels of logic	7	5
Module Difference	$\frac{14}{16} \times 100\% = 87.5\%$	
Level Difference	$\frac{5}{7} \times 100\% = 71.4\%$	



BIT POSITIONS AND VALUE				TOTAL 1'S	PARITY BIT	
	3	2	1		ODD	EVEN
OUTPUT AT A OR B	0	0	0	0	1	0
	0	0	1	1	0	1
	0	1	0	1	0	1
OUTPUT AT A OR B	0	1	1	2	1	0
	1	0	0	1	0	1
OUTPUT AT A OR B	1	0	1	2	1	0
OUTPUT AT A OR B	1	1	0	2	1	0
	1	1	1	3	0	1

Fig. 8-25. *Matrix decoder and equivalence logic for parity generation.*

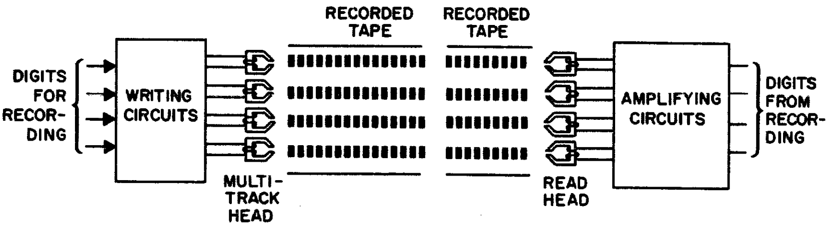


Fig. 8-26. *Writing digits on tape.*

The figures indicate that the matrix method of parity generation requires 12.5% less hardware and is 28.6% faster. But, the initial assumptions that each gate costs the same and has the same time delay is not realistic (nor are the other assumptions of the problem). However, the logic presented is sound. The reader is cautioned to avoid the pitfalls of oversimplified logic diagrams. When getting down to the specifics of implementation or hardware count, each alternative approach must be considered in terms of the actual digital module to ascertain a true module count. When using NOR or NAND digital modules, the inverting modules do afford economies and are preferable for certain types of logic operations.

Simultaneous Write Operation

Earlier chapters examined tape skew in terms of mechanical operations. Here, the problem of interchannel time displacement is viewed from an electronic circuit point of view. Basically, the main objective is to write the data on tape in such a fashion that any tape transport may be used to read the same tape. This is accomplished by placing the data on tape in a straight line.

A typical recording system is illustrated in Fig. 8-26. A multitrack recording takes place across the tape width when all the inline heads are energized. If excellent head construction and perfect head alignment exist, then with proper tape guiding the data written on tape would appear in a straight line perpendicular to the direction of tape travel (Fig. 8-27A). This reel of tape would be successfully read on any tape station facility of acceptable quality. The reason for this certainty is simply that the tape line of finite width is perpendicular to the reference edge of the tape. All tape handlers using the same reference edge and having adequate head construction and alignment will read the tape from the reel properly.

Now assume that a tape station writing operation placed the data on tape as shown in Fig. 8-27B. If the tape was read on the same equipment and

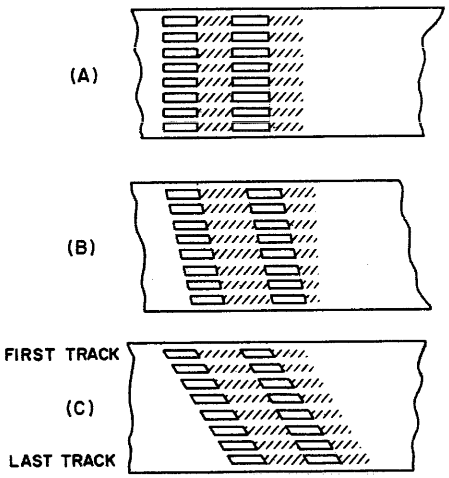


Fig. 8-27. *Effect of skew with increasing digit density: (A) no phase displacement; (B) phase displacement; (C) overlap due to insufficient separation.*

head (sequential read/write operation), no problems would develop. The tape would arrive at the head gap in the same manner as the data were written. If a dual gap head is used, though, each gap (write or read) would be constructed independently of the other, and each gap need not compensate for the other. In worst-case design, one gap can tilt from left to right and the other from right to left. Therefore, the first written bit would be the last one to be read. The same problem can occur when the tape is used with another tape station facility.

Before any remedial measures can be taken to correct interchannel time displacement, it is necessary to ascertain the magnitude of the displacement for each track for a writing operation. A master tape for head alignment may be used with an oscilloscope with a camera attached or a series of tape lines can be written and the tape reversed and read on the opposite side (layer side). With the latter method the skew is effectively doubled. Again the oscilloscope camera operation is used to obtain a permanent record. There are many variations of both methods.

For the moment, we are interested in determining the time displacement (phase) of each track. When this is determined, a delay line can be inserted in each writing track and adjusted to summarize the total amount of time delay for each track. In this manner, the data is effectively written on tape approximating ideal conditions.

It is possible to obtain interchannel time displacement as severe as that illustrated in Fig. 8-28C, overlapping. Here, the written information can not be retrieved with standard tape reading methods. When overlapping occurs, the data arrival of the last (slowest) track takes place after the arrival of the next line word in the first (fastest) track. The most recent data in the first track erase or remove their predecessor prior to the arrival of the last data track during a reading operation. There are electronic methods of retrieving data under these conditions. A special deskewing buffer operation is used.

Write Problem Areas

It is essential that correctly written data be retrievable. What may be correct with one tape control unit may be unacceptable on another tape control unit. A few specific problems concerning writing techniques will now be illustrated.

A beginning or reference point must be established on the tape so that writing and reading operations can be repeated. The beginning of tape (BOT) marker serves this purpose. The new supply reel pays out tape until the BOT marker is sensed and the tape is stopped. The tape is then ready for operation, a write signal is given, and the tape is accelerated. After a specified time interval, data is written on the tape. During the rewind, the edge of the BOT marker will be sensed and the tape stopped on the marker. In this fashion, the same procedure may be repeated for another write or the data may be read.

This appears to be an adequate write procedure, but there are pitfalls. Consider a seven-bit tape format using NRZ modified. Suppose that at the first writing operation the writing amplifiers are turned on concurrently with tape acceleration. The digits are in a 0 state, but the tape is being magnetized. The first tape line is written from the character register and all data is written sequentially. When the tape reel is completely written, it is returned to its load point. A reading operation is next. The tape is accelerated and, if the tape has any imperfections between the BOT marker and the first tape line, a change in magnetic field will be sensed. It will be assumed that this read signal is a valid signal and, as such, a reading operation will be involved. Immediately, a tape word will be read that results in the parity checker indicating error, or the tape flaw could cause a double error that a single parity will not detect on one tape line or several lines. The tape must be stopped to realign the data in its proper timing sequence.

Before showing how this is avoided, it will be advantageous to examine another similar problem with this type of data format and coding. In this case, after the data has been written, a longitudinal parity is written a sufficient distance after the last written data has been read (Fig. 8-20). If the write amplifiers are kept on the tape is magnetized, and if the amplifiers are turned off (no current through the write head), a change in magnetization occurs. This change in state can be interpreted as a new tape word. When the write amplifiers are left on, they will have to be turned off at a specific point.

By finding a solution to the second problem, the first problem becomes solvable. Generally, after the data is written and the longitudinal parity is inserted and read, the tape is still in motion and the write amplifiers are on. When the tape is stopped the write amplifiers are turned off. To continue to the next write operation, the write amplifiers are turned on before the tape is accelerated and have the same magnetization direction as when the tape was stopped. Under these conditions, from the last written parity (longitudinal) to the beginning of the next written word, the tape is magnetized in one continuous, uninterrupted direction, which poses no problems. However, the area between the last of the data of the previously-written information and the longitudinal parity may contain a tape flaw. One way to avert this possibility is to generate a time base that begins with the last information written that will inhibit any reading and ends just before the longitudinal parity. The inhibiting action is removed in time to read the longitudinal parity. (Another means of avoiding the problem is to write "dummy" words that effectively maintain synchronous operation until the parity tape line arrives.)

In regard to the parity checking error of the first problem, the write amplifiers are turned on before accelerating the tape during the intermessage gap length. The same instruction is used for every operation since there was a previous magnetic state. But, there is no previous magnetic state at the load point. Therefore, a distinction must be made relevant to the load point. A separate time delay is made during the write process. Only when writing from the load point (no previous magnetic state) are the write amplifiers turned on and the separate time delay is used with the first written data.

Auxiliary Functions

Write/Read Concurrently. A read after write may be considered almost common practice today. With this checking feature, the tape is read immediately after writing to check the writing operation's vertical or horizontal parity, or both. This checking feature should not be confused with reading and checking the written data by comparison. It takes a finite time for the tape to move from the write gap to the read gap. Also, since a heavy write magnetic field is present while a reading operation is in force, magnetic coupling may influence a reading operation or simulate a malfunction or a tape flaw. Therefore, preventative measures are necessary.

In the IBM tape stations, a magnetic shield is inserted to reduce or eliminate any strong magnetic field pickup. The dual gap length has been decreased considerably. In the past, the dual-gap length distance was 0.5 inch, which was reduced to 0.39 inch, then to 0.3 inch, and, most recently, to 0.15 inch. In the IBM 7340-7640 Hypertapes, the distance between the two gaps is 0.15 inch and an inter-record gap distance is approximately 0.45 inch (start-stop distance).

Format Coding. Generally, writing is accomplished in the forward direction. Writing in the reverse direction may not be justified unless there is a turnaround process at the end of the tape. However, reading in the forward and reverse direction has merit, and more and more tape stations are including this feature. To accomplish reading in both directions, the organization of data on tape must be bidirectional.

The data on present-day tape is unambiguously marked with start message symbols and end of message markers. With this data format, the write problem areas discussed earlier are minimized. Sensitivity to tape flaws and discontinuous magnetic fields is reduced in the area of the load point. The start message symbol is a unique marker and is mechanized to begin a reading operation. The end of message marker may be used for updating data on tape. The data to be retained is sensed for its end of message marker before selective editing, and then writing is permitted. Another method of updating is to note the end of message marker of the last retained data and await the start message symbol of data to be rewritten. After leaving sufficient unused tape for dual gap length distance, selective editing or writing begins. In the former approach, the end of marker is the reference point to measure from before selective writing. In the latter method, the end of message marker performs an alerting function, and the start message symbol initiates the writing operation. The second method requires an unused tape portion between the start message and the first written data tape line.

The write/read concurrently operation requires duplication of facilities whereas a write-or-read does not.

The concurrent write/read operation and the read in the forward and reverse direction operations are primarily accomplished in the tape control unit. Every tape station must be capable of writing and reading, but not necessarily simultaneously. The transport is capable of moving tape in either direction, independent of the tape electronics. These auxiliary features are independent of the tape transport, except for the dual-gap magnetic head. As stated earlier, tape recording versatility is achieved by the tape control electronics and not the magnetic recording device. Therefore, the features of magnetic recording devices do not, themselves, indicate which tape recording facility is the best.

Read (Playback) Logic System

There are many similarities between reading and writing on tape in the operation of the tape transport. The tape drive operation, tape motion, and tape threading are independent of either write or read operation. The method of start-stop operations is identical, with the possible exceptions of specific time delays. Where one method (write) may originate a function, the other (read) is fully determined and performs the complement to complete the process. The process of computer word disassembly and digital encoding during writing is complemented by computer word assembly and digital decoding during a read process. Such areas as organization of data on tape are left to the design engineer for determination.

The Read Operation

In Fig. 8-22 the data (or stored information) is on tape. Since a sequential read or write operation was assumed, a read/write switch is activated by the read or write address lines coming into the unit. For reading, the tape is moved and the read amplifiers supply the signal inputs to AND gate G-4 and OR gate G-5. Any signals present on these read lines pass through G-4 into the character register OR gate G-2. Concurrently, the same seven lines are OR'ed together in G-5. G-5 detects the presence of the first arriving signal on all seven lines and generates a delay, commonly known as a character gate. Basically, the parity generator evaluates the six data bits by generating a parity (as does the write operation) and comparing it with the parity bit in the character register for equality. This operation is completed on a time schedule set by the character gate. The character gate determines the elapse time from the arrival of the first signal on the seven read wires and initiates the transfer of the contents of the character register to the data source via AND gate G-6. Before the next read tape line arrives, the character register must be cleared of its contents. This can be scheduled with the use of the character gate, or a 14-wire destructive read-in may be used. In the read-in arrangement, there are 1 and 0 wires for each bit that set the flip-flop to a 1 or 0 state, depending on the state of the wire going to each flip-flop.

The read/write operation of Fig. 8-22 is based on a 7-track data format using NRZ modified coding.

In this read operation, not only is a parity check made on the contents of the character register as in the write operation, but a comparison is also made with the seventh bit parity to ensure a valid read-back operation. During a write operation, timing or clock pulses are supplied simultaneously to activate all the write heads. In the read-back operation, the write clock pulse is stored in the form of a tape line. Therefore, it must be reconstructed from each tape line. Each tape line is of finite width. The character gate is activated on the first arriving signal. Time is marked off to permit the slowest arriving signal to be stored in the character register. After this, the input gates to the character register are turned off and its contents are checked. If, for any reason, all the bits on a tape line are not read in the time interval set by the character gate, an error will be detected by the parity generator.

Simultaneous Read Operations

From the writing operation description, it can be seen that every attempt is made to place every written tape line perpendicular to a tape edge and equidistant from each adjacent tape line. Every written digit is within its cell location. However, during the reading process, it is almost impossible to activate simultaneously all the read heads. On the other hand, all the written digits on each tape track will eventually activate their corresponding read head. Some fixed time interval must be assigned in terms of cell length to permit the retrieval of a tape line (character word) in an error-free manner. The digit layout on the tape in Fig. 8-27 reveals that there is an upper boundary beyond which data retrieval is impossible. The character gate, therefore, is made as long as possible to await all the digits from each tape track and obtain a tape line without error. If it is too long, however, the next tape line will cause an error and, also, there will not be enough time to permit the transference of the data from the character register. If the character gate is made too short, the character register input gates are turned off too soon, and frequent errors will be detected in the parity circuits. Obviously, the character gate is a fixed adjustment that compromises the data layout and tape recording device. Probably, the weakest links in the read/write operation are the resolution capability of the read head and the problem of ascertaining the absolute width of a single tape line. If these two conditions can be improved, higher effective writing densities will become available.

Word Assembly

Even if the digits are stored in an ideal manner on tape, there is no assurance that each tape line will be read at a constant fixed rate. Therefore, word assembly is more difficult than a write operation. During the writing operation, a stabilized clock is used to disassemble the computer word and place it on tape. At this time, any control and edit information is generated

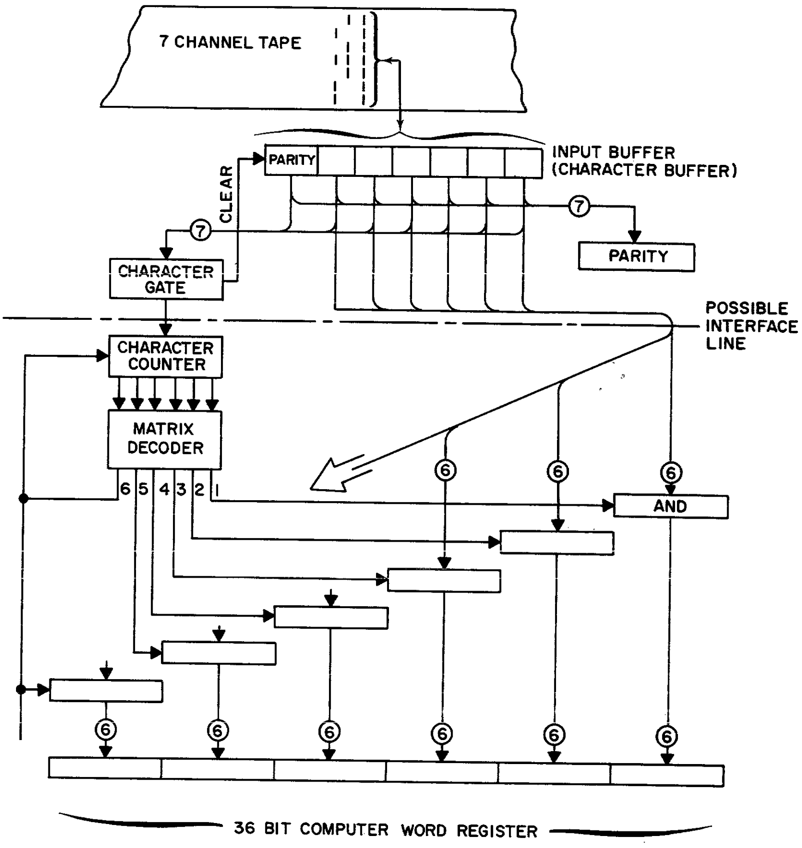


Fig. 8-28. *Computer word assembly.*

and placed on the tape also. With the read operation, however, no master or stabilized clock is used to define a cell length in units of time. This must come from the tape data. Any additional information generated during the writing process must be "stripped" before the stored information is transmitted from the tape station to any data receiver.

Two methods will now be described to illustrate the construction of a computer word. The process of accumulating tape words will be shown based on a 36-bit computer word. The character register buffer presented in Fig. 8-22 will be used as the input buffer for this description.

Figure 8-28 illustrates a typical process of accumulating a fixed number of tape lines in terms of a computer word. Many control lines and the location of the computer word register are not defined. However, the operational process is important and the use of a fixed format tape layout will become apparent. Digits are read from tape as shown in Fig. 8-22. The data are momentarily stored in the input buffer and the character gates detect the first received signal on one of the seven lines. Concurrently, the Character gate output advances the character count by one. The parity is checked for each line.

Parallel transfer of the input buffer contents is accomplished by the Character counter with the number 1 wire enabling the data to be transferred to the first six bit positions of a 36-bit register. The Character gate clears the contents of the input buffer and awaits the reading of the next tape line. This process is repeated five more times until the Character counter stores a count of six. At this time, a few basic system operations are necessary. A computer word has been assembled. Each tape line has been read and no parity errors have been detected. The information is assumed to be correct and is ready for routing.

The process shown requires six parallel 6-wire AND gates or 36 AND gates. (A more detailed parallel AND gate description is shown in Fig. 8-29.) Only set and reset flip-flops are required in the input buffer and computer word register. If the computer word register is not an integral part of the tape unit, then only 6 data wires and a strobe wire from the Character gate are necessary to transfer the contents of the input buffer to a remote location.

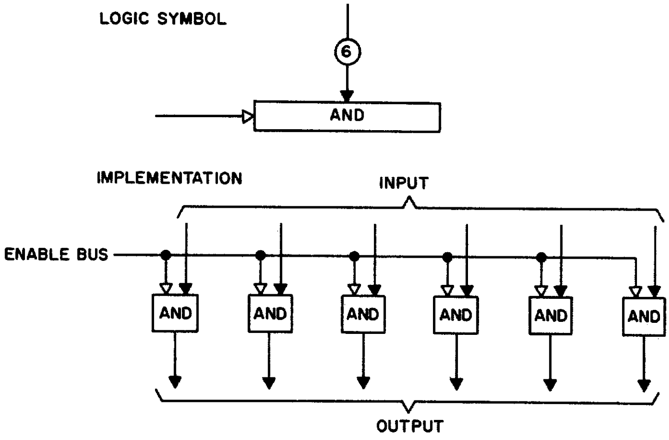


Fig. 8-29. *Detail description of a parallel multi-AND gate operation.*

Everything below the dashed line in Fig. 8-28, including the Character counter, matrix decoder, AND gates, and assembly word register (36 bits), is physically located elsewhere. Only a nine-wire cable plus a few control wires are adequate to dispatch the data from the tape. The interface arrangement shown is very simple with most of the complexity beyond the tape station.

The second arrangement for tape word assembly is shown in Fig. 8-30. Here, the computer word assembly register is a shift register. The input buffer, using only six parallel AND gates, drops the first six bits into computer bit positions 36, 35, 34, 33, 32, and 31. They are shifted one position to the right. After five transfers and five shifts to the right, all the data have been accumulated in the computer register. The other components shown in Fig. 8-28 above the dashed line, including the Character gate and parity, are necessary. The Character gate output to advance the Character counter is mechanized to supply the shift pulses to the word assembly register. The Character counter is still required to identify each transfer operation and index each computer word.

Again, the parallel and shift register approach are system techniques of accomplishing the same operation. The shift register approach eliminates five sets of six parallel AND gates or 30 AND gates. Trade-off for this reduction requires six shift registers, each of six-bit capacity. A shift register is a two-wire connection requiring a triggerable or multipurpose flip-flop. This assembly register is more complex and costly than one of 36 set and reset flip-flops.

Auxiliary Functions

As with the writing operation, there are various methods that simplify the operation of the tape station and reduce its operating time. Again, these auxiliary functions are accomplished by the tape control unit and not the tape transport itself.

Read in Both Directions. It is simple to read in the forward direction. The reference or load point is used to count from. Normally, when starting from the beginning of a tape in a seach operation, the selected information may be at any length of tape. Therefore, if it is required to go at random to any point on the tape from the load point, the average time of a tape search is 50 percent of the time it takes to run a full length of tape in the forward direction. On the other hand, if the tape can be operated in both directions for a read operation, a considerable saving of time can be achieved. The search may be performed by running the tape in the forward direction on the first request and leaving the tape at the location where the data are located. The next request is likely to be before (reverse direction) this location or beyond it. With a read in both directions capability, the average time required for this second selection is one-third of the average running time of a tape reel length at normal operating speed (see Appendix 3).

The arrangement for reading in both directions is not difficult. As shown in Figs. 8-28 and 8-30, the read information is stored correctly by having the six parallel AND gates enabled in the reverse order and the shift register operated in the reverse direction along with the data read-in at the opposite end of each shift register. The major problem is the data format and the layout of control and edit information on tape.

Error Detection and Error Correction. Checking systems were covered in Chapter 7. The vertical or lateral parity checking per tape line was shown in Fig. 8-22. The parity unit was multiplexed for either a write or read

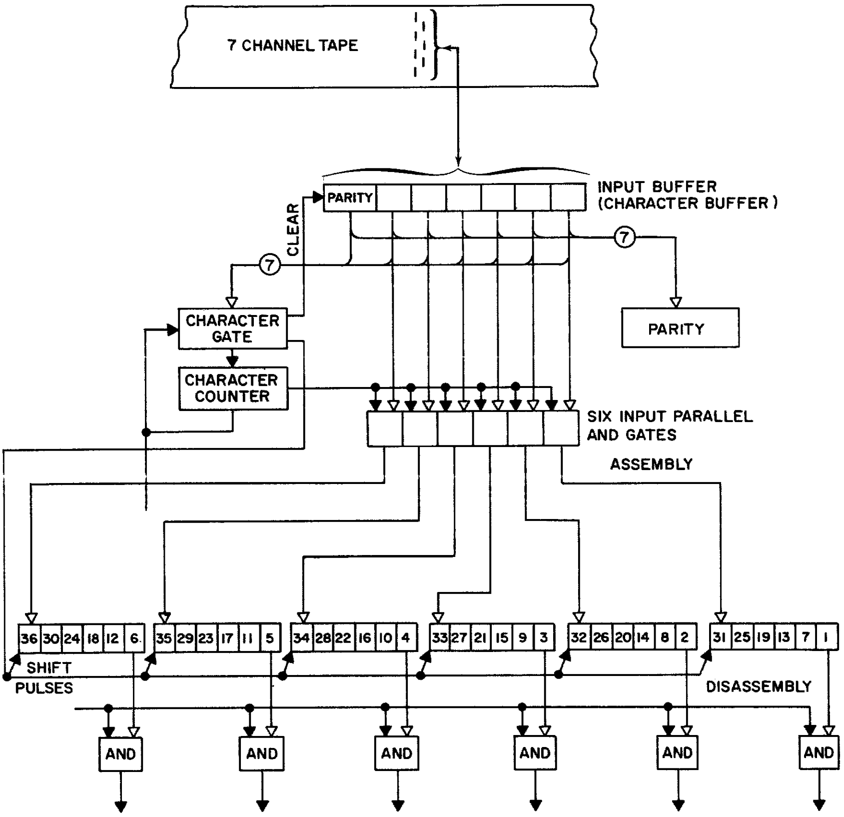


Fig. 8-30. *Computer word assembly and disassembly using a shift register.*

operation. The longitudinal parity checking is done on a message or block basis. It is written or read after the completion of a message. On this basis, each tape track is read and accumulated in an assembly register. The execution of the information is held in abeyance until an overall check is made of the data ensemble.

The longitudinal checking method is a simple operation. Beginning with a set of flip-flops, one for each track, each 1 digit is counted. After a complete group of tape words has been read, an even number of 1's would restore the flip-flop to its original state. On the other hand, if an odd number of 1's are read, the flip-flop would be left in a 1 state. This action is summarized in Fig. 8-31. In a reading operation, a checking operation is always performed, while a writing operation has a check generated. Therefore, a reading operation must not only store the checking digits but must also generate a set of digits to make a comparison. Furthermore, on the basis of an error, a prescribed routine, set up in advance, must be followed. Prior to acceptance of

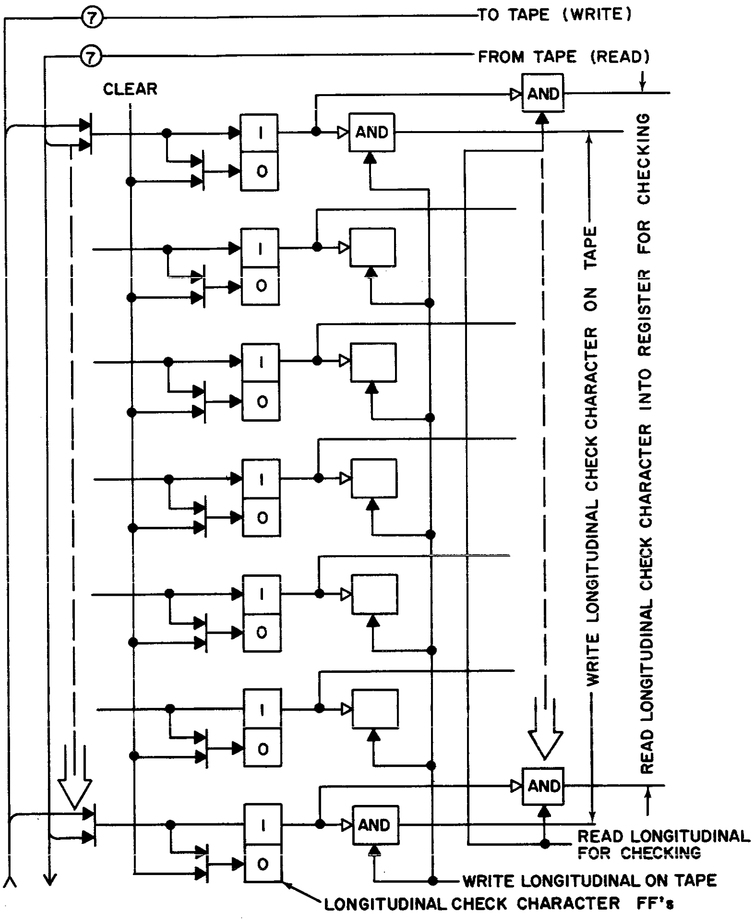


Fig. 8-31. *Longitudinal parity checking.*

read data, every check, datum, and equipment operation must be verified. Effectively, a lengthy check procedure is invoked for a reading operation. Before a tape station is released and put into standby, these checking operations will either indicate a repeat or a completion of a reading operation.

System Integration

Although digital tape recording is complex, it is apparent that information to be written on tape is disassembled in an orderly manner. This procedure, when followed correctly, can accept any digital data in any form and code the information so that it is compatible with the tape recording facility. Even when the information is in analog or optical form, there is no drawback in

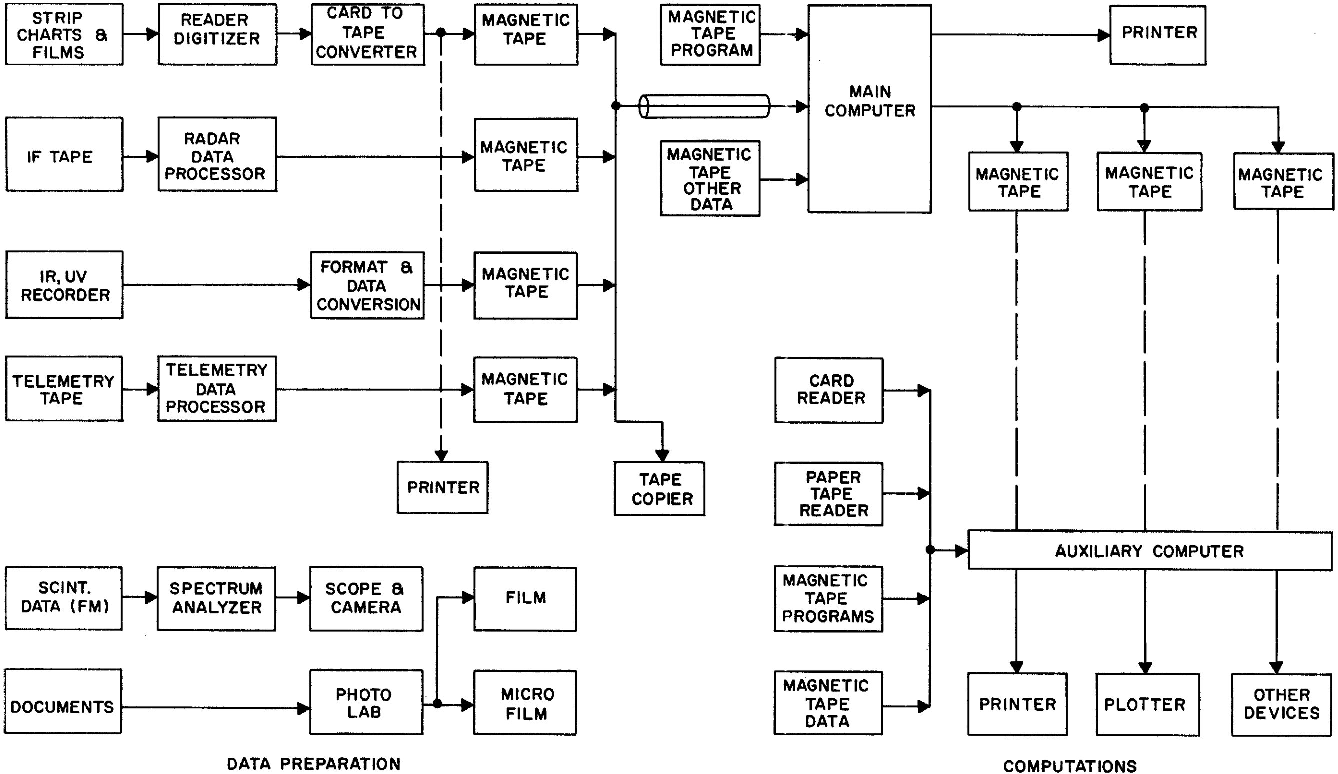


Fig. 8-32. *Data reduction center.*

using tape recording as a means of data preservation. There only remains a conversion process of analog to digital and a transformation of one medium into digital tape to transcribe information of any form onto tape. The data reduction center shown in Fig. 8-32 illustrates the possible variety of information and the storage media. Each type of data and its storage form are processed and reduced to digital magnetic tape. The main computer uses only magnetic tape as its input and output peripheral equipment with the exception of a printer output that is used as a monitoring device. In the event a computer operation is to be checked, printout is called for verification. To reduce the laborious chore of operating slow-speed peripheral devices with the main computer, an auxiliary computer of limited capability is used off-line to the main computer. As shown, the results of the main computer (tape reels) are shared with the auxiliary computer on a common tape transport or the tape reels are removed and assigned to the auxiliary computer operation. Any device containing information in digital nomenclature with tape units is used in the operation with the auxiliary computer.

In Fig. 8-32, the associated equipment complexes are not necessarily required to be housed in one building. As a matter of fact, it is common practice that the equipment complexes be widely dispersed throughout the country. This does not present a problem. The connective cable can be a communication transmission line joining any data source to a computer installation via a data link. The data link is not limited to a hard-wire system of point-to-point connection. The advent of high-speed data modems permits the collection of data over wire or through the air, removing all restrictions.

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9

Computer Applications

In this chapter, digital magnetic tape recording principles are applied to several tape recording applications. The tape recording systems to be examined include computer installations, data gathering systems (real time and non-real time), and data communications systems. Each system implementation will emphasize some facet of the digital tape recording area whether it be compatibility of equipments, organization of data on tape, speed limitations, code translation, format conversion, or tape recording operations.

Computers are a prime user of digital magnetic tapes. Presently, the internal computer operational speeds in nanoseconds (one billionth of a second, 10^{-9} second) find the tape recording operations in milliseconds (one thousandth of a second, 10^{-3} second) to be rather slow. This disparity in operational speeds between the computer and its peripheral equipments presents a problem. Matching of input-output devices to the computer is necessary for more efficient operation. The computer input-output units consist of storage registers for data, controls, synchronization, and other means of communication to maintain a flow of data between the computer main frame and its external equipment. Since the computer is much faster than its external equipment, it may perform calculations or other internal operations only when sufficient interlocks are installed to prevent interference. When a number of concurrent operations are being performed, the computer can be relieved of some housekeeping details by delegating certain autonomous controls to the peripheral devices. Within the device unit, a subcontrol station is established to "talk" to the computer and relay the "message" to the peripheral device. However, agreement of authority and procedures are necessary. Therefore, the details of preparing the data and their information content (data and control) are spelled out concisely.

The speed of operation has a direct bearing on the cabling structure configuration between the computer and its external equipment. Consequently, the tape control unit becomes the substation control for the external digital tape recording device. The tape control unit is assigned responsibility in areas of synchronization, transfer method, input-output configuration, and scheduling, compatible with and under the direction of the computer. In this manner, many tape control units are operated and controlled by the computer. Each tape control unit has an array of assigned tape transports, as depicted in Fig. 9-1.

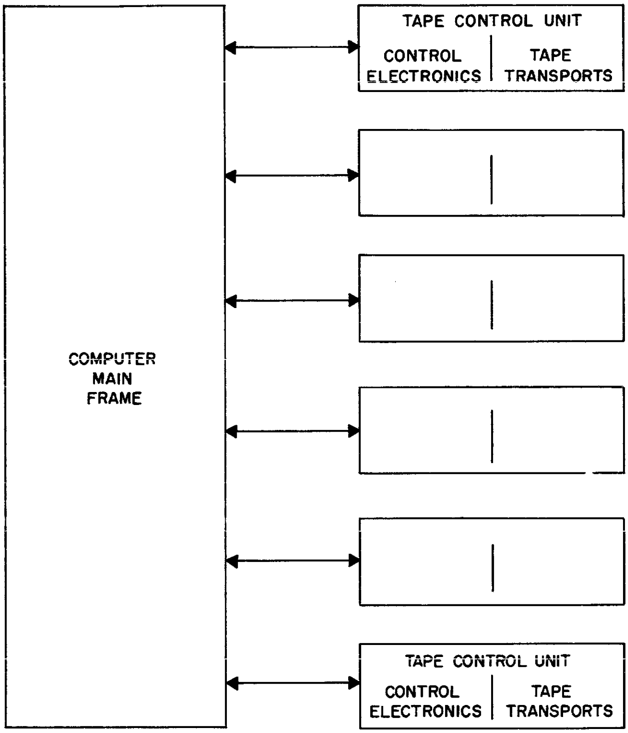


Fig. 9-1. *Computer and tape control unit configuration.*

The computer indirectly controls the tape recording device via the tape control unit. The computer capacity of tape transports is defined in terms of tape control units. The tape control unit has a fixed capacity determined by its command instruction repertoire. The maximum number of tape transports under the supervisory control of the tape control unit can be increased with a commensurate loss in speed. The range of tape control unit configurations is extensive (a few arrangements will be examined under *Computer Systems* later in the chapter).

"Data gathering" is an all-inclusive term. In a data gathering tape recording system some events are scheduled while others may occur at any time (random or unpredictable). When data occurs at random, tape recording is done on a real time basis. When time is not pertinent and no deadline is required, tape recording operations are classified as nonreal time. A few operations that fit this category are punched card and punched paper-to-magnetic tape, strip charts-to-magnetic tape, tape-to-printout, and plotting board operations. Generally, any tape operation not required to meet a time schedule is considered a nonreal time operation.

Nonreal time and off-line tape recording operations requiring extensive tape transports are tape translators and format converters. Valuable information may be collected and disseminated if data availability and format are convenient and economical. Digital magnetic tape makes this possible. Any information that can be reduced to digits can be recorded. Large masses of data can be stored on tape. Furthermore, the language of one computer can be translated into the language of another computer. Since there are a number of tape formats in use, the tape translation operation also invariably requires a format conversion and tape duplication of records. At a more advanced level, a basic data processor (small computer) may be used for merging, sorting, or collating the information on tape.

A number of digital tape systems are available that monitor a communication link and can relay or repeat the recorded data if required. This procedure has been used to transmit lengthy documents over conventional telephone lines during a nonactive period.

Computer Systems

Computers, regardless of application, have one thing in common: they can only perform as instructed. In practice, the instructions given to a computer are extremely detailed and their execution must be checked continuously for any errors.

Instructions to an electronic computing machine may be classified as follows: (1) arithmetical; (2) logical; (3) input; (4) output.

An *arithmetical instruction* is used to perform an arithmetical operation on two number words. It specifies where to terminate the result and where to store it. Arithmetical operations are complex; a number system of few symbols and few symbol positions is desirable for them but unobtainable. (The "worth" of a number system depends on the importance of each of the factors in a particular application. Any choice must represent a compromise.)

The *logical instruction* delegates the decision making to the machine under specific conditions. These instructions may include storage operations, shifting, jumping, transferring, and masking.

The *input instruction* is used to load the machine with instruction and number words for machine operation. The *output instruction* tells the particular terminal equipment to operate. The output instruction is used to record, display, or print a result. In many machines, the input/output instructions are treated as a single category since the buffering is similar and the operations are sequential.

The number word is generally numeric and made up of several parts: check, algebraic sign, radix point, and magnitude.

Within the computer, the instruction word and number word are identical in appearance. Instructions are generally executed in the sequence in which they appear on the program. Since the computer acts as the controller of the magnetic tape system, the computer instructions define the output operation by the same program. The magnetic tape system, under computer direction, processes the number words accordingly. It accepts the number words with instructions in the following possible transfer arrangements: parallel; serial-parallel; and serial.

In no way does the magnetic tape system perform arithmetic operations on the number words to be written or read. This operation is performed before or after the magnetic tape system.

Input/Output Configuration

There are a number of factors to be considered in establishing the integration of a digital tape recording device with a computer. A few of these are: (1) the transfer method (parallel, serial-parallel, and serial); (2) the operational method (synchronization); (3) buffering, as required, based on transfer and mode of operation for data and instruction control; (4) impedance and voltage levels; (5) one wire or two wires per bit; (6) signal type (pulse or d-c level and possibly bipolar).

Transfer Methods

The three methods (or word format) of transfer depicted in Fig. 9-2 are all used presently. The one shown as Fig. 9-2A is used in Fig. 9-1. All communication between the computer and the tape control unit is in parallel. Only one pulse time (strobe or transfer pulse) transfers the information content from the computer register to the tape control unit register. From there, the computer word is disassembled and written on tape as described in Chapter 8 (Figs. 8-28 and 8-30). Therefore, unless time is important, the high speed transfer and the large number of wires between the two units may not be justified under certain conditions.

On the other hand, the tape recording station shown in Fig. 8-1 was based on a character word buffer. This transfer arrangement is shown in Fig. 9-2C. As stated earlier, the character transfer method requires that the computer disassemble the word into parallel groups of digits compatible with a single tape line. In this manner, no further data handling is required by the tape control unit and the information is either written on the tape or read from the tape and transferred to the computer. Certainly all the functions performed by the tape control unit, such as counting, formating, synchronizing, error detection, etc., are performed by the computer. The computer arrangement shown in Fig. 9-4 would be applicable here.

In terms of equipment efficiency, a minimum of hardware is required to operate a digital tape transport. There is no duplication of operation, but the tape operation is quite time-consuming. However, this is not the problem.

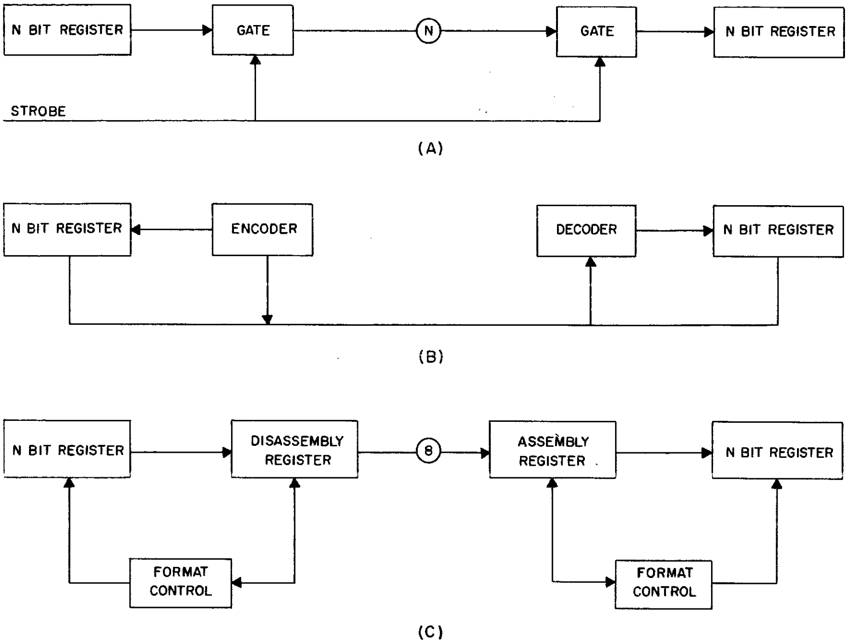


Fig. 9-2. *Data transfer formats: (A) parallel high-speed; (B) serial low-speed; (C) character, medium-speed.*

In Fig. 8-32, one of the two computers shown is used in an off-line arrangement. All the time-consuming operations are assigned to this auxiliary computer. Since it may be a reduced version of the main computer, it not only can accomplish the duties that a tape control unit may be required to perform but it also can perform other data processing and arithmetic operations. Where the investment in a computer installation warrants this configuration, the transfer method of Fig. 9-2C may be preferable.

The serial transfer method shown in Fig. 9-2B is very seldom used to "hook up" a computer and a digital tape recording device. Digital tape format implies parallel recording across the width of the tape; the serial data bits must be accumulated to satisfy a tape line. If the computer word is available in parallel, a shifting and counting operation is required to use a single wire transfer. At the other cable end for the tape control unit, the data bits are assembled into tape words by a counting operation prior to writing the information on tape. The process is reversed for a tape reading operation. This transfer method is the most time-consuming and requires extensive encoding and decoding operations. Yet, it has merit and is used for recording digits, but not in computer tape format (serial digit recording). This method of information transfer is used quite extensively in data communications. Since a single wire (or r-f link) is used, it must contain the synchronization, timing, data, checking bits, and any other special coding requirements to ensure an error-free transfer in one direction.

Fundamentally, the three basic transfer methods are equally applicable to the digital magnetic tape systems described later in the chapter.

Synchronization and Mode of Operation

There are two basic timing operations: synchronous (predictable) and asynchronous or random (unpredictable). In conjunction with each timing method, the mode of operation may be sequential or simultaneous, or both. Certainly in a synchronous system, a sequential method of operation is permissible. Here, every operation is ordered and predictable. Therefore, scheduling is not a problem and every operation may be arranged on a time schedule. Thus, equipment may be shared or multiplexed to perform specific operations without any overloading. Furthermore, no overload conditions are permitted to occur.

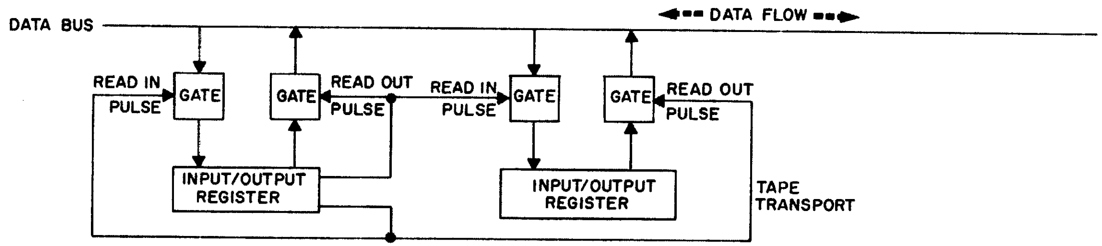
Asynchronous means non-synchronous. From a computer operation standpoint, evenly-spaced timing signals and scheduled operations are not a valid method of handling asynchronous operations. Instead, the method of mechanization is to sense a signal and to respond immediately. An operation is started as a result of an interrupting signal and then it is completed. Under these conditions, this type of interruption could conceivably interfere with an operation in progress. In any event, the interrupting signal must be acknowledged. It may be honored immediately and two simultaneous operations performed (the operation in progress and the random operation); or, each one of the two operations may be performed sequentially, based on a priority formula. In either case, a simultaneous operation capability must be available with an asynchronous operation of the interrupting signal.

Figure 9-3 illustrates three possible forms of interconnection between a tape transport and a computer. The cabling arrangement is shown for the data (information) transfer channels and a majority of the control lines are indicated on the same basis. There is a tendency to intermix the three arrangements for control cabling and to use any combination to operate the tape recording device. The control wiring for Fig. 9-3A is self-explanatory, but the other two arrangements require further explanation.

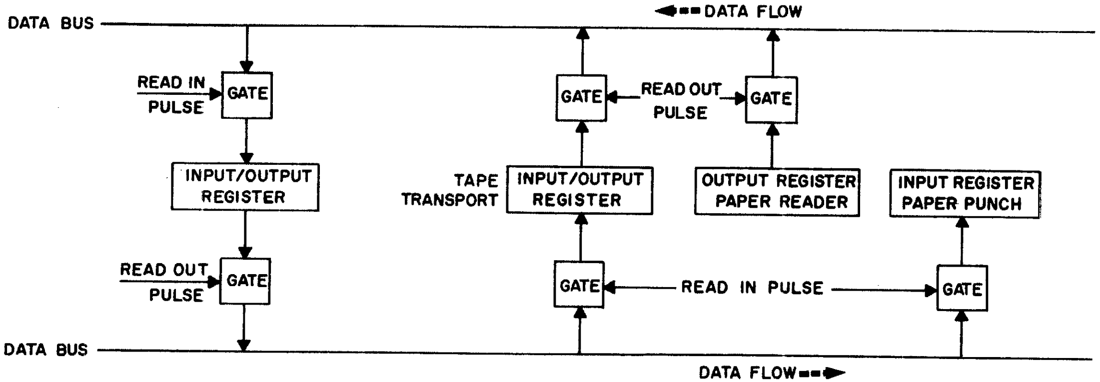
Basically, the buffering and device operation is identical in both Fig. 9-3A and 9-3B. The two independently-operated data transfer bus lines (input and output) permit some flexibility and versatility, and expansion into the configuration of Fig. 9-3C. The input and output indicate directional flow. The output of the computer is the input of the tape station and vice versa.

The equipment arrangement of Fig. 9-3B permits a synchronous and asynchronous operation, depending on the qualifications of the peripheral control units. The operation of Fig. 9-3B is sequential, as is Fig. 9-3A, if one bus transfer is in operation. If two transfer channels are operated, each one can be sequential in operation within itself and simultaneous between the two transfer channels (Fig. 9-3B).

The justification of incurring additional complexity and costs without taking the full advantage of the arrangement in Fig. 9-3C can be explained



(A) SEQUENTIAL-SYNCHRONOUS



(B) SEQUENTIAL & SYNCHRONOUS OR ASYNCHRONOUS

COMPUTER

EXTERNAL CONTROL-TAPE

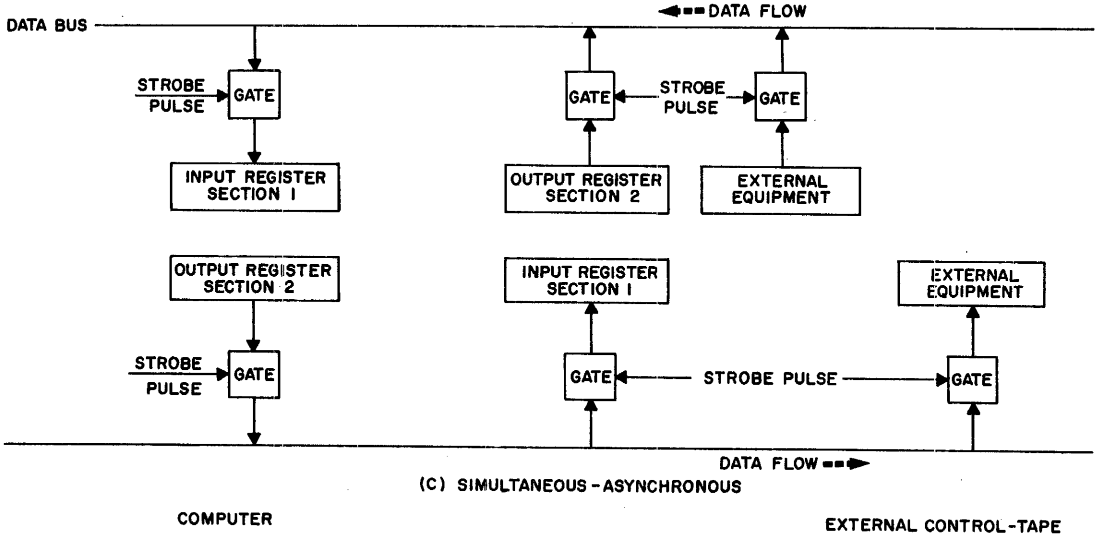


Fig. 9-3. *Input/output communications: (A) sequential, synchronous; (B) sequential, synchronous or asynchronous; (C) simultaneous, asynchronous.*

in the following manner. The two-transfer bus system saves time in setting up the operation and making a device selection, which is a major time-consuming operation for the computer. A device can be reserved in advance or remain connected or assigned after a data transfer has been completed. In the operational aspects of the latter system, the tape may be instructed to rewind but cannot be interrupted during this time interval. The data lines are disconnected but the status lines remain enforced. Although the buffering is multiplexed within a device unit (tape read or write, but not both), the two-transfer bus system of Fig. 9-3B instead of that of Fig. 9-3A permits the simultaneous operation of two devices synchronously or asynchronously with one exception. Only one peripheral device can supply data to the computer and only one device can receive data from the computer.

Because of the limited buffering capacity in the tape control unit for a peripheral device unit in Fig. 9-3B, only one tape transport can read or write, but not both. However, the other transfer bus may be utilized by another tape control unit or another device. In the Fig. 9-3B arrangement, two different devices of varying data forms and operational times can simultaneously be operated by the computer by activating its input and output registers concurrently.

The last configuration, Fig. 9-3C, has the maximum capability and flexibility. Separate facilities for writing and reading are present with a function decoder or instruction register within the tape control unit, which is a small version of a data processor and may include a storage memory capability of more than one computer word. The computer may transfer an instruction word to the tape control unit. Subsequently, a section of the internal memory of the computer is reserved or assigned and control is transferred over to the tape control unit, which assumes supervisory control and proceeds to write the internally-stored computer data on tape. The transferred instruction word is decoded and indicates the beginning address location and either the number of computer words for transferral or the terminating address of the data to be written. Concurrently, the instruction decoder of the tape control addresses the selected tape transport and its mode of operation. The tape operation is completed, checked, and supervisory control returned to the computer from the tape control. During the complete operational process, the tape control effectively performs the functions normally supplied by the computer, as illustrated in Fig. 9-4.

The read operation is similar. Consider two widely-separated data blocks on tape. The tape control unit is instructed by the computer to locate a desired block on tape independent of the computer (or the direction and number of blocks). The control unit and the computer are disconnected (data bus) and the control unit locates the desired blocks on tape while the computer performs other operations. When the desired data block is brought into position, the tape is stopped and the computer is signaled that the data is ready for transfer. Then, the normal start-stop sequence permits the data transfers between the control unit and computer to be accomplished. Here,

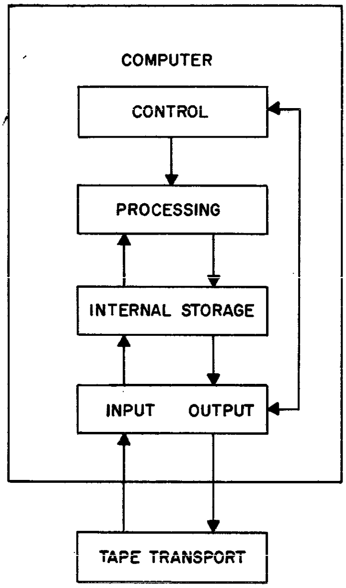


Fig. 9-4. *Computer control of direct input/output tape operations.*

the organization of data on tape permits the unused or unwritten length of tape to be positioned under the magnetic head when the tape is stopped. When called upon to read data from the tape, special coding on the tape logically signifies the beginning of the data block. For many tape applications, a file and retrieval tape library system uses a computer as a sophisticated tape control unit. Where a complex recording facility of only digital magnetic tapes is used, the tape control unit may perform such operations as collating, merging, and sorting.

Consider the 3-by-3 matrix arrangement of elements illustrated by Figs. 9-2 and 9-3 for the total input-output configuration of data transferral. The same arrangement is equally applicable for the control operation. In this case, a 9-by-9 matrix configuration supplies 81 tape control unit-computer combinations. The possible variations of actual data transfer per wire for synchronous and asychronous and counting operations (coding) will increase the possible connection combinations. A one-wire and two-wire transfer arrangement and counting operations will be shown to illustrate synchronous and asynchronous operations of a tape control unit.

Data Transfer Wire System

To transfer data from one physical location to another, the sender (or transmitter) must have the information available (generally in a storage register) and the receiver must be prepared to accept the data and store it for subsequent data handling. A typical single-wire system is shown in Fig. 9-5. The sender has a register comprised of a flip-flop (FF) for each storage bit. The FF stores a 0 or a 1 to indicate the information content of a single storage element. The wire connection is a single wire for each information element. The receiver must be in a 0 state to accept this information. The clear, or reset, wire of the receiver register is activated prior to the data transfer.

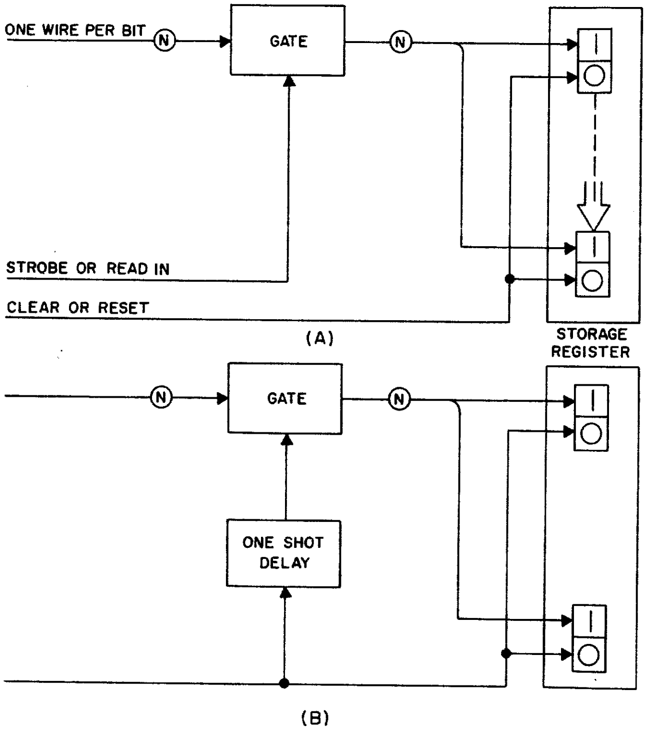


Fig. 9-5. *Single wire per bit transfer cable system.*

The sequence of events for data transfer (Figure 9-5A) is as follows. The data is stored in the sender register (computer) and the d-c levels are established on the interconnecting cables. Concurrently, if desired, the signal given to store the data in the computer register can be mechanized to reset or clear the receiver register. With the d-c levels established, the data is transferred with a write pulse (or strobe) from the computer. In Fig. 9-5B, the same procedure is followed, but one control wire is replaced by a delay element in the tape control unit. Generally, this is a synchronous method of data transmission. Clearing or resetting the receiver register to 0 may be performed in an asynchronous manner. The resetting or clearing to zero can be accomplished on termination of an operation. The latter method would require a master clear when the equipment is turned on.

The synchronized clearing method may not provide adequate time to accomplish a multiplicity of clearing operations and checking. Interlock, sense, and resume signals may be a complex operation in the tape control unit. In the asynchronous method, the termination or resume signal initiates the "all clear" and resets the interlocks and alarm circuitry. In addition, all the time needed to pursue an operation until completion is permissible with automatic read-in capability by the synchronous method.

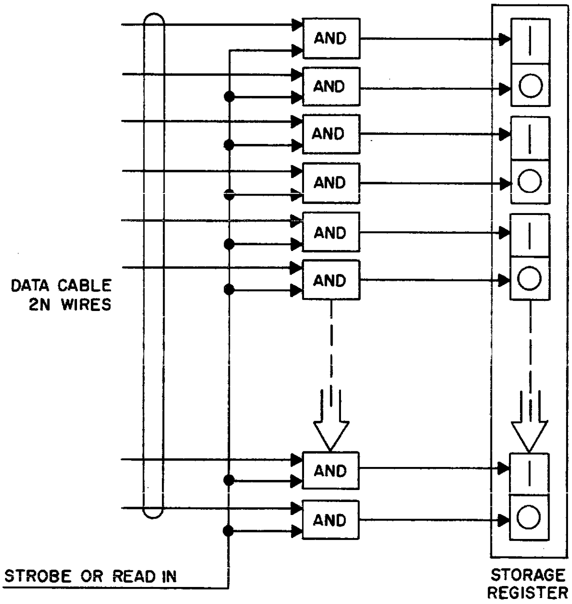


Fig. 9-6. *Two wires per bit transfer cable system.*

A two-wire data system is shown in Fig. 9-6. In this arrangement, there are two wires for each storage element; one wire is a 0 wire and the other is a 1 wire. The two-wire transfer method is a read-in operation (of the tape control register) with an automatic clear. At all times, either one of the two wires contains the logical storage content of a 0 or 1 on a per wire basis. This is not true of the one-wire system. In the one-wire system one state (or level) is assigned one logical state and the other level is assigned the opposite logical state. Although the two-wire system is inefficient on an information (or data) basis, the coding may be used in the following manner:

Logical State *Wire 1*	*Wire 0*	*Comments*
0	0	Sync, Start, Standby, or Neutral
0	1	Zero Information
1	0	One Information
1	1	Error or Halt

The additional coding that is available in the two-wire system permits greater operational speeds and detection of errors. If a unity distance code is used, the transition from either a 1 or 0 information state can only be accomplished by going through a neutral code (00). Of the two systems presented, the single-wire approach is used in a synchronous system and the two-wire approach is used in a high-speed line asynchronous system.

A combination of both systems is shown in Fig. 9-7. The tape control unit is normally operated using a one-wire cable system. In the event of an interrupting signal or aborting of an operation, the two-wire system is invoked. The interrupting information content is superimposed over the stored information without any loss in time or loss of the current information that is being held in the sending register (computer). The follow-up operations that implement this procedure are quite extensive and must be defined by system application.

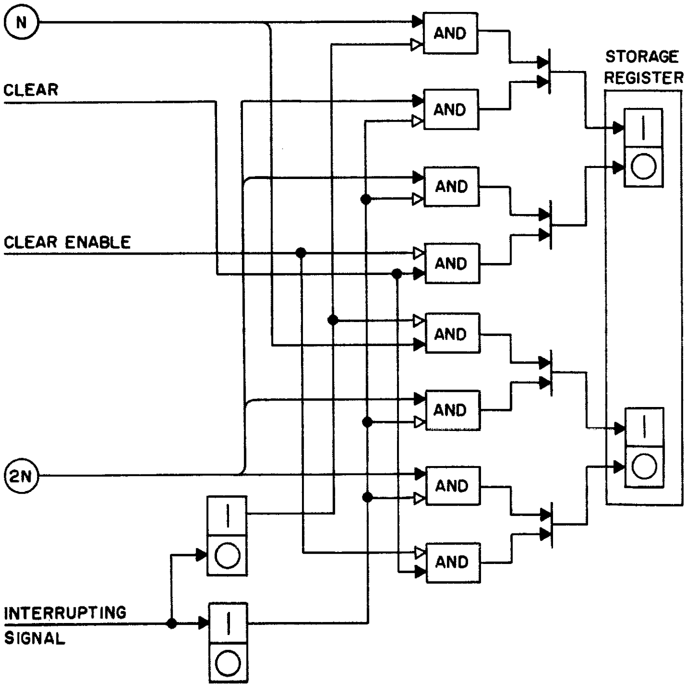


Fig. 9-7. *Asynchronous transfer cable system.*

Single-Word and Block-Word Transfers

In presenting the data organization on tape, a computer word is disassembled into tape words prior to a writing operation. Also, it is necessary to ensure that an adequate tape length of unrecorded tape will be available for start and stop operations. For maximum tape utilization, the unrecorded tape length of a reel should be a very small percentage of the entire reel length. Once a lengthy time interval is incurred for tape acceleration (start), it may be preferable to write (or read) several computer words. This can be done in several ways. In one method, an auxiliary storage, such as a drum, may be used to serve as an intermediate buffer. Obviously, this will add problems to an already complex operation. A more preferable solution is to count or keep track of the number of words being transferred to the tape device. This can be done by the computer or by the tape control unit, or both. A simple arrangement (Fig. 9-8) shows a flip-flop with start and stop signals supplied by the computer that does the counting operations and controls the complete block transfer of words to the tape control unit, which mechanizes the clock pulses (or pulse train) to perform its tape operations.

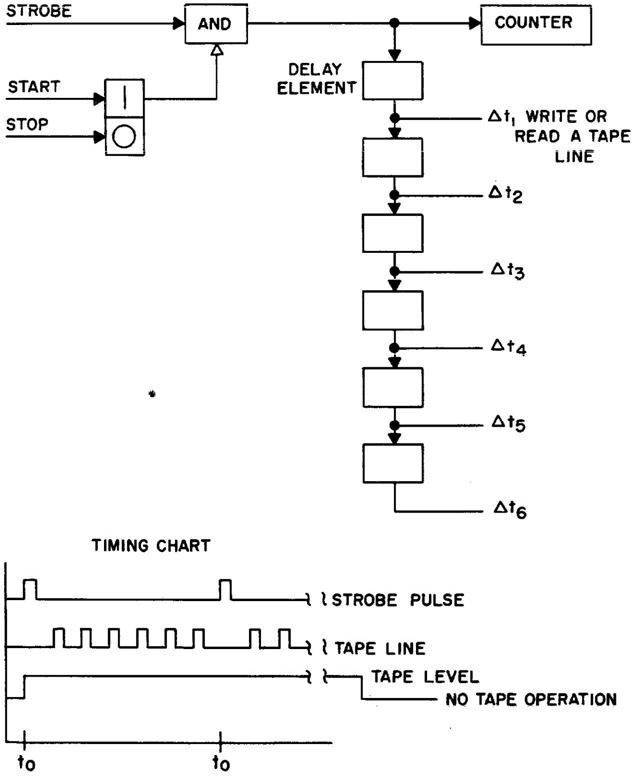


Fig. 9-8. *Start-stop counting levels.*

A cooperative arrangement between the computer and the tape control unit is shown in Fig. 9-9. The computer may select the first word address from its internal memory (or on tape) and send it to the tape control, along with the number of words in this block transfer. The computer then continues to transfer words, decreasing the stored number in the tape control unit with each transfer. When the number 0 is reached in the tape control counter, the computer is informed that a complete block of words has been transferred and any additional coding, checking, or editing digits are written on tape (or read from tape) by the tape control. The number of words can be a fixed value or any number up to the limit of the counter.

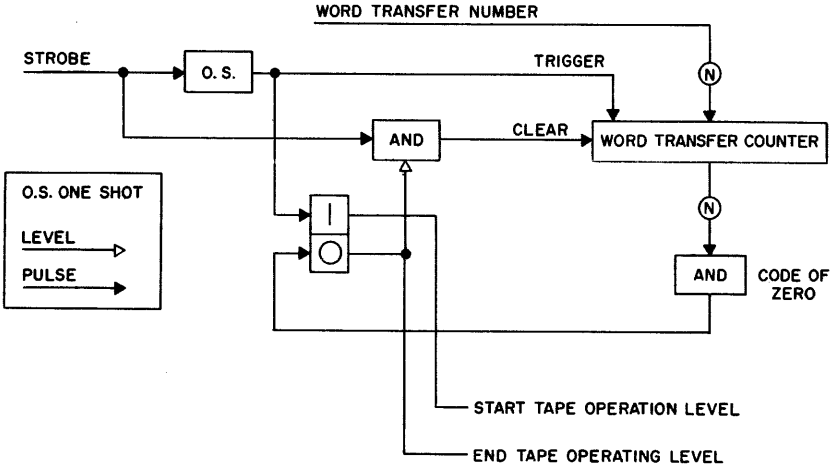


Fig. 9-9. *Block transfer counting process.*

The third method of counting with no restrictions is by storing the initial address of the first word from the computer internal memory and the final address (Fig. 9-10). The words are continuously transferred from the computer to the tape control unit. If the addresses are pulled out of memory in ascending order, the initial address is advanced by one for each transfer and compared with the final address for equivalence. The operation is terminated when both registers store the same number. If the addresses are pulled out of memory in a descending order, the lower address is advanced by one for each transfer and compared with the initial (larger) address for equivalence. The addresses may be pulled out of memory in a descending order and the initial address (larger) is decreased and checked for equivalence with the final address (lower). For this method of checking the number of words being transferred, a counting function is performed by a logical equivalence operation. Any number of words may be transferred in any sequence up to the limit of the computer word address section. Since two limits are given (initial and final address), the address counter storage register may be advanced by more than a single count.

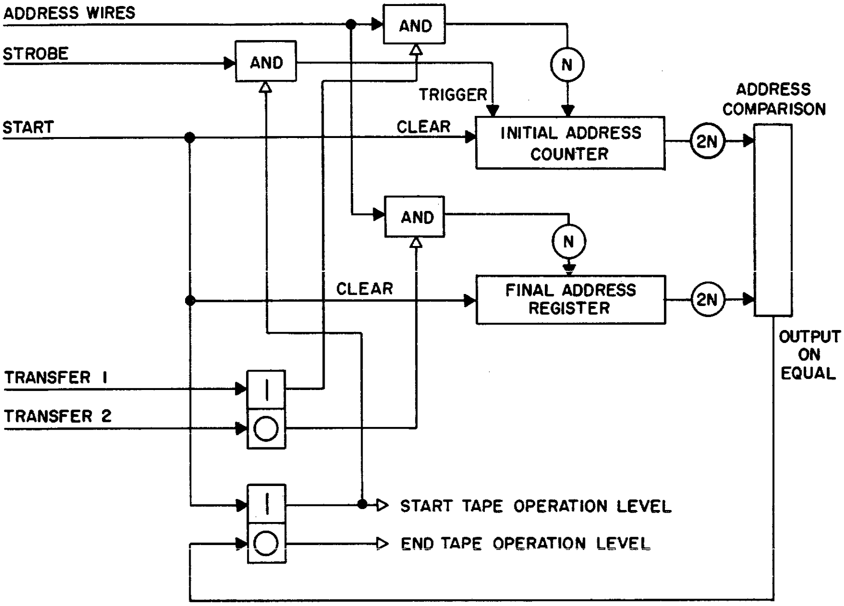


Fig. 9-10. *Block transfer using a two address register system.*

Transfer Interlock

The interlock between the tape control unit and the computer ensures a compatible operational system. The digital tape recording operation must include the operation aspects of a digital tape transport. The interlock circuitry accounts for reliable transfer of data to and from the tape control unit. Normally the tape is stationary until a command is issued for tape operation. Once a command is issued, a sequence of events takes place that prepares the recording system for data acceptance. When a tape transport is assigned or removed from a standby status, the tape must be accelerated to an operating velocity before any data writing can proceed. The tape is kept in motion until all the information has been written. Using a simultaneous write/read operation, the tape is kept in motion until the last written data has been read.

A normal sequence of events for integrating a digital tape recording device with a computer will illustrate the basic conditions performed by an interlock system. Generally, the interlock operation monitors and maintains communication between the computer and the tape station by ensuring valid tape operation. An interlock logic diagram is shown in Fig. 9-11. Six conditions are noted by the interlock system: (1) start of transfer; (2) first word of transfer; (3) hold; (4) second word to the last word; (5) alarm; (6) completion of transfer.

Condition 1 indicates that the addressed tape transport is ready to accept data from the computer (code 111). The recognition of the first word of a

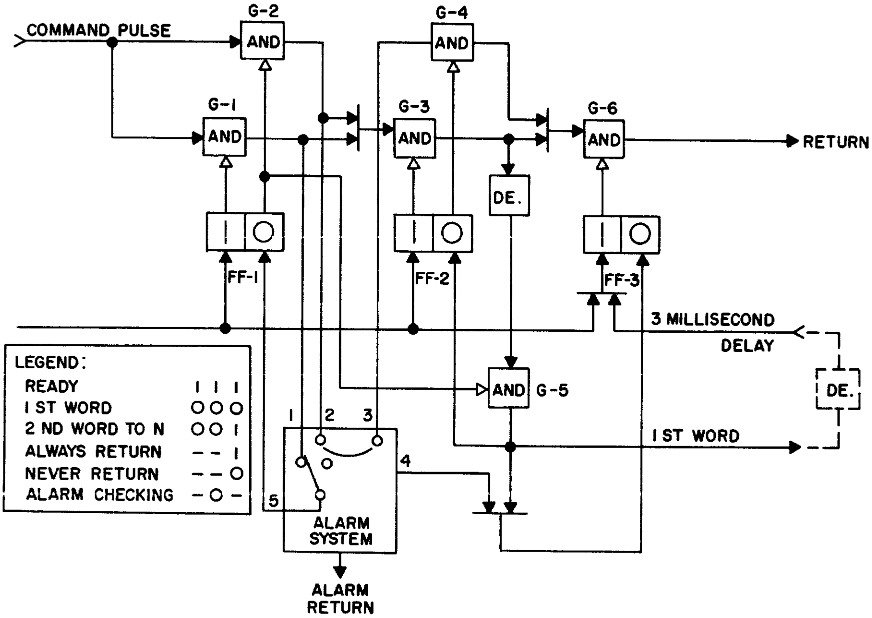


Fig. 9-11. *Transfer interlock.*

block transfer is important in that the first word contains control information (address, etc.). The hold condition is required after the first computer word is recognized to allow the tape to reach operating speed; a 3-millisecond delay is required after the first word before the data can be written or read. After the tape is up to its proper speed, writing and reading are permissible. The alarm system constantly monitors the data transfer. Initially, in the alarm system, the switch contact between terminals 1 and 5 must be closed. Secondly, all command pulses after the first pulse must proceed through terminals 2 and 3. Terminal 4 is mechanized with the alarm return. Finally, the completion of the transfer is determined by equipment external to the interlock system.

The interlock system permits synchronizing the tape station with the computer by noting the availability of the device and keeping it in step with each computer word transfer whether the operation is a word-at-a-time or a data block.

The command pulse is always answered affirmatively. A normal return (or echo) is always sent to the computer for confirmation or acknowledgement. If this is not done, an alarm return is sent. The normal return may be mechanized to serve as a strobe pulse to activate the read-in gates of the tape control unit or the read-out gates of the computer output register. Again, as shown earlier, the command pulse could be used to store the data in the computer output register and could, concurrently, be sent to the tape control.

A sufficient time delay occurs in the round trip of computer to tape control through the three levels of gating of the interlock and back to the computer. In some cases, this time interval may prove objectionable. If it is, the pulse is mechanized in the following manner. The tape control unit has a two-phase buffer operation. One buffer stores the current operations while the current command pulse is used to load up the alternate buffer in advance of the next operation. In this manner, the two buffers are alternated without any loss in time. This method of storing or preparation in advance is a normal technique used to gain time or to achieve higher computer speeds.

Each tape operation may require the execution of several references to the computer internal storage. Initial reference to the internal storage is made to read the appropriate control word to initiate the operation and obtain the address of the word to be buffered. A second reference is made to the computer internal memory location and the data is transferred to the tape control unit. The initial memory address is increased by one and a comparison is made. (This type of word transfer counting was previously covered.) If the new address and final address are equal, the buffer operation is terminated.

Selected Tape Operations

Ordering Information

Words are transferred by buffer registers located in each subsystem. The input and output controls cause the buffer register to operate in synchronism without operational interference with each other nor with any other subsystem external to them. Each time an operation is initiated, a set of interlocks and checking procedures are invoked and must be evaluated before a tape operation may proceed. After this has been accomplished, a programmed delay is required to place the recording device into operation. During the delay period, instructions and operational procedures are completed and the tape operations are permitted to proceed. Even though all the checks are satisfied, all subsequent operations are constantly monitored and the computer is informed of tape status throughout the operation.

The tape control unit requires a minimum of two cables. One cable is used for input data, input strobe, and control signals; the other is used for output data, output strobe, and tape transport status. (The data and strobe signal wires were described earlier — Fig. 9-3.) A brief description of the tape transport control wires used for control purposes is given in Table 9-1. By no means can this tabulation be considered complete. The variety of tape applications using a tape control unit will normally require a greater number of control lines and monitoring lines, depending upon the "conversation" between the tape control and the computer. Those presented in Table 9-1 are basic and are generally common to all digital magnetic tape transports.

TABLE 9-1. Control and Status Cables Between a Computer and a Tape Control Unit (TCU)

Input (to TCU) Control		*Output (from TCU) Status*	
Function	*Description*	*Function*	*Description*
Forward (FWD)	Commands the tape to move in the forward direction. Generally a level is maintained for the command duration.	End of Tape (EOT)	Signal is mechanized to prevent the tape from moving forward.
Reverse (REV)	Same as the Forward command except the tape moves in the opposite direction.	Beginning of Tape (BOT)	Signal is mechanized to prevent the tape from moving in reverse.
Fast Forward (FFWD)	Commands the tape to move forward at the high rewind speed. Unless programmed to return to normal forward speed or an advance warning signal is available, the EOT signal will terminate this operation.	Physical End of Tape (PET)	Tape is broken and interlocks are engaged to prevent any further operation of the tape transport.
Rewind (RWD)	Commands the tape to move in the reverse direction at the highest rewind speed. Generally the BOT signal is used to stop the tape.	Tape Error (EOR)	A data or transfer error has occurred — parity check read after write, error during a read operation, longitudinal parity, check sum error, etc. A repeat or backspace may follow an EOR.
Write (WRT)	Commands the tape control unit to perform a write operation. This command will not be executed if the interlock protection ring is not present on the tape reel.	Alarm (ALM) or Halt (HLT)	A malfunction has occurred due to component failure, operational restrictions, nonvalid operations, lack or loss of power or local control, or unit not connected.
Write Reset (WRST)	The write amplifier current is used to erase the tape. This command can only be executed when the tape transport is in a write operational mode.	Ready (RDY)	The tape transport is ready and the following conditions are met: 1. All tape transport interlocks are satisfied. 2. Capstan drives up to speed. 3. Tape is not in motion.

TABLE 9-1. (Cont.)

Input (to TCU) Control *Function*	 *Description*	*Output (from TCU) Status* *Function*	 *Description*
Read (RED)	Commands the tape control unit to perform a read operation. If a simultaneous write/read capability is present, a read operation will be performed without a command from the computer.	Load Point (LDPT)	Generally, this condition must be sensed after every tape reel loading. Furthermore, a different time delay is used for a WRT or RED operation when LDPT condition exists.
Clock (CP)	This signal is provided to maintain synchronism between the two subsystems.		

Independent Operations

A more efficient way of matching the tape transport to the computer is via the tape control unit. It has been previously stated that the disparity of speed between computer operation and the rate of writing (or reading) data on tape can be solved by creating a subcontrol station that performs a buffering action. This results in a computer system configuration with more than one set of input/output lines in order to load the computer fully, as shown in Fig. 9-1. The computer becomes time-limited when all the peripheral devices are operated simultaneously and the computer cannot accept this volume of data. Using a tape control unit per set of data buses (input and output), one tape transport could be reading and one could be writing, while the remaining tape transports within a single control unit are not actively engaged. If all the necessary preparations between the computer and a single tape control unit have been made, data can be written on tape and read from tape in a continuous fashion.

Consider a computer having a 4-microsecond machine cycle that would permit the internal memory to be addressed and data written in storage at this rate. This would mean that the computer could accept and store words in the memory at 250,000 words per second (250-kc rate). The tabulation of two tape transports given below is for a computer word length of 36 bits. The tape frequency rate is one-sixth of the computer word rate if the tape words are a 6-bit character.

In tape transport 1, a read or write operation can be accomplished at a 20-kc rate. If each control unit has one tape transport reading and one writing, the input/output lines would be addressing the computer internal memory at a 40-kc rate. It would only take six units to tie up completely the computer

TABLE 9-2.

	Tape Transport 1	*Tape Transport 2*
Packing Density	800 bpi	500 bpi
Tape Speed	150 ips	120 ips
Tape Frequency	120 kc	60 kc
Computer Word Rate	20 kc	10 kc

input/output buffers with little time to perform any other operation. Tape transport 2, at half the speed rate, would require twice the number of control units. Generally, however, this is not a valid operation. The 120-kc tape rate is not common practice as yet, and an operational setup of twelve simultaneously operated and synchronized tape transports is very difficult, if not impossible, to achieve at this time. Therefore, tape transports are sequentially operated and multiplexed as required on a per data bus line.

Multiplexing

Another way to increase the utility of a computer operation is to connect several auxiliary devices to the computer. If the computer has a fixed number of data buses, a doubling-up operation is required. With one set of data lines set aside for other peripheral devices, the tape control unit must perform its operation more efficiently. In this arrangement, one tape transport can be rewinding, another tape transport reading and sending data to the computer, another writing data as instructed, and still another performing a search or being positioned for the next operation.

If the data transmitted by the tape control unit is one sixth of the computer word rate, there is a time period of five tape words during which the data bus is not active. During this period, the same data bus line may be used by other auxiliary devices.

There are a number of approaches to multiplexing auxiliary devices and magnetic tape devices on a common data bus. A few methods will be outlined. An independently operated tape control unit has adequate buffering and an instruction decoder to address and operate each tape transport as commanded by the computer. The computer can supply portions of a computer instruction or the whole computer instruction word to the control unit. For illustrative purposes, a separate set of lines designated as function lines are established by the computer and service the tape control unit and all auxiliary devices associated with one input/output data bus set (Fig. 9-3C). (More will be said about the input/output computer instruction word in the next section.) For the moment, consider that the function line establishes the subsystem selection, such as control unit, device, etc., concurrently with the application of information on the data bus. Obviously, the function line performs a switching operation, permitting accessibility to the data line. Therefore, a tape operation and several devices may be multiplexed onto one data bus. A system block diagram of this concept is shown in Fig. 9-12.

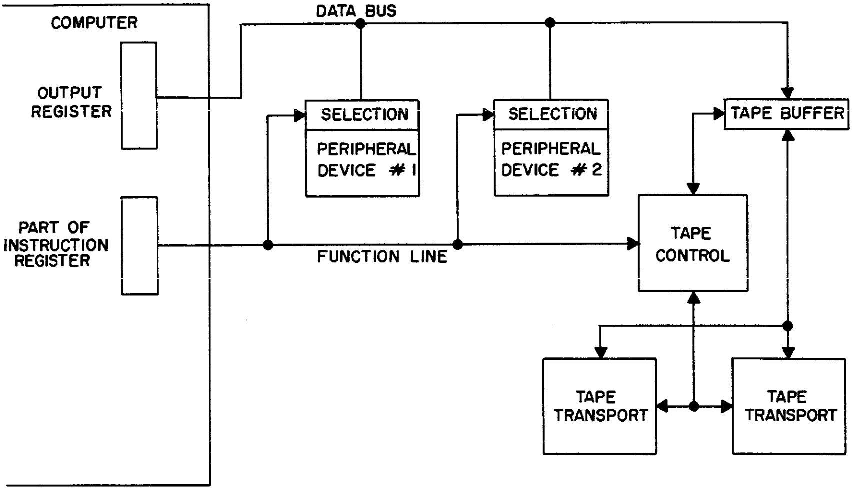


Fig. 9-12. *Multiple tape and auxiliary devices with function lines for control.*

A further extension of the previous system concept is digitally represented in Fig. 9-13. Here, the tape control unit acts as a focal point for all auxiliary devices of the main computer. Since the input buffer receives the computer word in parallel, it must be disassembled into tape words. If an 8-bit character word is used across the tape width (tape word), the same 8-bit character can be relayed to any auxiliary device attached to the 8-bit character optional line shown in the figure. As shown, the computer word can be received from the computer, disassembled, and reassembled in the output register. Here the computer word can be transmitted without being written on tape.

Greater flexibility and versatility can be further obtained by attaching a disc file to the 8-bit character line. The disc file and the Magnetic Tape System (MTS) communicate on a character word basis. The word is accumulated in the MTS output register and sent to the computer. If the data from the disc file is lengthy and the computer is busy, the file data are stored on tape and later read and supplied to the computer. Since some digital data communications links use 8-bit character words (six data bits, one control bit, one parity bit), the tape station can accumulate data via the 8-bit character transfer line and store it on tape.

A more advanced system of multiplexing uses two computers connected directly to each other. The MTS serves as a focal point or data terminal (Fig. 9-13). Within the MTS, two complete controls operate independently and two separate single-word registers are present. Therefore, the read channel may be used by one computer while the write channel is used by another computer, or vice versa. However, the bit capacity of each register (input and output) must be adequate for the largest computer word. Here

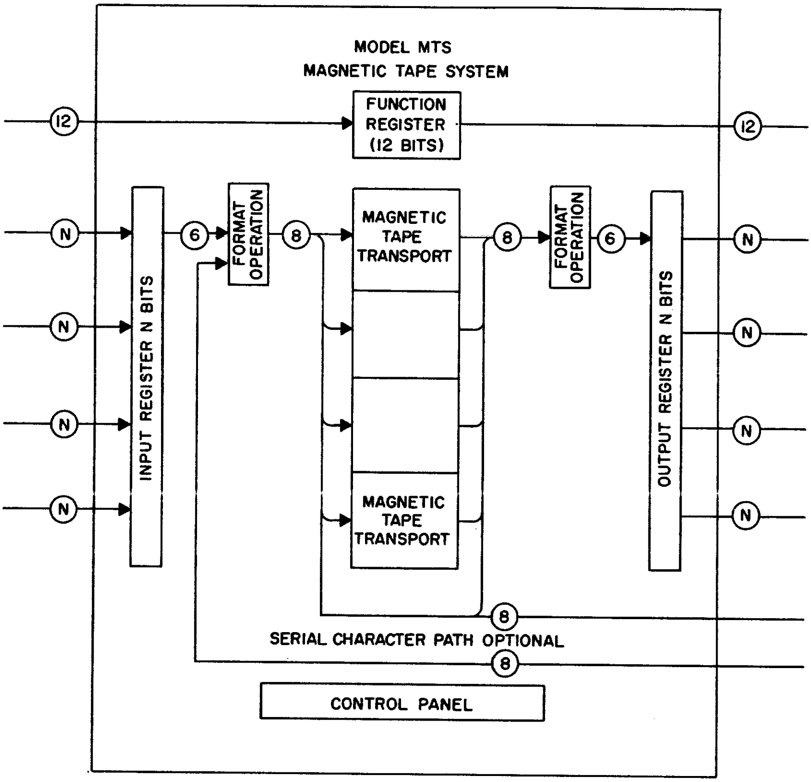


Fig. 9-13. *Digital module representation of a tape control unit.*

the smaller computer word can be converted into the larger computer word. The reverse method is applicable also. If the smallest element or field is assumed to be a six-bit data word, the larger computer word is disassembled into a multiplicity of six-bit characters to satisfy the smaller computer word. As stated earlier, the input data can be transferred to the output register without going through the tape transport. The MTS unit makes possible compatibility of two or more computers by assembling and disassembling each machine word in terms of the other when operating on-line. Basically, the MTS serves as a general-purpose interface equipment for storing data and formating operations.

The multiplex system concepts presented here are in practice separately and collectively. The tendency to integrate several computers in a multicomputer configuration in preference to one single, large, complex computer has merit. Computers can be installed as required to expand a facility with minimum cost. Furthermore, common instruction coding is possible. If the computer word lengths are whole integers (72, 36, 18 and 48, 24 and 12), then programs written for one computer to activate an MTS unit via a function line (12 lines) are equally applicable for the other computers in the system. Programs for computer operation may be written separately or collectively and will reduce the software computer costs with this type of tape control unit.

Block Operations

To reduce time consumed in initiating each tape operation, data is grouped together in batches to lessen the unused portion of tape and decrease the number of start-stop operations. Previous examples mentioned a continuous flow of data and methods of counting were illustrated. If the computer is to operate independently during a block transfer, additional conditions have to be met.

The operation of writing on tape during a block transfer requires strict adherence to certain timing criteria. The data must be written on tape at a uniform rate. If data is not available to be written, the tape continues to move past the head. Any tape system that is fixed frequency or sensitive to tape speed will either indicate several parity errors or perform unreliably. As stated earlier, sufficient buffering in the tape control unit is required for the most time-consuming computer operation. This will ensure that adequate data is available until the computer can service the tape control unit with more data to be written. If the tape format includes a timing track, this track can perform a control function by identifying each tape word. In this manner, the read-back operation is less sensitive to tape speed variation.

Block transfer operations are illustrated in Fig. 9-14. The computer word must be disassembled prior to its application of activating the writing heads. Also, the initiation and termination of the data writing time interval on tape must be precise. In this manner each tape line will have the same incremental distance (cell area) from each adjacent tape line. The computer word used here is a 36-bit word. It is stored in the Computer Word Register via a parallel transfer gate of 72 lines. The use of two wires per bit eliminates clearing the Computer Word Register and permits a high-speed transfer. Concurrently and independently, the Character Counter is cleared to zero and the word number of the block transfer is stored in the Word Counter. Up to this point everything is prepared for writing on tape and only the initiation or start signal is required. The writing of data begins with the Begin Data Recording signal stored in the Format Control FF. The first timing pulse via gate G-1 advances the Character Counter by one. The first 6 data bits of the computer word are made available to the Parity Generator and Data Lines. The Computer Word Register, via Character Gate one, supplies the hold-down voltage levels to activate the Parity Generator Exclusive OR Gates and the Data Lines. This process is repeated six times to store one 36-bit computer word on tape.

When one computer word has been written on tape, another word may be transferred to the Computer Word Register without any time loss. The output

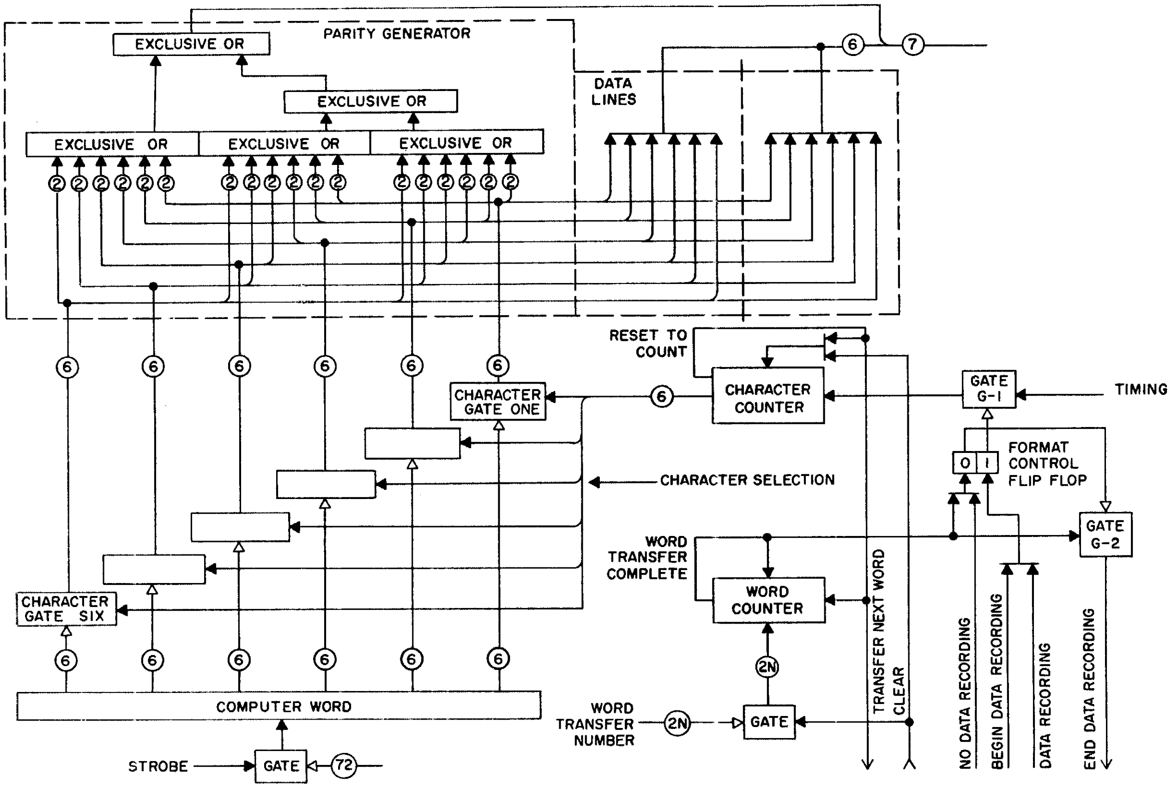


Fig. 9-14. *Block transfer tape format.*

of the Character Counter returns to zero and requests another word transfer. Simultaneously, the word counter is decreased by one. The process of character formation and word transfer will continue until the Word Counter signifies that a complete block of data has been transferred and written on tape. Generally, if the Word Counter is decreased by one for each transfer the Word Counter will attain a clear state and will issue a Word Transfer Complete signal. The Word Transfer Complete signal is mechanized to terminate the writing of data and issue an End of Data Recording via gate G-2.

In the organization of data on tape, the fixed computer word length and fixed number of computer words for a block transfer are established by the Character Counter and Word Counter, respectively. A constant writing tape density is as accurate as the timing pulses supplied to the Character Counter. In many cases, the timing pulses shown in Fig. 9-14 are part of a two-phase clock. One phase is used to disassemble the computer word and the other phase is used to activate the writing heads on the tape transport.

In attempting to simplify the block transfer tape format operation, certain hardware economies were ignored. If the Computer Word Register was a shift register, it would be cleared prior to a computer word transfer, and only one Character Gate would be necessary. Also, the complex diode oring operation of the Data Lines would be considerably reduced. The Character Counter and Word Counter can be combined into one physical counter of an adequate length. Then a matrix decoding operation for each whole integer of character words and computer words is used to format data appropriately for a digital tape magnetic recording facility.

It should be apparent that variable block lengths of data can be obtained by varying the word transfer number. Also, variable tape density recording is obtained by using different timing pulse rates to activate the Character Counter in Fig. 9-14.

Computer Instruction Word (Input/Output Operation)

Only the details of input and output operation associated with digital magnetic tape recording are examined here; programming aspects are not considered. The instruction word (control) and the number word (data or information), and their interdependence with tape operations, if any, are discussed in detail.

Two common input/output instructions are Read Select and Write Select. The former directs the computer to read information from the designated input/output unit into core storage; the latter prepares the computer to write information into the selected unit. These instructions can initiate either block transfer of data or, in conjunction with a copy instruction, the transfer of one word at a time.

Use of a break instruction permits an input/output unit to request access to the computer memory. The external request causes a jump in the program sequence and an evaluation of the request. If the computer communicates with the input/output unit, a block transfer of data may be initiated. A desirable feature is that the transfer can be carried out simultaneously with the main program, each having independent access to memory.

Most computers are able to handle two number word types: straight binary (numeric data) and binary coded decimal (alphanumeric). The important decision to be made for computer arithmetical operations is the choice of radix. Radix 2 is most attractive from the standpoint of machine simplicity and available storage devices. There is a need for special number coding for an output system. A special code may be required to operate an off-line printer and to feed a computer from magnetic tape. Since the plotting boards and strip charts use straight binary codes, this notation (straight binary) is used for online operations (input, computation, and output).

Word Length

There are two considerations that determine the word length of the computer. The first one is the instruction word structure, the second is the data. The instruction word must provide, at a minimum, room for memory address, order code, and index register selection. The word length within the computer must accommodate the largest value of each variable or parameter that is expected to be handled. Both the precision of the variable and its total range of value must be considered.

The length of the instruction word should be integrally related to the length of the number word. Generally, this integer is one or two; one or two instructions equal the length of one number word. Since there is no direct relation between instruction word format and precision in computation, this relationship must be judiciously chosen.

Input/Output Word Specifications

The standard instruction word format is inadequate and too rigid for input/output operations. Therefore, some modification of the instruction word to accommodate digital magnetic tape operations must be made. The instruction word must be able to transfer from a computer instruction to a tape instruction word and return to its original format. Generally this is accomplished by noting if the current computer instruction word is an internal or external operation by an assigned bit position in the word. A typical computer word having this word format is shown in Fig. 9-15. No decoding is required for this information and its digit value, in conjunction with another field (or segment) of the word, may be used to verify word structure compatibility. One possible checking arrangement is an external operation with all zeros in the function field. The address portion is used to obtain the external instruction. Every subsequent external instruction is checked in a similar way using some other bit position with another field in the word. This would indicate a three-word sequence: instruction word, tape instruction, and a transfer instruction.

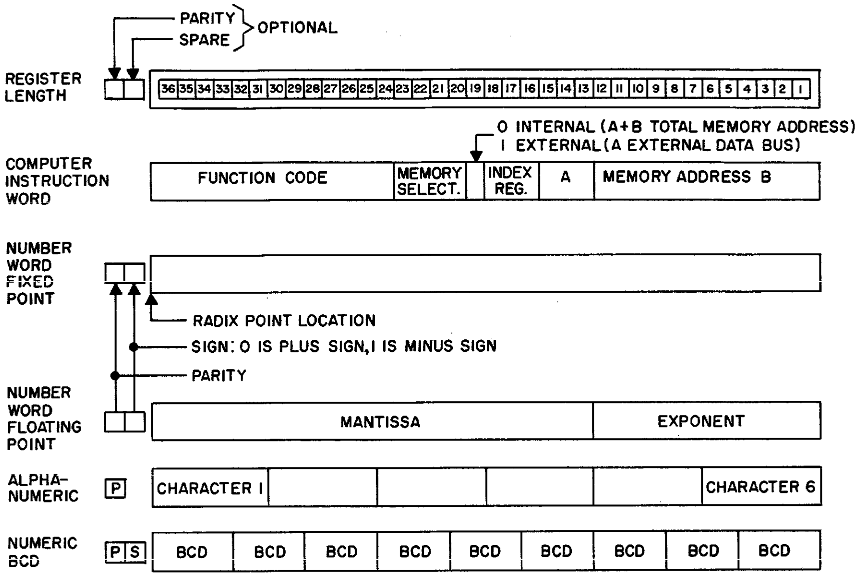


Fig. 9-15. *Computer instruction word, data word.*

Having established that the computer instruction word is an input/output operation, the following description is applicable to tape operations. The following is a composite of several possible methods of tape instruction word construction. These words may be stored in a fixed sequence, with one major exception. Specific tape operations may be a fixed routine but space is left to insert such variables as address locations (memory or tape), number of words contained in a block, coding (BCD numbers and straight binary only), selected packing densities, parity (odd or even), and other tape operations subject to change as a consequence of computer decision operations.

Up to this point, a general type of computer instruction word and computer number word (binary-fixpoint and floating point) was presented (Fig. 9-15). For tape operations, there may be a series of instruction words to be decoded prior to the actual operation of the tape transport. A number of word formats for tape operations is presented in Fig. 9-16.

Input/Output Instruction

The input/output word is used to acknowledge that the instruction being executed will require an external operation. During the decoding operation the corresponding register (input or output) becomes activated or assigned. If the instruction word has sufficient capacity, the following types of information may be included or accounted for in subsequent instruction words: device selection, external command or function, and the address portion containing subsequent instructions. The device selection may include the device

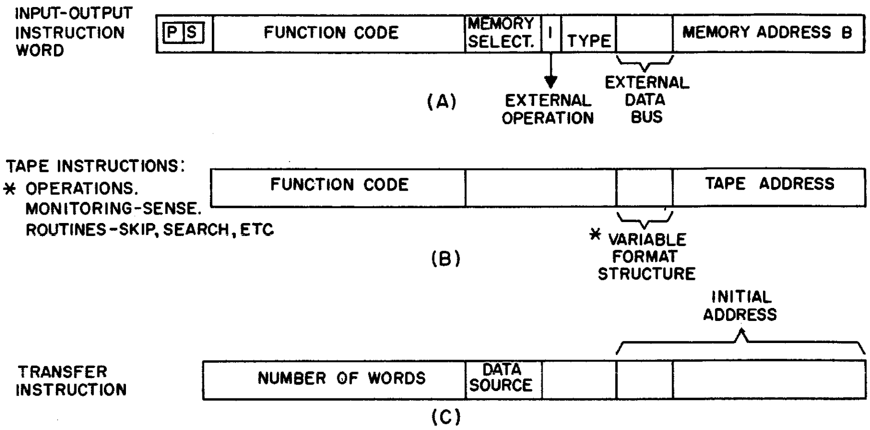


Fig. 9-16. *Tape word format.*

type by its number value. If there are numerous peripheral devices, then the device mnemonic code may spell TAPE. When the device type is established, the next order is a particular device selection. Again there are a variety of ways to identify a tape transport. The tape transport has an assigned number, which will also disclose the appropriate tape control unit. Conversely, the control unit may be addressed, and the tape transport is identified by its control unit's identification number. Finally, the particular computer program may store or retrieve information based on its contents and not on a particular device but on a device type. After the two instructions (input/output and TAPE), the computer external registers are assigned and a device type and device selection have been made. All that is required now is to proceed with the transfer. The tape transport is activated and a start time delay is invoked. Concurrently, a transfer instruction word is acted upon to execute the previous two instruction words.

Summing up, a three-tape instruction sequence was presented, but the word length has not been specified. It is possible by system configuration and word length to substitute a single instruction for the previous three instructions. This was deliberately not done to prevent any restrictions in developing the subject matter and to avoid associating a tape format word or instruction with any commercial computer configuration. This approach also brings out the fact that the word length may present some restrictions if it lacks sufficient capacity (bit length). A brief description of each tape instruction word will now follow.

Going back to the input/output instruction word (external operation), the device selected is TAPE. The function (or operation) field of the word (Fig. 9-16A) when decoded will define the operation to be performed by the device. If the device is not specifically stated with this instruction, then subsequent instructions will include the device type and operations to be performed by the contents stated in the address field. The function field may specify such basic operation as:

Operation	*Mnemonic Code*
Write (FWD or REV)	WRT
Read (FWD or REV)	RED
Search (High Forward Speed)	SRH
Rewind (High Reverse Speed)	RWD
Backspace (one data block or more)	BST
Forward Space (one data block or more)	FST

In the above tape operations, further instructions are obviously necessary. If coding is adequate, a code for write forward or write reverse will be adequate. But, consider the skip instructions (BST or FST). Either the instruction word of Fig. 9-16A supplies the additional information or another instruction must follow.

Another tape operation needed frequently is a load operation. As stated earlier, the load routine is necessary to position the tape with the beginning-of-tape (BOT) marker. Correspondingly, an unload routine is necessary. An input/output register of the computer with its attached tape transport is instructed to rewind from its current position to the load point and provide an interlock so the tape is not available for computer use.

Tape Instruction

After the input/output instruction, a tape instruction or a transfer instruction may follow, depending on the function field code. Whatever the case may be, if the tape must be put into operation, a start time delay is invoked. For simplicity of discussion, it will be assumed that a TAPE code was issued, and a device must be addressed if tape motion is to proceed. Therefore, the next instruction is the TAPE instruction shown in Fig. 9-16B. A tape address may occupy the same field as the device type of Fig. 9-16A or the address portion of the same word. The function field now contains a code that is clearly not an internal or external memory operation. Therefore, the bit position of an internal or external operation is not identified. However, the function field may contain any one of the appropriate tape operations using an unambiguous code:

Mode	*Direction*	*Speed*	*Density*	*Parity*	*Number*	*Format*
Write or Read	Forward or Reverse	High or Low	High or Low	Odd or Even	Binary or Alpha-Numeric or BCD Numeric	Fixed or Variable

The above instruction further specifies not only the tape transport operation but many control details for the tape control unit to supply the tape transports.

Transfer Instruction

Before the tape is up to speed, the data to be written (if a write is given) must be waiting in the tape control unit register. The computer word is disassembled and the first tape word is presented for writing. If a start message symbol, sentinal, or flag is used as a control code, it will precede the first data to be written. The information to be written is prepared and transferred to the tape control unit using a transfer instruction. A typical instruction that satisfies the transfer information will contain the initial address of data, the number of words in the transfer (or final address), and the data source if there are more than one. (This last statement needs some qualification: there may be several internal computer memory sections. Another data source for the transfer instruction may be another tape.) By using the initial address and the number of words in the transfer, an adequate word length is available. On the other hand, the address field of a computer word may be more than half of the word length (address). Obviously, the initial and final address cannot be available in one transfer instruction. This is no problem. It can be handled as a double precision number in the computer. Two sequential transfer instructions are required or the first transfer word is implied or specified as part one of a two-part transfer instruction.

Sense Instruction

To make ensure that the tape transport is available or working, a question and answer routine is occasionally required for each tape control unit operation. This is called *sense instruction.* Sense instructions enable the computer to determine the status or condition of a particular control unit. For example, they determine if the unit is ready or if an error was detected in the previous tape operation. Obviously, the sense instruction applies to a previously-selected tape control unit. Therefore, the control wires are enforced and the sense operation is permitted to proceed.

The sense operation is accomplished using the tape instruction word. The tape address is available and the function field is used to express a given sense operation. Some of the tape sensing instructions include the following: ready or busy; protection ring or write inhibit; manual or automatic mode; rewinding or not; tape supply or not; parity error or not; interrupt or not; standby or alarm; load point or other tape markers; end of operation; end of block, end of file, or end of tape, etc.

Multiple Computer Configuration

Computers are being used for nonarithmetic operations, pattern and character recognition applications, self-learning and self-organizing systems, instruction machines, inventory, plant, and business control, hybrid analog and digital computations, and many other already proven applications. Techniques have been under study for solving the problems encountered in constructing networks for these applications and for further advances of computer applications. Many of the problems of computer collaboration and hybrid instruction systems are being solved by co-operative modules such as those shown in Fig. 9-17. They can perform a majority of the applications mentioned above.

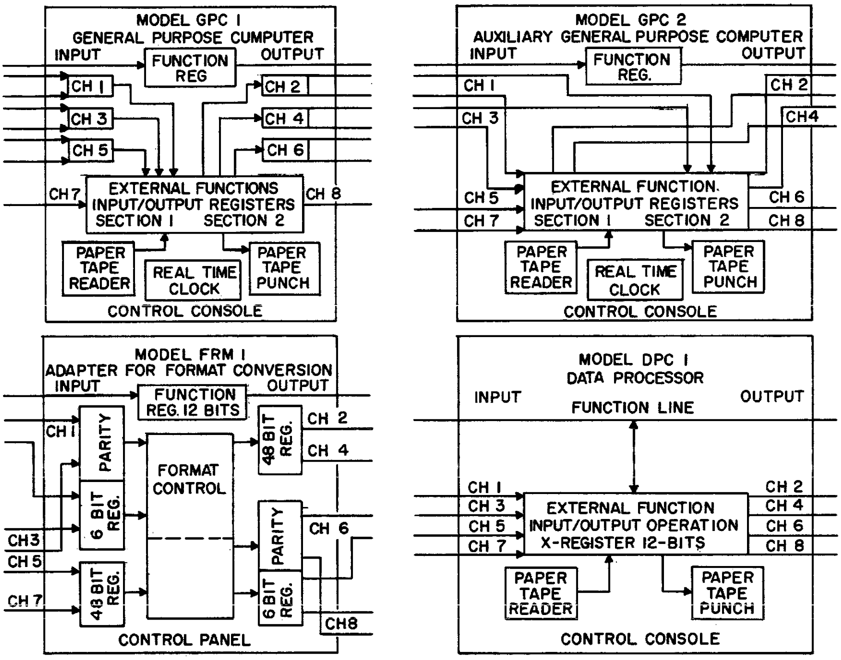


Fig. 9-17. *Digital representation of computer elements.*

The accepted alphanumeric or BCD notation is 6 binary bits. The present state-of-the-art and system requirements of nominal digital precision for analog information is 12 bits. Also, the punched cards in IBM (Hollerith) are a 12-level code, but can be converted to a 6-level code.

A computer system will now be constructed. Communication between equipments (and systems) can use 6 parallel data channels. Where analog inputs are present, the analog-to-digital conversion of 12 bits is assumed. In addition to the numbers mentioned previously, binary notation is used (multiples of two) to determine total numbers such as input/output lines, equipment selection, operational time, register length, etc. In this manner, greater efficiency is achieved by considering two-state devices for hardware construction.

The components comprising the system are:

TABLE 9-3. Equipment Compatibility Chart

	GPC-1	*GPC-2*	*DPC-1*	*MTS-1*	*FRM-1*
WORD LENGTH (in bits)					
Instruction	24	24	12	NA	NA
Operation Code	6	6	6	6	6
Function	15 (12 + 3)	15 (12 + 3)	12	12	12
Number	48	24	12	48	6 & 48
Channel Selection	3	3	3	3	3
Input Transfer	48	24 & 48	6 & 12	12 & 48	6 & 48
Output Transfer	48	24 & 48	6 & 12	12 & 48	6 & 48
MEMORY					
Word Length	48	24	12	NA	NA
Word Capacity Max.	32, 768	32, 768	4069	NA	NA
OPERATIONAL TIME					
Machine Cycle	Equal	Equal	Equal	NA	NA
Instruction Decoding	Equal	Equal	Equal	NA	NA
Function Decoding	Equal	Equal	Equal	Equal	Equal
Memory Access	Equal	Equal	Equal	Equal	Equal
Transfer	Equal	Equal	Equal	Equal	Equal
Addition & Subtraction	Equal	Equal	Equal	NA	NA
Multiplication & Div. per number word	Slower than GPC-2	Slower than DPC-1	Unit Time	NA	NA
Transfer Rate of					
Function Word	Two Times GPC-2	Two Times DPC-1	Unit (12 bits)	Unit	Unit
Number Word	Two Times GPC-2	Two Times DPC-1	Unit (12 bits)	4 times DPC-1	Same as MTS & same as DPC-1 on 6 bits
INPUT/OUTPUT FACILITIES	3 Buffer Input Channels 3 Buffer Output Channels	Two 48 Input Channels Two 48 Output Channels	5 Input/Output Channels Sequential Operation Only	4 Input/Output Channels	Two 6 Input Channels Two 48 Input Channels

TABLE 9-3. (Cont.)

	GPC-1	*GPC-2*	*DPC-1*	*MTS-1*	*FRM-1*
INPUT/OUTPUT FACILITIES	1 Hi-Speed Input Channels 1 Hi-Speed Output Channels Simultaneous 3 read and 3 write operations	2 24 Input Channels 2 24 Output Channels Simultaneous 1 read and 1 write operation		Simultaneous 1 read and 1 write operation Assembles 12 bit words into 48 bit words. Disassembles 48 bit words in 12 bit words	Two 48 Output Channels Two 6 Output Channels Simultaneous 1-6 & 1-48 read and 1-48 and 1-6 write
COMMUNICATIONS BETWEEN EQUIPMENTS					
Internal Voltage	0 & 2-4 volts	0 & 2-4 volts	0 & 2-4 volts	0 & 2-4 volts	0 & 2-4 volts
External Voltage	0 & 8-16 volts	0 & 8-16 volts	0 & 8-16 volts	0 & 8-16 volts	0 & 8-16 volts
Control Input/Output Lines	Same	Same	Same	Same	Same
Signal Exchange Sequence	Same	Same	Same	Same	Same
Number Coding	Same	Same	Same	Same	Same
MISCELLANEOUS					
Address Logic	Single Address (24 bits)	Single Address (24 bits)	Single Address	NA	NA
Address Features	Yes	Yes	Yes	NA	NA
Direct	Yes	Yes	Yes		
Indirect	Yes	Yes	Yes		
Relative	Yes	Yes	Yes		
Input/Output Features	Paper Tape Reader Paper Tape Punch Electric Typewriter	Paper Tape Reader Paper Tape Punch	Paper Tape Reader Paper Tape Punch	NA NA	NA NA
Multiple Precision	Yes	Yes	No	NA	NA
Peal Time Clock	Yes	Yes	No	NA	NA
Interrupt (Priority)	Yes	Yes	Yes (Programming)	NA	NA

Model No.	*Description*
GPC-1	General Purpose Computer 1
GPC-2	General Purpose Computer 2
DPC-1	Data Processor and Control 1
MTS-1	Magnetic Tape System 1
FRM-1	Formating 1

The computer elements are shown as five modules comprising four input and four output lines having odd and even numbers (Figs. 9-13 and 9-17). The coding can be expanded to eight lines with a binary bit defining an odd or even line (input or output). In addition, each line can be subdivided into two additional lines with the use of a flip-flop (FF). The concept of compatibility and modular construction is summarized in Table 9-3.

Rapid progress in computer development has resulted in increasingly large and complex computer systems. Presently, a combination of several single computers into a multiple-computer system is being used. Such a system combines the capabilities of a single main computer with other computers that are fast and versatile and with external communication facilities that are exceptionally versatile. This combination permits the internal capabilities of the main machine to be exploited readily by other automatic devices or by human operators.

This type of system, commonly called an "information system," places greater emphasis on the need for computers that can be adapted to a variety of problems, a quality absent in most system designs.

Multiplex information processing for real-time and on-line operations (non-real time) calls for a system capable of carrying out several operations simultaneously, requiring several separate memories with units of modular construction that can be joined in a flexible manner. A wide variety of input and output mechanisms can be attached and used efficiently. Further, the problems of computer rearrangement to accept a wide variety of applications are considerably simplified. Consideration here of this area of development will be restricted to those characteristics that describe the input/output features of the modules; it will not consider in detail the memory and central processor or arithmetic units.

Multiple Programming

Considerable attention has been directed toward attaining higher computational speeds. One method which has been investigated is concurrence of operations. This has taken several forms. In addition to overlapping input/output operations and data processing operations, it is possible to overlap the execution of one instruction with the interpretation and obtainment of operands for succeeding instructions. Furthermore, modern computers possess more than one arithmetic unit and several storage levels, permitting simultaneous execution of several programs. Finally, major information systems currently are composed of more than one large computer. The greatest promise of multiple programming lies not in more efficient input/output operation, but in the use of multiple equipments with provision for permitting closer collaboration among the wide disparity of operating speeds of equipments and problem solving.

The definition of multiple programming has not been formulated to the satisfaction of the author. Multiple programming might pertain entirely to the instruction or instructions being executed at any given moment, or to the task of maximizing the amount of time-sharing possible at any given time. A given instruction (or instructions) in which several units operate with overlapping time intervals in assembly fashion upon successive operations, or several units are at work simultaneously on instructions of many sequences, might be an acceptable definition or example of multiple programming. The former is identified as *vertical concurrence* and the latter as *horizontal concurrence.* Obviously, multiple programming has two degrees of freedom (vertical and horizontal), and equipment configuration may be regarded as an independent variable with time implied.

A surface of two dimensions has an ordinate (vertical) and an abscissa (horizontal). The vertical has a number scale while the horizontal has a descriptive identification. The vertical scale, numerically speaking, denotes multiplicity of the same item or operation (redundancy). So long as one of an item exists, the function (or operation) can be performed. Horizontally, a range or diversity of items is denoted so that any deletion of a single item would impair or prohibit a solution to a problem or the operation of a system. Hence, we refer to multiple when related to the vertical axis, and simultaneous, concurrent, or parallel when related to the horizontal axis. Up to the present time, multiple, multiplex, multiplicity, concurrent, simultaneous, and parallel have been used synonymously.

Since there may be more than one computer, we speak of multiple computers. For simplicity of discussion, assume that there are four basic units within a computer: instruction, indexing, arithmetic, and storage units. Within each unit there are redundant equipments permitting multiple addressing, multiple indexing, multiple computations, and multiple storage levels, respectively. When one of each operation is being performed at the same moment, the operations are simultaneous. Again, within each unit, a further subdivision of simultaneous operations can comprise external (input and output) operations and internal operations (decoding, incrementing, adding, and read and write.) The multiple computer units comprise one level, with two additional levels, as shown in Fig. 9-18. This arrangement of a matrix 3 by 3 permits the following multiple and simultaneous operations: (1) within a computer equipment module; (2) among computer equipment modules; and (3) between internal and external equipments.

The multiple computer configuration possesses several salient features, in addition to multiple and parallel operations, which may be significantly advantageous. Programming and system complexity can be reduced. Several

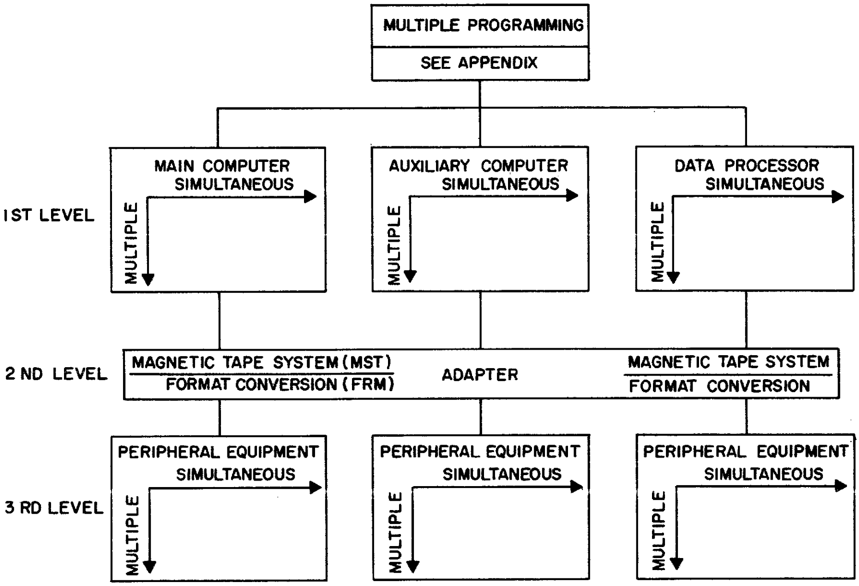


Fig. 9-18. *Multiple computers.*

independent processes may be interconnected in various ways within a problem-oriented, special-purpose computer, thus affording flexibility. However, the existence of a "fixed" general-purpose computer element in the system is essential; for example, a minimum vocabulary and a set of machine characteristics that are modified advisedly are desirable. The fixed plus variable structure (F + V) computer will consist of a set of independent digital complexes ranging in size from individual modules to a high-speed general-purpose computer. In Fig. 9-19 the fixed computer configuration contains a fully-loaded system (input/output channels) and a chain expansion into another system. No doubt a chain of fixed systems can be created, and the remaining block will assume the variable configuration. Multiple programming superimposes an entirely new level of logic complexity on the logical designer and/or programmer. This burden can be shared in many different proportions between the hardware and the program.

The Basic Multiple-Computer System

The basic configuration of the multiple-computer system usually comprises three major units. Although some difference of opinion exists as to the types of computers to be utilized and their respective assignments, the definitions as used here are main computer (GPC-1), auxiliary computer (GPC-2), and data-processing and control computer (DPC). Since each of the three computers (Fig. 9-18) is independently programmed, each contains not only a processing unit and its associated storage unit, but also a control unit for

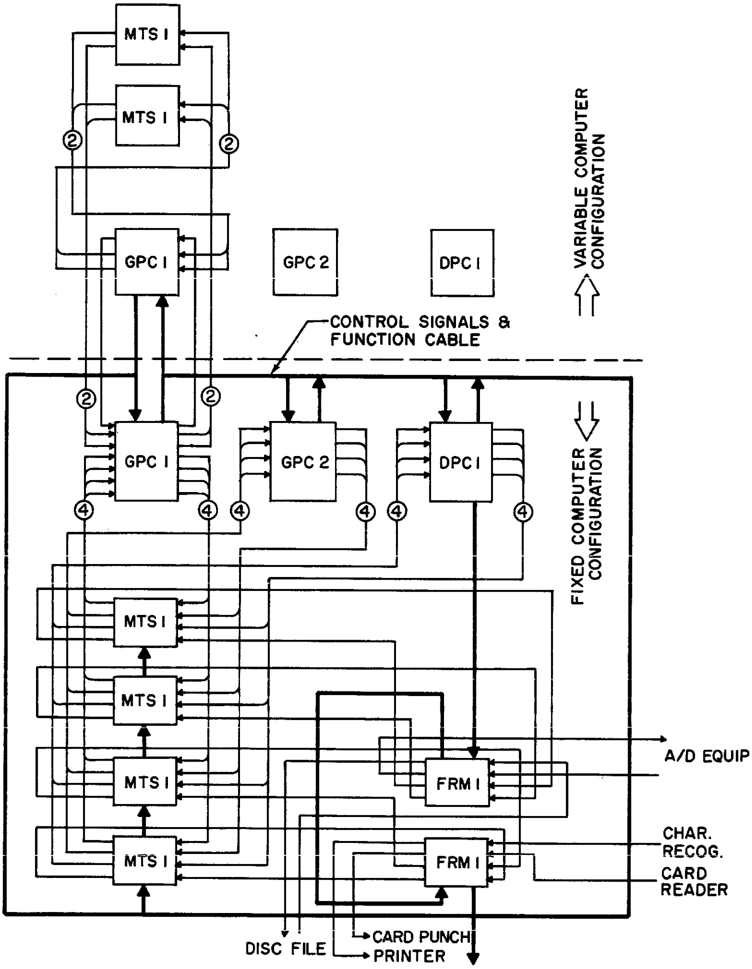


Fig. 9-19. *Fixed computer configuration with a chain expansion.*

instruction, decoding, and program sequencing. To keep the coding simple, only a 6-bit code is provided, but many possible format variations permit a large number of complex operations to be performed with few instructions.

The GPC-1 computer carries out the executive program of the system, assisted by the other two. The function of the data-processing and control (DPC) computer is to format or precondition the incoming or outgoing data (preprocessing). This independently-programmed processor is specifically designed for inspecting, editing, interpreting, and modifying the data that are flowing into or out of the system. In performing the formating operation, it has charge of transferring words (or groups of characters) between the internal and external storage units of the system. It can (with peripheral equipment) perform extracting, shifting, and code-converting operations on these words or characters in a continuous data flow. By the use of a function word, programs can be initiated, terminated, or reversed in the direction of data transfers that are entering or leaving the system.

The auxiliary computer (GPC-2) operates in conjunction with the GPC-1 computer. The logical and arithmetical organization differs in every multicomputer system. The auxiliary computer in this system is, by definition, an auxiliary device. Therefore, it can substitute for the GPC-1 computer or the DPC unit, or it need not be utilized at all in the system. For real-time applications, the GPC-2 computer concurrently carries out specialized procedures that assist the executive program, while the DPC unit performs formating operations. For non-real-time operation, the GPC-2 computer performs a hybrid operation of complementing the GPC-1 computer and the DPC unit by performing data-processing operations. In order to simplify its integration within the system and effect a cost reduction, the GPC-2 computer is usually a modified version of the GPC-1 computer, although this is not a requisite.

In a multicomputer system such as this, in which all the computers must be able to communicate with each other effectively, a magnetic tape system (MTS) performs as a master switchboard, along with tape-recording operations. Each computer must not only control its own program, but must also, from time to time, exchange data, instructions, and control messages with the other computers in the system. For example, each computer has a different machine word length. The MTS unit formats the transfer among all computers. The transfer of the function field (nominally 12 bit) permits overall tasks to be carried out continuously or intermittently under the executive program. Special initial instructions from the GPC-1 computer are accepted and distributed by the MTS unit. Time, selection, and command operations take place in proper sequence even though they are capable of being executed at completely unrelated rates. A simple example is the coordination of two completely incompatible data rates. Assume that external data are called for via the DPC unit by the GPC-1 computer. Upon completion of the data transfer operation, the GPC-1 computer is informed of the transfer. In the meantime, the data are stored indefinitely on the magnetic tape. Thus, interchange of information can take place at any time between the multicomputer system and the external equipments on a completely nonscheduled basis. In this manner, interrupt features are easily implemented and the human operator is able to communicate conveniently with the system.

The format unit (FRM) performs the communications function between the computer complex and the peripheral equipments in the same way that the MTS unit performs within the computer complex. The format unit accepts serial characters and arranges them into a machine word or reverses the procedure. It has the ability to accept and operate on the function word in a manner similar to that of the MTS unit. Although the MTS unit activates one type of equipment (magnetic tape units), the function decoding is required for many processing functions. The FRM unit does not perform as many processing functions as the MTS unit, but the function decoding is necessary for the wide variety of formating operations. The FRM unit is designed primarily for compatibility with other equipments and for operating convenience. Normally, peripheral equipments are slow-speed devices relative to the operating speeds of the main computer, and their word formats can assume any length from a single binary bit to the full storage capacity of the system. However, 6-bit alphanumeric words are used to process bits in the lowest order and still retain their significant characteristics. Therefore, the FRM unit can be considered a variable-length word and format transfer processor. Where data rates are unrelated and storage facilities are required, the FRM unit drives the MTS unit. As previously noted, the MTS unit also controls the information transfer among the computers, thus performing a dual function and obviating the duplication of facilities.

The function word transfer means one thing among internal operations of the multicomputer configuration and yet another thing when related to external operations. Its creation and bit length are a matter of convenience and the normalizing of many transfer functions. It is an artifice that permits the system designer to make changes in his design or corrections for any mistakes. It is a method of equipment and/or operation selection and execution. It performs as an executive element by supervising in/out operations. It permits the addition of computer equipments to the system with no need for advance preparation of special programs and, in the event of equipment breakdown, redistributes the work load among the remaining equipments.

In devising the plan just described, principal emphasis was placed on producing a flexible, logical plan rather than a fixed system. Its uniqueness is not in creating a new component, but in assembling existing components in a unique configuration, thus achieving maximum capabilities above and beyond those of each individual component.

Data Gathering

In a data-gathering operation, the digital information is collected, collated, sorted, and merged into a few basic media, such as magnetic tape, punched paper tape, and punched cards. Each medium has certain attributes that are essential in achieving an efficiently operating data reduction facility.

The merits of an efficient and high-speed central processing facility and an experienced, competent staff are quite obvious. In business, expanding markets have required branch offices and the location of production facilities close to the raw material source. This decentralization is economical provided that time, distance, and antiquated communication methods do not reduce or prohibit an adequate profit margin. The businessman has solved this problem aspect of economic growth by maintaining a close contact with his market and widespread facilities with high-speed computers interfaced with high-speed digital data communication links that permit a strong central control organization.

This system arrangement of distributed or remotely-located units communicating with one common focal point is basic in many organizations, which include government services, the military, industry, etc. In systems of this organizational type and operation, the central headquarters in burdened with the tasks of receiving, analyzing, evaluating, and utilizing the transmitted information in an efficient manner. The high-speed computer is a means of coupling or integrating all the remotely located sources of information. Examination of computer speeds with available teletype and telephone quality facilities shows that there is a fundamental mismatch of operational speeds. Digital magnetic tape recording with its start-stop capability can accept data at its highest writing rate with a computer and disperse the same data at the slowest data-link speed. On the other hand, it can accept data from slow-speed devices such as manual typewriters, mechanical paper tape readers, photoelectric paper tape readers, and punch card readers and can supply the same data at high speed. This versatility and wide range of operational speeds, large storage capacity, unlimited storage time, and random operation has made it possible to construct a satellite computer configuration such as that described in the following paragraphs.

Satellite Computer System*

An example of a multiple-computer configuration best illustrates the utility value of a versatile and flexible tape control unit. Control Data Corporation's (CDC) two general-purpose computers, the small scale 160 and the large scale 1604, and their 1607 magnetic tape system can be set up in a typical satellite computer system configuration. The basic CDC components are connected around the CDC 1604 in an arrangement shown in Fig. 9-20. This arrangement offers on-line and off-line operations for both central computer and any service depot. In this operation, the CDC 1604 monitors and operates the entire system and each 160 is able to enter or exit from the system. The 1604 can communicate with any peripheral device directly (excluding the 160) or indirectly via the 1607 magnetic tape systems. The 160 is a 12-bit word length machine and communicates with the 1604, whose word length is 48 bits. In this configuration, the two computers could be connected to each other directly, but with some loss of efficiency. The 1607 unit formats the word length of one computer into an acceptable structure for the other and allows either computer access to the tape transports. In view of 1607 placement, the 160 computer may be remotely located with certain restrictions. A variety of peripheral devices at long distance may be serviced by digital data communication links.

Data Transmission

The use of data communications systems as a means of information transmission and display is receiving wide attention. There are a number of

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* Based on Control Data Corporation Pub. 062.

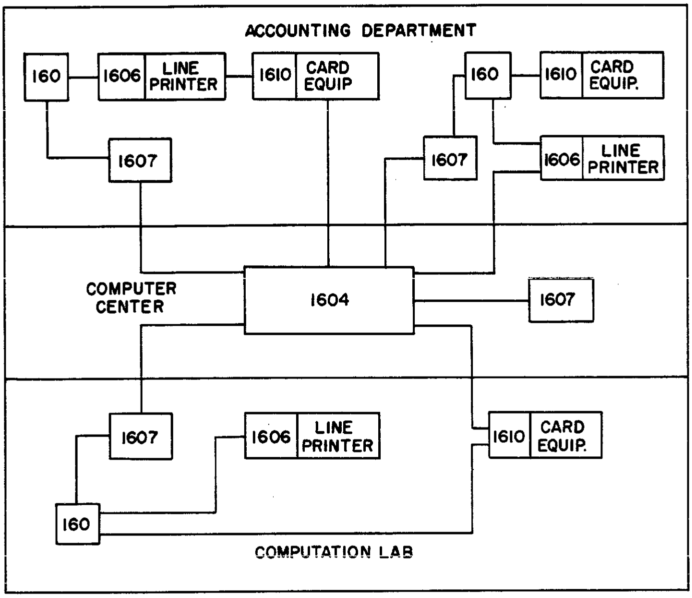

Fig. 9-20. *CDC computer satellite system.*

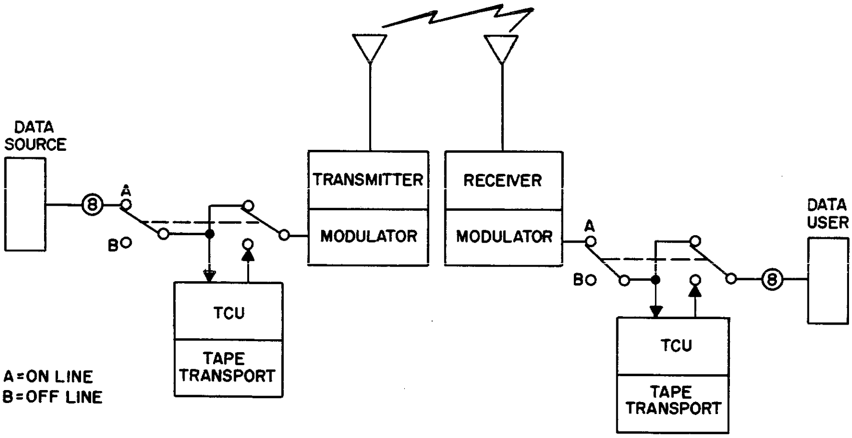

Fig. 9-21. *Tape and digital data communication configuration.*

equipments (transmitter and receiver combinations) that are capable of being actuated by digital data. All that is necessary is the mating of the communication equipment with the data source. In this case, the tape control unit and its tape transport are considered as the data source.

Most digital data equipment is specifically designed in conjunction with magnetic tape operations; a complete tape recording subsystem is a purchasable item. As an alternative, other digital communication equipments are adaptable to digital magnetic tape recording techniques.

A typical magnetic tape recording facility and a communication combination (transmitter and receiver) are shown in Fig. 9-21. The digital information is accepted by the tape control unit and the modulator. The digital data are recorded in a specified computer format by the control unit and the same digital data are accepted by the modulator, translated into a modulating r-f signal, and transmitted. At the receiver end, the r-f signal is received, detected, and translated into digital notation. The digital data are recorded by another tape control unit and made available to the data user.

A point-to-point wire system may be substituted for the r-f link. Correspondingly, the modulation is changed to drive a line transmitter. The complementary process of detection and translation to digital notation is repeated and the system operation is primarily the same. The major difference is the communication medium: air as opposed to a cable. For both data transmission configurations, the tape recording operations produce the same computer tape format to drive the modulator and the computer (at either data terminal).

Utilizing digital magnetic tape recording principles, the data communication equipment will accept 6 to 8 parallel input/output lines (transmitter/arrangement shown in Fig. 9-2. If the data equipment operates in a serial mode, bit by bit (Fig. 9-2B), the tape word (character) of 6 levels enters and exits the character register in a shift register routine. If the communication equipment will accept 6 to 8 parallel input/output lines (transmitter/receiver), no problems of interface exist and the transfer arrangement of Fig. 9-2C is applicable.

Many current data communication equipments utilize a 5-level type of coding (teletype). The same data format can be reproduced on magnetic tape. However, it is preferable to translate 5-level coding into a 6-bit alphanumeric computer character word. Additional equipment is not a major problem and, in many fixed transmission formats, the data equipment will accept data in parallel up to the maximum available input/output lines (Fig. 9-2A). The communication equipments accept data for transmission and internally format the data for activating the modulator. At the receiving terminal, a complementary process is performed. The data are detected, checked for errors, and transferred in parallel. All three modes of data transfer format shown in Fig. 9-2 are used in data communications and are easily accommodated by a tape control unit and its associated digital transport.

The Kineplex Magnetic Tape Transmission System manufactured by Collins Radio Company is one of many systems that incorporates tape recording operations with data transmission equipment. (The system is reviewed here in terms of its magnetic recording facilities and not in terms of its transmission equipment.) A two-way communication arrangement requires a transmitter/receiver and tape recording combination at each transmission terminal. Therefore, the tape transports may be operated to activate the data link in either direction. The Kineplex Tape System is capable of producing a number of computer tapes but the characteristics of the Kinetape Converter (Fig. 9-22), which handles IBM tape (Collins 768-2) will be described. The IBM designation supplies considerable information concerning the organization of data on tape. This information is tabulated below.

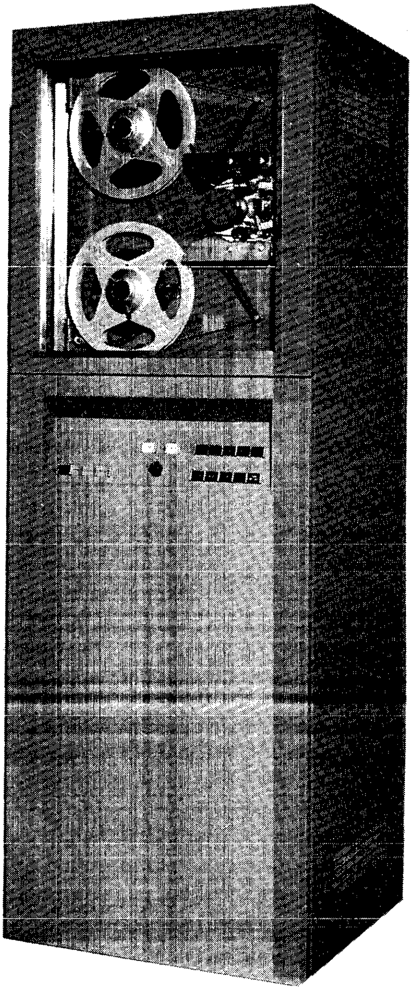

Fig. 9-22. *Collins Kinetape converter.*

Tape Format	*IBM Characteristics*
1. Head	7 parallel tracks
2. Tape density	200 bpi
3. Recording method	NRZ
4. Error detection	Lateral and longitudinal parity checking
5. Record gap	¾ inch
6. File gap	¾ inch
7. Record length	120 characters plus longitudinal check character
8. File length	Any number of 120 character records

Item 7 has a fixed record length of 20 IBM 36-bit computer words. The 120 character fixed record length is compatible with a 120-column page printer.

Although the tape reel can be prepared using a standard IBM format with restricted record length, tape transmit mode over voice-quality telephone lines requires some explanation. The IBM tape reel can not be operated at 75 ips or 15,000 cps (200 bpi × 75 ips). Instead, the tape speed is 3 ips and the effective pulse train is 4200 cps (200 characters/inch × 7 bits/character × 3 ips). The ability to compress twice as much data as normal sine-wave modulating techniques for a given bandwidth channel is one of the proprietary characteristics of the Kineplex communication equipment. This is how 4200 cps information can be compressed into an audio bandwidth channel.

Tape Translation

Commercial tape translators provide rapid and efficient translation of data between tapes of any data processing systems. Magnetic tape recorded in one computer format can be translated directly into magnetic tape usable by another computer. The translation process is a three-level operation, as shown in Fig. 9-23. The data input device (Problem Oriented Language) may be

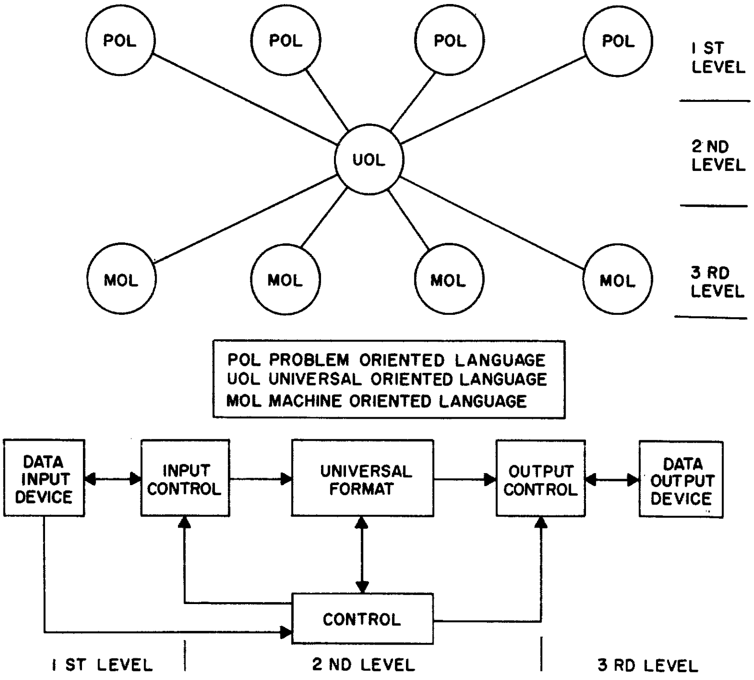

Fig. 9-23. *Language translation.*

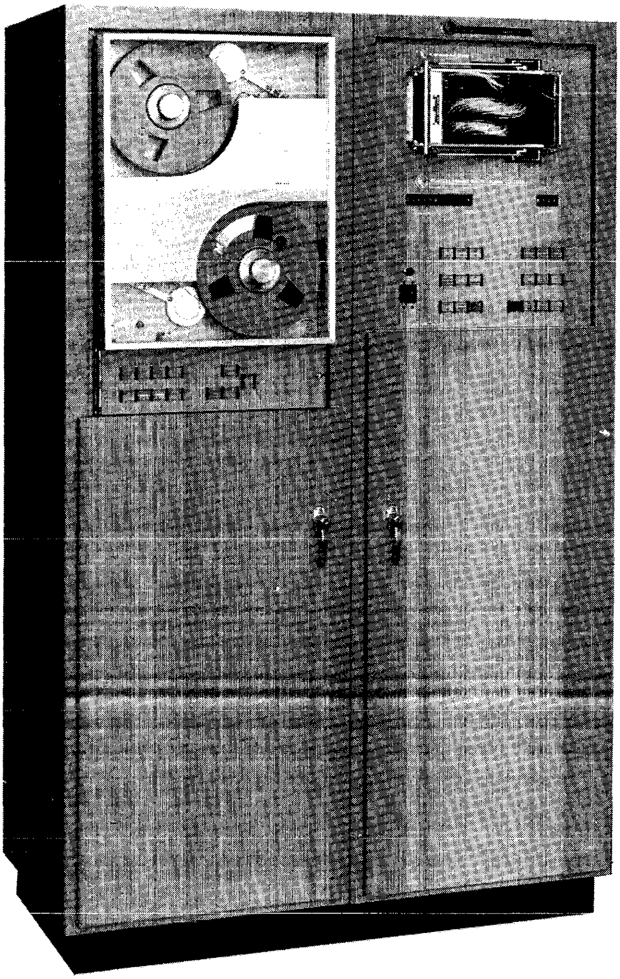

Fig. 9-24. *EECO-751 computer format control buffer equipment.*

magnetic tape of a machine code, punched card, or punched paper tape. The input control serves as a connecting link between the data input device and the universal format unit. The universal format comprises the data and all the necessary editing, translating, formating, parity generating, and control data to be supplied to the data output device via the output control.*

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* Several manufacturers of language translators or tape translation equipment are Computer Control Co. Inc., Electronic Engineering Company of California (EECO), EPSCO Systems, and General Devices, Inc., More and more companies are entering this field.

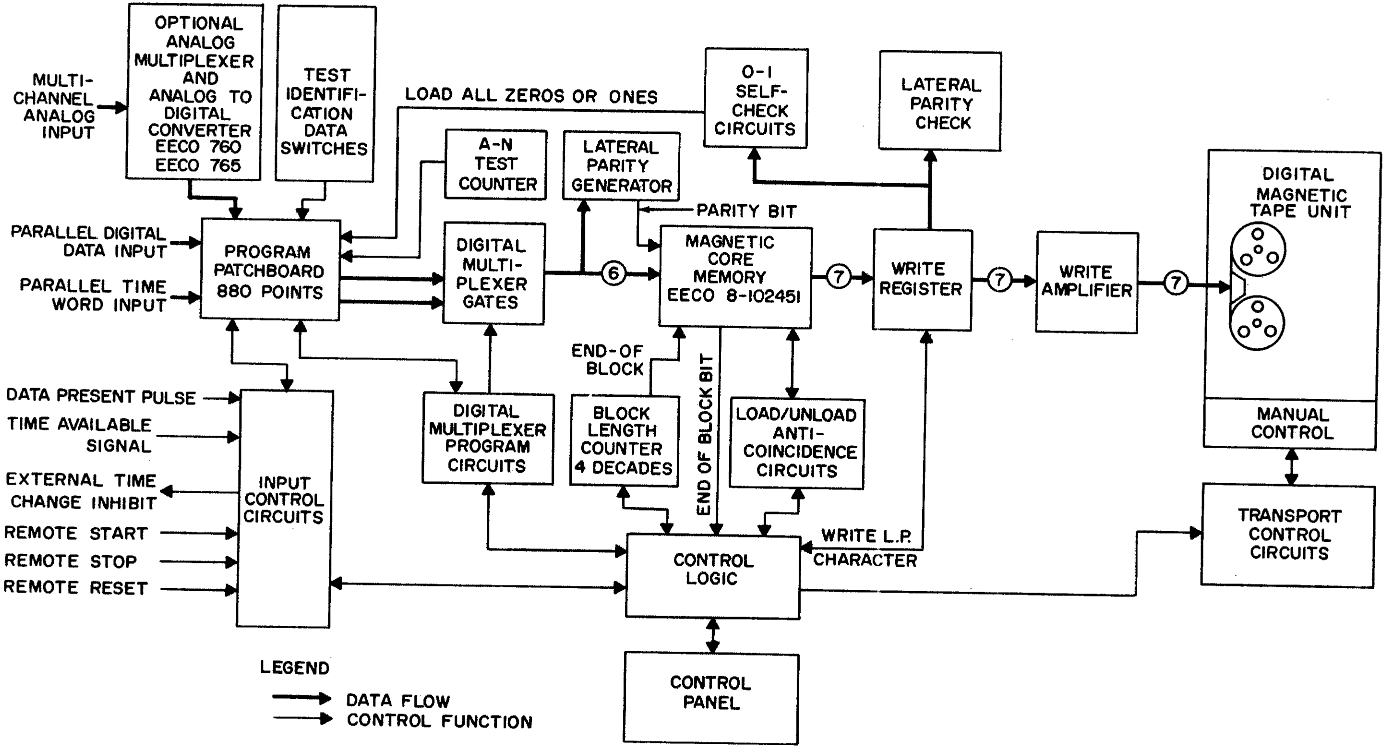
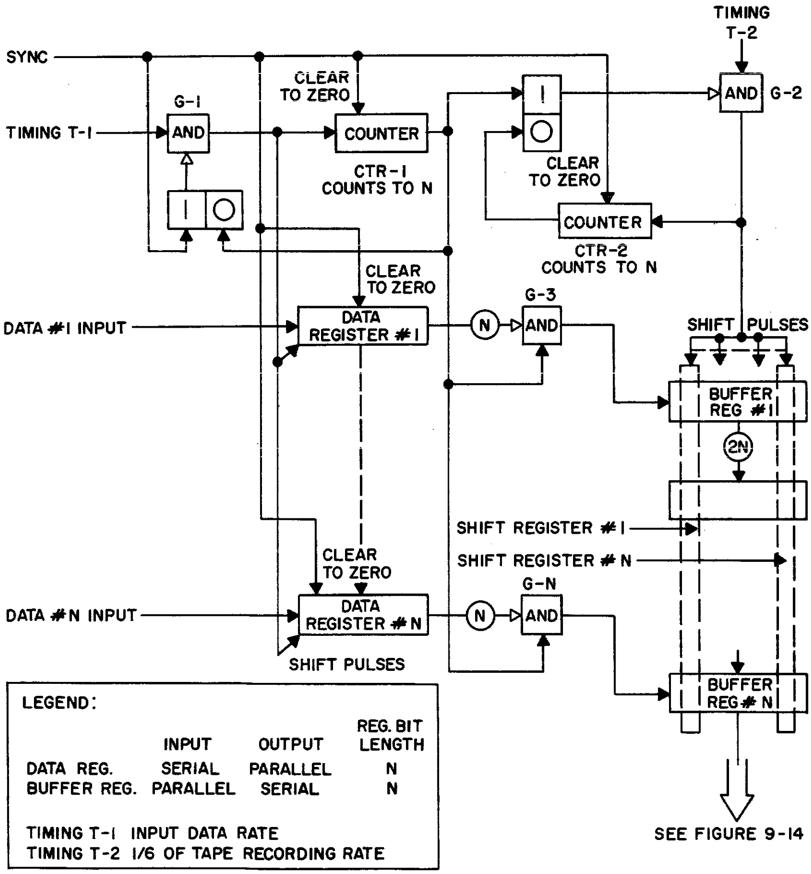


Fig. 9-25. *Computer format control buffer EECO-751 block diagram.*

Figures 9-24 and 9-25 show the EECO 751 Computer Format Control Buffer and its block diagram, respectively. The EECO 751 is manufactured by the Electronic Engineering Company of California and performs a universal tape-to-tape operation in conjunction with the appropriate accessories.

Serial-to-Computer Tape Format Operation

A tape translation of serial-to-digital format is illustrated in Fig. 9-26. It is preferable but not mandatory to operate the serial recorded tape at normal recording speed to minimize any reading errors. The computer tape is operated at any speed (higher or lower than the computer tape operation) in order to satisfy the packing density on tape. As long as the packing density of the computer tape is correct, the product of this value and the computer tape speed will always be the proper tape frequency in kilocycles for computer operation. In Fig. 9-26, the serial data is stored in a shift register until the



LEGEND:

	INPUT	OUTPUT	REG. BIT LENGTH
DATA REG.	SERIAL	PARALLEL	N
BUFFER REG.	PARALLEL	SERIAL	N

TIMING T-1 INPUT DATA RATE
TIMING T-2 1/6 OF TAPE RECORDING RATE

Fig. 9-26. *Serial-to-computer tape format logic diagram.*

last or longest word has been accepted by a counting operation. Then, at one pulse time, all the stored data in the data register is transferred to the buffer register. The data register accepts data in a serial manner and transfers it in parallel. The buffer register accepts input data in parallel and its output is serial. The serial input to the data register operates at the tape clock rate (Problem Oriented Language). The shifting rate of the working buffer (the dashed lines of Fig. 9-26) is one sixth of the computer tape speed (Machine Oriented Language). Both tape speeds are adjusted to be compatible for this tape translation operation without additional buffering and continuous tape operation, if possible.

In this process of tape preparation, other media such as punched cards and punched paper tape are equally applicable. It is just as desirable to reduce these two media to magnetic tape for high-speed data processing. In Fig. 9-27 translation of punched cards and punched paper tape is pictorially represented. Also included are several peripheral devices such as plotting boards, strip charts, and high-speed printers to verify the complete translation process.

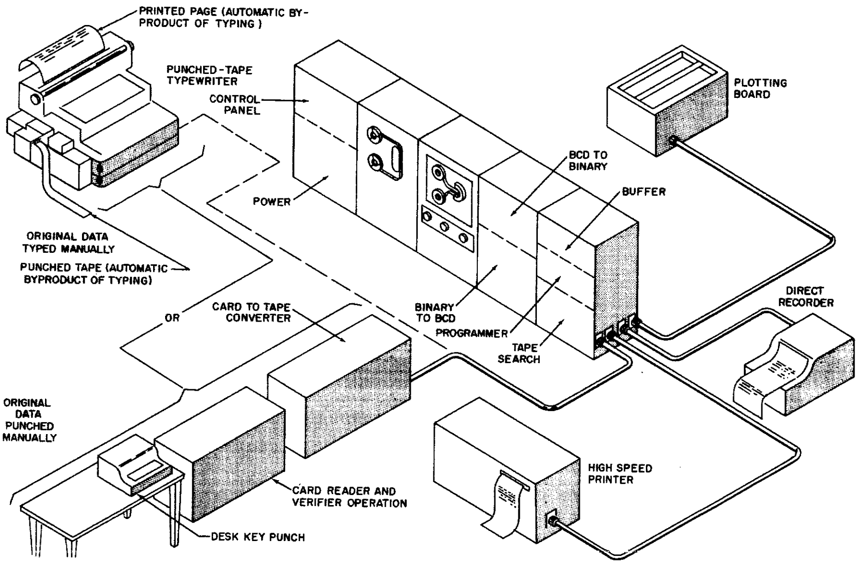


Fig. 9-27. *Control and data preparation and quick-look facility.*

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10

Recent Developments and Applications

Digital magnetic tape recording will play an increasing role in computer systems, documentation and data storage systems, and in communication. The tape transport is being continuously improved and refined to satisfy current, and anticipated, applications. Research promises new developments in digital tape drive, higher data transfer rates, higher storage-density capability and improved magnetic-recording performance, and lower costs.

In this chapter new developments are briefly surveyed to indicate technique trends and new applications.

Tape Transports

More efficient tape drives and tape-handling mechanisms have permitted new packaging concepts for tape transports. Tape transports that permit a variety of intermittent start-stop operations, contrasted with continuous-running tape transports used in instrumentation recording, reading, and writing, have expanded the utility of digital magnetic tape recording.

A few new tape-transport configurations now available are shown in Figs. 10-1 and 10-2. The DATAMEC quad-unit D-2020 (Fig. 10-1) uses four tape transport tapes, thereby taking advantage of the economy of shared data electronics. Note the horizontal vacuum loop configuration of this transport. The tape transports shown in Fig. 10-2 are used in the Bendix computer facility. They are manufactured by Potter Instrument Company, Inc.

Cartridge loading of tape reels, a new feature of the IBM Hypertape system, eliminates the touching of magnetic tape (Fig. 10-3). From the time the cartridge, which contains an 1800-foot reel of tape and a take-up reel, is inserted in the IBM 7340 drive, less than 20 seconds elapse before tape processing begins. The sealed cartridge is opened automatically only in a clean area of the drive. It can be removed, without rewinding, at any time in the course of processing.

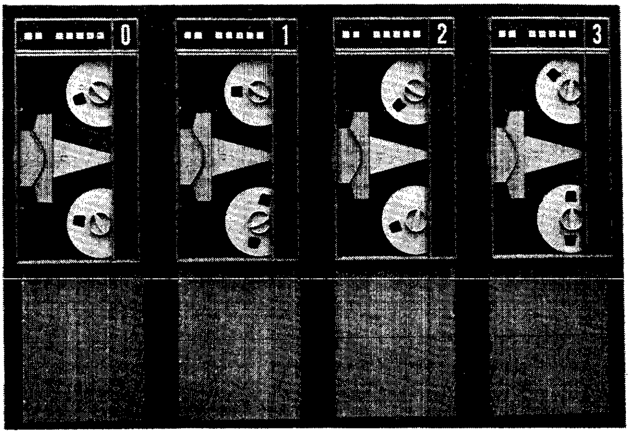

Fig. 10-1. *Datamec Corporation's D2020 Quad unit.*

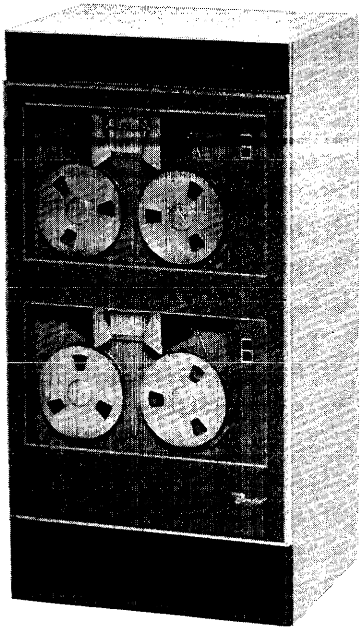

Fig. 10-2. *Bendix tape transports (Potter Model 906 II).*

Magnetic tape transports have handled tapes in numerous lengths and as wide as a sheet of typewriter paper. Endless loops of several feet to a single-reel cartridge have been developed and used for special applications. Tape

Fig. 10-3. *IBM Hypertape cartridge.*

has even been wound on shafts without a reel or without the benefit of any type of pile support.

The most advanced tape transports will eliminate or reduce tape wear, minimize skew, and, in general, reduce scheduled maintenance. They will ensure a more smoothly-performing digital magnetic recording operation, independent of the particular recording process.

Magnetic Tape

Neglecting the mechanical limitations of the tape transport, the difficulty in achieving the maximum possible magnetic-recording density results from limitations of the magnetic tape itself. Recording on magnetic tape imposes a rather severe limitation on high-density recording. In digital recording, a thick coating may be used so that a satisfactory signal level can be generated with ring-type heads. The thick coating limits the resolution because of the self-demagnetizing field and the homogeneity of the particles. Also, the separation of the particles within the tape coating prohibits the attainment of any significant recording density. Today progress is being made toward development and production of high-performance, magnetic micro-thin surface tapes for digital applications. Advanced research in digital tapes is complemented by research efforts in coding to detect random errors and supply their corrections.

Magnetic Heads

Mechanically, the severest limitation on the maximum recording density of magnetic recording is the playback process. The conventional ring-type head is limited by playback head separation and gap-effect resolution capability. Use of the ring-type magnetic playback transducer can no longer be taken for granted. Research is directed towards replacing this playback transducer with one that is insensitive to tape thickness and wavelength. Current laboratory experiments are using optical techniques for the playback process. It may become common to see magnetic heads for recording and an unrelated transducer capable of sensing magnetic imprints for playback.

A breakthrough in the state-of-the-art may make data compression of several orders possible (10,000 to 100,000 bits per inch). If this is achieved, it will influence magnetic head and tape design, and will, undoubtedly, render present digital magnetic tape coding methods obsolete.

Applications

Major emphasis on improving past limitations has added considerably to magnetic tape versatility. Today the point has been reached where a computer depends on magnetic tape as its major peripheral equipment. The magnetic tape station is more equally matched in speed with the computer. Generally, a two-step speedup input process results: punched paper tape and punched cards can be read faster than keyboard entry and magnetic tape can be read faster than punched paper tape or punched cards. The computer output process is the reverse. The computer results are written on magnetic tape and subsequently translated to punched paper tape or cards.

Magnetic recording is still moderately expensive relative to punched card or punched paper tape entry. However, the conversion from one storage medium (card or paper tape) to magnetic tape, or the initial storage of information on magnetic tape can add considerably to a modest computer installation in terms of speed, cost reduction, and flexibility. Some computer manufacturers have upgraded their card-oriented or paper-tape entry machines with the addition of magnetic tape.

Magnetic tape recording can greatly simplify terminal equipment in data transmission systems. Data communications enable computers to perform most economically and accurately. At the moment, however, the application of remote data sources associated with computers remains limited mostly to terminal equipment and the common carrier system. Previously, it had been necessary to store this type of data in an intermediate storage such as a punched paper tape and then reproduce it at a uniform standard rate for recording on magnetic tape. Kennedy Model M201 (Fig. 10-4), which operates at rates up to 65 characters per second and starts and stops for each character, is a direct replacement for paper tape punches and readers.

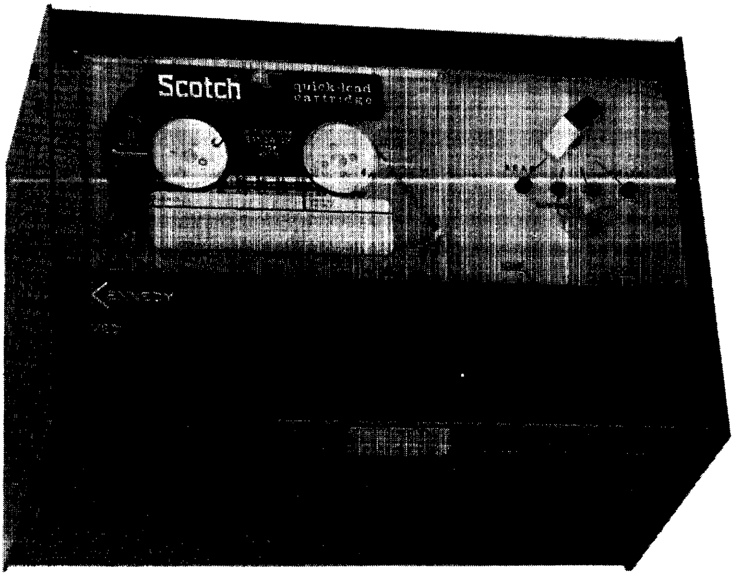

Fig. 10-4. *The Kennedy M-201.*

The incremental tape recorder is a recorder that can accept data either synchronously or randomly (asynchronously) and prepare it for computer entry. Such an incremental tape recorder as Precision Instrument's Model RSL 150 (Fig. 10-5) accepts data at widely varying rates and produces standard digital tapes at 200 bpi, eliminating the need for such intermediate storage devices as punched paper tape.

In certain areas of specialization, magnetic tape is confronted by competitive features of other bulk storage devices. However, magnetic tape is adaptable to the greatest number of storage applications. Most mass file and storage systems are capacity-limited. This is not so with magnetic tape systems. The addition of one or more tape units and an unlimited library of tape reels solves this problem. Furthermore, any information can be made available by duplicating it and forwarding it to the tape reel user.

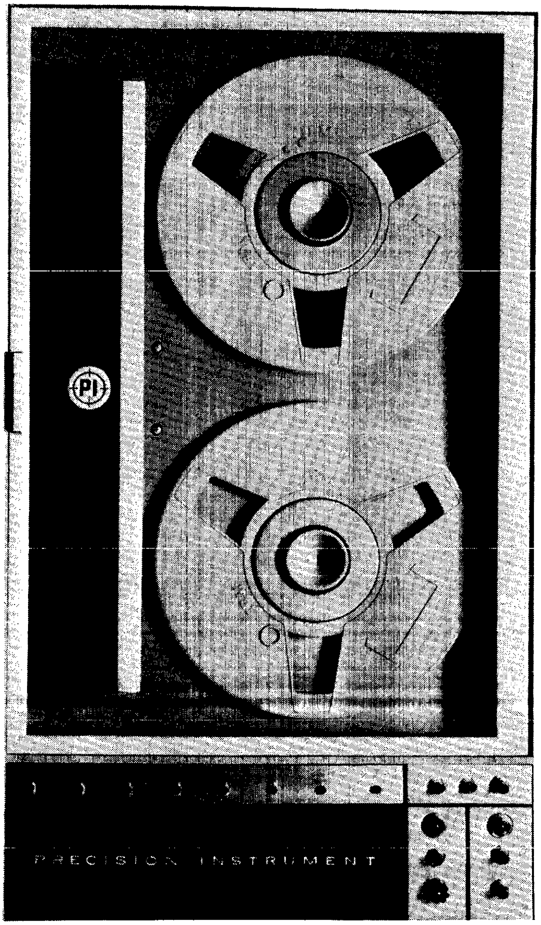

Fig. 10-5. *Precision Instrument Company's Model RSL150.*

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Appendix 1

Tape Reservoir Length

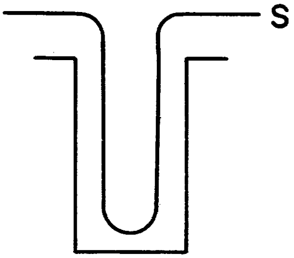

Fig. A1-1.

The power varies as the cube of the velocity and inversely as the length of the buffer loop.

Let V = design velocity

$$HP = \frac{TV}{33{,}000} = KTV$$

K = constant

Where the T for the reel $= I$

At constant acceleration, $\alpha \times t = V$ and $\alpha = \frac{V}{t}$

where t = time

α = angular acceleration

Also, for a given buffer S, the capstan will empty the tape reservoir in time

$$t = \frac{S}{V}$$

Substitution above yields

$$HP = K\frac{(IV)}{t}V = \frac{KIV^2}{S/V} = K_1\frac{V^3}{S}$$

where $K_1 = KI$

Appendix 2

Demagnetization

Similarity is assumed between a magnetic head and a wire-wound toroid with an inserted air gap. The cross-sectional area is constant throughout the length of the toroid and no fringe fields or leakage exists in the vicinity of the air gap. Therefore, the same number of lines that pass through the air gap are passing through the core of the coil: ϕ Air $= \Phi$ Core (Fig. A2-1). The permeability of the magnetic circuit is very high and uniform along the full length of the core material.

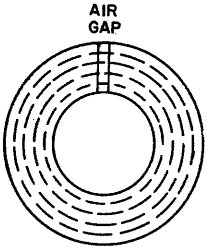

Fig. A2-1.

According to ohmic laws for magnetic circuits, the magnetic potential remains constant and is equal to the product of flux and reluctance. Hence, the magnetic potential, E_m, may be expressed in the following manner:

$$E_m = \Phi \cdot R_m$$
$$E_m = H \cdot l$$

where H = magnetizing force per unit of length
l = length of magnetic path

If E_m remains constant, Φ will diminish in value as R_m increases. Since $B = \Phi/A$, the induction will become smaller for a given H field. These conditions are illustrated in Fig. A2-2. The curve is flattened or stretched out, denoting a shearing or demagnetization effect.

The line OD is called the demagnetization line or shearing line, and makes an angle α with the B axis. The slope of the line OD is determined in the following manner.

$$\Phi = B_cA = H_aA$$

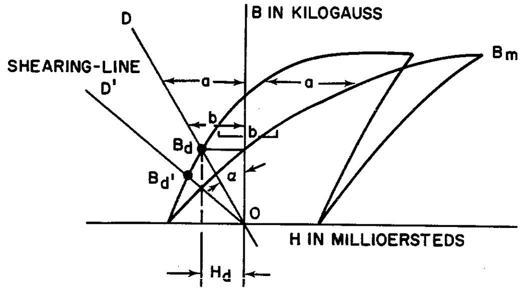

Fig. A2-2.

where B_c = flux density of the core

H_a = magnetizing force in the air gap region

The cross sections of the core and the air gap are considered equal and permeability of air is equal to unity. The sum of magnetic potentials around a closed magnetic circuit is equal to zero:

$$H_c l_c + H_a l_a = 0$$

where l_c and l_a are the equivalent mean paths for the core and the air gap, respectively. Dividing this equation by the one just previous to it, we obtain:

$$\frac{H_a}{B_c} = \frac{-l_a}{l_c} - \arctan \alpha$$

Allowing for no air gap ($l_a = 0$), α will become zero. On the other hand, if the air gap is increased in length, the slope of the shearing line will increase and the demagnetizing effect becomes more pronounced.

It is possible to construct a hysteresis loop for a toroid with an air gap from that of a closed-circuit toroid provided sufficient measurements are made. Drawing the load line OD on the closed circuit response B-H curve, a number of points along the shearing line to the B axis are measured and subtracted from the normal hysteresis loop. The procedure is shown in Fig. A2-2. Demagnetization not only occurs in iron core circuits with an air gap, but also in permanent magnets having open magnetic paths. Where an open magnetic circuit is present, the demagnetization for very long bar magnets is small and will increase as the bar magnet is shortened.

Appendix 3

Tape Access Time

The merits of being able to read in both directions can save considerable tape travel time and, also, reduce the abrasive wear of both the tape oxide coating and the head surface area. It is common to express travel time in units of tape length. Assume that a reel of tape is L feet long and, after the first block selection, the head is located X feet from the tape load point. When the tape is addressed to read at a location of D feet from the beginning, two cases are under consideration.

Case 1. $D \leqslant X$. In this case, the next tape address is located between X and the tape load point. The probability that $D \leqslant X$ is the probability that X includes D: $P(D \leqslant X) = X/L$. The average amount of tape to be moved to the left (Fig. A3-1) is the probability of D location along the X length of tape: $X/2$.

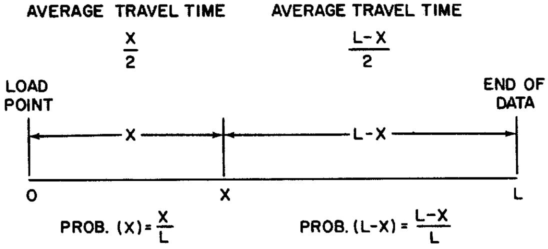

Fig. A3-1.

Case 2. $D > X$. If the addressed selection of tape is not between the load point and X, then the tape must be moved forward to the right. The probability of $X < D$ is a function of the length of remaining tape: $L - X$. Therefore, the probability that $D > X$ is the $P(D > X) = (L - X)/L$. The average amount of tape to be moved to the right is the probability of locating D along the $(L - X)$ tape length. As stated in Case 1, D is equally likely to occur along any distance within $(L - X)$ length of tape: $(L - X)/2$.

Assuming the head is located at a distance X from the load point, the next address may require tape motion in the reverse direction $(D < X)$ or in the forward direction $(D > X)$. Therefore, the expectation (E) of tape travel can range from 0 to L and is summarized in the following integral equation:

$$E = \frac{1}{L}\int_0^L \Bigg[P(D \leqslant X) \bullet \text{Tape travel to the left direction}$$

$$+ P(D > X) \bullet \text{Tape travel to the right direction} \Bigg] dx$$

$$= \frac{1}{L}\int_0^L \left[\frac{X}{L}\left(\frac{X}{2}\right) + \frac{L - X}{L}\left(\frac{L - X}{2}\right)\right] dx$$

$$= \frac{L}{L}\int_0^L \frac{1}{2L}\left[2X^2 - 2XL + L^2 \right] dx$$

$$= \frac{1}{L}\left[\frac{1}{2L}\left(\frac{2}{3} X^3 - X^2L + XL^2\right)\right]_0^L + k$$

$$E \approx \frac{L}{3}$$

The approximation sign is used instead of the equal sign because the constant of integration is dropped. The integration constant is a function of the actual written information on tape within the extremities of the load point and the end of written tape. Furthermore, in a variable length of tape format, the tape must be moved in discrete units of tape data layout and not in units of tape dimensions. Generally, k is relatively small ($k << L$) and can be neglected.

INDEX