TELEPHONE MEMORY DEVICES

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1. GENERAL

1.01 Memory has always been important in the telephone business. The operator uses memory to ensure that the requested services are received. As automated switching systems replace many operators with one machine, the need for memory remains. Each forward step in switching system design has added flexibility of operation by a greater use of common control. The development of common control has been through the use of logic devices to perform the decision-making functions of an operator. Logical decision making depends on comparisons of one situation with another, which can be done only by the extensive use of memory.

1.02 Automated data processing and billing equipment has been added to increase the capabilities of the telephone business office. This application of automation is also dependent on memory devices for its operation. Some memory devices which are associated with telephone functions are included in this section.

CHARACTERISTICS OF MEMORY SYSTEMS

1.03 Memory systems are often categorized by reference to the following basic characteristics:

- Permanence of storage
- Capacity of storage
- Mode of access to stored information
- Speed of operation.

(a) Permanence of information storage ranges from permanent storage to volatile storage. Truly permanent storage is unaffected by time or environmental changes. Volatile storage is such that a temporary interruption of supplied power causes a complete loss of all stored information.

(b) The capacity of a memory is usually described in terms of the number of binary digits (bits) that can be stored. Of course the minimum capacity is one bit. However, there is no theoretical limit to the maximum capacity which could be incorporated into most types of memory. The practical considerations of size and expense usually limit construction of memory facilities.

(c) The mode of access to information stored in a memory is basically either sequential or random. If previous storage locations must be passed through to retrieve some desired information from the memory, the mode of access is sequential. If each storage location is

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immediately accessible on an individual basis, the mode of access is random.

(d) Speed of operation is usually described in terms of the time required to store or retrieve information in the memory. The speed of operation is usually referred to as ***access time.*** Access time is generally least in random access memories and is greatest in sequential access memories.

2. MEMORY DEVICES

ELECTRICAL MEMORY DEVICES

A. Fuse

2.01 The simplest electrical memory device in use is the fuse. When current flow that is sufficient to melt the fuse link has occurred, the burned out fuse remains as a record of that fact. The usual function of a fuse is to protect circuitry from the effects of excessive current flow under overload conditions. However, in some power supply circuits, a fuse is provided to serve as an indication that a certain level of current flow has occurred. The fuse is by nature a one-time memory device, but a resettable circuit breaker can be substituted for the fuse for most applications.

B. Relay

2.02 Probably the most common, simple, reuseable memory element is the relay. A relay is operated when some particular event occurs. At a later time the state of the relay serves as a reminder that the event did occur. Although the ostensible purpose of a relay may be to control a circuit operation, the memory function is implicit in relay operation. Each relay can remember one bit of information; several relays together may remember a group of bits called a binary word.

C. Flip-Flop

2.03 An electronic memory unit, usually referred to as a flip-flop, is shown in Fig. 1. The flip-flop shown uses two NPN transistors as active devices. The flip-flop is little more than two amplifiers interconnected so that the output of one is the input of the other. The flip-flop has two stable states. One state exists when Q1 is conducting and Q2 is not conducting. The other state is represented by Q2 conducting and Q1 not conducting. A pulse on one of the set leads causes the flip-flop to assume the corresponding state. By arbitrarily assigning names, the two states may represent 1 and 0. As shown in Fig. 1, the 0 state corresponds to Q2 conducting and Q1 not conducting. The 1 state then corresponds to Q1 conducting and Q2 not conducting.

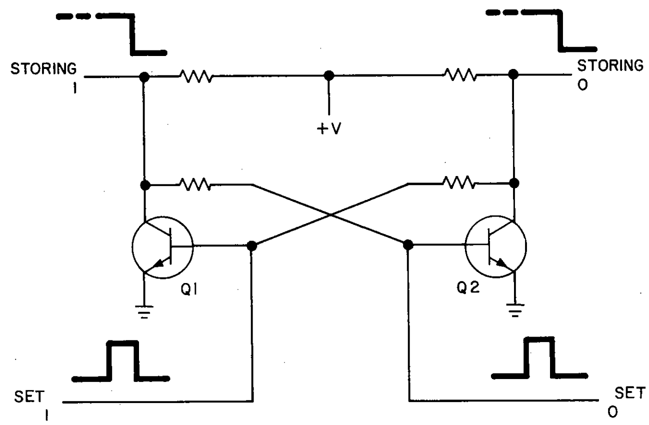


Fig. 1—Flip-Flop Circuit

2.04 The flip-flop is equivalent to a relay in memory applications. Each flip-flop is capable of storing one bit of information. A group of flip-flops, usually called a register, is used to store the bits which make up a binary word.

CHARACTERISTICS OF MAGNETIC MEMORY MATERIALS

2.05 A device that has two stable states fulfills the basic requirements for use as a memory. The magnetic properties of many materials are bistable. They are stable when magnetized in either of two opposite directions. Memory devices using magnetic materials are suitable for many applications.

2.06 In describing the properties of magnetic materials, the values of applied magnetizing force and the induced flux density are highly significant. The magnetizing field strength is measured in oersteds (H). The induced flux density is measured in gauss (B). In a typical case (Fig. 2) a saturating field (H_S) induces a magnetic flux (B_S) in the material. When the magnetizing field is removed, the material retains a remanent flux density (B_R).

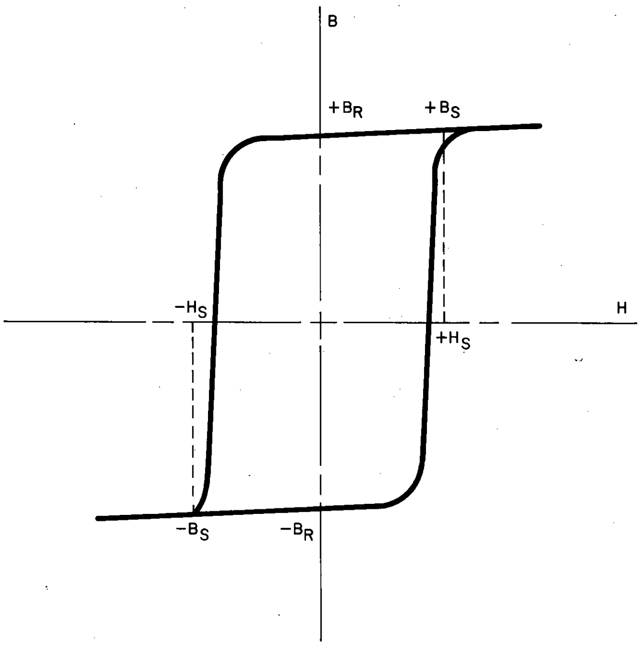


Fig. 2—Typical Magnetic Hysteresis Loop

2.07 Reversal of the magnetizing field induces a flux in the opposite direction. A corresponding remanent flux is retained when the magnetizing field is removed. A graph of this function is a closed loop as shown in Fig. 2. The area enclosed within the loop corresponds to the nonrecoverable energy expended in changing the magnetic state of the material while causing it to traverse the loop. The graph portrays the magnetic hysteresis of the material, and it is commonly called a hysteresis loop.

2.08 A fairly high level of remanent flux density is generally desirable in a memory element. To guard against stray field disturbances, a fairly large change in magnetizing force must be required to change the magnetic state of the memory element. Both characteristics are found in materials which have rectangular hysteresis loops. The values of Bs and Hs vary from one material to another and determine the memory applications for which a given material is best suited.

MAGNETIC MEMORY DEVICES

A. Magnetic Tape Memory

2.09 In the magnetic tape memory, information is recorded on a plastic tape coated with magnetic material. Information is recorded as a pattern of magnetized areas of the coating. The magnetization is done by a recording head, called a write head, which is located in close proximity to the magnetic coating. As the tape moves past the write head, the pattern of magnetization which corresponds to the current flow through the write head is formed on the tape.

2.10 Information is retrieved by moving the recorded section of tape past the read head. The write and read functions are often combined in a single head (Fig. 3).

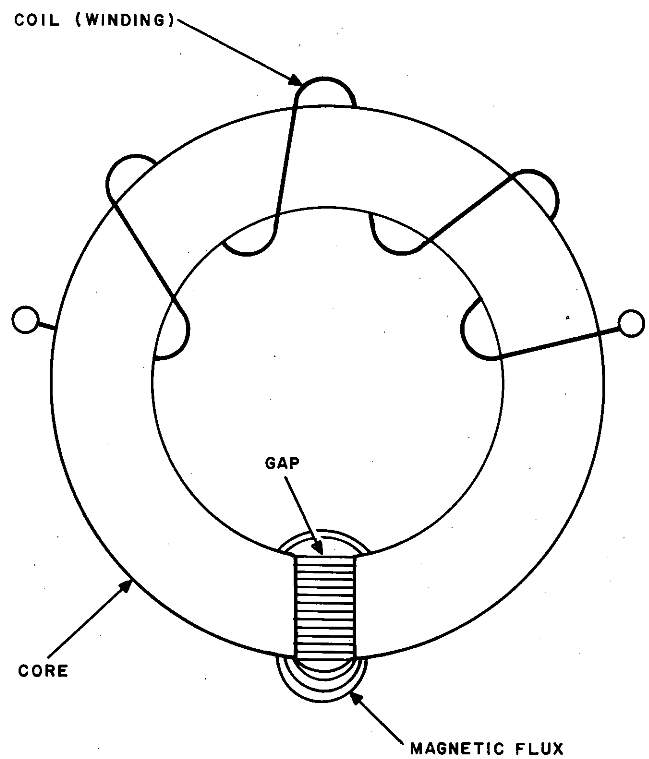


Fig. 3—Single Magnetic Write/Read Head

2.11 A typical magnetic tape memory (Fig. 4) uses a single write/read head. There may be several interchangeable reels each of which contains about 2000 feet of magnetic tape. The reel of tape in use is mounted on the reel drive mechanism. The tape transport mechanism moves the tape past the write/read head at a uniform rate, which is determined by the application.

2.12 The write/read head consists of a ring-like core of highly permeable material with a coil wound around it (Fig. 3). When information

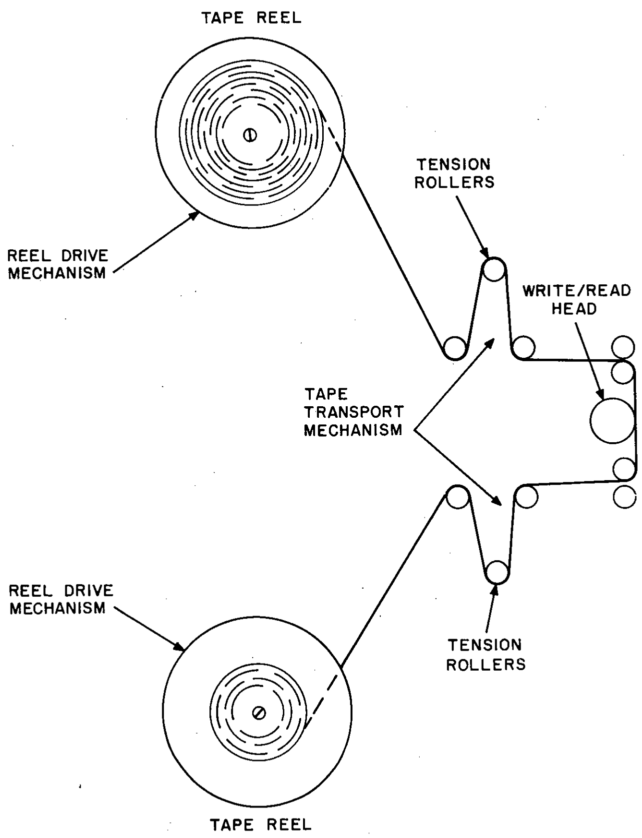


Fig. 4—Magnetic Tape Memory

is written, pulses of current are driven through the coil. The direction of magnetic flux through the core and across the gap depends on the direction of current through the coil. The gap in the core causes flux leakage from the head. Since the magnetic coating of the tape is close to the head gap, the tape coating is magnetized by the flux at the gap. The direction of the magnetic field produced in the tape depends on the direction of current flow in the coil.

2.13 When reading, the magnetization pattern on the tape induces a similar flux in the core of the head. The changing flux in the core induces currents in the coil. The currents are then amplified to retrieve the original information pulses from the tape memory.

2.14 The greatest efficiency is obtained when the tape is in contact with the write/read head. Maximum flux coupling between the head and the tape coating occurs then, and the magnetic effect in the coating is quite localized. However, wear is a serious consideration particularly at high tape speeds. It is desirable to operate without contact between the tape and the heads for longer tape life when a high recording speed is required. When there is separation between the tape and the heads, the individual bit areas become enlarged. The resulting decrease in permissible bit density (number of bits per linear inch) is more than compensated for by the increase in recording speed (bits per second) that is achieved.

2.15 The recording tape may be of any width. It is usually subdivided into a number of tracks along the tape (Fig. 5). Nine tracks are often used on a tape 1/2 inch wide. A separate write/read head is used for each track. These heads are often assembled into one unit for compactness and ease of adjustment.

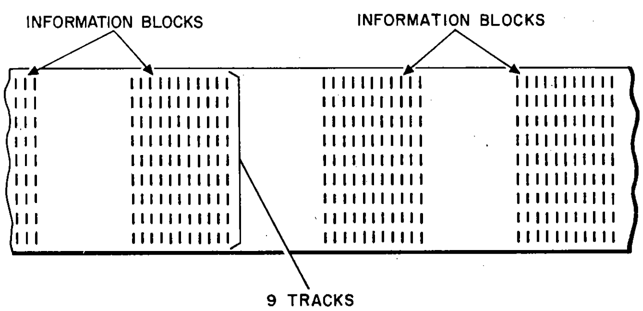


Fig. 5—Typical Magnetic Tape Recording Format

2.16 Information is stored on the magnetic tape in sequence as it arrives. Information is usually recorded in blocks which are separated by blank spaces. The amount of information stored in one block may vary with the application. A block usually consists of several hundred bits and occupies an inch or more of tape. The physical length of the block depends on the bit density. An identification code may be recorded with each block. When information in a specific block is required, it may be addressed by its identification code.

2.17 Typical magnetic recording tape is coated with synthetic red iron oxide. The magnetic characteristics of this material are shown in Fig. 6. A relatively strong magnetizing force (Hs) is required to magnetically saturate the coating and to cause it to become permanently magnetized. The relatively high Hs characteristic is advantageous because the effect of the write head is more localized than it would be otherwise. With only small local areas affected, these areas may lie close together without interference. Consequently, a high recording density may be achieved. The tape coating consists of individual particles, less than one micron in diameter, which are suspended in a suitable medium. The coating is applied to the tape by dipping or spraying to obtain a range of coating thickness from 0.0004 to 0.003 inch. The thickness of the coating varies with the intended use of the tape.

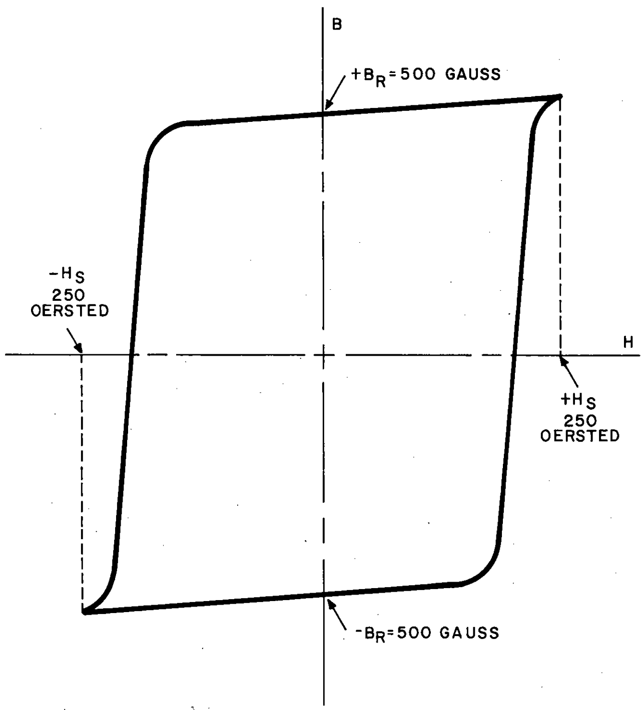


Fig. 6—Magnetic Characteristics of Red Iron Oxide

2.18 To obtain a reasonably high readout voltage without causing undue enlargement of the individual bit areas, the tape coating thickness is usually about equal to the separation of the tape and the recording heads.

B. Magnetic Drum Memory

2.19 In the magnetic drum memory, information is stored on a rotating drum coated with magnetic material. Information is recorded as a pattern of magnetized areas of the coating. The magnetization is done by a recording head, called a write head, which is located in close proximity to the magnetic coating. As the drum rotates, a pattern of magnetization which corresponds to the current flow through the write head is formed on the drum.

2.20 Information is retrieved by a read head. As the drum rotates, the area which has been recorded passes by the read head. The write and read functions are frequently combined in a single head (Fig. 3).

2.21 The typical magnetic drum memory uses one magnetically coated drum and a drive mechanism to rotate it at speeds on the order of 10,000 rpm. Several write/read heads and their mountings are also included.

2.22 Each write/read head consists of a core and coil similar to those used with the magnetic tape memory (Fig. 3). The heads must be mounted close to the drum to obtain good bit density. They either may be rigidly mounted, or they may ride on the layer of air which rotates with the drum. When the heads are rigidly mounted, the drum surface usually is machined after it is mounted in its support bearings in order to minimize eccentricity. The need for highly precise machining may be overcome by the use of what are called flying heads.

2.23 The flying heads (Fig. 7) ride on the layer of air which adheres to the surface of the drum and rotates with it. The head is shaped so that it is supported by the layer of moving air. While the drum starts or stops, there is no layer of air to keep the heads from dragging; therefore, some auxiliary support must be provided. One scheme for supporting the heads is shown in Fig. 7. Each head is retracted into its mounting by a spring. Air pressure is applied to a piston which overcomes the spring and forces the head toward the drum when the drum has reached its operating speed.

2.24 Since the drum rotates constantly, access is sequential; the greatest access time is the time for one drum revolution. In some applications a shorter access time is needed; therefore, one or more extra read heads are spaced around the drum for each write head.

2.25 The narrow band around the drum which passes under a head is known as a track. The location of an information bit is called a cell

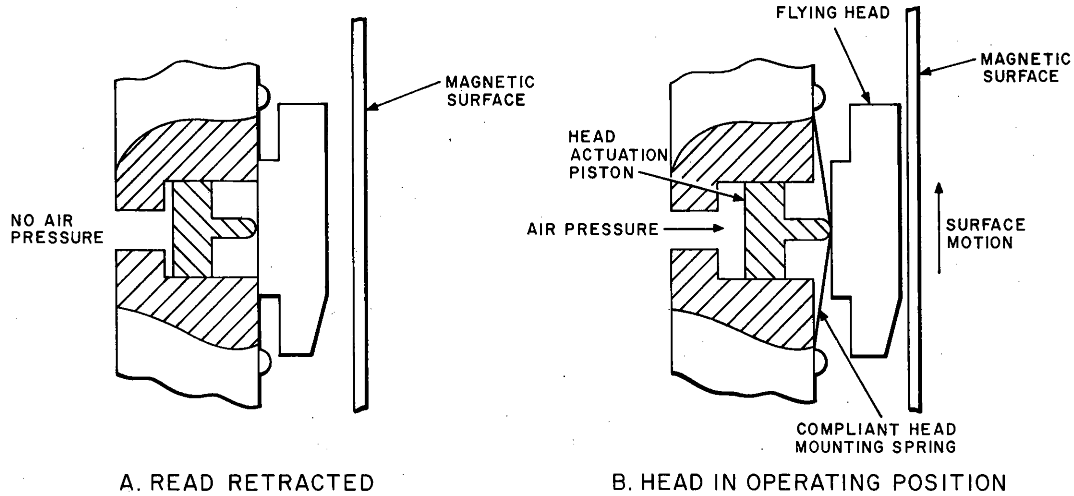


Fig. 7—Flying Heads in Mountings

in the track (Fig. 8). Each track is made up of a large number of cells. Each cell must be identified to retrieve a specific information bit. The problem of identifying the cells is usually solved by a special prerecorded track which contains information that varies with the angular position of the drum as it rotates. Any stored information bit can be addressed by a code which identifies the track and the corresponding angular position output from the special track (Fig. 9).

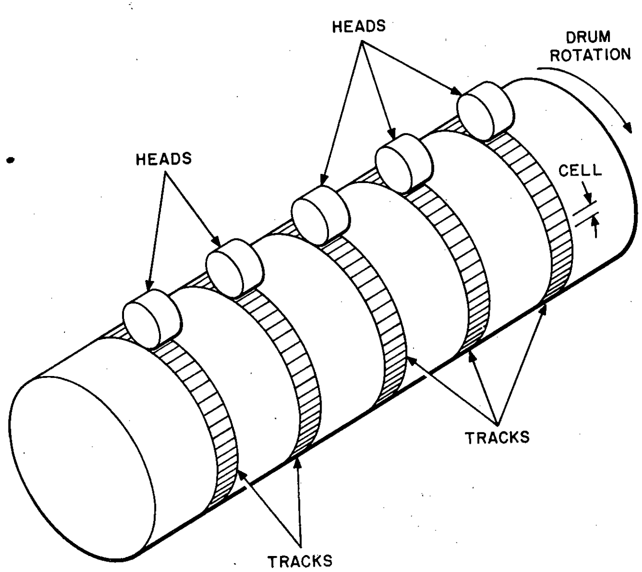


Fig. 8—Magnetic Drum Nomenclature

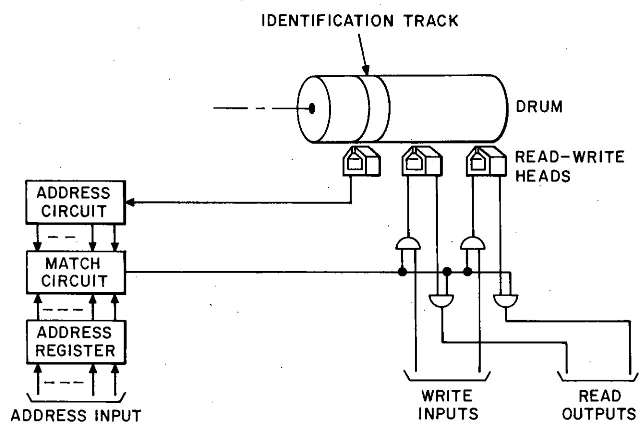


Fig. 9—Typical Access Circuits for Magnetic Drum

2.26 The number of tracks on a drum varies with the length of the drum and the width of each track. The tracks are usually only a few hundredths of an inch wide and lie close together. The number of cells in each track varies with the drum diameter and the bit density.

2.27 The magnetic drum is frequently made of aluminum and coated with the same type of synthetic red iron oxide that is used on magnetic tape. However, the usual arrangement of flying heads is not entirely foolproof; some emergency landings may be expected. The iron oxide coating is relatively soft and may be damaged by accidental contact with the heads. A coating of cobalt nickle alloy is often used on the drum because it is hard and resists abrasion.

2.28 The magnetic characteristics of the cobalt nickle alloy are shown in Fig. 10. A relatively high magnetizing force (H_S) is required to saturate and permanently change the magnetic state of the material. However, the remanent flux density (B_R) is so high that there is a tendency for flux leakages from adjacent bits to adversely affect each other. The spacing between bits must be great enough to prevent this type of interference. Since the cobalt nickle alloy has high electrical conductivity, it is susceptible to the formation of eddy currents. The eddy currents and their induced magnetic effects can cause degradation of the stored magnetization patterns. A very thin coating must be used to minimize the possibility of eddy currents.

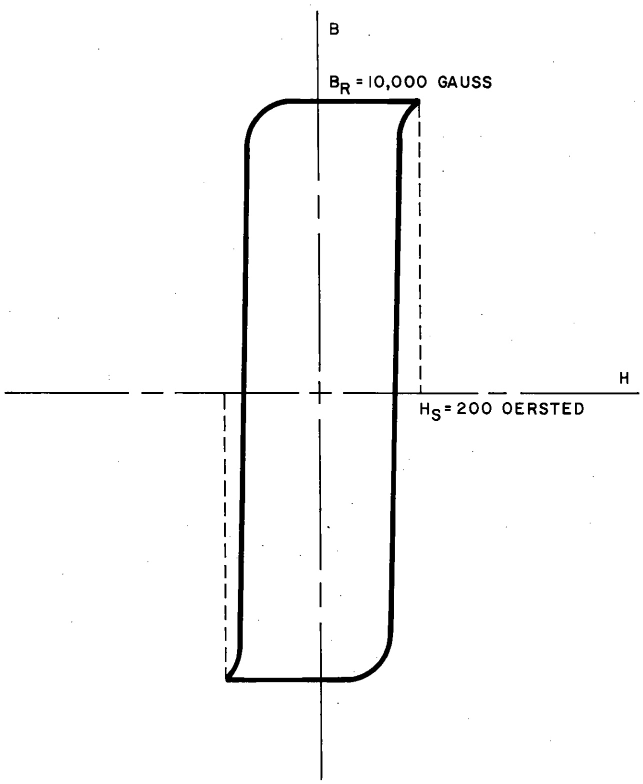


Fig. 10—Magnetic Characteristics of Cobalt-Nickle Alloy

C. Magnetic Disk Memory

2.29 In the magnetic disk memory, information is recorded on a rotating disk coated with magnetic material. Information is stored as a pattern of magnetized areas of the coating. The magnetization is done by a writing head which is located in close proximity to the magnetic coating. As the disk rotates, a pattern of magnetization, which corresponds to the current flow through the write head, is formed on the disk.

2.30 Information is retrieved by a read head. As the disk rotates, the magnetic patterns which have been recorded pass by the read head. The write and read functions are frequently combined in a single head (Fig. 3).

2.31 The typical disk memory includes one or more magnetically coated disks and the mechanism to rotate them at speeds in the order of 1000 rpm. There are frequently several write/read heads in special mountings.

2.32 Each write/read head consists of a core and coil and is similar to the heads used with the magnetic tape memory (Fig. 3). The heads must be mounted close to the disk to ensure good recording. The disks are often of fairly large diameter (up to 48 inches or larger). Disks may be interchangeable like phonograph records; therefore, it is not practicable to machine them after they are mounted in the apparatus. Since a certain amount of wobble is expected, flying heads are generally used. The flying heads maintain close head spacing and at the same time are not likely to collide with the wobbling disk. Each flying head is mounted as described for the magnetic drum (Fig. 7).

2.33 The number of heads used with a disk memory may vary widely with the intended application. Some disk memories contain several disks and only one write/read head. The head is moved by an indexing mechanism, similar to that used on a juke box, to select any desired track on any specified disk. For this setup, the access time may be in the order of one second, which is adequate for a filing system.

2.34 In some multiple disk memories, one head is provided for each disk. The access time is reduced proportionately as the head mechanism has less indexing to do in selecting the desired track. For those applications where a short access time is required, one head is provided for each track on each disk (Fig. 11). The maximum access time is then the time required for one revolution of the disk.

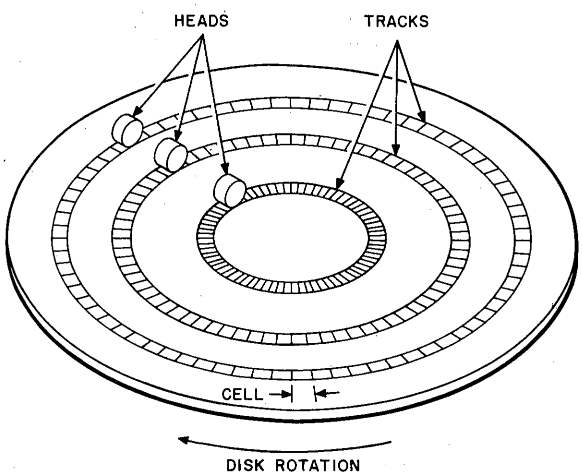


Fig. 11—Magnetic Disk Nomenclature

2.35 The number of tracks on each disk is dependent on the diameter of the disk and the width of each track. Track widths are usually a few hundredths of an inch, but the disk diameters vary greatly from system to system. The number of cells in each track is usually determined by the permissible bit density at the innermost track. Normally all tracks on a disk contain the same number of cells. One prerecorded track is used to provide angular position information to identify the cells in the tracks. On some large diameter disks, tracks are grouped for cell division purposes. The group nearest the outer edge can contain many more cells than the innermost group. A separate prerecorded position information track is usually provided for each group.

2.36 The magnetic disk may be made of aluminum, brass, or plastic. Since flying heads are used in most cases, the disk is usually plated with cobalt nickle alloy to provide a hard, durable surface. On some disks, the synthetic red iron oxide coating is used because of its superior magnetic qualities.

D. Magnetic Core Memory

2.37 The arrangement of a typical coincident current magnetic core memory matrix is shown in Fig. 12. One vertical and one horizontal control lead pass through each core. A single read output wire is threaded through all the cores of the matrix.

2.38 To store one bit of information in the matrix, pulses of current are applied to one of the horizontal and one of the vertical control leads simultaneously. The core at the intersection of the pulsed control leads stores the information bit. The magnetic fields surrounding the two current-carrying control leads combine. The combined field magnetically saturates the ferrite core. The ferrite core retains the magnetic state and thus remembers the information bit. Those cores not at the intersection of two current-carrying control leads are not subjected to a magnetizing field strong enough to cause a permanent change in magnetic state.

2.39 The magnetic characteristics of a typical ferrite core are shown in the hysteresis loop of Fig. 13. Within a core subjected to a magnetic field, the flux density (B) is determined by the field strength H as shown. To discuss the storage of an information bit in a core, an assumption must be made about polarity of magnetization. In Fig. 13 it is assumed that positive pulses are applied to store a 1 and that negative pulses are applied to write a 0. To write a 1, the magnetic field strength (H) is increased by the positive pulses and the flux density in the core increases along the right side of the loop to the extreme upper right point. When the pulses in the control leads subside, the field strength (H) decreases to zero. The core which has been magnetically saturated is stabilized at point 1 in Fig. 13.

2.40 When it is desired to read the stored information from the core matrix, a negative pulse is applied to the control leads. The field H then increases negatively until the flux density in the core follows along the left side of the loop to the extreme lower left point. As the flux in the core reverses (switches) the condition at point 1 to the lower left portion of the loop, a pulse is induced in the read output wire. When the pulses in the control leads subside, the field H decreases to zero. The core which has been magnetically saturated stabilizes at point 0 in Fig. 13.

2.41 The pulse induced in the readout lead indicates that a 1 was stored in the core. The readout procedure switched the core magnetization and that core is now storing a 0. Because the original information was destroyed by the reading process, the core memory is said to be subject to destructive readout. Additional circuitry is required to read a stored 1 out of memory and yet retain

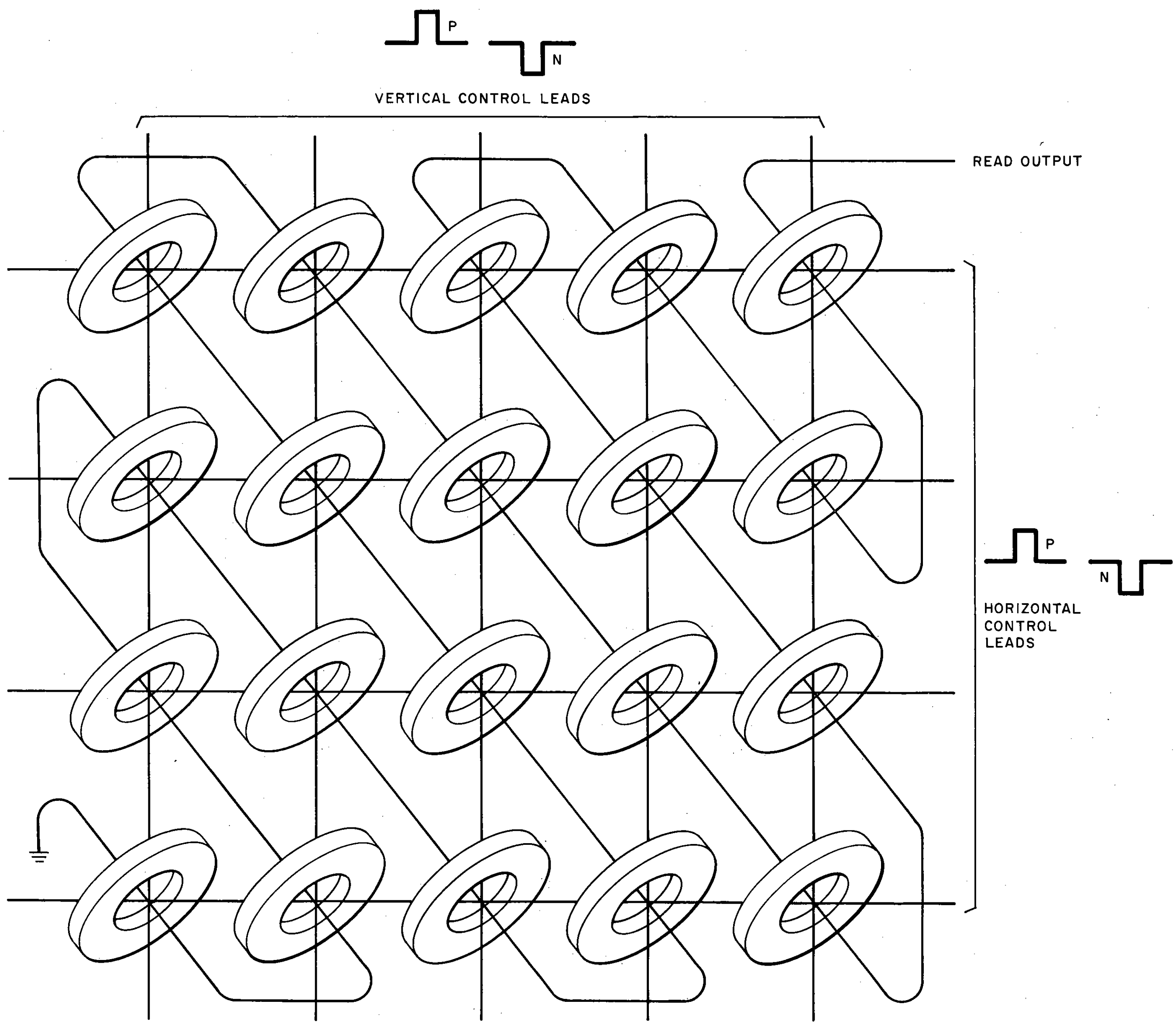


Fig. 12—Coincident Current Magnetic Core Memory

the information in memory. Each core which reads 1 is restored to the 1 state after the reading cycle.

2.42 A group of matrixes are often arranged to provide storage for large amounts of information. When the 2-dimensional matrixes are stacked in a 3-dimensional assembly, it is generally called an array. A core memory system includes the necessary circuits for pulsing the control leads and the automatic restore circuits as well as the core array.

E. Ferrite Sheet Memory

2.43 In order to make ferrite core memories smaller and more efficient, small cores are used. The small cores reduce the drive current requirements and decrease the time necessary to magnetize the bit locations. The small cores reduce the space requirements, but assembly of a matrix becomes more difficult and time consuming as smaller cores are used. The ferrite sheet provides many small cores in a compact unit. Printed circuit

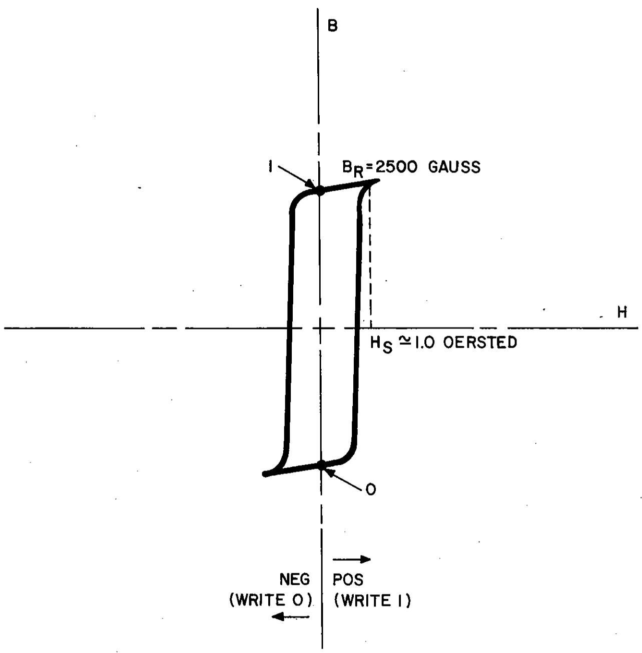


Fig. 13—Magnetic Characteristics of Typical Ferrite Core

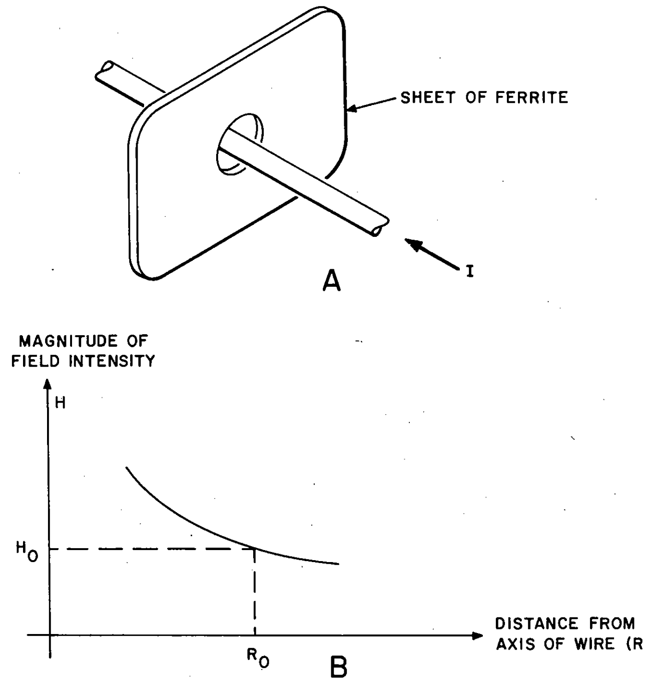


Fig. 14—Magnetic Field in Ferrite Sheet

wiring can be applied directly to the ferrite sheet to eliminate some of the hand wiring.

2.44 A sheet of ferrite material with a hole in it acts as a ferrite core. As shown in Fig. 14A, the magnetic field surrounding a current-carrying conductor through the hole can set up a remanent magnetization in the ferrite. The area of the ferrite affected by the magnetic field can be quite small. The field surrounding a conductor diminishes with the distance from the conductor. A short distance away, Ro in Fig. 14B, the field Ho produced by the current-carrying conductor is so weak that no change in magnetic state occurs in the ferrite. Each note in a ferrite sheet can act as an individual core. In order to prevent interference between core areas, the current pulses are limited to just meet the requirement to magnetize the ferrite in its immediate vicinity.

2.45 The magnetic characteristics of the material used in the ferrite sheet memory is shown in Fig. 15. The material has a low magnetizing force requirement so that a small current pulse can produce local magnetic saturation.

2.46 Many small holes with conductors carrying low currents through them may be placed in a small ferrite sheet. A matrix of ferrite ***cores*** can be produced in a small area. The ferrite sheets with holes and printed wiring (Fig. 16) may

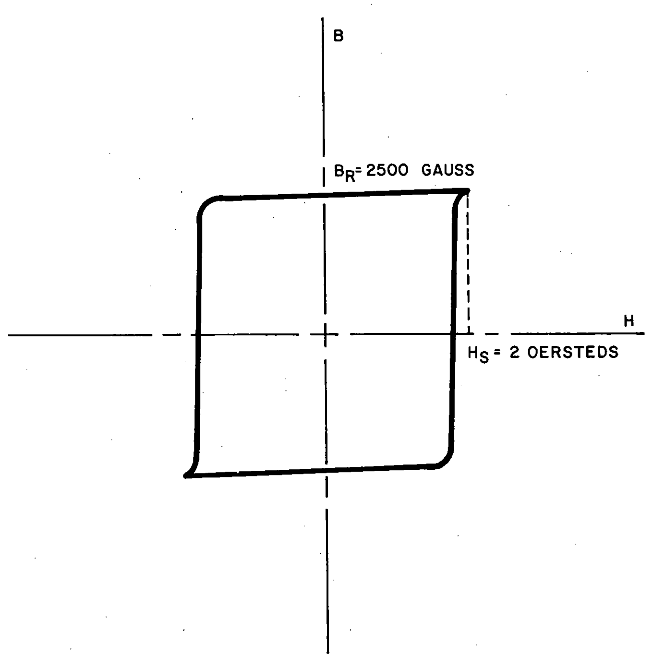


Fig. 15—Magnetic Characteristics of Ferrite Sheet

be made by precise production methods. Since each sheet is a core matrix and is very accurately made, assembly of the matrixes into an array can be readily accomplished. The sheets are stacked and leads are threaded through the holes which are in good alignment. Fig. 17 shows a typical assembly containing several arrays of ferrite sheets.

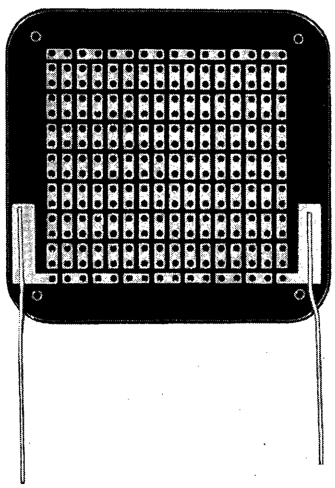


Fig. 16—Ferrite Memory Sheet

F. Twistor Memories

2.47 The twistor memories use the twistor element which is a composite produced by wrapping a thin strip of magnetic material, usually permalloy, around a copper wire (Fig. 18). The basic twistor memory configuration is shown in Fig. 19. The solenoid loops are insulated to prevent electrical cross-connections. They lie in close proximity to the twistor wires so that sufficient magnetic field strength results in the magnetic material without the need for inordinately large current pulses in the solenoids. Small current pulses result in small segments of twistor wire being included in each bit storage region. Rapid magnetic switching and a minimum interference between adjacent storage areas is realized because of the small amount of magnetic material involved. The magnetic characteristics of permalloy are shown in Fig. 20.

2.48 When writing information into the twistor matrix, the field produced by an individual pulse through the twistor wires or the solenoid is not capable of magnetizing the twistor segment. However, the resultant field from two intersecting fields is strong enough to magnetize the twistor material. The resultant field is also aligned with the magnetic material so that the segment of twistor wire adjacent to the intersection is magnetized by the coincident current pulses. The combined fields

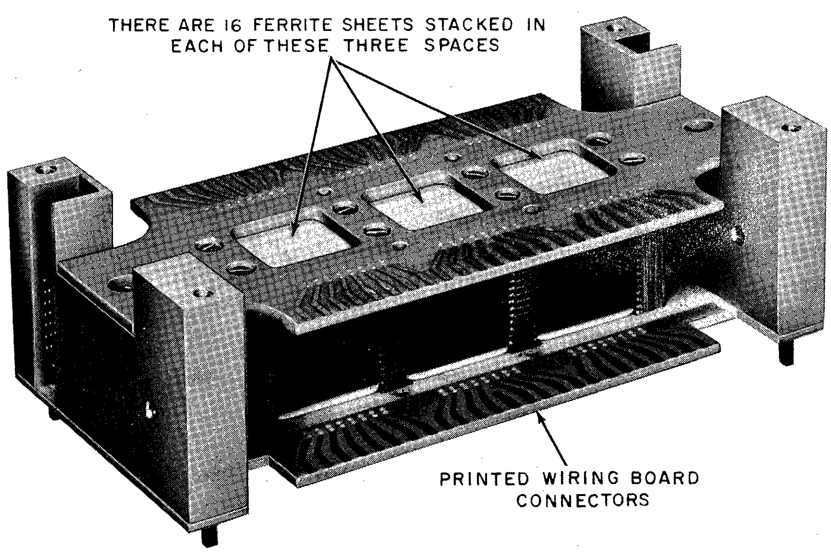


Fig. 17—Ferrite Sheet Memory Array Assembled

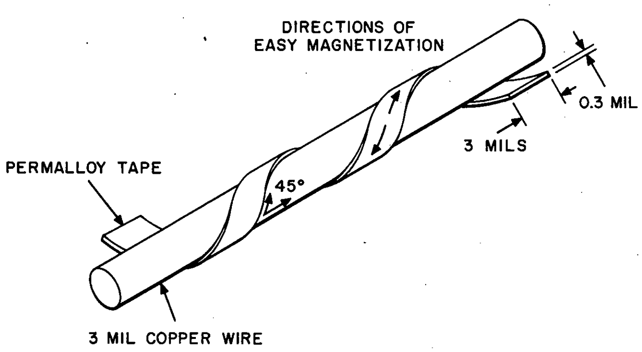


Fig. 18—Fabricated Twistor Wire

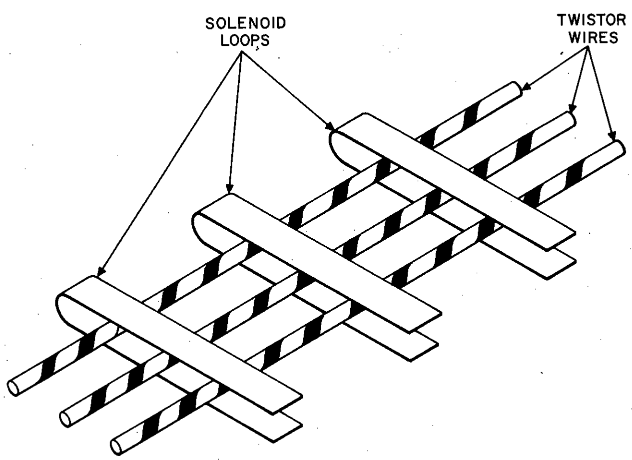


Fig. 19—Twistor Memory with Solenoid Loops

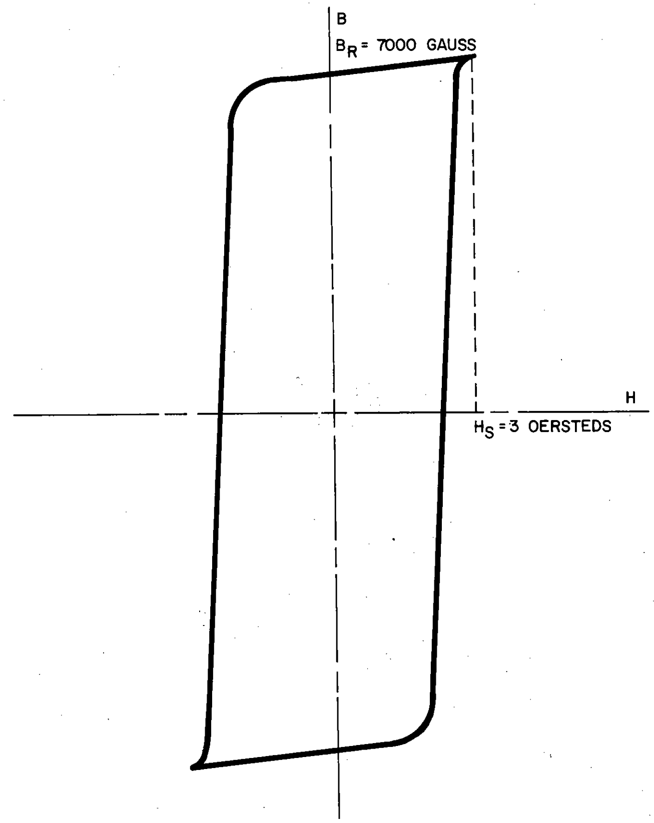


Fig. 20—Magnetic Characteristics of Permalloy

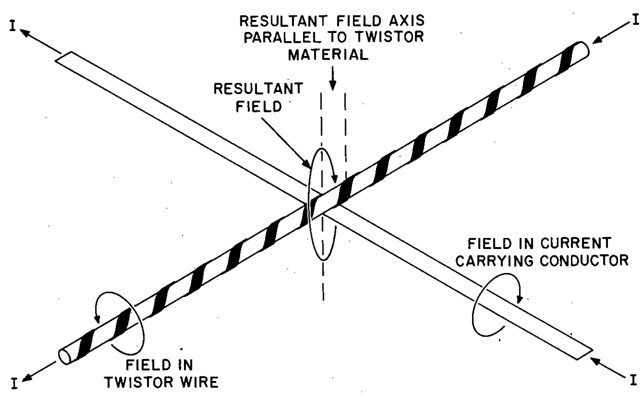


Fig. 21—Magnetization of Twistor Segment

at the intersection of a twistor wire and a current carrying conductor are shown in Fig. 21.

2.49 Reading stored information from the twistor matrix is done by sending a larger current (read) pulse through the solenoid. The read pulse produces a field strong enough to switch the magnetization of the twistor material adjacent to each of its intersections. A voltage is produced in the twistor wire where a 1 is stored. Those segments of twistor wire which are not storing a 1 remain magnetized as they were left by the last previous read pulse. Therefore, no switching occurs and a voltage is not produced in those twistor wires. Reading from the basic twistor is a destructive process. However, a modified arrangement of twistor wires and solenoids may be used to make a nondestructive reading memory.

Permanent Magnet Twistor Memory

2.50 By the addition of small permanent magnets, the twistor wires and solenoids used in the basic twistor memory may be modified to make a nondestructive readout memory. The small permanent magnets of vicalloy material are placed at the intersections of the solenoids and twistor wires to provide a permanent magnetic bias.

2.51 The twistor wires and their individual return leads are placed alternately and laminated into a plastic tape (Fig. 22A). The solenoid loop strips are also sandwiched into a plastic tape (Fig. 22B). The plastic tapes are assembled as shown in Fig. 23 to produce a 3-dimensional array of twistor memory elements. Each intersection of a solenoid with the twistor wire stores one bit of a binary word in memory. The vicalloy permanent magnets associated with the bit locations are mounted on an aluminum card (Fig. 24). The card not only keeps the magnets in place at the intersections of the solenoids and twistor wires, but it also serves as an electromagnetic mirror. Eddy currents in the aluminum produce a reflection of the magnetic field produced by the solenoid loop. Thus, the twistor wires between the aluminum card and the solenoid loop are completely enveloped by the magnetic field, although the solenoid loop is physically present on only one side of the twistor wires. The cards are easily removed for changing the magnet locations. Magnets are not removed or added to the cards; the pieces of vicalloy are permanently mounted on the cards. The vicalloy bars are either magnetized or demagnetized to produce the desired pattern of bits. Where a 0 is desired, the vicalloy is magnetized. The vicalloy is demagnetized where a 1 is required.

2.52 A current pulse is sent through the solenoid loop to read the information bits from the twistor wires. A matrix of ferrite cores is used to provide selective access for reading from the permanent magnet twistor. The current pulse is induced in the solenoid loop by the coincident current selection of its ferrite core (Fig. 25). Each core is threaded with X and Y selection wires and a bias wire as well as the solenoid loop.

2.53 A continuous current flows in the bias wire to keep the core magnetized in a fixed direction for reference. A current pulse in either the X or Y selection wire alone will not overcome the bias and switch the core (Fig. 26A). A specific core is selected by the coincidental arrival of current pulses in both the X and Y selection wires. The magnetic fields H_X and H_Y, set up by the selection wire currents, overcome the field set up by the bias wire current and force the core toward the opposite magnetic stage (Fig. 26B). As the flux

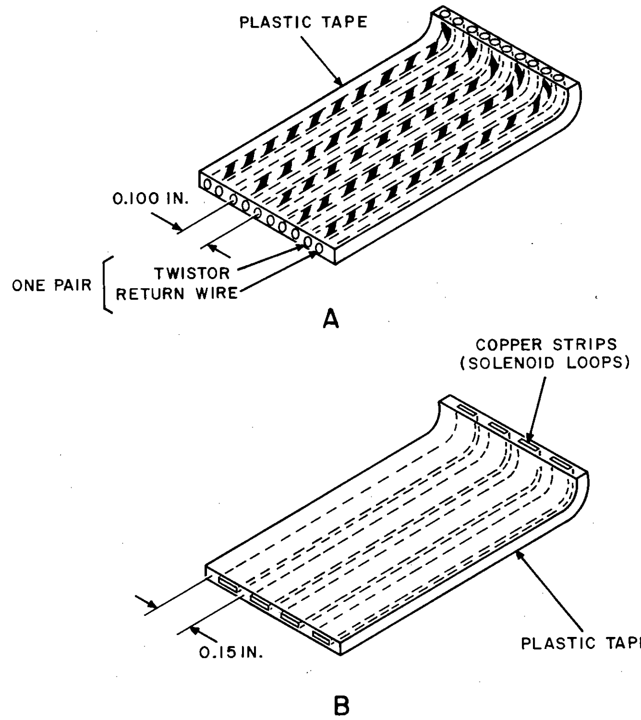


Fig. 22—Plastic Tapes of Memory Elements

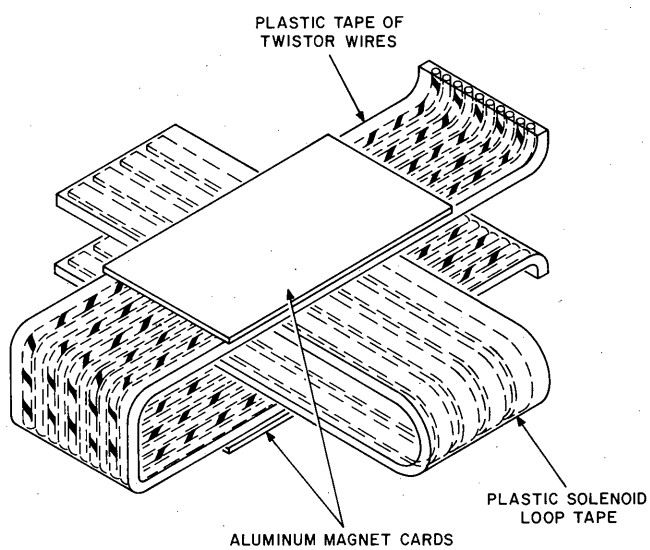


Fig. 23—Assembly of Permanent Magnetic Twistor

in the core is reversed, a current pulse (I_{SOL}) is induced in the solenoid loop (Fig. 26C). When the current pulses in the X and Y selection wires subside, the bias wire field (H_{BIAS}) restores the

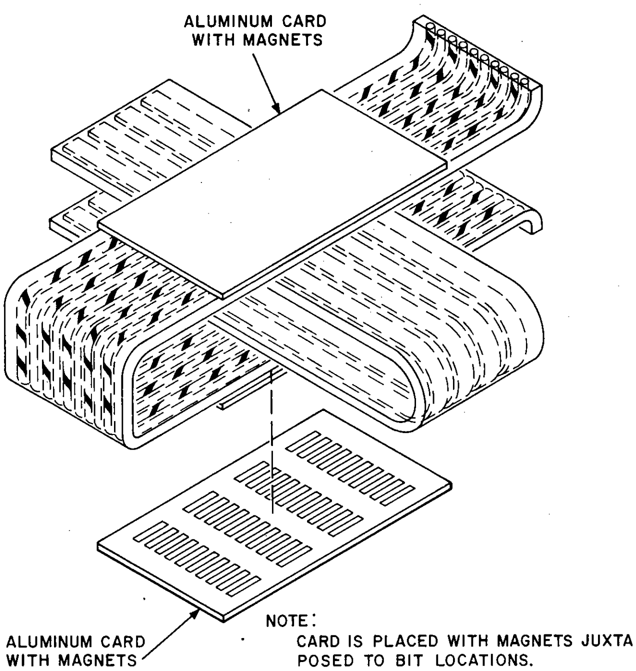


Fig. 24—Permanent Magnet Card

core to its reference state. The flux in the core is reversed in restoring the core to its biased condition. Another pulse of current is induced in the solenoid loop. The second pulse is opposite in direction to the first pulse. Thus, each time the core receives coincident X and Y current pulses, a bipolar pulse I_{SOL} is produced in the solenoid loop (Fig. 26C).

2.54 At each bit wire intersection where the vicalloy bar is demagnetized, the bipolar read pulse causes the permalloy to change its magnetic state. The permalloy is magnetized first in one direction and then in the other direction. The magnetic state traverses the hysteresis loop (Fig. 27A). The change in flux produces a voltage in the twistor wire. The voltage output indicates that a 1 is stored in the bit location.

2.55 At each bit wire intersection where the vicalloy bar is magnetized, the field produced by the read pulse in the solenoid is not strong enough to overcome the bias field produced by the vicalloy (Fig. 27B). The absence of an output voltage from the twistor wire indicates that a 0 is stored in that bit location.

Piggyback Twistor Memory

2.56 The piggyback twistor is an electrically alterable, nondestructive readout memory. The twistor wire differs from other twistor wires in that there are two layers of magnetic material wrapped around the copper wire core, hence, the name piggyback twistor (Fig. 28). The inner wrapping is the same type of permalloy metal which is used on the other twistor wires. The outer wrapping is coballoy metal. As shown in Fig. 29B, the coballoy has a square hysteresis loop similar to the permalloy (Fig. 29A), but it is harder magnetically. That is, it requires a stronger magnetic field to cause the material to traverse the hysteresis loop to saturation. It also remains strongly magnetized when it reaches a stable point and resists changes in magnetization.

2.57 The wrapping of coballoy performs the same function in the piggyback twistor that the vicalloy bar magnets perform in the permanent magnet twistor. However, in the piggyback twistor, the magnetization of the hard magnetic material is changed electrically without removing it from the memory module.

2.58 The hard coballoy tape has a remanent flux density about twice as great as that of the soft permalloy tape. Also, as it is used in the twistor wrappings, the hard tape has about 2 1/2 times the cross-sectional area of the soft tape; therefore, there is an approximate flux ratio of 5 to 1. The external magnetic field required to change the magnetization of the hard tape is approximately 15 times that required for the soft tape.

2.59 When the magnetic characteristics of short segments of the two materials are combined in the piggyback twistor, the result is a composite hysteresis loop (Fig. 29C). The small permalloy loop is superimposed on the large coballoy loop. Theoretically four stable states are possible at the four zero H points on the loop; in the practical situation found in the piggyback twistor, where unmagnetized buffer regions separate the magnetized segments, only two stable states are encountered.

2.60 When the piggyback twistor wire is subjected to a sufficient magnetizing force (H), both of the magnetic materials are in a state represented by either the extreme right or left of the loop. If a positive field is applied, the state is represented

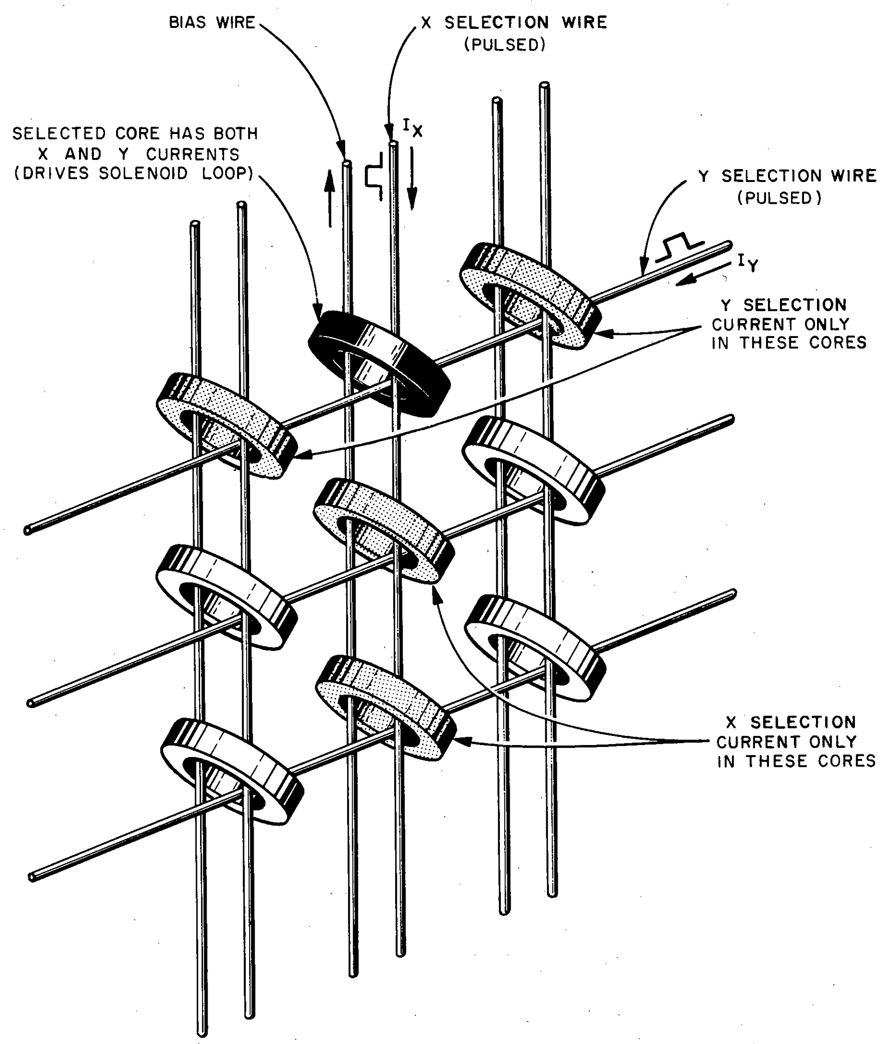


Fig. 25—Access Core Matrix

by the extreme right of the loop. After the field is reduced to zero, the hard material remains magnetized in the positive direction. The strong field of the hard material causes the soft material to be magnetized with opposite polarity. The resulting stable state of the combination is shown on the composite loop (Fig. 30). If the applied field was negative, the hard tape remains magnetized negatively and the soft tape is consequently positive in its magnetization. Thus, in the practical situation, there are only two stable states of the combination.

2.61 The skewness of the composite loop (Fig. 30) is primarily due to the air return paths of the magnetized segments of both the hard and soft tapes. The skewness of the large, hard material loop causes displacement of the small, soft material loop from 0 along the H axis.

2.62 The piggyback twistor wires are used in pairs. Each intersection of a pair of twistor wires with a solenoid loop stores one bit of a binary data word. A number of twistor wire pairs, which are called bit wires, are laminated in a plastic strip. The solenoid loop bands are also sandwiched in a plastic strip. The plastic strips are assembled (as shown in Fig. 31) to produce a 3-dimensional array of memory elements. In a typical configuration (Fig. 32), bit wire pairs which correspond to the individual bits of one binary word are within each solenoid loop. When a solenoid is pulsed, each bit is read from its pair of twistor wires. A pair of twistor wires is used for each bit to provide outputs

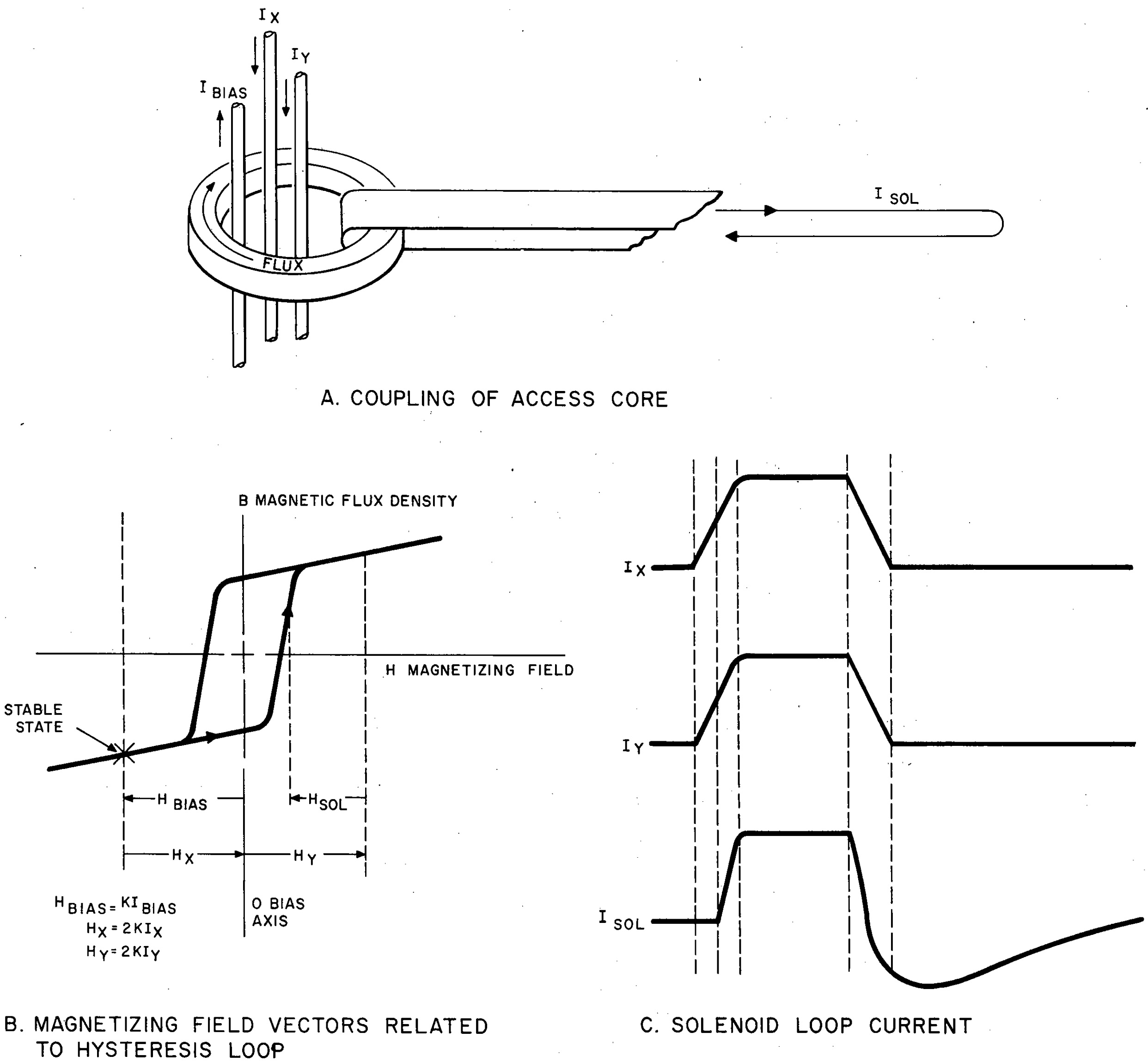


Fig. 26—Biased Core Switch Operation

of opposite polarity for 1 and 0 to aid in discrimination. Therefore, there are two segments of magnetic material which store each bit.

2.63 Access to the piggyback twistor memory is provided by a coincident current core matrix. The operation of the access circuitry is essentially the same for both read and write operations. However for optimum performance and reliability, the size and shape of the X and Y current pulses through the access cores are different for the read and write operations.

2.64 The pulse shapes for read and write access are shown in Fig. 33. It will be noted that the high amplitude long duration write selection pulse causes a correspondingly large negative portion of the solenoid pulse. The low amplitude short duration read access pulse causes a small negative portion of the solenoid pulse.

2.65 Writing a word into a specific address in the piggyback twistor memory requires that simultaneous current pulses be applied to the selected solenoid loop and each of the bit wire pairs. The bit wire pairs are joined at their ends

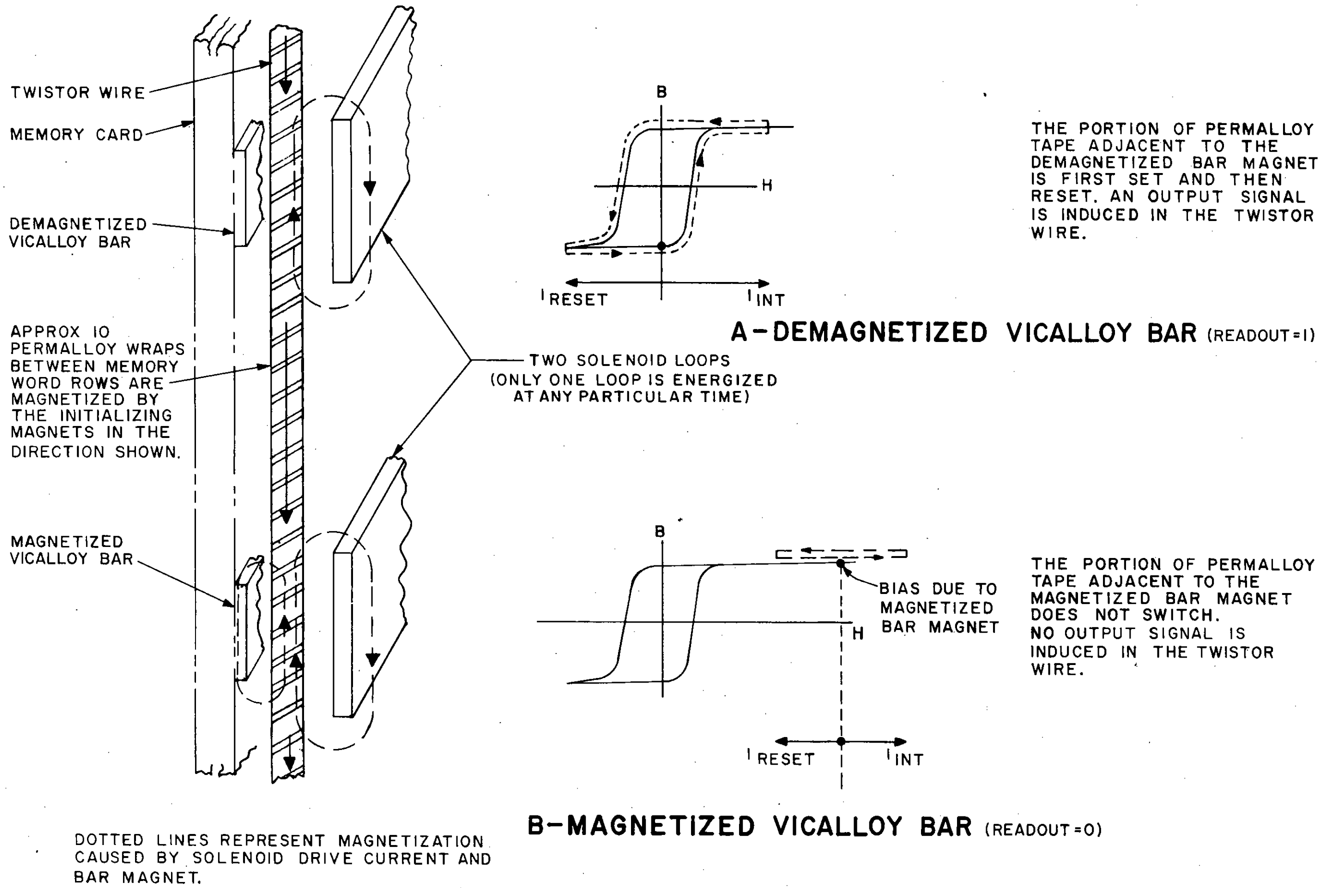


Fig. 27—Permanent Magnet Twistor Reading Operation

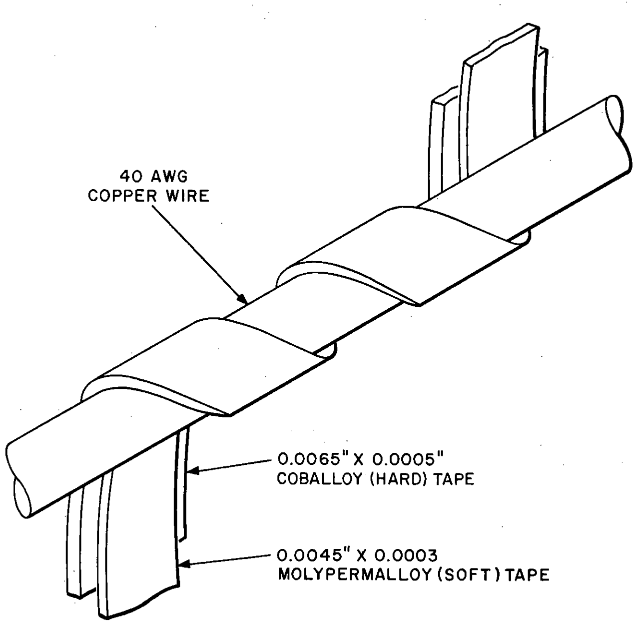


Fig. 28—Piggyback Twistor Wire

for writing. Therefore, the current pulse which passes through the top bit wire (Fig. 34B) from right to left also passes through the bottom bit wire from left to right. Since the fields set up by the bit wire currents are opposite, the fields which result from combining the solenoid field with the bit wire fields are at right angles. Therefore, the tapes on the bit wires are not magnetized in the same direction. The direction of current flow through each bit wire determines the direction of tape magnetization and consequently determines whether a 1 or a 0 is written.

2.66 The writing of a 1 is shown in Fig. 34. While the solenoid write pulse is positive, the combined effect of fields H_{BIT} and H_{SOL} magnetizes the hard tape segment of the lower wire of the bit pair (Fig. 34B). At that time, the resultant of the solenoid and bit wire fields at the upper wire is at a right angle to the magnetic tape so that no magnetic effect occurs there.

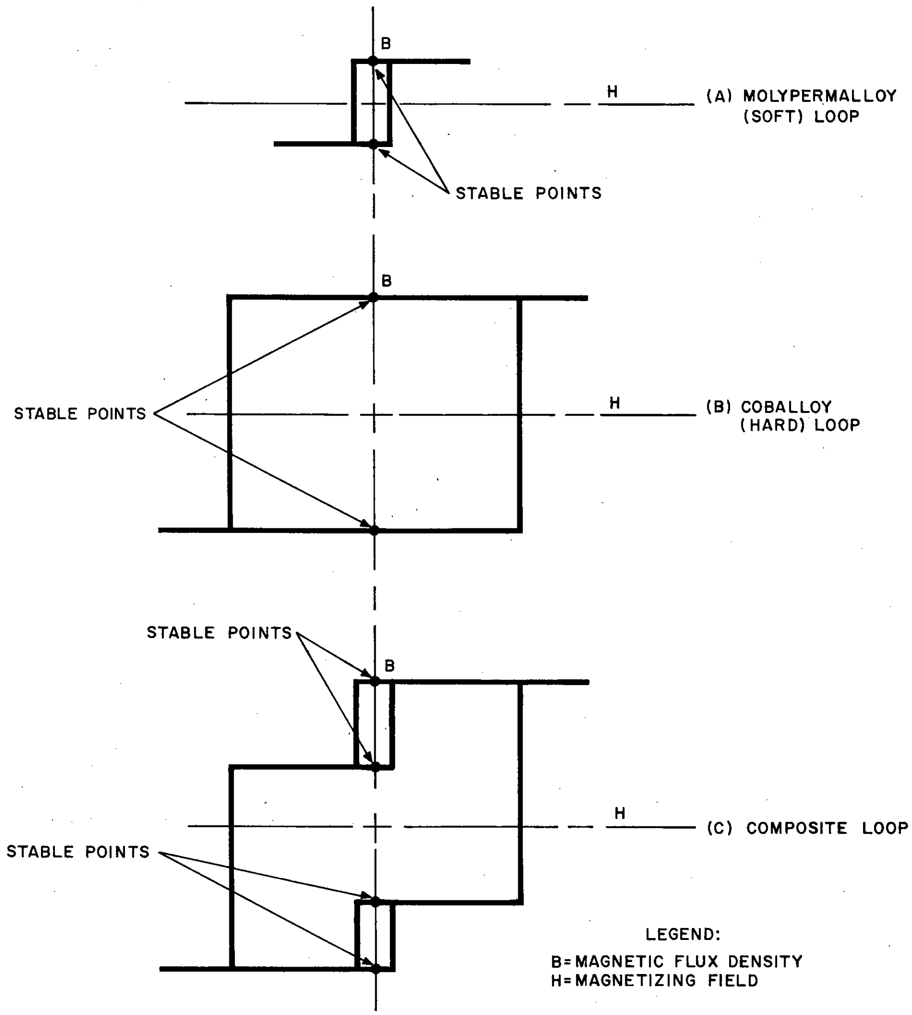


Fig. 29—Magnetic Characteristics of Piggyback Twistor Materials

2.67 When the solenoid write pulse is negative, the solenoid field H_{SOL} and the bit wire field H_{BIT} combine as shown in Fig. 34C. The resultant field magnetizes the hard tape segment of the top wire of the bit pair. The resultant of the solenoid and bit wire fields at the lower wire is at a right angle to the magnetic tape so that no effect occurs there. When the write pulses have subsided, the two hard tape segments of the bit wire pair are left in oppositely magnetized states.

2.68 A 0 is written in a manner similar to the writing of a 1. The bit wire current I_{BIT} is reversed. The resultant fields and the hard tape magnetization are also reversed.

2.69 Reading from a specific address in the piggyback twistor memory requires only a current pulse through the solenoid loop. The solenoid loop is selected by the X and Y selection currents which induce the current pulse through the access core. The magnetic field produced by the solenoid current is strong enough to change the magnetic state of the soft tape segment, but it does not affect the hard tape.

2.70 The read pulse is of lower amplitude and shorter duration than the write pulse. The states of the affected bit wire segments for a 1 and a 0 are shown in relation to the read pulse in Fig. 35. When the solenoid pulse produces a magnetic field in the same direction as the original write field, it causes the soft tape segment to traverse the small loop and a voltage is produced in the bit wire. A read field opposite in direction to the original write field produces no voltage in

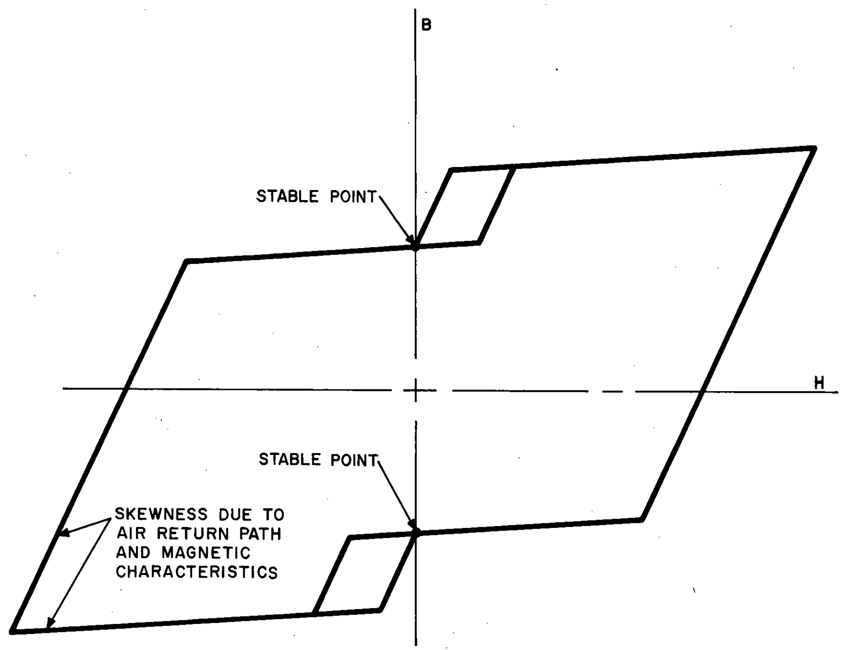


Fig. 30—Composite Loop for Short Length of Piggyback Twistor Wire

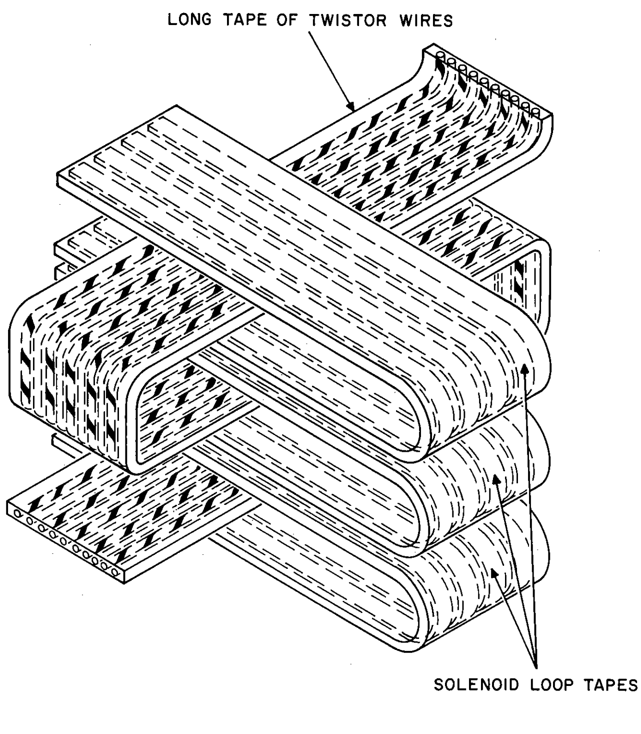


Fig. 31—Assembly of Piggyback Twistor Memory

the bit wire. Since the two bit wires are magnetized in opposite directions, only one bit wire produces a useful output at any time. The bipolar read pulse produces solenoid fields in one direction and then in the other direction, so that an output is obtained from both bit wires. Since the bit wire outputs are in series, the two outputs are of the same polarity. The output resulting from reading a 1 and a 0 are shown individually for each bit wire.

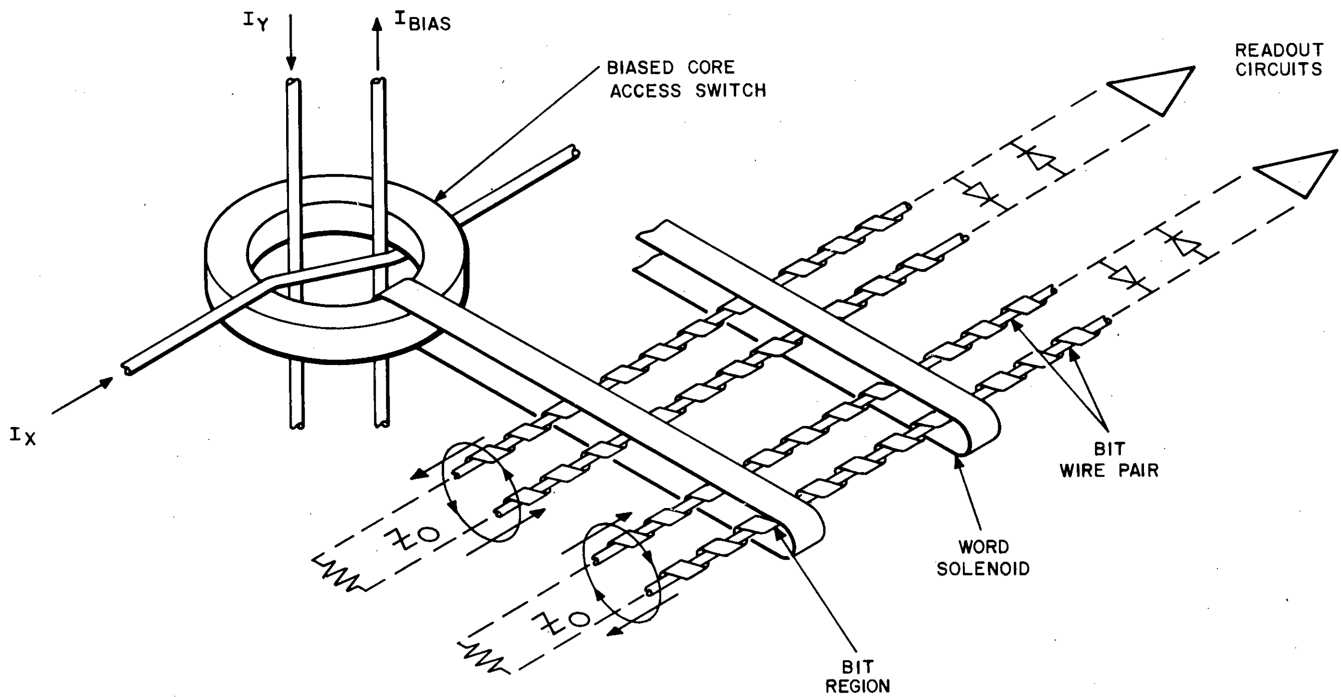
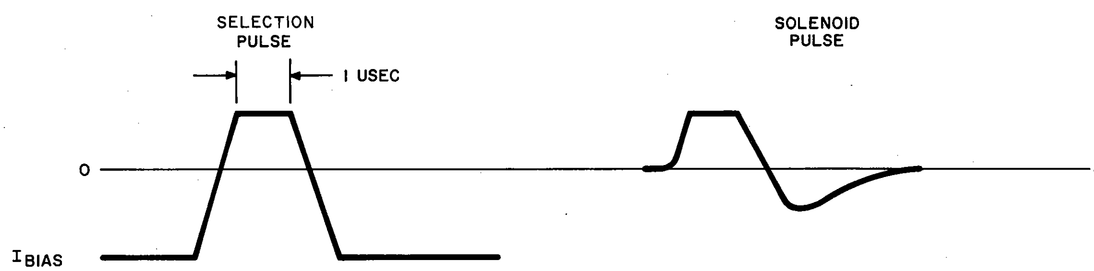
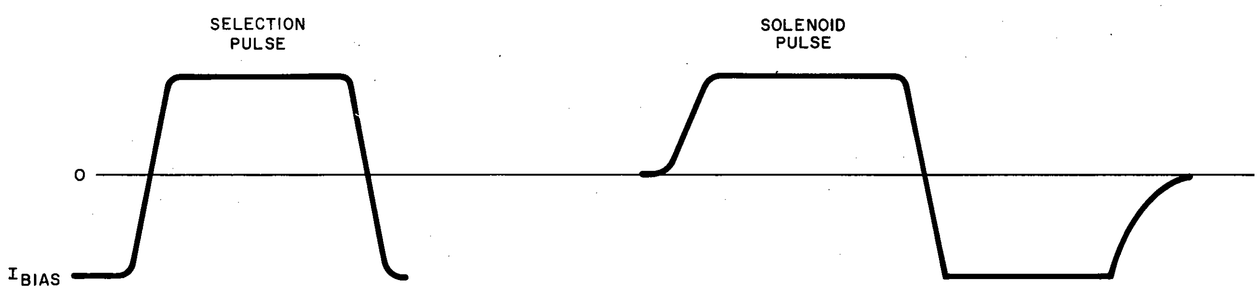


Fig. 32—Piggyback Twistor Word Configuration



A. READ ACCESS WAVESHAPES



B. WRITE ACCESS WAVEFORMS

Fig. 33—Comparison of Read and Write Selection Pulses and Solenoid Waveshapes

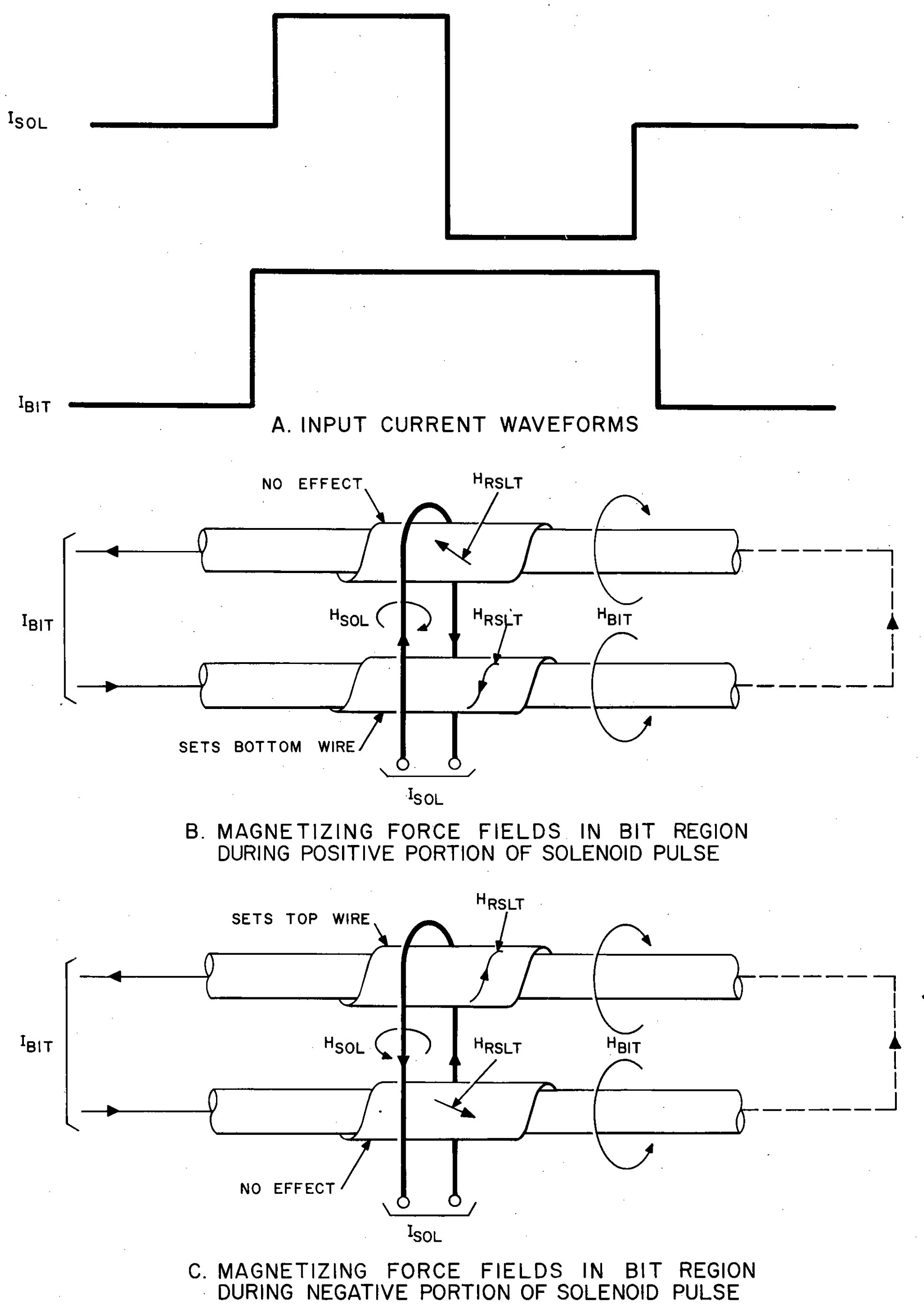


Fig. 34—Piggyback Twistor Write Waveshapes and Fields

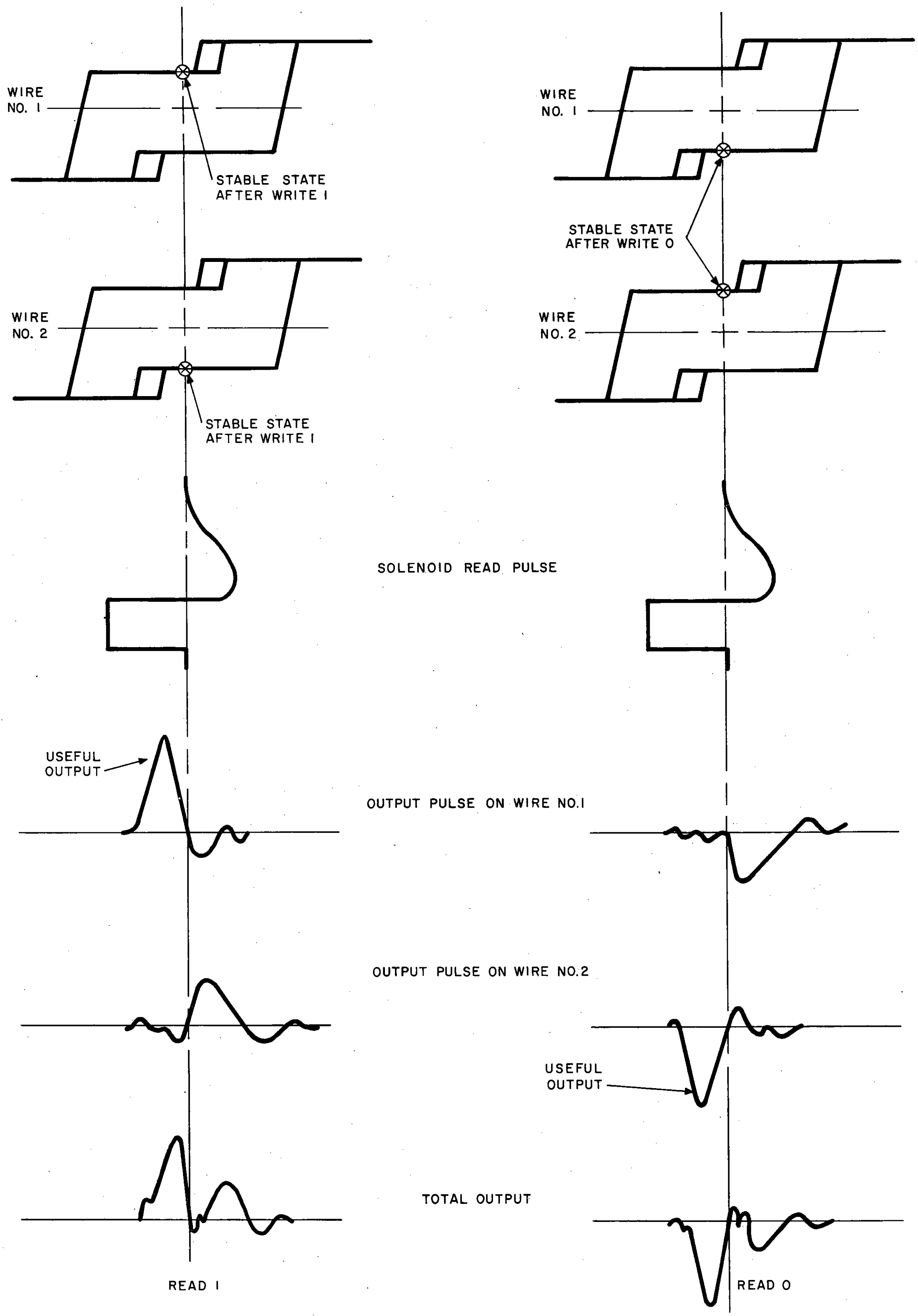


Fig. 35—Read Operation Pulses Related to Composite Loops