CHAPTER 2

MEMORY SYSTEMS.

Since the design of an electronic digital computer is dependent to a large extent upon the type of storage system, this chapter will be devoted to a description of the types of memory devices available.

Discussion will be restricted to the following main types

(1) Ultrasonic (mercury delay line)
(2) Magnetostrictive (nickel delay line).
(3) Electrostatic.
(4) Magnetic Drum.
(5) Magnetic Tape.
(6) Magnetic Matrix (ferrite core)

(1) Ultrasonic

(a) Principles The first full scale computer to operate using mercury delay line storage was the EDSAC (electronic delayed storage automatic computer).

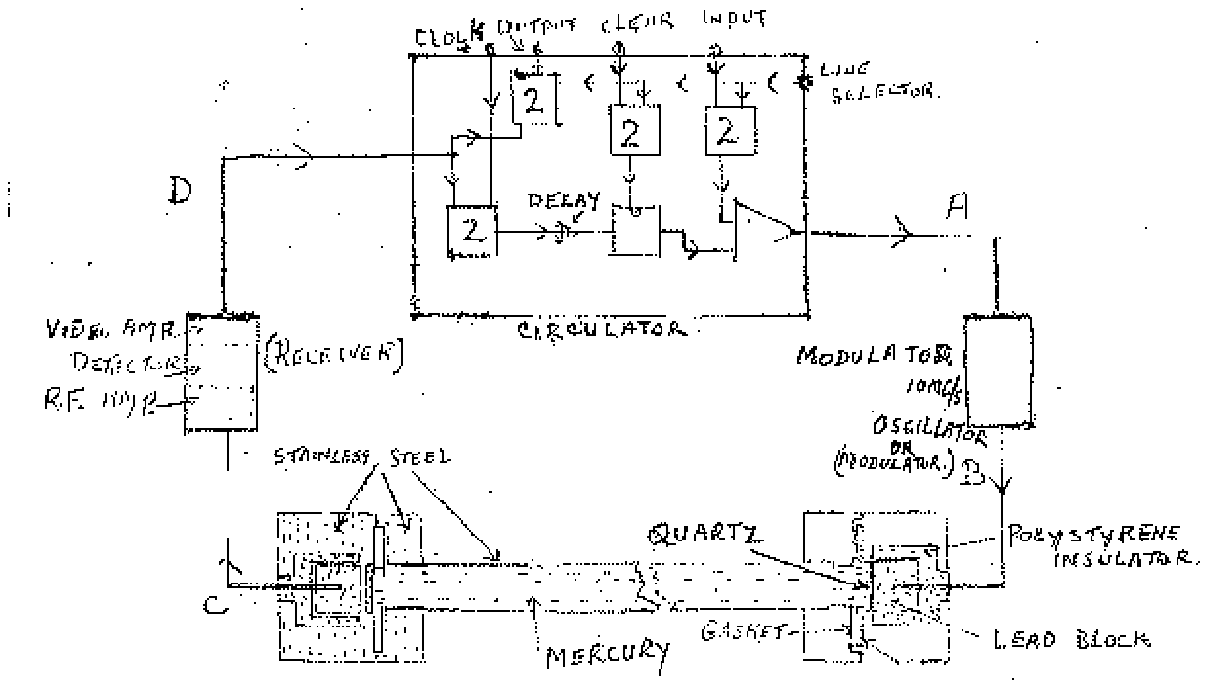


FIG 1
MERCURY DELAY LINE STORE.

The basic principles of ultrasonic storage will be described by referring to fig.1. A train of digit pulses (A) is used to modulate a 10 Mc/s carrier frequency. The modulated carrier pulses (B) so derived arrive at a quartz crystal and set it in oscillation at its resonant frequency (10 Mc/S) by the piezo-electric effect. The X-cut quartz crystal produces longitudinal oscillations in the mercury so that mechanical pulses at ultrasonic frequency move along the mercurv column with the velocity of sound in mercury (5.7×10^4 inch sec^{-1}). These pulses, on arrival at the second quartz crystal, cause it to resonate at 10 Mc/s with the result that attenuated modulated 10 Mc/s electrical pulses appear at point C.

In the case of the CSIRAC the distance between the quartz crystals is 54.77 inches so that the time delay experienced by a pulse train in passing through the mercury column will be 960 μs. Since the pulses are approximately 1μs in width and 3μs apart, then in such a line there is provision for an assembly of 960/3 = 320 pulses.

These pulses are amplified, detected and circulated and in principle could be fed back into the mercury line and be re-cycled. Thus they can be stored in such a system and a copy of these pulses could be taken from the output terminal once every 960 μs. The latter period is termed the "access time" of the memory system. This period is equivalent to a major computer cycle and the main computer clock produces pulses marking the beginning of the major cycles. There is a special frequency controlling delay line maintaining the computer clock and the circulating period of the delay line system in synchronism.

Since a word consists of 20 binary digits, a mercury loop therefore has the capacity of storing 16 words. By using such lines in a parallel array, a store of 1024 words can be arranged.

Band-pass Considerations and Echo Reduction In practice the situation is rather more complicated. Because of the nature of the pulse train (i.e. a modulated carrier) , in order to preserve pulse shape during transmission through the delay line, it is necessary for the latter to possess a band pass of 2.5 Mc/s either side of the centre frequency 10 Mc/s. The bandwidth is determined by:

the propagation characteristics of the delay line;
the damping imposed on the crystal by the mercury and the lead backing.

In an electrical tuned circuit (2) would be equivalent to adding resistance thereby reducing the Q.

A study of the propagation characteristics of the mercury line shows that the effective bandwidth increases with the factor $\frac{a^2f^3}{l}$ where

l = length of line
a = radius of mercury column
f = frequency of ultrasonic waves

whilst attenuation is proportional to the square of frequency becoming appreciable above 10 Mc/s.

Another important factor which must be considered when determining the operating frequency is the amplitude of the echo signal.

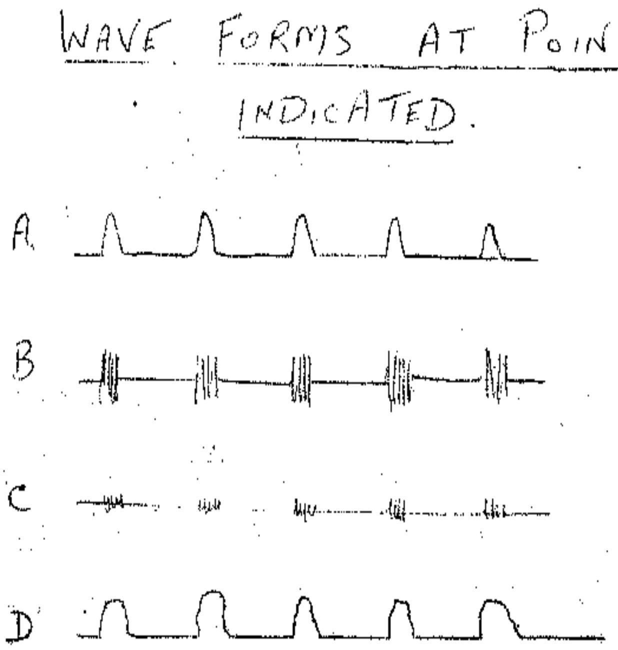
A pulse incident on the receiving crystal is reflected back along the line and again reflected at the transmitting end of the line. Thus an echo signal is produced at the receiving end twice the line delay period later than the original pulse. This is reduced by efficient matching of the crystal with a suitable backing.

Mercury has been used widely as a backing material, but for the CSIRAC, lead was used since in practice, it allows a firmer support for the extremely thin crystal (0.01125 inches thick).

An alternative method of operation would be to use a higher carrier frequency to attenuate the first echo 40 db down on the initial pulse and dispense with the lead backing. An output electrode not in contact with the quartz crystal is then required.

It is to be noted that in the CSIRAC delay lines the backing is electrically insulated from earth and acts as an electrode on which the signal is developed with respect to the mercury which is at earth potential.

(c) Clocking Although it has been mentioned that pulses are stored by circulating them in a mercury delay line plus amplifier loop, fig. 1 shows that the situation is more complicated and further details will be given.



The modulated pulses, on emerging from the mercury line, are amplified by a wide band RF amplifier (staggered quadruple circuit, bandwidth 7.5 - 12.5 Mc/s, gain 70 db) detected and fed to a video amplifier. Pulses (D) emerging from the video amplifier are rather ragged and would be of little use for feeding back into the delay line. Instead this ragged pulse is used to gate a clock pulse into the delay line circulation loop or to gate out a clock pulse to the computer output trunk.

Thus variation in the timing of a pulse due to the delay line being not exactly the correct length can be overcome (see fig.2).

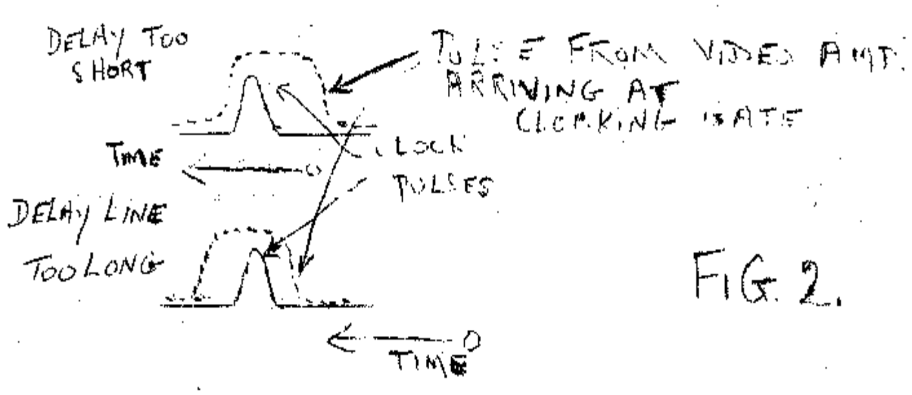


FIG. 2.

Furthermore, a “clean” pulse is re-injected back into the circulation network.

Pulses are inhibited from circulation by means of a clearing gate. Normally pulses will circulate but when reading in a new word into the memory, the line selector, together with the clearing pulses from the clearing trunk, eliminate the circulating pulses as required. At the same time, new pulses will be injected into the same line in the same time position via the input gate.

These new pulses or existing circulating pulses modulate the 10 Mc/s oscillator so that pulses of 10 Mc/s carrier frequency are incident on the transmitting crystal of the delay line.

(d) Interspacing of Pulses The spacing between digit pulses was set at 3 μs to obtain reliable operation of the flip-flop and gating circuits. However, the bandwidth of the mercury delay line is such that a much closer spacing of pulses is permissible. Thus inter-spacing of one complete digit train by another is possible, allowing the memory storage to be increased twofold (i.e. two loops. per line) with the same number of delay lines. Thus 32 delay lines are sufficient to store 1024 words, each of 20 binary digits.

With this node of operation, it is necessary to delay the first pulse train by 1.5 μs before combining it with the second, and on emerging from the delay line onto the computer output trunk the first proceeds normally whilst the second is delayed by 1.5 μs.

Naturally, compensation for this extra 1.5 μs delay is allowed for by slight shortening of the mercury delay line. Furthermore it is necessary to insert a 1.5 μs delay line in the circulation network to maintain correct timing. The interval between memory clock pulses is then 1.5 μs, whilst special clocking pulses must be provided for clearing and reading out “spaced” or “interspaced” digit trains.

The memory delay lines are kept in a hot box maintained at ambient summer temperature (36°C) so that there is no alteration of circulation time due to the variation of the speed of sound in mercury with temperature.

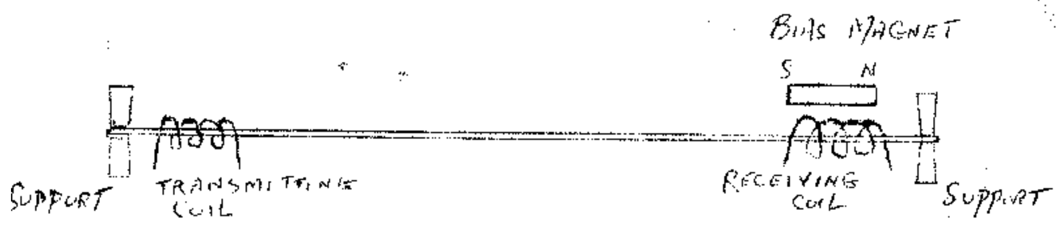
The short delay lines for the arithmetic registers are kept in a separate hot box maintained at a similar temperature.

Reference

R. D. Ryan "A Mercury Delay - Line Memory Unit."
Proc.Inst.Radio Engineers, Australia, Vol.15, No.4, April '54

2. <u>Magnetostrictive</u>

In 1951 it was found that the magnetostrictive properties of nickel could be employed to provide a suitable storage system. In fig.3 is shown a thin nickel wire clamped at either end. It is provided with a transmitting and receiving coil and a small permanent magnet to provide "magnetic bias". Unwanted echoes from the ends of the wire are damped out, using pads of rubber for clamping purposes.



NICKEL DELAY LINE

FIG.3.A

For convenience the wire can be bent into a circle, provided the radius of curvature of the latter is large compared with the diameter of the wire. This allows a considerable reduction in the space required to house the nickel delay line system. Stringent control of the temperature is not required, since the temperature coefficient of the variation of velocity of sound for pure nickel is less than for mercury; furthermore it is possible to make nickel alloys with negligible temperature coefficient.

The mode of operation is as follows. Current pulses representing the digits to be stored are fed directly to the transmitting coil (see fig.3) without modulating an R.F. carrier. With this arrangement, systems working with a pulse interval of 3 μs have been constructed. The magnetic flux produced by the current pulse in the coil constricts the nickel within the coil due to the magnetostrictive effect. This constriction is propagated along the wire in both directions with the velocity of sound in nickel. When the constriction passes through the receiving coil, thereby changing the permeability of the nickel, the flux threading the coil produced by the biassing magnet is changed. This results in an E.M.F. being induced in the receiving coil. The disturbance, propagated towards the clamped end is damped out by the rubber mounting.

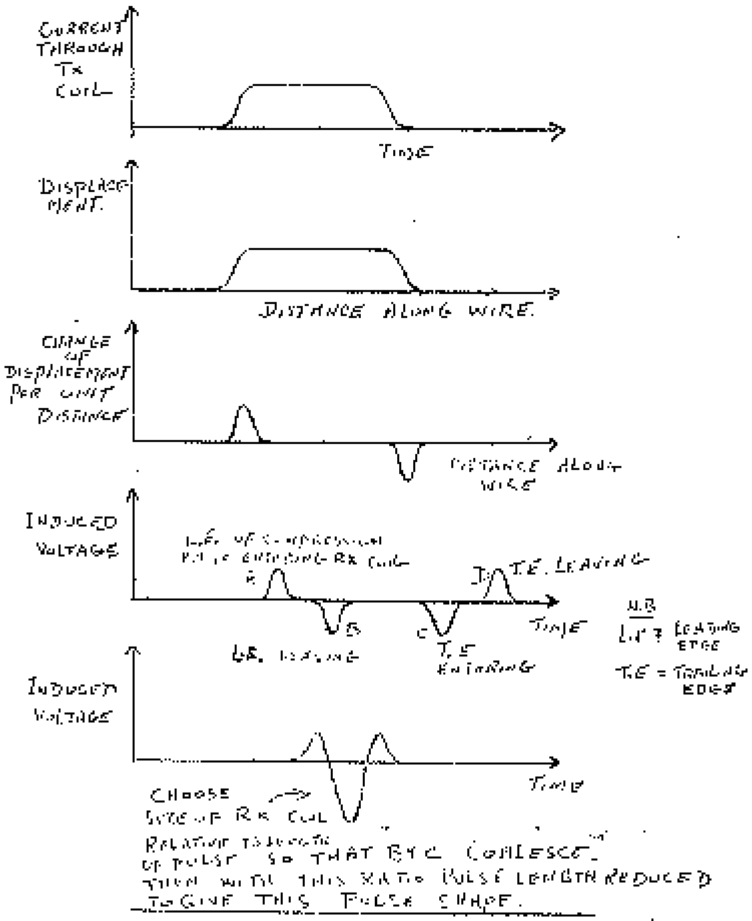


FIG. 4. WAVE FORMS OF NICKEL DELAY LINE

Operation of the nickel delay line system can be studied in more detail by referring to the wave forms depicted in fig.4. Fig.4a shows the current pulse which is fed to the transmitting coil. It is assumed that the length of the current pulse is long compared with the time t_o for the compressional disturbance to travel a distance in the wire equal to the length of the coil. Furthermore it is assumed that the rise and decay times of the current pulses are small compared with t_o. Fig. 4b shows the displacement of nickel particles of the wire from their initial positions as a function of distance along the wire. Fig.4c shows the rate of change of displacement of nickel particles plotted against distance along the wire (i.e. the result of differentiating the curve shown in fig.4b).

Induced voltage will only be present when there is a time rate of change of flux. This occurs as the leading edge of the compression enters and leaves the coil, induced voltages being A and B respectively on fig. 4d. When the uniformly compressed nickel is within the coil, there is no change of flux because, although the permeability has a different value to that existing initially, it remains constant. When the trailing edge of the compression moves into and leaves the receiving coil the induced voltages C and D shown in fig.4d are produced respectively.

If a suitable size of coil is chosen relative to the pulse length, the peaks marked B and C can be made to coalesce. Moreover, if this relationship is preserved and the current pulse is made short, the waveform shown in fig.4c is obtained. The negative going portion is selected by a discriminating circuit and is used to clock in a new pulse into the transmitting coil using a circulating system similar to that described for the mercury delay line store.

3. Electrostatic

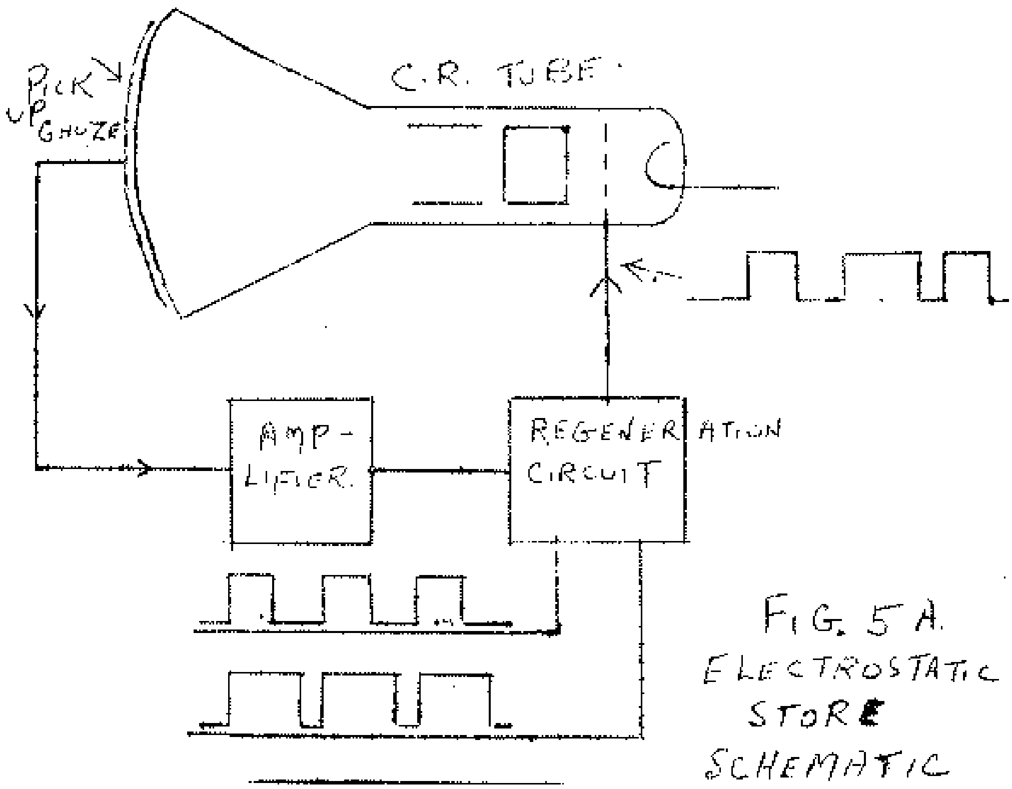


FIG. 5A.
ELECTROSTATIC
STORE
SCHEMATIC

The electrostatic method of storage was operated successfully by Williams and Kilburn in 1948. In this system binary information is stored on the fluorescent screen of a cathode ray tube (see fig.5a). By bombarding the screen with an electron beam of sufficient energy, secondary electron emission can be induced to produce a positively charged area on the tube face. To store a binary (0), the electron beam is modulated by applying a signal to the grid of the C.R. tube, so that a dot is written on the fluorescent screen. For storing a binary (1) the electron beam traces a dash as shown in fig. 5b. The potential distributions set up on the fluorescent screen are shown in fig. 6.

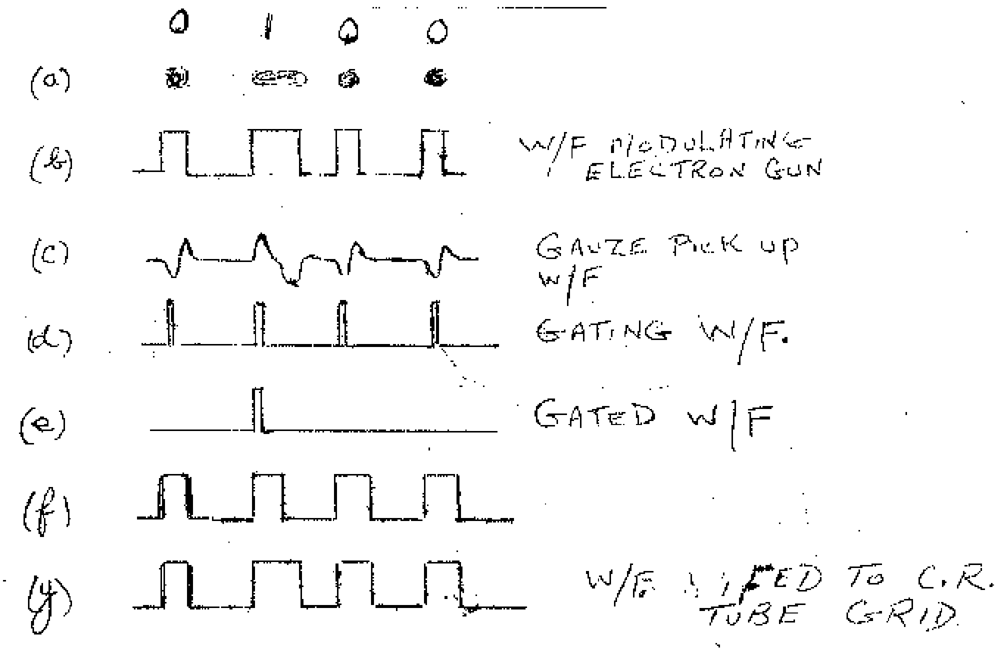


FIG 5B ELECTROSTATIC STORE WAVE FORMS

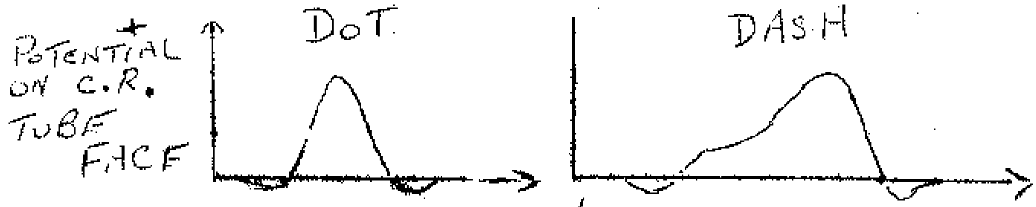


FIG. 6.

If, after an interval of time sufficiently short for no appreciable leakage of charge to have taken place, the pattern is re-bombarded, then the signal derived from the pick-up gauge is shown by the waveform (b) of fig.5b. The initial part of the waveform from either dot or dash signals is sufficiently early to re-write a dot when a dot is registered and a dash when a dash is registered.

The waveform (d) of fig.5b is used for gating purposes so that when gated with (c) the output (e) results.

Output (e) is then used for lengthening purposes so that waveform (f) is applied for regenerating the information in the memory. This would otherwise disappear gradually due to charge leakage at the tube face.

If other information is to be read into the memory, then its waveform would be used instead of (e) for lengthening waveform (f) appropriately.

Magnetic Drum

With this system, digital information is recorded on and later read off a magnetic coating applied to a rotatable drum in a manner similar to that used for the magnetic recording of sound. Fig. 7a shows a current pulse which is fed by a coil wound on a soft iron writing head thereby recording a binary digit (1) on the magnetic surface. The magnetic dipole produced rotates on the drum surface and passes the head again which now is used for reading purposes. An E.M F. is induced in the coil due to the change of flux produced by the dipole passing the reading head. The wave shape of this E.M.F is shown in fig. 7a.

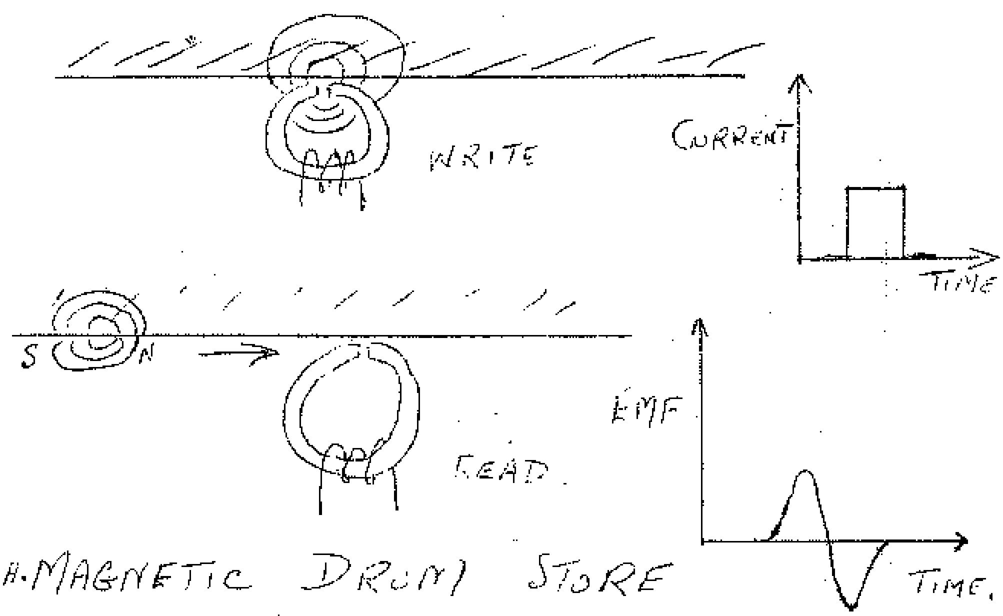


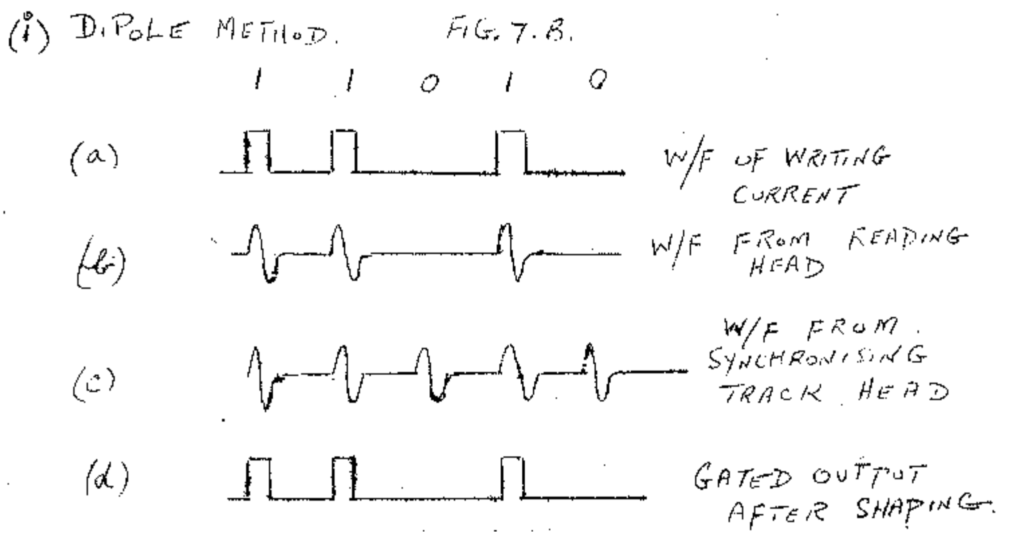
FIG. 7A. MAGNETIC DRUM STORE

Generally there will be as many read/write heads as there are binary digits in the word to be stored plus an extra head for reading pulses from a synchronising track. These pulses are used to designate a certain cell address for the drum. The read/write heads will operate on digits forming a word stored along a line parallel to the drum axis. Magnetic discs also are used for storage purposes. Here the digits forming a word would be stored along a radius. Although the digits are read to and from the drum in a parallel fashion, when a drum is used in conjunction with a serial type of computer, transfers from serial to parallel modes of digit representation or vice versa will require the interposition of a "buffer" register.

Several methods of operating magnetic drums are now given.

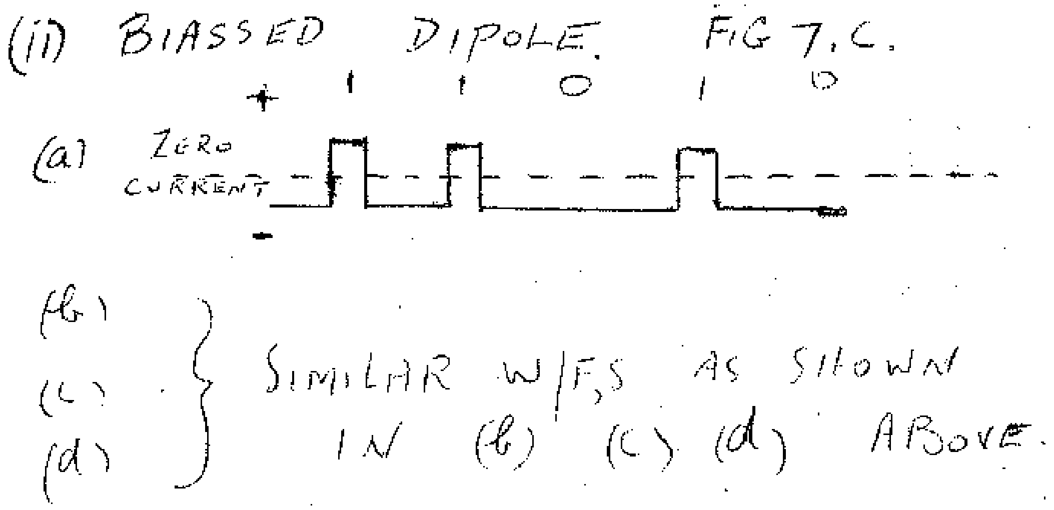
(i) Dipole Method

Here a dipole is impressed in a neutral magnetic surface. The waveform of the writing current is shown in fig. 7b(i). The waveforms from the reading head and synchronising tracks are shown underneath. The next line shows the output waveform obtained by gating the previous two after shaping and discrimination have taken place.



This system of recording has the disadvantage that the medium must first be demagnetized before new information can be recorded. Demagnetization requires the use of a high frequency alternating field to demagnetize the rapidly moving surface successfully.

(ii) Biassed Dipole Method

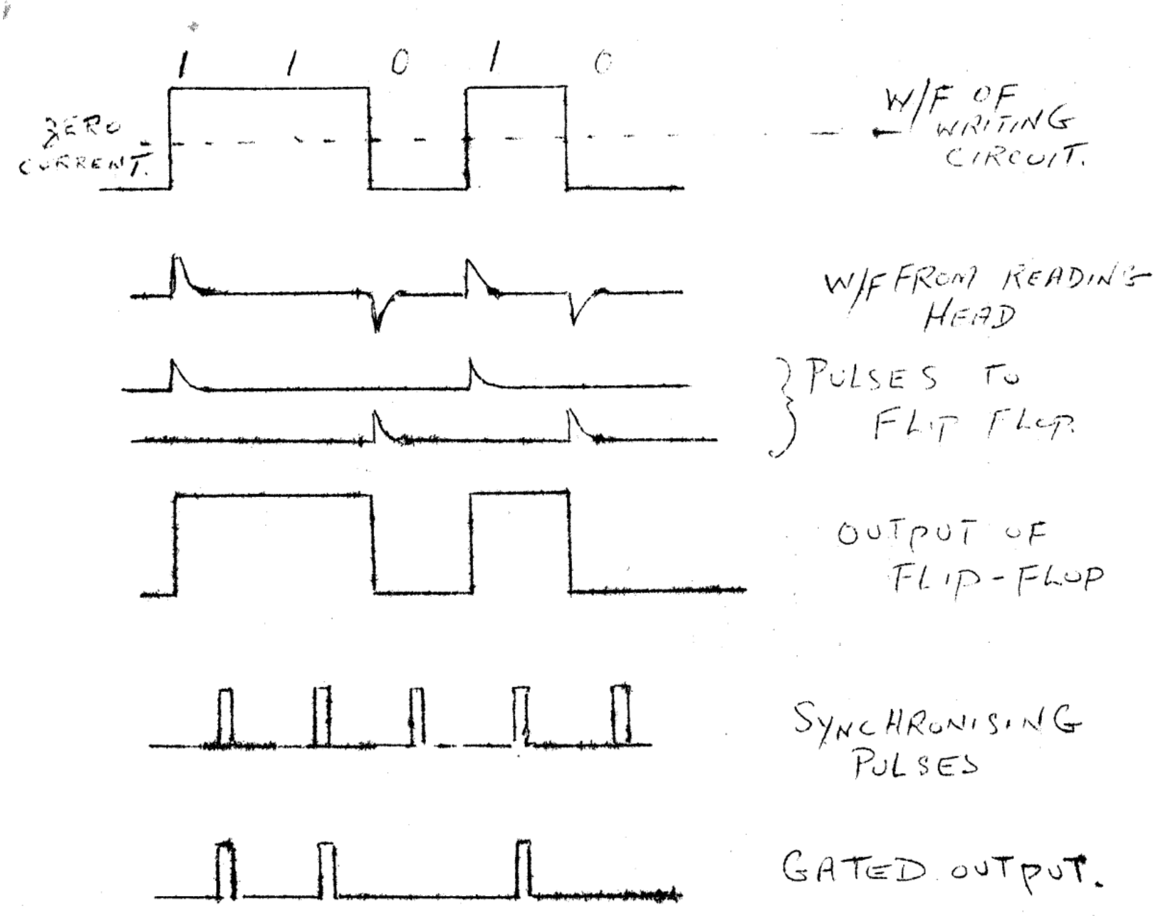


An improvement on the dipole method is obtained by using the writing waveform shown in fig.7c. Sufficient current normally passes through the writing head to saturate the magnetic material in a negative direction. When a binary (1) is written, the current is reversed and made to swing sufficiently positive to saturate the magnetic medium in the opposite direction. The (1) is thus recorded as a positive dipole in an otherwise uniformly magnetized negative medium. The waveform of the signal obtained from a reading head is the same as obtained previously, except that the amplitude is doubled. No demagnetization is needed, new information being written directly over information no longer required.

(iii) Non-return to Zero Method

Here the writing current swings from a negative to a positive value but when a sequence of 1's is being recorded, it remains constant at its positive value until the end of the sequence when it returns to its negative value.

NON RETURN TO ZERO METHOD. FIG. 7.D.



The waveform obtained from the reading heads consists of a series of short pulses, positive going to indicate the beginning of a sequence of 1's and negative going to indicate the end of such a sequence. The two sets of pulses are separated and the positive going pulses are applied to one input of a flip-flop whilst the negative going are applied after reversal, to the other input. The waveform of the positive going output of the flip-flop is then the same as the signal applied originally to the recording head. Again a synchronising signal is derived from a separate track which when gated with the flip-flop waveform, gives the required output.

The non-return to zero method allows a greater recording density than the dipole method since there is never more than one transition from a positive to a negative value of current or vice versa between the recording of successive digits.

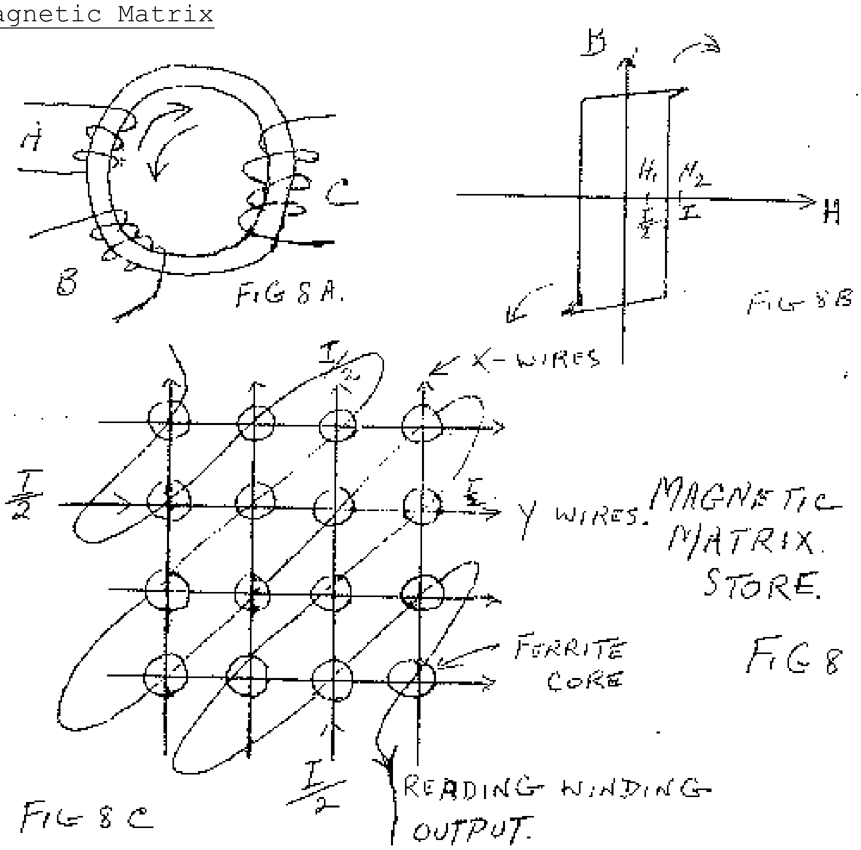
5. <u>Magnetic Tape</u>

The principles of recording binary information on magnetic tape are similar to those used in magnetic drum storage.

Generally 6 binary digits are stored across ½" wide cellulose acetate tape which has been coated with a suitable magnetic material.

In order to reduce errors in recording on tape generally a parity check is included along with the stored information.

6. Magnetic Matrix

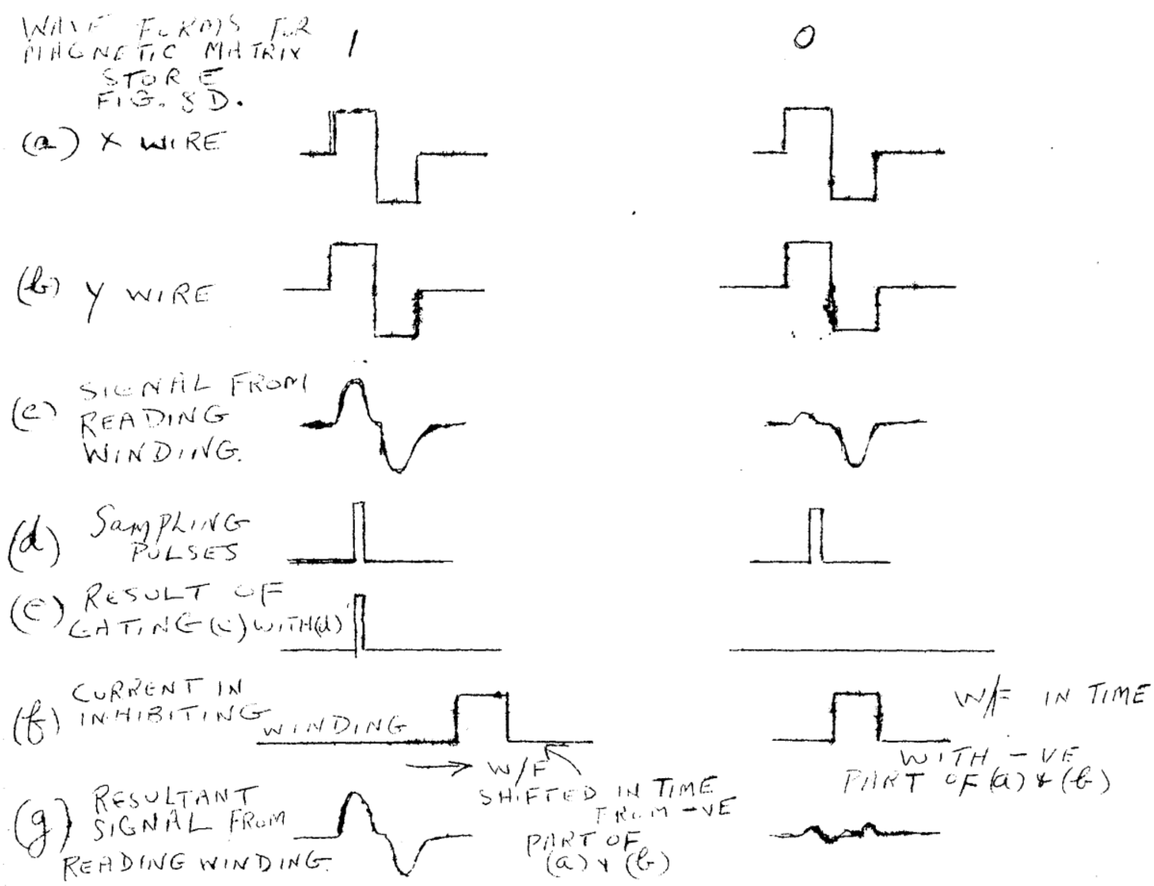


Magnetic matrix storage exploits the fact that certain magnetic materials (e.g. ferrite) have hysteresis loops somewhat rectangular in shape.

Consider that the magnetic core of fig. 8a has the rather idealised hysteresis loop shown in fig. 8b. The magnetic material forming the core can be magnetized say negatively (anticlockwise) by an appropriate current through coil C. If a current I/2 is passed through coil A the magnetic field H so produced is not sufficient to change the polarity of the magnetic flux. However, if simultaneously a current I passes through coil B, the magnetic field (H) produced by the combined current I is sufficient to change this polarity. Thus an E.M.F. would be induced in another output coil if it were wound on the ferrite core.

Fig. 8c shows one plane of a magnetic matrix store. There would be as many planes as digits in the word and the number of cells in the store would be equal to the number of elements of the matrix. (In the case of fig.8c the number of cells is 16.)

Broadly speaking, the action of the matrix store is as follows. A binary (1) is stored in a ferrite core forming an element of the matrix when there is an anticlockwise flux present. Say this is at the intersection of X and Y wires marked I/2 in fig. 8c. If a current of I/2 is passed through the X wire and Y wire, so indicated, then through the core at the intersection I will flow and this will cause the magnetic flux to change polarity and an induced E.M.F. will be present in the output winding. If the core were storing a binary (0) the flux in the core would be already anticlockwise and there would be no appreciable signal in the output winding. Furthermore, the flux direction of other cores on the X wire or the Y wire storing 1's would not be changed in polarity since the current through them is only I/2. There must be some method of originally setting the information in the matrix store and re-setting the information if a copy is taken.



The working of the matrix store can be studied in more detail by referring the waveforms shown in fig. 8d. Consider the situation when a binary (1) is stored at the intersection of the particular X and Y wires and also when a binary (0) is present. Waveforms (a) and (b) show the current in the X and Y wires respectively. The signal from the reading winding when the above mentioned signals appear on the X and Y wire is shown in waveforms (C). Sampling pulses together with (C) give rise to the gated output (d). Waveform (d) is used to modify the time position of an inhibiting pulse which is fed to an inhibition winding.

The latter winding threads all ferrite cores in a manner similar to the reading winding but is not shown in fig. 8c. If a binary (1) is copied from the store, with a result that it must be reset if continued storage of this digit is required, the waveform (e) ensures that the time position of the inhibition pulse is delayed so that it does not coincide with the negative going parts of waveforms (a) and (b). The negative parts of the latter are able therefore to reverse the flux direction thereby resetting the binary (1) in the memory.

In the case of the read-out of a binary (0), there is no gated output so that the inhibition pulse is not delayed. Hence it counteracts the negative going parts of the waveforms (a) and (b) and the flux in the ferrite core is not reversed and the storage of a binary (0) is continued.

If new information is to be read into the memory, the delay of the inhibition pulses is actioned by the incoming digits to be stored and not by waveform (e).

For modern computers, the magnetic matrix memory must be considered as the most important type of fast access storage.