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SELECTIVE ALTERATION OF DIGITAL DA

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IN A

MAGNETIC DRUM COMPUTER MEMORY

SUBMITTED TO
OFFICE OF NAVAL RESEARCH
UNDER THE PROVISIONS OF
CONTRACT N6onr-240 TASK 1

1 DECEMBER 1947

ERA

Engineering Research Associates, Inc.
1902 West Minnehaha Avenue, St. Paul 4, Minnesota

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PREFACE

This report describes an experimental investigation of certain techniques applicable to the magnetic drum type of computing machine memory. The work was performed in the laboratories of Engineering Research Associates, Inc., during the period from 1 July 1947 to 1 December 1947, as a special task under Contract N6onr-240 with the Office of Naval Research.

The personnel directly engaged in the execution of this problem were: Arnold A. Cohen, project engineer; William R. Keye, James G. Miles, and George A. Hardenbergh, engineers; and Arnold P. Hendrickson, technician.

The report was prepared by Arnold A. Cohen and William R. Keye. The assistance of Henry L. Cartier, publications manager, and his staff, is gratefully acknowledged.

A.A.C.

W.R.K.

1 December 1947

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ABSTRACT

Information coded in terms of binary digits (1's and 0's) may be recorded on a suitable magnetic medium bonded to a continuously rotating drum. An experimental storage system of this kind is described, in which individual digits may be selectively altered. High linear digital density and digital scanning rate are achieved through representation of digit sequences in each truck by a continuous, or "non-return-to-zero", pattern rather than by discrete magnetic marks. Recorded magnetic patterns containing 150 digits per linear inch are scanned at the rate of 210,000 digits per second, with a drum surface speed of 1400 inches per second.

1.0 INTRODUCTION

1.1 MAGNETIC DRUM DIGITAL STORAGE.

An essential part of certain types of automatic digital computer is a memory organ in which information may be stored for any desired length of time, and withdrawn from storage as required. The information stored in the memory consists, in general, of coded instructions for the control of the computer, and the numbers upon which the computer operates. The computer must automatically be able to insert information into its memory, and to read or alter information already there.

In one type of computing machine memory, information coded in terms of binary digits (1's and 0's) is recorded on a suitable magnetic medium, such as iron oxide coated paper tape, bonded to the surface of a continuously rotating drum. The small magnetized areas, or "cells", corresponding to individual digits are arranged in a number of peripheral tracks on the cylindrical surface of the drum. In proximity to each track are one or more stationary magnetic heads, which perform the operations of writing, reading, or erasing information in that track.

The techniques used in the magnetic recording of sound have been treated extensively in the literature. The recording process will therefore be described only briefly, and certain factors indicated which are peculiar to the recording of digital data for memory purposes.

To record information, the tape is passed before an air gap in the recording head, which is a suitably designed electro-magnet energized by a signal current. The head is oriented so that the fringing flux about the gap produces in the tape magnetization which is longitudinal, or parallel to the direction of motion. Each succeeding element of the tape is brought into a certain magnetized state, in which it tends to remain as it leaves the recording field. The recorded pattern of remanent magnetization along the tape is related, in a manner determined by the system characteristics, to the time variation of the recording current. This pattern may be read as the tape passes before the gap of a reproducing head, which in particular may be the same head previously used for recording. Some of the magnetic flux from the section of tape in close proximity to the gap follows the low reluctance path through the core of the head. Time variation of this flux generates an output voltage in the coil surrounding the core.

One way in which the recording and reading of digital information differs from the recording and reproduction of sound is that this output voltage need not be a replica of the recording signal. It is sufficient that the system reliably recognize the value of the digit stored at a specified location. For practical reasons, this type of recording is generally limited to binary digits, in which case the system need recognize only two possible values of digit. In other words, distinction need be made between only two magnetic states of the medium. These two states may correspond, for example, to positive and negative magnetization of the medium in the longitudinal direction.

Magnetic drum storage is readily applicable to the parallel-channel type of computer, in which the several digits forming one multi-digit number are transmitted simultaneously over as many channels. Thus the digits of a thirty-digit number may be entered simultaneously into their respective cells on thirty tracks. If there is room for 2000 cells on each track, then thirty tracks can be used to store 2000 thirty-digit numbers. At a given instant, all of the digits of a single number pass simultaneously under the gaps of thirty magnetic heads. The group of cells containing the digits of a single number may be called a memory box. An auxiliary track is used to generate timing pulses which are counted by a counting circuit to indicate at every instant which memory box is under the magnetic heads. Suitable circuits translate this information to permit reading out of, or writing into, any specified memory box.

Two desirable characteristics of a computer memory are large storage capacity and short access time. The storage capacity is the total number of binary digits which may be stored. This quantity depends, for a given size of drum, on the linear cell density, or number of digits stored per unit length of track, and on the number of tracks per unit length of drum.

The access time is the waiting time which may be required before insertion or withdrawal of the number in a specified memory box. The factors affecting access time are expressible by the simple relation

$$T = C/RH$$

where T = maximum access time in seconds

C = storage capacity (total number of cells)

R = scanning rate in digits per second

and H = total number of read-write heads

One way of decreasing T, for a given storage capacity, is to increase H. This may be done by using several groups of tracks instead of one group, thus reducing the circumference of the drum and the number of cells per track. Another way to increase H is to place several read-write heads about the circumference of each track. But, increasing the number of heads complicates the associated circuits and increases the number of tubes required. A different way to decrease T is to increase the cell-scanning rate, R. This quantity is the product of the cell density, or number of cells per inch, and the drum surface velocity in inches per second. Its upper limit is determined either by the maximum practical values of these two factors or by the response of the magnetic heads to high frequencies.

The maximum practicable cell density depends on the ability of the magnetic head to resolve digital patterns on the tape, both in writing and in reading. The factors influencing this resolving power are the geometry of the magnetic head -- particularly the width of the air gap -- the magnetic properties of the core and magnetic tape, and the separation between the head and the tape. The head cannot practically be maintained in contact with the tape, as in sound recording, because the relatively high tape speed required would result in very rapid wear of head and tape.

1.2 NON-RETURN-TO-ZERO RECORDED PATTERNS.

Even with a given set of physical properties of magnetic heads and tape, there is still another factor which can influence both the maximum attainable linear cell density and digital scanning rate. This factor is the type of recorded magnetic pattern chosen for representation of the sequence of binary digits in each track.

The reading process for two types of digital representation is illustrated in Figures 1 and 2. The horizontal coordinate in both of these is time. The distance between adjacent vertical lines represents one cell period, or the time required for the tape to travel one cell distance. A series of seven cells is shown in both cases. These cells contain the digit sequence 1101000. The wave form of the flux in the core of the reading head is shown in Figures 1a and 2a. To a first approximation, the time plot of the flux resembles the space plot of the intensity of magnetization along the tape.

Consider first the type of pattern shown in Figure 1a. The flux in the reading head remains at one level M to indicate a 0, but shifts momentarily to the other level to indicate a 1. Even if a series of successive 1's occurs, the flux shifts back to the M, or 0, level at the end of each cell period. In this "return-to-zero" type of pattern, the magnetized areas on the tape corresponding to individual digits are discrete, separated marks.

Figure 1b shows the electromotive force induced in the winding of the reading head.

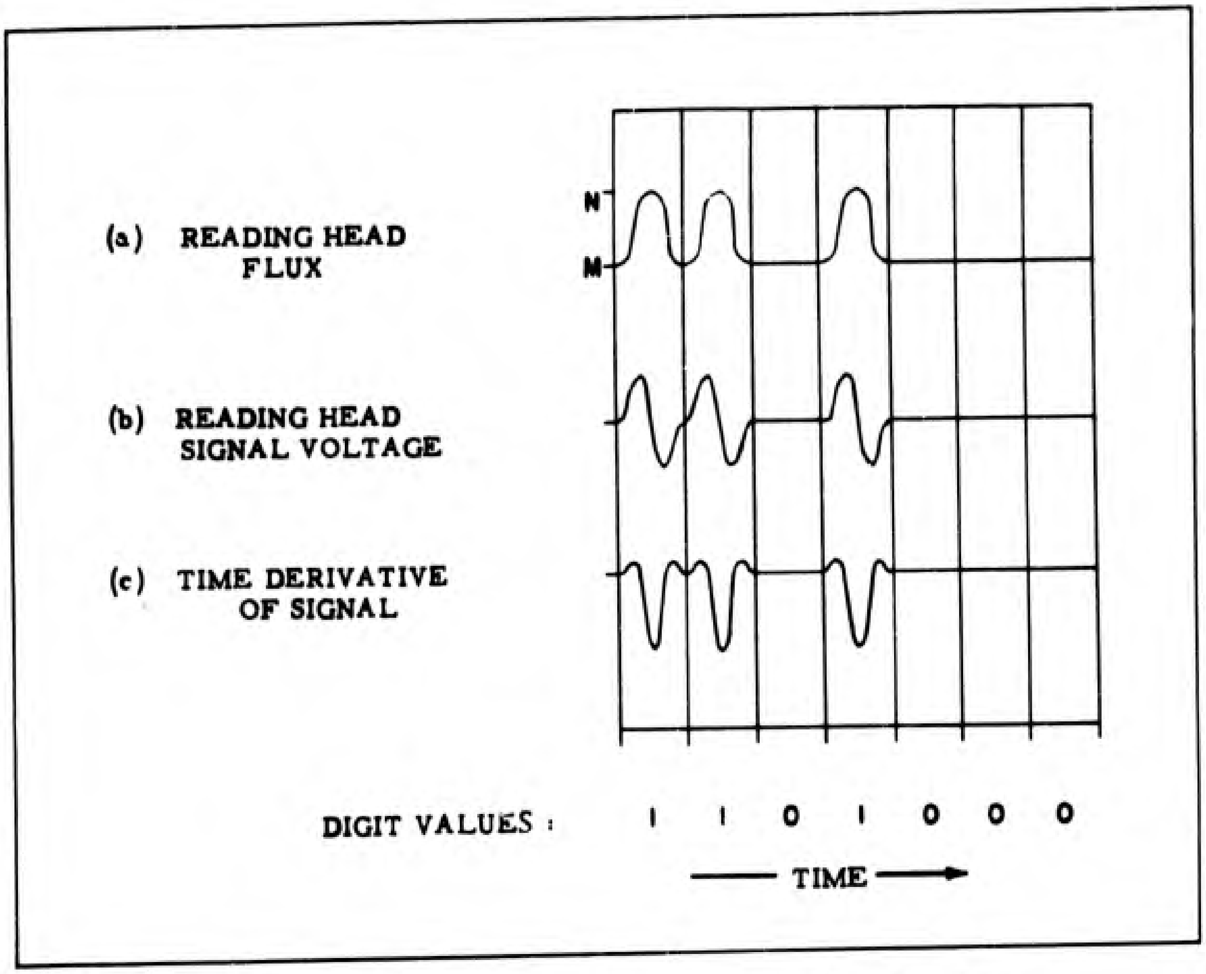


FIGURE 1 RETURN-TO-ZERO SIGNAL PATTERNS

If this voltage is differentiated by passing it through a suitable RC coupling network, the derivative voltage is of the form shown in Figure 1c. Presence or absence of the sharp derivative pulse denotes 1 or 0 respectively.

An alternate means of representation, shown in Figure 2a, is based on techniques commonly employed in telegraphic transmission. Magnetized areas corresponding to individual digits form a continuous pattern, rather than discrete marks. The flux in the reading head shifts from one value to the other only when the digit being scanned differs from the preceding one. A positive or a negative voltage pulse is induced in the winding only when a transition of this kind occurs (Figure 2b). Thus a positive pulse denotes the beginning of a train of 1's and a negative pulse the beginning of a train of 0's. Suitable trigger and gating circuits convert these signals back to trains of pulses, representing 1's, and blanks, representing 0's.

Comparison of Figures 1a and 2a reveals certain advantages of the latter, or "non-return-to-zero" type of representation (which will be referred to as NRZ). If the cell period is taken to be the same in both cases, it is evident that the maximum frequency which the magnetic head must handle in the NRZ case is just half the corresponding maximum frequency in the return-to-zero case. Furthermore, if the length of tape per cell is the same in both cases, it is seen that the shortest region of uni-directional magnetization is twice as long in the NRZ case. It follows that the heads and tape in a given system will, with the NRZ pattern, store effectively twice as many digits per inch, and permit scanning at twice the rate, as on a return-to-zero basis.

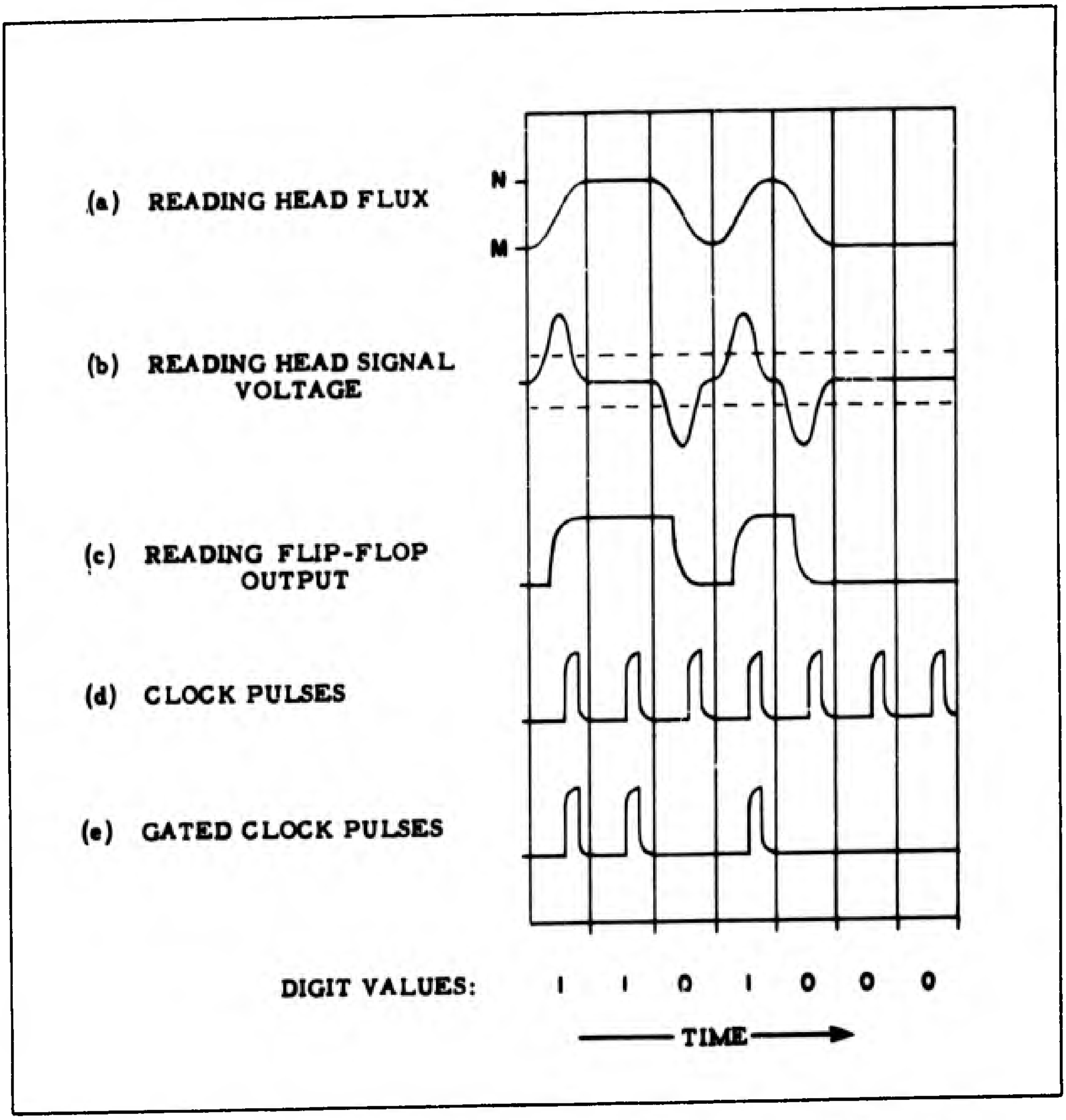


FIGURE 2 NON-RETURN-TO-ZERO SIGNAL PATTERNS

1. 3 SELECTIVE ALTERATION.

One method of inserting data into a track on the drum is to apply recirculating techniques similar to those used in acoustic delay-line memory systems. This requires separate heads for reading, erasing and recording. The erasing head continuously removes previously recorded data from the tape just ahead of the recording head. Signals from the reading head are reshaped and fed to the recording head. By means of interposed gates, it is possible to enter a new digit by impressing it on the recording head circuit at the proper time in place of the recirculating digit coming from the reading head. Reading, with or without removal of stored data, is also accomplished by suitably timed gating. Some objectionable features of this method are: (1) three heads are needed; (2) the stored information is volatile; i.e., vanishes on interruption of power or failure of any part of the recirculating circuit; (3) the stored pattern keeps shifting to new positions on the drum.

As an alternative approach, suppose there is no separate erasing head. If it is desired to write a digit into a given cell, the recording head is pulsed in the appropriate direction at the time this cell is passing the recording gap. If synchronization and pulse shape are correct, the new digit appearing in the cell will be independent of the digit previously contained in the cell. To read a given cell, the output circuit of the reading head (which in this case may also be the recording head) is gated through at the time the desired cell is passing the head gap.

This method, which may be called "selective alteration", presents the problem of entering a digit into a cell in such a manner that the previously stored digit is completely eradicated. Selective alteration may be used either for return-to-zero or for NRZ patterns. In the former case, the magnetized areas representing successive digits must be kept separate and discrete. In the case of NRZ, the magnetized areas representing successive digits must be made to blend into a smooth, continuous envelope, as in Figure 2a. The continuity of envelope must be maintained when digits are individually altered in any order. The recorded magnetization pattern for a single digit must be shaped to provide this continuity.

In addition to the possibility of using a single head, the outstanding feature of selective alteration over the continuous erasure method is that the stored information is fixed, or non-volatile. In fact, magnetic recording with selective alteration is one of the few known means of storage which is both erasable and non-volatile.

1.4 OBJECTIVE OF INVESTIGATION.

The experimental work described in this report was undertaken to determine the feasibility of selectively altering individual digits in a magnetic drum storage system employing the NRZ type of recorded pattern. The NRZ technique was selected in order to attain high digital densities and rapid digital scanning rates.

It was intended that only readily available physical components be used in this initial study of these storage techniques. Accordingly, no attempt was made to increase the cell density and the scanning rate by modifying the design of these components. The entire investigation, for example, employed magnetic heads of fixed geometry.

2.0 DESCRIPTION OF METHOD

2.1 FEATURES OF EXPERIMENTAL SYSTEM.

In order to study these techniques, a model storage system was built. The system included the following features:

(1) A small cylindrical drum carrying one timing track and one signal or storage track. The timing track provided the signal track with 32 storage cells, which seemed an adequate number for testing the principles involved. These 32 cells occupied only a very small portion of the total drum circumference; e.g., 0.220 inch for one typical operating condition.

(2) Means of locating a specific cell position on the basis of a binary-coded address.

(3) Means of writing the 1's and 0's into selected cells.

(4) Means of reading the stored information.

A general block diagram of the experimental system is shown in Figure 3. The cell locating portion of this system consisted of the timing track, means for converting its signal into a train of pulses, and a 5-stage predetermined binary counter. The generated train of pulses served to define the position of the train of cells on the signal track. The counter was used to select any desired cell and deliver a pulse at the instant this

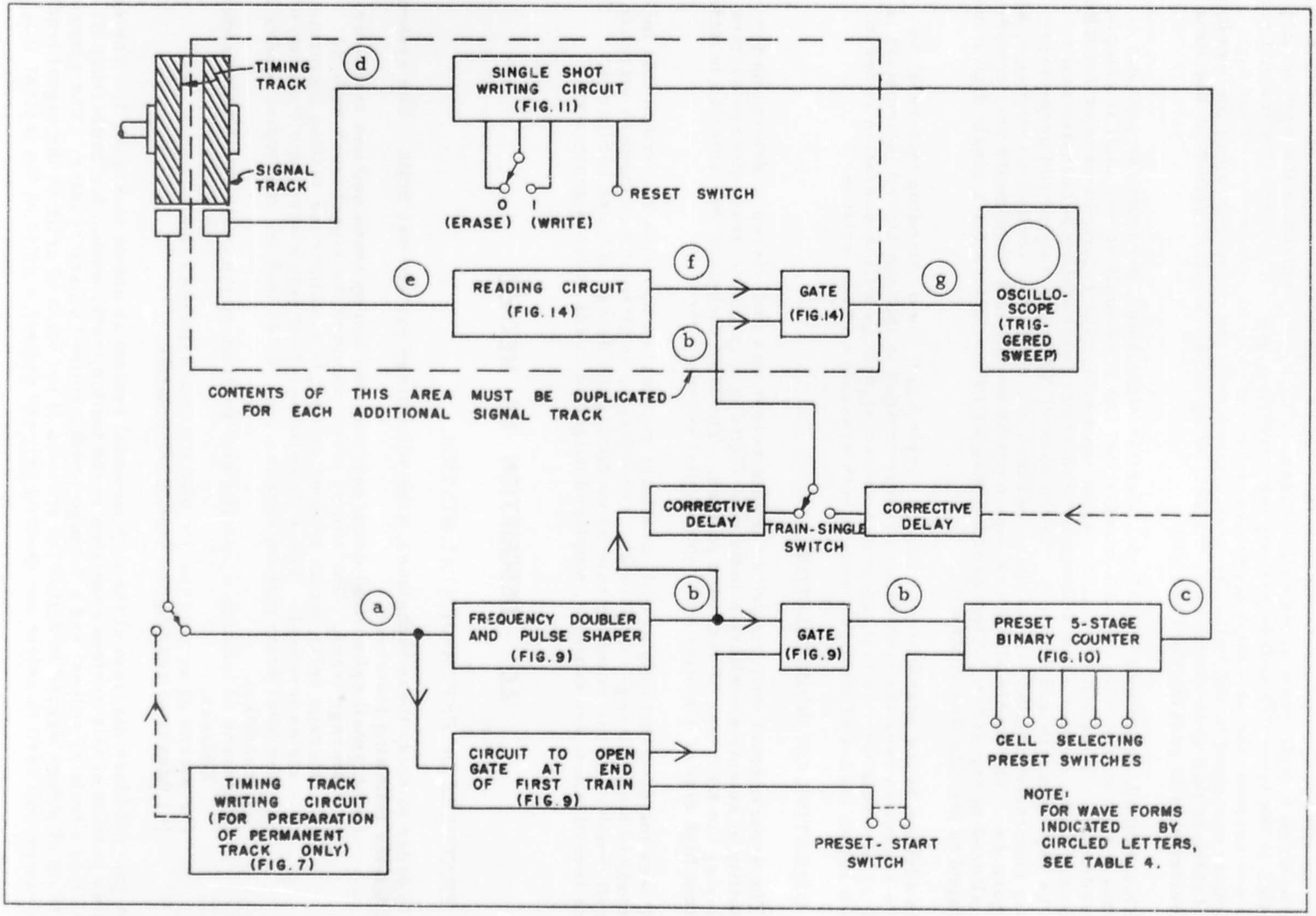


FIGURE 3 GENERAL BLOCK DIAGRAM OF EXPERIMENTAL MAGNETIC RECORDING STORAGE SYSTEM

cell traversed the gap. This pulse could be used either to trigger the writing circuit or to sample the output of the reading circuit.

A photograph of the experimental storage system is shown in Figure 4. The rack contains all of the components of the system except the drum and magnetic heads. The oscilloscope shown is a Dumont type 248.

FIGURE 4 EQUIPMENT USED IN EXPERIMENTAL INVESTIGATION

2.2 PHYSICAL COMPONENTS.

The magnetic tracks were recorded on two iron oxide coated paper tapes cemented to the surface of a machined aluminum drum. The magnetic tape used was Scotch Sound Recording tape (type A oxide, H_c = 330 oersteds) made by the Minnesota Mining and Manufacturing Company, St. Paul. This tape is 0.25 inch wide and approximately 0.002 inch thick. The drum was 5 inches in diameter and 1 inch wide. It was driven through a belt and pulley connection by a 1725 rpm induction motor. Tape speeds of 140, 280, 400, 680, 1000, and 1400 inches per second could be selected by changing pulleys. The maximum surface speed used in this investigation was 1400 inches per second. This limit was determined only by the motor speed and the largest pulley ratio on the avail able equipment. There was no problem of tape adherence at this speed.

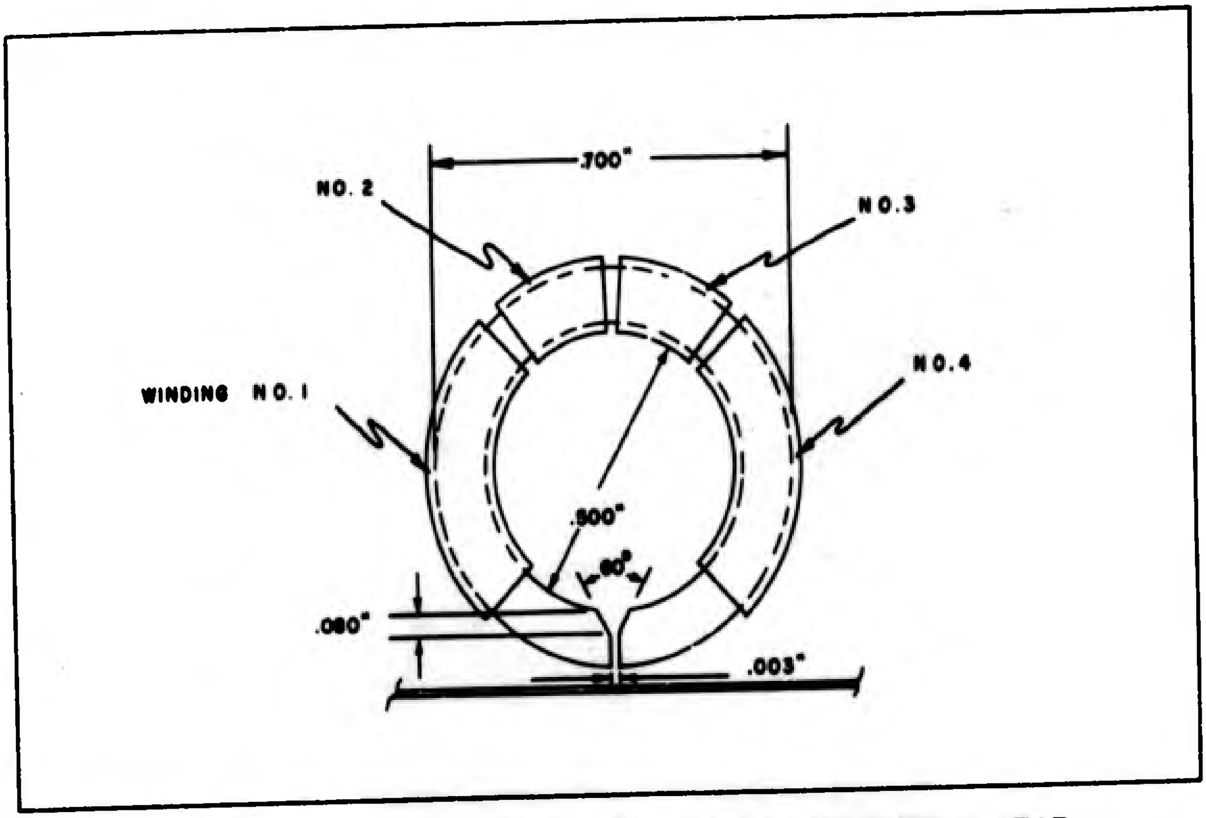


FIGURE 5 MAGNETIC READING AND RECORDING HEAD

All of the magnetic heads used in this investigation were of the shape shown in Figure 5. The core of each head was made up of stacked laminations of Mumetal (Allegheny Ludlum Steel Corp., Brackenridge, Penna.), with thin costs of polystyrene providing interlaminar insulation. The single air gap was 0.003 inch wide. All of the windings were of No. 36 copper wire, Formex coated. This particular head design was used because it was available from previous work.

Two heads having laminations of different thickness were used on the signal track. The first head was made up of 14 laminations, each 0.007 inch thick, while the second had 33 laminations, each 0.003 inch thick. Each head had very closely the same cross sectional area of core material. Each of these heads had a 100-turn reading winding (coils 2 and 3 in Figure 5) and two 100-turn windings (coils 1 and 4) for writing. These heads will be referred to hereinafter as the 7-mil head and the 3-mil head. These different heads were used to study the effect of lamination thickness on the reading and writing operations.

A head made up of 14 laminations of 7-mil Mumetal was used on the timing track. This head had two 100-turn coils connected in series to provide a 200-turn winding.

A different 3-mil head was used in conjunction with the simplified reading and writing circuits described in Appendix I. This head had a 200-turn winding for reading and two 10-turn windings for writing and erasing.

The heads were mounted in such a manner that the distance between the gap and the surface of the tape could be adjusted accurately to the desired clearance. This clearance was held at 0.002 inch except for one special test. This was considered a typical practical minimum for the clearance.

A photograph of the drum and magnetic heads with their holders is shown in Figure 6.

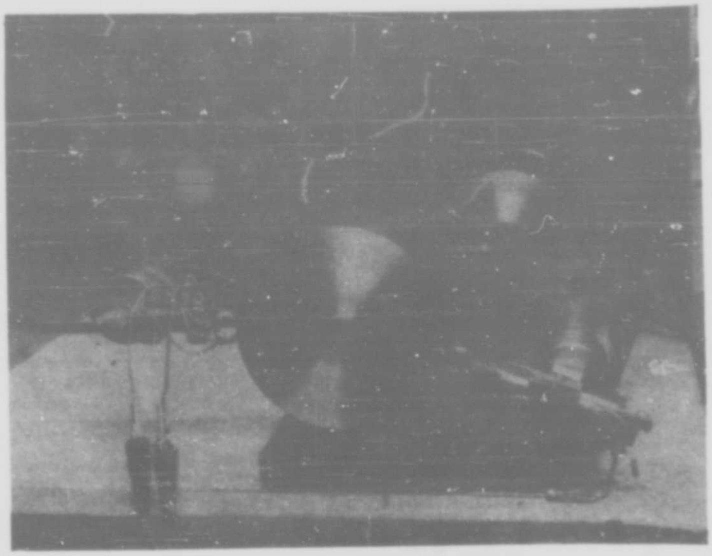


FIGURE 6 DETAIL OF STORAGE DRUM AND MAGNETIC HEADS.

2.3 TIMING TRACK: GENERATION OF CLOCK PULSES.

It was desired for cell locating purposes that a train of 32 pulses be generated once per revolution, in synchronism with the drum rotation. These pulses must be generated at the cell scanning or repetition rate. A train of approximately 20 sine waves was permanently recorded on the timing track. The frequency of the sine wave voltage picked up from this track is one-half the cell repetition rate. The voltage from the timing head is amplified and the frequency doubled (see Figure 3). The resulting signal is used for forming a train of pulses at cell frequency. The sine wave frequency was chosen to be half the cell frequency rather than equal to the cell frequency so that the limitation on the number of cells per inch would not be reached in the timing track.

Preparation of the timing track required the construction of a special circuit to generate a train of sine waves. The schematic diagram of this circuit is shown in Figure 7. A one-shot multivibrator provides a single rectangular gating signal which allows an oscillator to generate a train of sine waves for the duration of the gate. The train is amplified and fed to the timing track head winding through an isolation transformer. The frequency of the oscillator was adjustable from 5000 to 15,000 cycles per second. The duration of the gate signal was adjustable from 1 millisecond to 5 milliseconds.

The procedure for recording a timing track was as follows:

(1) The timing track was erased to a neutral, or demagnetized state. This was done by first passing a direct current of about 200 milliamperes through the head winding with the tape in motion. The current was returned to zero, and then raised in the opposite direction to a slightly smaller value than before. The process of successively diminishing and reversing the magnetizing field was continued until the current became small compared with the peak current to be used in writing the timing track.

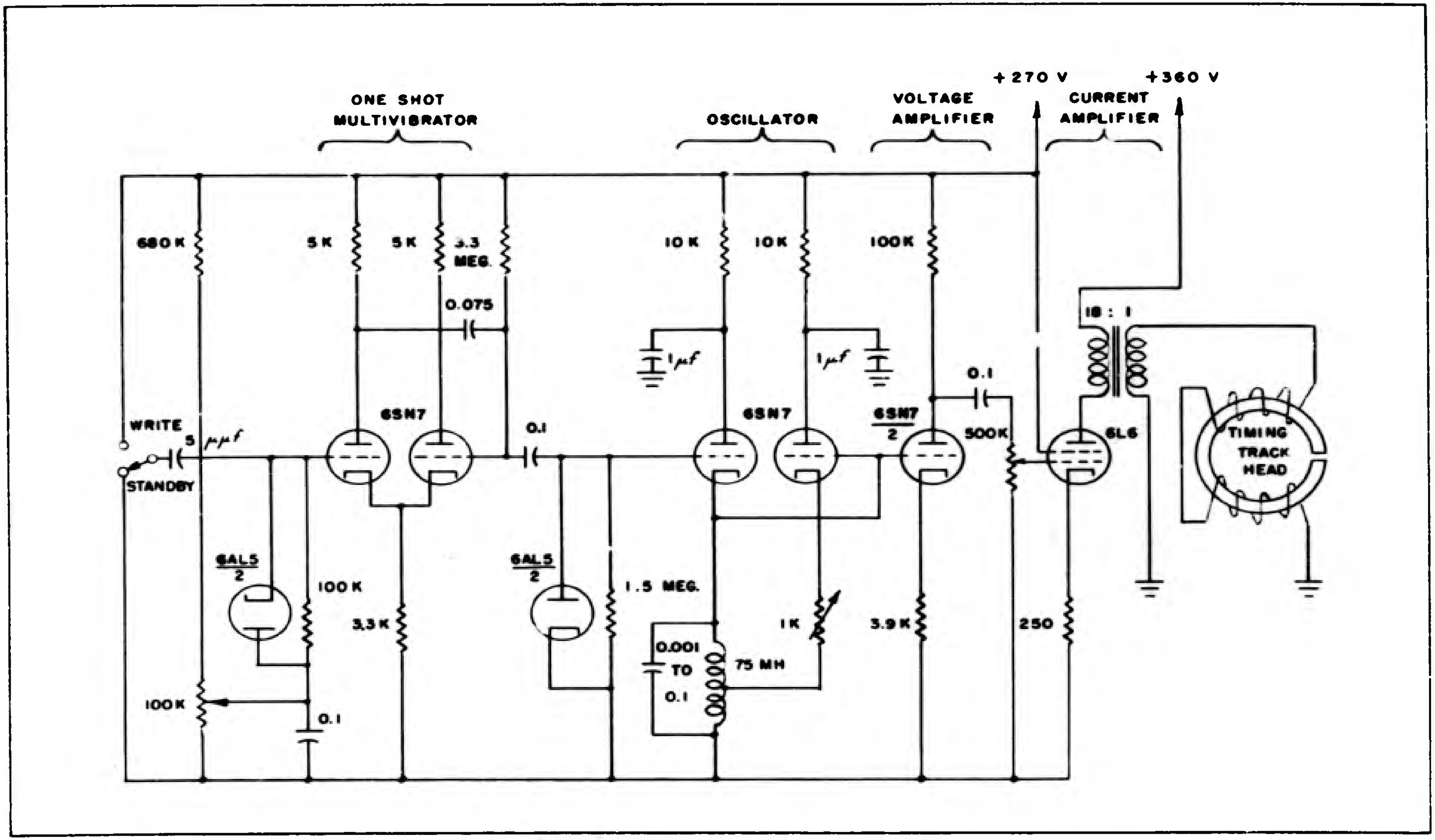


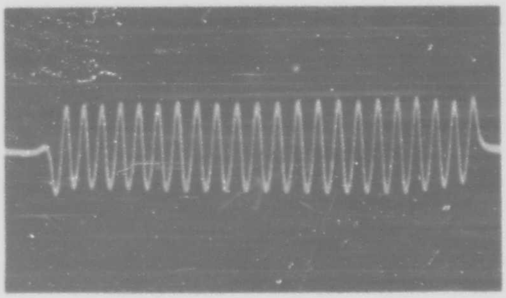
FIGURE 7 TIMING TRACK WRITING CIRCUIT

(2) The speed was reduced to 140 inches per second, and a single train of about 20 sine waves recorded. For densities of 100,150, and 200 cells per inch on the signal track the required sine wave frequencies were 7000, 10,000, and 14,000 cycles per second, respectively. These corresponded to timing track patterns of 50, 75, and 100 sine waves per inch.

(3) With the drum again operating at normal speed, the voltage generated at the coil terminals of the head provides a timing signal for locating cells on the signal track. An oscillogram of this signal is shown in Figure 8a. This timing track was written at a density of 50 sine waves per inch. The peak writing magnetomotive force was 40 ampere-turns. The played-back signal at the tape velocity of 1400 inches per second was 100 millivolts peak-to-peak.

The sine wave train is converted into a train of sharp clock pulses of twice the sine wave frequency by first amplifying the signal and then feeding it through a phase inverter into a full-wave rectifier. The double frequency wave form so obtained is then amplified, shaped, and clipped to provide the required shape of pulse. A schematic diagram of the circuit used for this purpose is shown in Figure 9. An oscillogram of the clock pulse signal train is shown in Figure 8b.

(a) TIMING TRACK HEAD OUTPUT VOLTAGE



(b) CLOCK PULSES

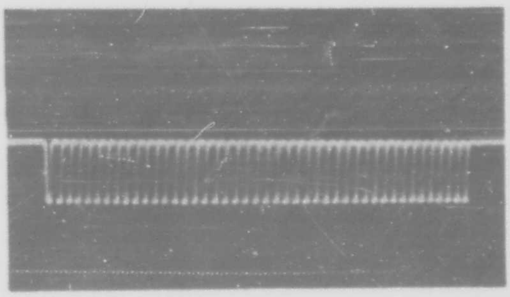


FIGURE 8 OSCILLOGRAM OF TIMING SIGNALS : COMPLETE TRAIN

2.4 CELL LOCATION.

A 5-digit binary number can be used as an address code to specify 32 possible cell positions. The purpose of the locator circuit is to translate the address code which it has received (in this case the positions of 5 manually set toggle switches), and to generate a single pulse which follows the corresponding clock pulse in the train by some short but constant time interval.

One method of accomplishing this might be to set up the address code on a 5-fold coincidence circuit. This coincidence circuit probes the five stages of a binary counter which is counting the clock pulses, starting from the beginning of the train. When the counter arrives at the binary pattern corresponding to the desired address, the coincidence circuit transmits a pulse.

This method would be satisfactory if the transitions occurring in a binary counter occupied a negligible time compared with the time between clock pulses. Actually, (unless the binary counter is capable of following pulse rates many times greater than the clock rate) the transition of a single stage may occupy a considerable fraction of the clock pulse interval. The time required for the counter to reach equilibrium in its new state after each clock pulse will be different from pulse to pulse, depending on the number of stages which must make transitions. For example, the fifteenth pulse produces a single transition (from 01110 to 01111), whereas the sixteenth pulse causes five stages to turn over (from 01111 to 10000). Indiscriminate application of this method would produce non-uniform cell spacing on the track.

If the counter transitions were sufficiently rapid, the coincidence pulse could be used to set up a flip-flop, which could be reset by the next clock pulse. The return transition of this flip-flop would then generate the desired pulse, correctly synchronized.

As an alternative to the coincidence method, the counter may be preset to a number which is the "one's-complement" of the address. (This complement, which is 11111 minus the actual address, may be used directly as an address.) Then when the first clock pulse in the train arrives, the counter starts counting, beginning with the number to which it is preset. When it reaches the count of 32, an output pulse is transmitted by the last stage. Although the output pulse may occur an appreciable time after the corresponding clock pulse, the delay is always that corresponding to the count of 32, and is therefore independent of the number of the selected cell.

As a further refinement, which was not used here, the output pulse might be used to set a flip-flop which is then reset by the next clock pulse, as described above. Although in this experimental set-up the preset method was used, the coincidence method would have an advantage in automatic computer work in that the coincidence circuit can become immediately operative without having to wait for the beginning of a new train of clock pulses.

The locating circuit as shown in Figure 10 consists of a conventional 5-stage binary counter employing 6SN7 tubes. A DPDT toggle switch in the cathode leads of each twin triode determines which cathode of each binary pair will be removed temporarily from ground by the "preset-start" switch (Figure 3). The 5-digit address code can be set up on five of these DPDT switches. After a certain number of pulses have been counted, as determined by the switch settings, the output stage of the counter produces a pulse.

However, it is obviously necessary to suppress further counter output pulses after delivery of this pulse. The initial pulse is therefore used to trip a flip-flop, which has been previously set by means of the "preset-start" switch. The tripping of this circuit produces the single pulse desired for operation of the writing and reading circuits.

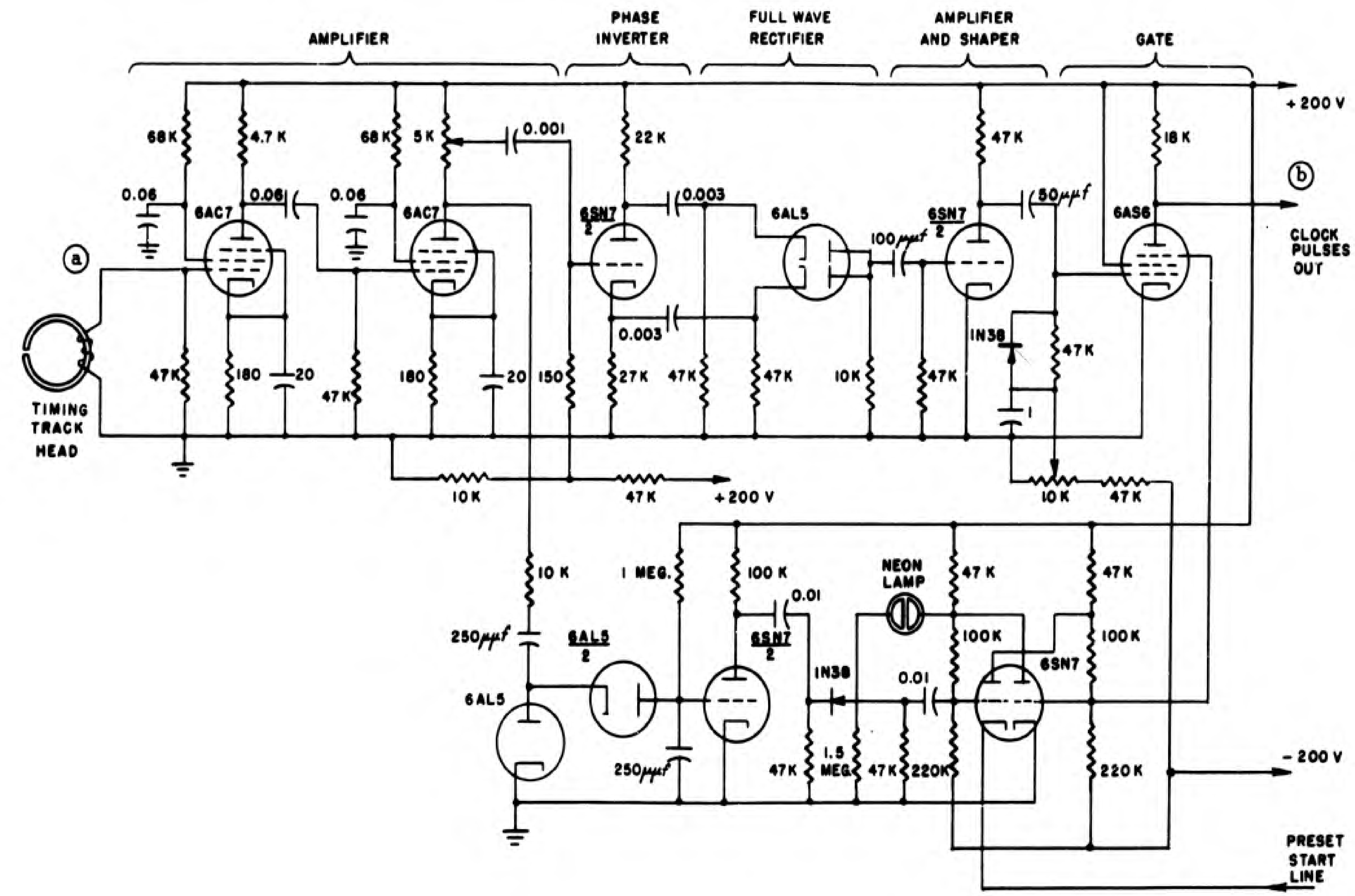


FIGURE 9 CLOCK PULSE FORMING CIRCUIT

ULSE FORMING CIRCUIT

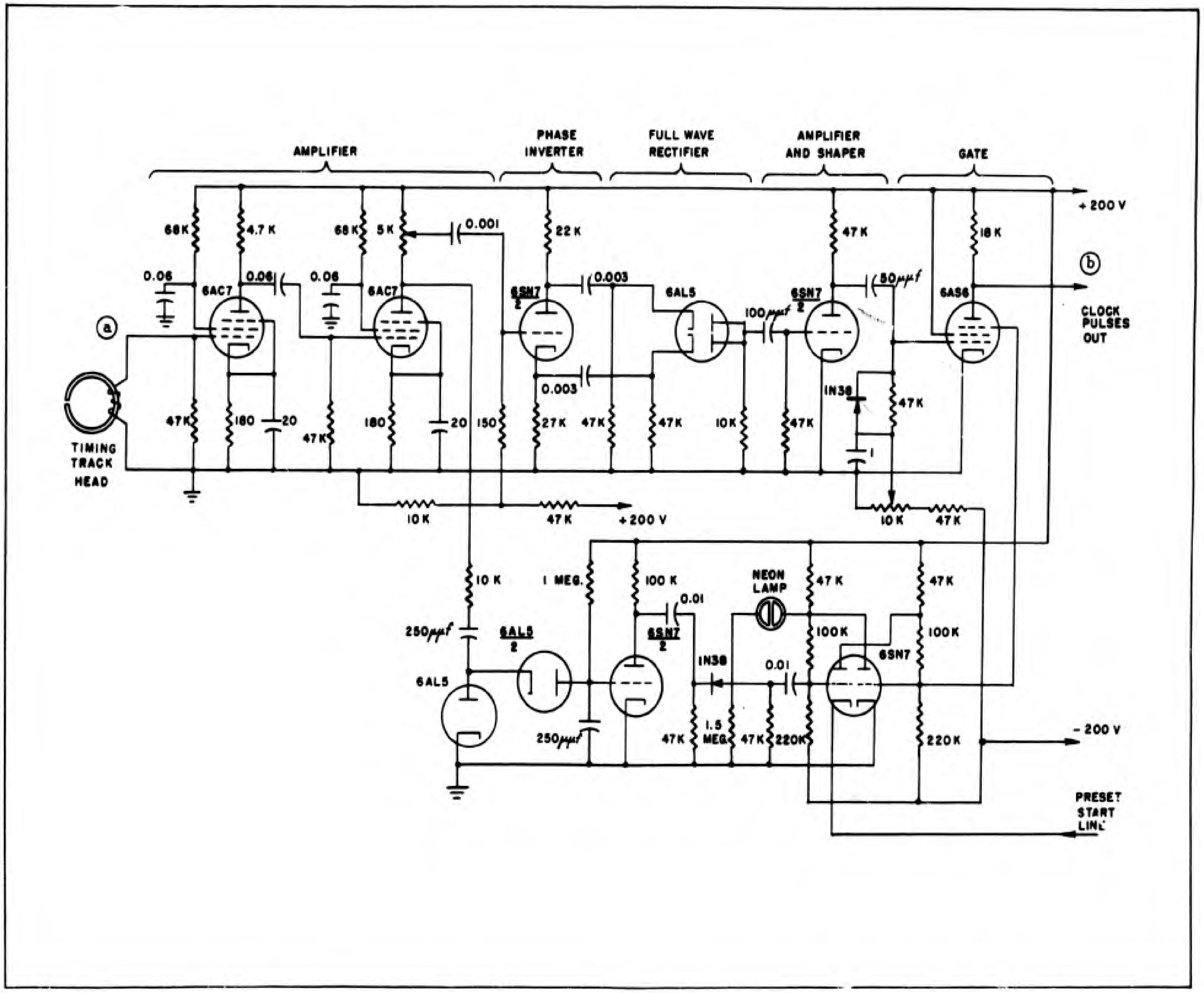


FIGURE 9 CLOCK PULSE FORMING CIRCUIT

FIGURE 9 CLOCK PULSE FORMING CIRCUIT

FIGURE 10 CELL LOCATING CIRCUIT

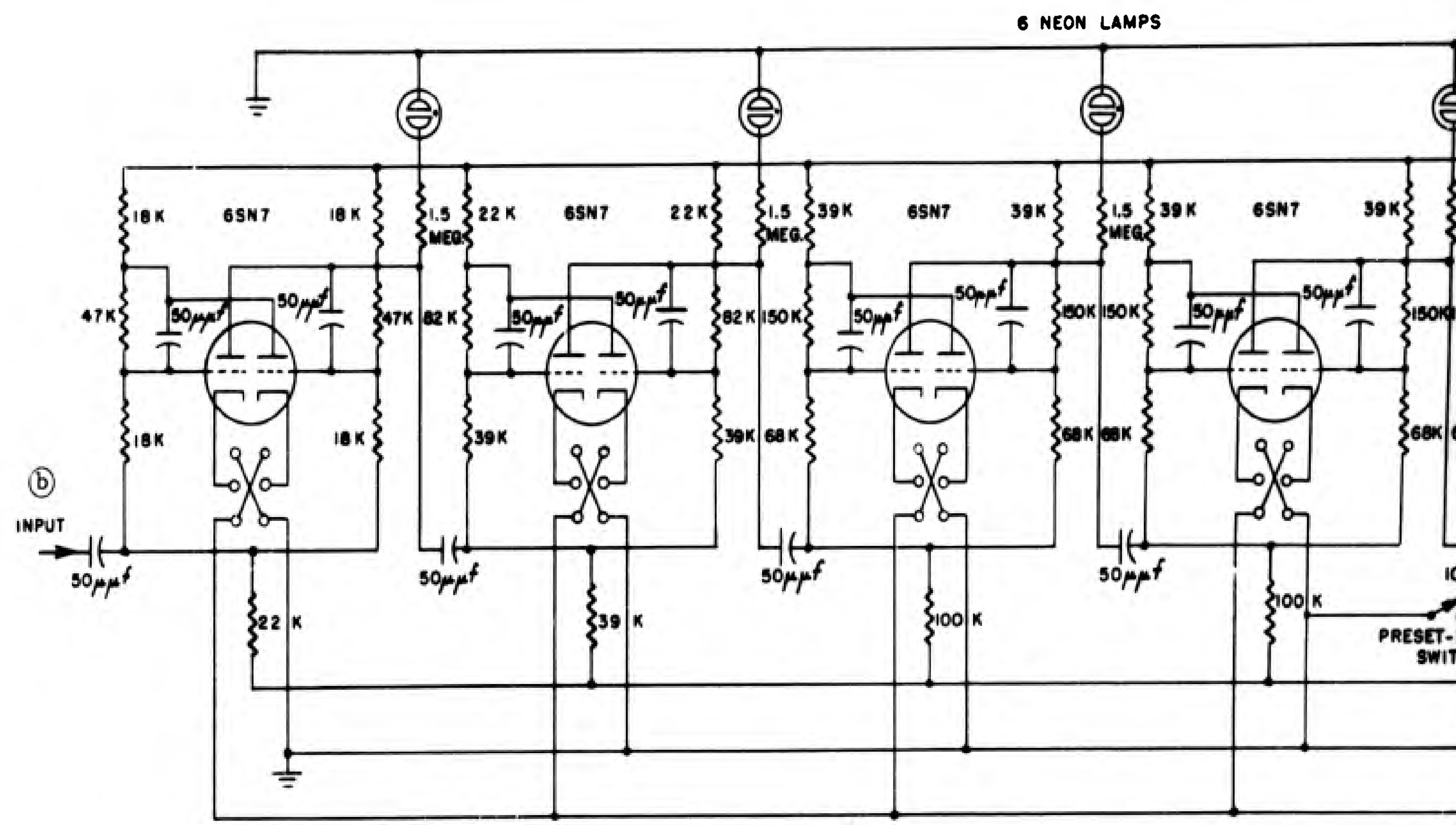


FIGURE 10 CELL LOCATING CIRCUIT

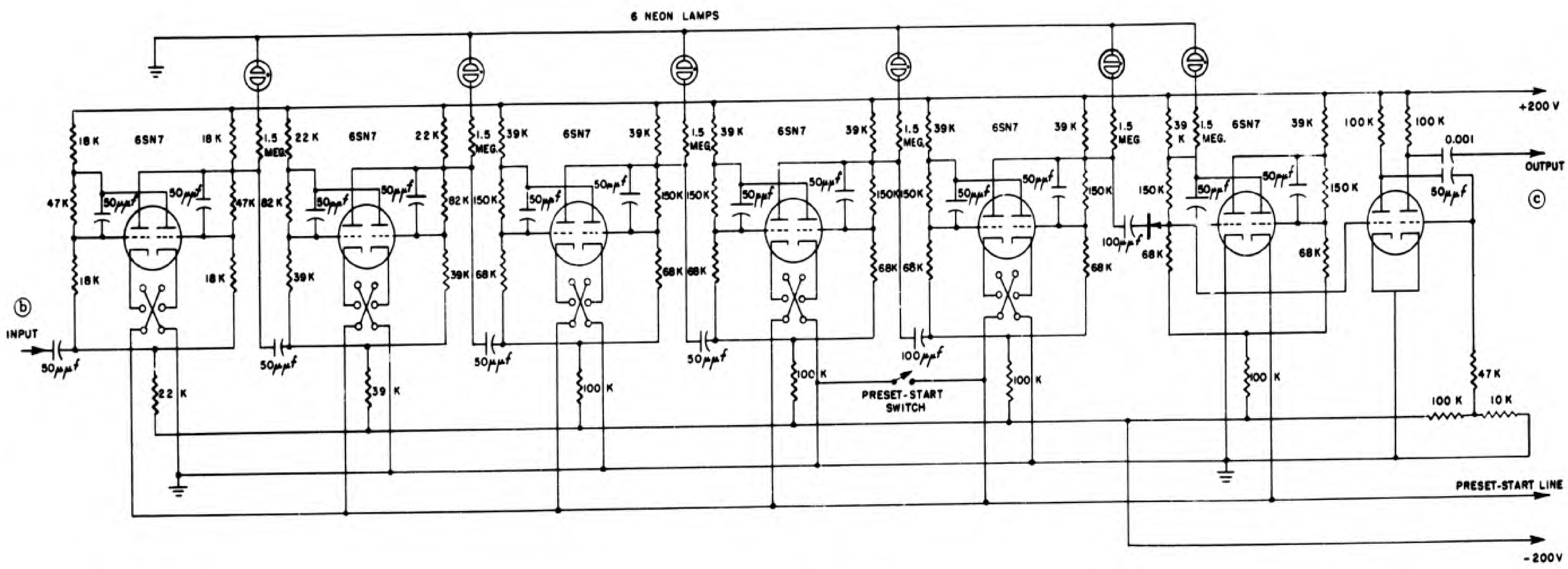


FIGURE 10 CELL LOCATING CIRCUIT

2

2.5 WRITING.

A 1 is represented on the tape by a small area magnetized in one direction, and a 0 by an area magnetized in the opposite direction. A binary digit may therefore be written by passing a current pulse of appropriate polarity through a winding on the magnetic head.

The writing circuit used for experimental purposes is shown in Figure 11. The single pulse from the locating circuit triggers a previously set flip-flop, and causes a pulse to be transmitted to the grid of a 2D21 miniature xenon thyratron.* The tube fires, and the condenser in the series RLC circuit discharges in such a manner that the discharge current and the voltage drop across the resistor are of the form of a single half sine wave. This voltage pulse is amplified and impressed on the control grids of a pair of 6L6 tubes which in parallel drive one winding of the magnetic head on the signal track. The current wave form is substantially identical with that of the voltage pulse impressed on the 6L6 grids. A similar pair of 6L6 tubes drives the other winding on the same head for recording a pulse of opposite magnetic polarity. Both windings conduct no current in the absence of signal. The 1-0 switch (write-erase) shown in Figures 3 and 11 selects magnetic polarity by reducing the bias on the desired half of the output amplifier from a value several times cut-off to just beyond cut-off. This method of selecting magnetic polarity is preferable to direct manual switching of the current in the winding, because the switching of grid voltages can be accomplished by electronic means when required.

A typical oscillogram of the writing current is shown in Figure 12. The peak current is 300 ma, corresponding to a peak magnetomotive force of 30 ampere-turns. Markers 1 microsecond apart appear on the trace as dark spots. The wave form shown is a half sine wave of 2 microseconds duration.

The 2D21 pulse-forming network was so designed that the duration of the writing current pulse could be varied from less than 1 microsecond to about 15 microseconds. The peak current could be adjusted from 0 to 550 ma. These quantities were made adjustable for the present investigation, since they have different optimum values for each value of drum surface speed and cell repetition rate.

The nature of the writing process for selective alteration, particularly in the case of NRZ, requires a writing signal current of short duration, preferably possessing symmetry about the peak value. The half sine wave shape was chosen because this appeared to be the most easily attainable signal having these properties.

The writing circuit shown in Figure 11 has a definite recovery time, since the recharging time of the pulse-forming network has a lower limit determined by the deionization time of the thyratron. The circuit as shown probably will not write two pulses in succession which are separated by less than several hundred microseconds. This is not a serious limitation, since in a parallel channel memory, numbers are written into random memory boxes at random times. However, in any application requiring more rapid recovery, other means of pulse forming may be used which do not employ gas tubes.

2.6 READING.

The purpose of the reading circuit is to convert the signals from the signal track head into distinct and accurately-timed pulses and blanks, as in Figure 2 e.

* IN NORMAL OPERATION, THIS FLIP-FLOP DUPLICATES THE FUNCTION OF THE FLIP-FLOP IN THE LOCATOR CIRCUIT OUTPUT. THIS ADDITIONAL SINGLE-ACTION FLIP-FLOP WAS INCLUDED ONLY FOR LABORATORY CONVENIENCE AND FLEXIBILITY.

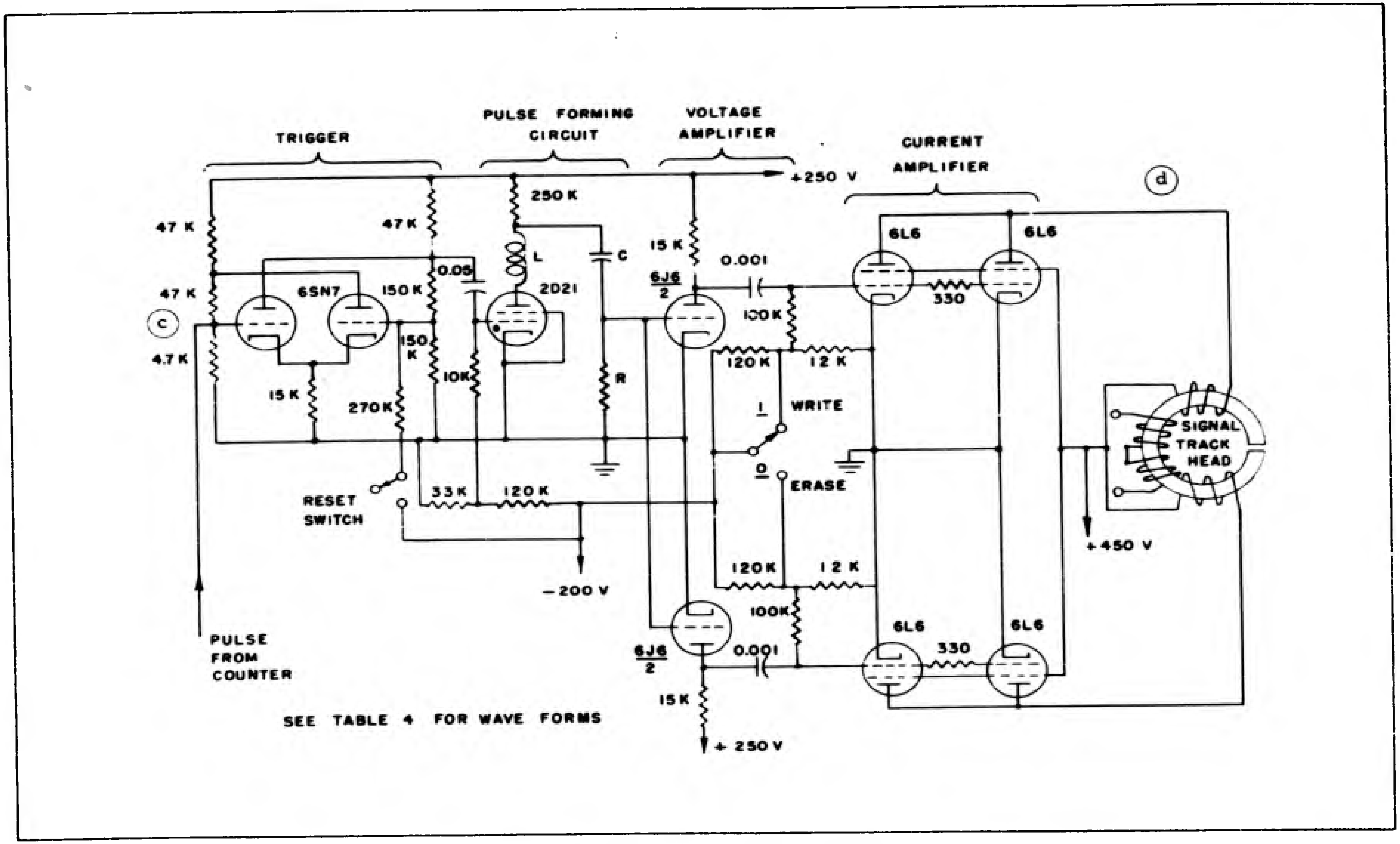


FIGURE 11 WRITING CIRCUIT

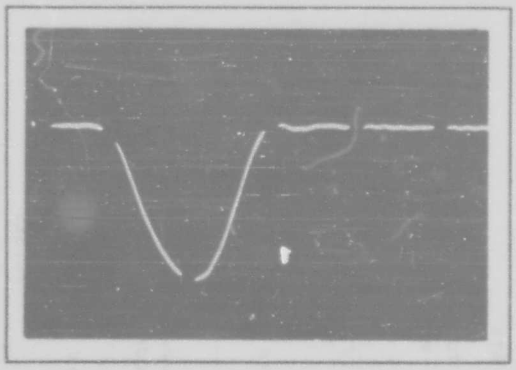


FIGURE 12 OSCILLOGRAM OF 2-MICROSECOND WRITING CURRENT PULSE

Initially, this was accomplished by the circuit shown in Figure 13. The signal from the head is amplified, and used to drive an integrating flip-flop which shifts to one state on a positive pulse and to the other state on a negative pulse. (It will be recalled that a positive pulse denotes the beginning of a train of 1's and a negative pulse the beginning of a train of 0's). The voltage wave form at one plate of the reading flip-flop is shown in Figure 2c. When this voltage is fed to one grid and the clock pulses to the other grid of a gating tube, the gate output wave form is similar to that shown in Figure 2e. This type of reading circuit presents a serious difficulty, in that the instant at which the transition from one state to another occurs is dependent upon signal amplitude. This resulted in erratic operation of the circuit under certain conditions.

This circuit was abandoned, therefore, in favor of the more stable circuit shown in Figure 14. The distinguishing feature of this circuit is that the flip-flop transition takes place essentially at the instant of the signal voltage peak, rather than when the signal voltage rises past a certain threshold level. The operation of this circuit can be explained with the aid of the oscillograms of Figure 15. These show the wave forms at various points in Figure 14, correspondingly marked, for a typical signal.

It should be pointed out first that the wave form of the reading voltage signal shown in Figure 2b is not quite achieved in practice. Ideally, a series of like digits should produce no change in flux in the core, and therefore no induced voltage. Actually, however, the reproduced signal corresponding to a series of 0's or a series of 1's is generally found to contain a residual ripple voltage. This is due to the nature of the writing process, in which the digits are written individually into each cell. The ripple can be seen in the oscillogram of Figure 15e, which corresponds to the digital sequence :

0 1 1 1 1 1 1 0 0 0 0 1 0 1 0 1 0 1 0

The reading circuit must be able to distinguish between ripple, which it must not follow, and transition pulses, which it is expected to follow. The problem of discriminating between these two types of signal is complicated by the fact that the ripple is generally superimposed on the rising or falling portions of the transition pulses.

The signal (e) from the magnetic head is amplified and fed into a cathode follower phase inverter, resulting in the delivery of two signals, (h) and (l), of opposite phase, to channels I and II, respectively.

In each channel a biased diode permits transmission of only that portion of the signal which is more negative than a certain threshold level, resulting in signals (i) and

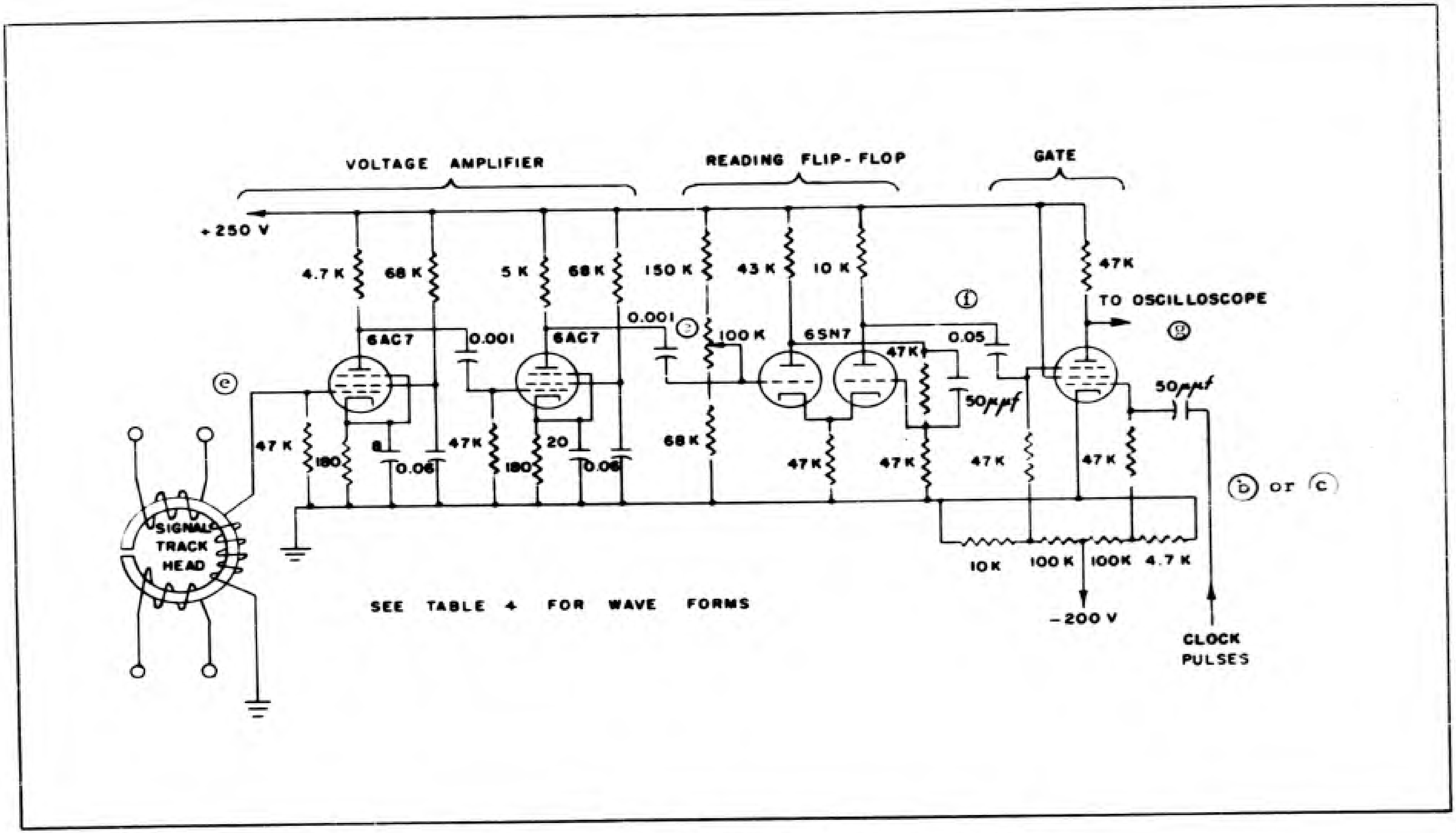


FIGURE 13 INITIAL READING CIRCUIT

1

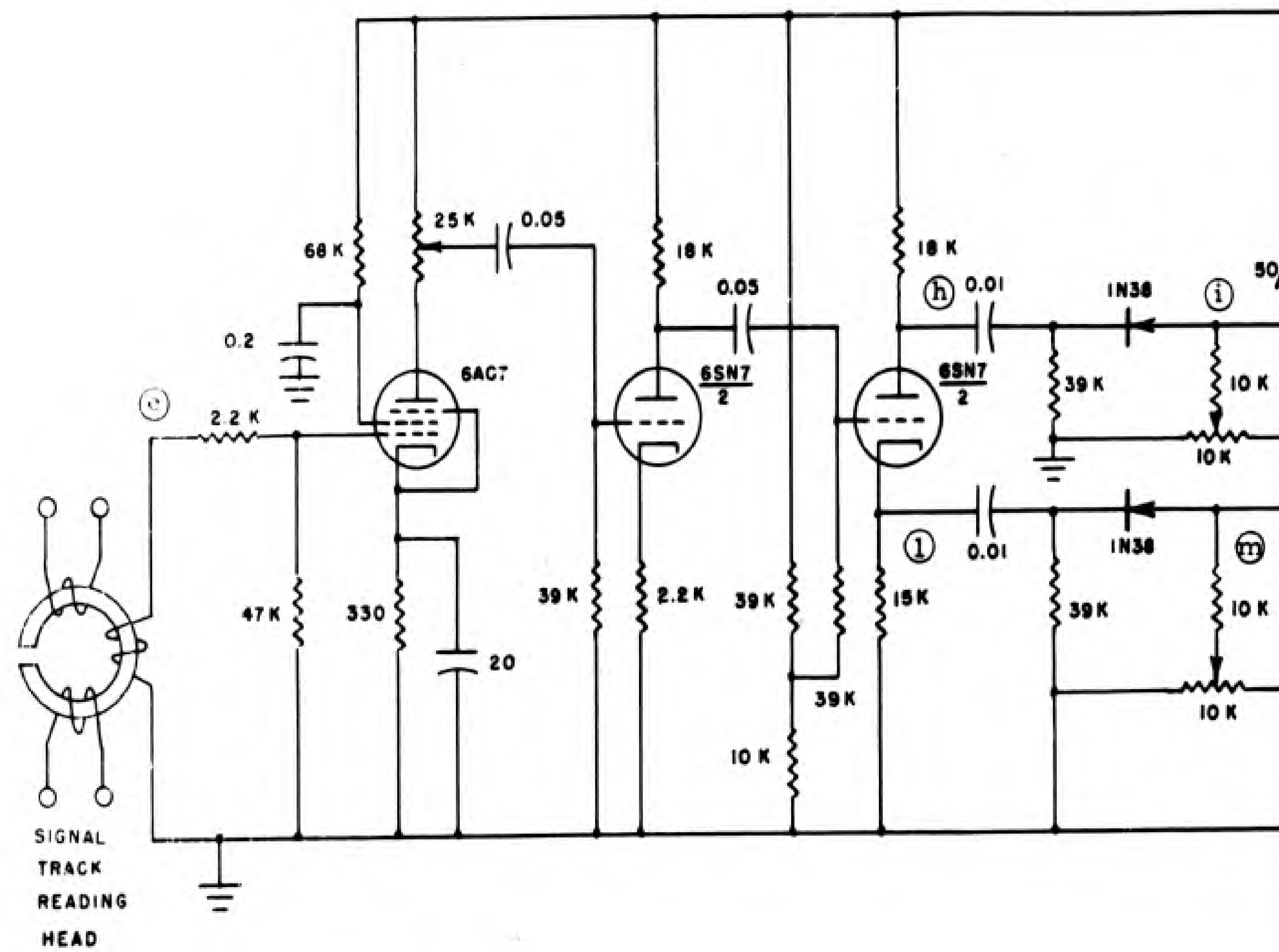
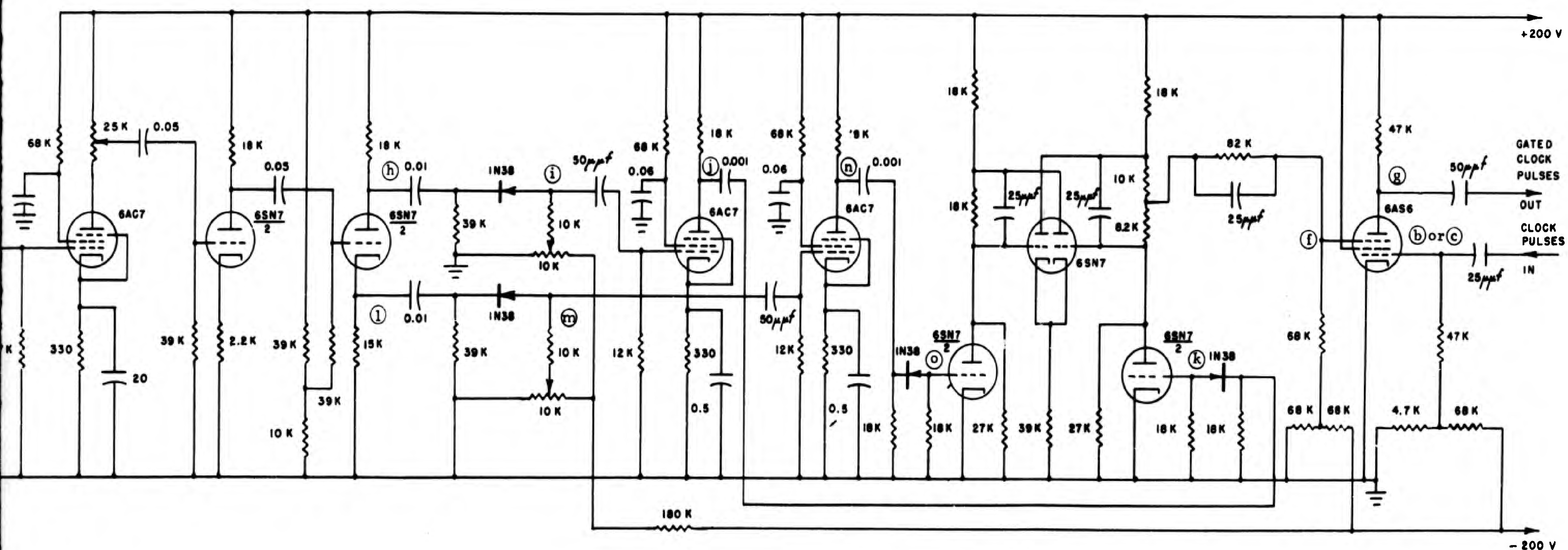


FIGURE 14 IMPROVED READING CIRCUIT

FIGURE 14 IMPROVED READING CIRCUIT



IMPROVED READING CIRCUIT

2

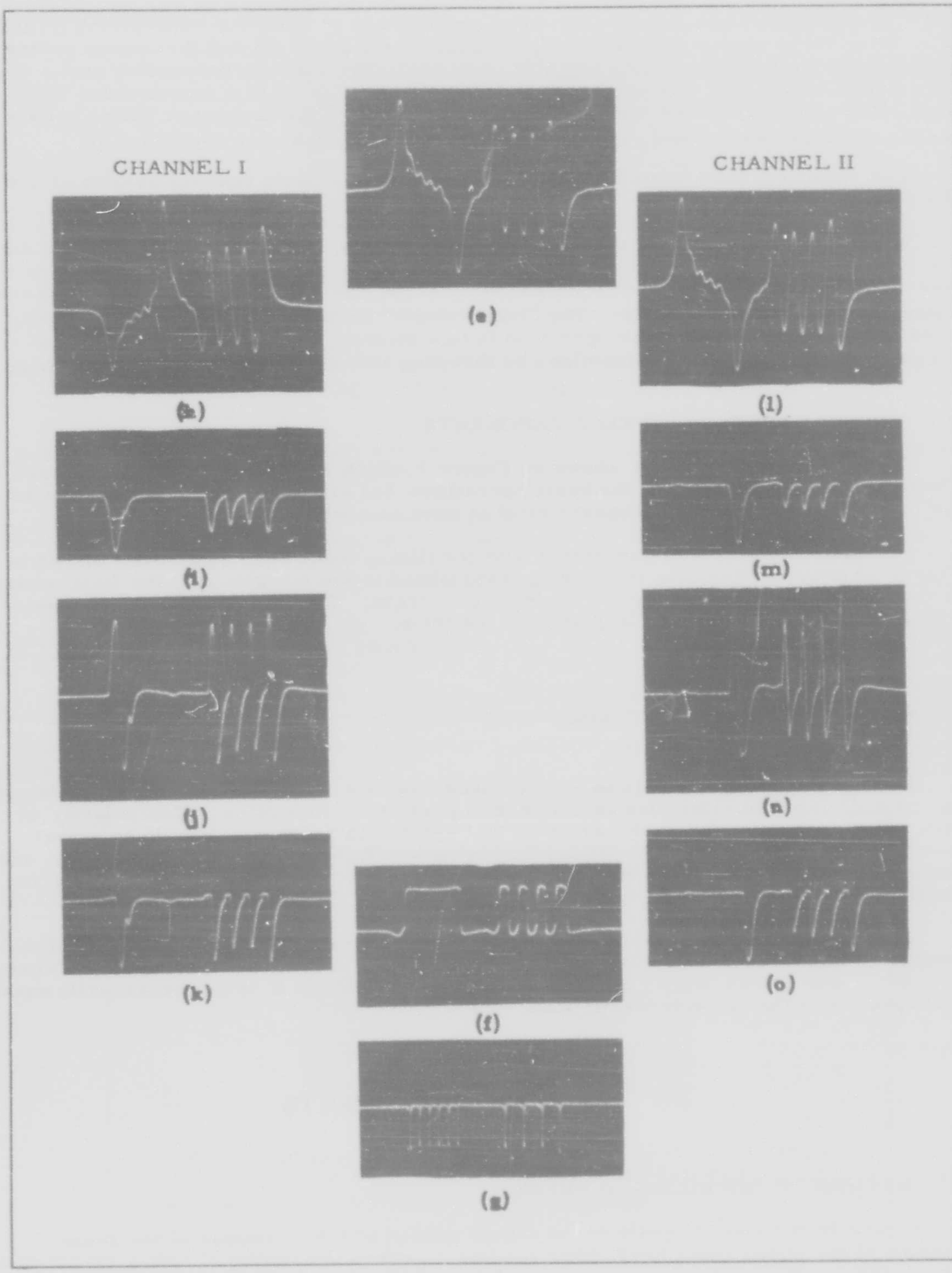


FIGURE 15 VOLTAGE WAVE FORMS IN IMPROVED READING CIRCUIT

(m). These signals are differentiated and amplified to produce the wave forms (j) and (n). When these signals are rectified, the resulting signals (k) and (o) contain pulses with steeply rising fronts which coincide very nearly with the corresponding peaks of the original signal (e). These pulses are fed to the two grids of a conventional flip-flop. The signal (f) at one plate of the flip-flop provides the necessary gating voltage for the clock pulses, as before. The final gated clock pulses are shown in (g).

The reading circuit described operated very satisfactorily and was used to obtain the data in this report.

In the memory system of a computer it is generally desired to select and read out the contents of a single cell at a time. For the purpose of the present investigation it was sufficient to be able to view on an oscilloscope the signal train representing the contents of a sequence of cells. The "train-single" switch in Figure 3 was normally used in the "train" position for operation in this manner. However, the contents of a single selected cell could be examined by throwing this switch to the "single" position.

2.7 MISCELLANEOUS SYSTEM COMPONENTS.

There are several items shown in Figure 3 which have not yet been explained. These are not fundamental to the basic operations, but are nevertheless necessary to the proper functioning of the experimental system as a whole.

For example, a circuit associated with the timing track reading circuit (shown in Figure 9) prevents anything from being transmitted to the counter until the first arrival of the "silent zone" preceding the timing signal train. This insures that the counter will start to count only at the beginning of the train.

2.8 MAGNETIC STATES OF TAPE.

In each of the experiments to be described, the tape was initially cleared, or wiped, by magnetizing it to saturation in a direction parallel to its motion. The polarity of this initial magnetization is the same as that adopted to represent 0. In an actual computer storage system, this wiping operation would be performed only initially, and would not be part of the normal operation of the system. Thereafter, all changes in magnetic state would result solely from the writing of 0's or 1's on the tape.

The operation of writing a 0 into a cell leaves the magnetic induction, B, of the section of tape occupied by the cell at a value near the initial, or wiped, level. Writing a 1 into a cell leaves B at a different value. This value of B is not necessarily equal and opposite to the value corresponding to a 0.

3.0 EXPERIMENTAL RESULTS

3.1 NATURE OF REPRODUCED PULSE.

Figure 16 is an oscillogram of the signal voltage at the terminals of the reading winding of the signal track head, when reading a pattern consisting of only a single pulse. The current pulse used to record this pattern was similar in shape to the one shown in Figure 12. The amplitude of the writing pulse was 50 ampere-turns and its duration 1

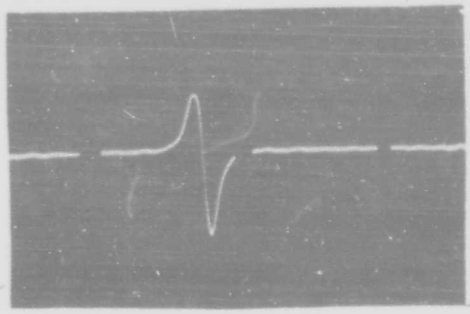


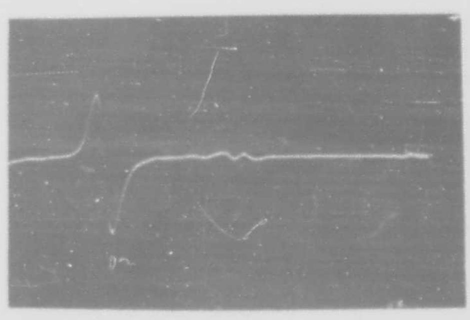
FIGURE 16 OSCILLOGRAM OF SIGNAL HEAD OUTPUT : DETAIL OF SINGLE PULSE SIGNAL

microsecond. The 7-mil head was used in this test. The tape speed for writing and reading was 1000 inches per second.

The dark timing spots in the oscillogram are 100 microseconds apart. The peak-to-peak amplitude of this signal is 60 millivolts. The duration of the single signal is about 30 microseconds, during which time the tape moves 0.030 inch. It will be demonstrated, however, that the minimum spacing between successive cells is by no means limited to this value.

3.2 EFFECT OF SINGLE ALTERATION.

Figure 17 is an oscillogram illustrating the order of magnitude of residual signal remaining when a single pulse, representing a 1, is first recorded and then selectively erased by imprinting at the same position a pulse of opposite magnetic polarity ; i.e., the 1 is changed to a 0.



THIS OSCILLOGRAM ILLUSTRATES THE EFFECTIVENESS OF SELECTIVE ERASURE. THE PROMINENT SIGNAL TO THE LEFT IS A 1, AND THE SMALL WAVER TO THE RIGHT IS THE RESIDUAL SIGNAL REMAINING AFTER A 1 IS SELECTIVELY ERASED.

FIGURE 17 OSCILLOGRAM OF THE EFFECT OF SINGLE ALTERATION

The oscillogram was made as follows. First, the signal track was wiped with the aid of a properly oriented permanent magnet. Then a 1 was written into each of two cells in the manner previously described. These operations were performed with a drum surface speed of 1000 inches per second (with all other operating conditions the same as in Section 3.1). The two marks were ten cells apart; i.e., spaced 0.100 inch or 100 microseconds apart. Then a 0 was written into the second cell. This recorded pattern was played back, producing the signal of Figure 17.

The prominent signal to the left is the unerased 1, and the small waver in the base line to the right is the residual signal due to the selectively erased 1. The selective erasure operation is seen to have reduced the signal amplitude to about 6 per cent of its previous value.

3.3 EFFECT OF REPEATED ALTERATIONS.

In the course of operation of a computer storage system, the element of tape occupied by each cell may experience many changes in magnetic state. It is desirable, therefore, to know how a recorded pattern occupying a given section of tape may be influenced by the previous history of that section of tape. A specific question is whether the operation of writing the same digit many times successively into a given cell will affect the behavior of that cell and its neighbors in subsequent patterns.

An experiment was devised to test this point. An initial pattern was prepared by first writing a series of seventeen adjacent 1's and then changing the right hand eight digits to 0's. The resulting signal is shown in Figure 18a. Then the fifth 1 and the fourth 0 in the pattern were rewritten 25 additional times. The result is shown in Figure 18b. A small change in the signal can be noted. This change was observed to occur after the first rewriting operation; no further change was noted on the 24 subsequent writings. Finally, the 1's were changed to 0's and the 0's changed to 1's, resulting in the signal shown in Figure 18c.

The effect of the previous treatment of the tape on the character of the final signal is not observable.

3.4 EFFECT OF WRITING CURRENT ON AMPLITUDE OF REPRODUCED SIGNAL.

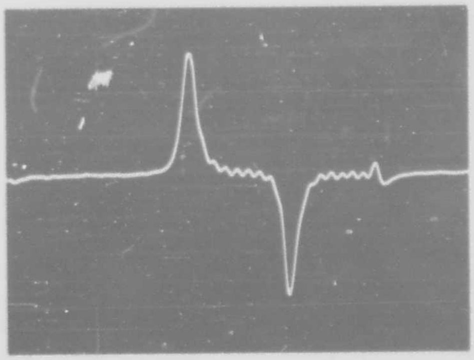
As the amplitude of the writing current pulse is increased, the reading voltage amplitude due to this recorded signal may also be expected to increase, until a value of current is reached at which either the core or the tape begins to saturate. In order to examine the saturation phenomena taking place, the following experiment was performed. With the tape stationary, a single 1-pulse was written with direct current; i.e., the current was raised manually to a specified peak value and then reduced to zero. Then the tape was run at 1400 inches per second and the amplitude of the signal voltage observed. Reading and writing were done with the same magnetic head, and at the same tape-to-head spacing. Data were taken over a current range of 0 to 600 ma DC. The procedure was repeated for the 3-mil and the 7-mil heads, each at two tape-to-head spacings. The results are plotted in Figure 19.

It is seen that the signal amplitude saturates at nearly the same value of writing current in all four cases. The fact that the saturation current is somewhat independent of tape-to-head spacing indicates that magnetic saturation of the core, rather than of the tape, is the dominant factor.

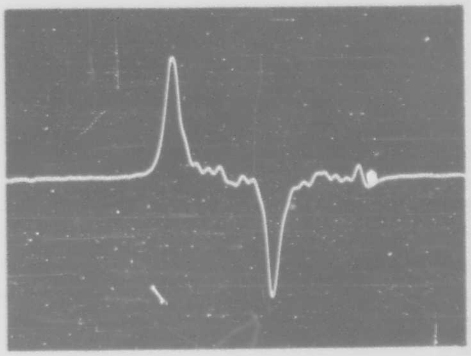
3.5 EFFECT OF WRITING PULSE DURATION ON SIGNAL AMPLITUDE.

For a given peak writing current in a given magnetic head, the reproduced signal may be expected, because of eddy current effects, to drop off in amplitude as the duration of the half sine wave writing pulse is made shorter. The effect of writing pulse

(a) 11111111 11111111 WRITTEN
AND ALTERED TO
11111 1111 0000 0000



(b) 1 and 0 WRITTEN
25 TIMES EACH



(c) SIGNAL ALTERED
TO 000000000 11111111

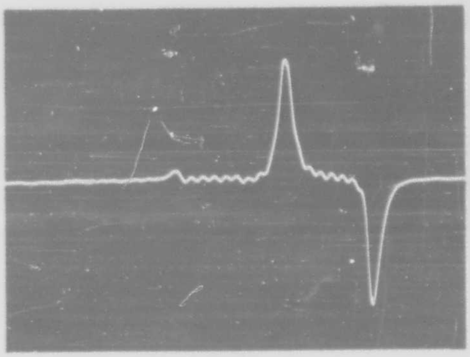


FIGURE 18 EFFECT OF REPEATED ALTERATIONS ON THE MAGNETIC HEAD READING SIGNAL

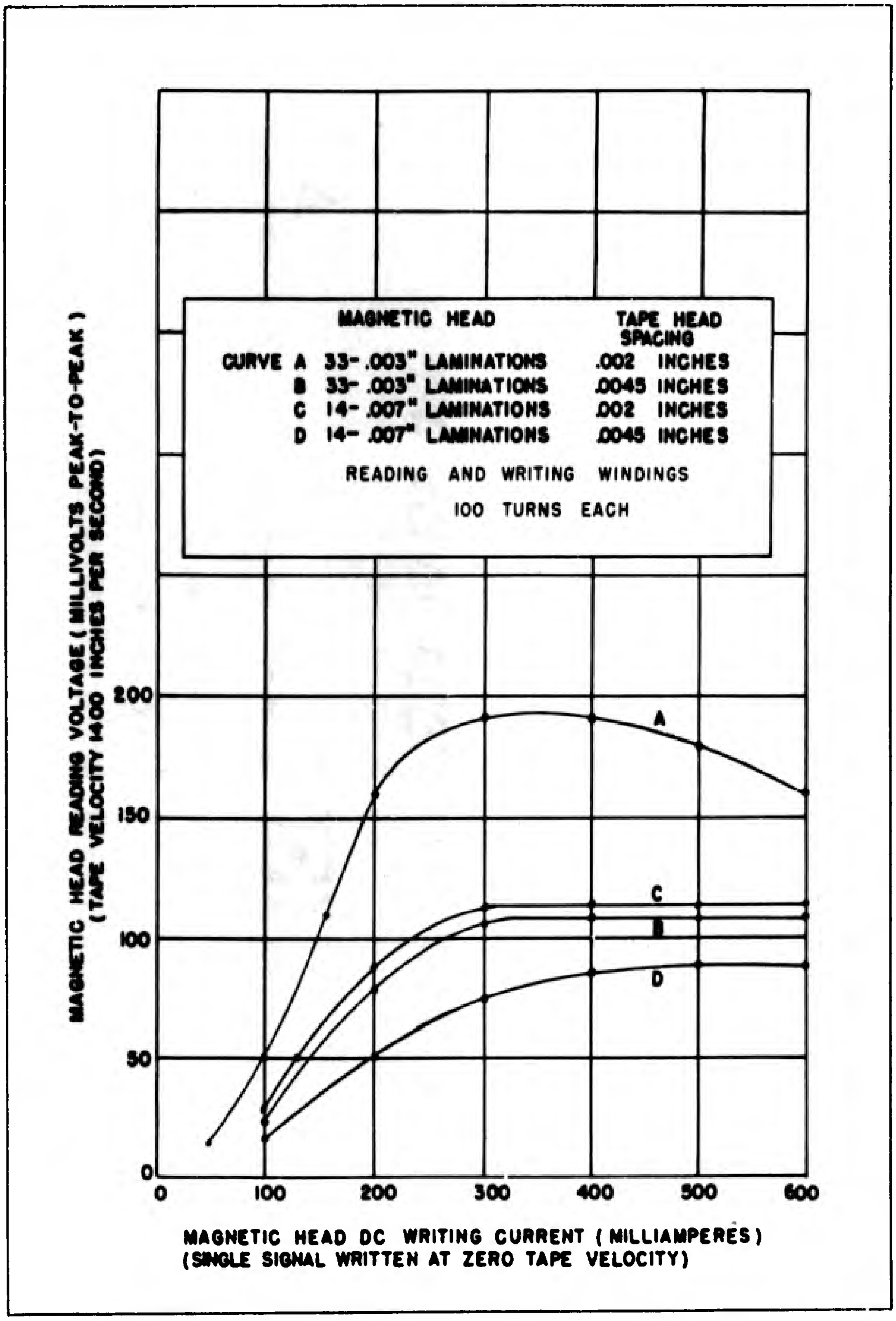


FIGURE 19 EFFECT OF WRITING CURRENT MAGNITUDE

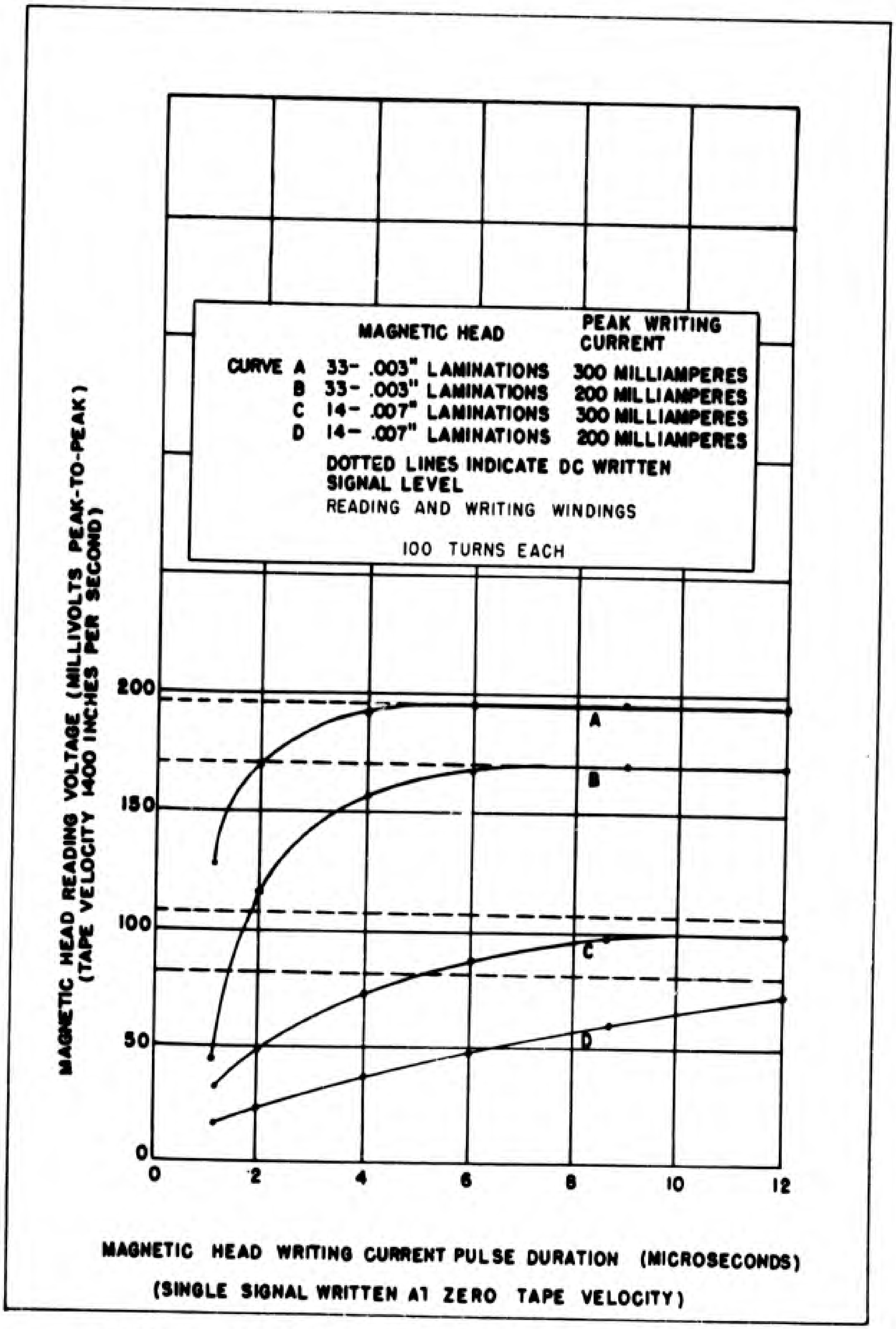


FIGURE 20 EFFECT OF WRITING CURRENT PULSE DURATION

duration on the amplitude of a single pulse signal is demonstrated in Figure 20. Curves are shown for the 3-mil and 7-mil heads, at two values of peak writing current. In each case, reading and writing were done with the same head.

The reproduced signal amplitude for a pulse written with direct current is represented by a dotted line for each of the four cases. It is seen that for pulse durations of 6 microseconds and longer with the 3-mil head the amplitude is the same as for a DC writing pulse. With the 7-mil head, however, this level is not reached until the pulse is made somewhat longer than 12 microseconds. The effectiveness of the thinner laminations in suppressing eddy current effects is apparent.

3.6 EFFECT OF WRITING PULSE PARAMETERS ON REPRESENTATIVE SIGNALS.

For each value of linear cell density, it is important to know the optimum values of writing current pulse duration and amplitude. The writing pulse parameters influence the characteristics of the reproduced signal, and their careful choice is of considerable importance in determining the maximum practical cell density attainable with a given set of components.

The quality of reproduced signal may be judged by several criteria. The transition pulses must be adequately large and clearly resolved. The ripple amplitude must be sufficiently small relative to these so that the reading circuit may easily discriminate between signal and ripple. The time interval between successive transition pulse peaks must be sufficiently accurate to gate correctly the appropriate number of clock pulses.

With these considerations in mind, an experiment was devised to study the characteristics of certain representative signals as a function of the writing pulse parameters, for several values of linear cell density.

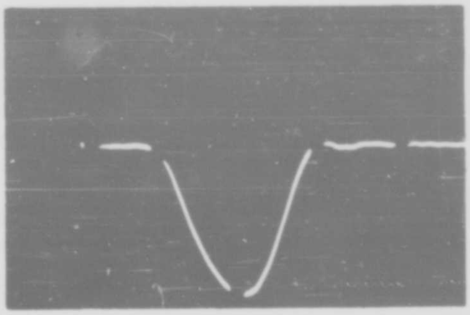
For each fixed set of conditions, the experimental procedure was as follows. First the tape was wiped to saturation in the usual manner. A single 1-pulse (Figure 21b) was written, and the amplitude V_B of the corresponding signal measured. (For purpose of comparison, the peak value from the base line was measured, rather than the peak-to-peak value). The time interval T_B between the positive and negative peaks was also measured. This time interval determines the length of the rectangular gating signal from the reading flip-flop, for the case of a 1 preceded and followed by 0's. This "unit gate" must be of suitable length to gate the passage of one and only one clock pulse. Its optimum value is one cell period. The greater the departure from the optimum, the more critical the clock pulse phasing becomes.

The written pattern was then altered to a series of eleven 1's, by writing 1's into the next ten cells. The reproduced signal, showing ripple, appears in Figure 21c. The peak ripple voltage V_C was measured, by definition, from the base line to the largest peak, whether positive or negative, in the ripple. Peaks were taken for this purpose as points of zero slope.

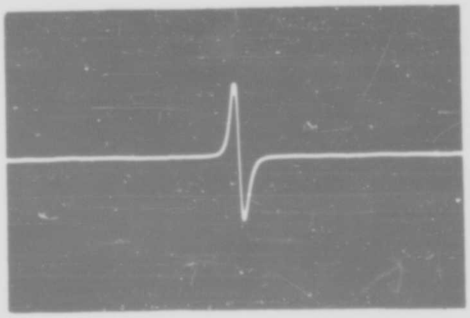
The pattern was then altered to 101010 ... by writing 0 into every second cell. The resulting signal is shown in Figure 21d. The amplitude V_D of the smallest peak in this signal was measured, taken again from the base line. If a negative peak was observed to remain wholly on the positive side of the base line, this value was recorded with negative sign.

Finally, the remaining 1's in the pattern were changed to 0's, leaving the ripple voltage shown in Figure 21e. The peak ripple voltage V_E was measured in the same manner as V_C.

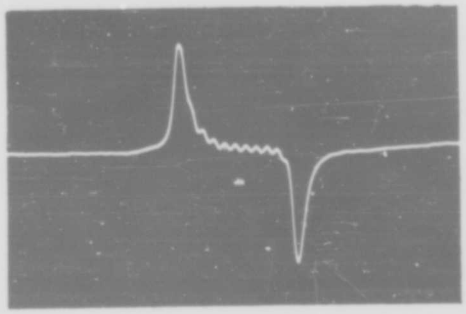
These signals were chosen for measurement because it was felt that they contribute significant information for evaluating signal quality in terms of the criteria outlined



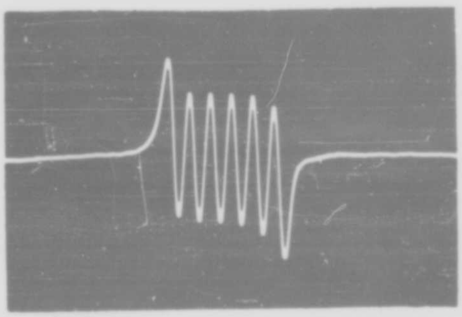
(a) Writing current pulse



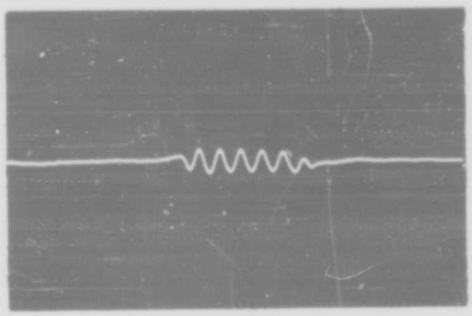
(b) Single 1 signal *



(c) 11111111111 Signal *



(d) 101010101010 Signal *



(e) Ripple resulting from alteration of (d) to 0's *

* The recorded patterns are preceded and followed by "wiped" tape, equivalent to trains of idealized 0's.

FIGURE 21 REPRESENTATIVE SIGNALS USED IN COMPARING WRITING PULSE PARAMETERS above. The 101010... signal of Figure 21d contains the smallest and most rapidly recurring transition pulses, or voltage peaks of the kind that the reading circuit must follow.

The ripple voltages in Figures 21c and 21e are examples of two quite different kinds of ripple. The former is characteristic of the ripple due to a series of 1's. The main component of ripple frequency is equal to the cell repetition frequency. This is observed to be the case regardless of the pattern previously written in the same section and regardless of the order in which the 1's are entered. However, in the case of a series of 0's, the appearance of the ripple is observed to be somewhat dependent on the previous pattern and on the order of entry. For example, if a series of 1's is changed to a series of 0's by altering each cell in consecutive order, the resulting ripple is similar to that generated by a series of 1's; i.e., ripple frequency is equal to cell frequency. But, if the change is made by first altering every second 1 to 0, and then altering the remaining 1's, the frequency of the resulting ripple is found to be half the cell frequency. This kind of ripple is shown in Figure 21e. The difference in hysteretic behavior of 1's and 0's is evidence of asymmetry between the magnetic states used to represent 1's and 0's on the tape.

This test was performed with the 3-mil head spaced 0.002 inch from the tape and at a tape velocity of 1400 inches per second, which was the maximum speed attainable with the available equipment. The results are tabulated in Tables 1, 2, and 3, for densities of 100, 150, 200 cells per inch, respectively.

At a density of 100 cells per inch, the signal-to-ripple ratio reaches a maximum value of 4.0, for a writing pulse of 8 microseconds duration and 200 milliamperes peak value. The single 1 signal is relatively large under these conditions. The unit gate length T_B is just a little greater than the cell period, which is quite satisfactory.

At 150 cells per inch, the signal-to-ripple ratio reaches a maximum value of 3.3, for a 1-microsecond, 350-milliampere writing pulse. The corresponding unit gate length is 5.5 microseconds, which exceeds the cell period by about 0.7 microsecond.

At 200 cells per inch, the signal-to-ripple ratio fails to rise above unity, and the reading circuit therefore cannot distinguish between signal and ripple. Data are shown only for a 1-microsecond writing pulse. If the pulse length were made shorter, the signal amplitude would become still smaller, as was shown in Section 3.4. If the pulse were made longer, the unit gate length would become far too great for the 3.5-microsecond cell period. This may be seen from the tabulated values of T_B in Table 2, since T_B is obviously independent of cell density.

Over the range of parameters studied, the amplitude of the smallest transition pulse is at best only about three or four times that of the largest encountered ripple peak. The ripple is mainly the result of altering digits individually, rather than of the NRZ representation. There is one component of the ripple, however, which is characteristic of NRZ. This is the ripple shown in Figure 21c. Its frequency is twice the maximum signal frequency, and might therefore be filtered out. It is seen from Tables 1 and 2 that such a filtering operation would significantly improve the signal-to-ripple ratio in some cases. For example, in Table 1, if it assumed that V_C can always be made smaller than V_E, the ratio becomes 6.4 for the 6-microsecond 200-milliampere pulse.

Figure 22 illustrates the appearance of the reproduced signal due to the same digital pattern at three values of cell density, with typical values of the writing pulse parameters. The digital sequence is:

0 0 0 0 0 0 0 0 1 0 1 0 1 0 1 0 0 0 0 1 1 1 1 1 1

3- MIL HEAD — DENSITY 100 CELLS PER INCH

TAPE VELOCITY 1400 INCHES PER SECOND. — CELL PERIOD 7.0 MICROSECONDS

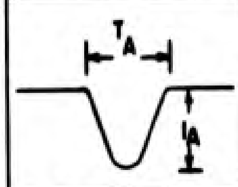
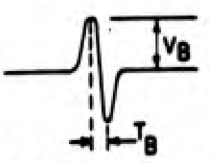
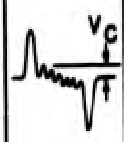
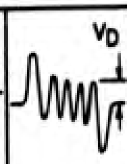
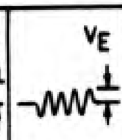
WRITING CURRENT PULSE		MAGNETIC HEAD OUTPUT SIGNALS					
							RATIO OF MINIMUM SIGNAL TO MAXIMUM RIPPLE
T_A MICRO-SECONDS	I_A MILLI-AMPERES	T_B MICRO-SECONDS	V_B MILLI-VOLTS	V_C MILLI-VOLTS	V_D MILLI-VOLTS	V_E MILLI-VOLTS	
1	400 350 250	6.5 5.5 5.0	72 60 33	25 24 17	52 50 23	9 9 5	2.1 2.1 1.3
4	400 350 250 200	10.0 9.5 7.5 6.0	85 80 76 63	13 8 23 31	43 36 52 50	17 16 9 7	2.5 2.2 2.3 1.6
6	250 200 150	8.0 7.5 7.0	80 70 50	16 14 30	47 45 30	12 7 8	2.9 3.2 1.0
8	250 200 150 100	9.5 8.0 7.5 7.0	85 80 60 20	0 12 12 14	34 48 42 16	15 10 9 6	2.3 4.0 3.5 1.2
10	200 150	9.0 7.5	80 65	8 13	40 45	12 10	3.3 3.5
12	200	10.0	85	10	34	16	2.1

TABLE 1 EFFECT OF WRITING CURRENT ON SIGNIFICANT SIGNALS AT A DENSITY OF 100 CELLS PER INCH

3- MIL HEAD

DENSITY 150 CELLS PER INCH

TAPE VELOCITY 1400 INCHES PER SECOND. CELL PERIOD 4.8 MICROSECONDS

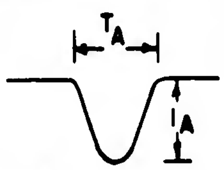
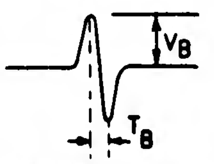
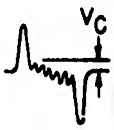
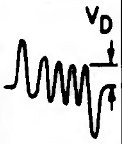
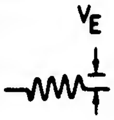
WRITING CURRENT PULSE		MAGNETIC HEAD OUTPUT SIGNALS					
							RATIO OF MINIMUM SIGNAL TO MAXIMUM RIPPLE
T_A MICRO-SECONDS	I_A MILLI-AMPERES	T_B MICRO-SECONDS	V_B MILLI-VOLTS	V_C MILLI-VOLTS	V_D MILLI-VOLTS	V_E MILLI-VOLTS	
1	400	6.5	72	7	15	9.5	1.6
	350	5.5	60	7	23	6.5	3.3
	250	5.0	30	10	18	5.0	1.8
	200	4.5	12	9	8	4.5	0.9
2	350	8.5	80	0	-4	12.0	-0.3
	250	7.0	65	7	10	8.0	1.3
	200	6.5	45	5	14	4.5	2.8
3	200	7.0	65	9	10	6.5	1.4

TABLE 2 EFFECT OF WRITING CURRENT ON SIGNIFICANT SIGNALS AT A DENSITY OF 150 CELLS PER INCH

3- MIL HEAD DENSITY 200 CELLS PER INCH

TAPE VELOCITY 1400 INCHES PER SECOND. CELL PERIOD 3.5 MICROSECONDS

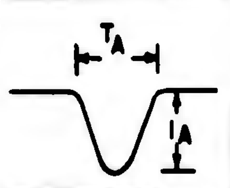
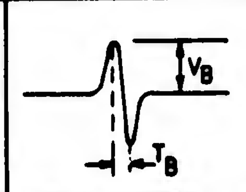
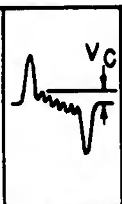
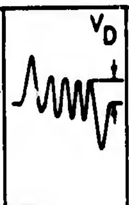
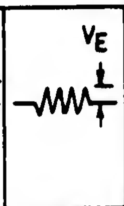
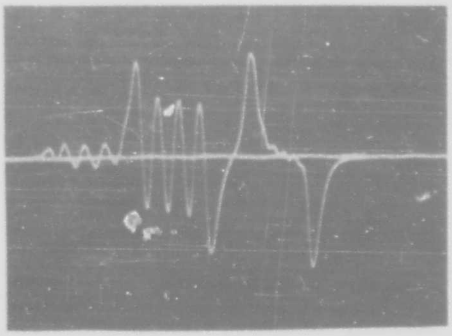
WRITING CURRENT PULSE		MAGNETIC HEAD OUTPUT SIGNALS					RATIO OF MINIMUM SIGNAL TO MAXIMUM RIPPLE
							
T_A MICRO-SECONDS	I_A MILLI-AMPERES	T_B MICRO-SECONDS	V_B MILLI-VOLTS	V_C MILLI-VOLTS	V_D MILLI-VOLTS	V_E MILLI-VOLTS	
1	400	6.5	72	0	-18	7.5	-2.4
	350	5.5	60	0	-12	7.5	-1.6
	250	5.0	30	0	3.0	6.0	0.5
	200	4.5	12	0	1.3	3.3	0.25

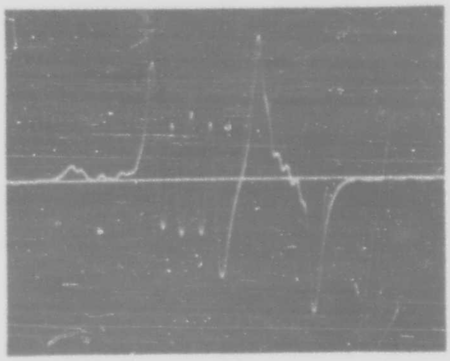
TABLE 3 EFFECT OF WRITING CURRENT ON SIGNIFICANT SIGNALS AT A DENSITY OF 200 CELLS PER INCH

If a given recorded pattern is played back at several different tape velocities, any changes in resolution which occur can be attributed to the frequency response characteristics of the magnetic core, reading winding, and reading circuit. Figure 23 shows signals obtained when a pattern of alternate 1's and 0's is played back at four different tape velocities. The density is 200 cells per inch. Although the resolution is seen to improve somewhat as velocity is decreased, it is still very unsatisfactory at 400 inches per second. Below this velocity, the 101010... signal at 200 cells per inch becomes too small for practical use. There is therefore little object in seeking to resolve 200 cells per inch by repeating the observations of Table 3 at lower tape velocities.

(a) 100 CELLS PER INCH.
SIGNAL WRITTEN WITH
6 μ SEC., 250 MILLIAMPERE
WRITING CURRENT PULSE



(b) 150 CELLS PER INCH.
SIGNAL WRITTEN WITH
1 μ SEC., 250 MILLIAMPERE
WRITING CURRENT PULSE



(c) 200 CELLS PER INCH.
SIGNAL WRITTEN WITH
1 μ SEC., 350 MILLIAMPERE
WRITING CURRENT PULSE

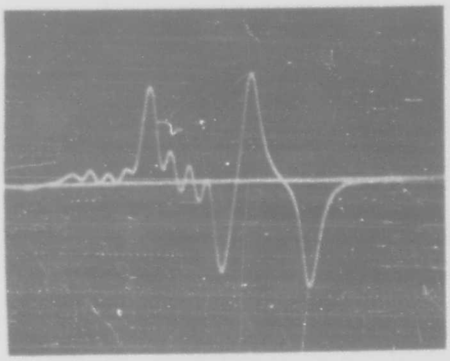


FIGURE 22 0000000010101010000111111 MAGNETIC HEAD READING SIGNAL (TAPE VELOCITY 1400 INCHES PER SECOND FOR READING AND WRITING)

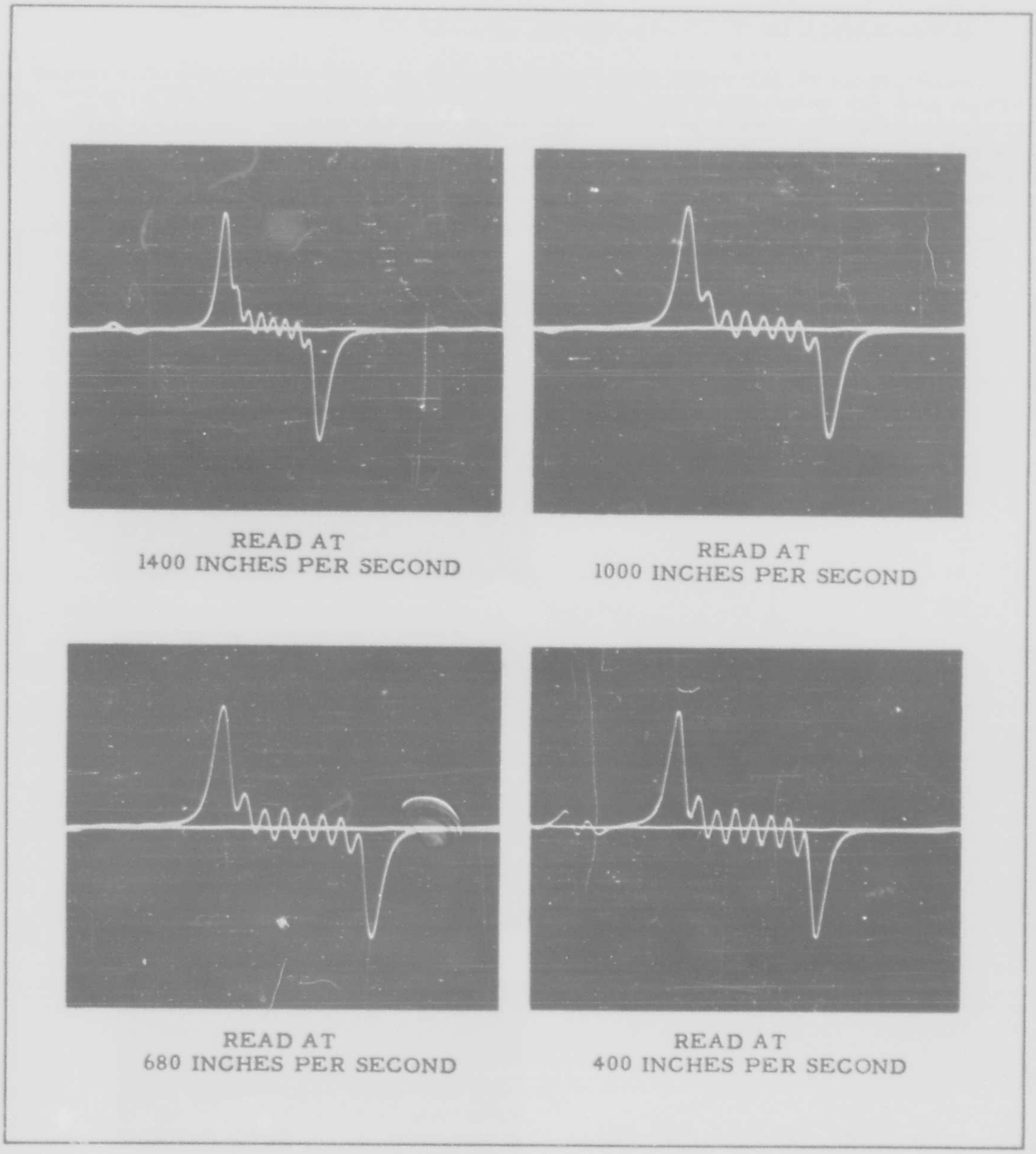


FIGURE 23 EFFECT OF TAPE VELOCITY ON RESOLUTION OF MAGNETIC HEAD READING VOLTAGE

(1010101010101010 PATTERN, 200 CELLS PER INCH, WRITTEN AT 1400 INCHES PER SECOND)

3.7 APPEARANCE OF TYPICAL SIGNAL PATTERNS.

Oscillograms of (a) magnetic head output voltage, (b) reading flip-flop output voltage, and (c) gated clock pulses are shown in Figures 24, 25, and 26 for three typical signal patterns. These patterns were recorded and read with the 3-mil head at a tape velocity of 1400 inches per second and a density of 150 cells per inch, corresponding to a scanning rate of 210,000 digits per second. A 1-microsecond, 250-milliampere current pulse was used in writing.

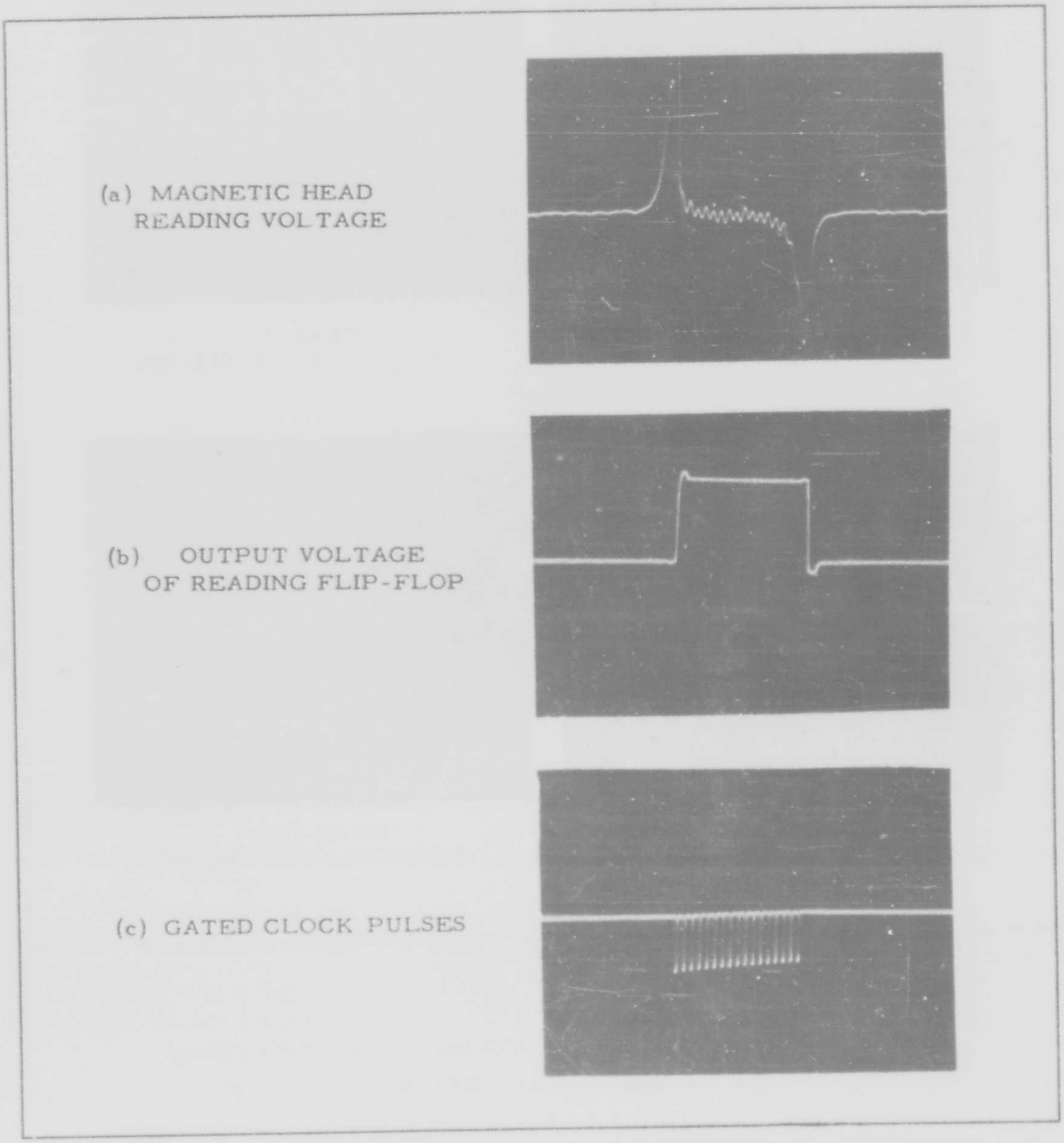


FIGURE 24 TEST PATTERN 1111111111111111
150 CELLS PER INCH

The pattern of Figure 24 corresponds to a train of 17 successive 1's. Figure 25 may be considered by halves. The first half is a train of 1's with a 0 in the middle; the second half is a train of 0's with a 1 in the middle. Figure 26 is a sequence of alternate 1's and 0's, preceded and followed by short trains of 1's.

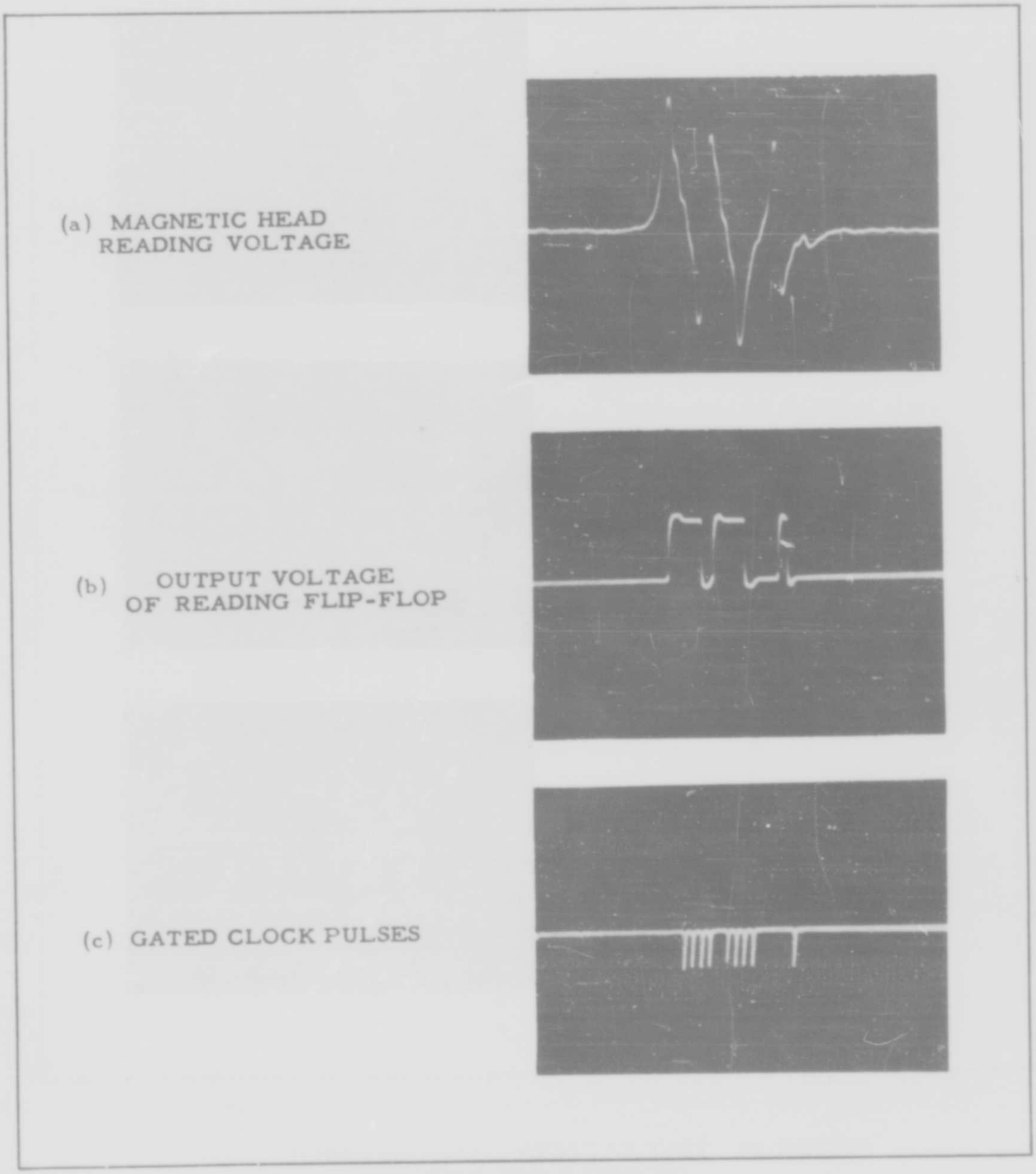
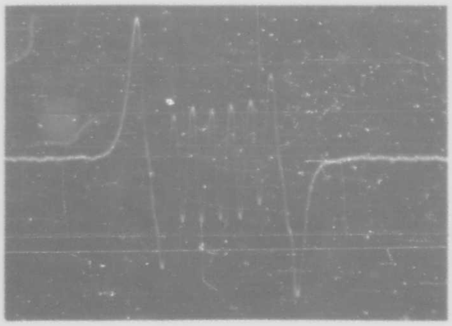
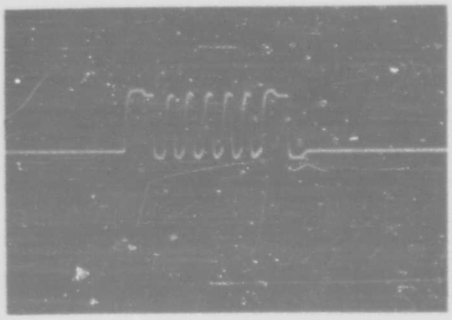


FIGURE 25 TEST PATTERN 11110111100001000
150 CELLS PER INCH

(a) MAGNETIC HEAD READING VOLTAGE



(b) OUTPUT VOLTAGE OF READING FLIP-FLOP



(c) GATED CLOCK PULSES

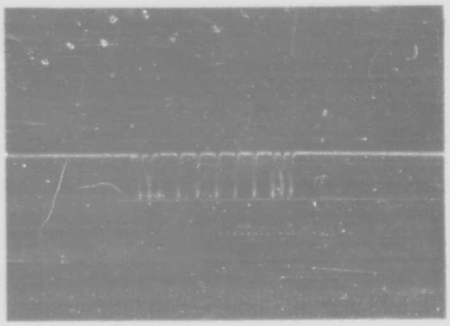


FIGURE 26 TEST PATTERN 11101010101010111
150 CELLS PER INCH

4.0 CONCLUSIONS

This investigation has demonstrated that individual digits may be selectively altered in a magnetic drum storage system operating at high digital densities and rapid scanning rates. The experimental system performed satisfactorily with recorded magnetic pattern containing 150 digits per linear inch at a surface speed of 1400 inches per second, corresponding to a scanning rate of 210,000 digits per second. High densities and scanning rates were achieved through representation of digit sequences in each track by the non-return-to-zero form of magnetic pattern.

Although the experimental system exhibited gratifying stability and operated very satisfactorily for long periods, it is recognized that additional development will be necessary before these techniques can be applied with the proper degree of conservatism to a practical computer. The chief item requiring improvement is the signal-to-ripple ratio.

This experimental work was performed with a given set of physical components, in order to study the properties of certain storage techniques. It is expected that the resolution and the scanning rate will be improved through detailed experimental studies of such factors as the geometry of the head and the material of which it is made.

Finally, there are two limitations of NRZ which should be pointed out. First, since each reading flip-flop and the amplifier stages which precede it must follow the digital pattern continuously, one reading circuit cannot be shared, through switching means, by several tracks. Second, when a digit is written by a magnetic head, the reading circuit which operates from the same head loses the sense of the pattern which it has been following, until after a transition pulse of either sign has again occurred. Suitable means must therefore be provided to disable the reading circuit output until a transition pulse (perhaps permanently recorded) occurs.

APPENDIX I

SIMPLIFIED WRITING AND READING CIRCUITS.

While the writing and reading circuits of Figures 11 and 14 are entirely satisfactory as laboratory tools for investigating magnetic recording techniques, they obviously contain too many tubes for use in a practical computer, where such circuits may have to appear in multiple. A writing circuit and a reading circuit capable of comparable performance, but containing fewer tubes, were therefore devised.

The simplified writing circuit is shown in Figure 27. The only tubes in this circuit are two 2D21 thyratrons. Each of the thyratrons serves to discharge a pulse-forming network, as before, except that the writing winding of the magnetic head is now contained directly in the series RLC network. One thyratron is fired to write a 1, the other to write a 0. The thyratrons are fired by impressing the pulse from the locator circuit on the control grids of both tubes. One of the thyratrons must be prevented from firing. This is done by applying to its shield grid a negative voltage which is derived in the present apparatus from the flip-flop shown in Figure 27. (This flip-flop is not regarded as part of the writing circuit, however. In a parallel channel computer, its function would be performed by a flip-flop in the storage register.)

The 3-mil head used in conjunction with the simplified circuits is described in Section 2.2. The writing winding is divided into two 10-turn sections, one for each thyratron circuit. Half sine wave current pulses of 0.5 to 6 microseconds duration and up to 5 amperes in amplitude (50 ampere-turns) are readily obtainable with this circuit by suitable choice of inductance and capacitance. A 1-microsecond, 2.5-ampere pulse is obtained with L = 38.0 microhenries and C = 0.0026 microfarad.

The simplified reading circuit is shown in Figure 28. This is similar functionally to the non-amplitude-sensitive reading circuit of Figure 14. It differs from the previous circuit in two ways. First, there is less overall amplification of signal. Second, the two-input flip-flop is replaced by a single-input, two-threshold trigger circuit. As a result of these simplifications, this circuit does not accept as wide a range of signal amplitudes. This limits its flexibility for laboratory purposes. However, it appears to operate very reliably under fixed operating conditions.

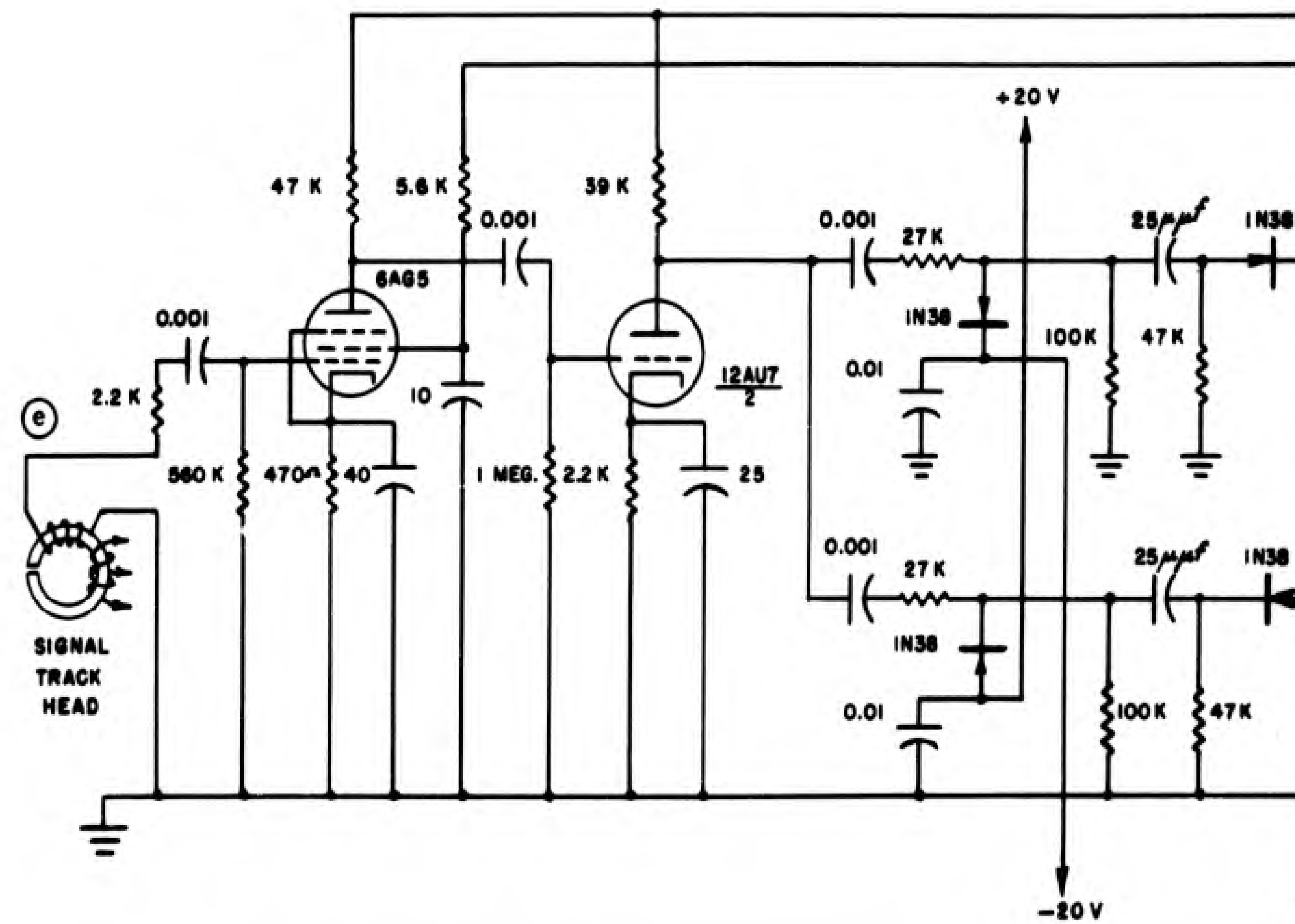
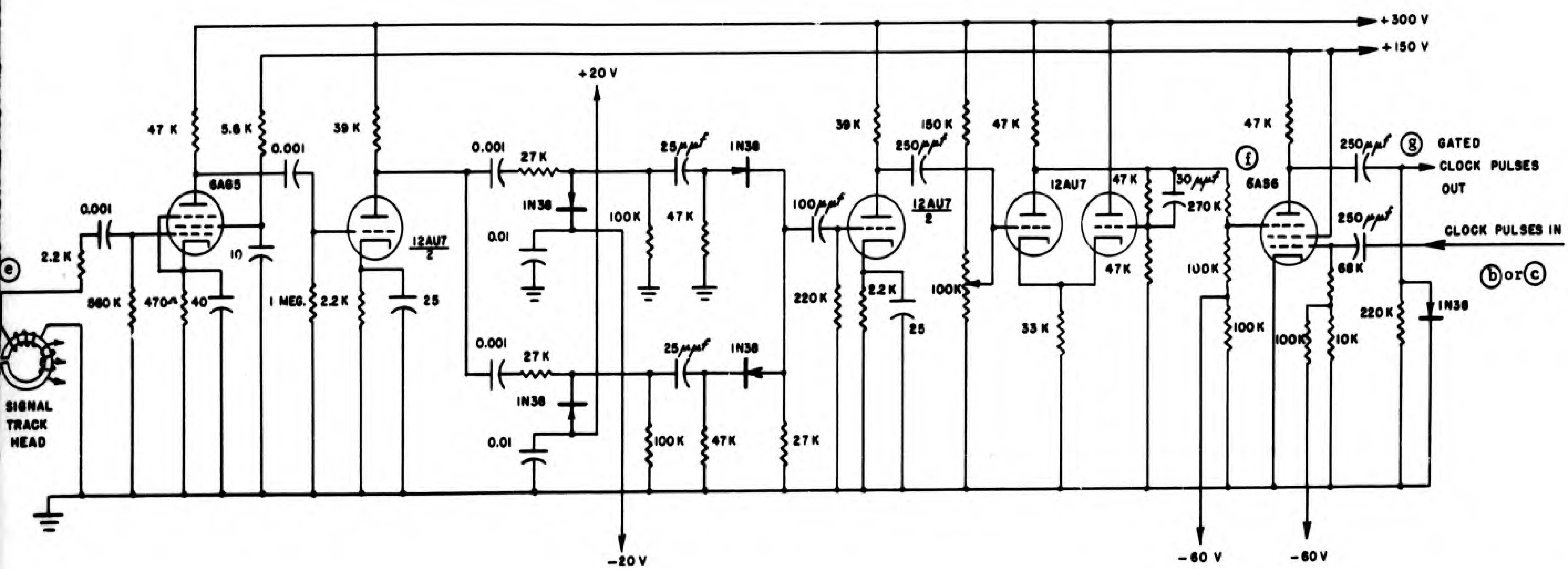


FIGURE 28 SIMPLIFIED READING CIRCUIT

FIGURE 28 SIMPLIFIED READING CIRCUIT



2

MPLIFIED READING CIRCUIT

APPENDIX 2

WAVE FORM DESIGNATION	SHOWN IN THESE FIGURES
(a) Timing track head signal voltage	Figure 8a
(b) Clock pulse train	Figures 2d, 8b
(c) Single selected cell pulse from counter	No oscillogram shown
(d) Writing current pulse	Figures 12 and 21a
(e) Output voltage of signal track head	Figures 2b, 15e, 16, 17, 18a, 18b, 18c, 21b, 21c, 21d, 21e, 22a, 22b, 22c, 23, 24a, 25a, and 26a.
(f) Reading flip-flop output voltage	Figures 2c, 15f, 24b, 25b, and 26b.
(g) Gated clock pulses	Figures 2e, 15g, 24c, 25c, and 26c.

TABLE 4 INDEX TO WAVE FORMS INDICATED IN FIGURES 3, 9, 10, 11, 13, 14, 27, and 28.