

Report R-219

ELECTRONIC SELECTION AND CONTROL OF
READ-RECORD HEADS OF MAGNETIC-TAPE UNITS

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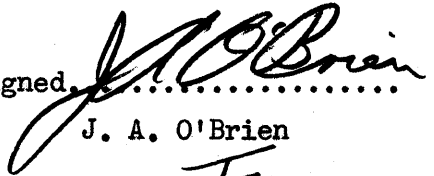
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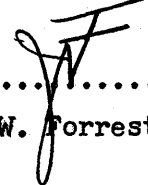
FOREWORD

When several magnetic-tape units are used for the storage of binary information in conjunction with a digital computer, it is necessary to include switching equipment to select a particular unit and mode of operation as specified by the computer at a certain time. It is sometimes desirable, in order to achieve high-speed operation, that the switch be electronic rather than electro-mechanical and further that the switching be done at the read-record heads of the tape units so as to allow one set of reading and recording circuits to serve all units.

Because the design of such a switching circuit is of wide interest, this thesis report, which has had only limited distribution, is being issued as a Project Whirlwind R-series report.

The author wishes to express his thanks to Mr. F. M. Verzuh for the supervision of this thesis and for helpful suggestions during its preparation, and to Mr. E. S. Rich for the benefit of several conversations concerning magnetic recording. The author is also grateful to Mr. J. W. Forrester, Director of the Project, for the use of Project Whirlwind facilities.

Signed.....
J. A. O'Brien

Approved.....
J. W. Forrester

ABSTRACT

ELECTRONIC SELECTION AND CONTROL OF
READ RECORD HEADS OF MAGNETIC TAPE UNITS

JOHN A. O'BRIEN

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In this thesis investigation equipment was developed to provide electronic control of the read-record heads of magnetic-tape equipment. The specific problem considered was control, by the Whirlwind Computer, of the heads on the magnetic-tape drive mechanisms manufactured by the Raytheon Manufacturing Company.

In the Raytheon equipment all operations on a single track, or channel, of the tape are accomplished through a single head. The head consists of a core structure with a single two-terminal winding. The saturation-reversal type of recording is used. A pulse is recorded by a momentary reversal of the current flowing in the head. This action produces a saturated spot on the tape of reversed flux polarity with respect to the background. During reading, the head winding is connected to an amplifier and detects the changes in the flux density on the moving tape.

The solution to the selection and control problem involves the design of an electronic switching circuit that will allow both information and current to pass through it in either direction to the winding of only the selected head.

In the circuit developed for this application, each head winding is connected into a four-terminal bridge circuit consisting of a double triode and associated resistors. One pair of opposite terminals of each bridge circuit is connected through crystal diodes to the plates of the record and erase tubes respectively. These two tubes are cathode coupled so that during recording, a negative recording pulse applied to the grid of the erase tube will cut it off and turn on the recording tube, thus reversing the current in the head. During reading, both the record and the erase tubes are cut off, and playback signals from the selected head appear at plates of these two tubes via the connecting crystals. These playback signals are coupled through another pair of crystals to the inputs of a difference amplifier in which the signals are amplified and reshaped.

The heads are selected by making the bridge circuit of the desired head more positive than the others, by means of voltages applied to the other terminals of the bridge circuits. This voltage difference cuts off the crystals connected to the undesired heads. The voltage levels used to accomplish switching are obtained from flip-flops, and all switching can be done in less than one microsecond.

The experimental work on the circuit has shown it to be practical, and there are only two drawbacks to its operation. Due to unavoidable slight unbalances in the bridge circuits, switching transients are coupled to the reading amplifier. The amplitude of the channel-selecting signals is about 20 volts as determined by the recording signals. The unbalance of the bridge circuits and connecting crystals causes about 0.5% of the switching signal to appear at the input to the amplifier. The 2-millivolt signals obtained during reading are superimposed upon the 0.1-volt switching transient, and they are separated by differentiation. The separation is not perfect, and the end result is a switching transient slightly less than 2 milliseconds long. The switching time during reading operations is therefore almost 2 milliseconds. In operations dealing only with recording, the switching transients are negligible, and the switching time is determined by the length of time required for flux to build up in the head.

The other drawback is the noise generated by crystals subjected to back voltage. It was found necessary to select certain of the crystals because of this. Test showed that some crystals would generate noise of much greater amplitude than the playback signals when operated in the circuit.

If a switching time of 2 milliseconds is acceptable, and if selected crystals are used, the operation of the circuit is quite satisfactory.

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CHAPTER I

INTRODUCTIONA. Background

The problem of selection and control of the reading and recording heads of magnetic-tape equipment is usually solved by the use of relays, or manual switches, but in the application of multi-channel magnetic-tape units to high-speed electronic-computers, the operate time of the relays can constitute a substantial portion of the entire operating time of the computer.

The information stored on the magnetic tape by the computer will consist of groups of words. A word is made up of 16 binary digits; and, because the magnetic tape is capable of recording only six digits at a time, a computer word will occupy several of the six-digit lines along the tape. In order to obtain a few extra digit positions for possible reference markers, it has been decided that four of the six-digit lines on the tape will be used to record one computer word. These words will be recorded in groups, or blocks, containing an arbitrary number of words, the exact number depending upon the problem. These blocks will be spaced far enough apart to allow the tape to stop between them.

In an otherwise all-electronic computer, the inclusion of a complicated relay control introduces new maintenance problems that require retraining of maintenance men. In high-speed operations, electronic circuits are usually more reliable and longer lived than relay circuits. For these reasons it is desirable to eliminate the relays in circuits requiring many thousands of high-speed operations.

In a relay control designed to handle 4 six-channel tape units it will take at least 2 relay operate times (to insure proper interlocking) plus the clutch operation to start or stop a unit. Assuming the average relay operate time to be 10 milliseconds (this is short for a multicontact relay), and a clutch operate time of 3 milliseconds, the total stopping or starting time will be 23 milliseconds. With a tape speed of 30 inches per second and recording 100 lines per inch, the tape will coast for 0.6 inch or 600 mils, before the clutch acts. Assuming that the clutch will stop or start the tape in $3 \times 30/2 = 45$ mils, the minimum blank space between recorded blocks of information would be 690 mils. Some extra space of say 210 mils would have to be added to this space during recording to insure that the tape would not coast over this space during the reading operation. This gives a total of 1 inch between blocks of information in relay controlled operation. If we assume electronic switching to be relatively instantaneous, then the block space will consist of only the clutching space and the safety margin, or a total of 255 mils. Actually the safety space need not be as long. If these figures are applied to the recording of 64-word blocks of information, where a word consists of 4 lines, then the total block length including the blank space is $2.56 + 1 = 3.56$ inches for a relay controlled block, and $2.56 + .255 = 2.815$ inches per block for electronic control. These figures show that electronic control might use 20% less tape than relay control on 64-word blocks.

Considering the relative times involved in recording or reading 64-word blocks, the information would be $\frac{2560 \text{ mils}}{30 \text{ mils/ms}} = 85$ milliseconds long,

and there would be an added 7 milliseconds for the safety space, giving a total of 92 milliseconds. The comparative times would be as follows:

RELAY CONTROL	ELECTRONIC CONTROL
$20 + 3 = 23$ ms/start or stop	3 ms/start or stop
$46 + 92 = 138$ ms/block	$3 + 92 = 95$ ms/block.

The saving from using electronic control for 64-word blocks would equal 31%.

The above savings, and the desire to eliminate relays where possible, are the reasons for the investigation into electronic control.

B. Requirements of Electronic Control

The magnetic-tape equipment that will be used on the Whirlwind computer, and for which electronic control must be designed, is the "Computer Magnetic Tape Mechanism" built by Raytheon Manufacturing Company. This equipment records or reads 6 channels of information along magnetic tape 1/2 inch wide. In order to obtain perfect registration between reading and recording heads, these two functions are performed by the same head for each channel, and the six heads are mounted side by side across the width of the tape. This type of construction results in a very narrow head assembly in which only two leads per head are brought out.

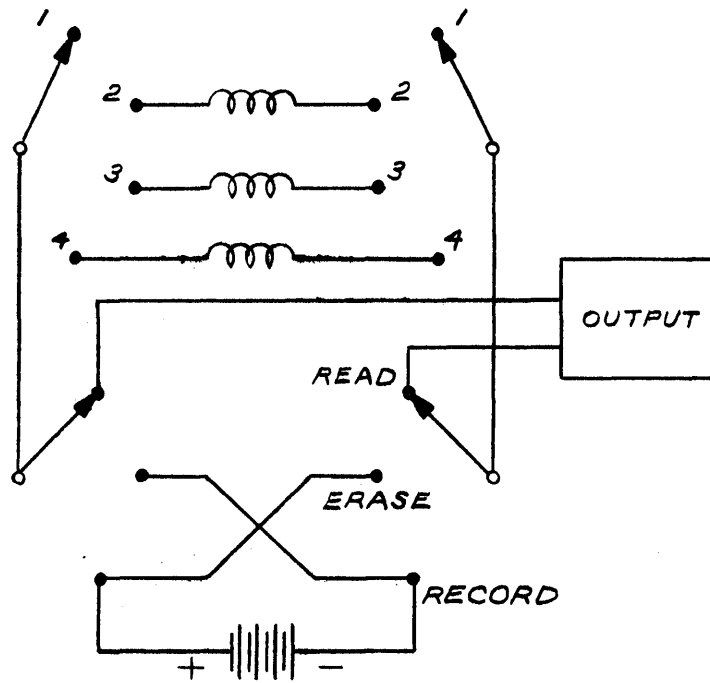
To eliminate the need for an erasing head, the type of recording used is saturation-reversal. A direct current sufficient to saturate the tape is passed through the head, producing a saturated background and effectively erasing any information that may have previously been recorded on the tape. When it is desired to record a pulse on a certain channel of the tape, the current through the particular head is momentarily reversed.

This action produces a short reversal of flux on the tape, which can later be detected during a reading operation. During the reading operation the head terminals are connected to the input of an amplifier and any changes of tape magnetization are detected, amplified, and sent to the computer. The magnitude of the recording current will be about 20 milliamperes and the reading signals will have an amplitude of 2 or 3 millivolts.

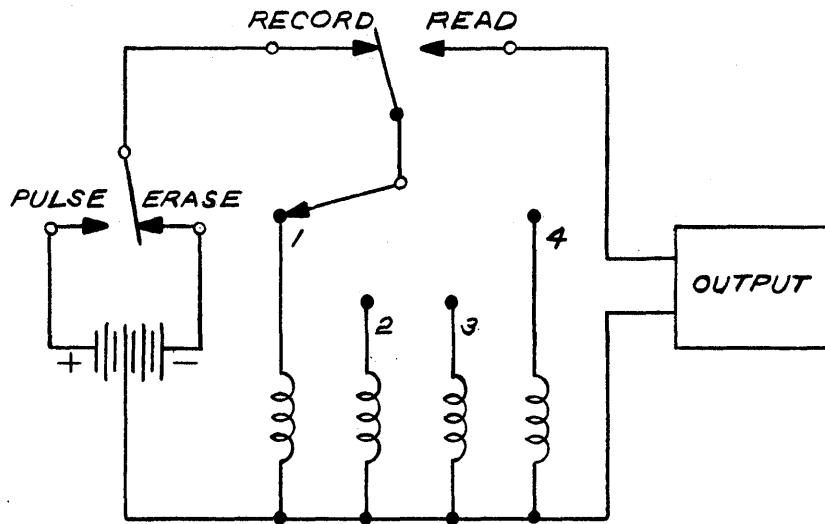
The above data defines the requirements of an electronic switch. The switch circuit must allow direct current to flow to the head in one direction, and it must allow pulses of current to flow in the opposite direction. The circuit must function to cut off these currents during the reading operation, and lastly the circuit must provide for the selection of different heads. Figure 1, in which the heads are represented by coils, shows two variations of a manual switching circuit to illustrate the above requirements. The problem is to accomplish this same type of switching using electronic elements.

C. Electronic Switching

Because of the large number of devices and substances that possess or exhibit characteristics that are applicable in the field of electronics, many different types of electronic switches have been developed or proposed. These vary from photoelectric devices using controlled light-sources to large matrices of interconnected crystal diodes driven by vacuum-tube circuits. In all of the many types of switches there is an element, or combination of elements, that acts analogous to the single



(a) BALANCED SWITCHING



(b) SINGLE ENDED SWITCHING

MANUAL SWITCHING CIRCUITS

FIGURE 1

switch contact in manual or relay switching. These "contacts" are called gates, gate circuits, or gating circuits. The name gate presumably comes from the word used to refer to an opening in a fence. The name fitted the use quite well in radar work wherein gate circuits were used to permit selection of echo signals coming from a certain segment of the area covered by the radar. The name has resulted in some confusion, however, because some people think of an open gate circuit as an open fence gate through which information can pass, while others think in terms of an open switch contact through which no information can pass. For this reason, at the risk of creating additional confusion, the terms "on" and "off" are used in this paper. "On" indicates a closed circuit, and "off" indicates an open circuit.

The two principal gating elements are the diode (crystal or vacuum) and the multigrid vacuum tube. Diodes are made to operate as gates by varying the voltage across them. If the cathode is negative with respect to the anode, the series resistance of the diode is very much less than when the cathode is positive. This resistance can be placed in series with the signal circuit and be used to control the signal, or it can be used as a shunt in combination with a series resistor to limit the signal.

The multigrid vacuum tube is constructed in such a way that the plate current can be cut off by application of a sufficiently negative voltage to any one of the two or more control grids. The signal to be controlled is applied to one control grid of the tube, and the switching, or gating, signals are applied to the remaining control grids. Present commercial gate tubes, the 6AS6 and the 7AK7, have only two control grids.

Very briefly, the relative characteristics of the two gating circuits are as follows. The diode gate circuit attenuates the signal and preserves its polarity; whereas, the gate tube amplifies and inverts. The input impedance of the diode gate circuit is lower than that of the vacuum-tube gate circuit, particularly in circuits designed for fast response times (less than one microsecond). Neither of these circuits will allow the passage of direct current in both directions, excepting the shunt diode at the center tap of a series limiting resistor. The gate tube, in particular, will not allow information to pass in both directions.

There are other means of accomplishing electronic switching, such as controlling a cathode ray beam with electrostatic or electromagnetic deflection, or with magnetic elements such as saturable core transformers. These types usually require specially-constructed components.

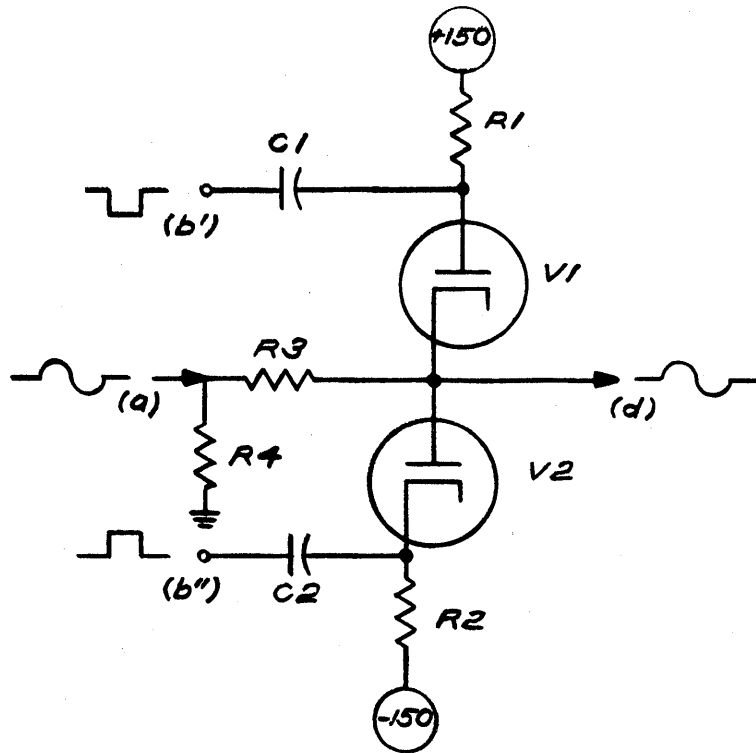
In all of the gating devices mentioned, if the base line of the signal to be controlled cannot be positioned at a voltage sufficient to cut off the current independently of the gating signal, then the gate circuit will pass the gating signal as well as the signal being switched. This is the case whenever it is not possible or permissible to clip the input signal and use only the positive or negative portions of it.

To eliminate the appearance of the gating signal at the output in the above cases, it is necessary to use some sort of balanced switching circuit in which the gate signal is cancelled. These types of switches are termed bi-directional switches since they will pass current in both

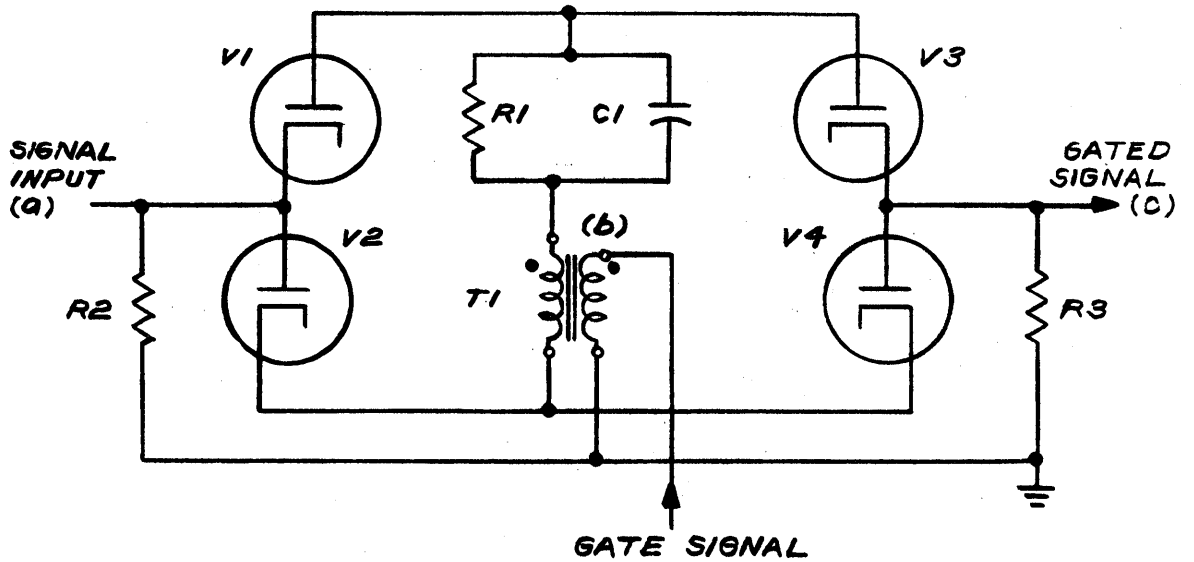
directions^{1*}. They might better be called bi-polar switches since they are designed to pass signals of both polarities, but will not necessarily pass information in both directions. Two bi-directional switches are shown in Figure 2. In the two-diode switch of Figure 2a, in the absence of gating signals, the diodes act to short circuit any signals at point (d) to the positive and negative power supplies. This shorting causes the signal voltage to be lost across the series resistor R_3 . When gate signals of opposite polarity are simultaneously applied to the two points (b') and (b''), as shown in the figure, then the two diodes are cut off. This action removes the shunt and the signal appears at point (d). If the circuit is balanced, then none of the gating signal will appear at point (d).

A different type of balanced circuit is shown in Figure 2b. In this circuit all of the diodes are normally biased off, due to residual bias across R_1 and C_1 , so that no signal can get from point (a) to point (c). When a positive gate signal is applied to point (b) all of the diodes conduct. The resistance between points (a) and (c) becomes relatively small and any signal at (a) appears at (c) as long as the magnitude of the signal current between (a) and (c) does not exceed the magnitude of the gate current provided by T_1 . This circuit is a true bi-directional switch in that signals of either polarity can pass in either direction, although it will not pass direct currents and appears as though it would be quite sensitive to the gate repetition frequency.

* Superscripts refer to numbered items in the bibliography.



(a) TWO-DIODE BI-DIRECTIONAL SWITCH



(b) FOUR-DIODE BI-DIRECTIONAL SWITCH

BI-DIRECTIONAL SWITCHES

FIGURE 2

A-36790

FROM REFERENCE #1, PAGES 49 & 374

The foregoing material is by no means a comprehensive treatment of electronic switching. The gating elements mentioned can be connected in many different ways to form control circuits to perform any desired function that can be expressed with Boolean algebra and a host of others that cannot be so expressed. Most of the work done on electronic switching in the past few years has been done in connection with electronic computers.^{2,3,4,5,6} The earlier work on switching was done in connection with multisignal displays on oscilloscopes,^{7,8,9} diversity radio reception,^{10,11} and radar.¹

There has been very little work done on electronic control of magnetic recording heads. Some work has been done at the Harvard Computation Laboratory on selecting reading heads on magnetic drums.¹² Their problem is quite different in that they are not reading and recording with the same windings, and due to the high speed of the drums the signals received from magnetic drum heads are usually about 100 times as large in voltage as those received from magnetic-tape heads. The University of California is also working on magnetic-drum-head switching.¹³ Here also, separate windings are used.

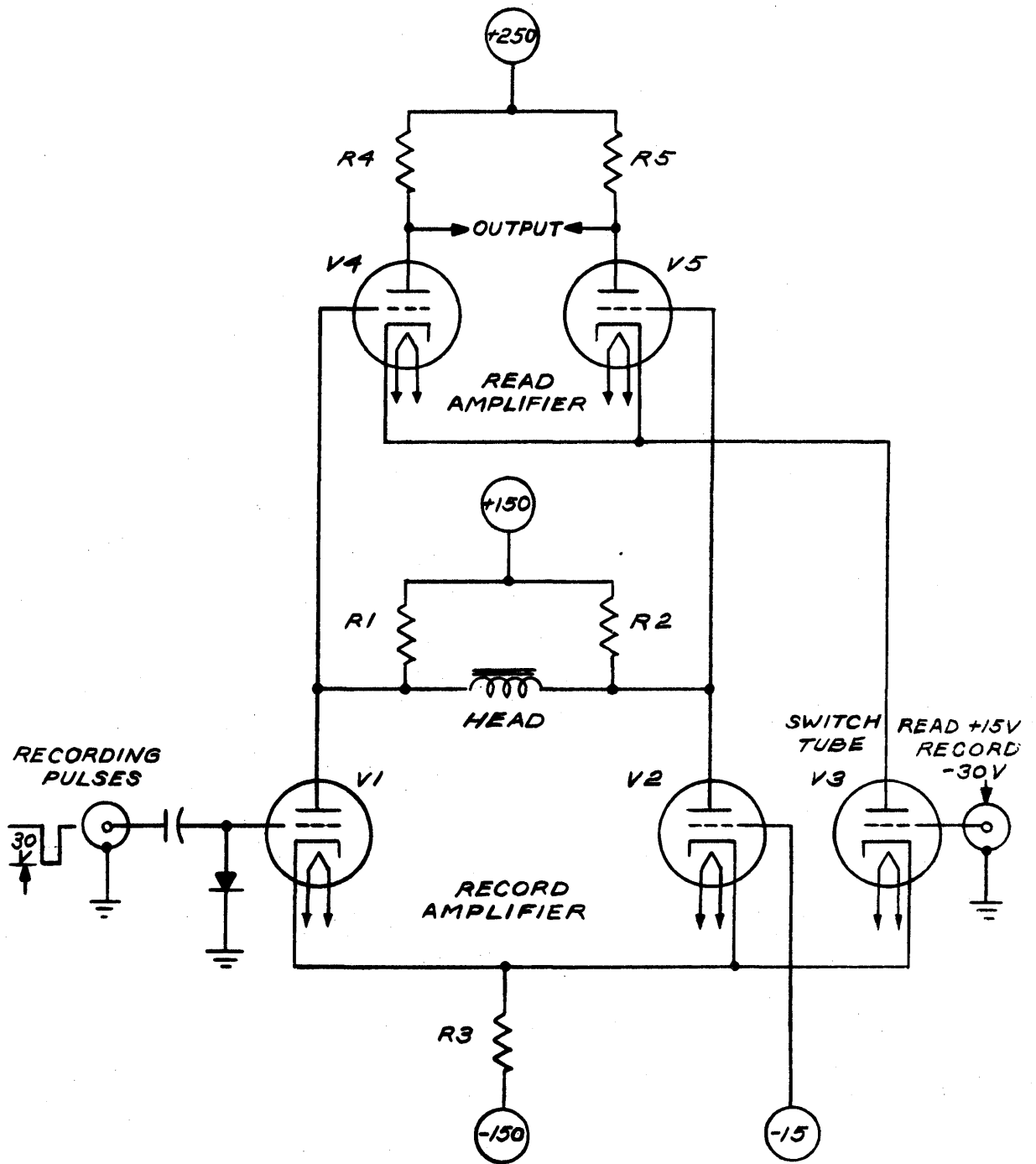
CHAPTER II

THE SELECTED SWITCHING NETWORKA. The Read-Record Switching Circuit

The first attack on the switching problem was to devise a circuit that would accomplish the saturation-reversal type of recording and at the same time be easily inactivated during reading. A circuit to satisfy these requirements is shown in Figure 3.

The operation of this circuit is as follows. Considering the record condition in which V_3 is cut off by a negative voltage on its grid, tubes V_4 and V_5 are effectively cut off, since their common cathode is floating, and V_1 is conducting. The cathodes of tubes V_1 , V_2 , and V_3 are at approximately ground potential, thus V_2 and V_3 remain cut off. If resistors R_1 and R_2 are equal, then half of the current of V_1 passes through the head, assuming it to have a negligible resistance. This current is the erasing current and has a magnitude determined by resistor R_3 . When a 30-volt negative recording pulse is received at the grid of V_1 , V_1 is cut off and V_2 conducts. The current through the head then reverses. Since the bias of V_2 is lower than that of V_1 , this recording current will be less than the erase current (about 10 per cent less with the values shown in the diagram). This difference is desirable as long as the recording current will saturate the tape.

During a reading operation, tubes V_1 and V_2 are cut off and V_4 and V_5 are turned on, by a positive change of the voltage applied to V_3 . The tubes V_4 and V_5 act as a difference amplifier, with an approximately



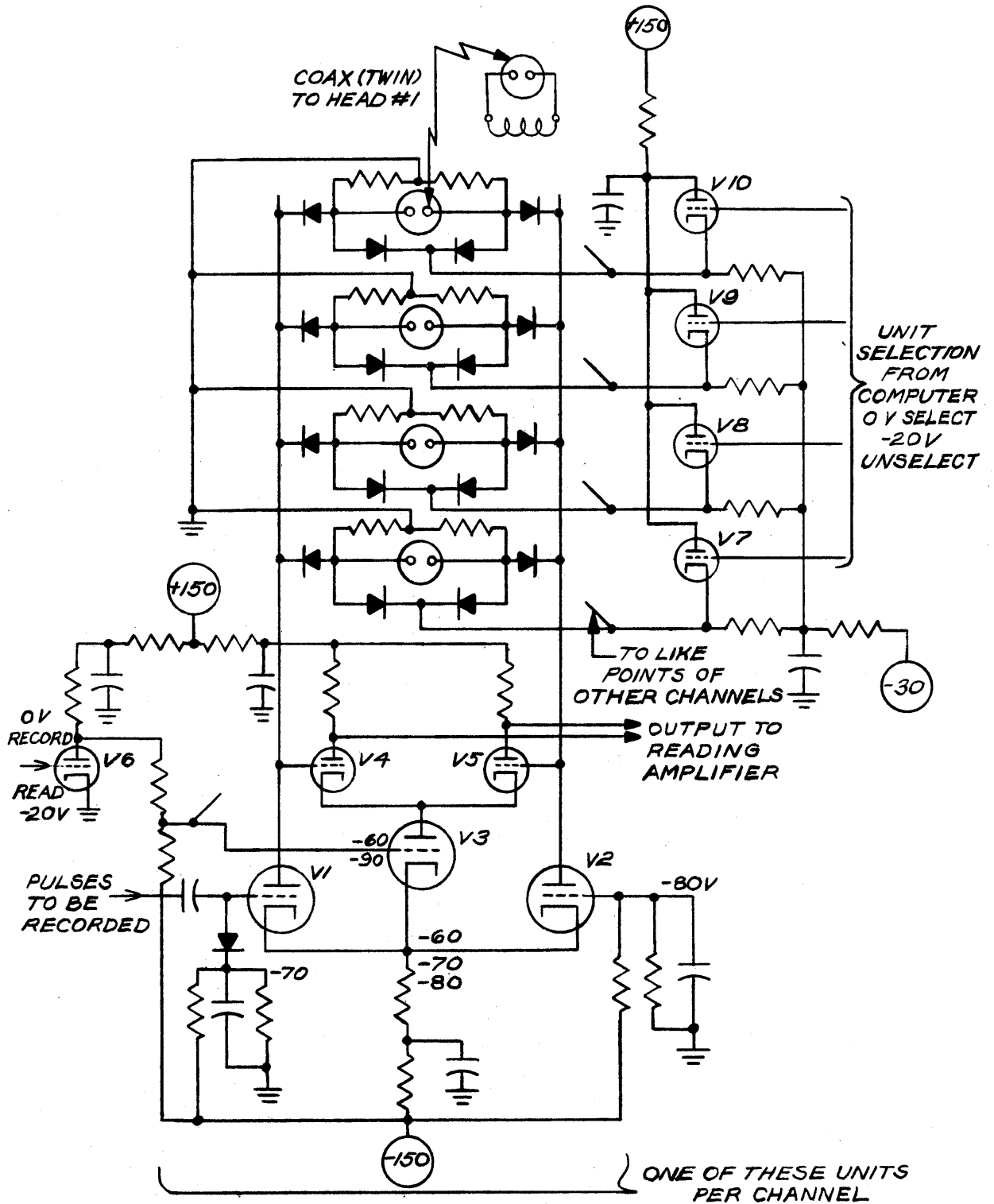
READ-RECORD SWITCHING CIRCUIT

FIGURE 3

constant current generator in their common cathode circuit to produce the effect of a cathode resistor of infinite dynamic resistance. These tubes amplify the difference in voltage between their grids. This voltage is the signal which the recorded spots on the moving tape generate in the head.

B. Head Selection

The means for accomplishing the selection of different heads is shown in Figure 4. This figure is the original proposal for the electronic control of the heads of the magnetic-tape units, and it illustrates the basic circuits for control of 4 magnetic-tape units each having six recording channels. The head selection is controlled by signal levels from the computer control which are applied to the cathode followers V₇ through V₁₀. It is assumed that control is such that always one, but only one, of the cathode follower cathode voltages is positive with respect to the other three. Due to current flowing through their associated resistors and crystals from ground to the minus-30-volt supply, the head circuits connected to the cathode followers with the negative outputs are drawn down to a negative voltage. The head circuit connected to the cathode follower with the positive output will be at ground potential (assuming for the moment a reading operation). The crystals connecting this head to the cathode follower will be biased off if the cathode follower is designed so that the cathode rises slightly above the grid in voltage. All of the heads are connected by crystals to the reading and recording amplifiers, but the crystals of the negative-head circuits will be biased off by the



A SCHEME FOR ELECTRONIC CONTROL OF MAGNETIC TAPE HEADS

FIGURE 4

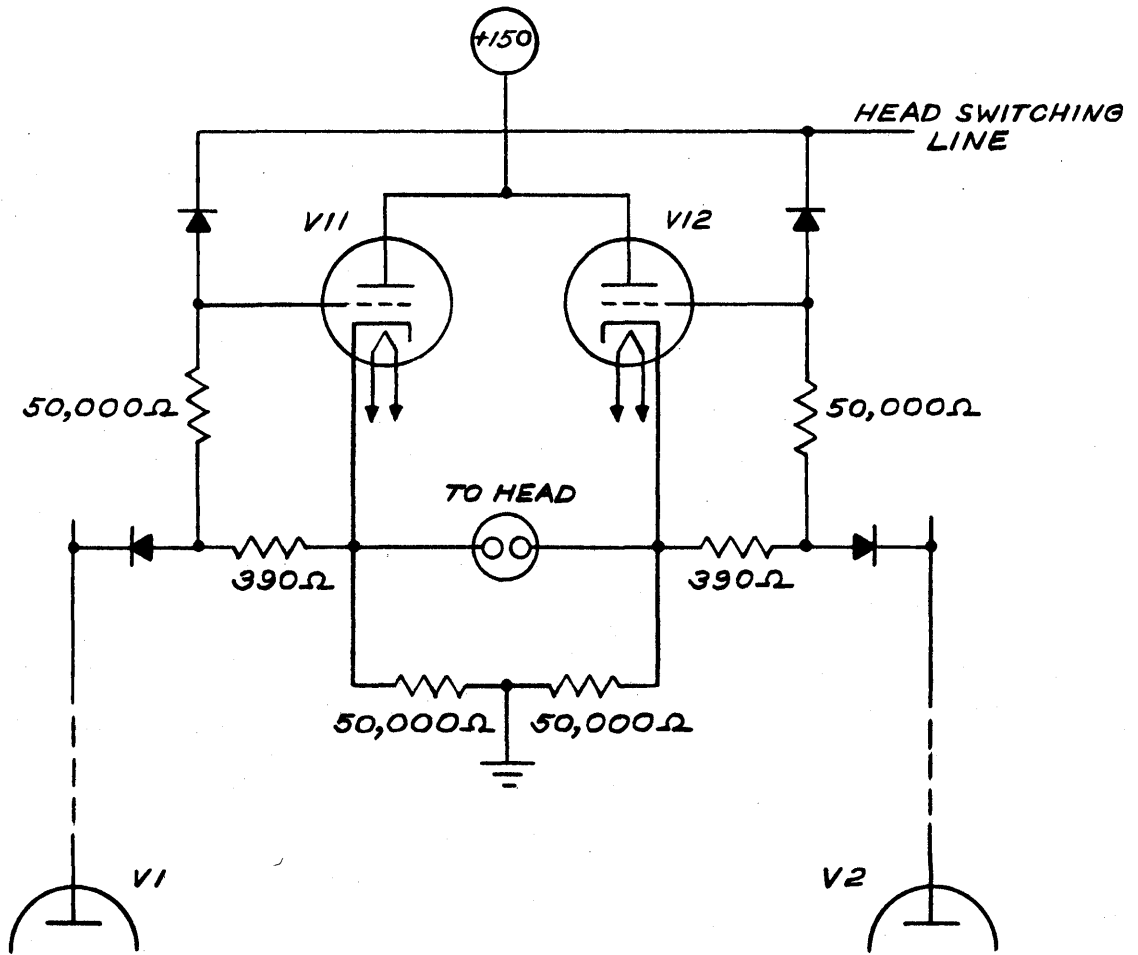
voltage between the negative-head circuits and the positive-head circuit. This same voltage will cause a very small current to pass through these crystals from the positive heads to the negative heads, thus insuring that the crystals connecting the positive head to the reading amplifier are "on", or conducting. Even without this slight current, the series resistance of crystals with zero bias is quite low, about 1000 ohms, and bi-polar signals of at least 30 millivolts could pass through to the reading amplifier with negligible attenuation.

During recording, selection is accomplished in the same manner. Care must be taken that the erase current does not cause a voltage drop sufficient to lower the voltage of the selected head to the level of the unselected heads.

The head-selecting scheme described above is quite simple and straightforward but there are several undesirable features.* The current drawn by the recording circuit is twice that needed in the head (approx. 20 ma needed), and the current drawn by the minus-30-volt supply for the full complement of 24 heads would be at least 24×40 or 960 milliamperes. The current passed by the crystals during recording is a little too close to the ratings of the crystals for reliable and conservative operation.

* It was later seen that the head circuit could be made much more simple by connecting the ground connections of the head circuits to the cathode follower outputs instead of ground and by eliminating the crystal connections to the cathode followers. This design could eliminate the negative voltage supply of the cathode followers.

The modified head circuit shown in Figure 5 eliminates these undesirable features at the expense of adding two tubes per head. These two tubes act as variable resistors replacing the grounding resistor shown in the head circuits of Figure 4. This circuit is connected so that when the erase tube, V_1 , is drawing current, the voltage drop across the 390-ohm resistor connected to the cathode of V_{11} cuts off V_{11} , and all of the current passes through the head from V_{12} . When V_2 conducts during the recording of a pulse, V_{12} is cut off and V_{11} conducts. The currents in the 50,000-ohm resistors in the selected circuit are negligible. When the head is unselected, voltage sufficient to cut off the tubes is developed across the 50,000-ohm grid resistors and the head circuit drops in voltage as before. The addition of the 390-ohm resistors in series with the heads should not contribute any objectionable amount of attenuation of the reading signals as long as the input impedance of the reading amplifier is relatively high.



MODIFICATION OF HEAD-SELECTING CIRCUIT

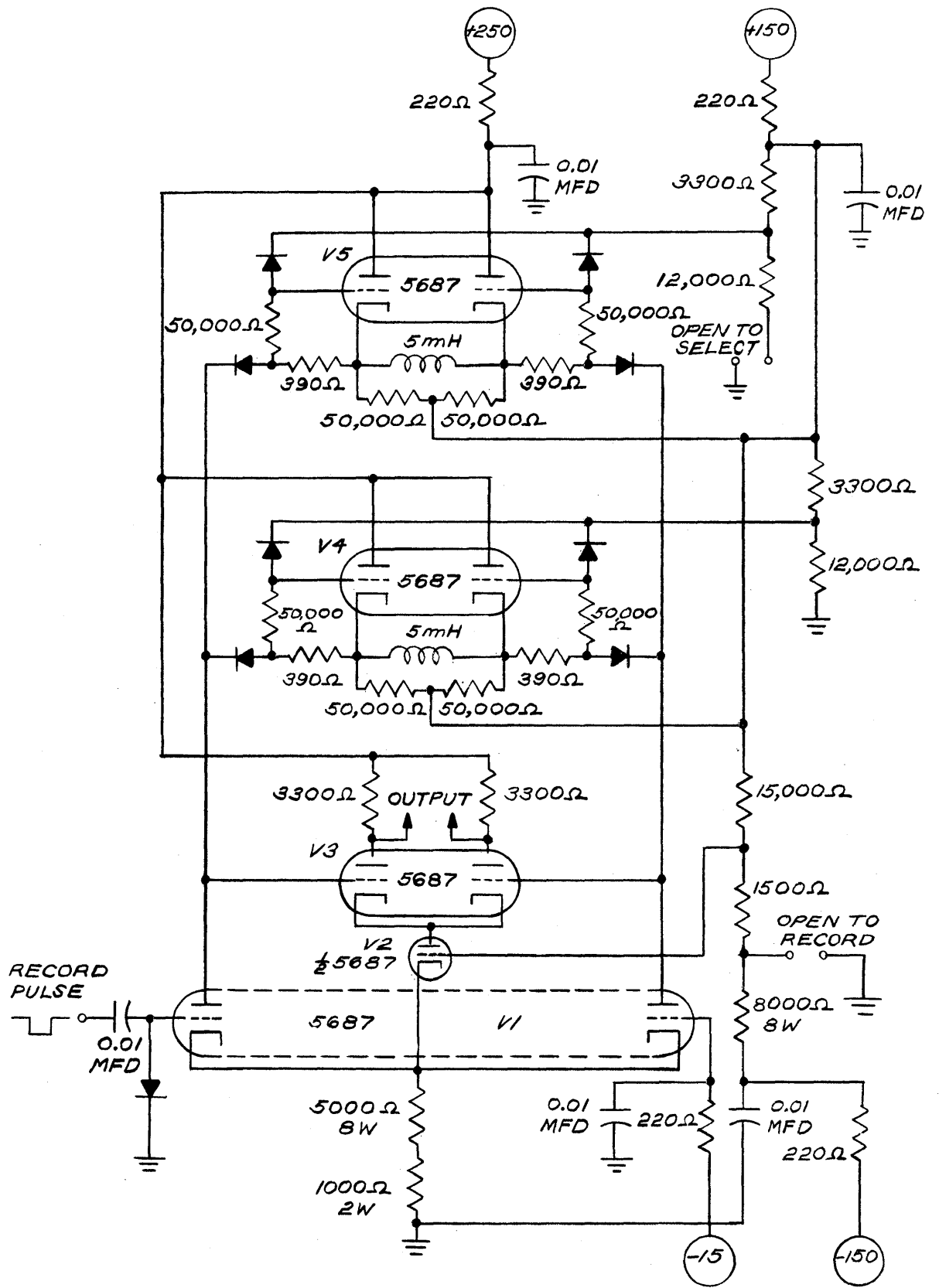
FIGURE 5

CHAPTER III

EXPERIMENTAL RESULTSA. Initial Testing

The first operation in the experimental work was to construct the circuit of Figure 6 on a simple breadboard in order to make static tests. The switching was accomplished by clip heads, and the magnetic tape heads were represented by 5-millihenry chokes since there was no magnetic tape equipment available at that time. In the testing of this unit, recording was simulated by applying the required recording pulses and observing the waveforms produced across the 5-mh chokes. Reading was simulated by replacing the chokes with a step-down transformer which supplied millivolt signals from an audio oscillator.

The results of these tests indicated that the idea was sound, but the design was not. The chief trouble was in the reading operation. The high-impedance amplifier and its floating input were extremely sensitive to power-supply-line noise and hum pickup. The equipment did indicate that all voltages entering the unit, including switching signals, would have to be stable and relatively free of noise. The design of the reading amplifier did not prove too practical, since any noise coupled into the switch tube in the cathode of the amplifier caused a variation in the d-c cathode resistance of the amplifier. This change caused changes in currents of the amplifier tubes. Because these changes were not necessarily equal, noise voltages were developed in the output.



MAGNETIC TAPE READ-RECORD CIRCUIT

FIGURE 6

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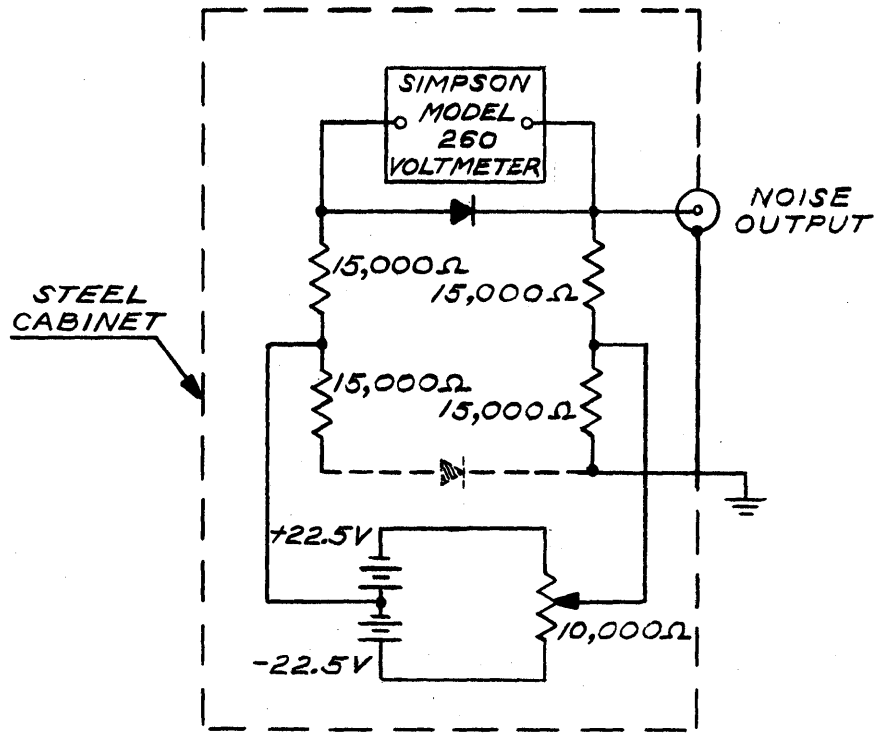
In view of the above difficulties, a new two-channel panel was built, with a larger amount of power supply decoupling, and a much better layout to exclude hum pickup. The reading amplifier was eliminated from the panel and replaced by a transformer that could be coupled to the test equipment amplifier. In addition it was found necessary to construct a separate filter panel in which each supply voltage was filtered. The power was then connected to the test panel through a shielded cable separate from the filament supply. An old magnetic tape drive unit and two narrow heads were obtained and connected into the new panel.

With this new set-up the hum and power-supply line noise were very low and it was possible to record signals and read them back in either channel with a signal to noise ratio of about 10 to 1. All of the switching was done by means of clip leads connected to potential dividers.

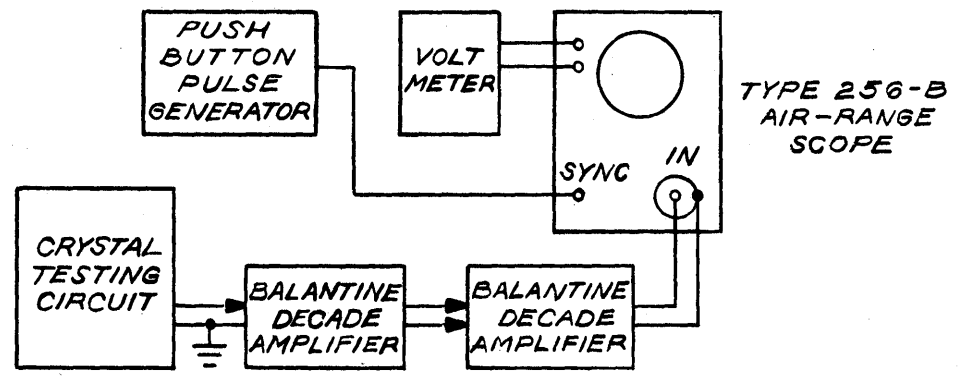
During these tests it was noticed that one of the channels was more noisy than the other. By interchanging and re-interchanging components it was finally deduced that this noise was originating in the crystals that connected the unselected head to the output transformer. It was also found that the noise could be reduced by reducing the bias across these crystals.

B. Crystal Noise

In order to substantiate the deduction that the crystals were the source of the observed noise, and to investigate this phenomenon, a test set-up was put together in which the noise generated by the crystals could be measured under conditions similar to those in the switching circuits. The circuit for this test set-up, shown in Figure 7a, was



(a) CRYSTAL TESTING CIRCUIT



(b) EQUIPMENT FOR OBTAINING CRYSTAL-NOISE OSCILLOGRAMS

CRYSTAL TESTING EQUIPMENT
FIGURE 7

A-36792

designed to accept two crystals to simulate conditions in the switching circuit, but it was found that one crystal alone was sufficient and desirable for testing. In this way the quality of the crystals could be checked by observing the amplified noise pattern on an oscilloscope. The results of these tests were very interesting. It was found that different crystals generated different amounts and different types of noise. Most of the noise seemed to be made up of flat-topped pulses of random frequency and duration. The amplitude of these pulses depended upon the crystal being tested and they increased in amplitude as the back voltage across the crystal was increased. With some of the crystals, a step of much greater amplitude than the usual pulses would appear occasionally. The noise sometimes appeared in long bursts separated by relatively quiet periods.

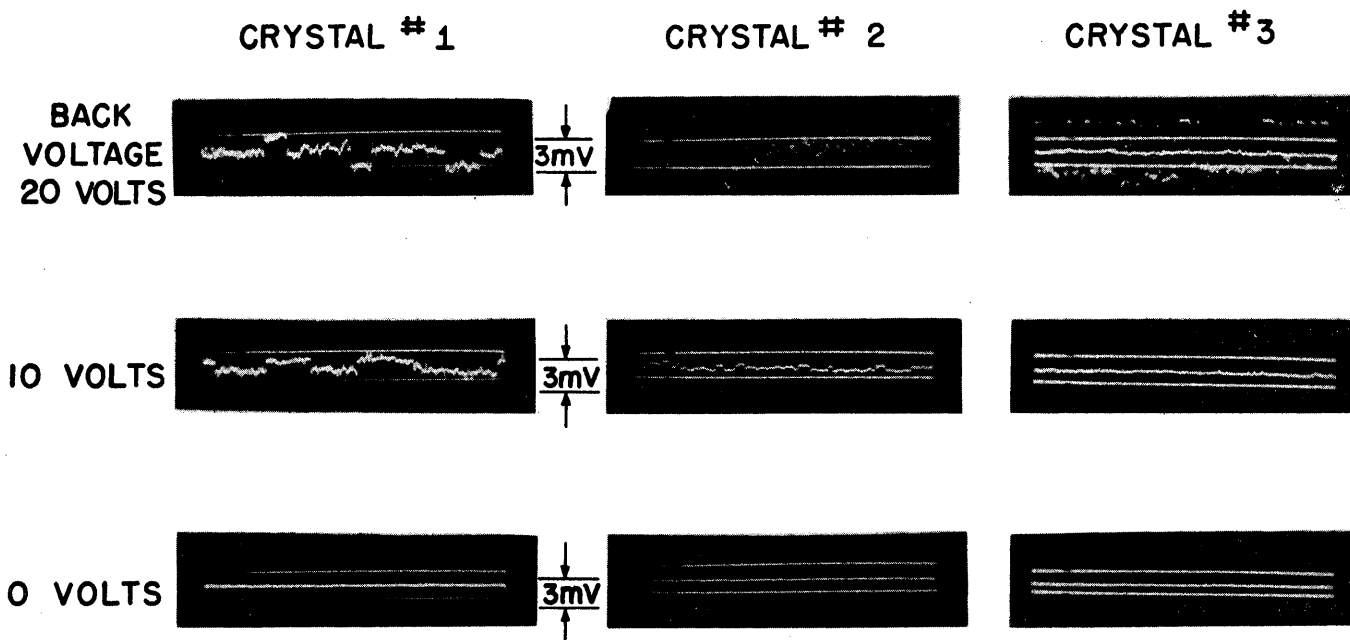
Most of the testing was done with a back voltage of 20 volts across the crystal, since this is the voltage used in the switching circuit. The voltage was varied, however, by means of the potentiometer, and it was noticed that there seemed to be two large steps in the noise voltage as the bias voltage passed through zero. This effect was somewhat hidden in the noise produced by the moving arm of the potentiometer.

Professors Torrey and Whitmer give a considerable amount of data on crystal noise in their book, "Crystal Rectifiers".¹⁴ Their data indicates that there is much more noise in crystals than can be accounted for by theory. This data was obtained from tests in which back voltages much less than 20 volts were used. The greatest noise seems to be produced by what is called fluctuation noise, the mechanism of which is not known.^{14*}

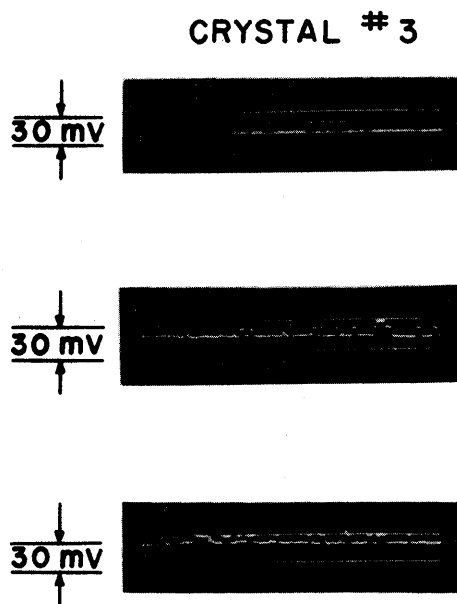
* Sec. 6.2.

Some examples of noise waveforms generated by particularly noisy crystals are shown in Figure 8. The particular types of these crystals are not specified since there is no reason to believe that the noise is peculiar to certain types. These oscillograms were taken with the equipment shown in Figure 7b. Two sweeps 30 volts apart were photographed first, and then the noise sweep was photographed between them. In the case of Figure 8a the amplifier gain was set to 10,000 and the gain was set to 1000 for Figure 8b. Figure 8a shows the noise generated by 3 different crystals with biases of 20, 10 and 0 volts. The figures are more or less self-explanatory; the noise is totally different in Nos. 1 and 2. Number 3 generated so much noise that it overloaded the amplifier in Figure 8a, and it is shown on an enlarged scale in Figure 8b for the case of a 20-volt back voltage. The photographs show a reduction in noise voltage with the 10-volt bias. The 10-volt bias case for crystal No. 3 is misleading in that the picture shows a very quiet length of time; however, in the middle of the sweep a very short pulse of about 2 mv amplitude may be observed. The photograph of the 20-volt-bias case of crystal No. 3 in Figure 8a is a double exposure. The center line is a 10-volt-bias sweep.

The primary objective of the testing was to obtain a few crystals that exhibited very little noise. The testing was continued until out of a collection of about 100 crystals, of different types and manufacturers, 6 crystals were found that exhibited a negligible amount of noise. The selected crystals were wired into the circuit and excellent operation was obtained. These selected crystals exhibited noise voltages that were less than the level of the amplifier noise, i.e., less than 0.1 millivolt.



(a) EXAMPLES OF CRYSTAL NOISE



(b) NOISE GENERATED WITH 20 VOLTS BIAS
ACROSS CRYSTAL #3 ON A 30 mV SCALE

NOTE: ALL SWEEPS ARE FROM RIGHT TO LEFT WITH A SWEEP LENGTH OF 4500 MICROSECONDS.

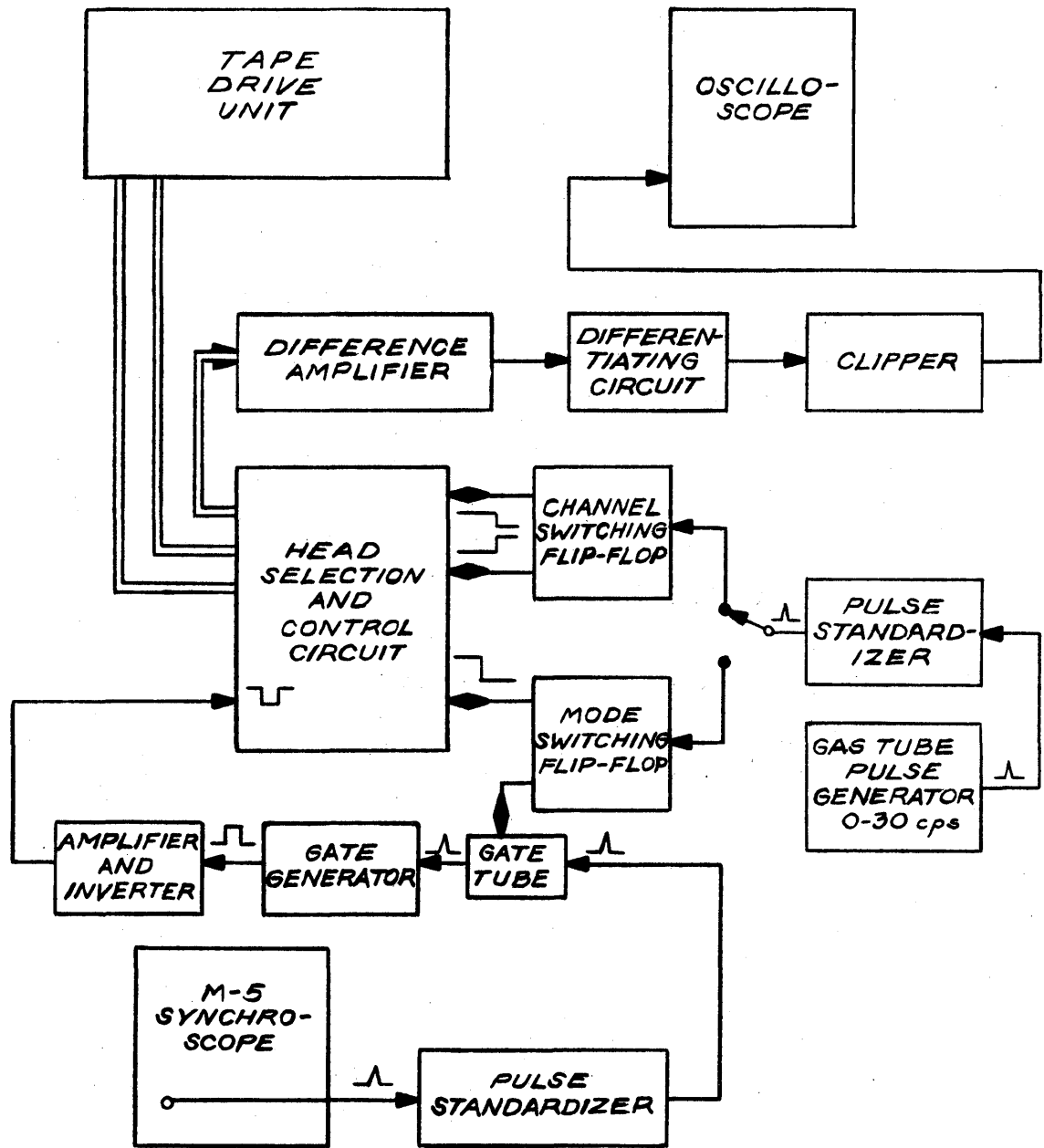
FIG. 8
CRYSTAL NOISE

C. Reducing the Switching Transients

After the objectionable crystal noise was eliminated, the equipment was set up to perform the switching dynamically by pulse-controlled flip-flops. The block diagram of the final circuit is shown in Figure 9. A gas-tube relaxation oscillator which could be operated as a simple pulse generator or as a free-running pulse generator was used to supply the pulses that operated the switching flip-flops. The circuit for the channel-switching flip-flop, shown in Figure 10, is a 6AN5 type of Whirlwind design used to produce output voltages at ground level. In this particular circuit, 6V6 amplifier tubes were used to raise the d-c level of the output up to +150 volts as was required for the channel-selecting signals. The plate lead resistors of these amplifiers were located on the head-switching panel to insure that the amplifiers operated on the same +150 volt power as the rest of the head-control circuit.

The circuit for the mode-switching flip-flop is shown in Figure 11. This flip-flop was designed to produce the 50-volt switching signal needed to switch between reading and recording. The upper level of the output voltage is at ground potential and the switching time of this flip-flop is less than 0.2 microsecond. A crystal gating circuit and a 7AD7 buffer amplifier were also included with this circuit to control the recording pulses.

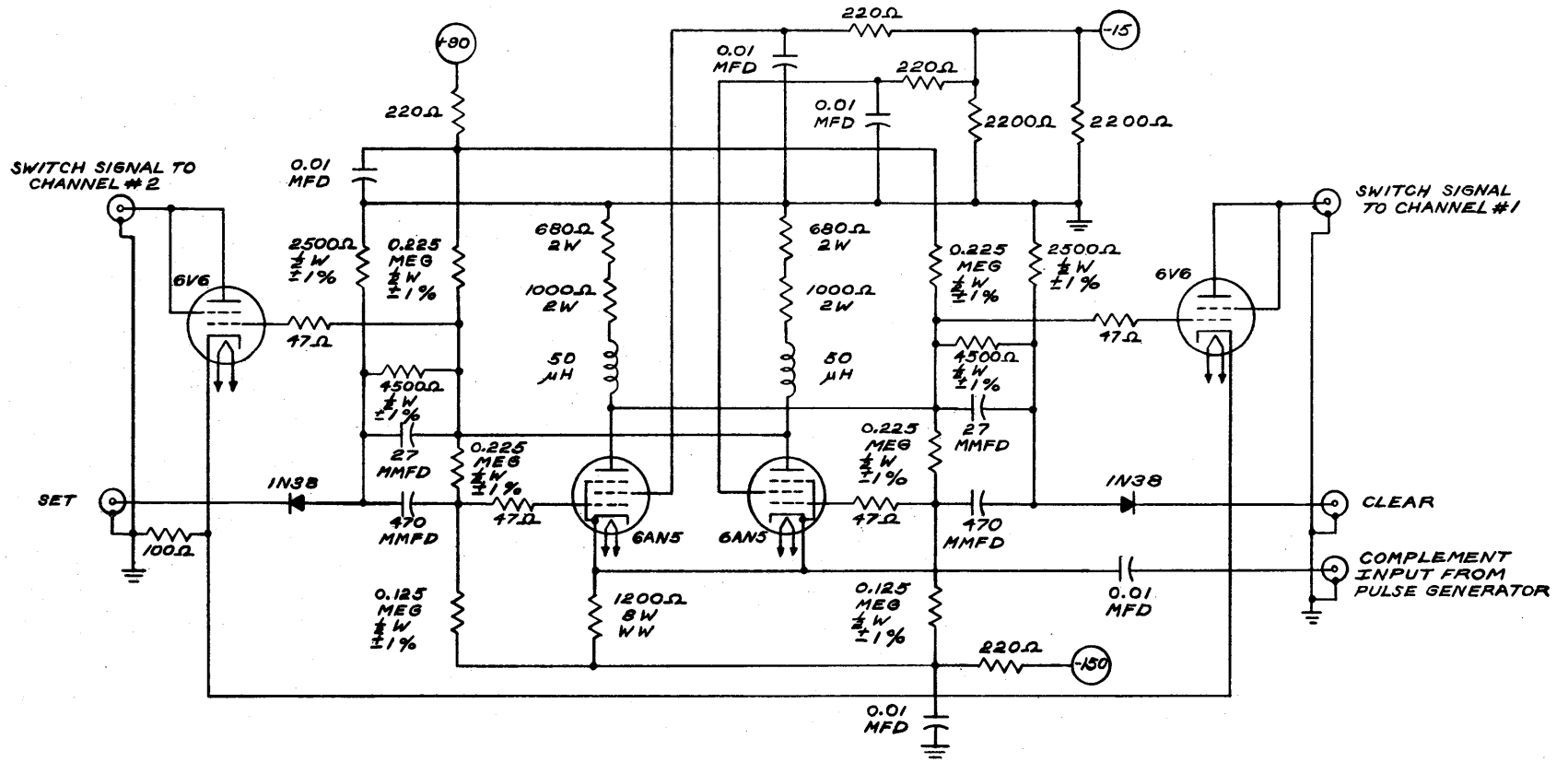
The recording pulses were supplied by a Model-5 Synchronoscope operating on internal triggers. Pulse frequencies of 500, 1000, 2000, and 4000 cps were available. These output pulses were standardized to 0.1 microsecond pulses in a pulse standardizer, a piece of Whirlwind test



BLOCK DIAGRAM OF TEST SET-UP

FIGURE 9

A-36789



FLIP-FLOP CIRCUIT
USED FOR
CHANNEL SWITCHING

FIGURE 10

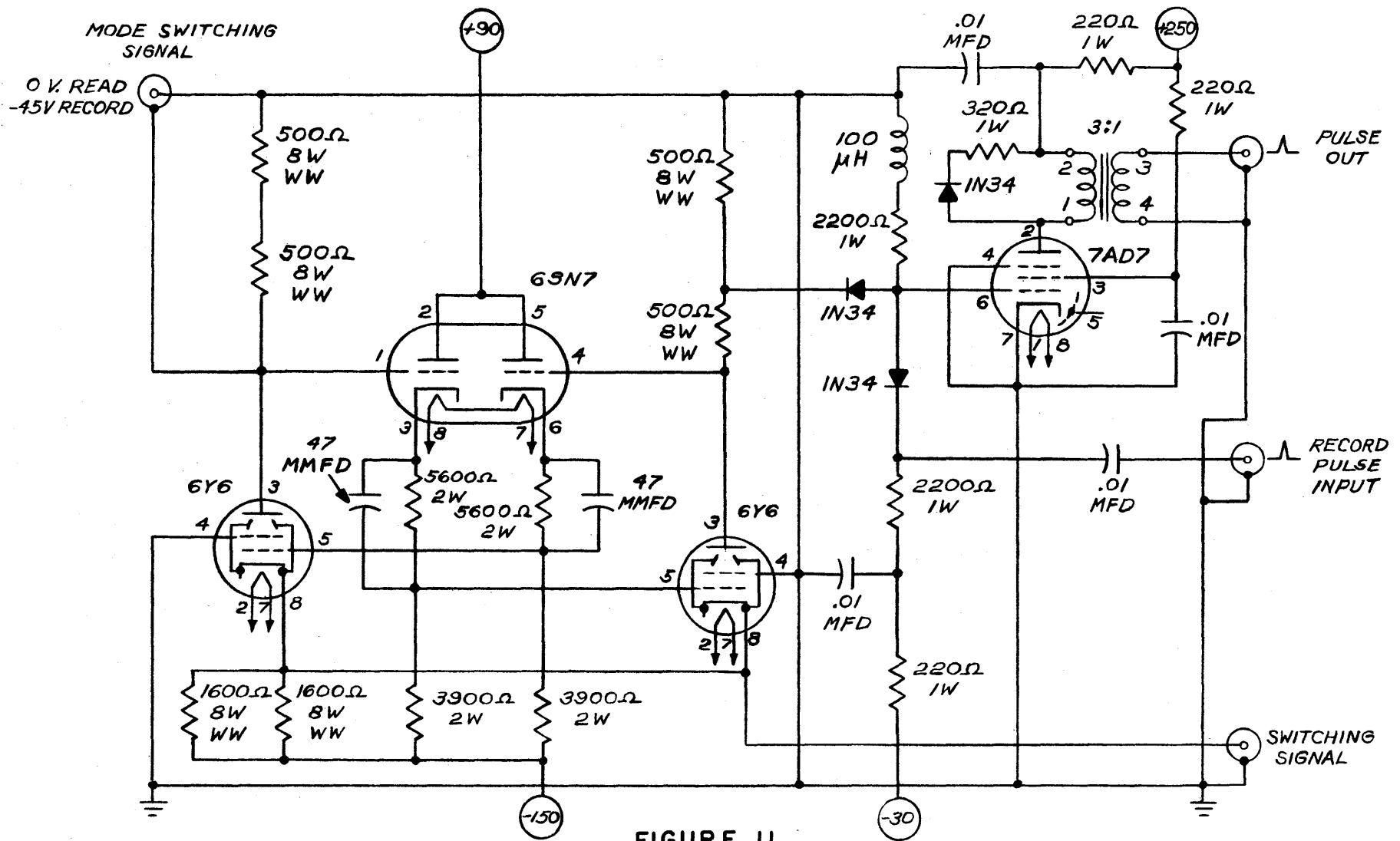


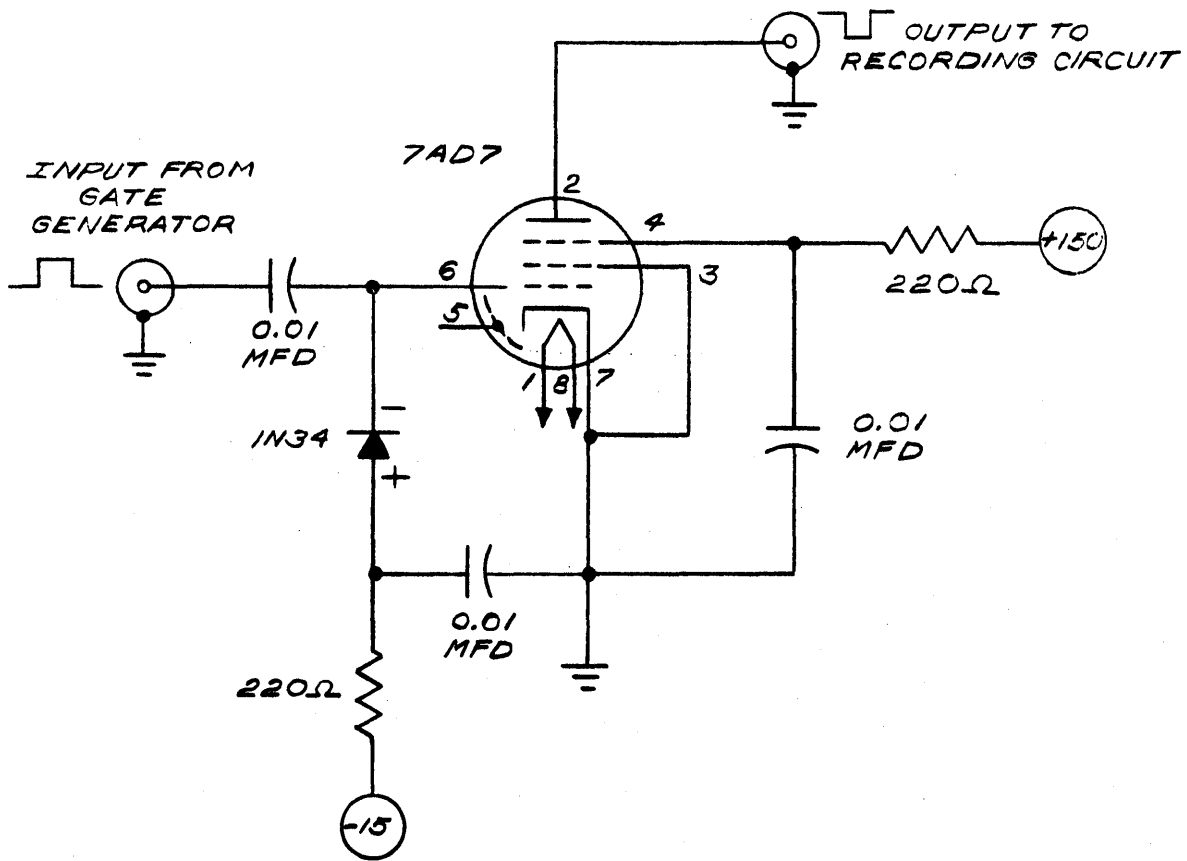
FIGURE II

FLIP-FLOP CIRCUIT USED FOR MODE SWITCHING

equipment. The pulses were then passed through the gating circuit on the mode-switching flip-flop to a gate generator used to control the length of pulses actually applied to the heads. (The gate generator is another piece of Whirlwind test equipment.) From the gate generator, the lengthened pulses were fed to an inverter-amplifier which supplied the negative recording pulses to the test circuit. Figure 12 shows the circuit for this amplifier, and, as is the case of the channel-switching amplifier, the load resistor was located on the test panel to insure properly filtered power.

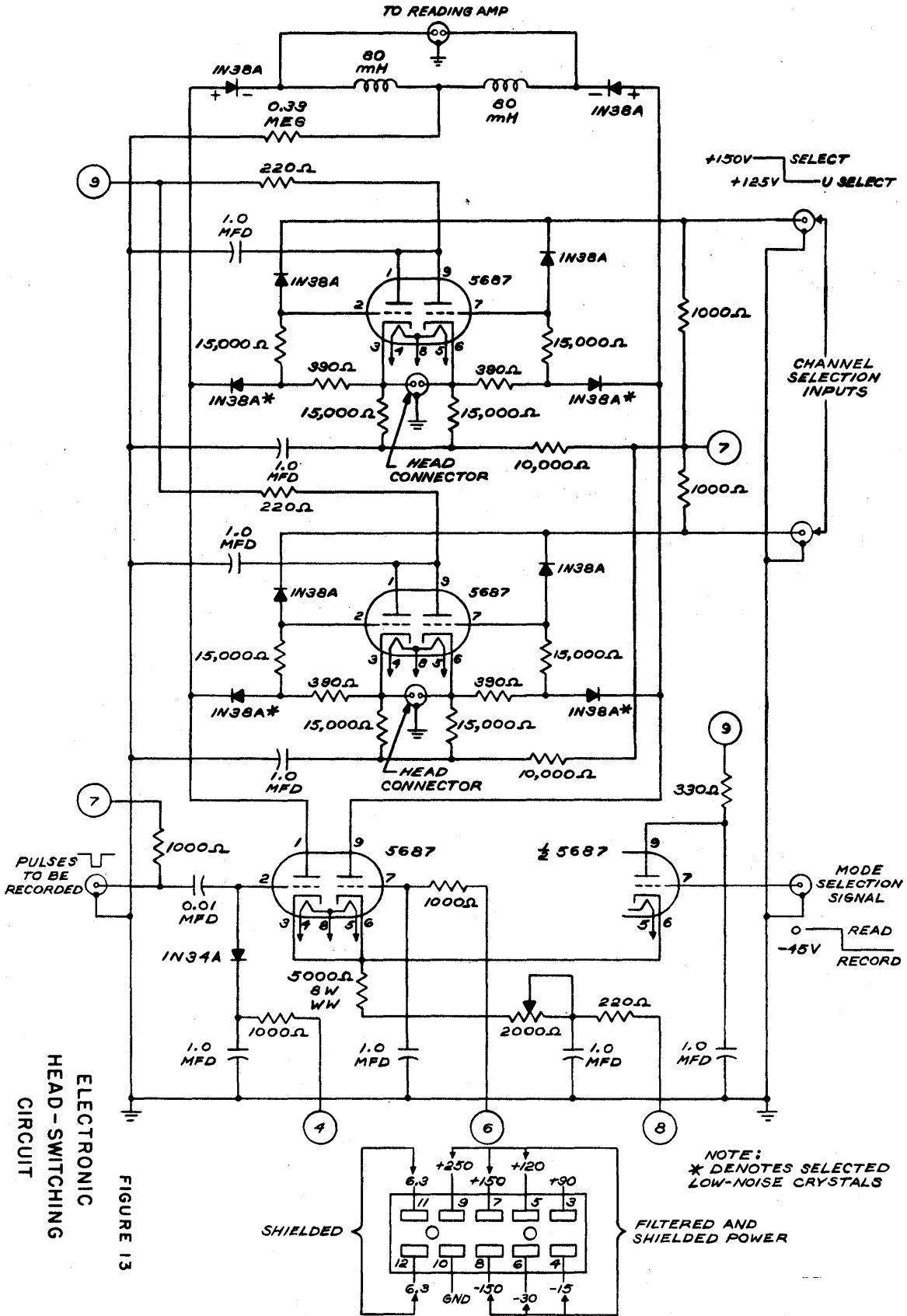
The final circuit of the head selection and control circuit is shown in Figure 13. The changes of this circuit from Figure 6 are described in the following material, as are also the circuits of the amplifier, differentiator, and clipper.

The first tests on dynamic switching were made by pulsing the channel switching flip-flop at a rate of about 30 cycles per second during a reading operation and observing the amplified output on an oscilloscope synchronized with the switching frequency. These test showed the switching transient to be many times the amplitude of the playback signals. It appeared that the transformer on the output of the switching circuit was not actually producing a difference signal. When the input to the transformer was short circuited, the transient remained even though the reading pulses disappeared. After considerable testing it was decided to construct a three-stage difference amplifier in order to be able to observe the signals between any two points in the switching network independently of the signals common to both points. This type of observation was necessary since the switching voltages are in the order of a thousand times as large as the playback signals.



RECORD PULSE AMPLIFIER

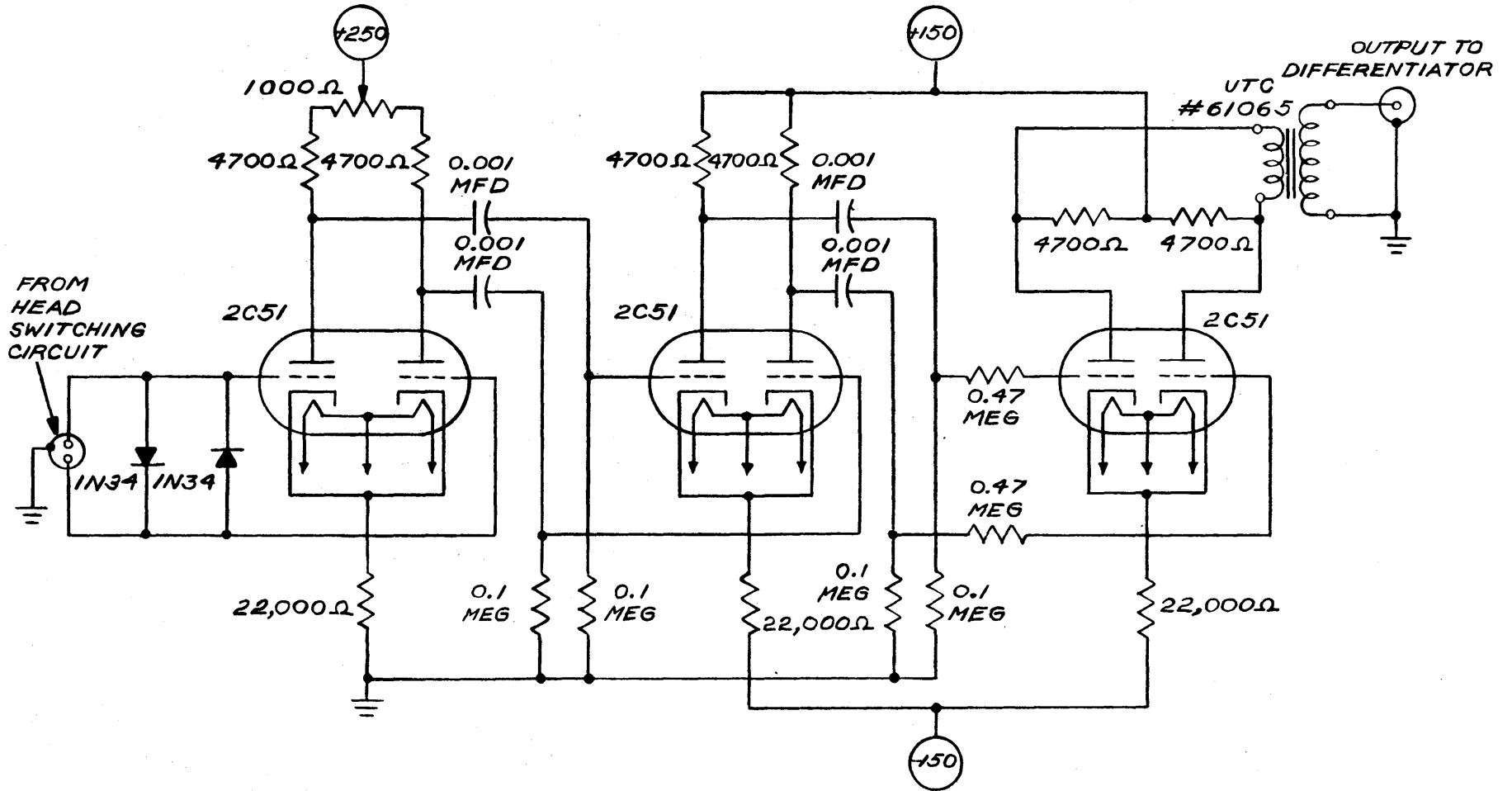
FIGURE 12



The circuit for the difference amplifier is shown in Figure 14. The design is such that common-mode signals at the grids are attenuated by a factor of about 8 per stage. The output transformer eliminates any common-mode signal left at the output. With 0.1 mfd coupling condensers, the over-all gain of the amplifier, including the transformer, is about 1000. Any unbalance in this amplifier leading to amplification of common-mode signals can be cancelled by unbalancing the plate resistors of the first stage in the proper direction.

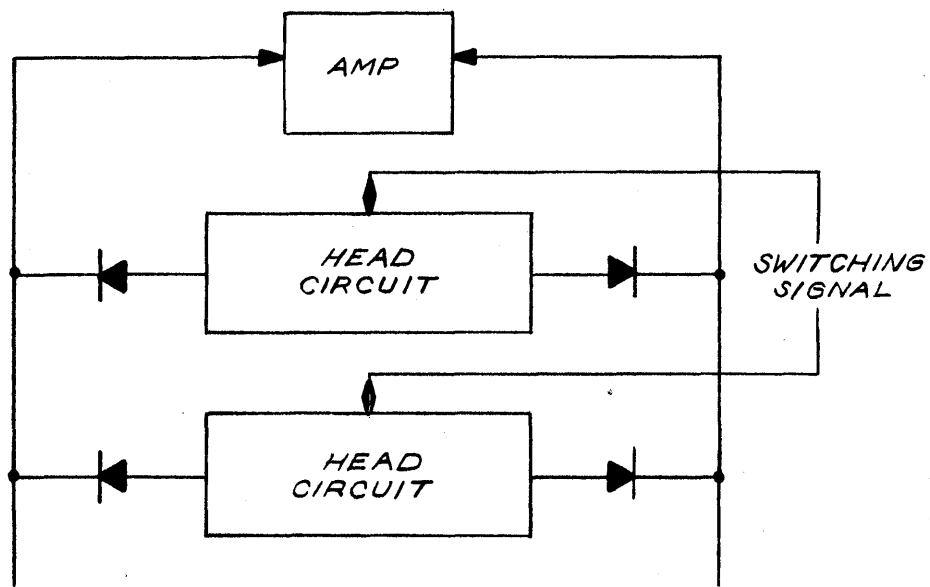
After removal of the transformer from the output of the switching circuit and replacing it with the new difference amplifier, the transients could be observed without the differentiation produced by the transformer. The switching transient was found to be due to a change in the d-c voltage between the output lines that occurred, whenever the selection was changed from one channel to the other.

The source of this d-c voltage was quite obvious when it was found. It was caused by inequalities in the components used in the head circuits. In particular, the unbalance was due to the mixing crystals. This unbalance is easily understood by reference to Figure 15. Figure 15a is a simplified diagram of the head-switching circuit. If it is assumed that there are no unbalances in the head circuits that might cause a d-c voltage to exist across the head, then Figure 15b can be drawn in which the head circuits are shorted out. From this simple bridge figure it can be seen that any slight difference in the characteristics of the individual crystals will cause an unbalance that will produce a d-c voltage difference between the amplifier inputs. This voltage was measured and found to vary

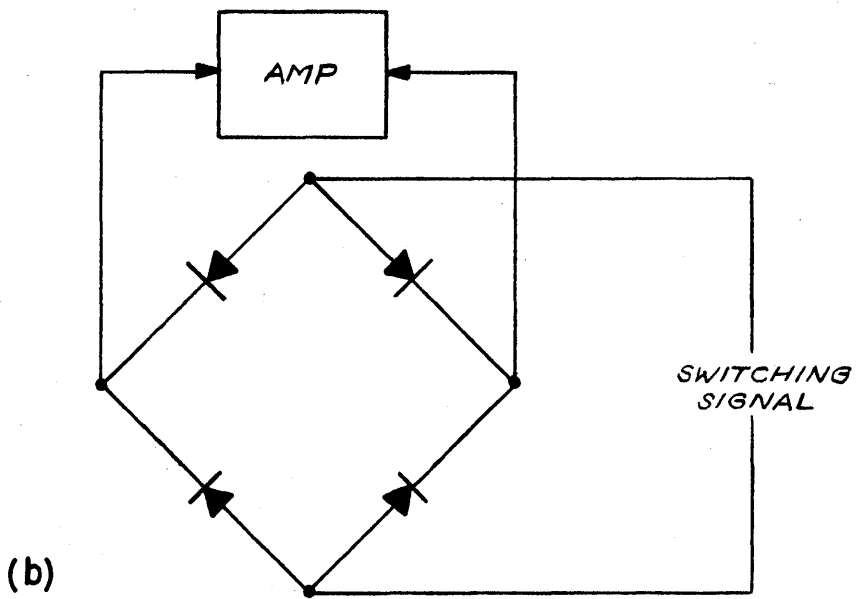


READING AMPLIFIER

FIGURE 14



(a)



(b)

THE CRYSTAL BRIDGE

FIGURE 15

by 0.1 volt between channel selections. Because of the unpredictable nature of crystal characteristics, it is quite impractical to balance the circuit. This was attempted by several means, but all proved to be unstable because of drift in crystal characteristics with time, temperature, and switching frequency.

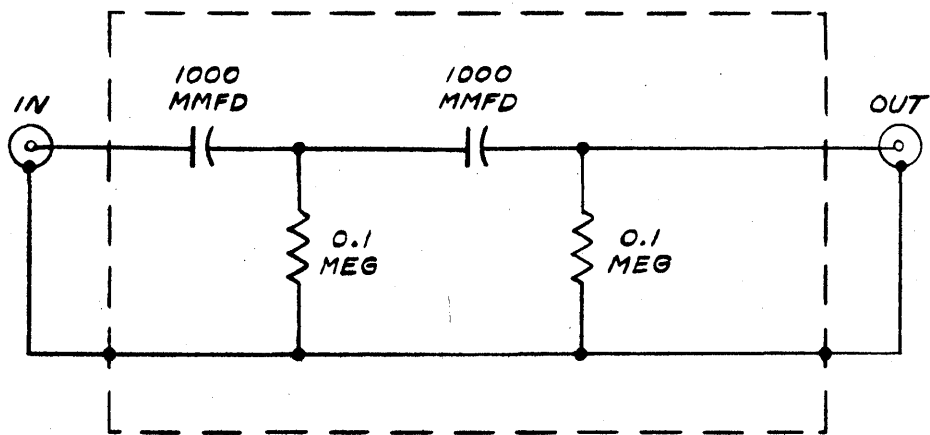
For this reason it was decided to eliminate the step function, caused by the switching, by differentiating the output waveform. To this end, the switching circuit was terminated by inductances, as is shown in Figure 13. In order to prevent these chokes from shunting the head circuits during a recording operation additional crystals were inserted in series with the chokes. These crystals also served to attenuate the recording signals that reached the amplifier. To make the forward resistances of the crystals slightly more uniform, the junction of the chokes was connected to ground through a high resistance. This resistor allowed a fraction of a milliampere of current to flow through the crystals, thus bringing the crystals out of the zero bias range to a range where the forward resistances were lower and more nearly equal. The grounding resistor is large enough to prevent large inequalities in the choke currents during switching.

No condensers were used in this phase of the differentiating because of the danger of charge build-up through the crystal diodes. For this reason, and to prevent unequal current flow in the crystals, the first stage of the difference amplifier was d-c coupled to the output of the switching circuit.

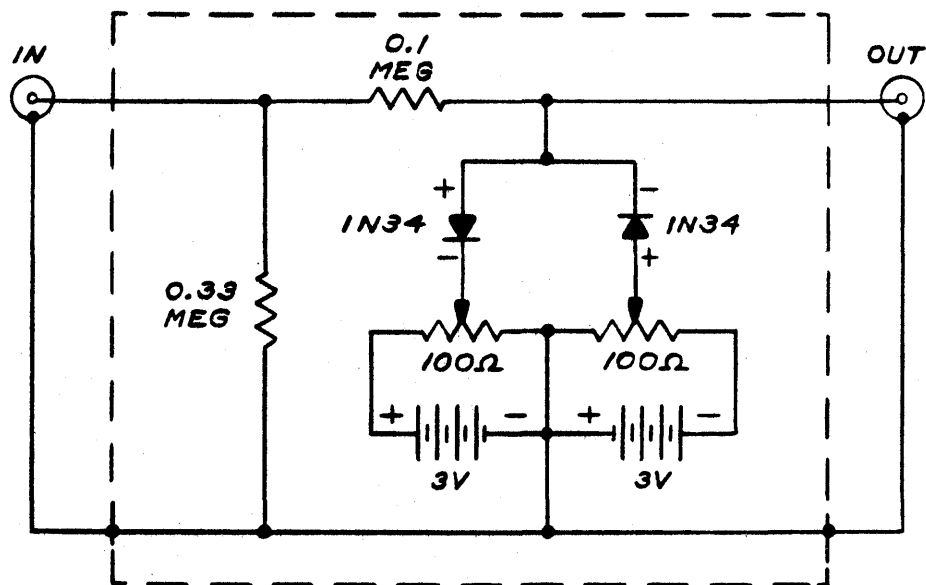
This differentiation was quite successful except that the d-c resistance of the chokes allowed some of the voltage step to pass through to the amplifier. Therefore the coupling condensers of the amplifier were reduced to 0.001 mfd and an external differentiator was added onto the output of the amplifier, Figure 16. This addition resulted in a compromise solution. The switching transients, both during channel selecting, and in switching between reading and recording, were reduced to sharp spikes of less than 2 milliseconds duration. The differentiation of the playback signals was such that the resultant positive pulse was almost as high as the positive half of the undifferentiated pulse.

Two limiting crystals were connected across the input to the amplifier to limit the spikes of the switching transient and recording pulses. These crystals have a resistance of about 1000 ohms to small signals and produce a negligible attenuation of the playback signals. The resistance of these crystals to switching transients and recording pulses is much lower and as a result these signals are attenuated. To further reduce the amplitude of undesired signals and to prevent overloading in succeeding amplifiers, a crystal clipping circuit was connected to the output of the external differentiator. By means of this device, Figure 17, the amplitude of the transients was reduced to only slightly higher than the playback signals.

The switching transients had no effect on the recording performance of the system, since the 0.1-volt step function is negligible compared to the 20-volt recording pulses. Switching could be made from channel to channel during recording, and the switching was fast enough to split a recording pulse, as some of the waveforms of the next chapter will show.



DIFFERENTIATOR
FIGURE 16



CLIPPER
FIGURE 17

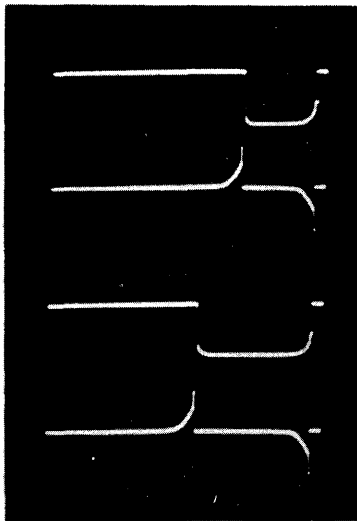
CHAPTER IV

PERFORMANCE DATA

This chapter presents the performance data of the equipment by means of photographs of cathode-ray-tube waveforms. Explanations of the photographs and the means by which the photographs were obtained are included. All of the waveform photographs were taken with a Dumont Oscilloscope Record Camera, Model 297 (Land Camera). This camera includes a single mirror in its optics and for this reason the sweeps in the prints go from right to left.

A. Recording Pulses

In the recording of pulses on magnetic tape the length of the pulse is usually chosen to be equal to the time that it takes the change of flux to complete itself on the tape. Since the playback signals depend upon changing flux, lengthening the recording pulses will not increase the playback signal amplitude, but will merely increase the separation between the positive and negative peaks of the playback signal. Figures 18 and 19 show that this simple relation between recorded pulses and playback pulses does not always hold. Figure 18 shows two examples of recording pulses each with the waveform of the consequent voltage developed across the recording head. Figure 18a shows a recording pulse of 90 microseconds duration as it appears at the grid of the recording amplifier in the switching circuit. The companion waveform shows that the voltage across the head drops to a steady value in about 20 microseconds. Figure 18b

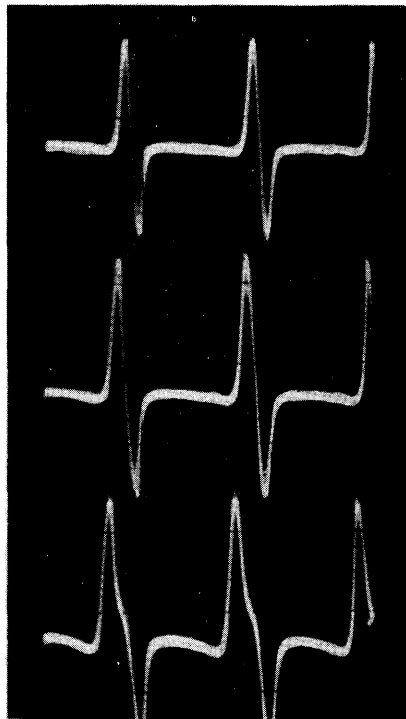


RECORDING PULSE
 (a)
 HEAD VOLTAGE

(b)

SCALE: $V = 135$ VOLTS/IN.
 $H = 230$ μ SEC/IN.

FIG. 18
 RECORDING PULSES



(a) 100 μ SEC RECORD PULSE

(b) 150 μ SEC

(c) 300 μ SEC

SCALE: $V = 1.7$ mV/IN.
 $H = 1.5$ mSEC/IN.

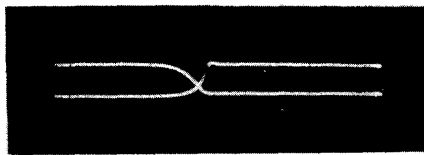
FIG. 19
 EFFECT OF RECORD PULSE LENGTH ON
 PLAYBACK SIGNAL

shows a recording pulse of 150 microseconds duration and its consequent head voltage. The recording pulses have an amplitude in both cases of -40 volts, and the amplitude of the voltage peaks across the head is 30 volts.

Figures 19a, b and c show playback pulses at a frequency of 1000 cps which were recorded by pulses with pulse lengths of 100, 150, and 300 microseconds respectively. These waveforms show a 20 per cent increase in amplitude in going from 100 to 150-microsecond pulses, and a 20 per cent increase in length. There is no further increase in amplitude in going to 300-microsecond recording pulses, and a separation between the peaks begins to appear. These comparisons show the effect of self-demagnetization of the pulses on the tape. With the shorter recording pulses, the pulse on the tape is so short in length that the adjoining areas act across it and tend to "level off" the magnetization. The 150-microsecond recording pulse appears to give the best results and it was used for all of the succeeding photographs. The playback pulses of Figure 19b have a peak-to-peak amplitude of 2.25 millivolts.

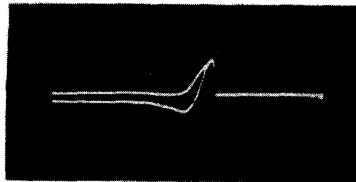
B. Switching Between Channels

The switching between channels is accomplished, as previously explained, by the channel-switching flip-flop. The switching signal as it appears at the input to one of the head circuits is shown in Figure 20a. The length of the sweep is 4.1 microseconds, and the amplitude of signal is 20 volts. The waveform shows switching "on" and "off", and in both directions the change is complete in less than 0.7 microsecond.



4.1 μ sec SWEEP
 V DEFL = 135 VOLTS/IN

(a) SWITCHING FLIP-FLOP WAVEFORM

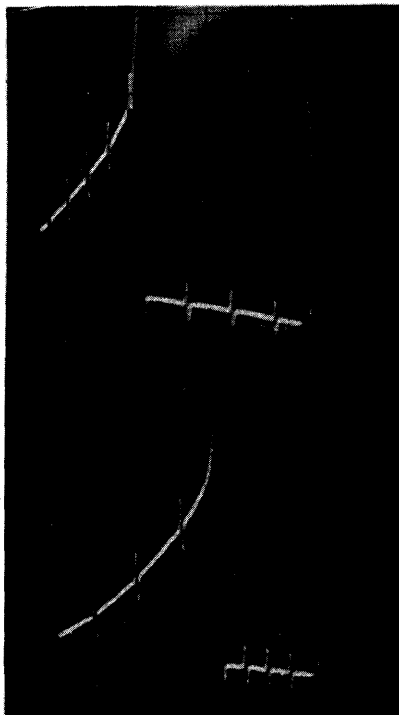


350 μ sec SWEEP
 V DEFL = 2.1 VOLTS/IN

(b) OUTPUT SWITCHING TRANSIENT

FIG. 20

CHANNEL SWITCHING SIGNALS



(a) 500 CYCLE CHANNEL TO
 1000 CYCLE CHANNEL

(b) 1000 CYCLE CHANNEL TO
 500 CYCLE CHANNEL

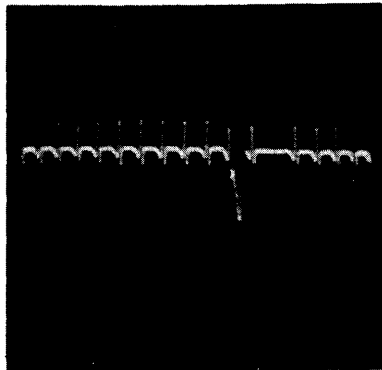
FIG. 21

CHANNEL SWITCHING DURING READING

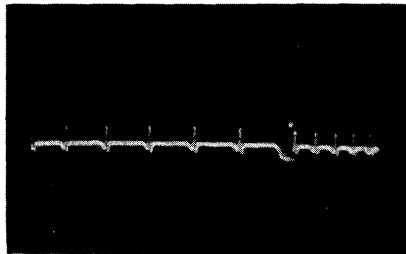
The effect of this switching on the output lines can be seen in Figure 20b. This figure shows the effect of the signal of Figure 20a as it appears across the primary of the output transformer of the difference amplifier. To obtain this waveform, the differentiation of the amplifier was reduced by increasing the coupling condensers in the amplifier to 0.1 microfarad. The sweep length in this waveform is 350 microseconds. The initial spike in the waveform is due to unbalance in the response of the tubes in the head circuit. The final difference in voltage is due to circuit component unbalances, and this is shown converging due to the chokes on the output of the switching panel. This difference represents a difference of 0.1 volt at the output of the switching panel.

In order to show the effect of channel switching on the playback signals, 1000-cps pulses were recorded on one channel of the tape and 500-cps pulses were recorded on the other channel. These recordings were then read with the channel-switching flip-flop being pulsed at about 30 pulses per second. Since it would be very difficult to synchronize the switching with the playback signals all photographs were taken with a single sweep.

Figure 21a shows the effect of switching from the 500-cycle channel to the 1000-cycle channel, and Figure 21b shows the inverse. The only differentiating is that due to the chokes and 0.1 mfd condensers in the difference amplifier. This signal was taken from the output of the difference amplifier. The pulses are about 2 volts peak-to-peak. Figure 22a shows the effect of adding the external differentiating circuit of Figure 16 to the output of the amplifier, and Figure 22b shows the



(a) CHANNEL SWITCHING WITH EXTERNAL DIFFERENTIATING CIRCUIT ADDED



(b) CHANNEL SWITCHING WITH DIFFERENTIATION AND CLIPPING

FIG. 22
DIFFERENTIATION AND CLIPPING OF PLAYBACK SIGNALS.

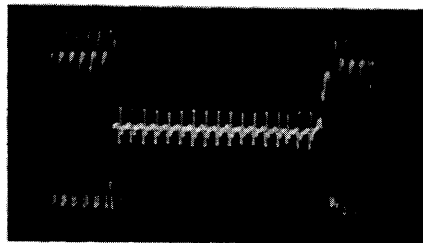


FIG. 23
READ-RECORD SWITCHING WITH DIFFERENTIATION AND CLIPPING

effect of adding the clipping circuit. The switching of Figure 22a was between two channels on both of which were recorded 1000-cycle pulses. The sample of the right-most channel of this figure shows the space between the beginning and the end of recording on the loop of tape.

C. Read-Record Switching

During recording there is no question about balancing the circuit to keep out the recording pulses, they exist across the head the same as the playback signals. Since they are 1000 times as large as the playback signals they have to be attenuated. The crystal in series with the switch-panel output chokes, and the crystals across the amplifier input serve to do this to a very considerable extent, but the remaining signals are still more than sufficient to overload the amplifier. For this reason the recovery time of the amplifier had to be shortened by reducing its coupling capacitors as mentioned above. The effect of this increased differentiating was to further differentiate the playback signals. This caused a loss of about 20 per cent of the amplitude of the positive peaks of the pulses.

Since the recording pulses were still extremely large at the output of the amplifier and differentiator, the crystal clipping circuit could not clip their amplitude down to that of the playback pulses. The same adjustment of the clipper as was used for Figure 22b resulted in the waveform of Figure 23. In this figure a period of reading is shown between two periods of recording. In a final system the signals will have to be reshaped, clipped to preserve only the positive half, and passed through a gate tube on the equivalent of the mode-switching flip-

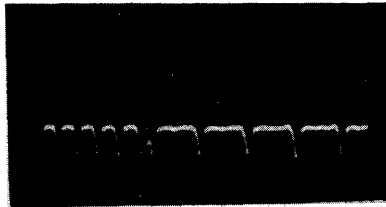
flop. The gate tube would then eliminate all pulses except those occurring during a reading operation.

In order to demonstrate the effect of switching channels during recording, 500-cycle pulses were recorded on one channel and then the frequency of the recording was changed to 1000 cycles per second, and the tape loop was passed under the head again. In this second recording the channel-switching flip-flop was pulsed so that the recording was done alternately in one channel and then in the other. By reading the channel that had had the 500-cycle pulses on it the effect of the switching could be seen. The results of this experiment are shown in Figure 24. These waveforms indicate that the switching has no effect on the tape and that the switching is practically instantaneous as far as the recording pulses are concerned. Figure 24a shows a 500-cycle and a 1000-cycle pulse almost superimposed, and in Figure 24c there is no indication as to the exact point at which switching occurred.

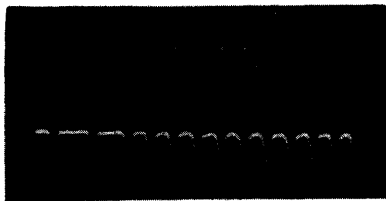
A photograph of the principal pieces of equipment used in this work is shown in Figure 25. The functions of the various components are indicated in the figure.



(a)



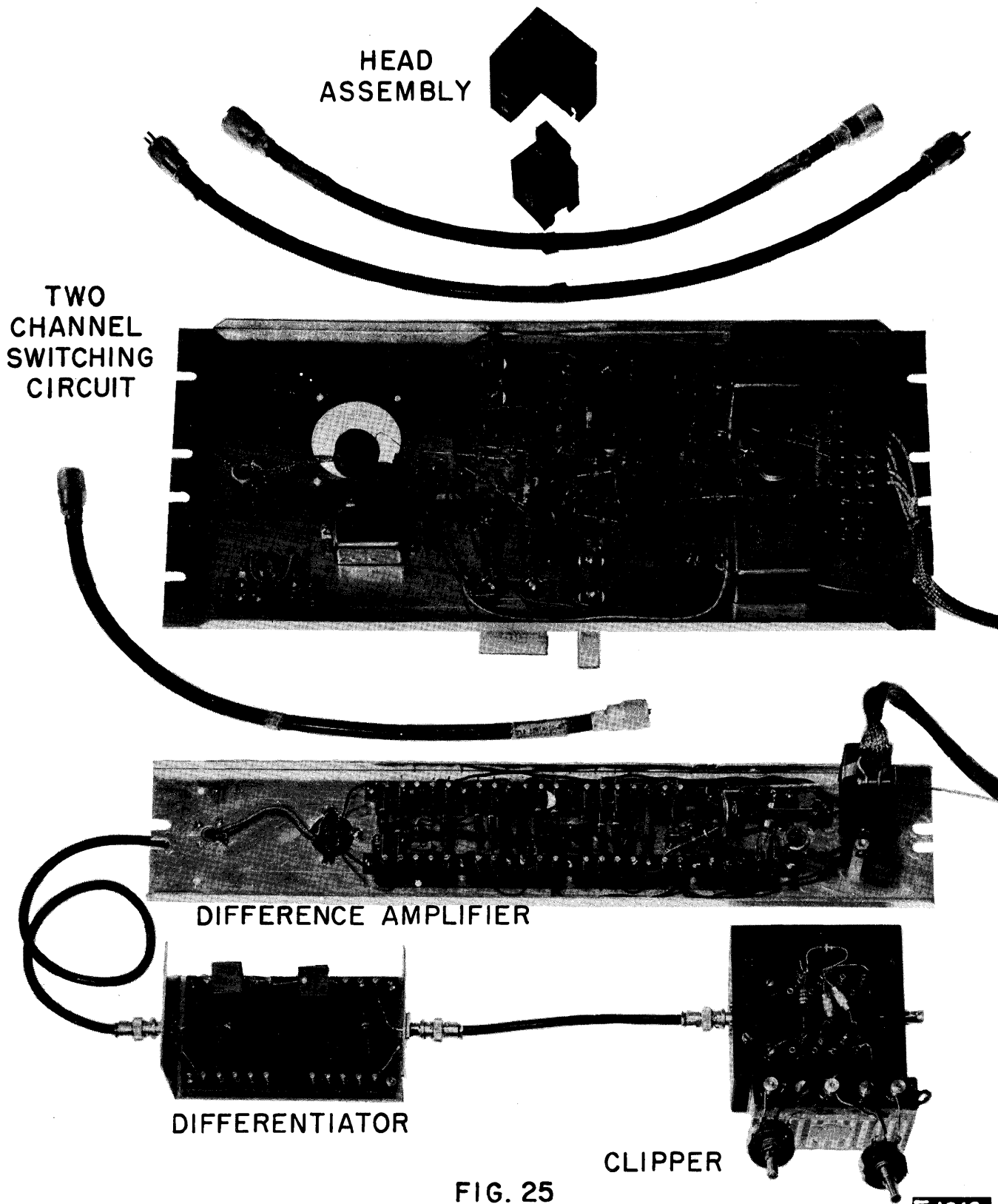
(b)



(c)

FIG. 24
EXAMPLES OF READING SIGNALS
THAT WERE CHANNEL-SWITCHED DURING RECORDING

A-36/84
F-13



HEAD
ASSEMBLY

TWO
CHANNEL
SWITCHING
CIRCUIT

DIFFERENCE AMPLIFIER

DIFFERENTIATOR

CLIPPER

FIG. 25

F-1312

TEST PANELS USED IN ELECTRONIC SELECTION
AND CONTROL OF MAGNETIC TAPE READ-RECORD HEADS

CHAPTER V

CONCLUSIONSA. Practicability

The data presented in the previous chapters shows that it is practical to accomplish electronic control and selection of the read-record heads. The design of the equipment used in this work is not meant to be a final design. A complete system designed to work with a computer, would include additional pulse shaping and clipping circuits together with re-design of those used in this work. The principal drawback to the system appears to be in obtaining crystals with low noise, although, as mentioned below, this may not be serious.

The switching time of less than 2 milliseconds in all of its phases is compatible with the requirements presented in Chapter I. Presumably this switching can take place during the clutch acting-time.

Considering that the switching circuit handles signals during recording that are 10,000 times as large as those handled during reading, it appears to work quite well.

B. Design Considerations

In designing equipment to perform the electronic head-control the most important point to be considered is noise elimination. The greatest danger from noise lies in the power supplies, but this is probably the most easily remedied noise source. If the noise on the power lines is reduced to include only those frequencies below the band-pass of the system, then very little difficulty should be had.

Hum pickup can be reduced to a negligible amount by shielding the panel and the power cables. The tube filament supplies need not be direct current as long as the wires are tightly twisted to prevent external fields, and are laid close to the metal chassis away from other wiring when possible. Care should be taken in the design of circuits to produce switching signals. The level of the signal that turns "on" a gate circuit should be established by ground potential or by the same potential used as the other reference of the gate circuit. That level of a switching signal that is controlled by the conduction of current in a vacuum tube should preferably be used to cut off the gate circuit. In this way fluctuations in the signal level are not as apt to be felt at the output of the gate circuit.

In this particular equipment the mixing crystals, as mentioned in Chapter III, have to be selected for their noise characteristics. Just how difficult this will be is not known, but it appears that the high-back-voltage crystals generally have the lowest noise. In a test of 10 Raytheon CK-707 crystals, 9 were found to generate low enough noise to be used in the equipment. Of course, if crystal noise is too objectionable, vacuum diodes can be used.

The final design consideration is microphonics. The amplification in the amplifier need not be so high as to allow ordinary room noise to cause objectionable microphonics, but in an electronic computer, every pulse must be present and no extra pulses introduced. This makes the system sensitive to transient noise that would not be too objectionable in an audio system. Such a noise might be caused by dropping something

near the rack containing the equipment, or by bumping the rack with a chair or some other hard object. Provision should be made to shock mount at least the first stage of the amplifier.

C. Future Work

Future work in this field should include a study of crystal noise with a view toward obtaining low-noise crystals even if the exact cause of the noise cannot be determined or remedied.

It is quite possible that a better head circuit can be designed depending upon what is desired. Different circuits, such as mentioned in the footnote in section B of Chapter II, should be investigated. In addition, the design of the external circuits, including the amplifier, needs to be refined.

Other applications for this type of electronic switching have not been sought or investigated. It appears, however, that this type of switching is suited to the switching of balanced signals in systems requiring bi-lateral or unilateral communication, particularly if the signals are of the same order of magnitude. In these cases the crystal bias could be made only slightly larger than the signals and thus reduce the relative noise.

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