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Massachusetts Institute of Technology

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TECHNICAL REPORT NO. 154

MARCH 27, 1950

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RESEARCH LABORATORY OF ELECTRONICS
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

The research reported in this document was made possible through support extended the Massachusetts Institute of Technology, Research Laboratory of Electronics, jointly by the Army Signal Corps, the Navy Department (Office of Naval Research) and the Air Force (Air Materiel Command), under Signal Corps Contract No. W36-039-sc-32037, Project No. 102B; Department of the Army Project No. 3-99-10-022.

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A. J. Lephakis

Abstract

A storage system which will store binary (ON or OFF) pulses has been constructed, and should prove useful in laboratory studies of certain communication problems. The system comprises two storage channels, each utilizing an M. I. T. electrostatic storage tube, and switching circuits which route incoming pulses into one channel while stored pulses are being recovered from the other. Pulses are stored in each tube in a square array of discrete spots of charge; each spot may assume one of two possible potentials, corresponding to the two possible states of a binary pulse. The order of occurrence of incoming pulses is preserved during storage, but the time relationship is not; the time relationship of pulses recovered from storage is determined by an independent pulse source under control of the user. Consequently, the system may be used to compress, expand, or delay a group of pulses. In order to facilitate testing of the system, special circuits have been provided. The capacity of each storage channel is, at present, 256 pulses. The system operates reliably at all frequencies up to 33 kc/sec when storing incoming pulses, and up to 70 kc/sec when supplying stored pulses.

* Part of this report is based on a thesis "Storage of Pulse Coded Information" submitted in partial fulfillment of the requirements for the degree of Master of Science at the Massachusetts Institute of Technology, September, 1949.

AN ELECTROSTATIC-TUBE STORAGE SYSTEM

I. Introduction

Several problems exist in the field of communication which apparently cannot be solved by applying conventional theory. These problems are parts of the more general problem of obtaining more efficient communication, and include reduction of noise, reduction of the bandwidth of the transmitted signal, and reduction of the time required for the transmission of a given amount of information. The new statistical information theory, recently developed by N. Wiener, C. E. Shannon, W. G. Tuller, and others, offers a promising approach to these basic problems. The M.I. T. Research Laboratory of Electronics is one of the organizations carrying out research in the practical application of information theory to communication problems.

In some of the laboratory investigations, signals which are generated in one part of a process are used, at a later time, in a different part. Consequently, a system is required which is capable of storing the generated signals until they are needed. In some cases, the type of storage required is merely a time delay; the output of the storage system must be a replica of the input. In other cases, the time scale of the storage-system output must be either compressed or expanded with respect to the time scale of the input.

Although it is possible to construct a storage system having the required characteristics whenever storage is necessary, it is not practical to do so. Both money and time can be saved by constructing one general-purpose storage system which is sufficiently flexible to be used in a large number of investigations. The project described in this report consisted of the selection, design, and construction of a storage system which serves this purpose.

The first step in the selection of a suitable storage system was to specify the electrical form of the information which is to be stored. Possible methods of conveying information electrically are to vary the amplitude or frequency of a voltage wave continuously, to vary the amplitudes, widths, or relative positions of pulses in a pulse train, and to vary the states of pulses in a pulse train, each pulse of which has only the two possible states of existence and non-existence. The last method mentioned deserves further consideration, because it has advantages not found in other methods. A pulse which has only two states, namely, it either exists or does not exist, will be termed a binary pulse; the former state will be referred to as ON, and the latter as OFF. A train of binary pulses can convey information in several different ways. Since each pulse has two possible states, each pulse can convey one of two units of information. A group of two adjacent pulses can convey one of four units of information, since the group has the four possible states of OFF-OFF, OFF-ON, ON-OFF, and ON-ON. In general, a group of N pulses can convey one of 2^N units of information. The pulse groups which make up a train may occur either periodically or non-periodically. The term pulse-coded information will be applied to information which is contained in the states of binary pulses.

The main advantage of using pulse-coded information is that electrical equipment through which the information passes need preserve only the ON-or-OFF states of pulses. Such equipment is simpler to design and less critical in operation than equipment which must preserve amplitudes or time durations. Because of the simplified equipment requirements, it is desirable to use pulse-coded information in laboratory investigations of communication problems. It was therefore decided that the utility of a general-purpose storage system would not be impaired if the system could store only pulse-coded information.

The proposed characteristics of a storage system which is sufficiently flexible to be of general use in the laboratory are:

1. Storage of only pulse-coded information is satisfactory.
2. The system should be capable of storing pulse groups and pulses which occur both periodically and non-periodically.
3. The minimum and maximum time intervals between adjacent pulses which are required for proper operation of the system should be respectively as small and as large as possible.
4. It should be possible to take pulses out of the system at a rate different from that at which pulses are inserted into the system. This feature would permit compression or expansion of the time scale of a group of pulses.
5. The system should be capable of accepting new pulses while stored pulses are being taken out, so that a continuous flow of information may be maintained.
6. The number of adjustments required in the equipment in order to set up the system for a particular type of operation should be kept at a minimum.

The characteristics of a storage system are primarily determined by the storage device which is used as the nucleus of the system. Flip-flop (bistable multivibrator) circuits, ultrasonic delay lines, electrostatic storage tubes, and magnetic recording media are the storage devices which were considered for use in the storage system. A flip-flop circuit has two stable electrical states, and can therefore store a binary pulse. Ultrasonic delay lines have been employed in closed-loop circuits which are capable of storing several hundred pulses (1); stored pulses circulate around the loop and are reshaped after each circulation by a coincidence circuit synchronized with standard clock pulses. Several special electrostatic storage tubes have been developed, among which are the M. I. T. Servomechanisms Laboratory tube (2), the R. C. A. selectron (3), the Raytheon repeller tube (4), the R. C. A. barrier-grid tube (5), and the Haeff tube (6). Conventional cathode-ray tubes have also been successfully used as storage tubes (7, 8). The two distinct states of potential which can be created on the target of an electrostatic storage tube by secondary-electron-emission phenomena are used to represent the states of stored binary pulses. The states of binary pulses can be stored in magnetic recording tape and drums as two different states of magnetization.

The properties of possible storage systems employing suitable existing storage devices were investigated. Flip-flop storage systems are highly flexible, but require an excessively large quantity of equipment. The flexibility of storage systems utilizing ultrasonic-line storage loops is limited by the synchronization required between the standard clock pulses and the input and output pulses. Flexibility characteristics similar to those of a flip-flop system can be obtained in an electrostatic-storage-tube system without the use of an excessively large quantity of equipment; the best storage tube for this application seems to be the M. I. T. tube. The uses of storage systems employing magnetic recording media are restricted by limitations in the associated mechanical equipment. The investigation showed that the most flexible, and yet practical, general-purpose storage system which can be devised from existing storage devices is an electrostatic-storage-tube system employing M. I. T. tubes. Consequently, it was decided to construct a system of this type. The construction has been completed, and the system is operating satisfactorily.

Figure 1 is a photograph of the storage system. The system comprises two storage channels, each consisting of an M. I. T. tube and the circuits which are necessary to

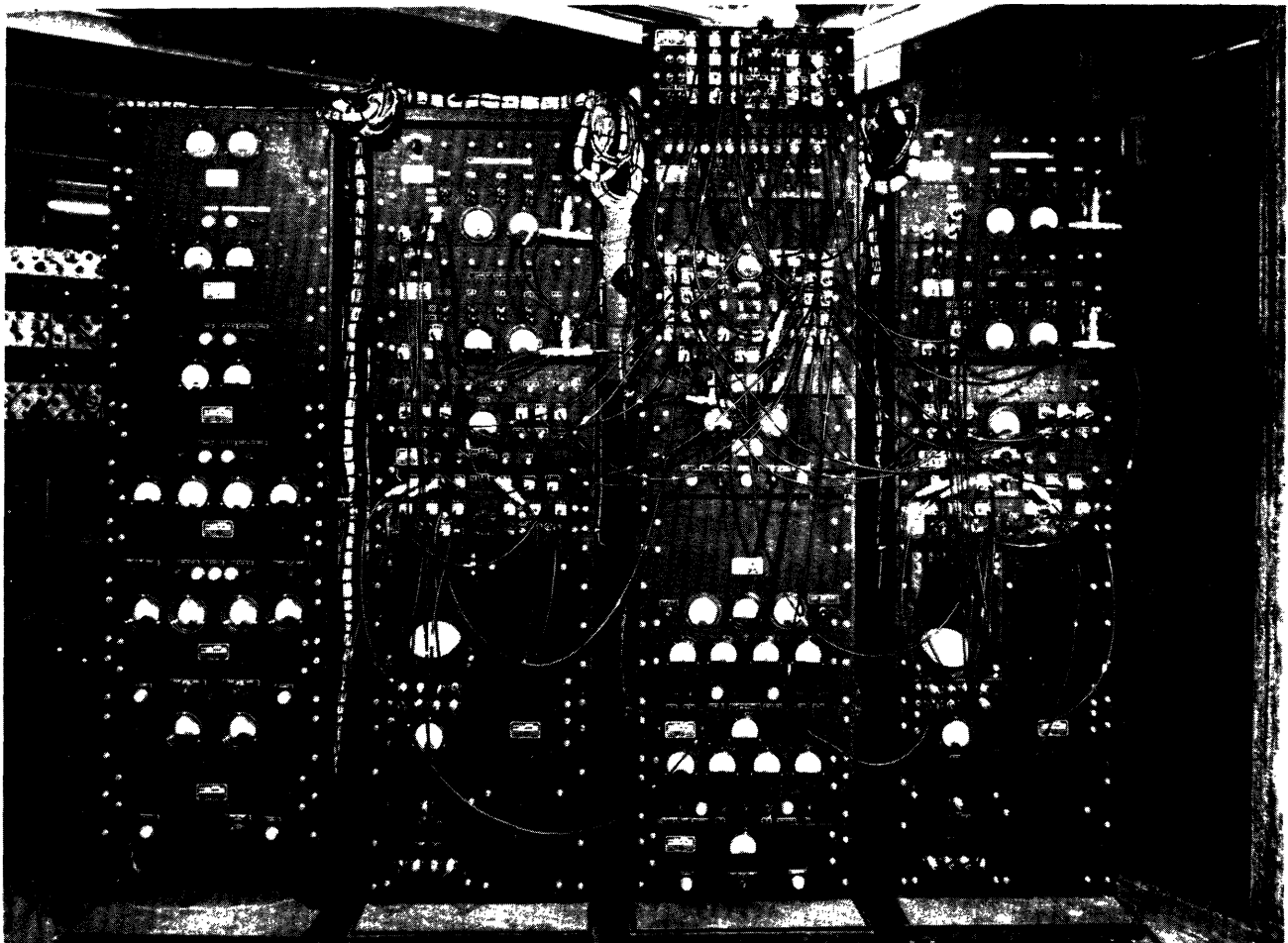


Fig. 1. Front view of the storage system.

operate the tube. Incoming pulses are routed to one of the two storage channels while pulses which have previously been stored in the other channel are being recovered; these operations are reversed when the channel in which storage is taking place is completely filled. The two storage channels occupy the second and fourth racks from the left in Fig. 1. The unit which controls the operations taking place in the two channels is in the middle of the third rack from the left; the unit on the top of this rack contains circuits which are used only when the system is being tested. The remainder of the equipment consists of power supplies.

A continuous flow of information can be maintained through the system, since the two storage channels perform opposite functions at any given time; one receives incoming pulses while stored pulses are being recovered from the other. The circuits have been made insensitive to pulse-repetition-frequency effects; the system will operate with non-periodic pulses, and when periodic pulses are used no adjustments are necessary if frequencies are changed. Compression, expansion, or delay of a group of input pulses may be easily obtained because the order of these pulses is preserved during storage but their time relationship is lost; the time relationship of pulses recovered from storage is determined by an independent pulse source.

A detailed description of the storage system will be postponed until pertinent properties of the M.I.T. storage tube, which is the basic element of the system, have been presented.

II. Operation of the M.I.T. Electrostatic Storage Tube

The M.I.T. electrostatic storage tube was developed for use in the Whirlwind computer, and is designed to store binary pulses. A sketch of this tube is shown in Fig. 2.

Operation of the tube is based on secondary-electron-emission phenomena. The electron-beam target consists of a dielectric surface covered on the front by a mosaic of conducting beryllium squares and on the back by a metallic coating termed the signal plate. A screen of fine wire mesh, the collector screen, is placed close and parallel to the face of the target. The secondary-emission ratio of the target face is determined by the energy of the bombarding electrons. If this energy is below a certain critical value, the secondary-emission ratio is less than unity. For electron energies in a large range above the critical value, the secondary-emission ratio is greater than unity. Therefore, when a target spot is bombarded by high-energy electrons, more than one secondary electron will be emitted by the spot for each incident primary electron. If the initial potential of the spot is below the potential of the collector screen, the collector screen will attract most of the secondary electrons and the potential of the spot will rise to an equilibrium value such that for each primary electron, one secondary electron escapes to the collector screen and the remaining secondary electrons return to the spot. The spot equilibrium potential will be slightly above collector-screen potential. If the initial potential of the spot is above the potential of the collector screen, most of the emitted secondary electrons will return to the spot and the potential of the latter will drop until

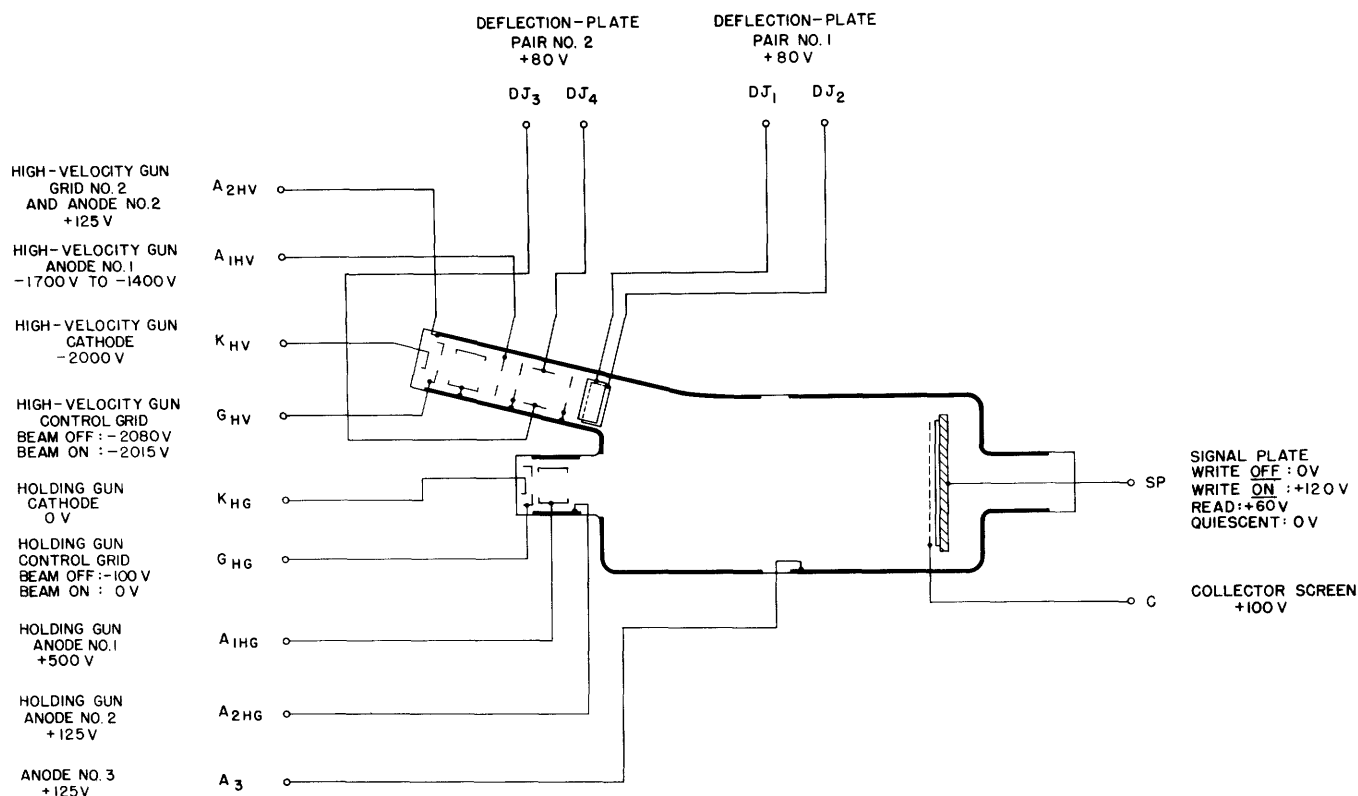


Fig. 2. The M.I.T. electrostatic storage tube.

the equilibrium condition is reached. When a target spot is bombarded by electrons having an energy below the critical value, the spot will gain negative charge and its potential will drop to the potential of the electron-gun cathode.

It is seen that two stable potential states can be established and maintained on the target surface by electron bombardment. High-energy bombardment produces collector-screen potential and low-energy bombardment produces the cathode potential of the electron gun.

The M.I.T. tube contains two separate electron guns, the high-velocity gun and the holding gun. The high-velocity gun has a narrow beam which can be positioned on any point of the target by applying appropriate voltages to the deflection plates. This beam is normally turned off. It is turned on only when signal pulses are written or stored pulses are read*. The holding gun sprays the entire target with a diffuse electron beam. This beam is on at all times except when writing or reading is taking place, and its purpose is to preserve the target potential pattern established by the high-velocity beam.

The critical energy of the target face is approximately 50 volts. Therefore, the holding beam permits the existence of two, and only two, stable potential states on the

* The terms write and read are used to refer, respectively, to the operations of storing a pulse and recovering a stored pulse.

target. These potentials are collector-screen potential (+100 volts) and holding-gun-cathode potential (0 volts). A pattern of +100-volt and 0-volt spots produced on the target by the high-velocity beam can be maintained indefinitely by the holding beam.

The two stable target potentials are used to represent the two states of binary pulses. Before a pulse is stored, the high-velocity beam is positioned on a target spot and the holding beam is turned off. An OFF pulse is stored by keeping the signal plate at its normal potential of 0 volts and turning on the high-velocity beam for a short time. The incident high-energy electrons drive the target spot to collector-screen potential. After this process is completed, the holding beam is turned on. An ON pulse is stored in a similar manner, except that the signal-plate potential is raised to 120 volts before the high-velocity beam is turned on. Because of displacement-current flow in the target dielectric and in the space between the target face and the collector screen, the effect of raising the signal-plate potential to 120 volts is an increase of approximately 100 volts in the potential of the whole target face. When the high-velocity beam is turned on, the bombarded spot will be driven to collector-screen potential. After the high-velocity beam is turned off, the signal plate is returned to 0 volts; the potential of the whole target face is decreased by 100 volts. Target points other than the bombarded spot will return to their initial states, but the bombarded-spot potential, which was left at +100 volts by the high-velocity beam, drops to 0 volts.

A stored pulse is read by first positioning the high-velocity beam and turning off the holding beam, then raising the signal-plate potential to 60 volts and intensity-modulating the high-velocity beam with a radio-frequency voltage. A tuned circuit placed in the signal-plate lead is excited by the radio-frequency variations in the signal-plate potential which occur as the bombarded spot is driven to collector-screen potential. The signal-plate potential variations which excite the tuned circuit consist of either positive or negative half-cycles, respectively corresponding to an ON or OFF stored pulse, because the potentials of target spots corresponding to ON and OFF stored pulses become respectively +50 and +150 volts when the signal-plate potential is raised to 60 volts. The state of the pulse being read is determined by amplifying the tuned-circuit output and determining its polarity by means of a phase-sensitive detector.

A summary of the various storage operations follows:

1. When writing or reading is not taking place, the holding-gun electron beam is turned on and the high-velocity-gun electron beam is turned off.
2. To write an ON pulse:
 - a. Position the high-velocity beam on a storage spot not containing a pulse which must be preserved.
 - b. Turn off the holding beam.
 - c. Apply a +120-volt gate to the signal plate.
 - d. Turn on the high-velocity beam. After the bombarded spot has reached equilibrium with the collector screen, turn off this beam.
 - e. After the signal-plate gate has decayed, turn on the holding beam.

3. To write an OFF pulse:
 - a. Position the high-velocity beam on a storage spot not containing a pulse which must be preserved.
 - b. Turn off the holding beam.
 - c. Turn on the high-velocity beam. After the bombarded spot has reached equilibrium with the collector screen, turn off this beam.
 - d. Turn on the holding beam.
4. To read a stored pulse:
 - a. Position the high-velocity beam on the spot in which the pulse is stored.
 - b. Turn off the holding beam.
 - c. Apply a +60-volt gate to the signal plate.
 - d. Intensity-modulate the high-velocity beam with a pulsed radio-frequency oscillation.
 - e. After the pulsed oscillation and the signal-plate gate have decayed, turn on the holding beam.

It is expected that a capacity of 1024 pulses will eventually be obtained in the M. I. T. tube. Deflection circuits providing 32 distinct potentials on each set of deflection plates will create a 32-by-32 square array of spots on the target; proper excitation of the deflection circuits will permit access to any given spot. The present maximum capacity of the tube is 400 pulses, stored in a 20-by-20 square array (9). The time required to write an ON pulse is approximately 13 μ sec, and an OFF pulse, 8 μ sec. The time required to read a pulse is about 6 μ sec. It is expected that improved tubes will have writing and reading times of the order of 2 μ sec.

III. Description of the Storage System

A. General Design

The design of the storage-system circuits was based on tentative storage-tube data which were available in the early part of 1949. Provisions were made to change easily the pertinent operating characteristics of the circuits so that future storage tubes might be accommodated. Although circuit flexibility has been obtained at the expense of more complicated equipment, it is believed that the increased complexity is justified by the fact that the equipment will not likely become obsolete.

A block diagram of the storage system is shown in Fig. 3. It is seen that a large number of interconnections between the various units exist; a consistent system of notation, which is explained in Table 1*, has been adopted and has been used on all diagrams and on the labels on the equipment. The storage-system circuits consist of four basic units. The deflection unit generates the 32 distinct voltage levels which are required by one set of storage-tube deflection plates. A voltage level is maintained until a trigger pulse is applied to the deflection-unit input; the pulse causes the output voltage to jump to the next level. Each thirty-second input pulse causes the deflection unit to return to its initial state and to emit an output pulse. Sixteen, instead of 32, voltage levels may be

* Page 30.

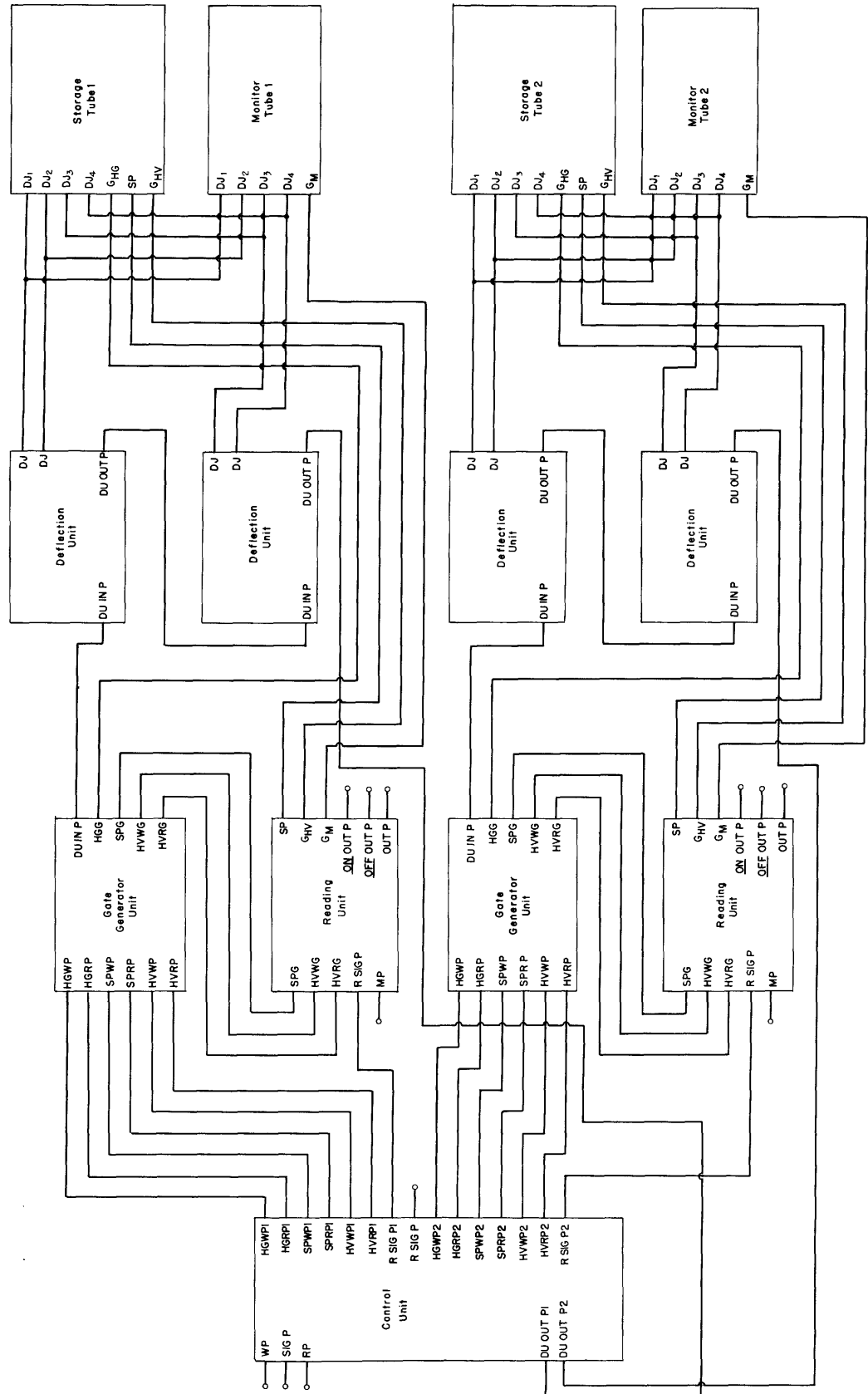


Fig. 3. Block diagram of the storage system.

obtained by making a simple change in the deflection unit. Although the storage tubes which are at present installed in the system are capable of storing a 20-by-20 array of pulses, they are operated with a 16-by-16 array because 20 voltage levels cannot easily be obtained from the deflection units. The gate-generator unit generates the writing and reading gates which are required by the signal plate, the high-velocity-gun control grid, and the holding-gun control grid. Each gate is initiated by a trigger pulse. The gate-generator unit also provides the deflection-unit input pulses. The reading unit generates the pulsed oscillation which is applied to the high-velocity-gun control grid during reading, and detects the pulses which are read. The duration of the pulsed oscillation is determined by a gate from the gate-generator unit. The control unit provides the pulses which trigger the gate-generator units associated with the two storage tubes, and determines whether writing or reading is taking place in each storage tube. Switching of the writing and reading operations is caused by pulses which are produced by the deflection units whenever a storage tube is completely full or empty. When tube 1 is full, writing commences in tube 2 and reading commences in tube 1. Tube 1 must be emptied before tube 2 is filled. When tube 1 is empty, its circuits become quiescent and remain quiescent until tube 2 is filled, at which time writing commences in tube 1 and reading commences in tube 2. The circuits of tube 2 become quiescent as soon as this tube is empty, and when tube 1 is full, the cycle of operations is repeated.

The two deflection units which accompany each storage tube produce the storage spots in sequence. Trigger pulses are applied to the DJ_1 - DJ_2 unit; as the voltage output of this unit jumps from the highest level to the lowest, the accompanying output pulse causes the voltage output of the DJ_3 - DJ_4 unit to jump to the next level. The monitor tubes which are associated with the storage tubes are type 5CP1-A cathode-ray tubes, and are used when the system is being tested.

It has been attempted to keep the current drain of the various circuits at a minimum, consistent with satisfactory operation, in order to simplify power supply requirements. The low-impedance, high-current, circuits which are generally required to obtain extremely narrow pulses and extremely small rise and fall times of gates have been avoided. The widths of pulses generated by the equipment are approximately $0.2 \mu \text{ sec}$, and the rise and fall times of generated gates are approximately $0.2 \mu \text{ sec}$. The deflection units require, after being triggered, a maximum time of $2 \mu \text{ sec}$ to establish a new set of deflection voltages. Pulse transformers have been employed to invert the polarities of negative pulses and to obtain pulses at a low output-impedance level in order to prevent waste of current in inverter tubes and in cathode-follower output tubes.

Pulse-repetition-frequency effects have been minimized by using clamping diodes in all capacitively coupled circuits.

B. Characteristics

The storage system has three inputs: the write pulses, the signal pulses, and the read pulses. The write and signal pulses must occur simultaneously; a write pulse initiates the write cycle during which the accompanying binary signal pulse is stored. The

read pulses initiate the read cycles. The write, signal, and read pulses must meet the following specifications:

1. Polarity: positive.
2. Minimum amplitude: 20 volts.
3. Width: 0.1 to 0.3 μ sec.
4. Minimum time interval between adjacent write pulses: approximately 30 μ sec if present storage tubes are used.*
5. Minimum time interval between adjacent read pulses: approximately 15 μ sec if present storage tubes are used.*
6. Maximum time interval between adjacent pulses: unlimited.
7. Periodicity: either periodic or non-periodic pulses can be used.
8. Synchronization between write and read pulses: none required.
9. Other relationship between write and read pulses: during each complete writing operation, there must be at least as many read pulses as there are write pulses so that the full storage tube may be emptied before, or at the same time that, the empty tube is filled.

The impedance level at the three inputs is high.

Several types of outputs are simultaneously provided. Positive pulses which represent ON stored pulses appear at the ON OUT P output of each reading unit. Positive pulses which represent OFF stored pulses appear at the OFF OUT P output of each reading unit. Positive and negative pulses which represent, respectively, ON and OFF stored pulses appear at the OUT P output of each reading unit. All output pulses have an amplitude of approximately 30 volts and are 0.2 μ sec wide; an output pulse occurs approximately 7 μ sec after the read pulse which initiates the read cycle. The impedance level at the three outputs is low. The system output can be obtained on a single line by mixing the outputs of the two reading units in a mixer provided for this purpose in the control unit.

The capacity of each storage channel is, at present, 256 pulses. Compression of the signal-pulse time scale may be obtained by using read pulses which are more closely spaced than the write pulses; the system output will consist of a sequence of spaced groups containing 256 pulses each. Expansion of the signal-pulse time scale may be obtained by using read pulses which are less closely spaced than the write pulses; the signal pulses must be arranged in a sequence of spaced groups containing 256 pulses each. Periodic signal pulses may be delayed for an interval 256 times as large as the period by using read pulses which are obtained from the same source as the write pulses.

* See Section VI-C.

IV. Circuit Details

A. The deflection unit

A block diagram of the deflection unit is shown in Fig. 4*. Five pentode current sources, which supply weighted currents in the ratio 1:2:4:8:16, are turned on and off by five flip-flops connected in a binary-counter circuit. The current-source outputs are

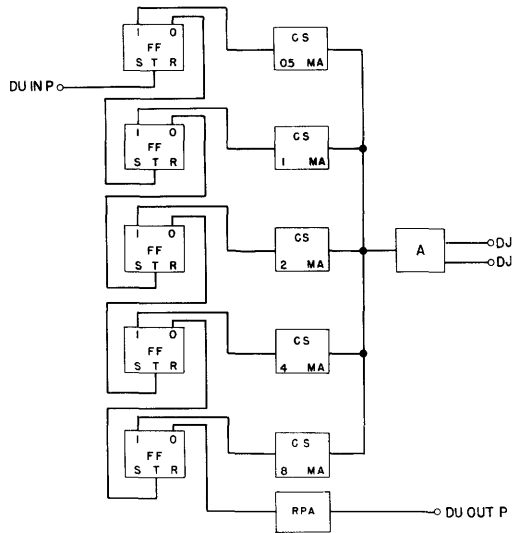


Fig. 4. Block diagram of the deflection unit.

added in a common load resistor, and the resulting voltage is applied to an amplifier which provides the balanced voltage necessary to drive the deflection plates. Each input trigger pulse shifts the output voltage to the next level. An established level is maintained constant until another input pulse is applied because direct coupling is used in the amplifier and between the current sources and the flip-flops. Thirty-two input pulses are required for a complete cycle of operation; at the end of each cycle, an output pulse is obtained from the counter.

The deflection-unit schematic diagram is shown in Fig. 5. Tubes V_{16} - V_{21} are the current sources, and V_1 - V_{10} are the flip-flop tubes. The flip-flops are isolated by trigger-tubes V_{12} - V_{15} . The counter-output pulse is supplied through a regenerative pulse amplifier, V_{11} .

A current source is on whenever the flip-flop tube to which the current-source grid is returned is not conducting. The plate load of each flip-flop tube consists of the two 8,200-ohm resistors and the 1N34 diode. The diode conducts when the tube is conducting; it does not conduct when the tube is cut off, because of the voltage developed by current flowing through the grid voltage divider of the opposite tube. This arrangement permits the plate of a non-conducting flip-flop tube to rise to the plate-supply potential; the grid potential of a conducting current-source tube is therefore a fixed reference value, and is not affected by changes in the characteristics of the flip-flop circuit (10). A swing of approximately 40 volts is obtained at the flip-flop plates. The current sources may be turned on and off manually by means of the push-button switches associated with the flip-flops.

The output of each current-source tube is determined by the bias voltage developed across its cathode resistors, and can be adjusted over a small range by means of the cathode potentiometer. The effects of possible changes in the characteristics of the current-source tubes have been minimized by using large cathode resistors. The use of

* The symbols used on block diagrams are explained in Table 2, p. 31.

large cathode resistors was made possible by returning the current-source-tube cathodes to a potential which is 20 volts below the flip-flop plate-supply potential.

The amplifier tubes are V_{22} - V_{25} . Tube V_{22} is a cathode-coupled phase inverter which converts the single-ended current-source output to a push-pull signal. A current source, pentode V_{23} , provides the cathode coupling between the two halves of V_{22} . An increase in the plate current of one half of V_{22} causes a corresponding decrease in the plate current of the other half because the sum of these currents is maintained constant by V_{23} . The gain of V_{22} from the input to either output is approximately 2. The push-pull output of V_{22} is amplified approximately 4.5 times by V_{24} , and is applied to cathode-follower V_{25} which drives the lines leading to the deflection plates. Cathode degeneration in each half of V_{22} and V_{24} was used to obtain linearity. The amplifier response was improved by using cathode compensation in both stages. Controls have been provided to balance the amplifier, to vary the amplitude of the output voltage, and to vary the average value of the output voltage with respect to ground.

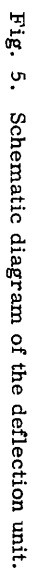
In one of the system tests, a linear sweep is required on the storage tube deflection plates. The purpose of the NOR-TV switch in the deflection unit is to enable such a sweep to be obtained; when the switch is placed in the TV position, the amplifier input is brought out to the TV jack, to which an externally generated linear voltage may be connected.

The deflection unit provides a balanced output, consisting of 32 equal-increment voltage levels, which may have a peak-to-peak value as high as 220 volts. The peak-to-peak deflection voltage which is required for operation of the storage tube is 100 to 200 volts. A maximum time of 2 μ sec is required for the establishment of a new voltage level after the deflection unit is triggered. The 16, instead of 32, voltage levels which are used in the system at present were obtained by transferring the deflection-unit input from flip-flop stage V_9 - V_{10} to stage V_7 - V_8 .

B. The gate-generator unit

A block diagram of the gate-generator unit is shown in Fig. 6. All gates are generated by cathode-coupled, one-shot (monostable) multivibrators. The gates are amplified and are applied through suitable circuits to the output lines. The loads on the outputs are capacitive.

All the output circuits except the one for the high-velocity-gun read gate operate in the same manner, and were designed to drive the capacitive loads. The gate is applied to the grid of a cathode follower, and the load is connected to the cathode of this tube. A discharge tube, which is normally not conducting, is connected across the load. Because of the load capacitance, the cathode potential of the cathode follower cannot change instantaneously. The positive-going edge of the gate, therefore, causes the grid-to-cathode potential of the cathode follower to increase by a considerable amount, and the resulting high cathode-follower current rapidly charges the capacitance; a large cathode resistor is used in order to allow most of the cathode-follower current to flow into the capacitance. The negative-going edge of the gate cuts off the cathode follower. A regenerative pulse



amplifier, which is triggered by a pulse coincident with the negative-going edge of the gate, turns on the discharge tube; the latter discharges the capacitance.

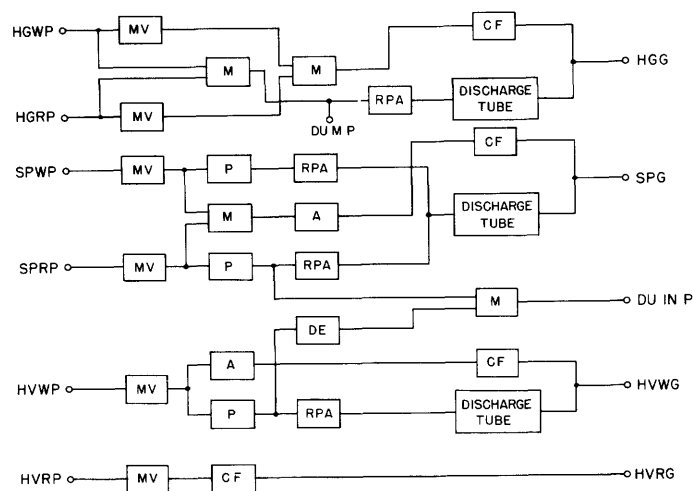


Fig. 6. Block diagram of the gate-generator unit.

The pulses which operate the gate-generator unit are supplied by the control unit. When writing is taking place in the storage tube with which the gate-generator unit is associated, pulses are applied only to the SPWP, HVWP, and HGWP inputs. When reading is taking place, pulses are applied only to the SPRP, HVRP, and HGRP inputs.

A pulse applied to either the HGWP or HGRP input initiates the 100-volt negative gate which turns off the holding beam during the writing or reading of a signal pulse. The pulse which triggers the multivibrator generating the gate also triggers the regenerative pulse amplifier in the output circuit, and appears at the DU M P output. The deflection pattern may be monitored by using the pulses obtained at the DU M P output to intensify the beam of the monitor tube.

A pulse applied to the HVWP input initiates the 65-volt positive gate which turns on the high-velocity beam during the writing of a signal pulse. A pulse which is formed at the trailing edge of this gate triggers the output-circuit regenerative pulse amplifier, and is delayed and applied to the deflection-unit input; the delay is necessary to prevent triggering of the deflection unit before the high-velocity beam is completely turned off.

A pulse applied to the HVRP input initiates the gate which energizes the pulsed oscillator in the reading unit. A conventional cathode follower is used as the output circuit because the capacitive load on this circuit is small and the amplitude of the gate is small.

Pulses which are to be stored are applied to the SPWP input. An OFF pulse does not trigger the multivibrator, and the signal-plate potential remains at its quiescent value. An ON pulse initiates the 120-volt positive gate which is applied to the signal plate; a pulse formed at the trailing edge of this gate triggers the output-circuit regenerative pulse amplifier.

A pulse applied to the SPRP input initiates the 60-volt positive gate which is applied

to the signal plate during the reading of a stored pulse. A pulse which is formed at the trailing edge of this gate triggers the output-circuit regenerative pulse amplifier and the deflection unit. Since the high-velocity beam is turned off before the signal-plate gate decays, it is not necessary to delay the pulse which triggers the deflection unit.

Two regenerative pulse amplifiers are provided in the signal-plate-gate output circuit because the load capacitance which is driven by this circuit must be discharged from two different initial potentials, namely, +120 volts and +60 volts. The regenerative pulse amplifiers can be adjusted to produce optimum discharging in both cases.

The schematic diagram of the gate-generator unit is shown in Fig. 7. The pulse transformers in the input lines have a 1:3 turns ratio, and step up the amplitudes of the pulses which come from 3:1 transformers in the control unit. The trigger tubes (V_1 , V_{15} , V_{24}) which are provided between the inputs and the multivibrators (V_2 , V_3 , V_{16} , V_{17} , V_{25} , V_{26}) amplify the trigger pulses and isolate the multivibrators from the inputs. The widths and amplitudes of the multivibrator gates are stabilized by the clamping diodes (V_4 , V_{18} , V_{27}) which are connected to the grids of the right-hand halves of the multivibrator tubes; the diodes define the quiescent potentials of these grids, and therefore eliminate the effects which would be caused by changes in tube characteristics if the grids were returned to the plate-supply potential. The diodes also hasten recovery of the multivibrators by providing low-impedance paths through which the multivibrator coupling capacitors can discharge.

Split loads are used in the right-hand-plate circuits of V_2 , V_3 , and V_{16} because these multivibrators drive both gate amplifiers (V_7 , V_{19}) and pulse-forming tubes (V_5 , V_{19}). When the multivibrators are triggered the 1N34 diodes in the multivibrator plate circuits stop conducting, and therefore the gate-amplifier inputs are isolated from the pulse-forming-tube inputs. This arrangement prevents pulse-forming-tube grid current from affecting the shapes of the gates applied to the gate amplifiers.

The signal-plate gates are mixed in tube V_7 and are amplified by V_8 . Tube V_{10} is the output cathode follower, V_{14} is the discharge tube, and V_{12} and V_{13} are the regenerative pulse amplifiers. The pulses which trigger the regenerative pulse amplifiers are formed in V_5 . The gate at the plate of V_8 is differentiated, and the negative pulse which is thus obtained at the trailing edge is fed back to V_2 and V_3 . This pulse speeds up the multivibrator switching action which terminates the gate, and eliminates a pronounced "droop" which otherwise appears just before the end of the gate. The S ZERO control is used to adjust the quiescent signal-plate potential to 0 volts.

The high-velocity-gun write gate is amplified by the left-hand halves of V_{19} and V_{20} . The right-hand half of V_{20} is the output cathode follower, V_{23} is the discharge tube, and V_{22} is the regenerative pulse amplifier. The pulse which triggers the regenerative pulse amplifier is formed in the right-hand half of V_{19} .

The high-velocity-gun read gate is applied directly to the output cathode follower, which is the left-hand half of V_{29} .

The holding-gun gates are mixed in V_{28} . The right-hand half of V_{29} is the output

cathode follower, V_{32} is the discharge tube, and V_{31} is the regenerative pulse amplifier.

The pulses which are applied to the deflection unit are mixed in V_6 . When the DU IN P SELECTOR switch is in position N, the deflection unit is triggered after a pulse is written and after a pulse is read. When the switch is in positions W or R, the deflection unit is respectively triggered only after a pulse is written or read. When the switch is in position O, the deflection unit is not triggered. For normal operation of the storage system, the switch is kept in position N; the W, R, and O positions are used when the system is tested. The L-C network in the grid circuit of the left-hand half of V_6 provides a 0.3- μ sec delay which insures that the high-velocity beam is completely turned off when the deflection unit is triggered after a write cycle.

The widths of all gates can be adjusted from 0.5 μ sec to approximately 25 μ sec by the potentiometers in the multivibrator circuits. The amplitude of the signal-plate write gate is adjustable from 20 to 200 volts; that of the signal-plate read gate, from 20 to 175 volts. The amplitude of the high-velocity-gun write gate is adjustable from 20 to 100 volts. The amplitude of the high-velocity-gun read gate is adjustable from 5 to 25 volts. The holding-gun-gate amplitude is adjustable from 70 to 170 volts.

The signal-plate-gate output circuit can drive a capacitance of 0.001 μ f to 200 volts with a rise time of 1 μ sec and a fall time of 0.2 μ sec; the rise time is limited by V_8 , not by the output circuit. The high-velocity-gun-gate output circuit and the holding-gun-gate output circuit can drive capacitances of 0.0003 μ f to 150 volts; gate rise and fall times of approximately 0.2 μ sec are obtained.

The tubes used in the gate output circuits have been selected because they can provide the necessary high peak plate currents. Triodes operated at high plate voltages are used as the cathode followers in order to permit the load capacitances to charge before the cathode followers draw grid current. Pentodes are used as the discharge tubes. The cathode of a discharge tube is returned to a potential such that the plate-to-cathode potential of the tube falls on the knee of the plate characteristics when the load capacitance is fully discharged. This method of operation is optimum; if the knee of the plate characteristics is reached before the capacitance is fully discharged, the discharging current is reduced and a longer time is required to accomplish the discharging; if the knee is not reached when discharging is completed, the capacitance is charged appreciably in the negative direction unless the regenerative-pulse-amplifier pulse is terminated at exactly the right time.

C. The reading unit

A block diagram of the reading unit is shown in Fig. 8. When writing is taking place in the storage tube with which the unit is associated, the signal-plate write gate and the high-velocity-gun write gate are applied, through the 10-Mc filters, to the signal plate and to the high-velocity-gun grid. The capacitances which are driven by the gate-generator-unit SPG and HVWG output circuits are components of the filters.

When reading is taking place, the signal-plate read gate is applied through the filter to the signal plate. The high-velocity-gun read gate operates the 10-Mc/sec pulsed

oscillator. The oscillator output is amplified and is applied to the high-velocity-gun grid; the filter in the HVWG line presents a high impedance to this signal. The radio-frequency signal-plate output is amplified and is compared with the pulsed-oscillator

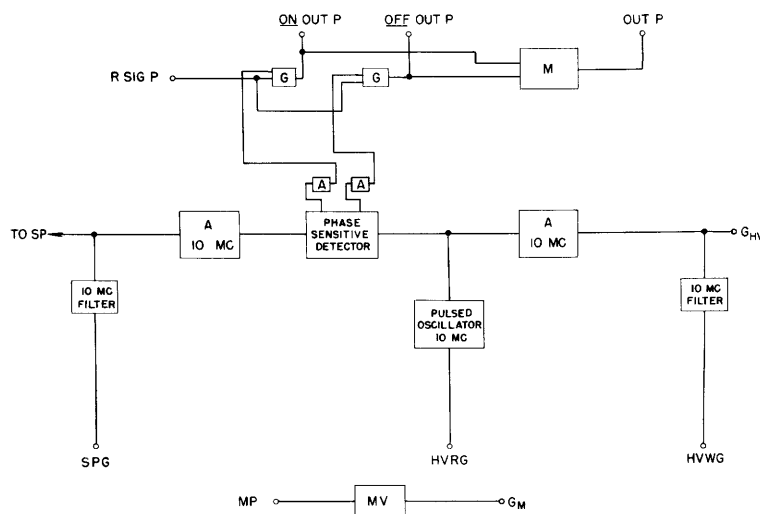


Fig. 8. Block diagram of the reading unit.

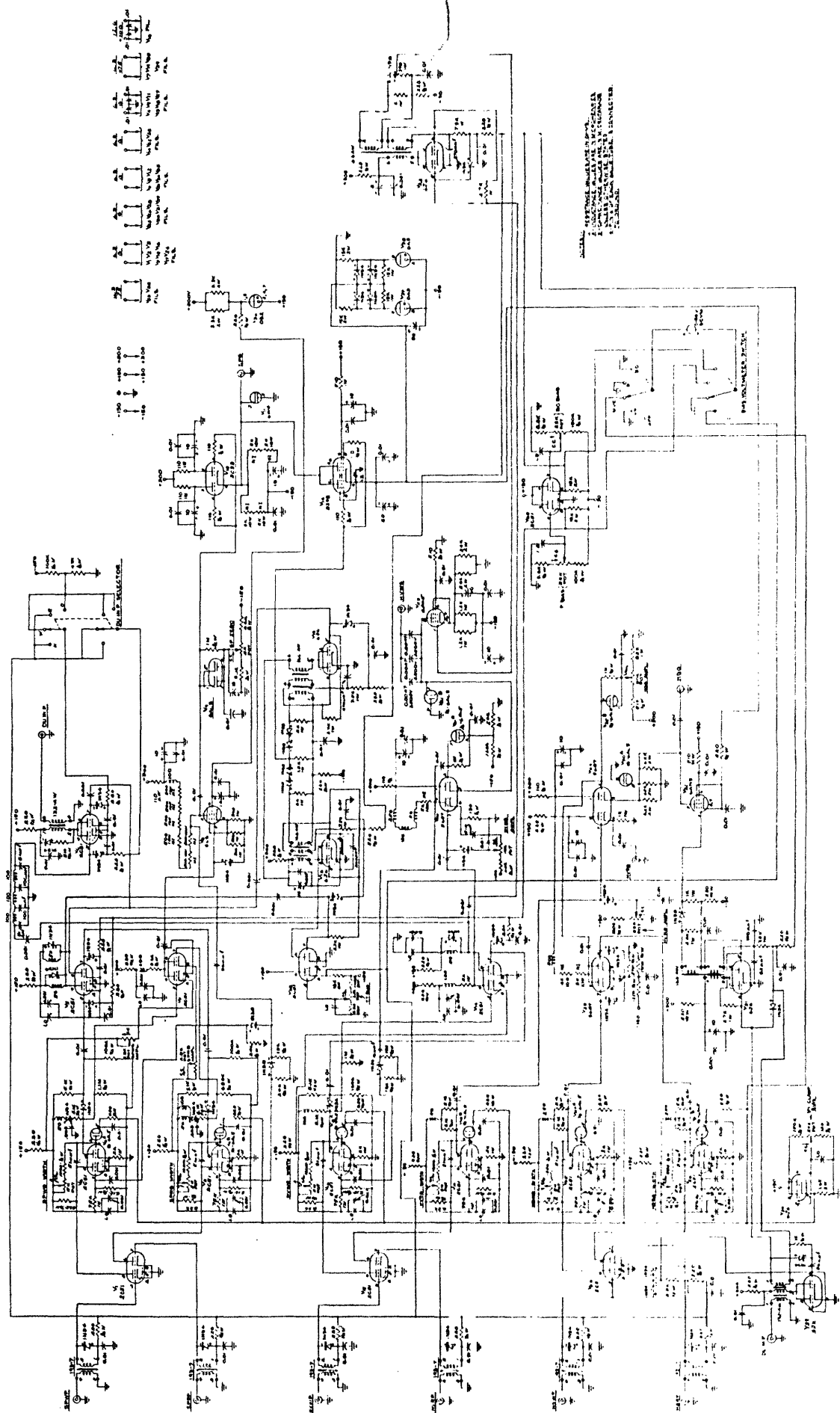
signal in the phase-sensitive detector. The positive gate appearing at one of the two amplified detector outputs opens the appropriate output gate tube, which passes the read signal pulse supplied at the proper time by the control unit. Separate outputs are provided for ON and for OFF recovered pulses. A combined output in which positive and negative pulses respectively represent ON and OFF recovered pulses is also available.

At the start of a read cycle, a transient signal is produced in the signal-plate radio-frequency amplifier by the leading edge of the signal-plate read gate. This transient must be allowed to decay before the remainder of the read cycle is carried out, otherwise an erroneous output may be obtained. Since the amplitude of the transient is affected by the signal-plate-gate rise time in an inverse manner, an extremely small rise time is not desirable.

A multivibrator has been provided in the reading unit to operate the monitor tube. The monitor-tube electron beam is intensified by the gate which is generated each time that the multivibrator is triggered.

The reading-unit schematic diagram is shown in Fig. 9. The signal-plate radio-frequency amplifier consists of tubes V_1 - V_5 . The gain of the amplifier is controlled by R_1 , and has a maximum value of approximately 10^6 . The AMP terminal has been provided to permit observation of the amplifier output on an oscilloscope; a terminated line connected from this terminal to an oscilloscope will not have any effect on the operation of the circuit.

Stage V_6 is a two-terminal oscillator (11). The tuned circuit of this stage is normally damped by the low cathode impedance of V_7 . Oscillation occurs only when V_7 is turned off by the amplified high-velocity-gun read gate which appears at the plate of the



right-hand half of V_9 . It was found that the rise and decay of the pulsed oscillation can be limited to less than one-half of a cycle by properly adjusting the plate current of V_7 .

Tube V_8 amplifies the oscillator output. The left-hand half of V_9 damps the amplifier tuned circuit and prevents ringing of this circuit when the pulsed oscillation is terminated. An oscilloscope may be connected to the RF SIG terminal without affecting the circuit.

Coils L_3 and L_{11} are parts of the filters shown in Fig. 8. High-Q coils were used to make the filters have high impedances at the reading-unit radio frequency. These filters must have this property in order to minimize radiation of the 75-volt signal which is present at amplifier V_8 and to minimize stray pickup at the input of preamplifier V_1 ; care was taken to insure that the stray pickup is small, because the r-f signal-plate output is of the order of 100 microvolts.

The phase-sensitive detector consists of stages V_{16} and V_{17} . Each of the negative bias voltages which are applied to the suppressor grids and control grids of these tubes is sufficient to prevent plate-current flow; plate current will flow only if positive signals are simultaneously applied to both grids. The pulsed-oscillator output is applied to the suppressor grids of the tubes, and the signal-plate-amplifier output is applied to the control grids. The former signal has the same phase relationship at both tubes; the latter appears in phase opposition at the two control grids. Since the signal-plate output is either in phase or 180° out of phase with the pulsed-oscillator signal, these signals coincide in one, and only one, of the two detector tubes. The output of the tube in which coincidence takes place is a negative gate. The positive gate which is obtained from the corresponding half of amplifier V_{15} is applied to the suppressor grid of V_{13} or V_{14} . The coils at the input of the signal-plate amplifier are arranged to cause coincidence to take place in V_{17} when an ON pulse is read and in V_{16} when an OFF pulse is read. An oscilloscope may be connected to the ON GATE or OFF GATE terminals through a short unterminated line without affecting operation of the circuit.

The read signal pulses are applied to both output gate tubes (V_{13} and V_{14}) and are timed at the control unit to occur after the phase-sensitive-detector gates have risen. Since each of the negative bias voltages applied to the suppressor grids and control grids of these tubes is sufficient to cause plate-current cut-off, a read signal pulse will pass only through the tube opened by the detector gate. ON and OFF recovered pulses appear as positive pulses at the two outputs of amplifier V_{19} . An output consisting of both ON and OFF recovered pulses appearing respectively as positive and negative pulses is obtained from mixer tube V_{12} .

Stage V_{16} is the monitor-tube multivibrator. The G_M GATE switch permits the application of an external intensifying gate to the monitor tube.

D. The control unit

The major function of the control unit is to route the write and signal pulses and the read pulses to the gate-generator units which operate the two storage tubes. Another function of the control unit is to delay by appropriate amounts the pulses which initiate the signal-plate and the high-velocity-gun gates; it will be recalled that at the start of a

write or read cycle the holding beam is turned off first, then the signal plate is brought to the proper potential, and finally the high-velocity beam is turned on. The control unit also supplies the read signal pulses to the reading units; these pulses are delayed read pulses.

A block diagram of the control unit is shown in Fig. 10. Pulses are delayed by means

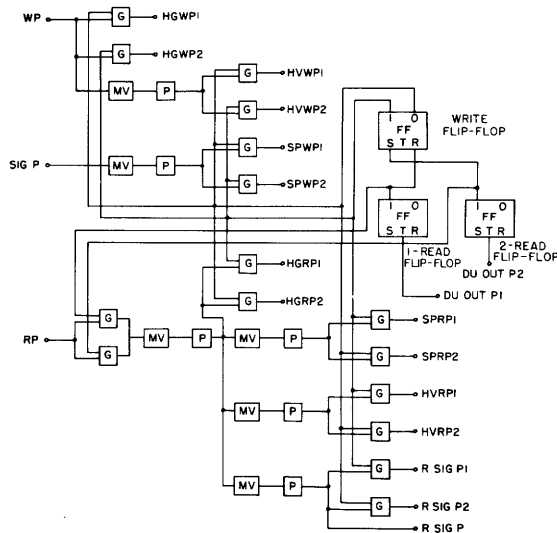


Fig. 10. Block diagram of the control unit.

tubes are operated by the 1 output of the write flip-flop, and when open, cause writing to take place in storage-tube 2 and permit reading to take place in storage-tube 1. It is seen that the write flip-flop serves two purposes: it switches the writing and reading operations from one storage channel to the other, and it prevents the occurrence of both writing and reading in the same channel.

Whether or not reading is taking place in the channel selected by the write flip-flop is determined by the states of the 1-read and 2-read flip-flops, since these flip-flops operate gate tubes in the RP line. The purpose of the read flip-flops is to remove the read pulses from a storage channel as soon as reading has been completed.

The write flip-flop is reset by positive pulses which are formed when tube 1 of the 1-read flip-flop stops conducting, and is set by positive pulses which are formed when tube 1 of the 2-read flip-flop stops conducting. The state of the write flip-flop does not change when tube 1 of the 1-read or 2-read flip-flop starts conducting, because diodes prevent the application of negative pulses to the two write-flip-flop inputs.

As soon as writing is completed in a storage tube, reading commences in this tube and writing commences in the other tube. When reading of a storage tube is completed, its read circuits become quiescent and the tube is ready to receive new signal pulses. Suppose that writing is taking place in storage-tube 1 and that reading of storage-tube 2 has been completed. Under these conditions, tube 0 of the write flip-flop is not conducting and tube 1 of each read flip-flop is conducting. As soon as storage-tube 1 is

of one-shot multivibrators and pulse-forming tubes; the pulse applied to a multivibrator initiates a gate, and the pulse-forming tube generates a pulse at the trailing edge of the gate. The routing is accomplished by means of gate tubes which are opened and closed by flip-flops. Direct coupling is used between the gate tubes and the flip-flops.

The 0 output of the write flip-flop operates the three WP1 gate tubes, the three RP2 gate tubes, and the R SIG P 2 gate tube. When these gate tubes are open, writing will take place in storage-tube 1 and reading may take place in storage-tube 2. The WP2, RP1, and R SIG P 1 gate

filled, the pulse from its deflection unit triggers the 1-read flip-flop and tube 1 of the latter stops conducting. Consequently, the gate tube operated by this flip-flop is opened, and the state of the write flip-flop is changed. Subsequent write and signal pulses are sent to storage-channel 2. Reading of storage-tube 1 commences with the first read pulse which occurs after the switching operation. When reading of storage-tube 1 is completed, the deflection-unit output pulse triggers the 1-read flip-flop and tube 1 of the latter starts conducting; read pulses are removed from storage-channel 1, but the state of the write flip-flop is not changed. A switching sequence similar to the one described occurs when storage-tube 2 is filled.

In addition to rendering the read circuits of a storage channel quiescent upon the completion of reading, the two gate tubes in the read-pulse input line, and the delay multivibrator which follows these tubes, insure proper reading of the first pulse stored in a storage tube in the case where the write and read pulses are not synchronized. Both gate tubes are closed after reading of a storage tube is completed, and remain closed until reading of the other storage tube is commenced. As soon as the 1-read or 2-read flip-flop initiates reading, one of the gate tubes is opened. The first read pulse occurring after this operation triggers the delay multivibrator, which is adjusted to provide the 2- μ sec delay required for the establishment of a new set of deflection voltages. The multivibrator output pulse starts the first read cycle. When the write and read pulses are not synchronized, a read pulse may occur while the gate tube is being opened. Such a pulse will pass through the gate tube, but will have a reduced amplitude at the output of the gate tube. The gate-tube output pulse either will or will not trigger the delay multivibrator. If it triggers the multivibrator, the first read cycle will be initiated. If it does not trigger the multivibrator, the next read pulse will initiate the first read cycle. In either case, the first stored pulse will not be lost.

The control-unit schematic diagram is shown in Fig. 11. Stages V_1 - V_{11} are the write circuits, and V_{14} - V_{38} are the read circuits.

The write pulses are applied to gate-tubes V_2 and V_3 and to the left-hand half of tube V_1 . The left-hand half of V_1 triggers the high-velocity-gun delay multivibrator, which is V_4 . A pulse is formed in the left-hand half of V_7 at the trailing edge of the multivibrator gate, and this pulse is applied to gate-tubes V_8 and V_9 .

The binary signal pulses trigger delay-multivibrator V_5 , through the right-hand half of V_1 . The delayed pulses are formed in the right-hand half of V_7 , and are applied to gate-tubes V_{10} and V_{11} . The state of OFF signal pulses is preserved by the control unit, since such pulses do not trigger V_5 .

Stage V_{12} is the write flip-flop. Stage V_{13} is a buffer which is used to isolate the flip-flop from the capacitance of the gate-tube suppressor grids.

Stages V_{36} and V_{37} are respectively the 1-read and 2-read flip-flops. The gate tubes which these flip-flops operate, through buffer-stage V_{38} , are V_{14} and V_{15} . The circuit which insures proper reading of the first stored pulse includes multivibrator V_{17} and pulse-forming-tube V_{19} . The high-velocity-gun read pulses, signal-plate read pulses,

and read signal pulses are delayed respectively by multivibrators V_{24} , V_{25} , and V_{26} . Pulses which are synchronized with the read signal pulses are available at the output of the right-hand half of V_{29} ; these pulses can be used to synchronize other equipment with the storage-system output.

The pulse transformers in the gate-tube output circuits supply positive pulses at a low impedance level.

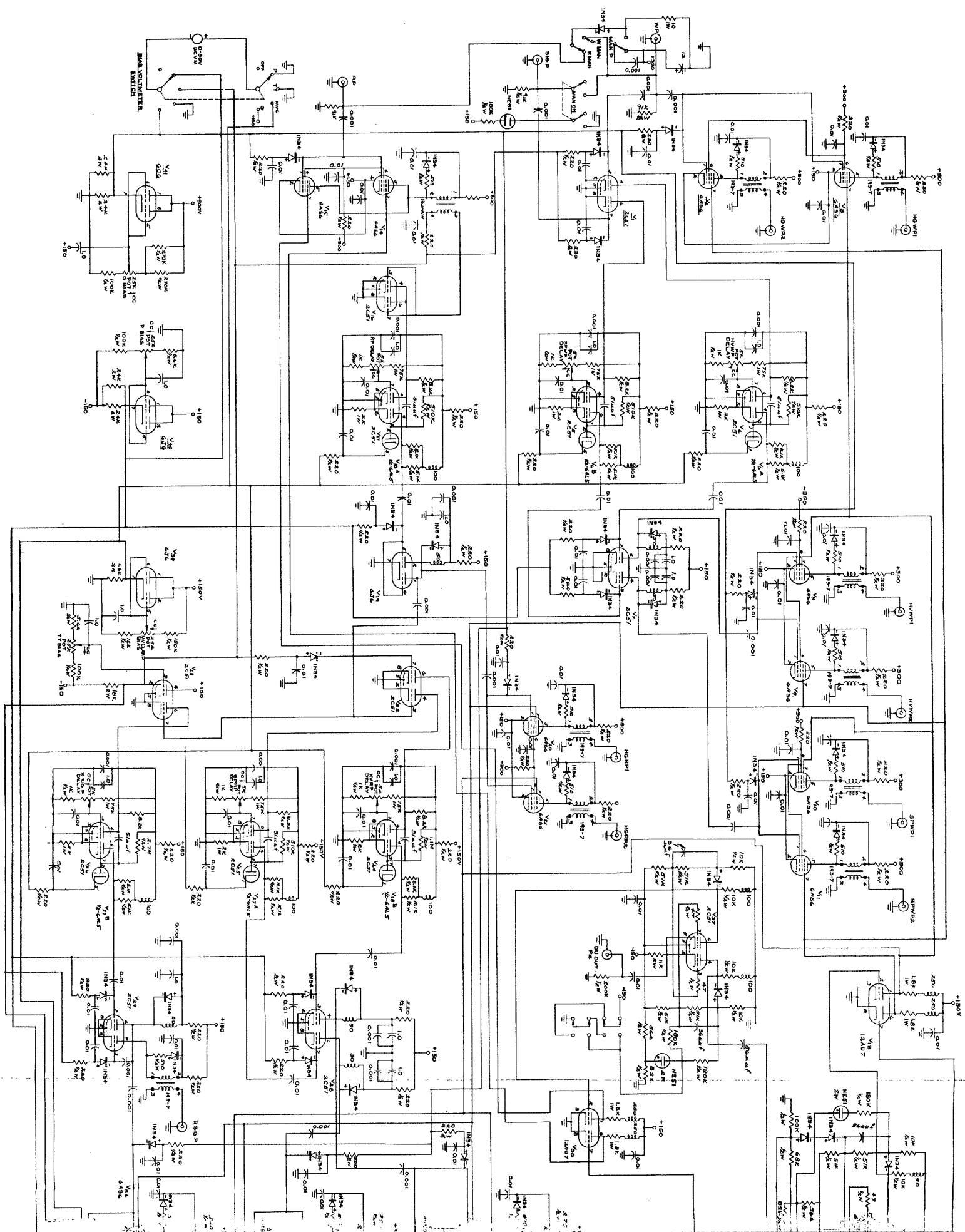
Stages V_{42} - V_{47} are two pulse delay channels which are used when the storage system is being tested. The two pulse mixer channels (shown above tube V_{42} on the diagram) can be used to mix the positive ON output and OFF output pulses obtained at the two reading units.

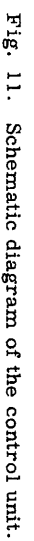
Provision has been made, by means of the switches shown to the left of tube V_1 on the diagram, for manual operation of the storage system. When the W MAN-R MAN switch is in the R MAN position, a read pulse is generated each time the MAN P switch is depressed. When the former switch is in the W MAN position, the MAN P switch produces write pulses accompanied by OFF signal pulses; if the MAN ON switch is held in the depressed position, the MAN P switch produces write pulses accompanied by ON signal pulses.

E. Protective circuits

Damage to a storage-tube gun cathode may result if the control-grid-to-cathode voltage of the high-velocity gun is allowed to become positive. In order to guard against such damage, protective circuits which were recommended by the M. I. T. Servomechanisms Laboratory have been incorporated in the storage system. These circuits include tubes V_{21} and V_{22} in the reading unit (Fig. 9). Diode V_{22} becomes a low impedance between the electron-gun grid and cathode for positive grid-to-cathode voltages. Diode V_{21} offers further protection; a high electron-gun cathode current will develop a voltage across the 180,000-ohm resistor associated with V_{21} which is sufficient to open-circuit the diode; the resistor will limit the electron-gun current. A circuit in the high-voltage power supply prevents rapid build-up of the high voltage when the supply is turned on; coupling condensers are charged slowly, and large transients which might overcome the electron-gun grid bias are prevented.

All power from the 115-volt a-c lines is supplied to the storage system through the power-control unit. This unit contains a number of relays which are connected in an interlocking circuit, and protects the system in several ways. When the equipment is turned on, an interval of 90 seconds is provided to allow the filaments of all tubes to warm up; no d-c voltages are applied during this interval. The primaries of the plate transformers of all power supplies are combined in groups, and these groups may be turned on and off only in a certain order. Although the power supplies are individually fused, failure of any fuse causes all supplies in that group to be turned off. The last two features protect direct-coupled circuits, and insure that bias voltages are applied whenever plate voltages are applied. In case of a power line failure, or of failure of a filament-line fuse, all power to the system is turned off. The power-control unit will not





automatically turn on the equipment after a failure has been corrected; the relays must be reset manually before operation can be resumed.

In addition to protecting the equipment, the power-control unit serves two other purposes. The first is division of the total power-line load, and the second is prevention of power-line transients when the equipment is turned on. The total power-line current required by the storage system is about 30 amp. This load is divided into approximately three equal parts in the power-control unit, and may be connected to a three-phase line. Large power-line transients are prevented by the application of reduced voltage to the tube filaments during the first 30 seconds of the 90-second warm-up period.

F. Construction of the equipment

The general type of construction used in the storage-system equipment is illustrated in Fig. 12, which is a photograph of the control unit. The deflection units, the gate-

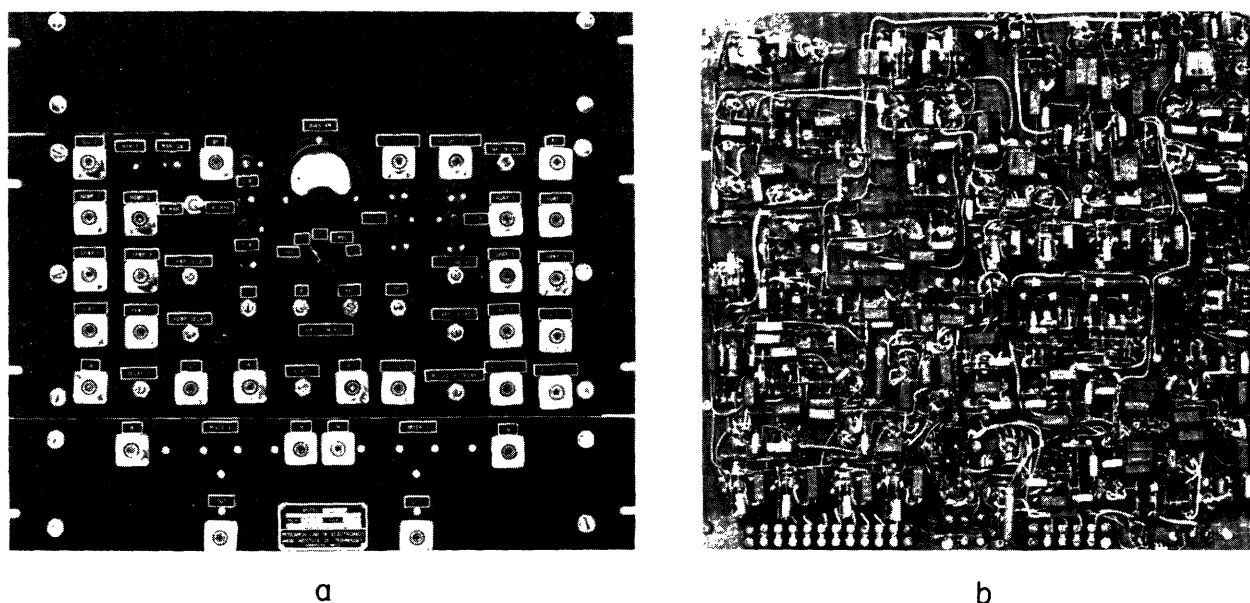


Fig. 12. The control unit; (a) front view, (b) rear view.

generator units, and the control unit were constructed on bakelite sheets instead of on metal chassis in order to minimize capacitive loading of the circuits; such loading might result if metal were used because of the capacitance between the metal and the unavoidably long wires which interconnect some of the circuits. The reading unit was constructed on a metal chassis, and the radio-frequency circuits were well shielded.

Figure 13 is a rear view of the storage system, and shows further details of construction. The first and third racks from the left are occupied by the two storage channels. In each channel are, from top to bottom, two deflection units, a gate-generator unit, and an ST/MT assembly. The ST/MT assembly contains a storage tube, a monitor tube, and a reading unit. The reading unit is the chassis on the left-hand side of the assembly; the storage tube is mounted vertically, between the reading unit and the front panel. The control unit can be seen in the second rack from the left; above the control unit is the

power-control unit, and on top of this rack is the test pattern generator, a unit which facilitates testing of the equipment and is described in Section VI-B. Power supplies constitute the remainder of the equipment.

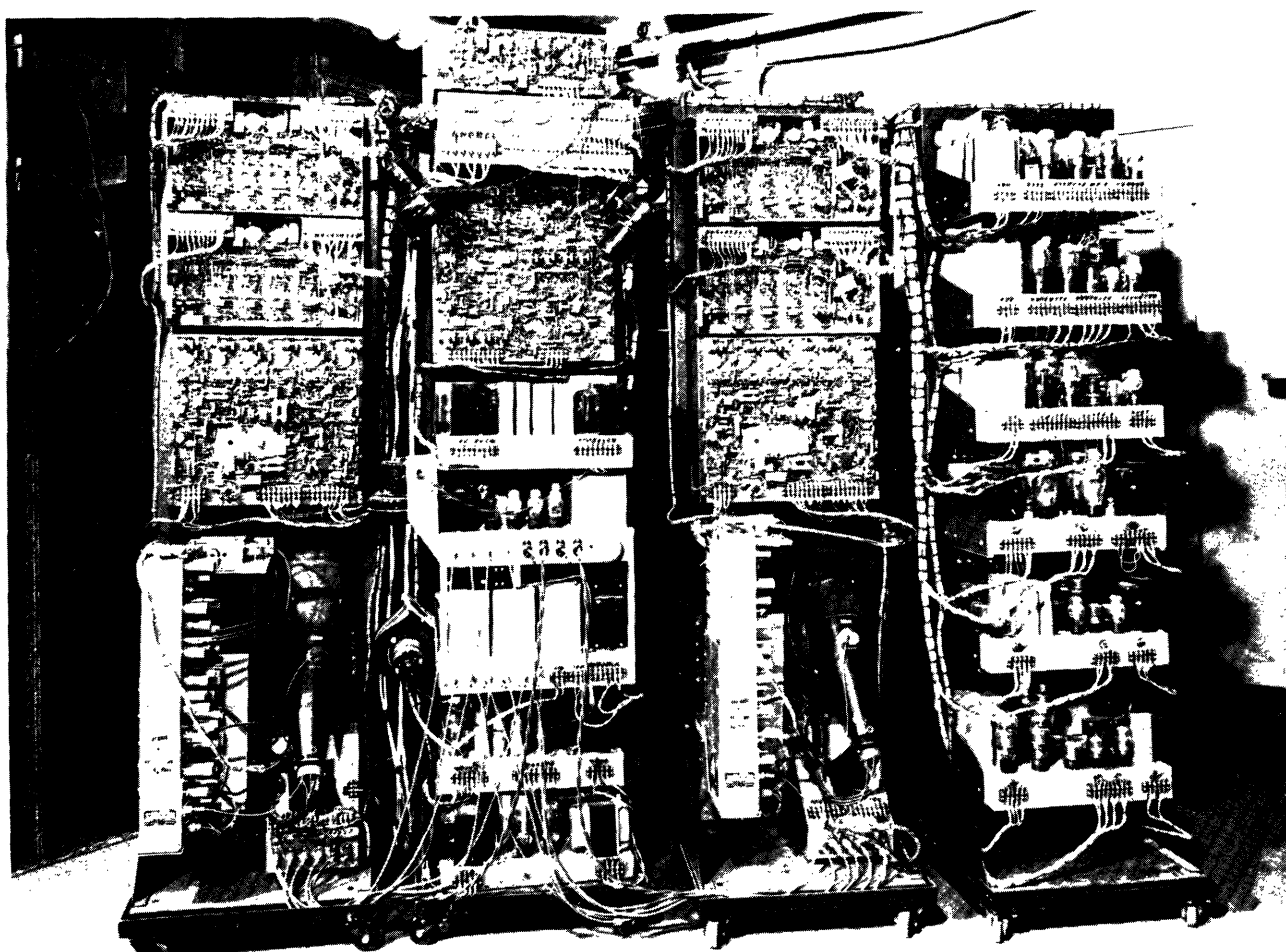


Fig. 13. Rear view of the storage system.

VI. Operating Features

A. Adjustments

The storage system is simple to operate. The controls associated with the gate-generator units, the reading units, and the control unit were adjusted when the system was first put into operation, and require no further adjustment, unless possibly after a vacuum tube or a storage tube is changed. The deflection-unit controls ordinarily require no adjustment, but should be checked periodically to insure that the proper deflection voltages are being generated.

It is not necessary to place the deflection-unit or the control-unit flip-flops in any particular state preparatory to operating the storage system because the writing and reading operations are self-synchronizing.

B. Provisions for testing

Provisions have been made to test each storage channel separately and to test the operation of the complete system.

Several ways in which the channels can be tested separately are:

1. Manually store a pulse, and repeatedly read and rewrite the pulse in the same spot.
2. Manually store a pulse, and successively read then rewrite the pulse in the adjacent spot.
3. Manually store a pattern of ON and OFF pulses, and successively read then rewrite each pulse in its original spot.
4. Manually store a pattern of ON and OFF pulses, and successively read each pulse then write a pulse of the opposite state in the same spot.

Operation of the storage tube may be observed while a test is in progress by using the ON or OFF pulses from the reading-unit output to intensify the beam of the monitor tube. An actual picture of the storage-tube target, similar to a television image, may also be obtained (12). To obtain this picture, it is necessary to stop the test, apply linear voltages to the amplifiers of the deflection units, allow the oscillator in the reading unit to free-run (by removing tubes V_7 and V_9), and use the ON GATE from the reading unit to intensify the monitor-tube beam.

The complete system may be tested by manually storing a pattern in a channel, and then transferring this pattern from one channel to the other; the states of the pulses may be either preserved or reversed during the transfer operations. The monitor tubes are used to display the patterns.

To carry out a test, it is necessary to set up the system properly. For example, one of the channel tests consists of successively reading each pulse then writing a pulse of the opposite state in the same spot. In this test, the DU IN P SELECTOR of the gate-generator unit is placed in the W position, to trigger the deflection unit only after a pulse is written; the pulses from the R SIG P output of the control unit and the OFF OUT P output of the reading unit are delayed by equal amounts, sufficient to allow completion of reading, in the two control-unit delay channels and are respectively applied to the WP and SIG P inputs of the control unit; alternate writing and reading in the same channel is obtained by using pulses from the R SIG P output of the control unit to trigger both of the read flip-flops of this unit; pulses from an external source are applied to the RP input of the control unit. Patterns may be stored manually by means of the switches provided for this purpose in the control unit.

The test pattern generator, the schematic diagram of which is shown in Fig. 14, was added to the storage system to simplify testing procedures. The necessary connections for most tests can be made by means of switches in this unit, and test patterns consisting of all ON pulses, all OFF pulses, or a checkerboard arrangement of ON and OFF pulses can be easily written in either storage tube. The checkerboard pattern is

particularly useful because its symmetry makes the visual detection of errors a simple matter, and because it causes the storage tube target to operate under stringent conditions, namely, each stored spot is surrounded by spots of the opposite polarity.

When the OPERATION SELECTOR switch is in either of the two TEST positions, pulses from an external source are applied to gate-tube V_{14} ; blocking-oscillator V_{13} is a convenient external pulse source. When tube V_{11} of flip-flop V_{11} - V_{12} is not conducting, the pulses pass through the gate tube and trigger flip-flop V_1 - V_2 . The latter flip-flop and pulse-forming-tubes V_5 and V_6 divide the input pulses into two interleaved trains, which are then mixed in stage V_7 and are ordinarily applied to the RP input of the control unit. The interleaved pulse trains are also used to generate the checkerboard test pattern, as will be explained shortly.

Gate-tube V_{14} , in conjunction with flip-flop V_{11} - V_{12} , is used to stop a test operation either at the end of a line or at the end of a frame. The switches in the lower left-hand corner of the diagram may be used to apply a pulse from the output of the horizontal or vertical deflection unit of either storage channel to the flip-flop, which will then turn off the gate tube.

To write a test pattern, operation of the system is stopped at the end of a line or frame by means of the STOP switch, and the PATTERN switch is depressed. The relay which is energized by the latter switch transfers the output of V_7 from the RP input of the control unit to the WP input, connects the SIG P input of the control unit to an appropriate source of pulses, and energizes another relay associated with flip-flop V_{11} - V_{12} . This second relay starts the writing of the pattern by causing gate-tube V_{14} to open, and also stops the writing of the pattern at the end of a line or frame by connecting the pertinent stop pulse to the flip-flop. After a test pattern has been written, operation of the system is started by using the appropriate INPUT GATE switch to trigger flip-flop V_{11} - V_{12} manually.

The PATTERN SELECTOR switch determines which test pattern is written. When this switch is in the ON position, pulses from V_7 are routed to the SIG P input of the control unit; no pulses are applied when the switch is in the OFF position. Pulses which are in the proper sequence to produce the checkerboard pattern are made available when the switch is in the ALT position. The checkerboard sequence is obtained by gating the two interleaved pulse trains from V_5 and V_6 through V_8 and V_9 ; the two gate tubes are operated by flip-flop V_3 - V_4 , which is triggered by output pulses from the horizontal deflection unit of the channel in which the pattern is being written.

Provision has been made for making a test proceed either a line at a time or a frame at a time. Such operation may be obtained by properly setting the CHANNEL SELECTOR and LINE STOP-FRAME STOP switches, and repeatedly depressing the READ switch.

The TEST SIG P switch determines the type of signal pulses which are used while a test is in progress. When this switch is in the INTERNAL position, signal pulses are obtained from the output of a storage channel; pulses which are actually the output of a storage tube are used as signal pulses. When the switch is in the OFF or ON positions,

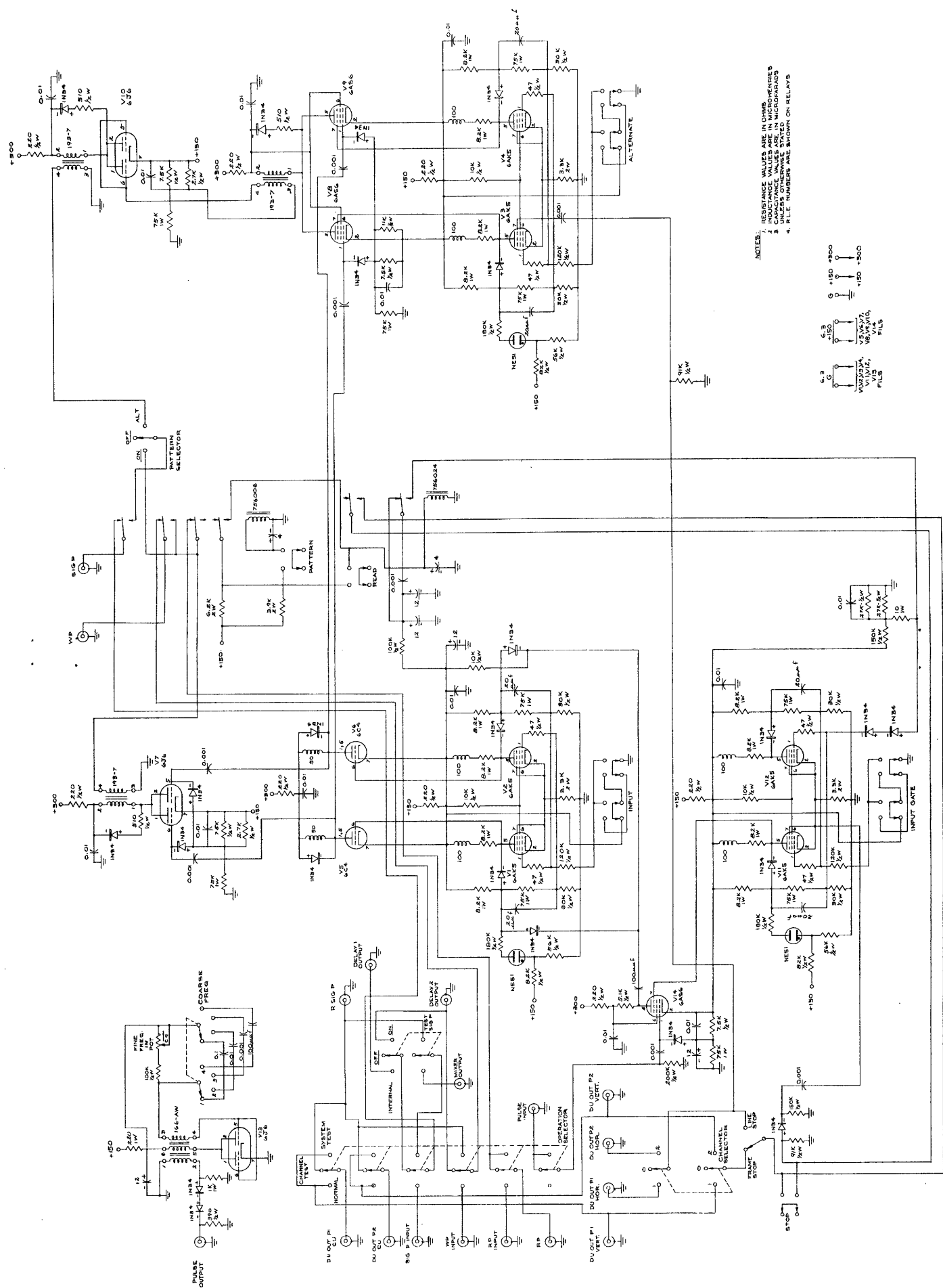


Fig. 14. Schematic diagram of the test pattern generator.

the signal pulses have these respective states and are independent of the outputs of the storage channels. It is convenient to use signal pulses which have known states and are independent of the storage-channel outputs when trouble-shooting and when making adjustments in the reading units.

Another unit, the MT display selector, has been added to each channel of the storage system in order to further facilitate testing. These units can be seen in Fig. 1, and are located on small panels placed between the gate-generator unit and the ST/MT assembly of each channel.

The schematic diagram of the MT display selector is shown in Fig. 15. The MP SELECTOR switch determines the type of picture displayed on the monitor tube. The deflection pattern is monitored when the switch is in the DU position. OFF and ON pulses from the reading unit outputs are respectively displayed as bright spots when the switch is in the corresponding positions. Pulses from an external source may be used to intensify the monitor-tube beam when the switch is placed in the EXT position. The CYCLE position is used only in two particular types of tests.

It will be recalled that in one of the channel tests, a pulse is read, then one of the opposite state is written in the same spot. In order to monitor the operation of the channel accurately, therefore, only alternate frames must be displayed; a stationary display will not be obtained if every frame is seen. In one of the system tests, a pattern is transferred from one channel to the other, with pulse states preserved in the transfer from channel 1 to channel 2 but reversed in the transfer from channel 2 to channel 1; if four consecutive frames of channel 1 are identified as A, B, C, and D, and a pattern is written during frame A, this pattern will be read during frame B (and transferred to channel 2), a pattern of pulses having states opposite from the states in the A-frame pattern will be written during frame C, and the C-frame pattern will be read during frame D. It is evident that a stationary display can be obtained on the monitor tube only if alternate frames during which reading takes place are shown; since frames during which reading takes place are separated by frames during which writing takes place, it is sufficient to allow the output of a channel to be displayed during alternate pairs of frames.

The CYCLE position of the MP SELECTOR switch, and the CYCLE TEST SELECTOR switch, provide means for properly displaying the patterns encountered in tests involving reversal of pulse states. When the latter switch is in the CHANNEL TEST position, pulses from the vertical deflection unit, which occur at the end of each frame, trigger flip-flop V_1-V_2 ; gate-tube V_3 will therefore be open only during alternate frames. When the CYCLE TEST SELECTOR switch is in the SYSTEM TEST position, flip-flop V_5-V_6 is placed in operation, and the gate tube will be open only during alternate pairs of frames. The gate-tube output is amplified by a regenerative pulse amplifier, V_4 . Either ON or OFF pulses may be displayed as bright spots; this choice is made by means of the CYCLE SELECTOR switch.

It is frequently necessary to change the positions of switches during testing operations.

In order to avoid switching transients, all pulse-carrying lines which are associated with switches have been placed at ground d-c potential. This precaution was taken in the test pattern generator and in the MT display selector, as well as in other units of the storage system.

C. Performance

Representative waveforms which are obtained when an ON pulse is written and read are respectively shown in Figs. 16 and 17. Part "a" of each figure shows the pulse which initiates the operation; parts "b", "c", and "d" show the gates generated by the gate-generator unit. The waveforms of parts "e" through "i" of Fig. 17 were observed at the reading unit; waveform "i" is an expanded view of the middle portion of waveform "f". Waveforms similar to those in Figs. 16 and 17 are obtained when an OFF pulse is written and read, except that the signal-plate write gate is zero.

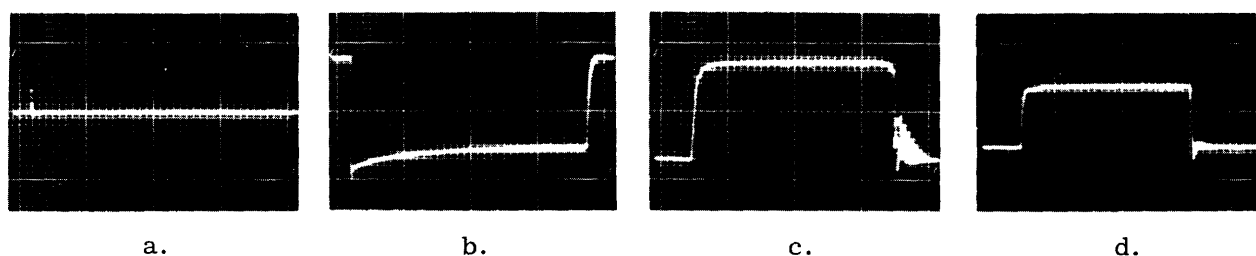


Fig. 16. Waveforms obtained when an ON pulse is written. Vertical scale, 90 volts/large division. Horizontal scale, 5 μ sec/large division.

a. WP b. HGWG c. SPWG d. HVWG

The ringing which is seen at the trailing edges of the signal-plate gates is due to the high Q of coil L_3 in the reading unit (Fig. 9). Since both electron beams are turned off during the ringing interval, operation of the storage tube is not affected. The radio-frequency transient which the signal-plate read gate causes in the reading-unit amplifier is visible in part "f" of Fig. 17; the type of phase-sensitive detector used in the reading unit prevents the appearance of this transient at the detector output (part "g" of Fig. 17). The dip which occurs in the detector-output waveform is not generated by the detector; this dip is a reflection of the output pulse, and is produced in the gate tubes (V_{14} or V_{13} of Fig. 9) which are coupled to the detector.

Figure 18 shows some monitor-tube displays which were obtained during tests.

The gate-generator units have been adjusted to allow a writing interval of approximately 15 μ sec and a reading interval of about 7 μ sec. These units require 2 μ sec to recover after a set of gates has terminated; gate widths and amplitudes are altered if faster operation is attempted. The deflection units will provide a new spot location within 2 μ sec after being triggered. On the basis of these figures, the maximum frequency limits for periodic operation of the storage system should be approximately 60 kc/sec when writing and 110 kc/sec when reading. It was found, however, that reliable operation did not occur under these conditions. Stored patterns degenerated, probably because of the low holding-gun duty cycle; the holding beam was on only 2/17 of the time during

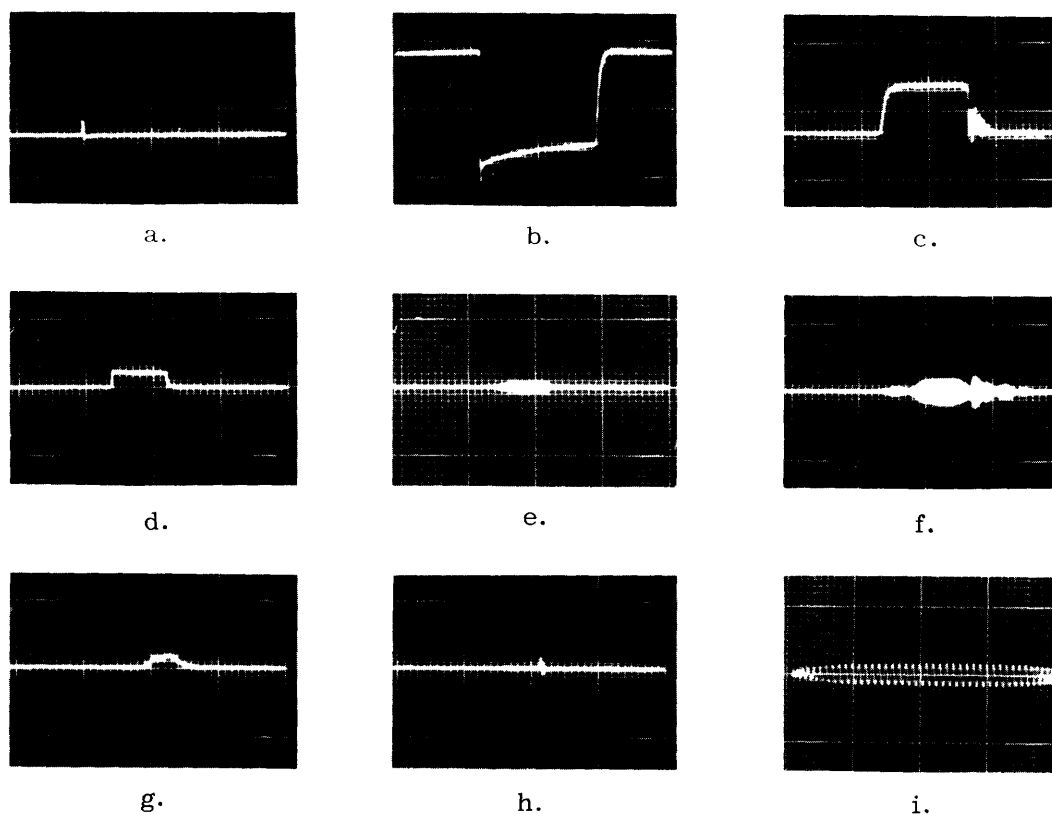


Fig. 17. Waveforms obtained when an ON pulse is read. Vertical scales, 90 volts/large division in parts a-e, g, h; 0.9 volts/large division in parts f, i. Horizontal scales, 5 μ sec/large division in parts a-h; 1 μ sec/large division in part i.

- | | | |
|-------------------|--------------------|---------|
| a. RP | b. HGRG | c. SPRG |
| d. HVRG | e. RF SIG | f. AMP |
| g. <u>ON</u> GATE | h. <u>ON</u> OUT P | i. AMP |

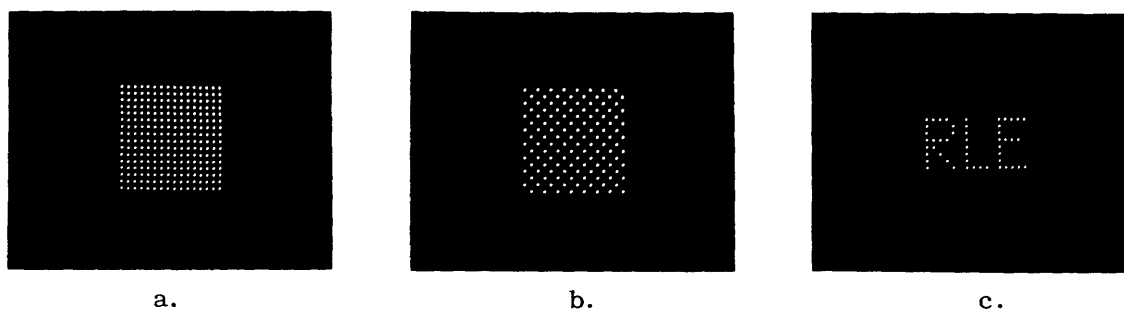


Fig. 18. Some monitor-tube displays.

- a. Deflection array. b. Checkerboard test pattern. c. "R L E" pattern.

writing, and 2/9 of the time during reading. The degeneration may have been aided by a slight defocussing of the high-velocity beam caused by stray magnetic fields.

Reliable periodic operation of the system, independent of frequency, was observed with holding-gun duty cycles of 1/2 or greater. That is, reliable operation occurs at writing frequencies of 33 kc/sec or less, and at reading frequencies of 70 kc/sec or less. Tests involving non-periodic operation have not been performed; the figures given in Section III-B regarding minimum spacing between pulses are based on data obtained from periodic operation. However, reliable non-periodic operation may take place if some pulses are more closely spaced, provided that a long train of such pulses does not occur.

Acknowledgement

The writer takes this opportunity to express his gratitude to Professor J. B. Wiesner for supervising this research and to Mr. J. W. Forrester for extending the cooperation of the Servomechanisms Laboratory; to Mr. H. E. Singleton, who contributed to the research by making many valuable suggestions; to Mr. S. H. Dodd and his colleagues of the Servomechanisms-Laboratory Storage-Tube Group for many interesting demonstrations and explanations, and numerous helpful suggestions; to Professor H. J. Zimmermann and to Professor Y. W. Lee and the members of the Communication Group for offering useful suggestions and advice; to Mr. E. D. Ralowicz, who constructed all of the equipment, for his many practical suggestions and excellent workmanship.

The writer also expresses his appreciation of the services and facilities of the Research Laboratory of Electronics, where the research was carried out.

Table 1

Glossary of Symbols Used in Storage-System Diagrams

Symbol	Definition
DU IN P	Deflection-unit input pulse; pulse which triggers deflection-unit counter.
DU M P	Deflection-unit monitor pulse; pulse which is used as monitor pulse (MP) when deflection pattern is monitored.
DU OUT P	Deflection-unit output pulse; output pulse of deflection-unit counter.
HGG	Holding-gun gate; gate which turns off holding beam during writing and reading.
HGRG	Holding-gun read gate; gate which turns off holding beam during reading.
HGRP	Holding-gun read pulse; pulse which initiates HGRG.
HGWG	Holding-gun write gate; gate which turns off holding beam during writing.
HGWP	Holding-gun write pulse; pulse which initiates HGWG.
HVRG	High-velocity read gate; gate which turns on pulsed oscillator during reading.
HVRP	High-velocity read pulse; pulse which initiates HVRG.
HVWG	High-velocity write gate; gate which turns on high-velocity beam during writing.
HVWP	High-velocity write pulse; pulse which initiates HVWG.
MP	Monitor pulse; pulse which initiates gate intensifying monitor-tube electron beam.
<u>OFF</u> OUT P	OFF output pulse; pulse which represents a recovered OFF pulse.
<u>ON</u> OUT P	ON output pulse; pulse which represents a recovered ON pulse.
OUT P	Output pulse; pulse which represents a recovered ON or OFF pulse.
RP	Read pulse; pulse which initiates a read cycle.
R SIG P	Read signal pulse; pulse which becomes an OUT P and an <u>ON</u> OUT P or <u>OFF</u> OUT P after being gated by reading-unit gate tubes.
SIG P	Signal pulse; binary pulse which is to be stored.
SPG	Signal-plate gate; gate which raises signal plate to proper potential during writing of an ON pulse and during reading.
SPRG	Signal-plate read gate; gate which raises signal plate to proper potential during reading.
SPRP	Signal-plate read pulse; pulse which initiates SPRG.
SPWG	Signal-plate write gate; gate which raises signal plate to proper potential during writing of an ON pulse.
SPWP	Signal-plate write pulse; binary pulse which, if ON, initiates SPWG.
WP	Write pulse; pulse which initiates a write cycle.

TABLE 2
EXPLANATION OF BLOCK SYMBOLS

SYMBOL	CIRCUIT
	FLIP-FLOP
	ONE-SHOT MULTIVIBRATOR
	GATE TUBE
	PULSE-FORMING CIRCUIT
	MIXER
	CATHODE FOLLOWER
	PENTODE CURRENT SOURCE
	REGENERATIVE PULSE AMPLIFIER
	DELAY
	AMPLIFIER

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