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EIGHT-CHANNEL DIGITAL SYSTEM

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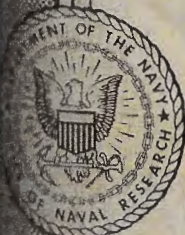
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ABSTRACT

Digitar is an NRL-developed system capable of the simultaneous digital representation and subsequent serial recording of the angular positions of as many as eight one-speed shafts at preset sampling rates of 1, 2, 5, or 10 times per second. Angular increments of 0.01 degree in the position of the one-speed shaft may be resolved by the coded-disc device used in obtaining the digital representation of the angular shaft position. Data from each of the eight channels and from an independent time-counter channel are recorded in a given sequence at the specified sampling rate on a single-channel magnetic tape. The recorded data are later transcribed from the magnetic tape to a punched-paper-tape medium for insertion into the Computer Mk 22, a relay-type digital computer used for data-reduction purposes. A system of recording the coded data on photographic film is also described. Although Digitar has been developed to aid in the collection of data for the evaluation of gun fire control systems at NRL, it is applicable to the general problem of quantizing and recording angular shaft position at discrete intervals of time. At missile test ranges, a modified Digitar would be useful in recording bearing, elevation, and range, for determining the trajectories of missiles tracked by precision radar sets.

PROBLEM STATUS

This is a final report on this phase of the problem; work on other phases continues under NRL Problem R05-54D.

AUTHORIZATION

NRL Problem R05-11D and R07-36R
RDB NO 274-606 now closed.

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NRL REPORT 3658

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EIGHT-CHANNEL DIGITAL SYSTEM

D. H. Gridley

May 10, 1950

Approved by:

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EIGHT-CHANNEL DIGITAR SYSTEM

INTRODUCTION

The Operational Research Branch of Radio Division III evaluates the performance of Navy gun fire-control systems by operating them against actual targets of nonfiring runs. This method of evaluation requires the simultaneous recording of the present position of the target and the outputs of the fire-control system so that an accurate description of the output error function can be determined. The information required for the determination of the output error is generally available from rotational shafts. At the present time the shaft positions are transmitted by synchro to a dial box, and repeater synchros in the dial box are photographed by a motion-picture camera at time intervals of either 0.1 or 0.05 second. After the photographic film has been processed, the recorded data are read at suitable time intervals. The transcribed data are then reduced to a punched-paper tape which is required for the insertion of numerical information into the Computer Mk 22,¹ a relay-type digital computer. From the data supplied to it on the punched paper tapes, the Computer Mk 22 automatically calculates the output errors of the fire-control system.

Since considerable amounts of time and manual labor are required in transforming the photographically recorded data to the punched paper tape, it was obvious that some kind of machinery should be developed to handle automatically this portion of the data collection and processing procedures. During World War II, the urgency of other work precluded undertaking the development of such machines at the Naval Research Laboratory. However, NRL has since proposed² and developed an automatic system called Digitar for quantizing shaft position by converting it to an electronic digital indication for recording the data on a magnetic tape at sampling rates as high as ten times per second, and for transcribing the information from this magnetic tape to the punched paper tape required by the Computer Mk 22.

During the preparation of the present report, the Digitar system has been considerably improved by incorporating cyclic coding and numerous circuit changes. The system, as finally modified, will be presented in a subsequent report.

¹ "Computer Mk 22 Mod O Development and Description" (Restricted), BuOrd Report 178-45, 6 December 1945

² NRL conf ltr Report Serial C-N3600-1/48, "Digitar -- A System Proposed for Conversion of Rotational Shaft Position to Electronic Digital Data for Storage of Such Data in a Form Suitable for Automatic Reduction," 24 May 1948

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GENERAL DESCRIPTION

Digitar, as developed at the time of this report, is shown in block form in Figure 1. It consists of the Converter Unit, the Data Storage Unit, and the Transcription Unit. In normal operation of the Digitar system, the first two units are at the test location, and the remaining unit is located near the data-reduction facilities provided to handle the computational work. The Converter Unit consists of eight Digital Converters,³ each of which provides a digital reading of the angular position of a particular shaft at sampling rates of 1, 2, 5, or 10 times per second as determined by the Data Storage Unit. Angular increments of 0.01 degree of the position of a one-speed shaft may be resolved by the coded-disc device used to obtain the digital representation of the angular shaft position. The Data Storage Unit transcribes the electrical output of each Digital Converter in a given sequence so that the information is stored serially as pulses on a single-channel magnetic tape. The Transcription Unit converts the data stored on the magnetic tape to the electrical signals required for the preparation of a punched paper tape for use with the Computer Mk 22. The Transcription Unit operates at the speed of the paper-tape punching equipment, which is considerably slower than the rate at which the data are recorded. Figure 2 shows the various units of the Digitar system constructed at NRL for use of magnetic tape storage; only one of the eight Digitar Converters of the Converter Unit is shown. A similar illustration of the Digitar system for use of photographic film storage is given in Figure 3.

In the Converter Unit of Digitar, eight Digital Converters are provided to permit the digital representation of as many as eight information-transmitting shafts. Each Digital Converter contains a synchro-signal-operated servo which reproduces the shaft position representing the information desired. The servo drives a set of discs, each of which is marked in the decimal system peripherally and in a coded decimal notation radially by means of a series of transparent and opaque blocks. A very narrow sector of each of the discs is illuminated from a fixed light source by a flash of short duration whenever the Converter Unit receives a signal from the Data Storage Unit to make a digital reading of the shaft positions. The particular combination of opaque and transparent blocks appearing in the narrow, illuminated sector of each of the discs is recorded electronically by the energizing of a corresponding combination of phototubes. The electrical signal from each phototube is amplified and stored in its associated memory circuit. When the information thus stored has been transferred to the Data Storage Unit, these circuits are reset to accept the next reading.

The Data Storage Unit (see Figure 1) consists of the Master Synchronizer, the "Read" Counter, the Decimal Digit Selector, the Code Sequencer, and the Recorder. The circuits included in the Data Storage Unit control the reading and transcription operations and provide for the serial sequencing of a time-indicator value and of the eight variable quantities read by the Converter Unit. The reading cycle is started by the transmission of the electrical "Read" pulse from the Master Synchronizer to the Digital Converters and to the "Read" Counter. Accurately timed "Read" and subsequent "Reset" signals are derived from the points of a commutator in the Decimal Digit Selector. The mechanical drive of the commutator is controlled by a synchronous motor which is located in the Master Synchronizer and driven from a suitable 60-cycle a-c source. Upon the reception of the "Read" signal in the Converter Unit, instantaneous readings of all shaft positions are made and simultaneously stored in the memory circuits of the Converter Unit. An independent coded-decimal number is available in the "Read" Counter and, since the entire operation of the equipment is time-synchronized, the number in the "Read" Counter may be used as a time indicator.

³ An early model of the Digital Converter described in NRL Report R-3340, "The Digital Converter," (Confidential) 26 August 1948

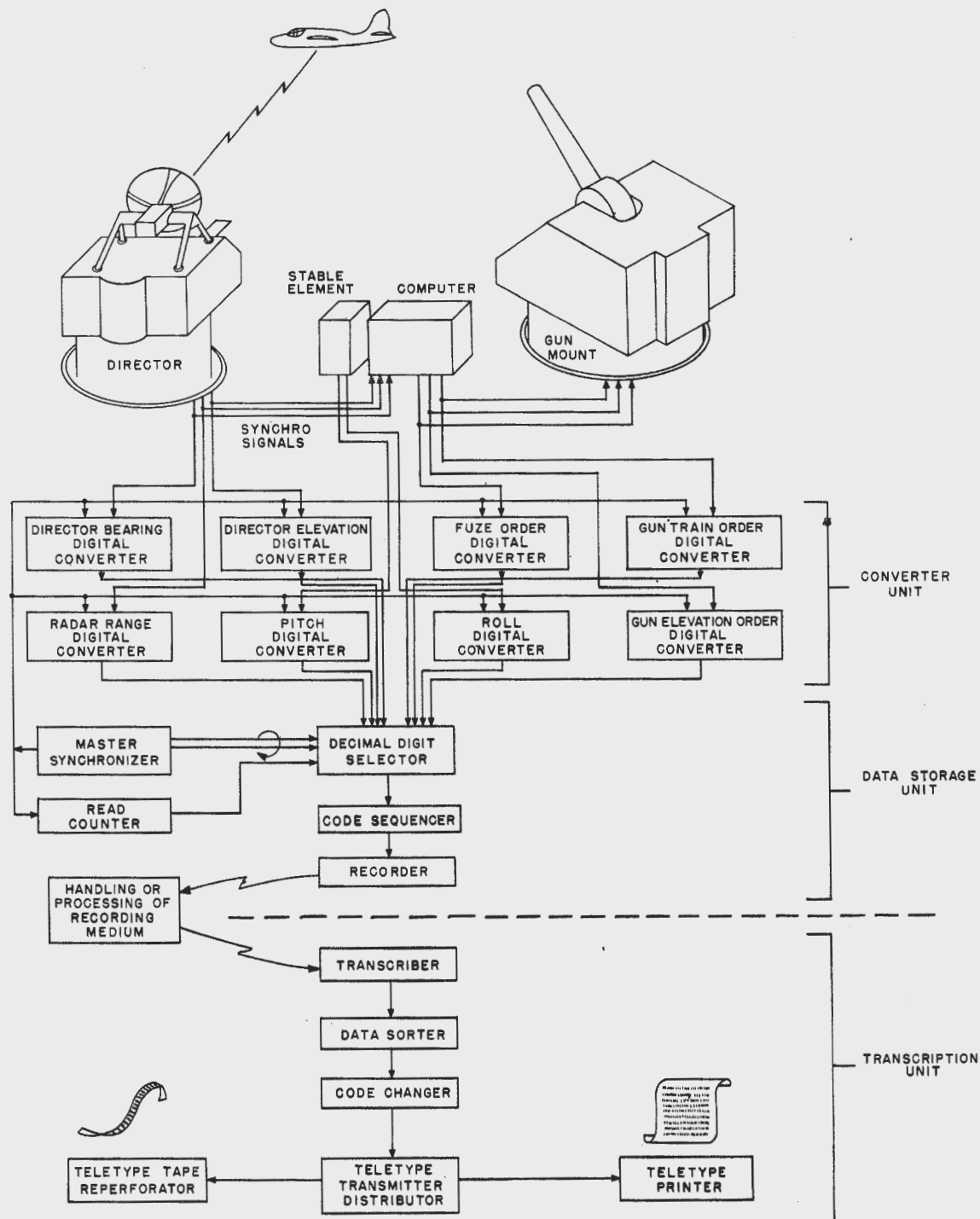


Figure 1 - The Digitar system

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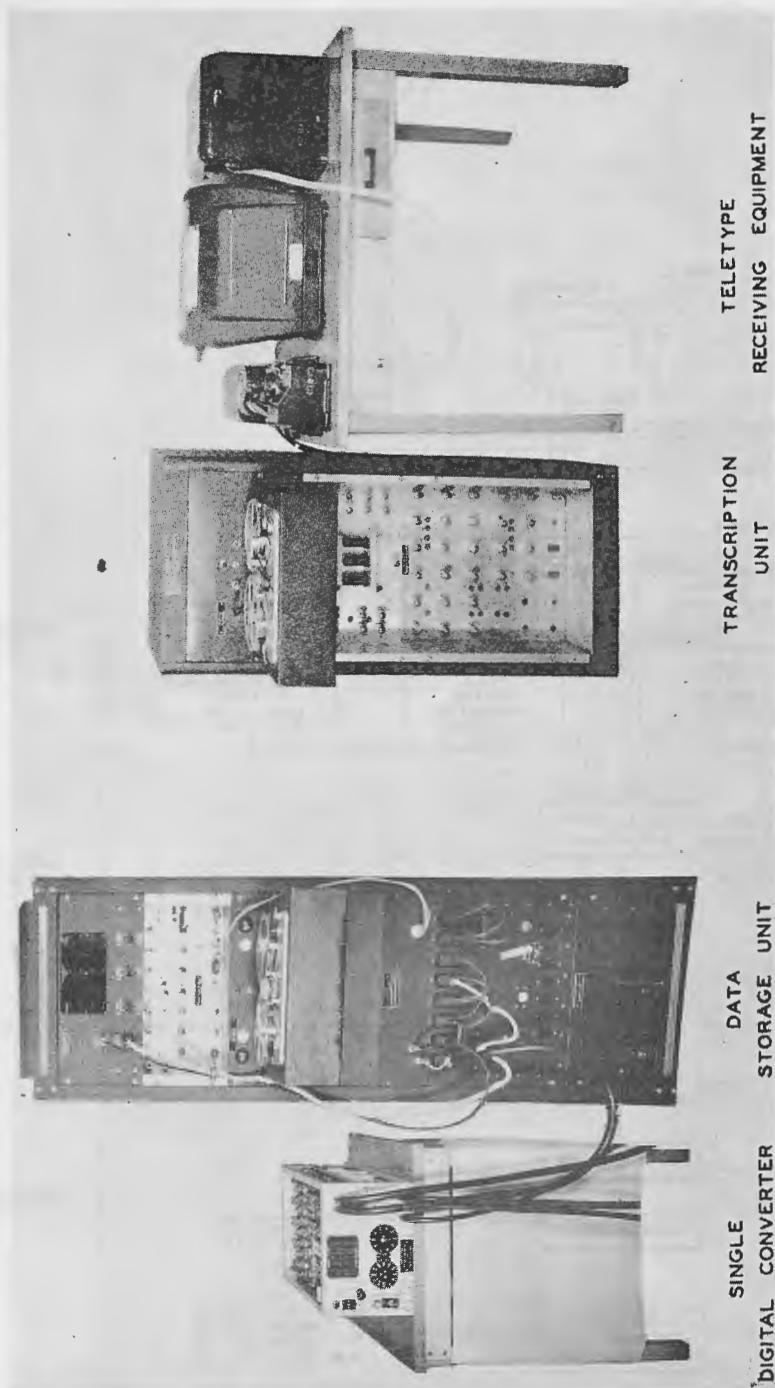


Figure 2 - Digitar system

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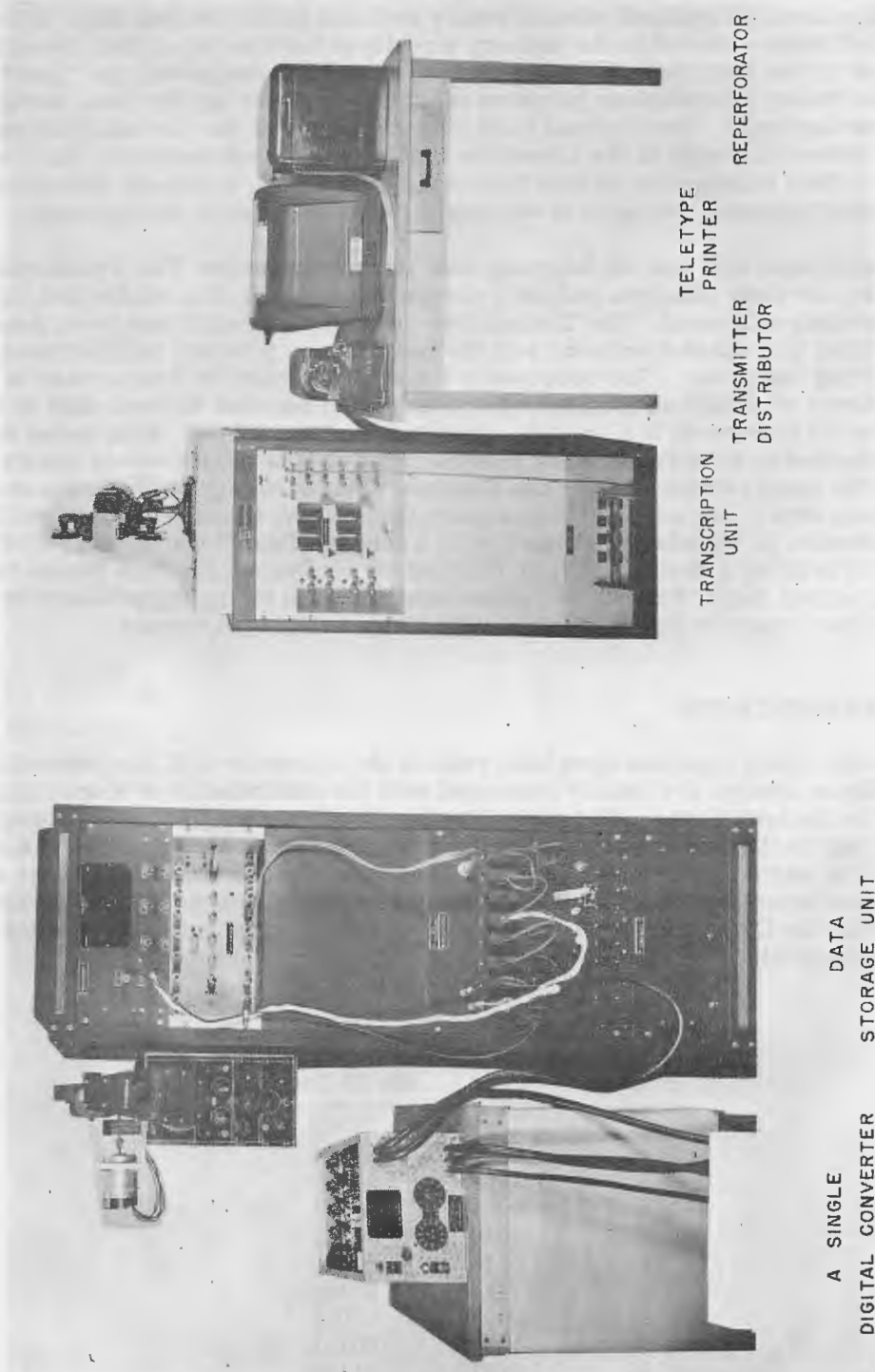


Figure 3 - Digitar model O (photographic recording)

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As the mechanical shaft to the Decimal Digit Selector is rotated by the motor in the Master Synchronizer, the multiple-contact rotary switches in the Decimal Digit Selector transfer the information stored in the memory circuits of the Converter Unit through the Code Sequencer to the Recorder. When this transfer has been completed, the "Reset" pulse from the Master Synchronizer prepares the Converter Unit and the Data Storage Unit for another reading cycle. The Decimal Digit Selector arranges the decimal information stored in the memory circuits of the Converter Unit in an ordered sequence. Since each decimal digit is then represented by four binary digits, the Code Sequencer through gating circuits provides the serial sequence of the binary digits required by the Recorder.

The Transcription Unit has the following four basic components: The Transcriber, the Data Sorter, the Code Changer, and the Teletype Transmitter-Distributor and tape punching or printing equipment. The Transcriber reads the magnetic tape record (or photographic film) at a speed consistent with the punching (or printing) capabilities of the teletype recording equipment. The information transmitted from the Transcriber in the form of a sequence of electrical pulses, representing each selected decimal digit in a binary code form, is registered in a memory circuit of the Data Sorter. Each coded decimal digit is then changed to its corresponding teletype notation by a crystal-diode matrix and registered in the relay circuits in the Code Changer. Electrical signals from the relay circuits are then sent to the teletype Transmitter-Distributor, which sequences and transmits the information to the teletype Printer or to a teletype Tape Reperforator. During the operation of printing a decimal digit by the teletype equipment, the Data Sorter registers the next decimal digit. The punched-paper tape produced by the Reperforator is used as the input to the Computer Mk 22 for automatic computational processing.

NUMBER REPRESENTATION

Once the input shaft positions have been read by the converter unit, the internal operations of the Digitar system are mainly concerned with the manipulation of electrical signals representing the decimal digits. All information handling from the phototube reading in the converter unit to the code changer in the transcription unit is accomplished in a code, each character of which consists of four binary elements. Unique characters of the code represent the numerical symbols 0 through 9 and the special identifying symbols required by the circuits of the Computer Mk 22 for processing the collected data. Each of the code characters is listed with its corresponding symbol in Table 1.

TABLE 1
Digitar Symbols and Codes

Symbol	Digitar Code	Computer Mk 22 Code
1	1000	11010
2	0100	11001
3	1100	10110
4	0010	10101
5	1010	10011
6	0110	01110
7	1110	01101
8	0001	01011
9	1001	00111
0	0101	11100
ER	1101	11111
R	0011	00001
E	1011	10000
A	0111	00100

It may be noted that the four elements of a Digital code-character correspond to what is referred to as the "binary-coded decimal" system for the decimal digits 1 through 9. If the left element is assigned the weight 2^0 , and the other elements 2^1 , 2^2 , and 2^3 in succession left to right, the code characters for the decimal digits 1 through 9 are identical with the true binary representation of these digits. The decimal digit, zero, was assigned the character 0101 instead of 0000, so that no character of the code would have all of its elements equal to zero. The binary nature of the elements of each code character allows the use of relatively simple vacuum-tube circuits; for example, the digits "1" and "0" may be represented by the two mutually exclusive conditions of the "flip-flop" circuit, and the "1" and "0" may be transmitted over a wire by negative and positive pulses respectively.

The importance of employing binary elements in the formation of code characters is also illustrated by the Computer Mk 22 code given in Table 1. In this case each character consists of five elements. The translation from the Digital code to the Computer Mk 22 code is performed by the code changer of the transcription unit.

The information transmission from the converter unit through the data storage unit is illustrated in Figure 4. Two digital converters are shown at the top of the figure; each contains a five-digit decimal number registered in the Digital code. The corresponding decimal notation is also given. The decimal digit selector reads the separate decimal digits from the memory circuits of the converter unit and, at the proper points in the sequence, insert symbols to identify the various numbers. Code characters representing each decimal digit or identifying symbol are transmitted to the code sequencer in the time order shown. The binary pulses of each code character are developed into a train of four pulses by the code sequencer for use by either the magnetic recorder or the film recorder. Recorded patterns for both mediums are detailed in the lower half of the figure. The film record is made by photographing the face of an oscilloscope with a continuous strip camera. The cathode-ray beam is intensity-modulated by the code signals, and the pattern is produced by a synchronized sweep applied to the horizontal deflection plates. The left-hand spot position on the film record

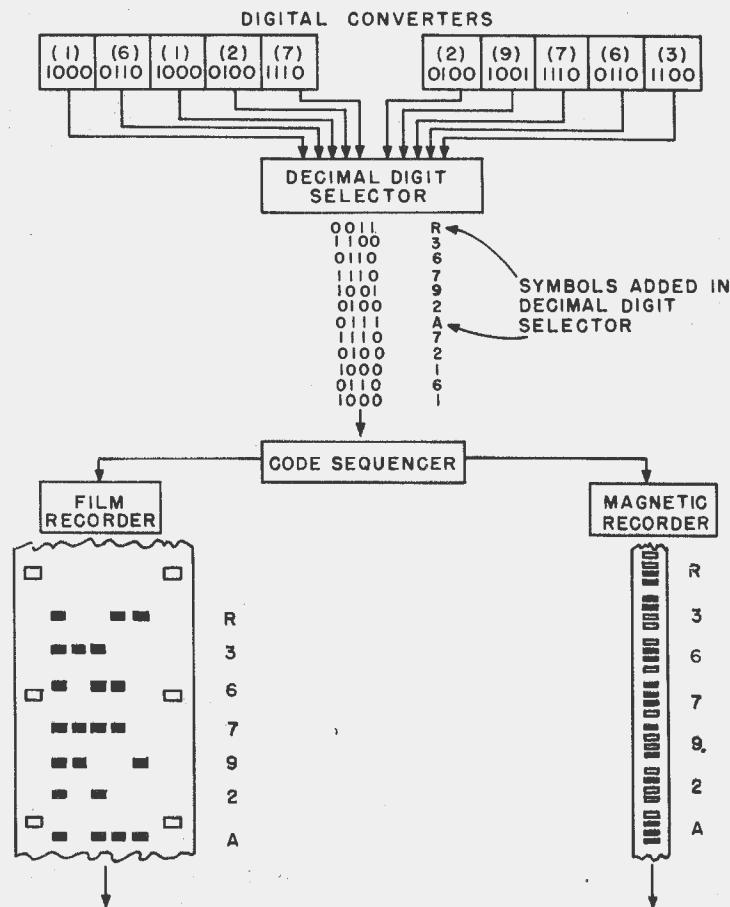


Figure 4 - Data recording process.

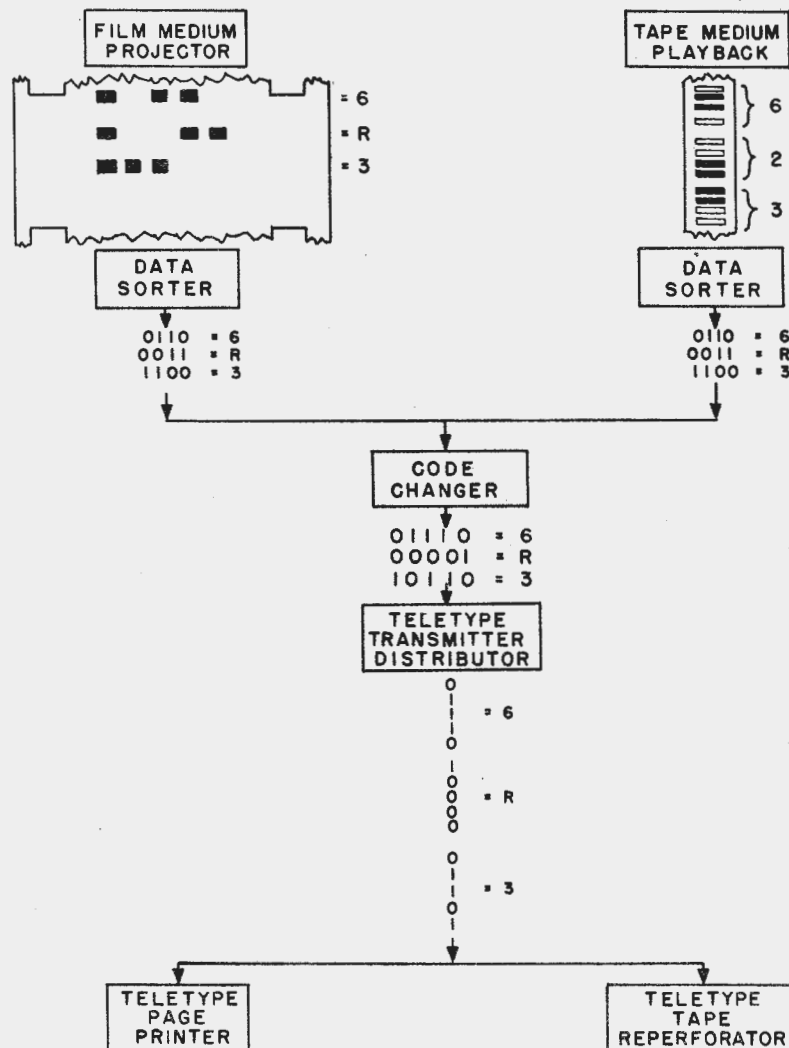


Figure 5 - Data transcription

is used to indicate the presence of a code character representing a decimal digit or identifying symbol and is generated by the code sequencer. The magnetic tape storage is in the form of plus and minus pulses recorded by a modified commercial recorder.

The flow pattern for the code characters in the transcription unit is illustrated in Figure 5. From either of the two record mediums, the information is read by the transcriber and reproduced in essentially the same form as it was recorded. The operation of regrouping the four binary elements of a code character is accomplished quite simply by the film data sorter, but this process is more difficult for the magnetic tape data sorter. The data sorter transmits the individual code characters to the code changer, which translates the Digitar code into the Computer Mk 22 code (see Table 1). The teletype transmitter-distributor serializes the elements of the received code characters and transmits the resulting signals to the teletype printer (or reperforator).

THE CONVERTER UNIT

The operational details of the digital converter, which is duplicated eight times in the converter unit, have been described in an earlier report;* but additional development of the digital converter has resulted in a reduction in the size of the device and a decrease in the number of its components. The digital converter changes the angular shaft position to a digital representation. A rear view of a single digital converter with phototube assembly removed to show the coded discs is given in Figure 6; and a view of the converter in the open position may be seen in Figure 7. Its case measures 13 x 9 x 20 inches, and approximately one-third of the volume is required for the servo drive motor and amplifier control circuits.

Several improvements have been included in the revised converter. The neon indicators display the converter reading in the Digitar code instead of the true decimal notation. This change eliminated the decoding matrix used in the earlier model, and it was felt that maintenance and operating personnel could easily learn to relate the indicated value to its decimal equivalent. A servo in-out switch and read-reset switch are on the front panel for use during the alignment of the converter. In order to make the circuitry and mechanical equipment more accessible, the converter is constructed in two sections which are hinged at the back. The top section contains the input-trigger and flip-flop memory circuits, and the lower section contains the servo-control circuits and motor, coded discs, gearing, flash-tube circuits, optical system, and phototubes. The power supply and the servo amplifier driver circuits are external to the converter chassis.

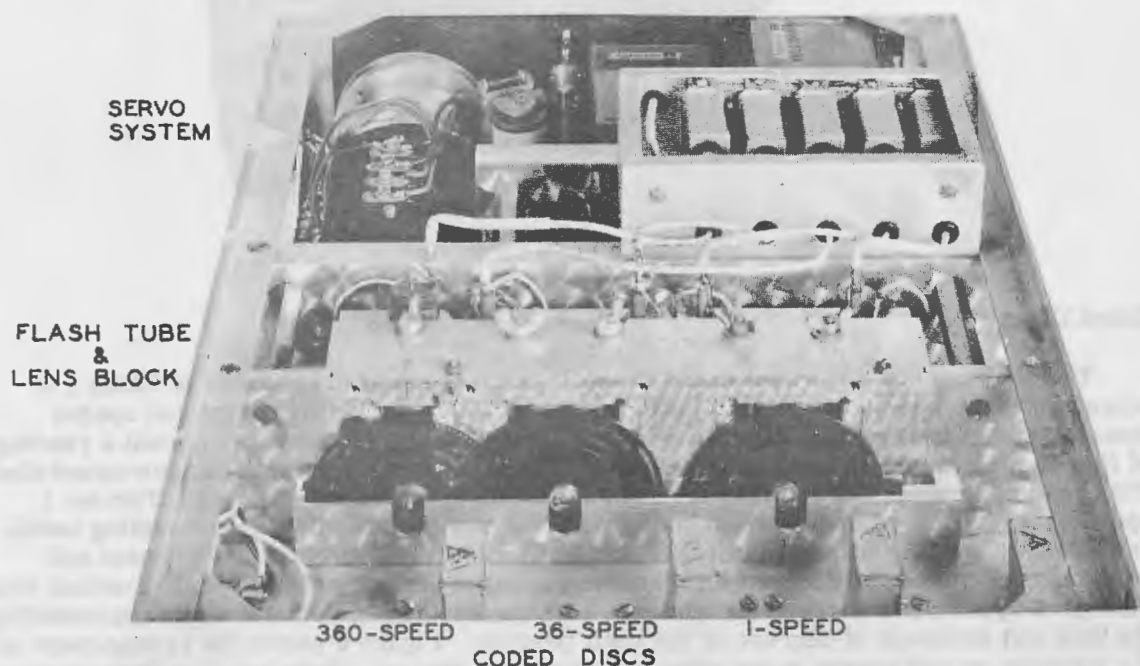


Figure 6 - Digital converter chassis

* See footnote 3, page 2.

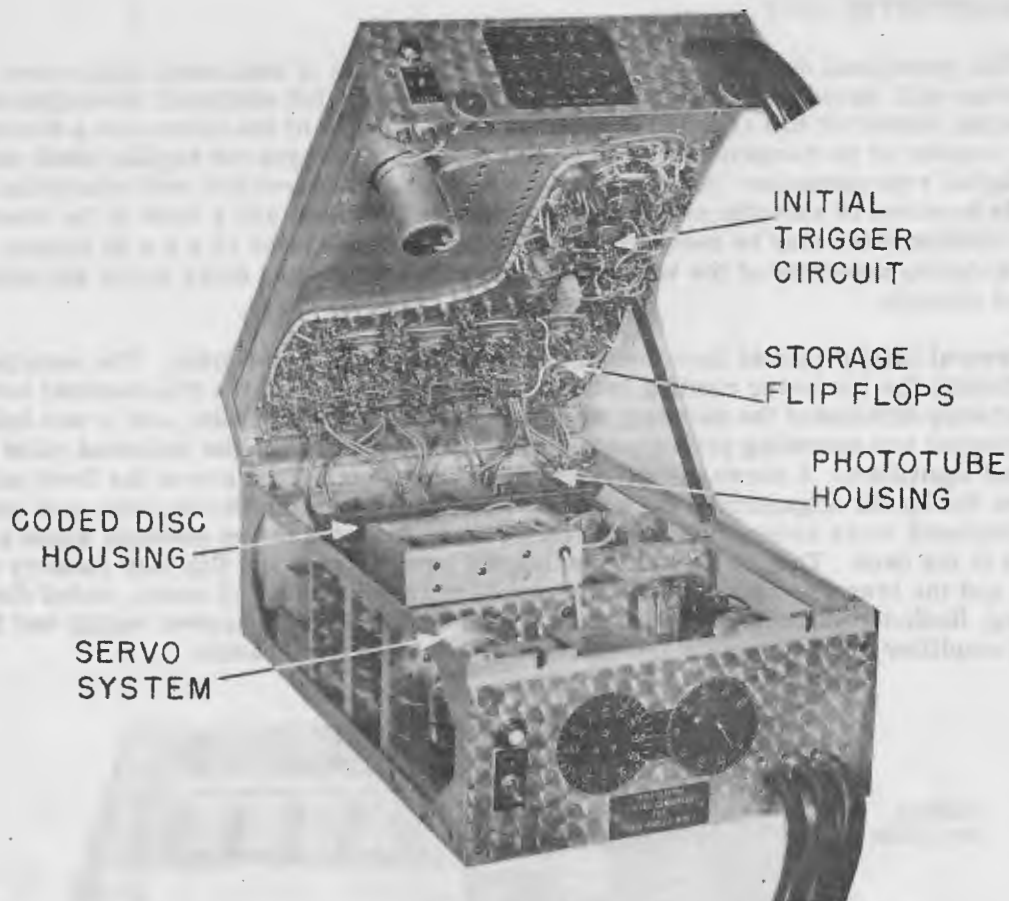
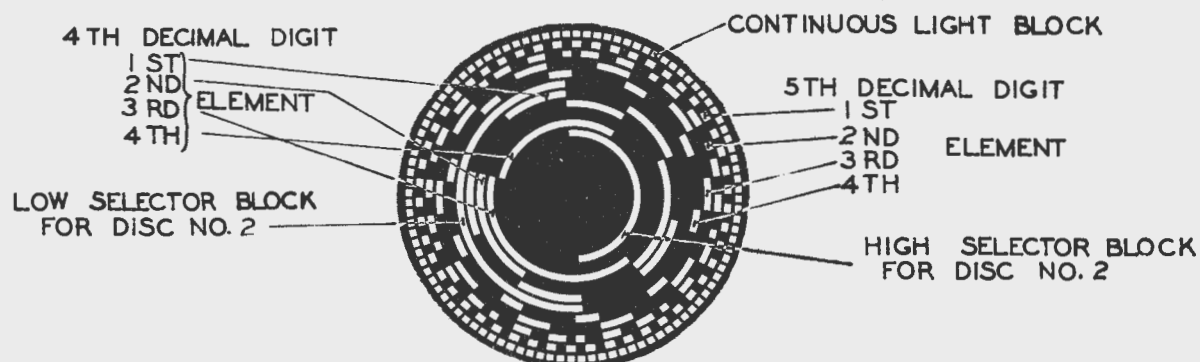


Figure 7 - Digital converter

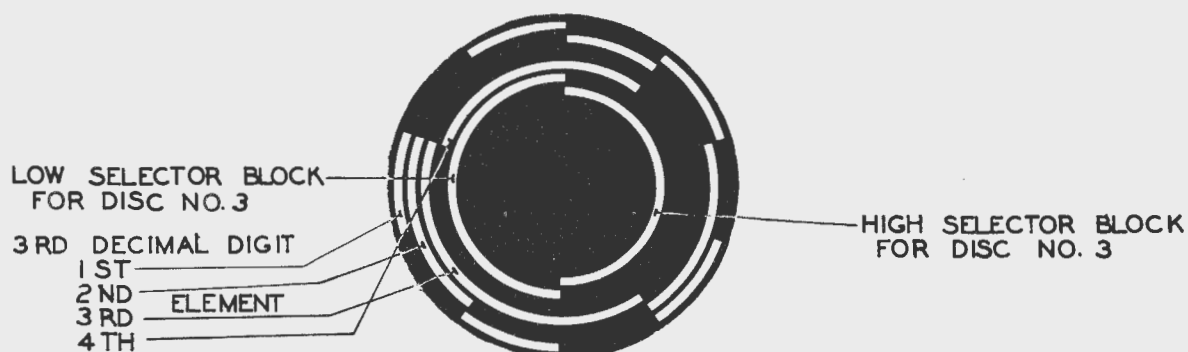
Coded Discs

The Digitar code described in the preceding paragraphs and tabulated in Table 1 is placed on three wheels of unplasticized Vinylite in the form of transparent and opaque spots as shown in Figure 8. The three coded discs of a digital converter permit a reading of five decimal digits with a resolving power of 0.01 degree referred to the one-speed shaft. This reading accuracy is obtained from the following arrangement of discs: Disc no. 1 operates at 360-speed and contains codings for the two decimal digits representing tenths and hundredths of a degree of the one-speed shaft; disc no. 2 operates at 36-speed and contains codings for the decimal digit representing the units digit of the shaft position; and disc no. 3 operates at 1-speed and contains codings for the two decimal digits representing the tens and hundreds of degrees of the shaft position. Figure 8 shows the arrangement of the transparent and opaque spots which represent the decimal digits and also the selector and light-block rings which will be described in a later section.

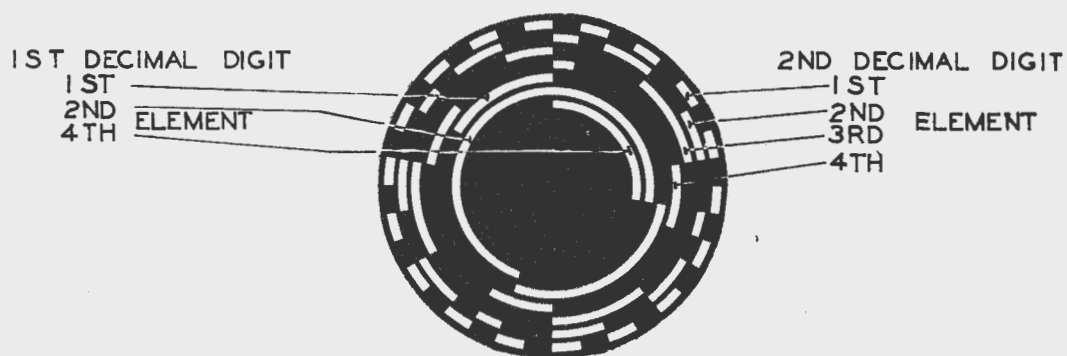
The coded discs illustrated in Figure 8 are used for the digital representation of director of gun train angles transmitted by 1- and 36-speed synchros. Table 2 lists the variables which may be recorded by the various digital converters of the NRL Digitar system. The Navy transmission speeds and the number of digits to be recorded are also



CODED DISC NO. 1
360-SPEED



CODED DISC NO. 2
36-SPEED



CODED DISC NO. 3
1-SPEED

Figure 8 - Coded disc arrangement

listed for each of the variables. The adaptation of the Digitar system to other synchro transmission systems may necessitate additional speed combinations and possible rearrangements of the decimal digit distribution among the coded discs.

TABLE 2
Variables Recorded by the Digitar System

Variable	Synchro Transmission Speeds	Number of Decimal Digits in Reading
Director Bearing	1* and 36†	5
Director Elevation	2 and 36	4 and ± sign
Director Range	72,000 yds/rev and 2000 yds/rev	5
Gun Train Order	1 and 36	5
Gun Elevation Order	2 and 36	4 and ± sign
Gun Fuze Order	100 sec/rev and 2 sec/rev	4
Roll of Deck	2 and 36	4 and ± sign
Pitch of Deck	2 and 36	4 and ± sign

* One revolution of a 1-speed shaft represents 360^0 of the variable.

† One revolution of a 36-speed shaft represents 10^0 of the variable.

Table 2 shows that certain of the digital converters must be able to record a plus or minus sign indication of the angular position of the shaft. These variables require only four decimal digits in the digital representation, and the fifth decimal digit position is available for the sign indicator. Since the Computer Mk 22 identifies a negative angle by the decimal digit 9 in the far-left, decimal-digit position, the digital converters are constructed to indicate a negative angle by the presence of the decimal digit 9 in the far-left digit of the appropriate coded disc. A corresponding positive angle is indicated by a zero in that digital position.

The coded discs used in each of the digital converters were constructed by engraving the opaque portion of the disc to a depth of 0.005 inch in a sheet of 0.045-inch-thick unplasticized Vinylite. The recessed portion formed by the engraving operation was then filled with black lacquer, and the unengraved portion was left clear.

Flash Tubes

The light for illuminating the very narrow sector representing a code character on each of the coded discs is provided by a miniature flash tube developed by the NRL Vacuum Tube Model Shop. This flash tube replaced the 631-P1 strobtron previously used, and permitted a reduction in the dimensions of each of the digital converters. The developed flash tube provided a line, 1-1/2 inches long, of high-intensity light matched to the sensitized surface of the 1P42 phototube. The tube shown in Figure 9 was made by sealing two tungsten elements into a formed glass tube of 2.5-millimeter diameter. After complete evacuation of the prepared tube, it was filled with xenon to a pressure of 15 centimeters of mercury and sealed.

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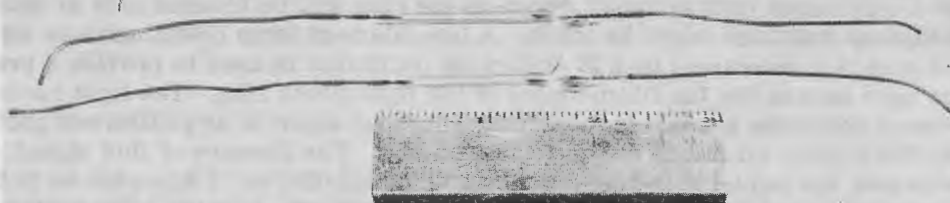


Figure 9 - Miniature flash tubes developed at NRL

A comparison of the output from a phototube which was energized by the NRL flash tube with measurements made under similar conditions but with light from the 631-P1 strobtron indicated that a five-to-one improvement had been gained by the use of the new tube. A 500-hour life test of the NRL flash tubes, flashing at ten times per second, indicated a slight darkening of the glass at the cathode location, but the efficiency of the flash tubes was not impaired. The circuit used for routine testing of the NRL-manufactured flash tube is shown in Figure 10. A voltage of 800 volts across the flash tube and a discharge condenser of 0.25 microfarads provided an average power input to the flash tube of 0.8 watts for 10 flashes per second.

Several 12-tube batches of flash tubes have been constructed by the NRL Vacuum Tube Model Shop. The operation of these tubes in the development and test of the various components of the Digitar system indicates that the tubes will provide good service. Most of the tube failures have been caused by contamination of the xenon by air leaking through checks which developed in the glass tubes after the normal period of aging.

Elimination of Ambiguous Readings

The three coded discs of each digital converter are positioned by the servo system to represent the position of the information-transmitting shaft. This angular position is read from the coded discs as a discrete value by means of a slit of light which transmits particular code characters to the memory circuits of each digital converter. Since the sector of each coded disc examined is of finite width, there is a possibility that the read signal might occur when parts of two adjacent code characters are in the read sector.

A light-block ring has been added to the periphery of coded disc no. 1 of each

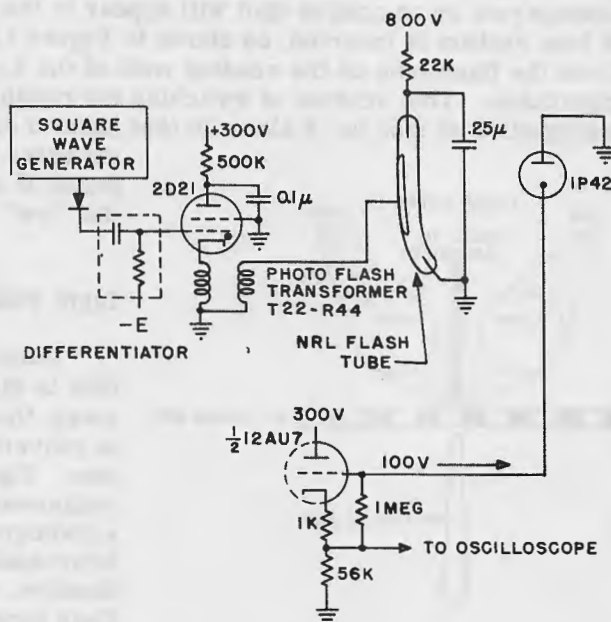


Figure 10 - Flash tube testing circuit

set of discs, as shown in Figure 8, to eliminate this possible cause of reading ambiguity for the first coded disc of the digital converter. The marking of the light-block ring insures that a continuous light source imaged on the ring will be blocked only at those points where ambiguous readings might be made. A line filament lamp (Westinghouse Exciter Lamp 0.75 amp, 4 v) energized by a 20-kilocycle oscillator is used to provide a practically continuous light source for the illumination of the light-block ring. The light received by the light-block phototube generates an electrical signal which is amplified and applied as an input to the trigger circuit of the digital converter. The absence of this signal, which occurs whenever the light-block ring markings on coded disc no. 1 are such as to block the light, prevents a trigger pulse being sent to the flash tube supplying the sector illumination for coded disc no. 1. Such action insures that the flash tube illuminating the reading sector will operate only when a single code-character on the coded disc appears in the reading sector. A negligible time delay is introduced by this action; however, a digital reading to the nearest 0.01 degree of the one-speed shaft is assured, since the light-block opaque spot which prevents the reading is only 0.004 degree wide in terms of the one-speed shaft.

The light-block scheme used to avoid ambiguous readings on disc no. 1 of the digital converter is not applicable to the resolution of similar ambiguities on discs no. 2 and no. 3, because of the much slower rotation of these discs. Ambiguous readings on these two discs are avoided through the use of two flash tubes: one is displaced slightly ahead of the normal reading position, and one slightly behind that position, as shown in Figure 11. It was necessary to allow the light to strike the coded disc obliquely, because of the physical size of the flash tubes and the lens system. Only one of the flash tubes is operated on any given reading operation. The selection of the operating flash tube is performed by disc no. 1 for disc no. 2, and by disc no. 2 for disc no. 3. The selection by disc no. 1 is performed by an examination of the tenths digit which has been read on that particular cycle. If the reading is between 0.0 and 0.4 inclusive, the "high" flash tube of disc no. 2 is energized; if the reading is between 0.5 and 0.9 inclusive, the "low" flash tube of disc no. 2 is energized. The switch from the "high" to "low" flash tube of disc no. 2 insures that either a transparent or an opaque spot will appear in the reading position of the operated flash tube. A lens system is inserted, as shown in Figure 11, to focus the narrow line of light coming from the flash tube on the reading ends of the Lucite rods used to transmit the light to the phototubes. This scheme of switching the reading position is used to eliminate reading ambiguities of disc no. 3 also. In this case, if disc no. 2 gives a reading between 0 and 4 inclusive, the "high" flash tube of disc no. 3 is energized; if disc no. 2 gives a reading between 5 and 9, the "low" flash tube of disc no. 3 is energized.

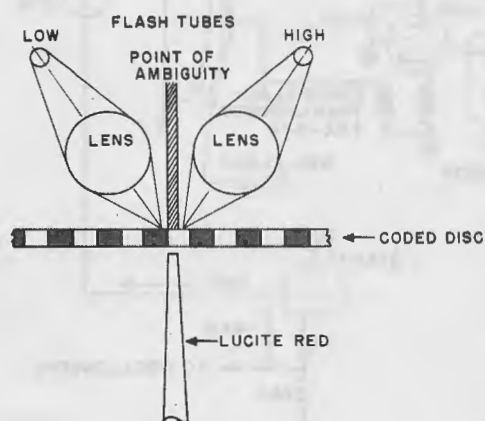


Figure 11 - Lighting arrangement for coded disc

Light Path and Detection

During a reading operation, light from a flash tube is directed through a cylindrical lens, a slit mask, the coded disc, the Lucite rods, and finally is converted to electrical energy by a 1P42 phototube. Figure 11 schematically illustrates the arrangement of the optical system, and Figure 12 is a photograph of the mounting block showing the individual holders for the flash-tube and lens combination. The use of a separate holder for each flash tube and its associated cylindrical lens permits easy adjustment of a particular flash-tube lens. The lens is a polished cylindrical glass rod of

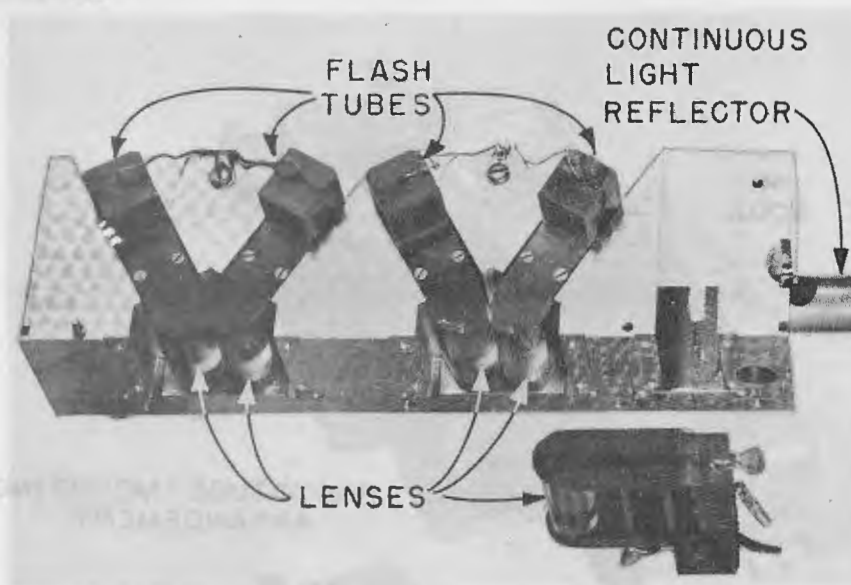


Figure 12 - Flash tube and lens mounting block

0.625-inch diameter. It is positioned with respect to the flash tube and the associated coded disc so as to provide about a three-to-one reduction in the width of the light line as focused on the coded disc.

The light which passes through the transparent patches of a coded disc illuminates the ends of Lucite rods and is transmitted to the associated phototube through the highly polished Lucite rods. The Lucite rods used in each of the converters were constructed from molded Lucite rods turned with a 1/4-inch-per-foot taper. A high polish was applied to the surface before the rods were heated for the bending process. After heating and bending, the rods were cooled slowly to reduce strain, cut to length, and polished. The larger end of each of the Lucite rods is terminated at the inner surface of the indented portion of the phototube housing. Each of the phototubes is mounted on a clip-in holder which places the sensitized surface of the phototube close to the ends of the rod. The holder also forms a part of the light-tight box surrounding each of the phototubes. Figure 13 is a view of the phototube and Lucite-rod assembly.

Reading Operation

The digital converter is ordered to read the coded disc associated with it by a signal received from the master synchronizer. The read signal is applied directly to a trigger circuit in the converter where it sets a flip-flop register. An instantaneous examination of the light-block ring of disc no. 1 is made to determine if a single code-character appears in the reading sector of disc no. 1. A trigger pulse is transmitted to the flash tubes of the disc no. 1 of each digital converter the moment light is passed through the light-block ring of each disc no. 1. Light is allowed to pass through the light-block ring only when a single code-character appears in the reading sector of disc no. 1. The flash of high-intensity light passes through the transparent elements of the code character in the reading sector of disc no. 1 and is directed to the phototubes by the Lucite rods. The phototubes in the converter receive the light signals and generate electrical signals which

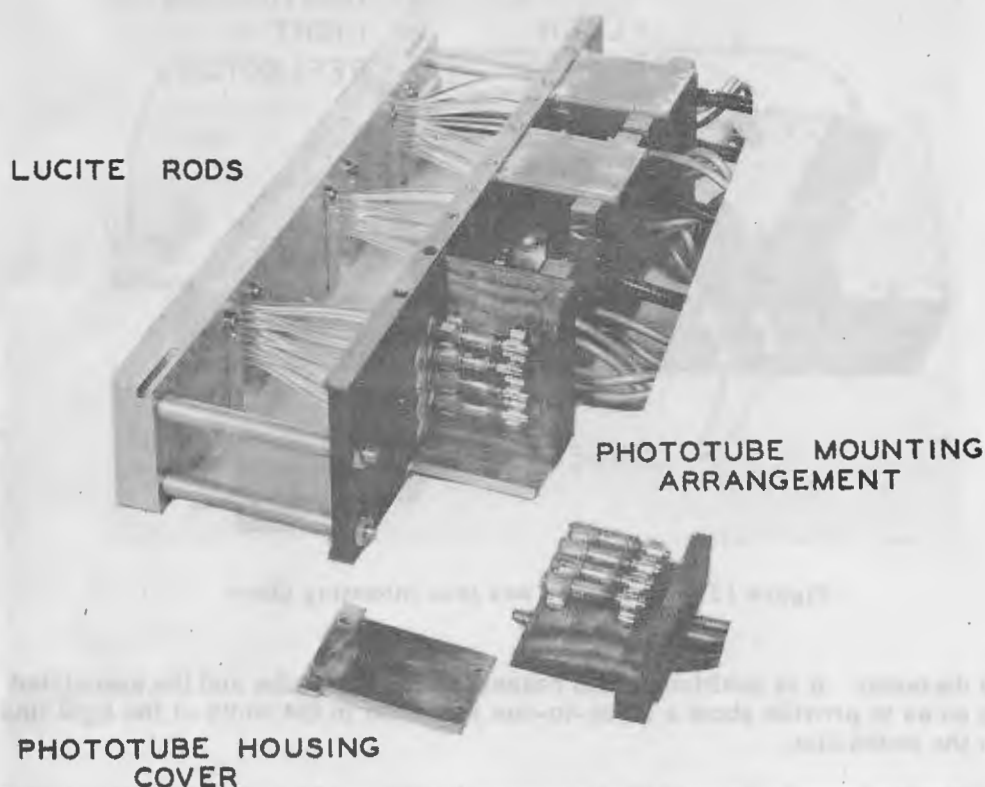


Figure 13 - Phototube and lucite rod assembly

are used to register the indicated digital shaft position in the memory flip-flop circuit. At the same time, the high-low phototube selector signal associated with disc no. 1 is amplified and triggers the proper flash tube of disc no. 2.

In a manner similar to that described for disc no. 1, the code character and high-low phototube selector indications are read from disc no. 2. The code character is registered in the memory flip-flop circuit, and the high or low flash tube of disc no. 3 is energized by the amplified signal originating from the phototube selector ring of disc no. 2. This reading cycle of the coded discs results in the flip-flop storage of the decimal digit representation of the position of the shaft associated with each digital converter. The numbers in the memory circuit of each digital converter are read and recorded by the equipment in the data storage unit. Following this recording operation, a reset pulse from the master synchronizer of the data storage unit returns the memory flip-flops to a zero indication. The digital converter unit is then ready for the next read operation.

Trigger Circuit

The trigger circuit used to fire the flash tube of each of the coded discs no. 1 of the digital converter is given in the upper left-hand corner of Figure 14. The negative-pulse initiating signal is transmitted from either the master synchronizer of the data storage unit or the local trigger circuit to the digital converter. At the time of the read signal,

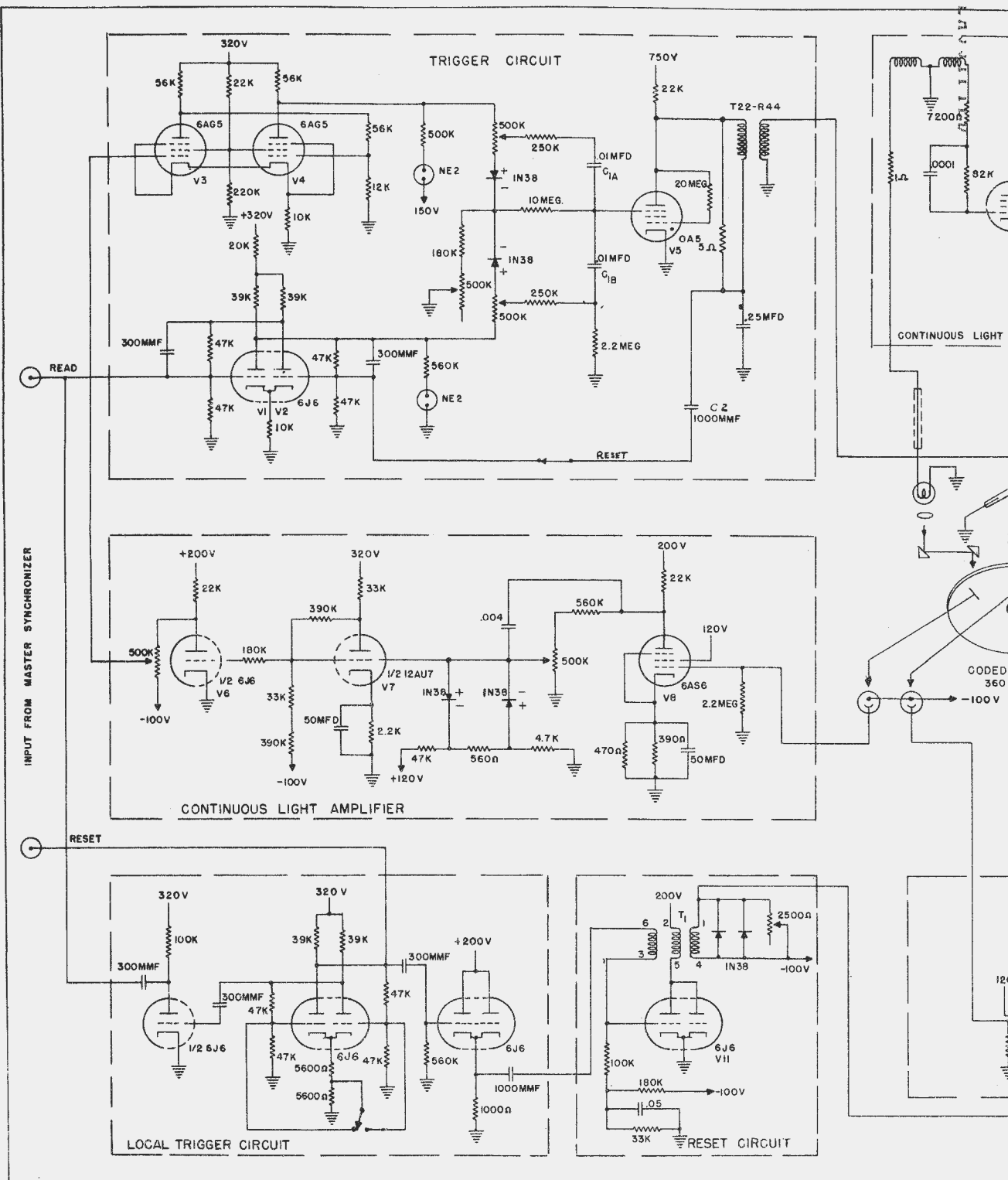
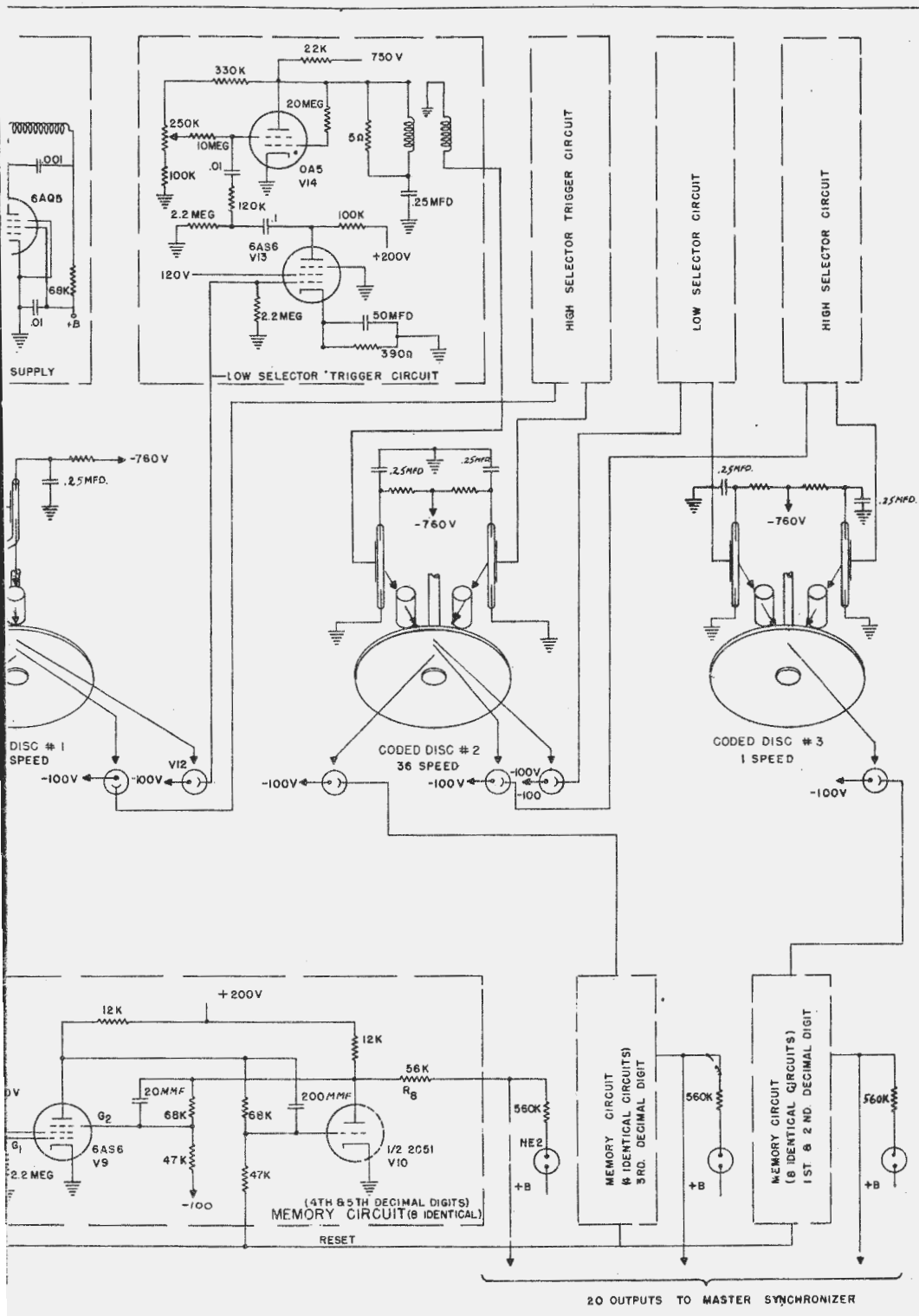


Figure 14 - Digital control



verter

There are four memory units required for the registration of each decimal digit. Each memory unit consists of a 6AS6 pentode (V9) and one-half of a 2C51 (V10) connected as a flip-flop circuit. The pentode of the flip-flop unit also serves as a voltage amplifier for the phototube signal. The pentode control grid G1 terminates the high impedance input circuit from the phototube and introduces the signal from the phototube into the flip-flop memory circuit. V9 is normally conducting; thus, a negative pulse on grid G1 is amplified, and the resulting voltage rise on the pentode plate is impressed on the triode grid to raise it above the cutoff point. V10 then attains the conducting condition.

Regenerative feedback is obtained by connecting the triode plate to the pentode suppressor grid G2. Because of the regenerative feedback employed in this circuit, an input signal to G1 of V9 sufficient to cause a +10 volt change on the pentode plate is all that is required to change the state of the flip-flop switch. The condition of the flip-flop memory unit is transmitted to the decimal digit selector of the data storage unit from the plate of V10 through the isolating resistor R_8 . If a transparent element of a code character has been sensed by means of the phototube, then the V10 triode is in a conducting state; if an opaque element has been sensed, V10 is nonconducting.

A visual indication of the condition of the memory flip-flop is obtained from the neon bulb (NE-2) connected between the B+ voltage and the plate of V10. The flip-flop memory circuit retains its information until the digital information has been transferred from all digital converters to the data storage unit. At that time the flip-flop memory circuits are prepared for another read operation by an action which causes all V9 tubes to attain a conducting condition.

The reset action applied to the flip-flop memory circuits is initiated through the secondary winding of the pulse transformer T1, which is connected to the grids of V10 triodes. Tube V11 (6J6) of the reset circuit operates as a blocking oscillator and superimposes a minus-polarity damped oscillation of about 5 microseconds duration on the minus 100-volt bias supplied to the grids of all V10 triodes. This minus pulse from the blocking oscillator cuts off any triodes (V10) which may be in a conducting state. The crystal diodes, which are connected in parallel with the secondary output coil of the pulse transformer, cancel any positive swing of the reset pulse. The reset signal to V11 is received through the local trigger circuit of the digital converter from the master synchronizer of the data storage unit.

High or Low Flash Tube Trigger Circuit

The trigger circuit which provides the firing pulse for the flash tube of coded disc no. 1 has been described in a preceding section. It has been indicated in the discussion of the reading operation that the pulses used to fire each of the flash tubes associated with coded discs no. 2 are derived from the high or low selector ring on wheel no. 1. The high and low flash-tube trigger circuits are identical, and one such circuit is given in detail in Figure 14. The pulse of light transmitted through a transparent spot of one of the selector rings of coded disc no. 1 energizes one of the two phototubes associated with the high and low selector trigger circuits of coded disc no. 2. Figure 14 shows only the low selector trigger circuit of coded disc no. 2, and the operation of the circuit may be explained by assuming that phototube V12 is energized.

The energizing of V12 causes the application of a negative electrical pulse to the control grid of amplifier tube V13. The amplified positive pulse from the plate of tube V13 is applied to the grid of trigger tube V14 (0A5). When V14 begins to conduct, the current which it draws through the primary of the pulse transformer causes a high voltage

pulse on the secondary of the pulse transformer. The high voltage pulse fires the low flash tube associated with coded disc no. 2. In the same manner, the high flash tube associated with coded disc no. 2, would have been ignited had the transparent spot appeared in the high selector ring of coded disc no. 1. Identical circuits are provided to ignite either the high or low flash tubes associated with coded disc no. 3 from a phototube sensing of the high and low selector ring of coded disc no. 2.

Servo Drive

In practical applications the converter unit will be located at a distance from the device containing the shafts whose positions are to be recorded. In most cases, electrical synchro outputs representing shaft position in the form of two-speed indications will be available. For this reason, each digital converter contains a 10-watt servo motor and matching amplifier. The drive motor positions the three coded discs and the synchro control-transformer rotors through an associated gear train in such a manner as to reduce the electrical output of the control transformers to zero. The output of the control transformers is the input to the servo amplifier.

Figure 15 is a picture of an external servo power amplifier. The servo system and the servo amplifiers are shown schematically in Figure 16. The two error outputs from the 1- and 36-speed synchro control transformers are sent through a single-pole, double-throw relay, which normally connects the 36-speed error to the input leads of the servo amplifier. If the error of the 1-speed CT becomes greater than $\pm 2\frac{1}{2}$ degrees, the relay (Clare No. 380) is energized and connects the 1-speed error signal to the input leads of the servo amplifier. The relay is released when the error becomes less than $\pm 2\frac{1}{2}$ degrees, and the input leads of the servo amplifier are again connected to the 36-speed error signal.

The servo used in each digital converter is provided with velocity feedback from an a-c generator attached to the drive motor. The open-loop characteristic of the servo was obtained by measuring the ratio of the peak-to-peak amplitude of the output shaft (A_0) to that of a sinusoidal input signal (A_i) for various frequencies (ω). The amplitude of the input signal was held constant at ± 0.1 degree as shown in Figure 17a. The open-loop characteristic (A_0/A_i versus ω) consisted of a line of slope -6 db/octave at low frequencies changing to a line of slope -12 at high frequencies. For the gain setting used, the intercept of the -6 db/octave asymptotic line with the 0-db axis was at $\omega_0 = 80$ radians/sec. The intersection of the -6 db/octave asymptote with the -12 db/octave asymptote occurred at $\omega_1 = 15$ radians/sec. The -12 db/octave asymptote crossed

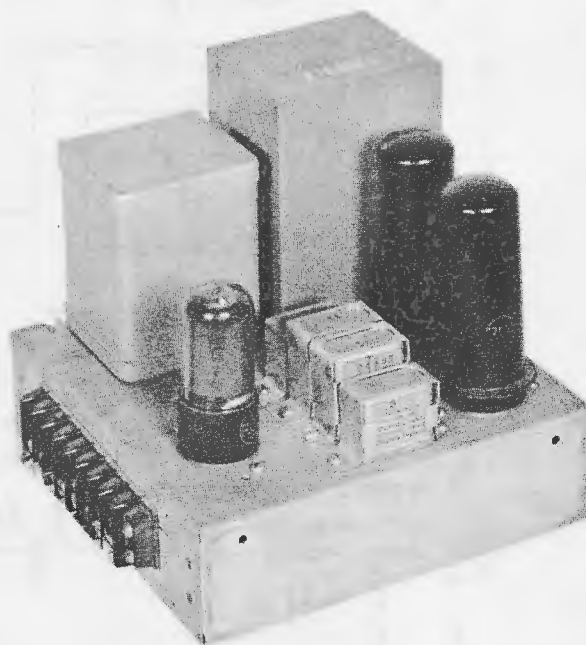


Figure 15 - Servo power amplifier

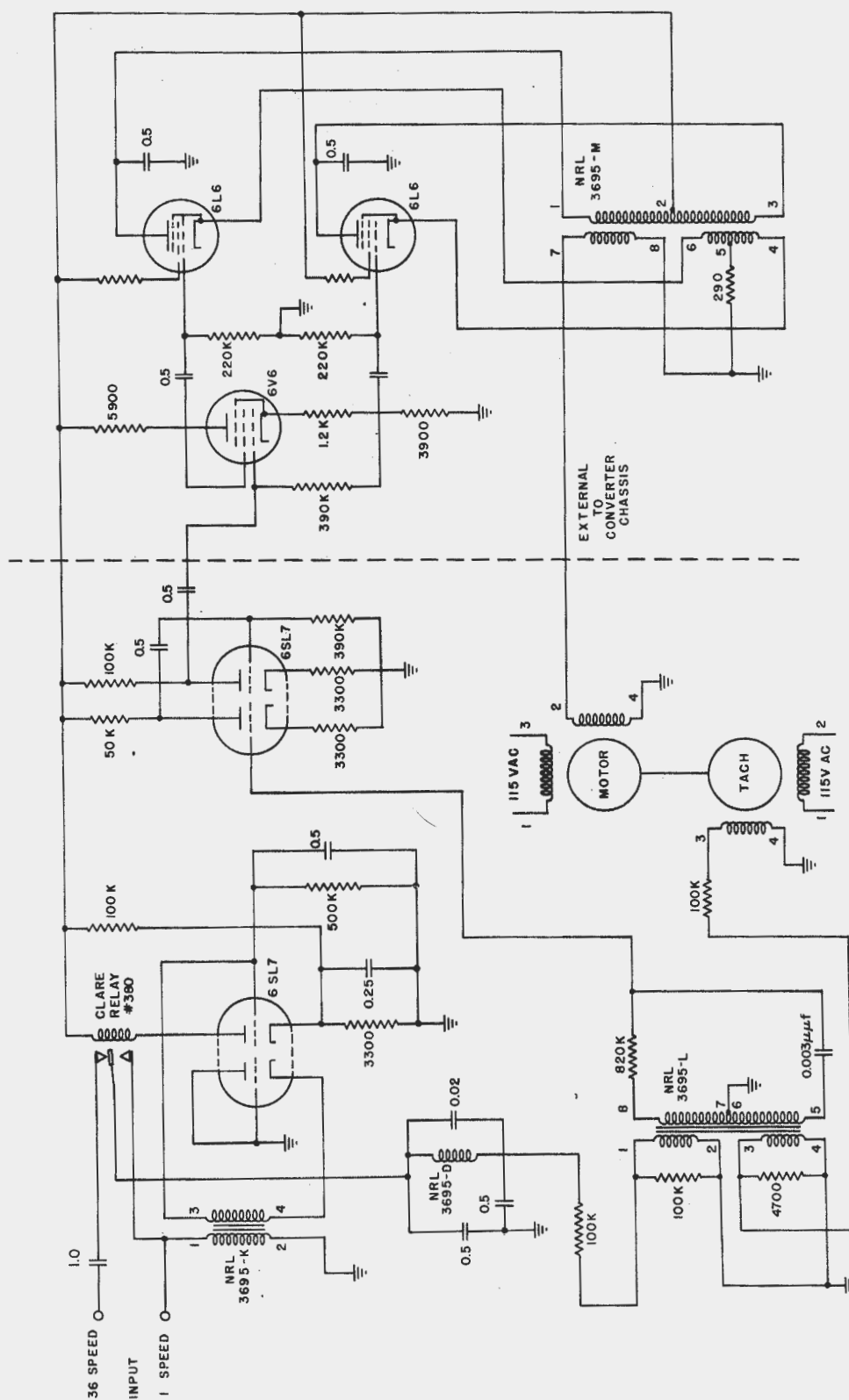


Figure 16 - Servo for digital converter

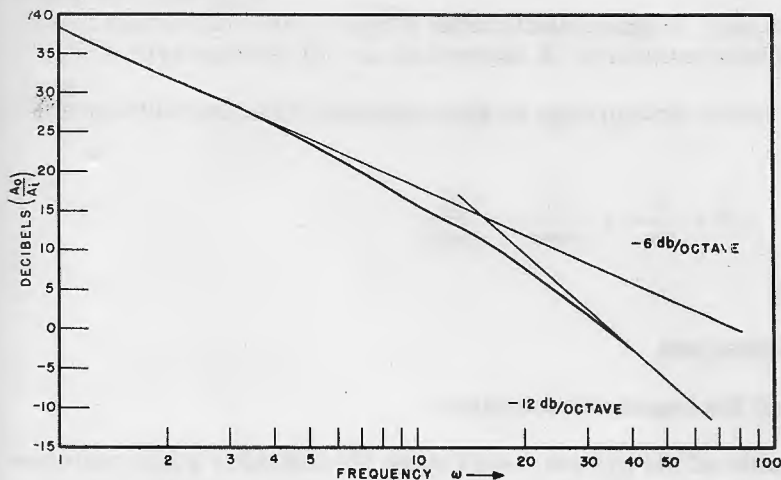


Figure 17a - Open-loop frequency of photoelectric converter servo with ± 0.1 -degree sinusoidal input

Figure 17b - Phase-shift characteristic

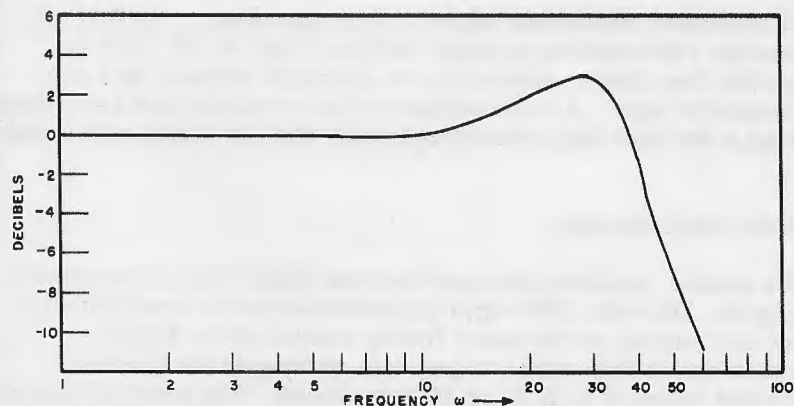
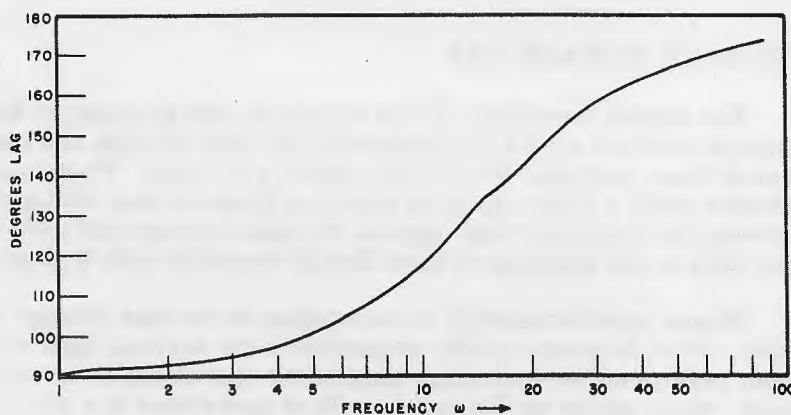


Figure 17c - Closed-loop servo response

Figure 17 - Servo response curves

the 0-db axis at $\omega = 35$ radians/sec. A phase-shift curve (Figure 17b) constructed from this characteristic indicated a phase margin of 18 degrees at $\omega = 35$ radians/sec.

Dynamic accuracies of the servo system may be approximated from the following equation

$$E = \frac{\dot{\theta}}{\omega_0} + \frac{\ddot{\theta}}{\omega_1 \omega_0} - \frac{2\ddot{\theta}}{\omega_0 \omega_1}$$

where $\dot{\theta}$ is the angular velocity

$\ddot{\theta}$ is the angular acceleration, and

$\ddot{\theta}$ is the first derivative of the angular acceleration.

The closed-loop characteristic of the system (see Figure 17) indicates a flat response to $\omega = 10$ followed by a rise to 3 db at $\omega = 30$. Variations of these characteristics can be obtained by altering either the system gain and the amount of velocity feedback or both.

THE DATA STORAGE UNIT

The digital converters of the converter unit accomplish the positional readings of the various shafts at a rate determined by the data storage unit and store the digital representation of those positions in flip-flop memory circuits. These values remain in the memory circuits until a reset signal is received from the data storage unit. During the period between the read and reset signals, the data storage unit selectively sequences each decimal digit of the readings of each digital converter onto a single channel of a magnetic tape.

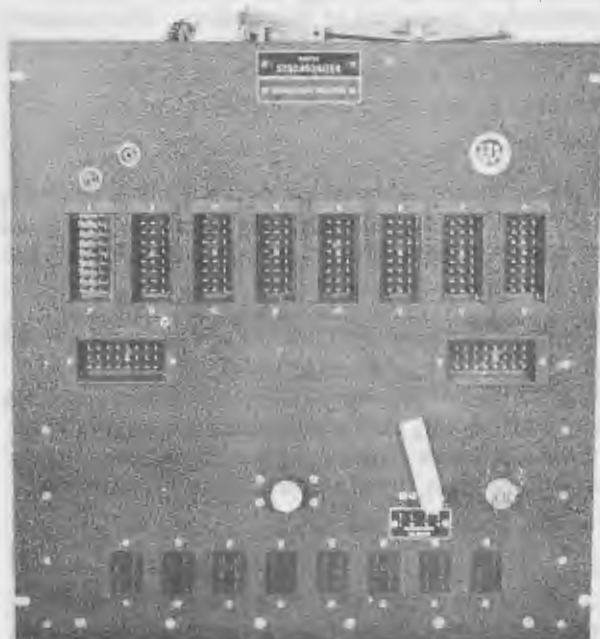
Proper synchronization is maintained in the data storage unit by the master synchronizer, which is mechanically connected to the decimal digit selector. The timing of the read, reset, and the individual sequencing operations is controlled by the master synchronizer, which performs the basic cycle of operations at a preset rate of 1, 2, 5, or 10 times per second.

The decimal digit selector transmits electrical signals corresponding to the four binary elements of the code character representing a single decimal digit to the code sequencer. In the code sequencer the four binary elements are arranged serially and are recorded on a single-channel magnetic tape. A code sequencer and recorder for recording the binary elements representing a decimal digit photographically has also been developed.

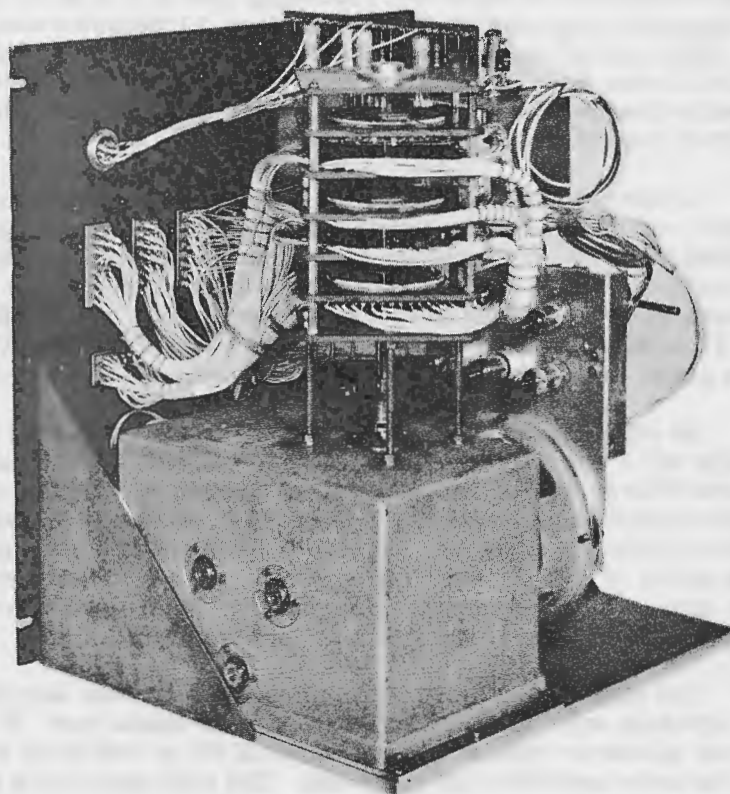
Master Synchronizer and Decimal Digit Selector

Front and rear views of the master synchronizer and decimal digit selector assembly are given in Figure 18. A 60-cycle, 115-volt, 1800-rpm synchronous motor mechanically drives the master synchronizer and serves as the basic timing source of the Digital system. A gear box is provided to cause this motor to produce cycling of the decimal digit selector commutator at preset rates of 1, 2, 5, or 10 per second. The gearing associated with the various possible reading rates is controlled by an adjuster mechanism on the front panel.

A schematic drawing of the master synchronizer and decimal digit selector is shown in Figure 19. Wafer no. 1 of the five-wafer commutator is actually the controlling element



Front View



Rear View

Figure 18 - Master synchronizer
and decimal digit selector

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for the master synchronizer. The read and reset pulses governing the operation of the digital converters are initiated from the commutator elements of this wafer. The commutator elements of wafer no. 1 also generate trigger pulses for initiating the scanning and gating operations of the code sequencer. The circuitry shown to the left of wafer no. 1 (Figure 19) is used to develop three timing pulses: the read pulse; the reset pulse; and, the read counter stepping pulse.

The circuitry to the right of wafer no. 1 generates the initiating pulse for the scanning operation of the code sequencer. These circuits eliminate the ragged make-and-break action of the mechanical contacts of the commutator and provide appropriately shaped pulses for use in initiating the desired Digital operations.

A voltage from a tap-down point in the common cathode of V6-7 is applied to the continuous ring of wafer no. 1, and this signal is carried to the other contacts by the brush assembly as the commutator arm rotates. When applied through the commutator contacts to a grid of one of the electronic switches (V1-2 or V6-7), this signal causes the switch to assume one of its two stable conditions. This action is aided by the positive feedback action of the circuit connections. The switch will remain in this condition until altered by a similar signal applied to the opposite grid.

The grids of V1 and V2 are connected to the read and reset contacts respectively of the commutator wafer no. 1. As the brush of the commutator strikes the read contact, the grid of V1 is lowered below the cutoff level of the triode, and the circuit assumes the stable condition of V2 conducting and V1 cut off. The reverse condition is imposed when the brush strikes the reset contact near the end of the commutator cycle. The commutator arm rotates at the preset recording rate of 1, 2, 5, or 10 times per second. When the commutator arm strikes the read contact, V1 becomes nonconducting and V2 conducts. A differentiated negative signal from the plate of V2 is used to lower the grid of the cathode follower V4. The negative pulse from the cathode of V4 is the read signal, which is used to position the read flip-flop of the trigger circuit (see Figure 14) of each of the digital converters.

A pulse of positive polarity is obtained from the plate of V1 and is transmitted to the read counter through the cathode follower V5. When the commutator arm has almost completed its cycle, it strikes the reset contact. A negative electrical signal applied to the contact by the commutator arm causes the V1-2 electronic switch to return to the condition where V1 is conducting and V2 is nonconducting. The resulting positive signal on the plate of V2 is differentiated and applied to the cathode follower V3. From the cathode of V3 the signal is transmitted to the reset circuits of the several digital converters.

As shown in the schematic of Figure 19 the remaining contact points of the commutator wafer no. 1 are alternately connected to one of two bus leads. One of these leads terminates at the grid of V6 and the other at the grid of V7. The alternate connections of the commutator wafer cause the switch (V6-7) to change its condition as the commutator arm moves from one contact to the next. The negative portion of the differentiated signal from the plates of both V6 and V7 are passed by the diode clipper circuits and are applied to the grid of V8. The inverted and amplified output pulses from the plate of V8 are supplied to the code sequencer for initiating its scanning operation.

The connections illustrated in Figure 19 provide means for indicating 58 decimal digits or symbols expressed as four-element code characters. If the positive read counter and reset pulses are mixed with the output of V8, a total of 60 code characters may be applied to the code sequencer for recording. The code characters furnished to the code sequencer by the commutator contacts between the read and reset contact points must be either symbol

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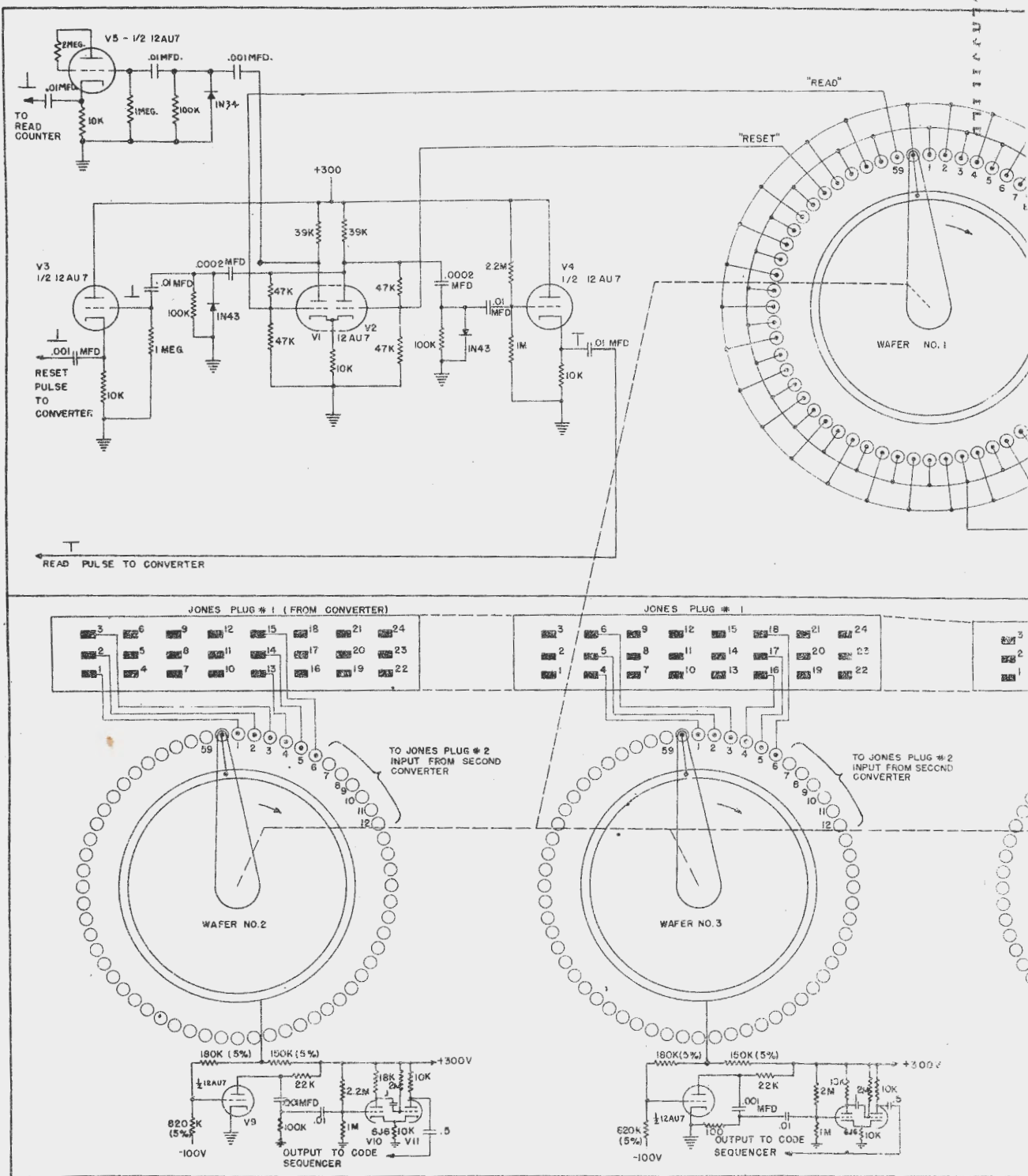
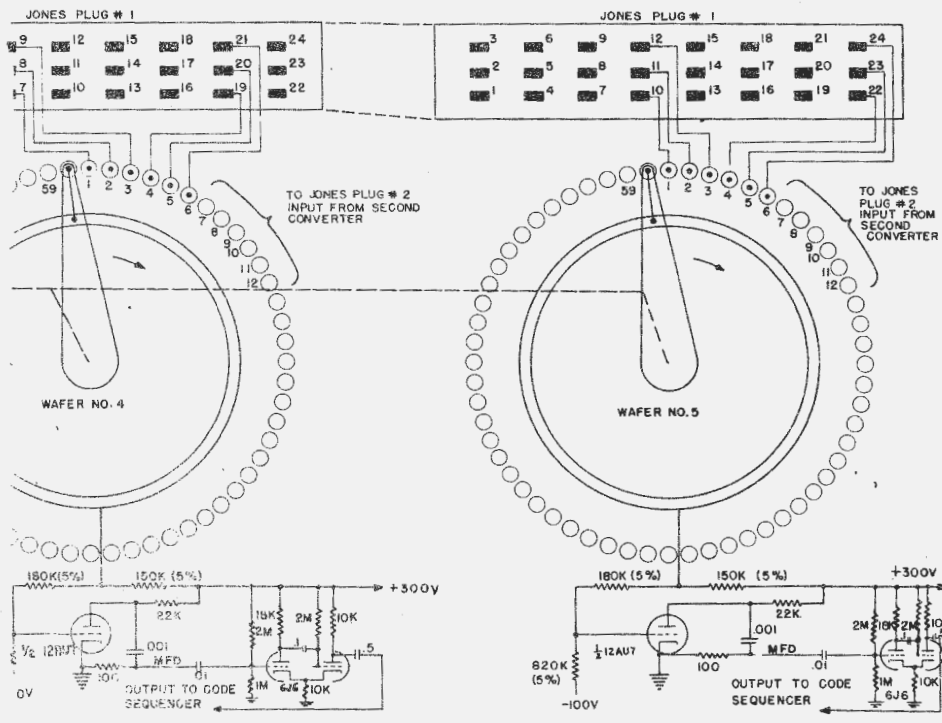
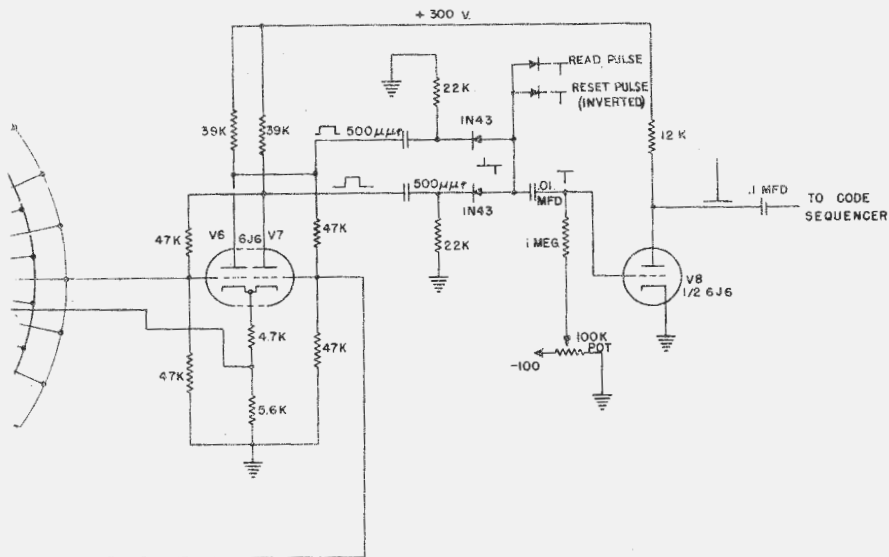


Figure 19 - Synchronizer and dec

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digit selector

or read counter indications, since all digital converters are returned to the zero-indicating condition by the reset signal.

The contacts between the reset and read contacts have been assigned as follows:

Contact	Print Operation
Reset	ER - Carriage Return and Line Feed
Reset + 1	ER - Carriage Return and Line Feed
Reset + 2	Time - Hundreds Digit
Reset + 3	Time - Tens Digit
Reset + 4	Time - Units Digit
Read	Identifying symbol of number from first Digital Converter
Read + 1	First decimal digit from first Digital Converter

The remaining contact points are assigned to successive digital converters allowing for an identifying symbol followed by five code characters representing the five-digit decimal number.

The alignment of the commutator brushes on wafers no. 1, 2, 3, 4, and 5 is such that, when a positive pulse is delivered to the code sequencer from V3, indications of the binary elements of the code characters are available on the digit selector commutator wafers 2, 3, 4, and 5. For example, when the commutator arm of wafer no. 1 is positioned on the read-plus-one contact, the arms of the other commutator wafers are similarly positioned. The function of wafer no. 1 is to supply the initiating signal for the scanning operation of the code sequencer. Wafer no. 2 supplies the first element of the code character stored in the flip-flop memory circuit of the first digital converter. Wafer no. 3 supplies the second element of that code character, and wafers nos. 4 and 5 supply the third and fourth elements, respectively, of that code character. Circuits associated with commutator wafers nos. 2, 3, 4, and 5 transmit each of the code-character elements over separate wires to the code sequencer.

The lower half of Figure 19 is a schematic drawing of the decimal digit selector circuitry. Ten 24-pin Jones plugs carry the input leads from the digital converters and read counter to the decimal digit selector which consists of commutator wafers nos. 2, 3, 4, and 5, and their associated circuitry. The Jones plug shown schematically in Figure 19 is associated with a single digital converter. The same plug is drawn four times, so that the order of connections to the commutator contacts of each wafer could be clearly indicated. Each Jones plug carries the four elements of six code characters from a digital converter. These characters consist of representations of five decimal digits and an identifying symbol for the five-digit number. The Jones plug pin assignments are listed in Table 3.

TABLE 3
Pin Assignments for Jones Plugs

Code Character	Binary Element			
	#1	#2	#3	#4
Decimal Digit #1	1	4	7	10
Decimal Digit #2	2	5	8	11
Decimal Digit #3	3	6	9	12
Decimal Digit #4	13	16	19	22
Decimal Digit #5	14	17	20	23
Symbol	15	18	21	24

Jones's plug no. 2 (not shown in Figure 19) carries the input from the second digital converter. Its 24 pins are assigned as in Table 3, and the pins are connected to the commutator wafer as shown in Figure 19. Similar connections are used for the other six digital converters.

The symbol identifying the number registered by each digital converter is the same for every number read from a given converter. For this reason pins 15, 18, 21, and 24 of each Jones plug are permanently connected to either a high or low voltage indication (160 V or 60 V) to simulate the outputs of the flip-flop memory circuits of the digital converter.

An electronic circuit is provided at the output of each commutator wafer of the decimal digit selector to develop a sharp, clean pulse for use with the associated gate circuits of the code sequencer. Tube V9, associated with wafer no. 2, is a normally conducting triode which is cut off when a low indicating voltage of the memory flip-flop associated with the first binary element of a code character is applied to the grid of V9 through the commutator arm of wafer no. 2. The positive pulse from the plate of this tube is differentiated and applied to the grid of V10. Tubes V10 and V11 form a delay multivibrator, which is triggered by the application of a positive pulse to the grid of V10.

Additional pulses caused by the ragged action of the mechanical contact have no effect on the one-shot multivibrator output-pulse waveform, which is taken from the plate of V11. The duration of the delay imposed by the multivibrator covers the instant that the brush leaves a particular contact. This delay eliminates sporadic signals caused by contact roughness. The circuitry supplying information pulses to the code sequencer through commutator wafers nos. 3, 4, and 5 is identical with that just described for commutator wafer no. 2.

The Read Counter

The read counter of the data storage unit provides a numerical indication of the relative time at which a reading is made by the digital converters. As each read signal is transmitted to the digital converters, a second signal causes the read counter to be advanced one step. The read counter is capable of counting from 000 through 999. Each of three decimal digits is registered on relay circuits in the form of four binary elements of the

code character representing each decimal digit. Outputs from this relay circuit are transmitted to the commutator wafers of the decimal digit selector, which transmits the time indicator code to the code sequencer by the commutator action as described in the preceding section.

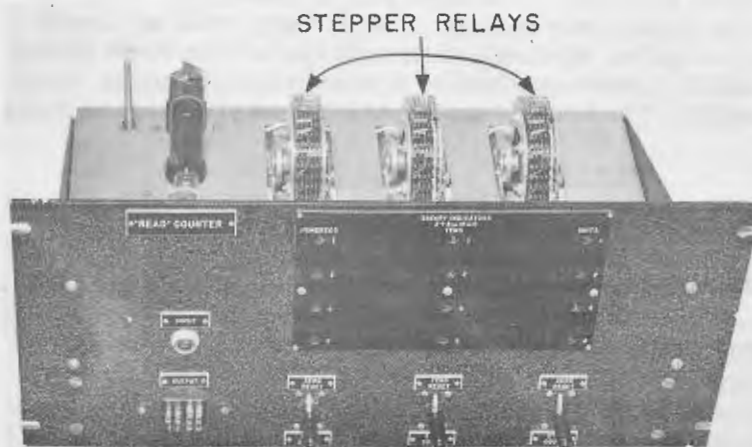


Figure 20 - Read counter

Figure 20 illustrates the physical arrangement of the read counter, and Figure 21 is a schematic drawing of the read counter. The basic element of the read counter is the 20-point, 6-level, spring-return, stepping switch.

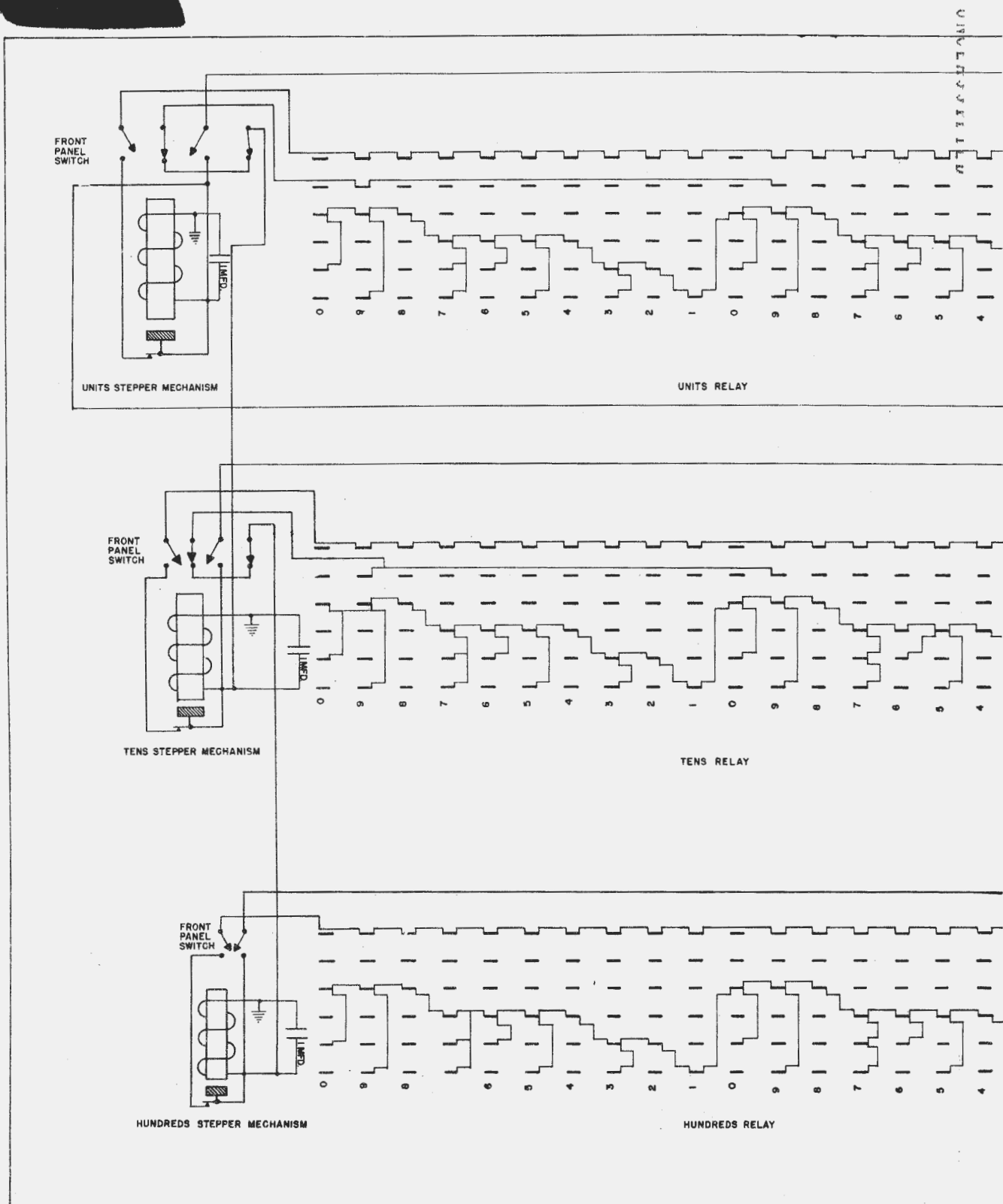
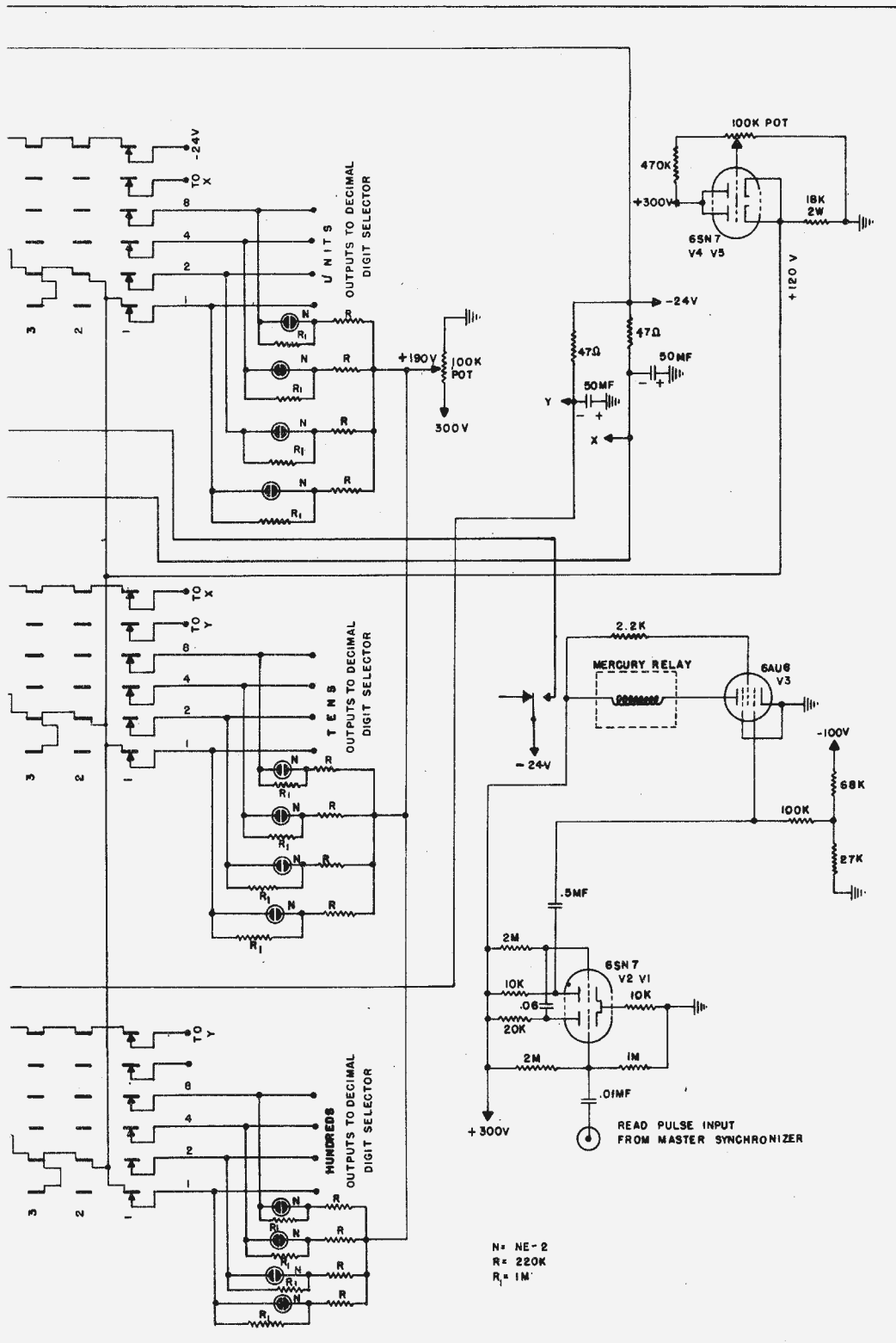


Figure 21 - Read cour



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Three of these stepping relays are connected so that they form a three-decade counter. Reading rates up to 10 per second are within the operating limits of these relays. The contacts of the lower four levels of the stepping relays are wired so that the four elements of a code character representing a single decimal digit are developed in parallel on the four output leads of each relay.

The fifth level of contacts on both the units and tens stepping relays is wired so that a pulse is delivered to the "advancing" relay of the next higher decade relay whenever the decimal digit 9 is indicated by the next lower decade relay. The stepping operation of the next higher decade relay is performed when its stepper relay circuit is de-energized by the next lower decade relay moving from 9 to the 0 position. This operation provides the carry-over action from one decade to the next.

The sixth level of contacts is used to position or to zero the three stepping relays from appropriate control devices on the front panel of the read counter. The circuits connected to a three-position switch located on the front panel are arranged so that, if the switch is thrown in one direction, the read counter advances one count; and, if thrown in the other direction, the read counter advances itself automatically to the zero indication. In normal operation of the Digitar equipment, this switch is in its center position so that the read counter is controlled by the master synchronizer.

The stepping pulse for the read counter is initiated by the one-shot multivibrator V1-2. The short, squared pulse from V2 drives V3, which in turn draws current through the mercury-reed type of relay to close the contact between the 24-volt supply and the advancing mechanism of the units relay stepper mechanism. A front-panel indication of the value of the read counter is provided by neon indicators.

Code Sequencer

Each decimal digit is presented to the code sequencer as a four-element code character. The binary elements appear in parallel on four electrical pulse lines. The code sequencer converts this parallel form of representation into a time-positioned serial form. For magnetic recording, a recorded pulse is required for each of the time-positioned elements of a code character. The code sequencer generates plus and minus pulses corresponding to the two possible conditions of a binary element. A plus pulse signifies the presence of binary information, and a minus pulse indicates lack of binary information. If the recording is to be performed photographically, the code sequencer generates only the positive pulses corresponding to the presence of binary information.

A picture of the code sequencer is given in Figure 22, and a schematic of its circuits is given in Figure 23. The five input leads to the code sequencer are shown on the left-hand side of Figure 23. Four of these input leads originate in the decimal digit selector, and the fifth input lead comes from the master synchronizer. The first four leads transmit pulses corresponding to the binary elements of a code character representing a single decimal digit.

The fifth lead transmits a signal from the master synchronizer to the code sequencer to initiate the recording process for the four binary elements presented on the first four leads. Positive pulses on the four input leads from the decimal digit selector are applied to the control grid of an associated gating pentode (V1, V2, V3, or V4). The pulse required to complete the gating operation of each of these tubes is applied to the suppressor grid by a multivibrator sequence (V7 through V22).

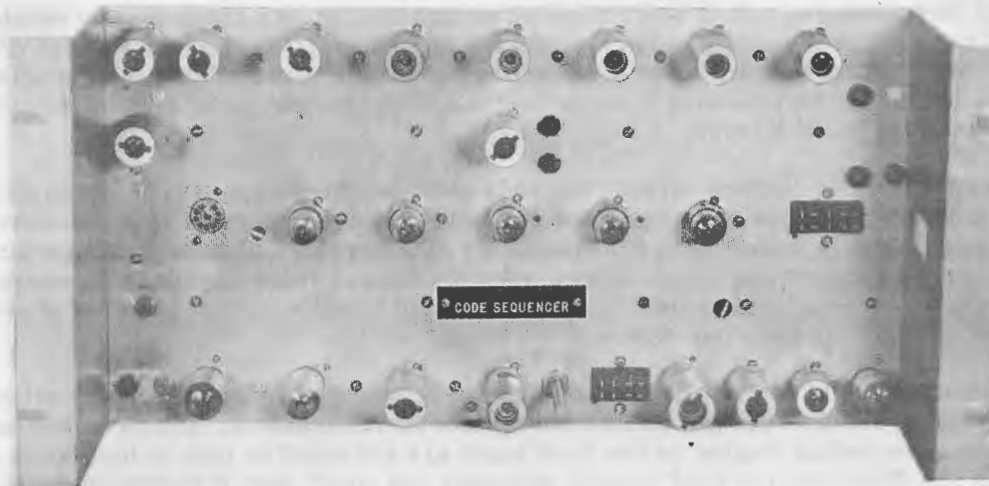


Figure 22 - Code sequencer

Tubes V7 through V22 form a chain of eight delay-type multivibrators, and a positive initiating pulse is supplied to the chain at the grid of V7 by the master synchronizer. The first multivibrator (V7 and V8) has a delayed reset of 150 microseconds. When this multivibrator returns to its normal position (V8 conducting), the change in plate voltage of V7 causes V9 to assume a conducting position. V9 and V10 make up the second multivibrator, and the circuitry is arranged to give a reset delay of about 100 microseconds. The remaining six elements of the multivibrator chain operate in a similar manner, with alternating reset delays of 150 and 100 microseconds. The square pulses developed at the plates of V10, V14, V18 and V22 are used as the pulse signals to the suppressor grids of tubes V1, V2, V3 and V4 respectively. These pulses are also passed to the grids of V24, V25, V26 and V27 respectively.

A positive signal applied to the control grid of the gating pentode V1 is transmitted to the grid of V23 at the instant the second multivibrator pair (V9 and V10) assumes the condition of V9 conducting and V10 nonconducting. The positive pulse which occurs at that time at the plate of V10 is applied to the suppressor grid of V1, and the occurrence of positive pulses on both the control and suppressor grids of V1 causes V1 to conduct. The negative signal at the plate of V1 is applied to the grid of V23 where it is inverted and amplified. The signal from the plate of V23 serves as a plus-signal indication on the output lead to the recorder amplifier.

The positive signal from the plate of V10 is also transmitted to the grid of V24. Tube V24 inverts and amplifies this signal. The output of the plate of V24 is applied to the grid of the normally conducting tube V28, where it is again amplified and inverted. The resultant positive signal at the plate of V28 is applied to the suppressor grid of V29. If the condition described in the preceding paragraph exists, there is a pulse to be transmitted over the plus channel to the recorder amplifier, and no information is to be transmitted over the minus channel. The registration of the positive pulse has been described. The negative pulse from the plate of V1 is applied to the control grid of V29 as well as to the amplifier V23. A negative voltage on the control grid of V29 causes it to remain in a nonconducting condition; hence, there is no output on the minus channel to the recorder amplifier.

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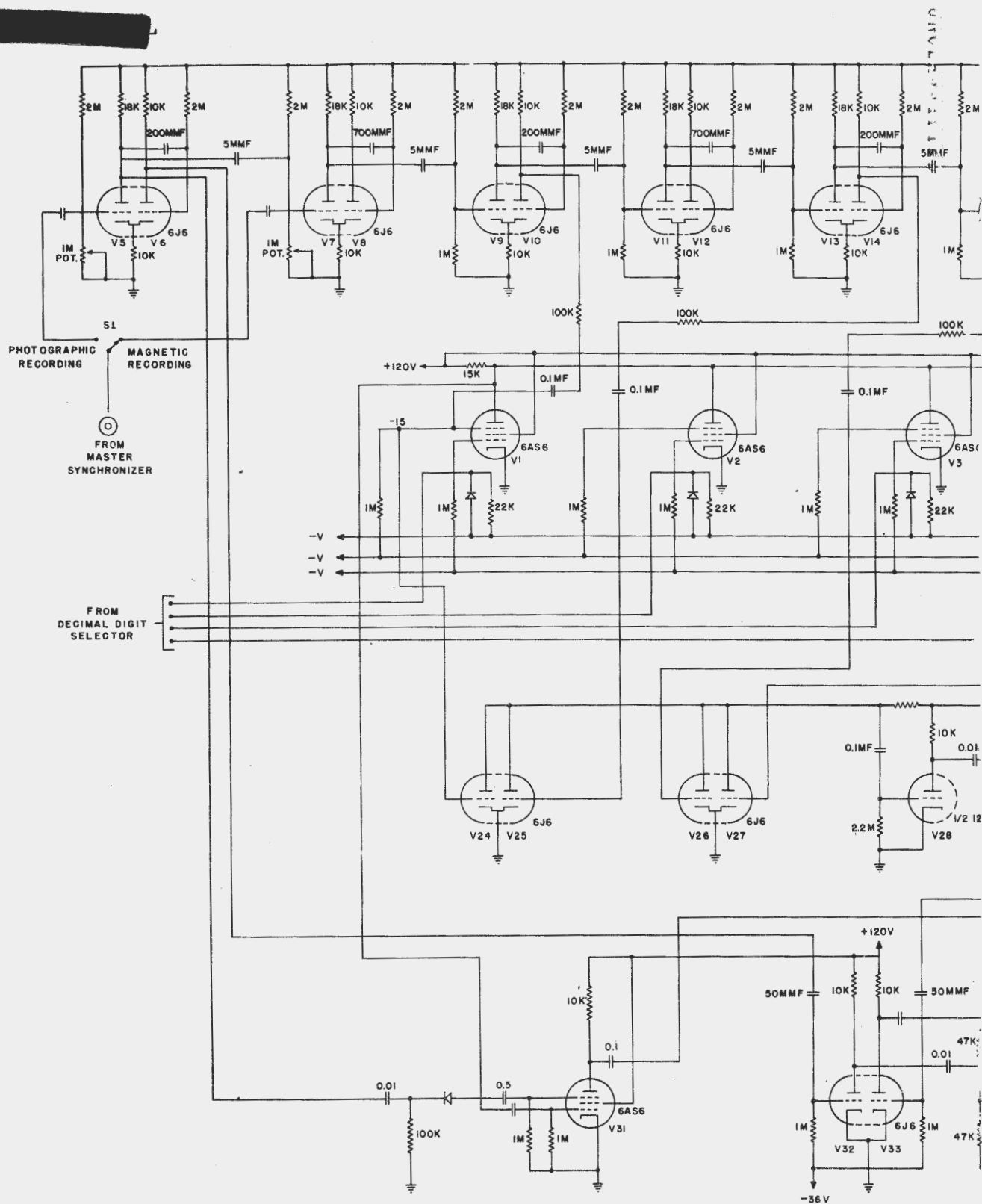
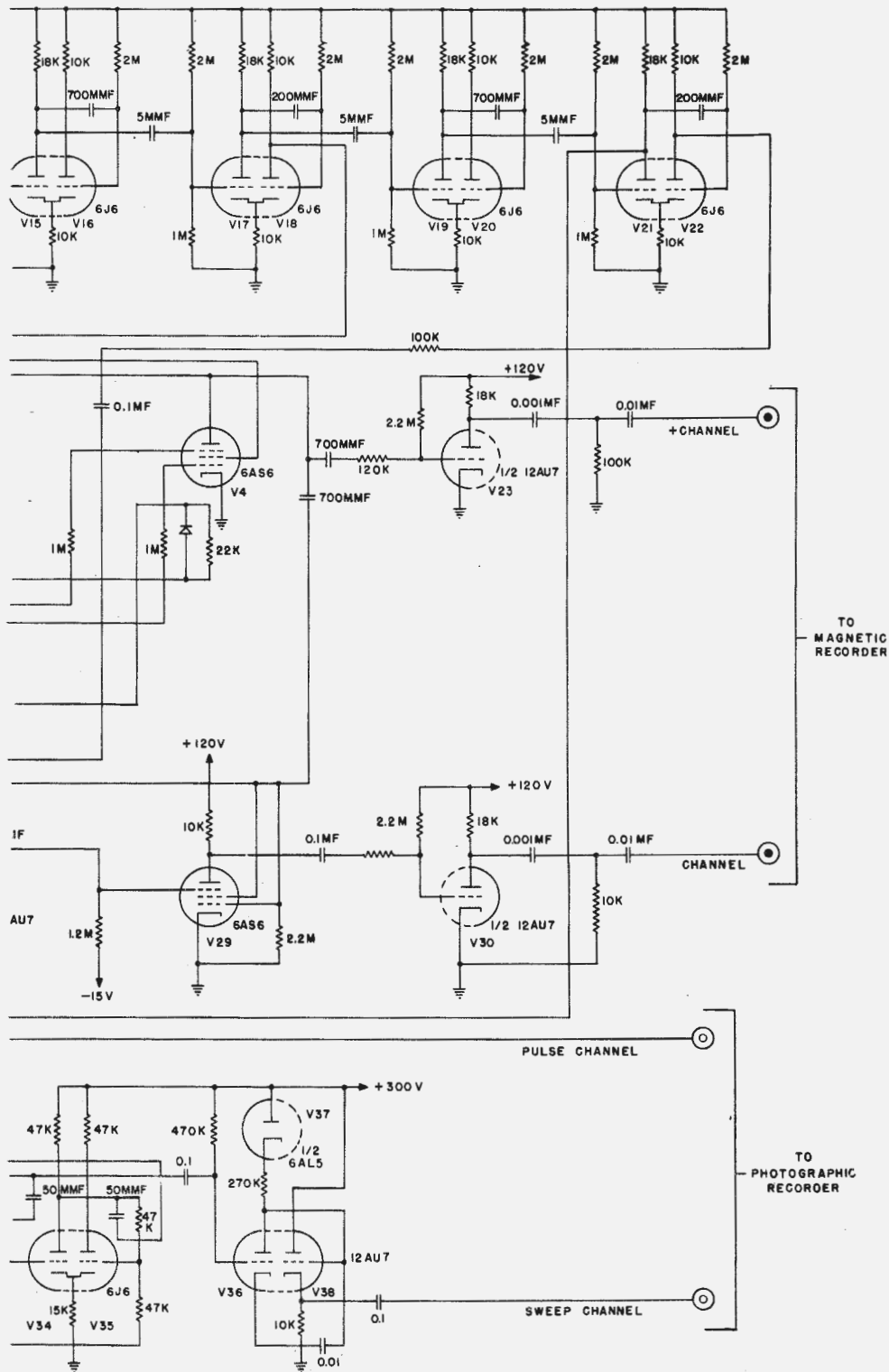


Figure 23 - Code sequence

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If an information pulse had not been supplied to the control grid of V1 from the decimal digit selector, V1 would remain in a nonconducting state, and there would be no output at its plate to be transmitted to V23 and V29. Consequently, there would be no output on the plus channel. Pentode V29, however, would conduct because of the positive pulse on its suppressor grid. The negative pulse on the plate of V29 is applied to the grid of V30, where it is inverted and amplified. This action produces a positive pulse on the minus channel to the recorder amplifier.

The same basic circuitry is used in cases where it is desirable to record the digital output information photographically. In order to perform this function, the code sequencer need only generate positive pulses corresponding to the presence of digital information, since a lack of information will be indicated by the absence of a transparent spot on the photographic record. In addition, the code sequencer provides an identifying pulse for each decimal digit representation. It is this pulse which is used to control the automatic reading of the photographic record. All information pulses are displayed on the face of a cathode-ray tube and the face of the tube is photographed by a continuous-strip motion-picture camera. The code sequencer also provides the synchronized sweep for the generation of the code pattern on the face of the cathode-ray tube.

The switching of the equipment from magnetic recording to photographic recording is controlled by switch S1. This switch diverts the positive pulse originating at the master synchronizer from the grid of V7 to the grid of V5. This action in effect places another multivibrator pair in the chain of eight described in the preceding paragraphs. The positive pulse on the grid of V5 causes it to conduct. The negative signal on the plate of V5 is differentiated and applied to the suppressor grid of V31, which inverts and amplifies the negative pulse. The resulting positive pulse on the plate of V31 is the output to the photographic recorder. The first pulse is thus automatically provided by the code sequencer preceding each reading of the decimal digit representation.

After a delay of about 100 microseconds, the multivibrator action of V5-6 causes V6 to become again the conducting tube of the multivibrator pair. The positive pulse on the plate of V5 has no effect on the condition of V31, since it has already returned to a conducting state, but it does energize the second multivibrator pair V7-8 by causing V7 to conduct. The operation of the multivibrator chain is similar to that previously described. Information pulses gated from tubes V1, V2, V3, and V4 by the operation of the multivibrator chain are transmitted to the control grid of the pentode V31. V31 amplifies and inverts the signals, and the positive output pulses from the plate of V31 are the time-sequenced output to the photographic recorder equipment.

The synchronized sweep signal for the photographic recorder equipment is generated by the multivibrator chain. At the beginning of the chain operation (V5 forced to conduct), the positive signal at the plate of V6 is transmitted to the grid of V32, which amplifies and inverts it. The resulting negative pulse is applied to the grid of V34, which becomes nonconducting. V34 and V35 are connected as a flip-flop, so V35 becomes the conducting tube of the pair, and the negative pulse from the plate of V35 initiates the action of the sweep generator (V36 and V37).

The output of the sweep generator is taken from the cathode follower V38 and applied to the horizontal amplifier of the cathode-ray oscilloscope in the photographic recorder circuits. The sweep generator is cut off by the positive pulse from the plate of V21 (when the multivibrator train has completed its cycle). This pulse is applied to the grid of V33 where it is amplified and inverted. The negative pulse from the plate of V33 is used to reposition the V34-35 flip-flop, with V34 conducting and V35 nonconducting. This condition

prevents further operation of the sweep generator, and the sweep generator is returned to its starting position in preparation for the next operation.

Recorders

The electronic details of preparing the coded data obtained from the digital converters for recording on either a magnetic or photographic medium have been described in the preceding paragraphs. The actual recording procedure will be described in the following paragraphs.

Figure 24 is a photograph of the chassis containing the recording circuits and the recorder mechanism for the magnetic tape. Figure 25 is a photograph of the rear side of the magnetic recorder mechanism, and Figure 26 shows the oscilloscope and synchro-drive, continuous-strip 16-mm camera used for recording the output data of the Digital System photographically. For either type of recording, a clearly defined, readable signal

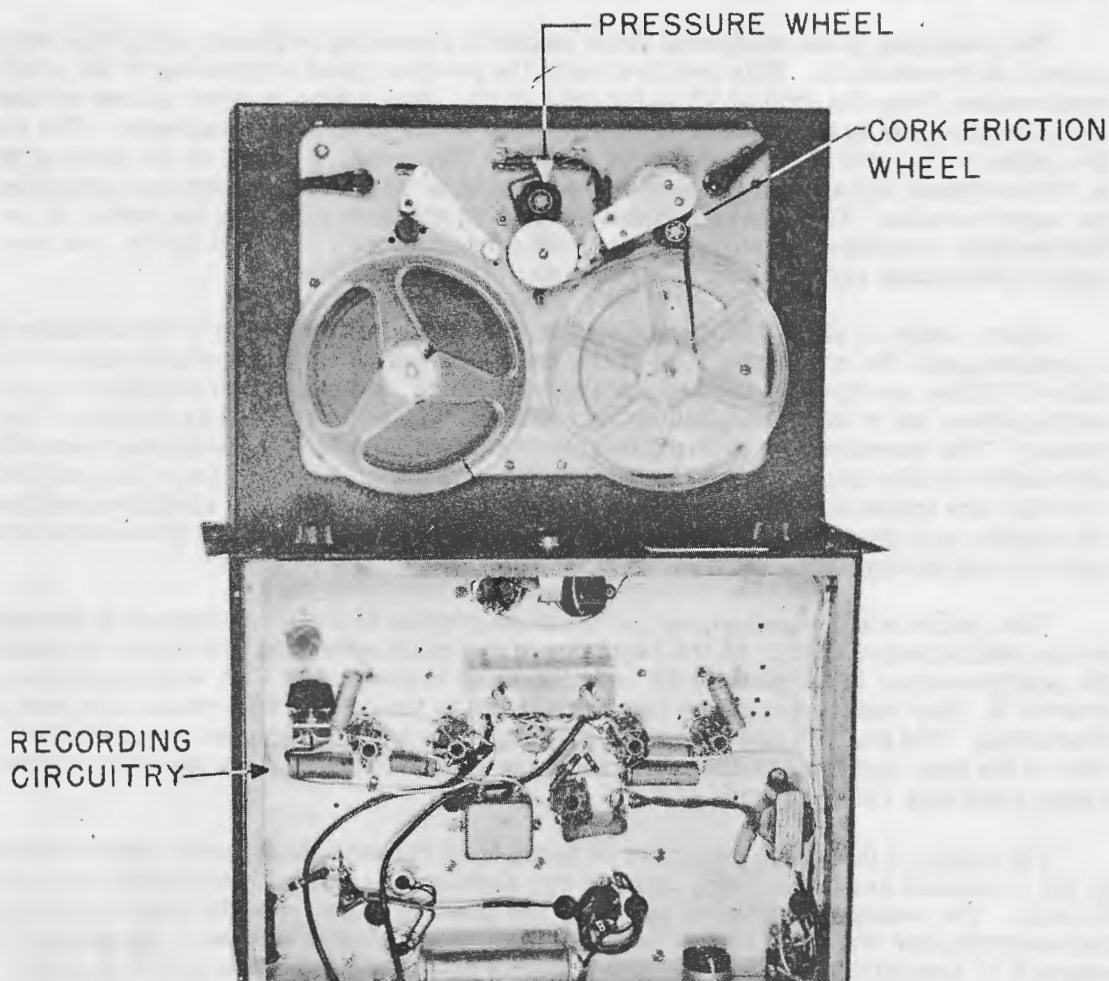


Figure 24 - Magnetic tape recorder

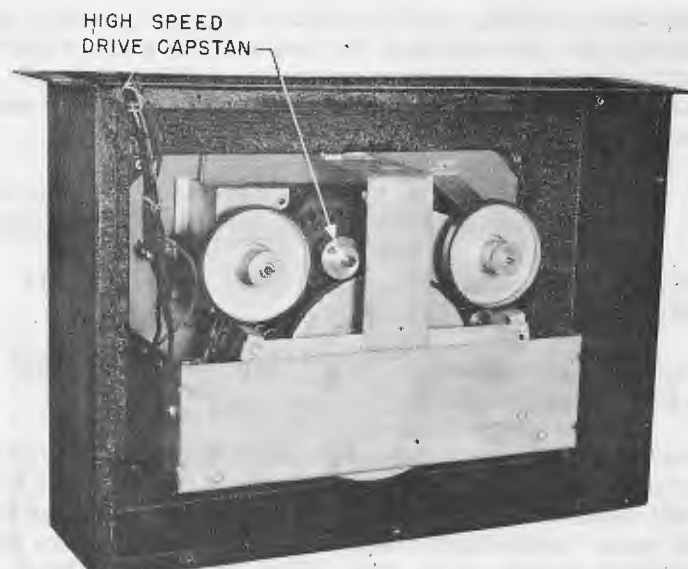


Figure 25 - Magnetic recorder mechanism

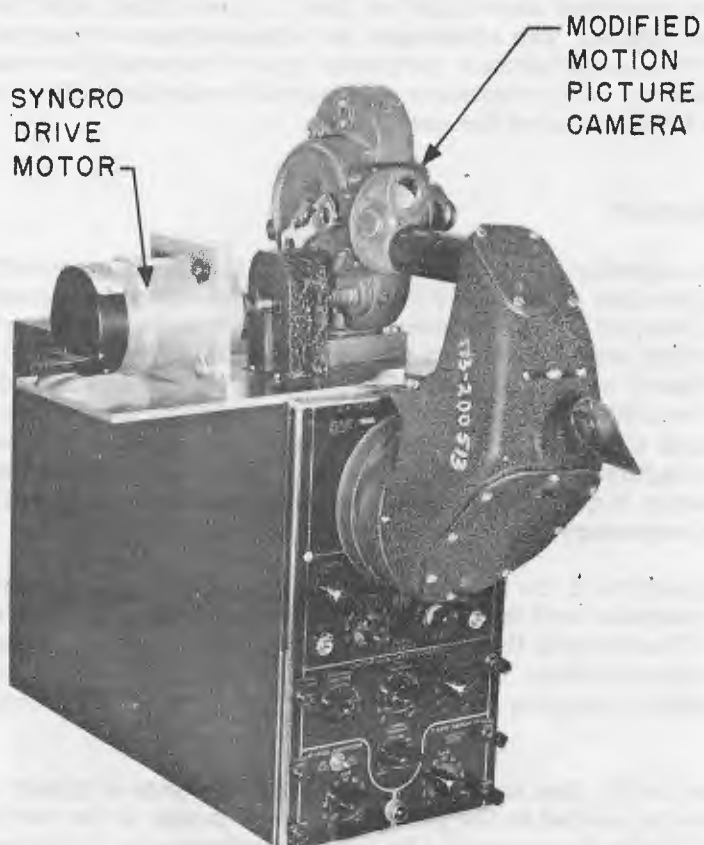


Figure 26 - Photographic recorder

must be impressed on the recording medium, since it must be possible to reproduce, positively and accurately, the recorded data for use with the transcription unit. As a result of experience gained in the preliminary operation of this equipment, it was found that the following concentration of data for each of the recording mediums would permit continuous, dependable operation:

	<u>Binary Points Per Inch</u>	<u>Decimal Digits Per Inch</u>
Magnetic tape recording (single channel)	75	15
Photographic tape recording 16-mm film (five channels)	410	82

Further refinements of equipment and recording techniques will result in increases of binary data densities for both mediums. The choice of the magnetic tape or film as a recording medium will depend on the particular purposes for which the equipment is used. The magnetic tape is easily handled and requires no processing before playback. It provides relatively permanent storage of the data. Film, on the other hand, is delicate to handle in the unexposed form and must be processed. The processing of the film might require several hours or even days, depending on the relative locations of the Digitar and photographic processing equipments. The equipment required for magnetic tape recording and transcription is somewhat more complex than that associated with the photographic recording and transcription. The advantages and disadvantages of each of the systems should be carefully evaluated before a particular type of recording is chosen for data recording under a given set of circumstances. Magnetic recording will be used in the Digitar which is to be constructed for use of NRL.

The Magnetic Recorder

Single-channel magnetic recording has been used for the data recording operation of the Digitar system because satisfactory twin- or multiple-channel recording and playback heads could not be obtained in time to meet the desired completion date of the project. Twin-channel recording would have been preferable to the single-channel system which was used. In the present system, pulses of either polarity are impressed upon the neutral background of the recording tape medium. The neutral background of the magnetic tape is prepared by forcing a complete erasure of all magnetic signals contained on the tape. This erasure is accomplished by slowly rotating the roll of tape in the field of an open-core, 60-cycle inductor (e.g., a Goodell Magnetic Noiserasure). A high-frequency bias erase circuit is not necessary, since recording is to saturation.

The electronic portion of the magnetic recorder is illustrated schematically in Figure 27; pictures of the recorder and the mechanical tape-carriage assembly were given in Figures 24 and 25. The input to the magnetic recorder is received as positive trigger signals from the code sequencer. These pulses appear on one or the other of two leads depending upon whether a positive or a negative indication is to be recorded on the magnetic tape.

A positive pulse on the plus channel indicates the presence of binary information. In this case the pulse is applied to the grid of V1 which is one of the two tubes of a one-shot multivibrator. The pulse generated by the multivibrator is of 125-microsecond duration, and this period can be altered by varying the time constant of the RC network. The

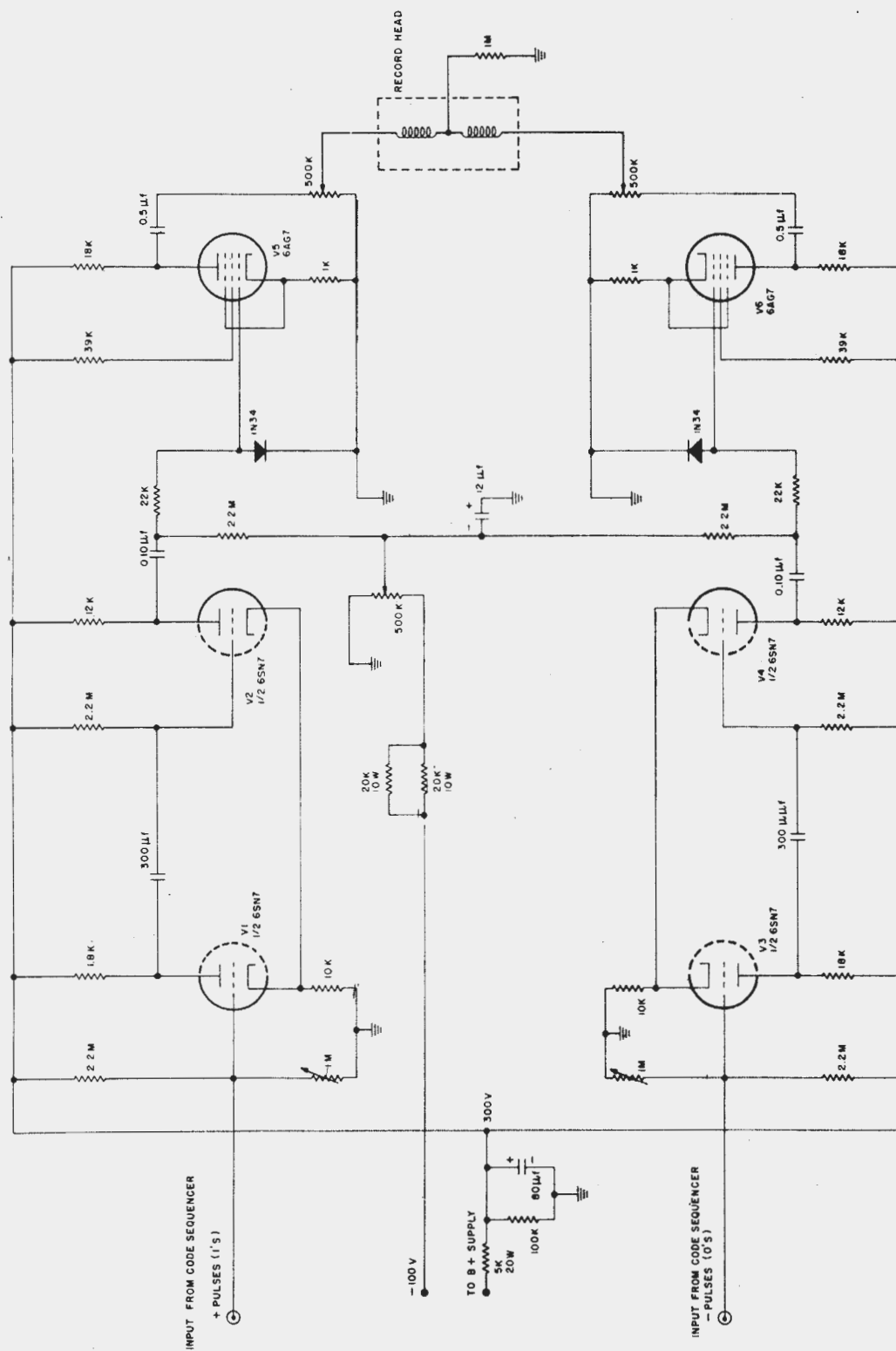


Figure 27 - Recording circuit

output positive pulse from the plate of V2 is applied to the negatively biased control grid of V5. The negative pulse on the plate of the 6AG7 tube (V5) is used to drive the magnetic recording head. The pulse from the plate of the driver tube may be adjusted in amplitude through the 500-K potentiometers. With this circuit arrangement, a recording current of 3.5 milliamperes through the BK-919 Brush recording head is required for the best reproducible signal. Positive pulses appearing on the minus channel of the magnetic recorder are treated in a similar manner, except that the recording head is arranged to impress a signal of opposite polarity on the magnetic tape.

The mechanical tape-reel carriage system is a "Twintrax" recorder mechanism so modified as to provide the desired recording speed and constant tape tension. Figure 25 shows the capstan which was added to increase the speed of the magnetic tape to 40 inches per second. Figure 24 illustrates the tape tension device and recording head arrangement. Early work in recording at high speeds showed the possibility of the tape fluttering as it passed over the recording-head gap; consequently, a cork-covered friction wheel is used on the take-up side of the recording head to eliminate this fault. The tape is carried over this friction wheel, and a rubber belt from the central-drive capstan to the cork-tension wheel gives the wheel a peripheral speed which is slightly greater than the magnetic tape speed provided by the capstan driver. This arrangement causes a slight tape tension across the recording head and eliminates the tape flutter.

The Photographic Recorder

Inspection of Figure 26 shows the equipment necessary for photographic recording of the digital information provided by the digital converters and prepared for recording by the data storage unit circuitry. The basic element is the cathode-ray oscilloscope upon which the coded pulse signals, as derived from the code sequencer, appear. Both the pulse pattern and the synchronized sweep are derived from the code sequencer. The illuminated spots on the blue-screen, short-persistence-type, 5AP11 CR-tube face are registered on the film through the use of a synchro-driven, modified Bell and Howell 70DA 16-mm motion-picture camera. The camera modifications were made to enable continuous constant-speed film motion at transport rates determined by the rate set in the master synchronizer speed-selecting gear box. Energizing voltages for a size-5 synchro motor, mounted on the camera drive, are supplied by the size-y synchro generator located on the master synchronizer speed-selecting gear box. A film speed of about twenty-five 16-mm frames per second is required for recording the 60-decimal digits at a 10-per-second reading rate. An f/1.9 lens of 5-cm focal length is used to record the information on 16-mm motion-picture film. The transparent line-segments representing the coded digital information can be sharply defined by using a high-contrast developing process. The contrast is required to obtain positive reading of the film by the transcription unit.

DATA TRANSCRIPTION UNIT

In order to obtain large amounts of data at high recording speeds it is necessary to record these data either on magnetic tape or photographic film. Since neither of these mediums is directly usable in the subsequent data processing methods available to NRL, it is necessary to convert the recorded data either to a printed record or a punched-paper tape. The first form permits visual inspection of the recorded data, and the second form is that required to insert the data into the Computer Mk 22. Magnetic-tape or photographic-film recording is an expedient which was adopted because there are no printing or tape-punching mechanisms capable of operating at the recording speeds required. Once the data have been recorded, however, they may be transcribed from either medium at speeds compatible with the printing or tape-punching equipment.

In the transcription process, the serialized binary elements representing a single decimal digit or identifying symbol must be detected and converted to electrical signals. These signals are so gated that groups of four binary elements (completely defining a decimal digit or symbol) are directed to and registered in the code changer. The code changer consists of an electronic register and a decoding matrix. The four elements of a code character are registered in the electronic register, and the decoding matrix is so wired that the registered number is translated to the Computer Mk 22 code as given in Table 1. The combination of voltages on the five output leads of the matrix define a particular Computer Mk 22 code character corresponding to a decimal digit or identifying symbol. The output signals of the matrix are sent to a teletype transmitter-distributor for transmission to teletype tabulating or tape-perforating equipment.

The speed at which the transcription unit operates is much slower than the original recording made by the data storage unit. For example, a slow-down ratio of a hundred-to-one is necessary when transcription is made of records containing groups of 60 code characters recorded at a rate of ten groups per second. The speed of transcription is set by the capabilities of the teletype output equipment, which operates satisfactorily at about 6 characters per second. Since an absolute speed control is not provided between the teletype equipment and the magnetic tape or film-carriage systems, a rate of 5-1/2 characters per second is used to assure that proper synchronization between teletype and transcriber equipment.

Transcriber for Magnetic Tape Record

Sharp pulse signals were impressed on the magnetic tape to produce well-defined magnetic dipoles, but in the playback of these pulses the derivative of the original signal is detected. It is not desirable to use an integrating circuit for redefining the pulse form, since the handling of the plus and minus combinations of the integrated signals through amplification and separation circuitry presents difficult problems in the maintenance of bias values. A picture of the magnetic-tape playback unit is given in Figure 28, and the signal detector and amplifier circuitry is shown schematically in Figure 29.

The magnetic tape is transported over the gap of the Brush Type BK-919 playback head at a tape speed of about 1/4 inch per second. The combination of tape speed and the strength of the impressed magnetic dipole induces a signal across the head of about 0.8 millivolt peak-to-peak. The magnetic tape drive mechanism is basically identical with the recorder mechanism. The low tape-carriage speed is provided by a Bodine 60-rpm synchronous motor, which was used in place of the 300-rpm motor supplied with the "Twintrax" unit. A picture of this mechanism is given in Figure 30. Additional friction between the tape and the capstan is provided by a small pressure wheel.

Signals from the playback head are passed by the matching transformer (left-hand side of Figure 29) and are applied as the input to a four-stage push-pull amplifier. The first two stages of this amplifier are shock-mounted for protection against microphonics. A fifth 2C51 push-pull stage has been added to serve as a clipper amplifier for accentuating the positive swings of the differentiated pulse in one tube and accentuating the negative swings of the differentiated pulse in the other. Further clipping and amplifying provides clean sharp pulses at the output of the two 6AG5 squaring circuits.

Figure 31 is a plot of waveforms at various points in the circuit of Figure 29 and illustrates the passage of a signal through the amplifying and shaping circuits. The output waveform at the plate of V16 shows a shaped signal in time position with the negative swings of the differentiated tape-record signals (as seen from the plate of V7). The

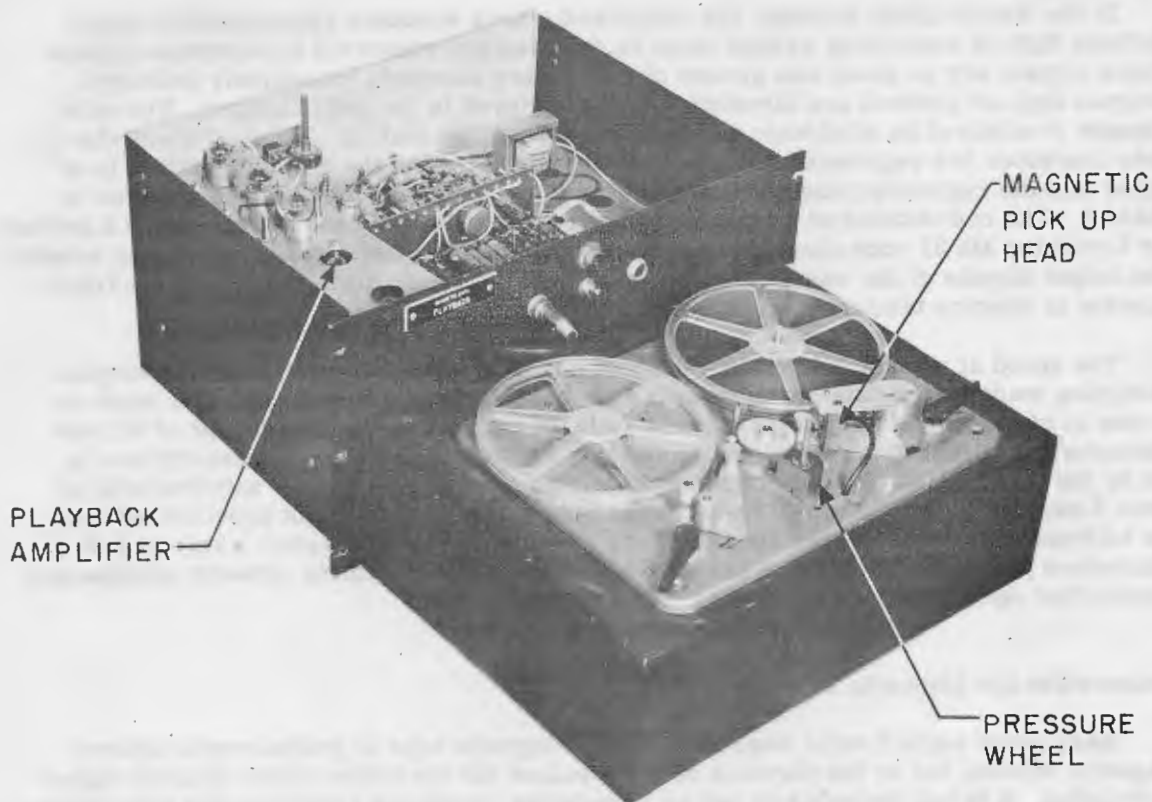


Figure 28 - Magnetic tape playback for transcriber

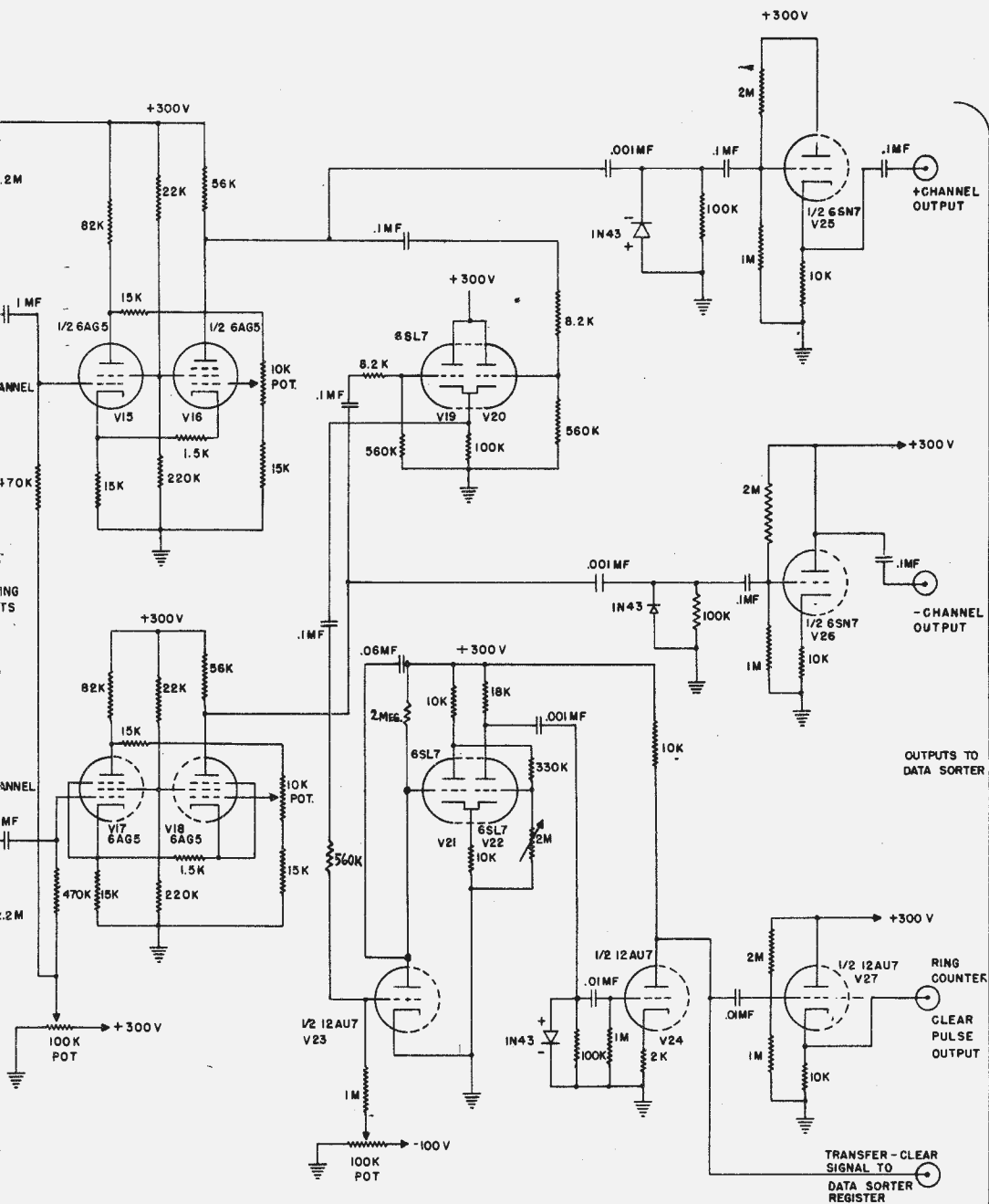
waveform for the plate of V18 shows shaped pulses time-positioned with the positive swings of the differentiated tape-record pulses.

Both squaring circuit outputs are differentiated and the positive pulses applied to the data sorter through triodes V25 and V26. The squaring circuit outputs are also mixed in tubes V19 and V20. The cathode output is a series of eight pulses and two blanks for each code character transcribed. The multivibrator circuit (V21 and V22) detects the point at which the pulses are absent from the mixer output. V21 is kept cut off by the succession of negative pulses applied to its grid from the plate of V23. The absence of a negative pulse allows V21 to conduct, and the plate of V22 consequently goes high.

The signal indicating the blank (end of code character) is taken from the plate of V22. The signal is differentiated and the positive pulse is clipped, then amplified by V24. The signal is applied to the cathode follower V27, and the output from the cathode is transmitted to the data sorter where it serves to check and clear both ring counters in preparation for the sorting of the following pulse group. The same pulse applied to the grid of V27 is used to transfer the four developed binary element representations of the decimal digit from the data sorter register to the code changer input register and to clear the data sorter register.



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Amplifier circuits

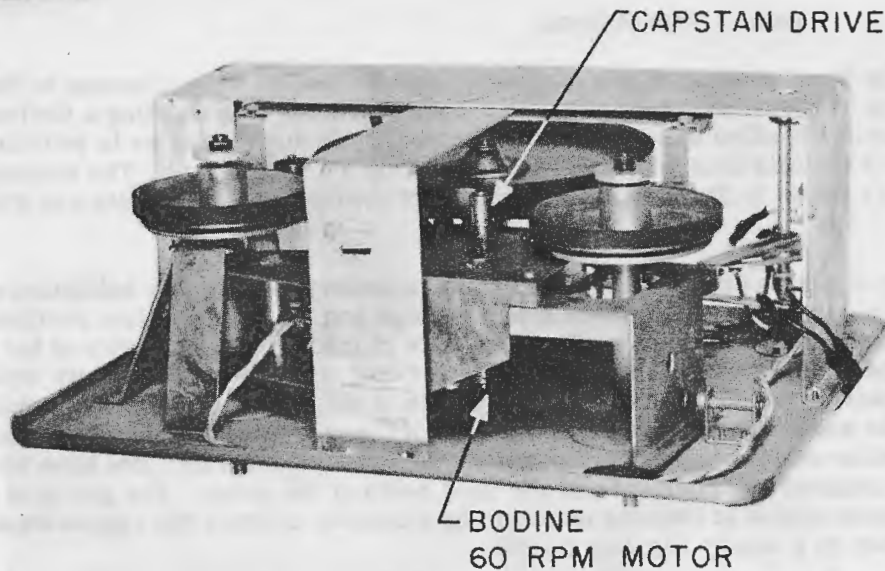


Figure 30 - Magnetic tape drive mechanism for transcriber

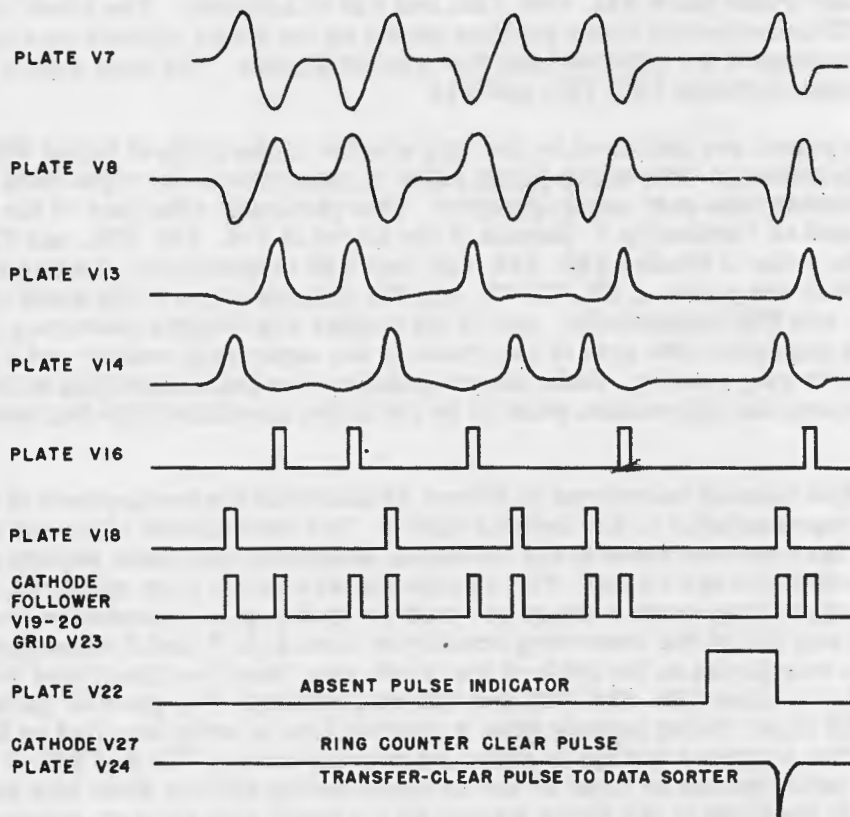


Figure 31 - Transcriber waveforms

Data Sorter for Magnetic Tape Record

The eight time-positioned pulses, four in each of the two input channels to the data sorter, define the four binary elements of a code character representing a decimal digit. These pulses are handled by the data sorter circuitry in such a way as to provide a register reading of the four binary elements representing a decimal digit. The schematic of this circuit is shown in Figure 32, and pictures of the data sorter chassis are given in Figure 33.

In order to obtain such a registration it is necessary to obtain an indication of polarity of the original signal recorded on the magnetic tape and the relative time position of this signal within the four binary elements of the code character. The polarity of the original signal may be obtained by detecting the order of occurrence of pulse polarity within each successive pair of the eight pulses. For example, a pulse on the plus channel followed by a pulse on the minus channel indicates one polarity, and a pulse on the minus channel followed by a pulse on the plus channel indicates the opposite polarity. The time position of the pulse is obtained by counting from the first pulse of the group. The gating of the positive information pulses at instants indicated by a counter permits the registration of the code character by a binary flip-flop circuit.

The data sorter associated with the transcriber accomplishes these functions with the circuits shown schematically in Figure 32. The upper ring counter V4 through V11 is sequenced by the positive pulses on the plus channel, which correspond to the negative pulses of the differentiated tape record signals. This ring counter provides a gating bias signal to the four triode gates V23, V24, V25, and V26 in sequence. The lower ring counter V15 through V22 is sequenced by the positive pulses on the minus channel corresponding to the positive pulses of the differentiated tape record signals. The input pulses to the counter are shaped by tubes V12, V13, and V14.

Sharp gate pulses are delivered by the ring counter to the grids of triode V23, V24, V25, and V26 in sequence. The sharp gating pulse is generated as the right-hand plate of a lower ring counter tube-pair swings positive. This particular tube-pair of the counter is then designated as "indicating." Outputs of the plates of V16, V18, V20, and V22 are connected to the grids of triodes V23, V24, V25, and V26 respectively. Similarly in the upper ring circuit, the plates of V5, V7, V9, and V11 are connected to the grids of triodes V23, V24, V25, and V26 respectively. One of the triodes can become conducting only when a gating bias is supplied to the grid of the triode by the upper ring counter and a gating pulse by the lower ring counter. Under these conditions the pulse appearing at the cathode of the triode causes the information pulse to be set in the associated flip-flop memory circuit.

The first four lines of waveforms in Figure 34 illustrate the development of shaped pulses for the representation of the decimal digit 9. The development of the waveforms of line 3 and 4 has been described in the preceding paragraph, and these waveforms are the input to the data storage circuit. The bias-gating waveforms from plates V5, V7, V9, and V11 of the upper ring counter are paired with the gating-pulse waveforms from plates V16, V18, V20, and V22 of the lower ring counter on lines 5, 6, 7, and 8, respectively, of Figure 34. The waveforms at the grids of the triode gate tubes are illustrated on lines 9, 10, 11, and 12 for triodes V23, V24, V25 and V26 respectively. The positive gating pulses on lines 9 and 12 occur during periods when a positive bias is being supplied by the upper ring counter. The combined voltage is sufficient to raise triodes V29 and V38 to a conducting state. The gating pulses on lines 10 and 11 occur during periods when bias is not being supplied to the grids of the gating triodes by the upper ring counter; consequently, triodes V32 and V35 are not forced to conduct. The negative pulses from the plates of

INPUTS FROM TRANSCRIBER

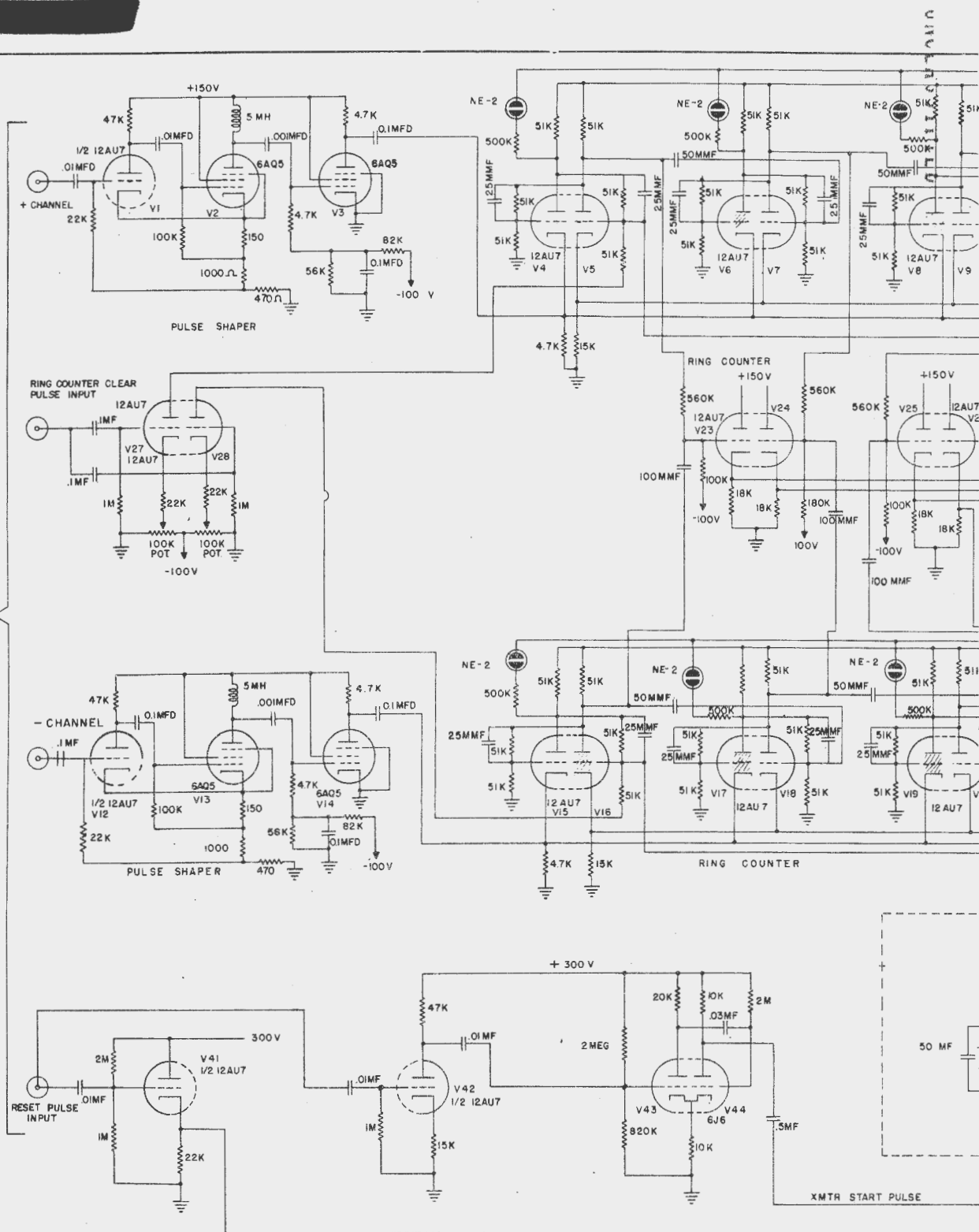
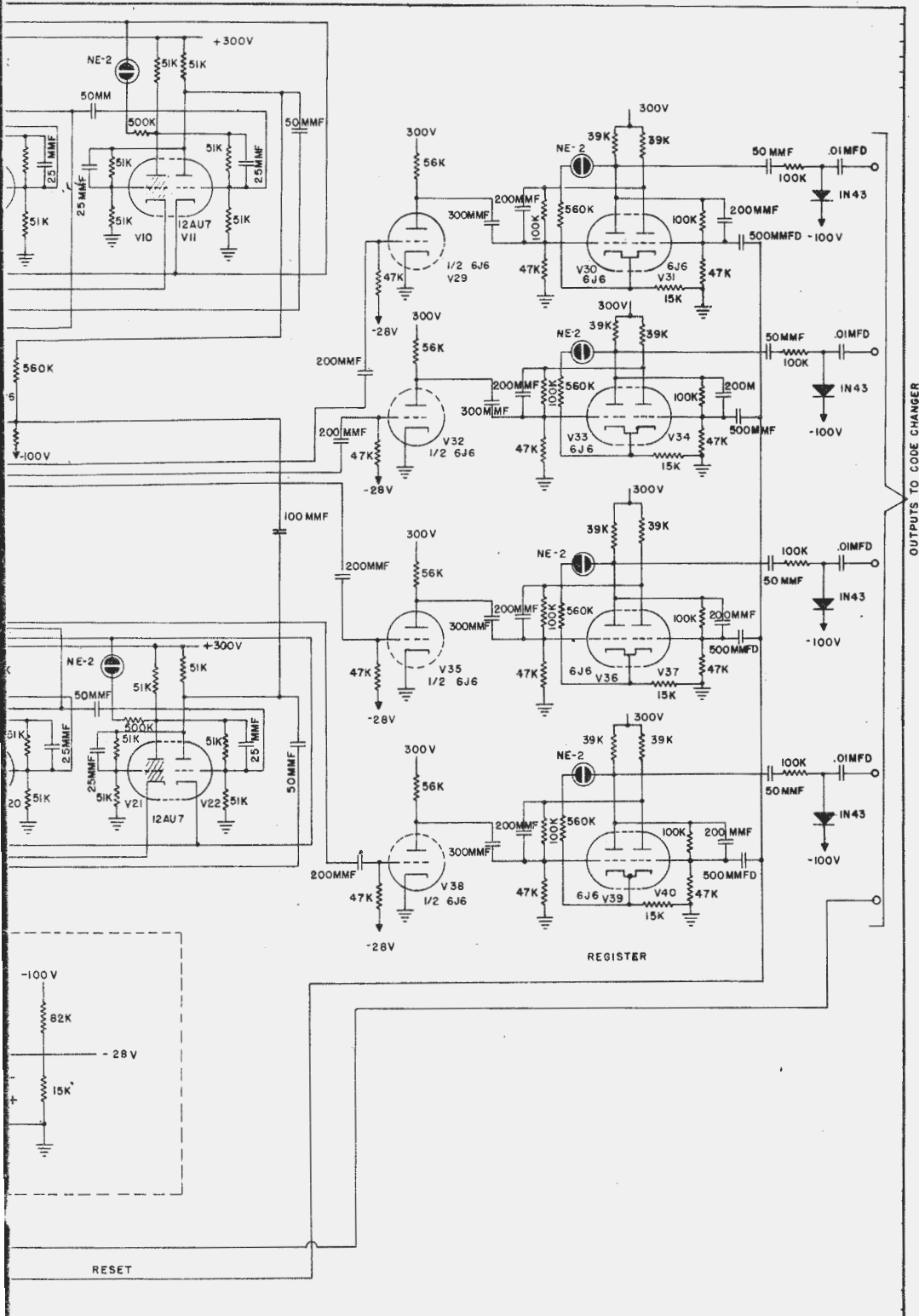


Figure 32 - Data sorter for magnet





Front View



Front View

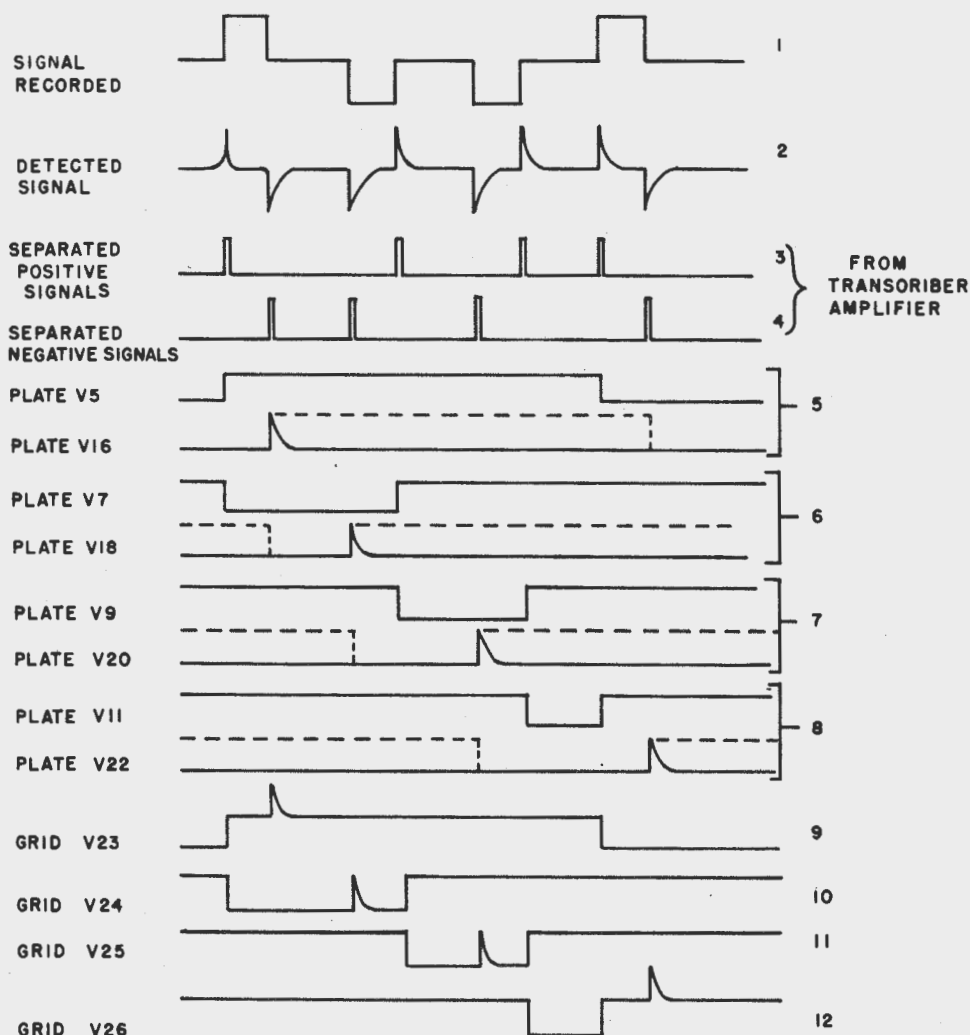


Figure 34 - Data sorter waveforms

triodes V29 and V38 are used to set their respective memory flip-flops (V30-31 and V39-40). The setting of the four flip-flop memory circuits of the data sorter results in a static recording of the four elements of either a code character representing a decimal digit (in the case cited the digit 9) or an identifying symbol.

The upper and lower ring counters are reset to the condition of tube conduction shown by the cross-hatched lines of Figure 32 by a signal originating in the transcriber circuitry. The transcriber supplies the signal for the reset action at the instant the blank in the train of signals on the combined plus and minus channels is noted. This negative pulse is applied simultaneously to the grids of V27 and V28. The positive pulses at the plates of V27 and V28 are applied to the grids of V5 and V16, which then conduct. The ring connections provide for the cutoff of tubes V11 and V21 at the instant V5 and V16 begin to conduct. The ring counters are then prepared for the next sorting operation. This positive

reset of the ring counters is used even though, in normal operation, the ring counters automatically return to their starting positions.

A pulse is also supplied to the data sorter by the transcriber to transfer the contents of the memory flip-flop to the code changer register and to reset the data storage flip-flop register to its neutral position (indicating 0000). The transfer and reset signal from the transcriber is applied to the grids of the right-hand tube of each flip-flop pair (V31, V34, V37, and V40) through the cathode follower V41. The return of a flip-flop pair to its normal position (left-hand tube conducting) is used as the impulse for transferring registered information to the code changer. The reset pulse is also used to trigger the delay multivibrator (V43 and V44) which supplies the "start" signal for the teletype transmitter-distributor located in the code changer.

Transcriber for Photographic Record

The transcription of the signals recorded on the photographic film presents a problem which is relatively more simple but entirely different from that encountered in the detection of signals from the magnetic tape medium. The binary elements of each code character representing a decimal digit are stored on film as transparent spots on an opaque background. Five binary element positions are provided in each horizontal reading position of the film (see Figure 5). The first element, far left, always contains a transparent spot, and this signal is used to synchronize the transcriber. The remaining four binary-element positions may have transparent spots or not, depending upon the decimal digit or identifying symbol which is represented. The equipment required for transcribing such data consists of a modified motion-picture projector and photographic data transcriber, the former being shown in Figure 35.

A low-speed film carriage was built for the projector, since the rate of reading data from the film is determined by the printing rate of the output teletype equipment. The film-carriage rate built into this particular system is about twelve 16-mm frames per minute. Figure 35 shows the film-drive motor and its position on the modified Bell & Howell, Filmo-Master, 16-mm motion-picture projector. The reflecting mirror and the synchronous drive motor for the light chopper are also evident in this picture. The light chopper serves to break the light beam at a frequency of 741 cycles per second. This frequency was selected because it is radically different from any harmonic of the 60-cycle frequency present in the light beam, stray room-light or filament excitation. The projected pattern of transparent and opaque spots is reflected downward by the front-surfaced reflecting mirror located directly ahead of the projector lens. At the receiving position a tank prism directs the beam into the phototube housing of the transcriber chassis. This chassis is pictured in Figure 36 and illustrated schematically in Figure 37.

At the left-hand side of Figure 37 are the five phototubes used to detect the light which has passed through transparent line-segments on the film record. The top phototube (V0) receives signals from the first (far left) channel of the film. The light signal received by the phototube V0 is converted to an electrical signal. This signal is applied to the grid of V1, which allows the cathode follower V1 to deliver a 741-cycle amplitude-modulated signal to the amplifier V2. The cathode follower arrangement matches impedance to V2. The tuned-plate circuit of V2 amplifies the 741-cycle signal envelope for detection by the diodes of V3. The detected envelope is amplified by tubes V3 and V4, and the pulse is squared by tubes V5 and V6. The positive differentiated pulse from the plate of V6 is used to drive the multivibrator gate-pulse shaper V7. The signal from the right-hand plate of the tube envelope V7 is transmitted to the suppressor grid of the gate tubes V15, V23, V31, and V39 through the cathode follower V8.

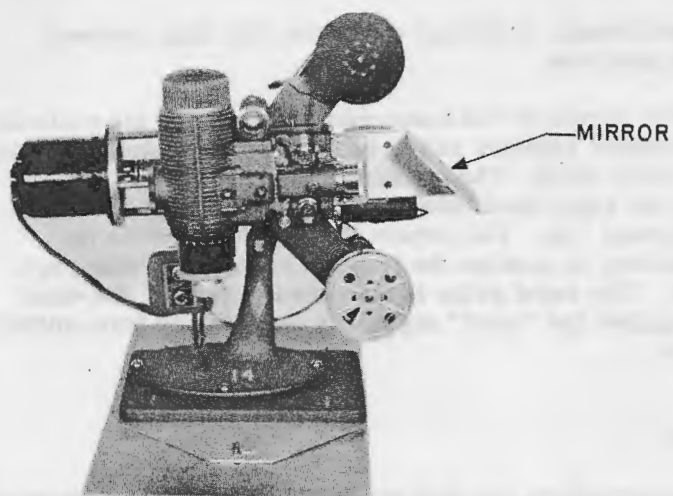


Figure 35 - Projector for photographic transcriber

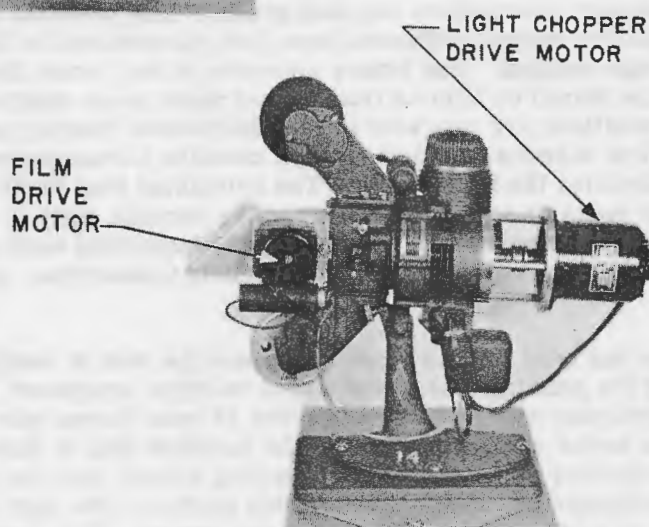
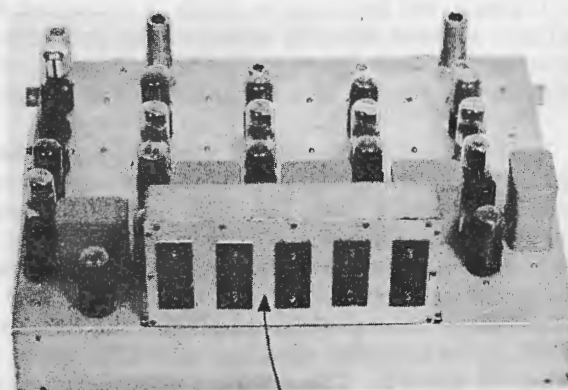
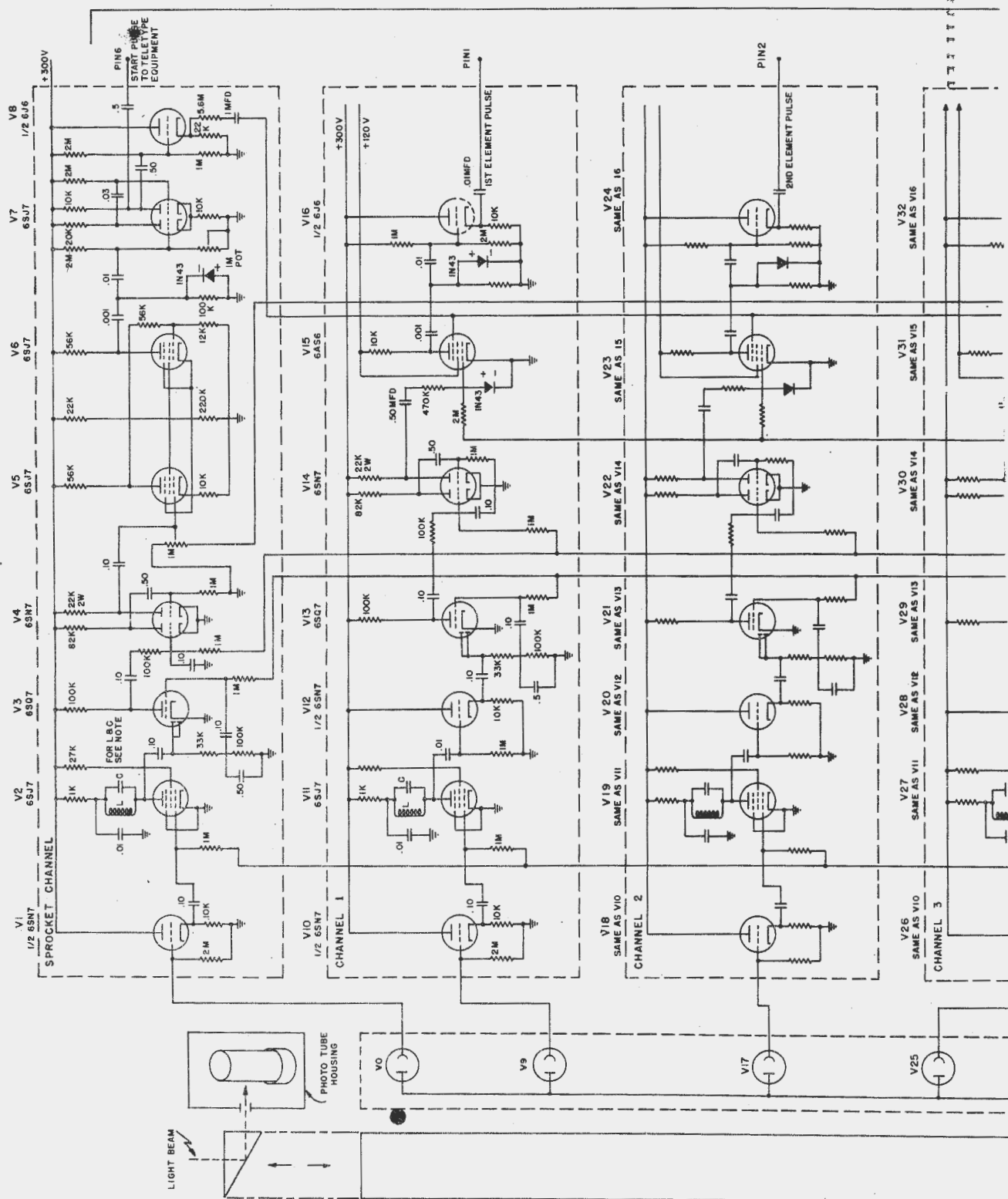


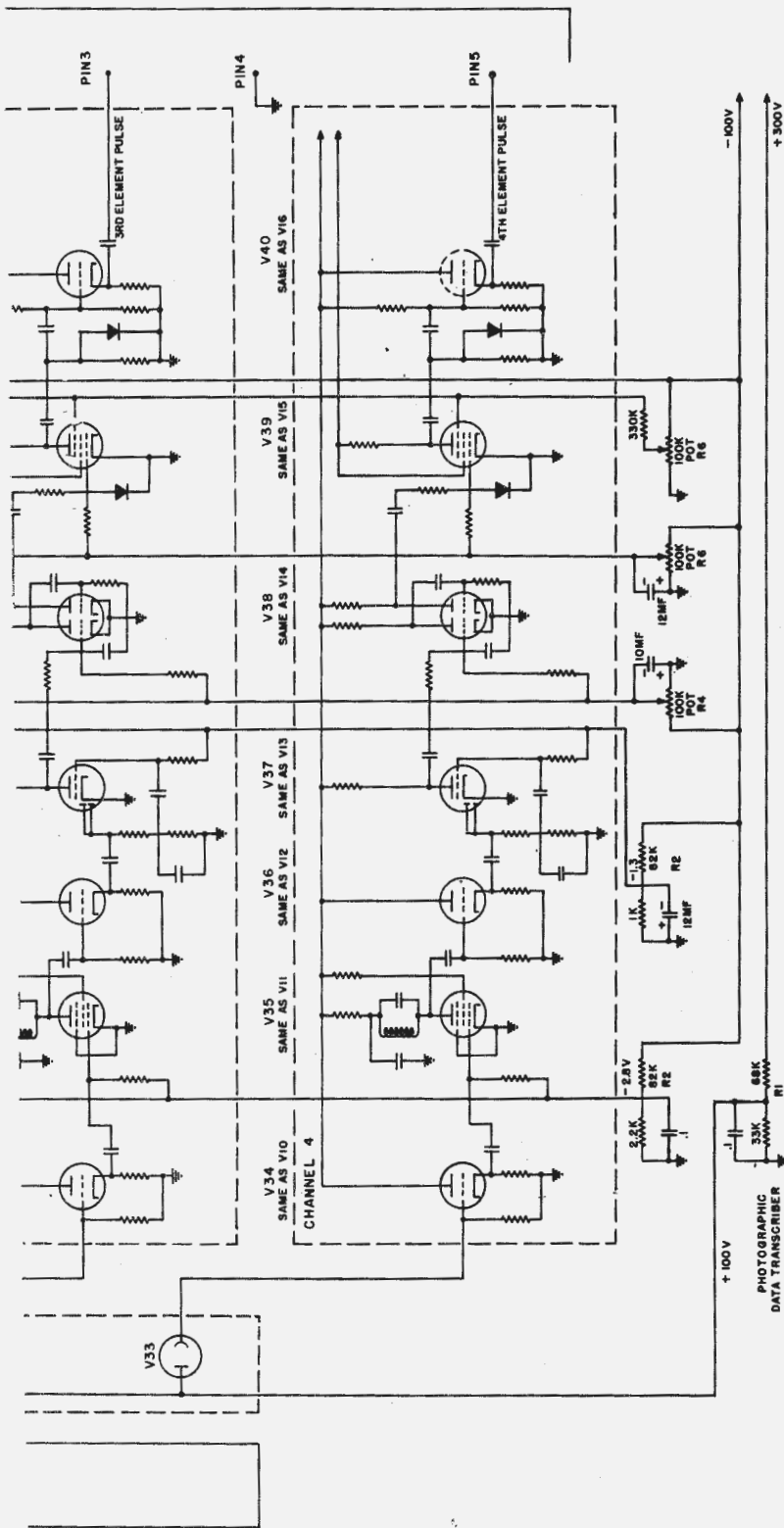
Figure 36 - Photographic record transcriber



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The phototubes V9, V17, V25, and V33 convert light energy received from an associated film channel to electrical signals. A process of detection, amplification, and squaring similar to that described for the synchronization channel is performed for each of the four binary information channels. The output of each channel appears on the control grid of the gate tubes V15, V23, V31, and V39. If a positive pulse appears on both the suppressor and control grids of a gate tube, a negative pulse is transmitted through an associated cathode follower (V16, V24, V32, or V40) to the code changer. The output of the right-hand plate of tube envelope V7 is transmitted to the code changer chassis to initiate the scan action of the teletype transmitter-distributor.

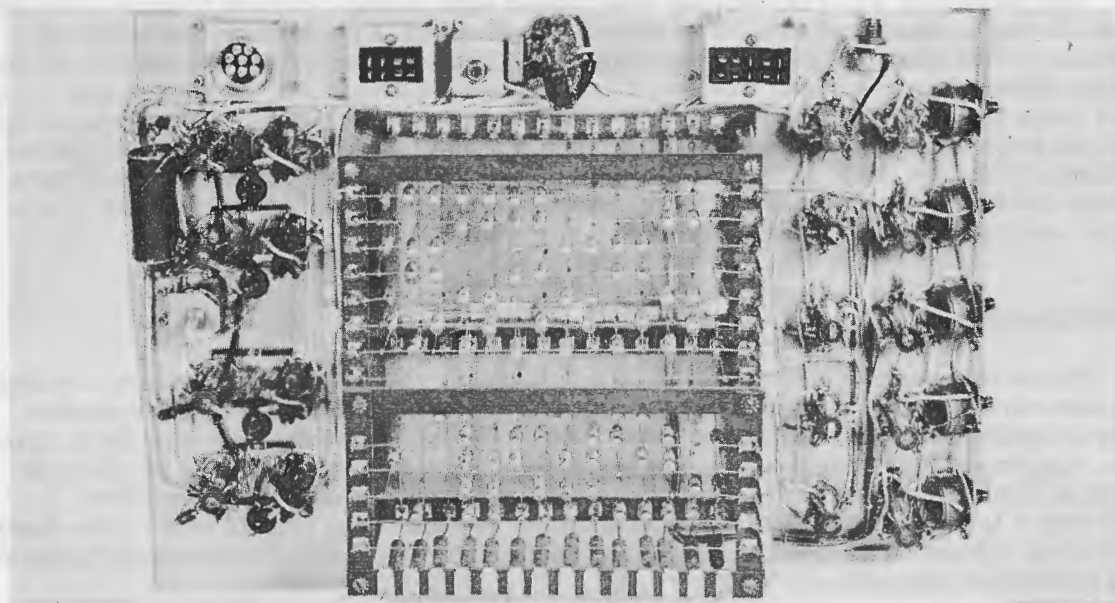
Code Changer

The code changer circuitry accepts the four binary elements of a code character from the data sorter circuit (either the magnetic or photographic). The code characters are part of the Digitar code itemized in Table 1. It is the function of the code changer to translate from the Digitar code to the particular code employed by the Computer Mk 22 (also given in Table 1). Once the translation has been performed, a teletype transmitter-distributor is energized which transmits and time sequences the outputs of the code changer to teletype tabulating or tape punching equipment. The code changer is shown in Figure 38 and illustrated schematically in Figure 39.

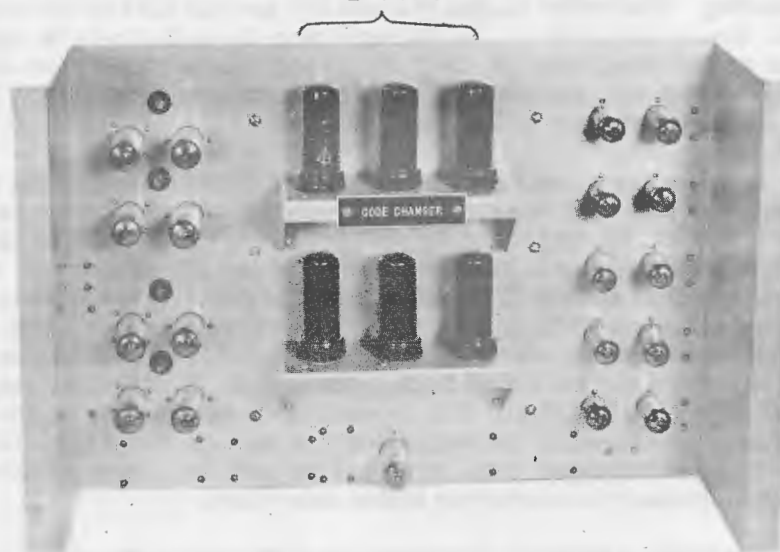
At the left of Figure 39 are the input tubes and the register circuits, which receive and register the binary indications transferred from the data sorter. The negative pulse indicating binary information in the first element position is transmitted from the data sorter to the grid of V1. V1 is not conducting, and its high plate voltage is applied to the grid of V3, which becomes a conducting tube. The interaction between V3 and V4 causes V4 to become nonconducting. The buffer stages (V5 and V6) provide current for activating the decoding matrix. Binary information for the remaining three channels is registered in the same manner as that described for the first channel through the action of tubes V7 to V24. High and low output voltages are applied to the matrix by tubes V11, V12, V17, V18, V23, and V24 in a manner similar to that just described.

The matrix shown is composed of 96 crystal diodes (1N34). Conducting and nonconducting combinations of the input register develop driving voltages for the output circuits which set up the equivalent Computer Mk 22 code patterns. As a result of the conduction patterns set up by the buffer stages, one (and only one) of the 14 resistors R1 through R14 will not have a voltage drop across it, i.e., no current is drawn through one of the resistors. An example of the matrix operation can be described on the basis that a high voltage (90V) at the lower end of a particular resistor (R1 to R14) constitutes an indication and a low voltage (78V) no indication for the output leads A through E. If the buffer stages are set in the 0000 condition (V5, V11, V17, and V23 conducting) a voltage drop will be noted across each of the resistors; consequently, the output leads A through E are low. When the buffer tubes are in the condition indicated, there is a current path from each resistor through one of the driver crystal diodes to a conducting buffer-tube plate.

As a further example, if the code character 8 is indicated by the buffer tubes, the tubes V5, V11, V17, and V24 will be conducting. Current paths are provided through each of the resistors, through the driver crystal diodes to conducting buffer-tube plates, except in the case of R8. There is then a high voltage indication at the lower end of R8 and along the vertical bus connected to it. This high voltage indication is passed to leads B, D, and E by the code translating diodes in the upper portion of the matrix (diodes concerned are indicated by squares). The high voltage of leads B, D, and E are applied to the grids of V28, V32, and V34 of the 6J6 twin triodes. When these tubes conduct, the current drawn

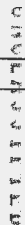


Rear View

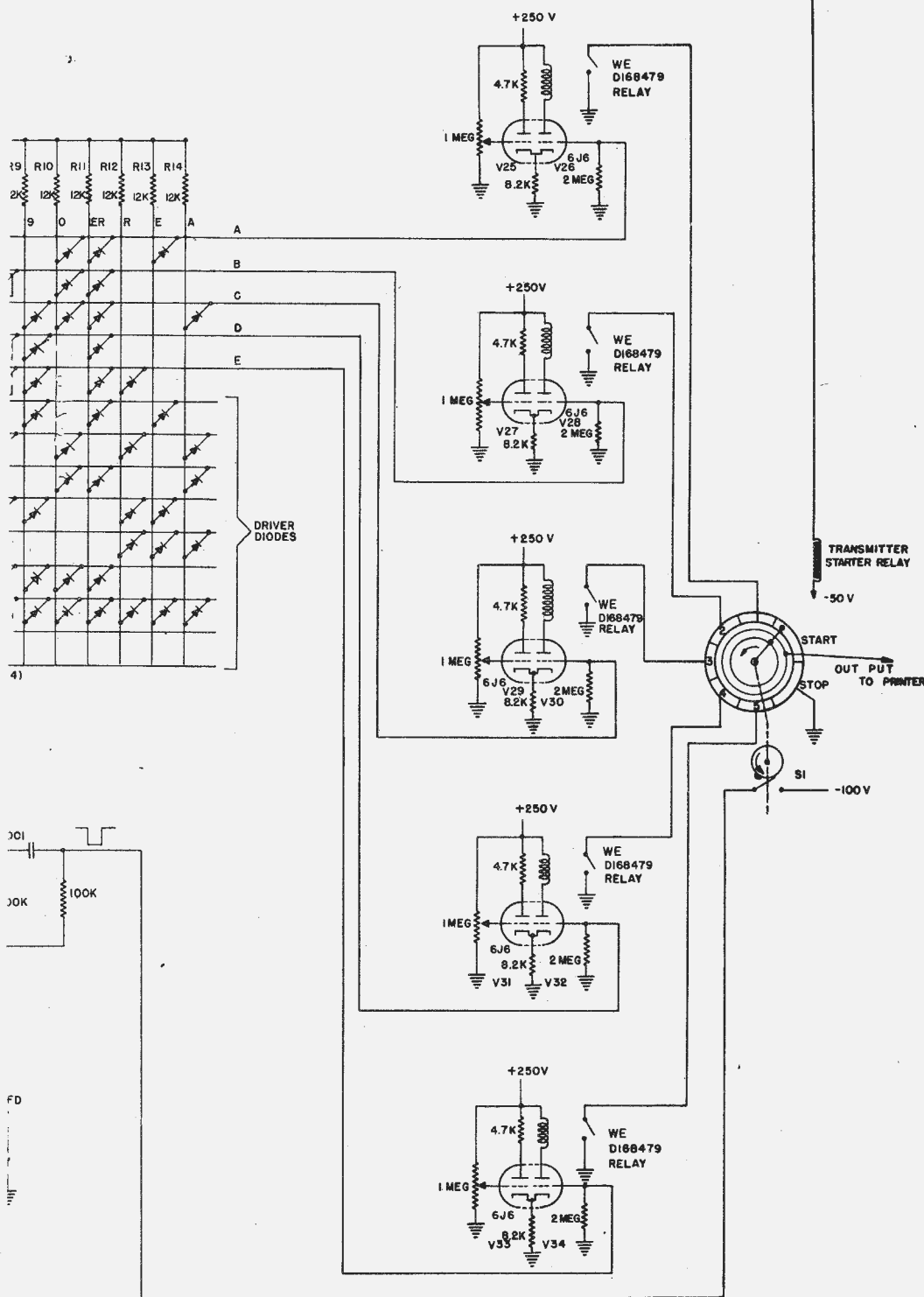
MERCURY RELAYS
WE TYPE

Front View

Figure 38 - Code changer



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through the relay coils energizes the mercury-type relays (Western Electric No. D168479) and closes a contact to ground. This ground is applied to the appropriate segment of the teletype transmitter-distributor. The relays match the high-impedance electronic circuitry to the low-impedance teletype transmitting and receiving equipment. The relay registration of other decimal digits and identifying symbol is accomplished by the buffer tubes and diode matrix in a manner similar to that described.

The translation from the Digital code to the Computer Mk 22 code is accomplished almost instantaneously; therefore, the pulse to energize the teletype transmitter-distributor start-solenoid is generated at the same instant the binary elements of a code character are transferred from the data sorter to the code changer. The circuit in the upper left-hand corner of Figure 39 closes a mercury-type relay which in turn energizes the start-solenoid for a period of time sufficient to permit the clutch on the transmitter-distributor to override its stop pin. The solenoid is deactivated in time to prevent no more than one scan-cycle of the transmitter brush arm. An additional switch assembly (S1) has been mounted on the teletype transmitter-distributor to indicate the completion of the teletype transmitter-distributor scan cycle. This square wave signal is differentiated, and the negative portion of the differentiated square wave signal is clipped and applied through cathode follower V38 to the reset tubes (V2, V8, V14, and V20) of the input register of the code changer. This reset action clears all circuits of the code changer and prepares it to receive a new code character from the data sorter.

VACUUM TUBE REQUIREMENTS

The number of tube envelopes required in the Digital system is shown in Table 4, where the list has been subdivided to indicate the tube types used.

TABLE 4
Number of Tubes Required in Digital

	1P42*	0A5	2C51	6AG5	6AQ5	6AS6	6AU6	6J6	6L6	6AG7	6SL7	6SN7	6V6	12AU7	NRL Flash Tube	1N34†	Sub Total	Total
Converter Unit																		
One Digital Converter	25	5	10	2	1	25		5	2		2		1	1	5			84
Data Storage Unit																		
Master Synchronizer & Decimal Digit Selector								6						5			11	
Code Sequencer						5		10						2			17	
Recorder							1			2		2					4	
Read Counter												2					3	
Transcription Unit																		
Transcriber			5	4							5	1		1			16	
Data Sorter					4			7						13			24	
Code Changer								10						9		96	19	59

* Phototube

** Crystal diodes

POWER REQUIREMENTS

The power supplies used in the Digital system are listed in Table 5. For the most part, the voltage levels indicated were used because such power supplies were already available. In a final design of the system, the number of voltage levels will be reduced to a minimum.

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TABLE 5
Power Requirements for Digitar

<u>Converter Unit</u>	Voltage	Current
<u>Digitar Converter (One)</u>		
DC Supply		
Filtered	+ 320V d-c	350 ma
Filtered	+ 200V d-c	350 ma
Filtered	+ 120V d-c	180 ma
Filtered	+ 750V d-c	150 ma
Regulated ($\pm 1\%$)	- 100V d-c	80 ma
Filament Supply (60-cycle)	6.3V a-c	18 amp
<u>Data Storage Unit</u>		
DC Supply		
Filtered	+ 300V d-c	140 ma
Filtered	+ 180V d-c	100 ma
Filtered	+ 120V d-c	100 ma
Filtered	+ 24V d-c	500 ma
Regulated ($\pm 1\%$)	- 100V d-c	50 ma
Filament Supply (60-cycle)	6.3V a-c	20 amp
Motor Power (60-cycle)	115V a-c	
<u>Transcription Unit</u>		
DC Supply		
Filtered	+ 300V d-c	260 ma
Filtered	+ 150V d-c	65 ma
Filtered	+ 90V d-c	40 ma
Filtered	100V d-c	16 ma
(From Teletype Equipment)	- 50V d-c	2 amp
Filament Supply (60-cycle)	6.3V a-c	20 amp

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