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THE DIGITAL CONVERTER

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THE DIGITAL CONVERTER

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August 26, 1948

Approved by:

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ABSTRACT

The Digital Converter, a component of DIGITAR, is a device that will provide digital representation (to five significant figures) of the angular position of a shaft. Equipped with a servo drive system, the Digital Converter receives transmitted synchro data and converts it to the closest one one-hundredth of a degree. For application with this system, the converter will function at reading rates up to 10 times per second and although this reading rate is the maximum to be used with System DIGITAR, reading rates of 100 times per second can be obtained within an individual Digital Converter. The applications of the converter are not necessarily restricted to DIGITAR; its basic design features should be of interest to other activities.

PROBLEM STATUS

This is an interim report on this problem.

AUTHORIZATION

NRL Problem No. R05-11D (BuOrd Problem 0-195-TE-C).

[redacted]

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THE DIGITAL CONVERTER

A UNIT OF DIGITAR FOR TRANSFORMING THE ANGULAR POSITION OF A SHAFT TO ELECTRONIC DIGITAL CODING

INTRODUCTION

To aid in the operational evaluation of missile control devices, NRL has proposed a system for the conversion of rotational shaft position to electronic digital data and for the storage of such data in a form suitable for automatic reduction.[1] This system, designated as DIGITAR, is shown in block form in Figure 1. Here a series of digital converters are used to digitalize the shaft positions as indicated by the synchro transmission systems. The coded electrical signals indicating the digital values are recorded in proper sequence through the action of the Digit Selector, Code Sequencer, and Recorder, respectively. The record of the coded signals is then reviewed at a reduced speed by the Transcriber and directed into the Data Sorter and Code Changer where the signals are placed in proper order to drive the teletype Printer and Reperforator.

The several digital converters used in DIGITAR are the basic units upon which the operation of the entire system is dependent.[2] This report describes the operation and details of a converter built at NRL for DIGITAR. Additional reports will be issued on the Data Storage Unit and the Transcription Unit as these units of DIGITAR are completed and tested.

Although it is being designed specifically for operation with the Computer Mk 22,[2] the DIGITAR system under development at NRL provides for greater flexibility than required for this computer. Further applications of the Converter and associated components to the instrumentation of guided missile test ranges are obvious.

GENERAL DESCRIPTION

The problem of converting shaft position into digital representation has been solved by the converter shown in block form in Figure 2. The conversion is accomplished by the use of three wheels, coded in a pattern of transparent and opaque patches through which light is transmitted and registered on a series of phototubes. The wheels are driven at 1-speed, 36-speed, and 360-speed with respect to the input shaft position; and, by this arrangement of code-patterned wheels, a reading can be made from a fixed zero point that

[1] NRL Ltr Report serial C-N3600-1/48 "DIGITAR – A System Proposed for Conversion of Rotational Shaft Position to Electronic Digital Data and for Storage of Such Data in a Form Suitable for Automatic Reduction," dtd 24 May 1948.

[2] BuOrd Report 178-45 "Computer Mk 22 Mod 0 development and description" dtd 6 Dec 1945.

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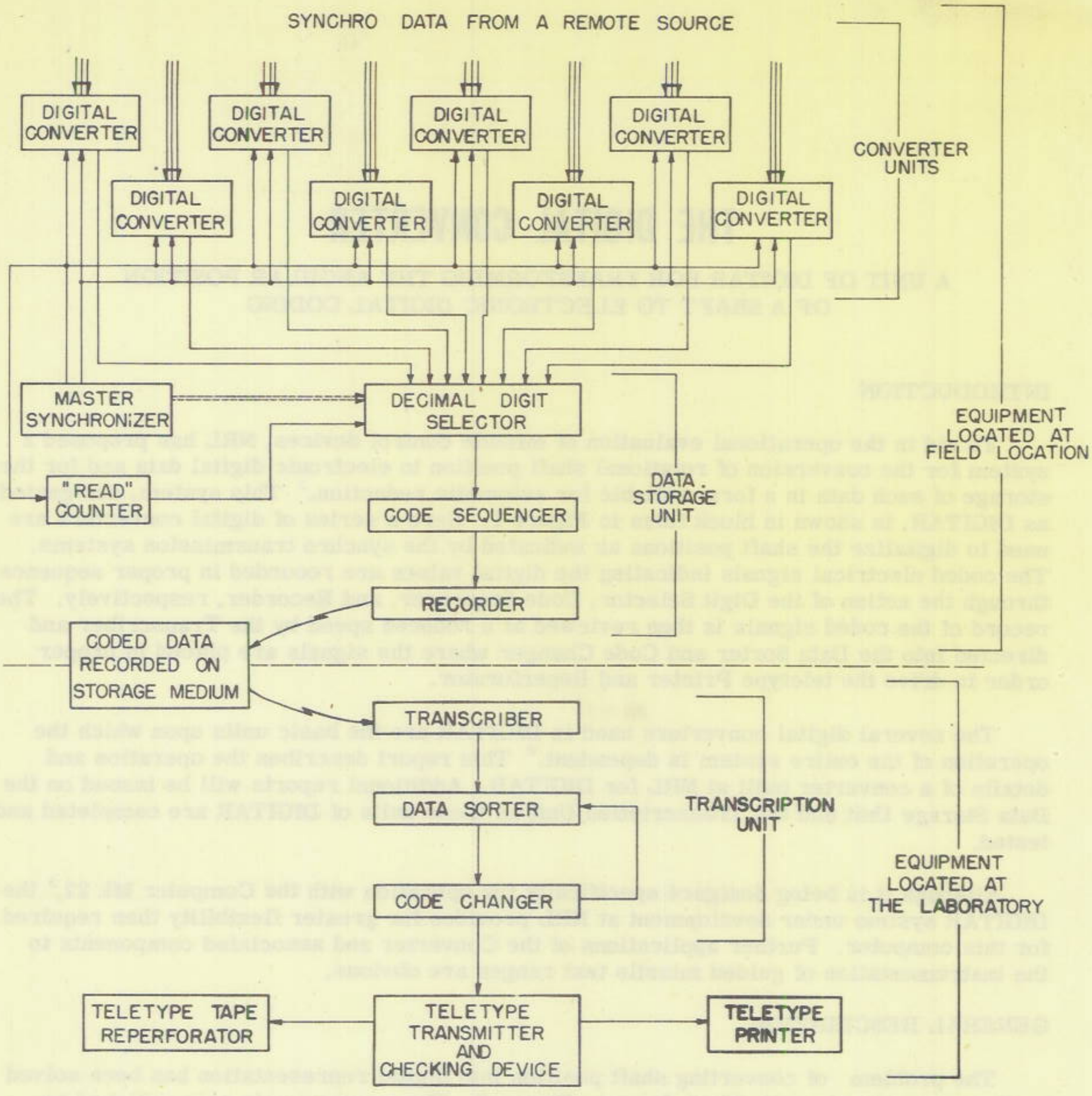

Fig. 1 - DIGITAR (General Block Diagram)

will positively register the position of the wheels at a particular instant of time. The light for reading the wheel positions is provided by high light intensity strobotrons, one strobotron circuit behind the 360-speed wheel and two behind each of the other wheels.

Ambiguous readings would normally be possible with the discrete code positions as indicated on the code wheels of Figure 3; but by proper design of circuitry controlled by the light block and high-low selector patches of the 360-speed wheel, ambiguous readings of this wheel and the 36-speed wheel are eliminated. Similar high and low selector patches and associated circuitry for the 36-speed wheel prevents ambiguous readings on the 1-speed wheel. Through the light block on the 360-speed wheel is directed a continuous beam of light.

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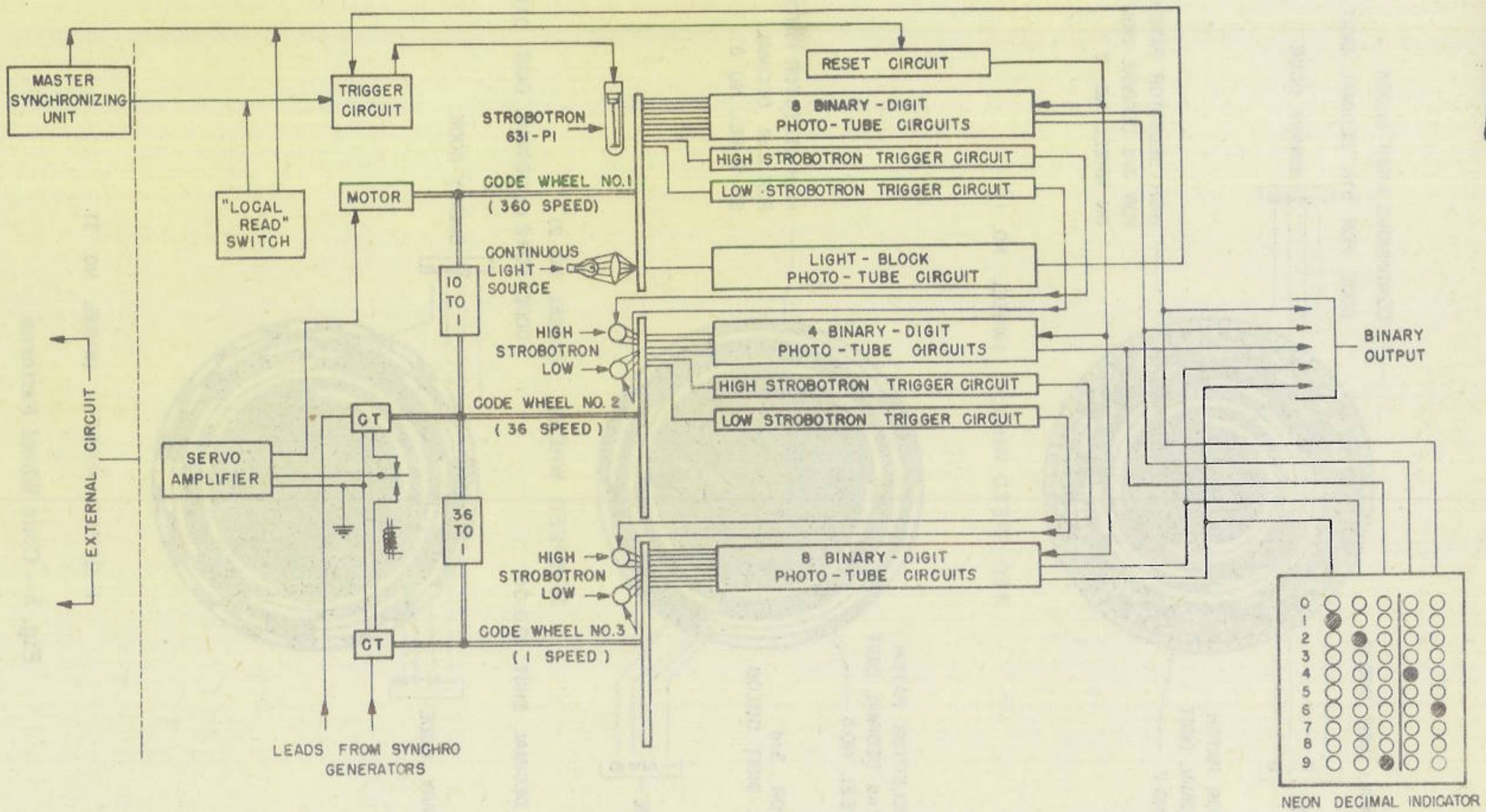

Fig. 2 - Digital Converter for Angles
(Block Diagram)

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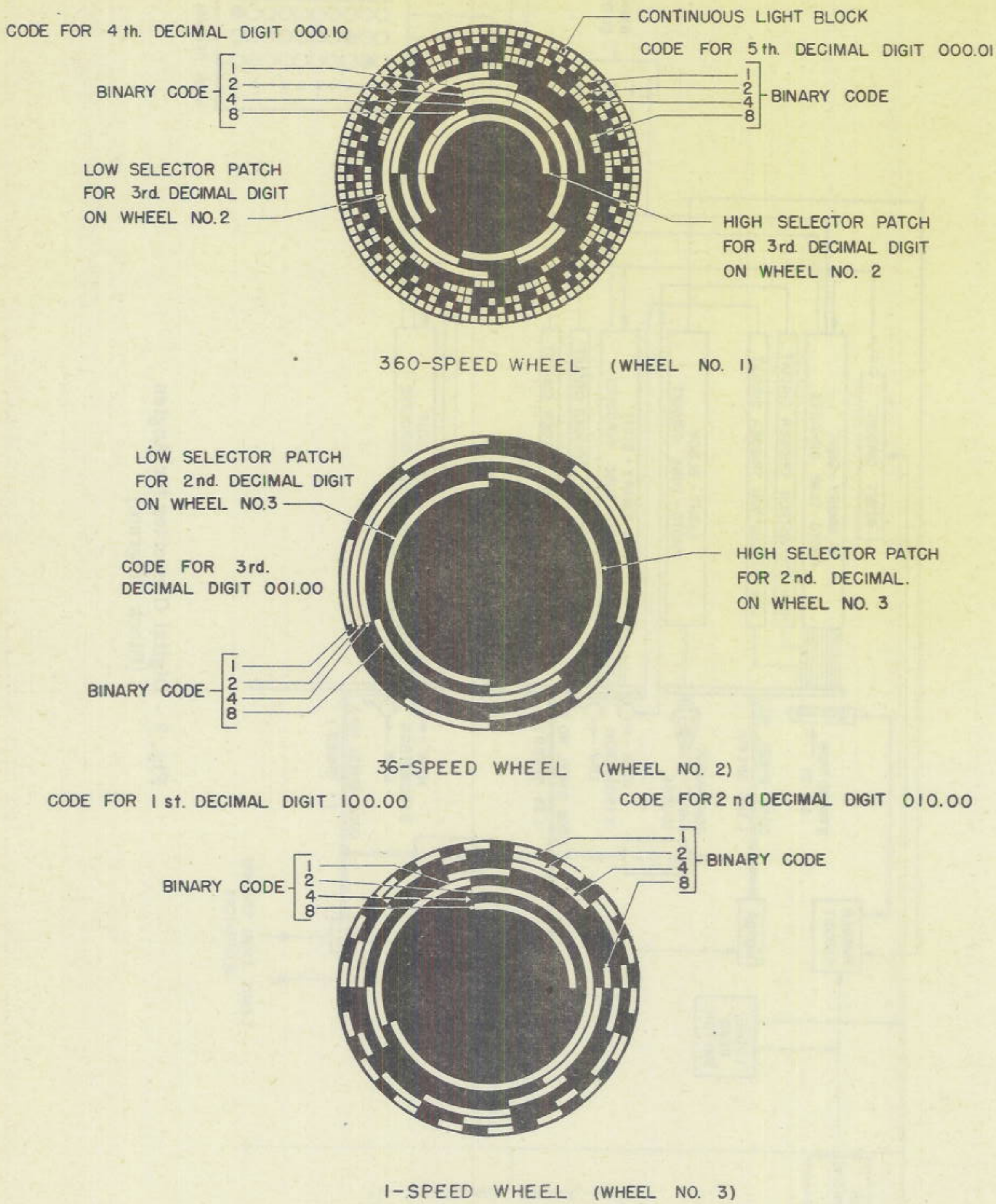

Fig. 3 - Code Wheel Patterns

When this beam is interrupted by the light block, the converter reading is prevented; but, the instant the 360-speed wheel moves to a position where the possibility of ambiguity no longer exists, light is passed through the light block ring, thereby allowing the trigger circuit to cause the reading of the 360-speed wheel. The high and low selector patches serve to indicate to their associated circuitry the ((0 to 4) or (5 to 9)) position of the dial upon which they are carried. The selector circuitry then causes the next slower speed wheel to be read from the high or low side of the point of ambiguity. This reading is made by flashing respectively either the high or low strobotron.

The sequence of operations for reading a converter is started by the reception of a "read" pulse from the master synchronizing unit. This "read" pulse causes the strobotron circuit behind Wheel #1 to be fired if the continuous light beam is not blocked. In the case that the beam is blocked, a momentary delay is caused until the wheel moves the light block. The strobotrons behind Wheels #2 and #3 are ignited by the high-low strobotron trigger circuitry associated with each strobotron.

The light passed through the code wheels is registered on phototubes and electronic-switch memory circuits. An indication of the converter's internal reading is made from these electronic-switch registers. The neon decimal indicator on the front panel of the converter presents the reading visually while electrical indication (in the form of binary coded decimal numbers) is sent directly to the data storage circuitry. When the reading has been "stored," a "reset" signal is received from the master synchronizer and all electronic switches within the converter are returned to their neutral position. As a result of resetting all memory elements in the converter, it is prepared to receive the next "read" signal. This "read," "memorize," and "reset" action is repeated continually at rates up to ten times per second, a value which is not a limitation of the converter but rather that of the particular type of Data Storage Unit used to sequence and store the data developed in the several converters of the DIGITAR system.

The converter is provided with a servo system for reproducing the remote shaft position transmitted by a synchro data link. This conversion method presents one definite advantage over the devices using the mechanical commutation method because electrical contacts and their troubles at high switching rates are eliminated. Relatively high reading rates are also possible, associated with high accuracy. Inherent in both types of conversion devices is the inertia of the indicating member. In the case of the Digital Converter, it is made up of the gearing and the coded dials; while in mechanical commutation essentially the same inertia is present but with an added load due to the friction between rotor and contacts. In either case, it is obvious that a "husky" servo drive system is necessary.

From the experience gained in the design and construction of the Converter described in this report, it is apparent that considerable reduction in size and circuitry can be realized by the use of miniaturized components and by improving the optical system and light source. An improved model is now in the process of construction and it will be described in a later report.

DETAILED DESCRIPTION

The block diagram of Figure 2 shows the general functions of the equipment within the Digital Converter; Figure 4 shows the details of the front panel of a converter for train angles. Upon reception of the "read" pulse from the master synchronizing unit, the trigger circuit, when permitted by the light block position, actuates the strobotron behind the first code wheel (highest speed). The pulse of light passing through this code wheel energizes phototube circuitry which stores the tenths and hundredths of a degree in the binary digit circuit; the light also energizes the high or low strobotron for the second

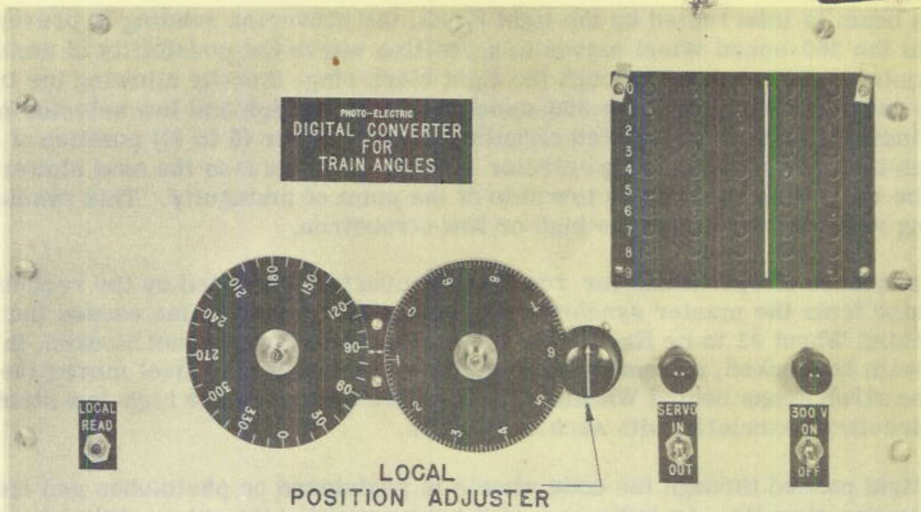

Fig. 4 - Front Panel of Converter

code wheel (intermediate speed) for reading the unit degrees. The progress is automatically repeated to provide binary-digit storage of the tens and hundreds of degrees from the third code wheel. The binary representation of the decimal digits giving the angular position is stored in the circuits of the digital converter only until this information can be transferred to the Data Storage Unit. In the present application, the angle to be measured is received at the Digital Converter as synchro signals at 1- and 36-speed; therefore, a control-transformer (CT) type of servo has been incorporated to position the code wheels. The drive is operated from the 36-speed control transformer, except when the error becomes greater than two degrees, at which time the sunchronizing relay (Figure 2) switches to the 1-speed control transformer.

Several aids are provided for initially aligning the converter with the reproduced shaft position. The front panel shown in Figure 4 indicates the internal position of the converter on the dials attached to the 1- and 36-speed shafts, and, in addition, on the neon indicator. The "Local Read" button and the Local Position Adjuster are also provided on this front panel. The "Local Read" button provides for operation of the converter under local control, while the Local Position Adjuster enables the internal mechanism of wheels to be positioned without use of the servo system. The neon decimal indicator of Figure 2 indicates a reading of 129.46 degrees.

NUMBER SYSTEM USED

By using suitable gearing, the three code wheels are driven at speeds with respect to the original shaft so that the first wheel is divided into 100 equal sectors (tenths and hundredths of a degree), the second into 10 equal sectors (degrees), and the third into 36 equal sectors (hundreds and tens of degrees). However, instead of marking a decimal number indication in each sector, a binary representation of this number is used. To illustrate the system used, the following table is presented to show the relationship between the binary and decimal representation for numbers up to 15:

TABLE I

RELATIONSHIP BETWEEN BINARY AND DECIMAL REPRESENTATIONS

	Binary Notation				Decimal Notation	DIGITAR Notation
Values	2^0 or 1	2^1 or 2	2^2 or 4	2^3 or 8		
	0 +	0 +	0 +	0 =	0	Not Used
Values Used in Converter	1	0	0	0	1	1
	0	1	0	0	2	2
	1	1	0	0	3	3
	0	0	1	0	4	4
	1	0	1	0	5	5
	0	1	1	0	6	6
	1	1	1	0	7	7
	0	0	0	1	8	8
	1	0	0	1	9	9
	0	1	0	1	10	0
Values Used Elsewhere in System DIGITAR	1	1	0	1	11	ER
	0	0	1	1	12	R
	1	0	1	1	13	E
	0	1	1	1	14	A
	1	1	1	1	15	Not Used

As seen from Table I, if the number 2 is raised to the zero, first, second, and third powers (corresponding to 1, 2, 4, and 8) respectively, it serves as a basis for constructing a binary number system. Any value from 1 to 15 can be obtained by adding various combinations of the numbers 1, 2, 4, and 8. The table was made by marking the number "1" where a binary digit is present and the number "0" where it is not present. Thus, the binary notation is readily adapted to vacuum tube circuits where digits "1" or "0" may be represented by the two mutually exclusive conditions of a countertype, multivibrator circuit (called a "flip-flop" for conveniences). The binary coding was chosen in preference to the decimal and other codes because it yielded the simplest circuitry when considered from the viewpoint of the whole DIGITAR project.

In the Digital Converter, the decimal numbers 1 through 9 are represented by their corresponding binary numbers but zero is represented by the coding for the binary number equal to 10. Thus, for each number from 0 through 9, electrical impulses are present in the circuitry so that non-operative circuits cannot cause zeros to appear erroneously. The binary code for the decimal numbers 11, 12, 13, and 14 are not used in the converter, but are used in the DIGITAR as value indicators.

CODE WHEELS

The code described in the previous section is placed on three Lucite discs in a pattern of opaque and transparent patches as shown in Figure 3. Since the Digital Converter is to have a reading accuracy of five significant decimal digits, Wheel #1 is operated at 360-speed and carries the code for the last two decimal digits. Wheel #2 is operated at 36-speed and carried the code for the third decimal digit. The first two digits representing the shaft position are coded on Wheel #3 operated at 1-speed. The transparent patches read radially in groups of four corresponding to the binary code for one decimal digit. To be certain that the proper reading of the code wheel is made by the light beam, selector rings are carried by Wheels #1 and #2, and, in addition, Wheel #1 carries a ring of narrow opaque patches at its periphery, called "light blocks."

Certain converters in the DIGITAR must be designed so that they will indicate negative angles. Fortunately, all of these converters need have only four decimal digits indicated. Because of this, the fifth digit of the converter can be used as a sign indicator. The Computer Mk 22 detects a negative angle when it sees a number 9 in the fifth decimal digit position for quantities having only four-digit values, a condition noted by the value indicator. Since the converters are being built to provide information for the Computer Mk 22, this number nine can also be used to indicate a negative angle as seen on the code wheel. The angle indicated by the converter is actually the complement of the negative angle with the number nine in the fifth digit position. The Computer Mk 22 detects this fact and converts the angle to a figure useable in the machine.

The code wheels were constructed by drawing the code arrangement with India ink on a white surface such that the diameter of the wheel was 18 inches. The drawing was reduced by photography at the U. S. Hydrographic Office, Washington, D. C. and printed on a sheet of 1/16 inch Lucite by means of a special, high-contrast, wet photographic process. After the emulsion side of the Lucite sheet had been covered with a protective coating of thin lacquer, the discs were cut out and trimmed to size on a lathe. A photograph showing the code wheels mounted in the Digital Converter is presented in Figure 5.

READING OPERATION

In the Digital Converter, a continuous variable, such as an angle, is read from code wheels marked for discrete values of that variable. Because the light beam transmitted through each code wheel has a finite width, it can cause two adjacent codes to be read simultaneously whenever the code wheel is positioned about half way between the codes. To eliminate this (in the case of Wheel #1), the Digital Converter has added to it a light-block

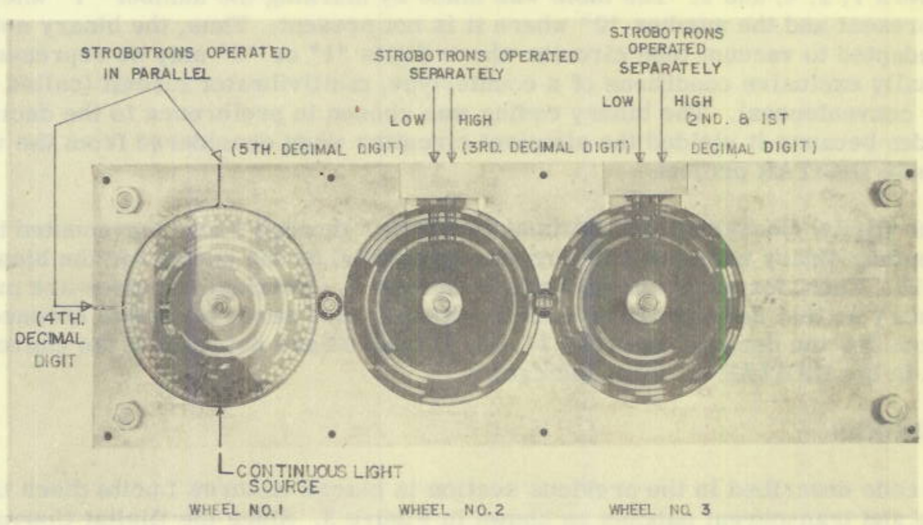

Fig. 5 - Rear View of Code Wheels (With Cover Plate Removed)

coding on the periphery of Wheel #1, as shown in Figure 3, so that readings can be made only when the periphery coding is transparent. To provide a practically continuous light source for the light-block coding, a line-filament lamp (Westinghouse Exciter Lamp .75a 4v) is energized by a 20-kilocycle oscillator. The light received by the phototube results in an electrical signal which is amplified and used as an input to the trigger circuit (Figure 2) to prevent a trigger pulse being sent to the strobotrons of Wheel #1 while the wheel position is such that it would result in two position codes being read simultaneously. Since no commercially available strobotron had sufficient length to provide a line source of light for coverage of the 11 code rings on Wheel #1, two strobotrons that displace 90 degrees were used (Figure 5). A negligible time delay is caused by this action, and a reading to the closest 0.01 degree is assured, since the light-block code which prevents reading is only 0.002 degree wide in terms of the one-speed input angle. If the input is not changing, the servo will oscillate sufficiently to drive Wheel #1 into a readable position.

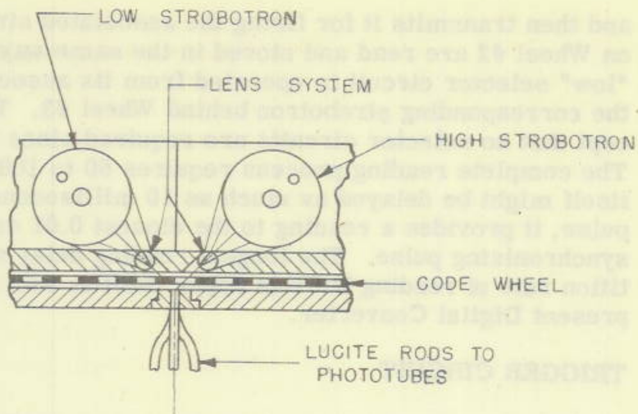

Fig. 6 - Arrangement for Oblique Lighting of Code Wheel

To avoid reading two adjacent codes simultaneously on Wheels #2 and #3, it is not possible to make use of the light-block scheme without introducing significant errors into the system. Therefore, two strobotrons are used so that the light from one is transmitted through one part of the code wheel and the light from the other is transmitted through an adjacent part of the wheel. Because of the size of the strobotrons, this can be accomplished only by transmitting the light obliquely through the code wheels (Figures 1, 5, and 6). If the reading of digit 4 on Wheel #1 is between 0.00 and 0.49 degree, a selector ring on that wheel causes the "high" strobotron behind Wheel #2 to be energized; if the reading is between 0.50 and 0.99 degree, another selector ring on Wheel #1 causes the "low" strobotron behind Wheel #2 to be energized. In this way the most accurate readings determine the integer to be recorded as the third decimal digit (e.g., 0.00, or 1.00, or 2.00 degrees). In a similar manner, the two selector rings (transparent for 180° each) on Wheel #2 determine whether the high or low strobotron behind Wheel #3 is to be energized. Wheel #3 has no selector rings since it is not used for directing any further reading.

When the Digital Converter is ordered to "read" by an external Master Synchronizing Unit, the read pulse is transmitted to the trigger circuit. As soon as Wheel #1 is in a readable position, the trigger circuit provides pulses for simultaneously firing the strobotrons mounted behind this wheel. The pulse of light on a given ring of the wheel is either blocked by an opaque patch or allowed to be transmitted by a transparent patch. If the light is transmitted, it is directed through a Lucite rod to a phototube where it becomes an electrical pulse. The electrical pulse is amplified and used to change the conducting state of a flip-flop so that a binary digit is thereby stored. If no light is passed on a given ring, the conducting state of the associated flip-flop is not changed so that this information is also stored. Four phototubes and associated circuits, including a flip-flop for each phototube, are required to register a decimal digit in the binary representation. In addition, a portion of the pulse of light from the strobotron passes through either the "high" or "low" selector ring on Wheel #1 and is directed by a Lucite rod to a phototube. The corresponding selector circuit first amplifies and shapes the electrical pulse received from the phototube and then transmits it for firing the associated strobotron behind Wheel #2. Then the codes on Wheel #2 are read and stored in the same way as for Wheel #1, and either the "high" or "low" selector circuit is operated from its associated selector ring to direct the firing of the corresponding strobotron behind Wheel #3. The process is repeated at Wheel #3, except that no selector circuits are required since there is no further reading to be directed. The complete reading process requires 50 to 100 microseconds and, although the reading itself might be delayed as much as 10 milliseconds with respect to the master synchronizing pulse, it provides a reading to the closest 0.01 degree corresponding to the time of the synchronizing pulse. The longest reading delay also presents an upper limit for the repetition rate of reading but this upper limit is well above the 10-per-second rate used in the present Digital Converter.

TRIGGER CIRCUIT

The trigger circuit used to fire the strobotron of Wheel #1 in the Digital Converter is illustrated in Figure 7. The "read" order to the Digital Converter is transmitted as a negative pulse, either from the external Master Synchronizing Unit or from the "Local Read" circuits. This negative pulse is applied to the grid of tube T1, changing it to a non-conducting state from its usual conducting state. At the same time tube T2 becomes conducting, and the flip-flop composed of tubes T1 and T2 remains in this condition, thus memorizing the "read" signal until it is reset to its original state by a pulse from tube T9. When T1 becomes non-conducting, the voltage is suddenly raised. The thyratron is fired if the voltage on the grid is also raised by the signal from the light-block phototube circuit passing through the flip-flop shaper formed by tubes T3 and T4; otherwise, it is not fired because of the bias voltage applied. The light-block phototube circuit is energized by a tungsten light bulb which continuously illuminates the coding on the periphery of Wheel #1 so that the grid voltage on the thyratron is raised when an unambiguous code reading can be made and is lowered when there is a possibility of two adjacent codes being registered simultaneously. Thus, when both the memory flip-flop and the light-block pulse raise the voltage on the grid of the thyratron T5, the bias is overcome and the tube conducts. The consequent lowering of the voltage on the plate of tube T5 causes the blocking oscillator T6 to generate one highly damped cycle, the first half of which is a 200-microsecond positive pulse. The signal from the plate of T6 is applied to the grids of tubes T7 and T8 (a 12AU7 tube). This tube acts as a cathode-follower and isolates the stages for providing a positive pulse to fire the strobotrons behind Wheel #1. The signal in the grid circuit of the blocking oscillator is applied to the grid of tube T9, which serves as a buffer providing for a negative reset pulse to the flip-flop at the grid of tube T2. When the memory flip-flop is reset, it lowers the voltage on the grid of Tube T5 and cuts the tube off. Thus, the trigger circuit has fired the strobotrons and returned to its initial condition of waiting for an order to read.

LIGHT PATH AND DETECTION

All six strobotrons, two behind each code wheel, are neon-filled Sylvania Type 631P1 tubes, which emit relatively high-intensity light, principally in the red and infrared portion of the spectrum. Gas-filled cartridge phototubes (RCA Type 921 with an S2 plate surface) are used for receiving the light from the strobotrons. The strobotrons are fired by a 175-volt positive pulse having a width of about 200 microseconds.

The light from the strobotrons is directed through Wheel #1 by the use of small tapered Lucite lenses and through Wheels #2 and #3 by cylindrical Lucite lenses. The diameter of the the spot of light formed on the code wheel by one of these lenses is about one-half of the code ring width. When each spot of light is directed to the center of a code, there is a minimum of interference between the codes due to fringes of light around the spot. The light transmitted through the code wheel is carried to the phototubes by highly polished Lucite

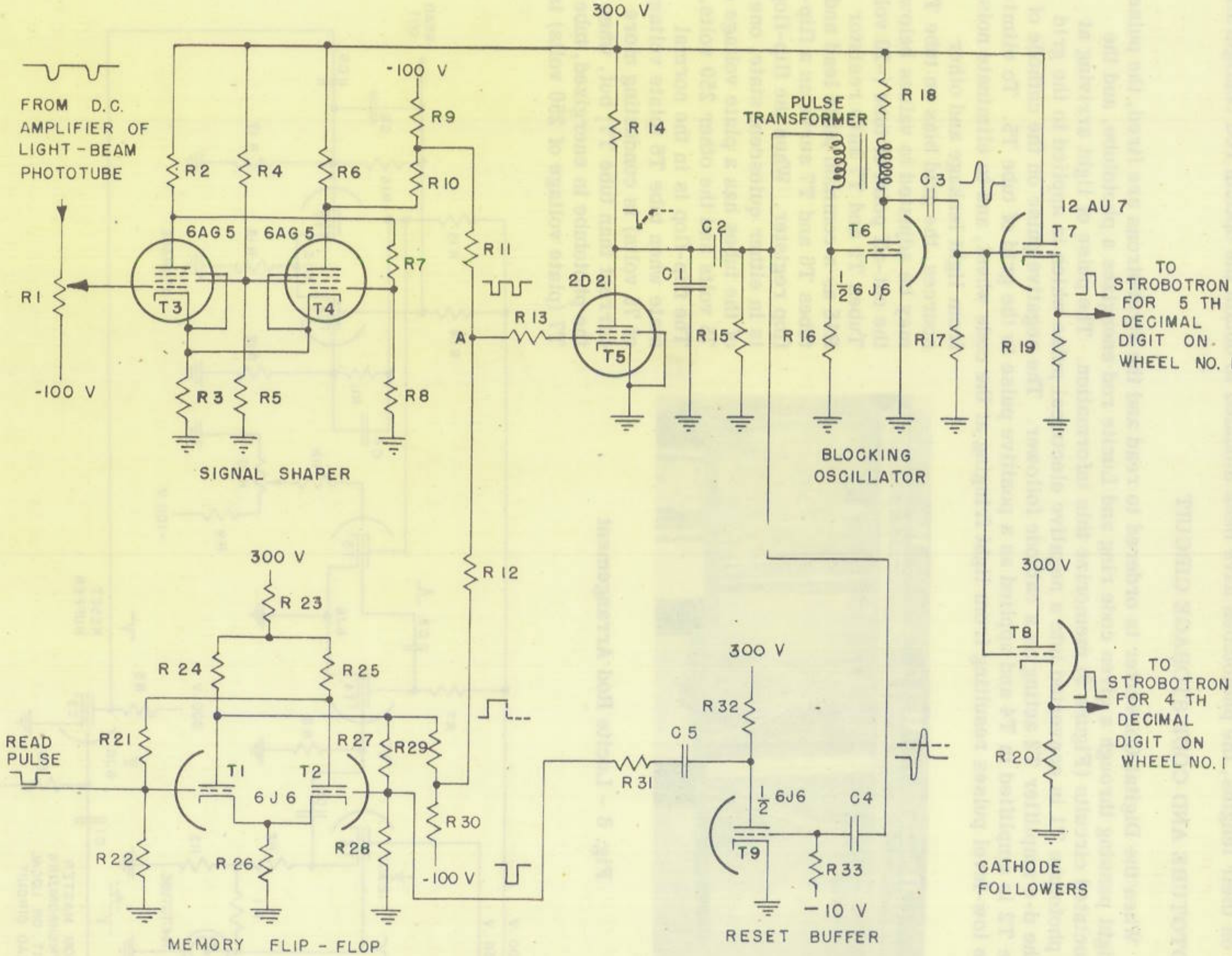

Fig. 7 - Trigger Circuit

rod of 1/8-inch diameter (Figure 8). Since the efficiency of light transmission through the rods depends not only on their degree of polish but also on the amount of curvature present and on their lengths, the phototubes have been mounted to obtain the optium rod configuration.

PHOTOTUBE AND CODE STORAGE CIRCUIT

When the Digital Converter is ordered to read and the strobotrons are fired, the pulse of light passing through a given code ring and Lucite rod energizes a phototube, and the associated circuits (Figure 9) memorize this information. The pulse of light arriving at the phototube T1 is converted into a negative electrical pulse which is applied to the grid of the d-c amplifier T2 acting as a cathode follower. The negative pulse on the cathode of tube T2 is amplified in T4 and applied as a positive pulse to the grid of tube T5. To eliminate low-level pulses resulting from light fringing at the code wheel, and to eliminate noise from light leakage and other sources, the grid bias on tube T5 may be adjusted to values below the cut-off point of tube (-20 volts). Tubes T5 and T7 have resistor R15 as a common plate lead and tubes T6 and T7 serve as a flip-flop register. When the flip-flop is in either quiescent state, one of the tubes has a plate voltage of 75 volts and the other 250 volts. The flip-flop is in the normal state when tube T6 (plate voltage of 75 volts) is conducting more current than tube T7; but, when the phototube is energized, tube T7 (plate voltage of 250 volts) is

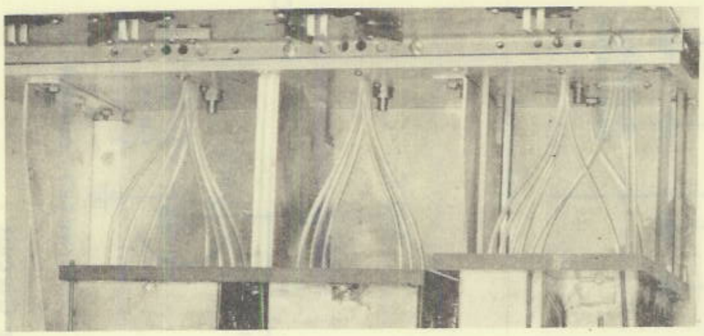

Fig. 8 - Lucite Rod Arrangement

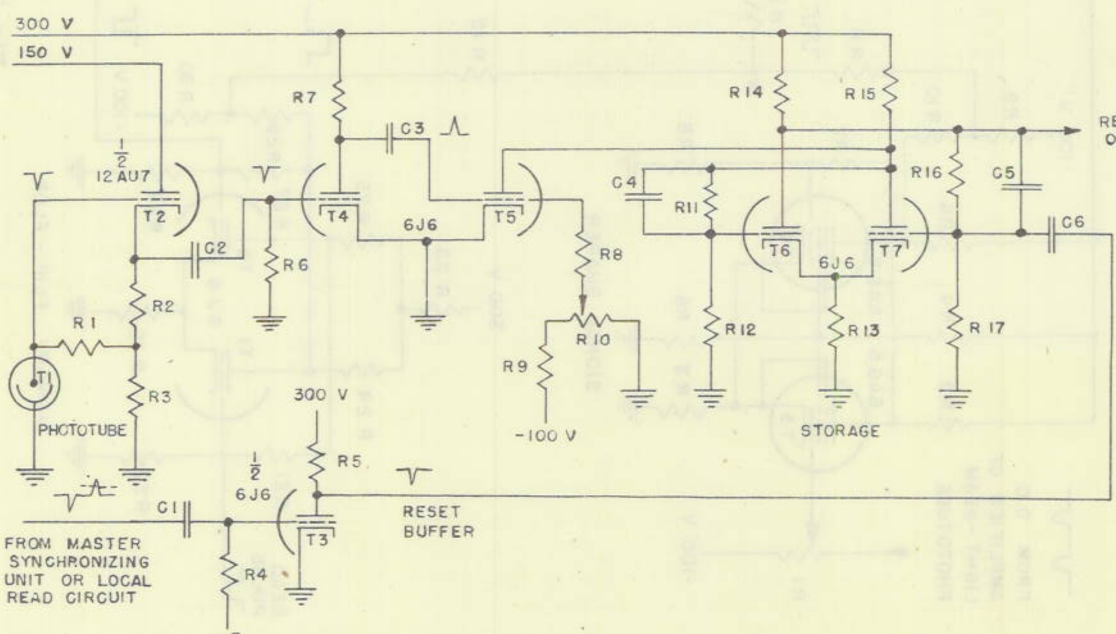

Fig. 9 - Phototube and Code Storage Circuit

lowered by the action of T5 and thereby made to conduct more current than tube T6 through the resulting flip of steady state conditions. The information denoting whether or not a pulse of light was transmitted through a given code ring is stored in the flip-flop until it has been transferred to a more suitable storage medium such as magnetic tape for later use. After such a transfer has been completed, the flip-flop is reset to its normal state (tube T6 conducting more current than tube T7) by introducing a negative pulse on the grid of tube T7.

The negative pulse used to reset the code storage circuit is supplied through the reset buffer amplifier tube T3. This amplifier performs several functions. The first function is to clip the read pulse from the input signal and pass only the reset pulse. Secondly, it inverts the signal to present a negative pulse to the flip-flop. Finally, it performs the task of isolating the flip-flop storage circuits from similar circuits of the other binary digits in the converter assembly which are being reset by the same reset pulse.

"LOCAL READ" CIRCUIT

Although the Digital Converter is designed to be used with an external Master Synchronizing Unit which provides reading and resetting pulses, a local means for reading the binary output and resetting the circuits is required for making adjustments and operating checks on individual converters. Therefore, a "Local Read" circuit has been built into the converter such that it may be operated by a push-button switch on the front panel (Figure 4). This switch causes the Digital Converter to read when it is pushed in, and to reset when it is released. A diagram of the circuit used is given in Figure 10. When the push button is in, the plate voltage of tube T1 is suddenly lowered since the flip-flop made up of tubes T1 and T2 is forced to change from the one stable condition to the other. This sudden drop in voltage is differentiated by the short-time-constant circuit formed by the capacitor C3 and resistor R9 to give a negative pulse on the grid of tube T3. The pulse is amplified and inverted by tube T3 so that its base may be clipped in the cathode follower T4. The base of the pulse is again clipped in the final stage T5, from which the negative "read" pulse is sent to the memory flip-flop of the trigger circuit for initiating the reading operation. In passing through the last two stages, the "reset" pulse is eliminated and the amplitude of the "read" pulse is adjusted by potentiometer R12. As long as the "Local Read" button is held in, the registered shaft position at the time of the switch closure is stored in the code flip-flops and is also registered on the Neon Decimal Indicator.

When the "Local Read" push button is released, the flip-flop made up of tubes T1 and T2 is switched back to its original state, thus causing the voltage on the plate of tube T1 to rise suddenly. This voltage rise is differentiated to give a positive pulse which is sent to a reset amplifier (tube T3 of Figure 9). The reset amplifier is grid-biased to eliminate the negative "read" pulse and also serves to amplify, invert, and isolate the "reset" pulse. The negative reset pulse is then sent to all code storage circuits (Figure 9) to place them in their original condition. Although the reset pulse is amplified by tube T3 (Figure 1), it is completely eliminated in the two following stages, thus effecting separation of the read pulse from the reset pulse.

"HIGH" AND "LOW" STROBOTRON TRIGGER CIRCUIT

The trigger circuit to provide the firing pulse for the strobotrons behind Wheel #1 was shown in Figure 7. As indicated in the discussion of the reading operation, the pulses used to fire the strobotrons of Wheel #2 are derived from the "high" or "low" selector ring on Wheel #1 in order to avoid registering two adjacent codes simultaneously. The "high" and "low" strobotron trigger circuits are the same and are illustrated in Figure 11. The pulse of light transmitted through one of the selector rings of the code wheel energizes the phototube T1 and results in a negative electrical pulse being applied to the grid of the cathode

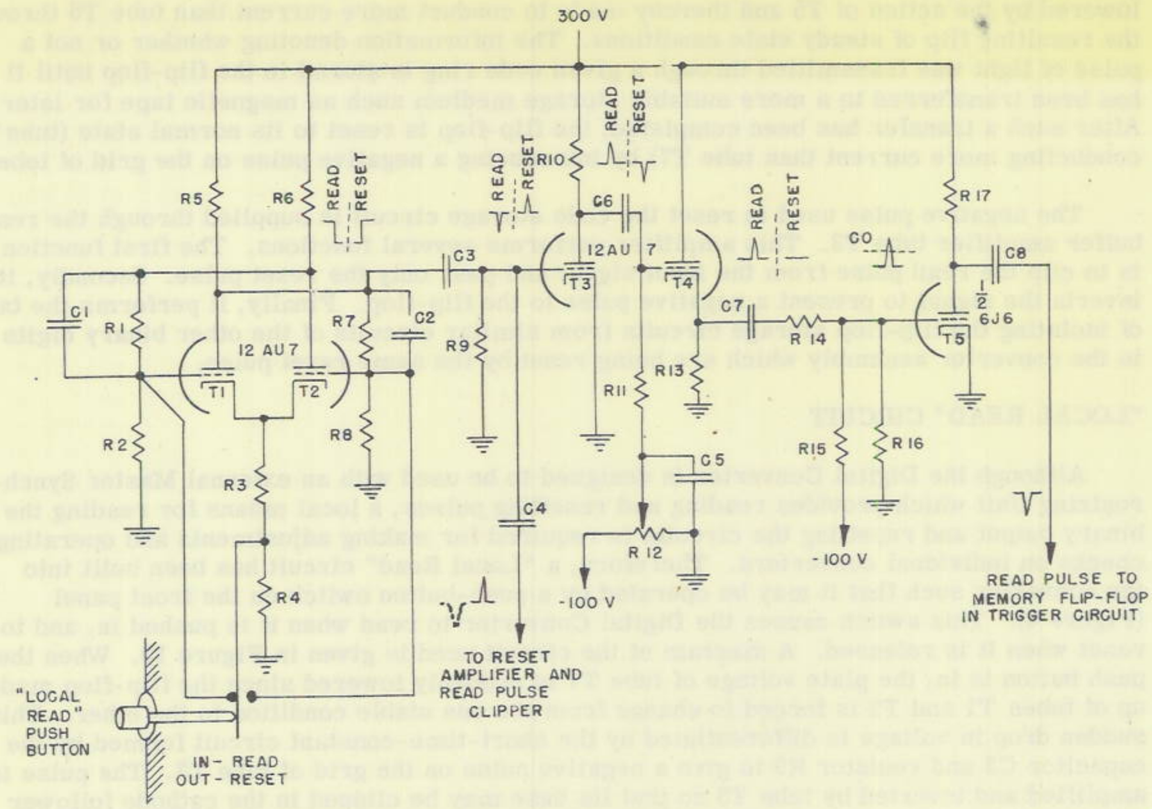

Fig. 10 - "Local Read" Circuit

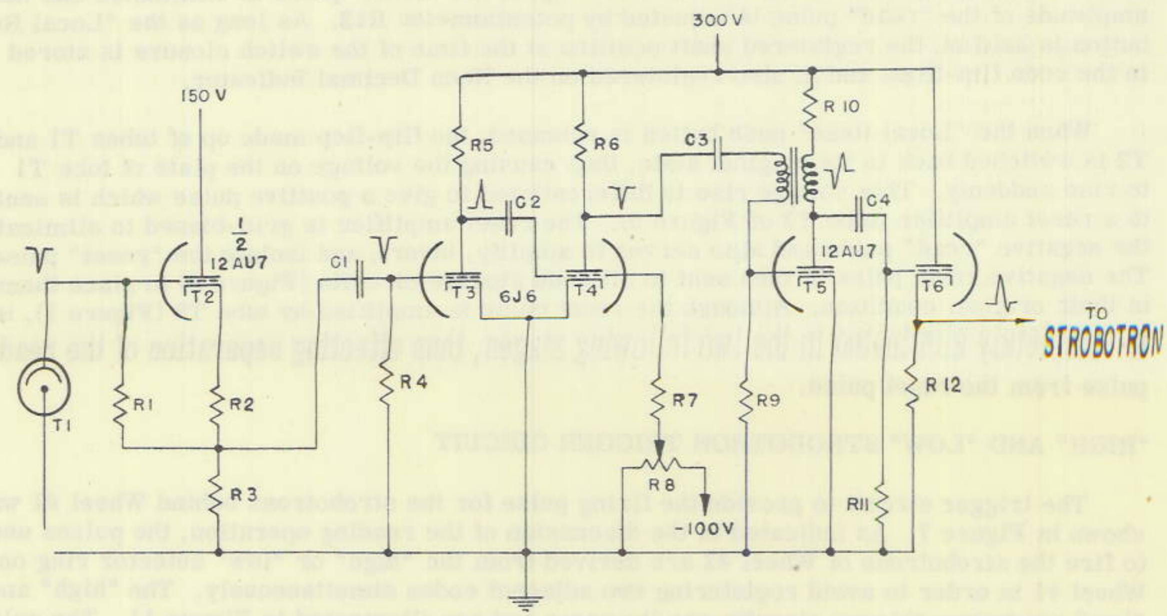

Fig. 11 - "High" or "Low" Strobotron Trigger Circuit

follower T2. This pulse is amplified in tube T3 and base-clipped in the amplifying stage T4. The resultant negative pulse is applied to the grid of tube T5 to block the normal current flow. The blocking oscillator then provides one highly damped cycle, the first half of which is a 200-microsecond positive pulse. This signal is passed through a final cathode-follower stage to clip the negative peak and to provide low impedance for matching the strobotron. The resultant positive pulse is used to fire either the "high" or the "low" strobotron of Wheel #2. In exactly the same manner, the selector rings on Wheel #2 and the associated circuits result in the firing of the strobotrons of Wheel #3.

NEON DECIMAL INDICATOR

The Neon Decimal Indicator mounted on the front panel of the Digital Indicator (Figures 2 and 4) provides a visual indication of the readings made by the unit. A reading (for example, 129.46 degrees, Figure 2) is indicated by glowing neon lamps, each representing a given decimal number. Fifty neon lamps arranged in five columns are used to provide a complete indication of the five decimal digits representing the angular shaft position. Figure 12 presents a sample diagram illustrating the use of a resistance matrix to convert a binary to a decimal number. The resistances of the matrix are arranged so that the highest voltage available energizes the neon bulb of the decimal number corresponding to the binary input. Since the highest voltage is 20 volts above the next highest, a given neon tube is

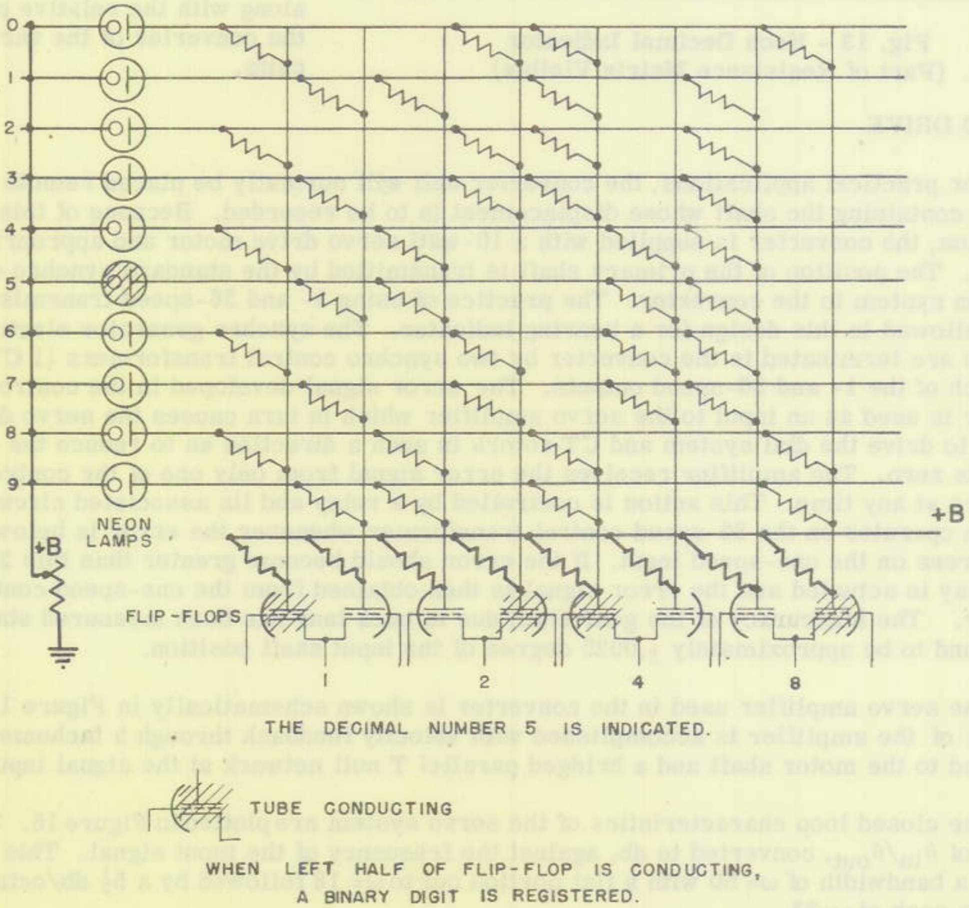

Fig. 12 - Resistance Matrix for One Decimal Digit of the Neon Decimal Indicator

 [redacted]

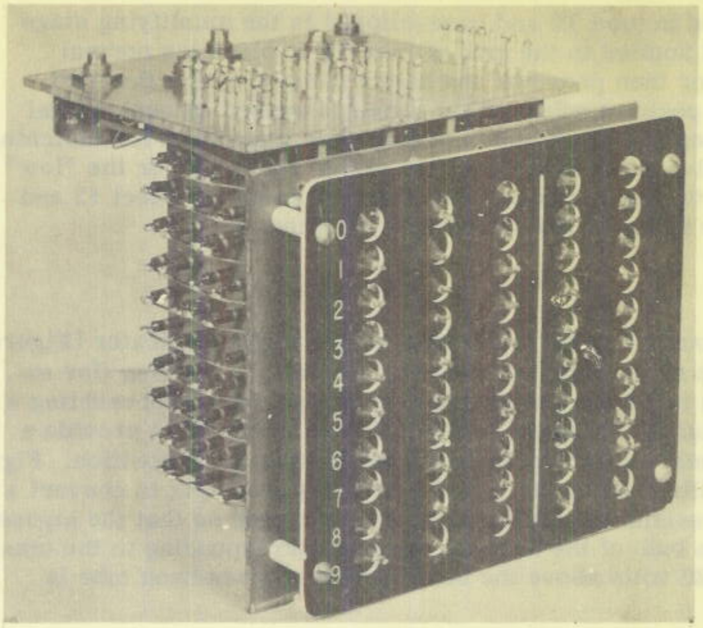

Fig. 13 - Neon Decimal Indicator
(Part of Resistance Matrix Visible)

biased so that it is energized only for the highest voltage, although four different lower voltages are also present in the output of the resistance matrix. In Figure 12 the neon lamp representing the decimal number five is energized by the binary input of 1010, represented by conduction in one side or the other of each of the flip-flops. Part of the resistance matrix is visible in Figure 13, a photograph of the Neon Decimal Indicator removed from the cabinet of the Digital Converter.

A composite schematic drawing of the circuits previously described is shown in Figure 14. Here the values of resistance and capacitance components are indicated along with the relative position in the converter of the various circuits.

SERVO DRIVE

For practical applications, the converter unit will normally be placed remote from the device containing the shaft whose displacement is to be recorded. Because of this probable condition, the converter is supplied with a 10-watt servo drive motor and appropriate amplifier. The position of the primary shaft is transmitted by the standard synchro data transmission system to the converter. The practice of using 1- and 36-speed transmission has been followed in this design for a bearing indicator. The synchro generator electrical outputs are terminated in the converter by two synchro control transformers (1 CT), one for each of the 1- and 36-speed outputs. The error signal developed in the control transformer is used as an input to the servo amplifier which in turn causes the servo drive motor to drive the dial system and CT rotors in such a direction as to reduce the error towards zero. The amplifier receives the error signal from only one of the control transformers at any time. This action is controlled by a relay and its associated circuits. The system operates on the 36-speed control transformer whenever the error is below about $2\frac{1}{2}$ degrees on the one-speed input. If the error should become greater than this $2\frac{1}{2}$ degrees, the relay is actuated and the error signal is then obtained from the one-speed control transformer. The inaccuracy of the gear train due to back lash has been measured statically and found to be approximately $\pm.0025$ degree of the input shaft position.

The servo amplifier used in the converter is shown schematically in Figure 15. Equalization of the amplifier is accomplished with velocity feedback through a tachometer attached to the motor shaft and a bridged parallel T null network at the signal input.

The closed loop characteristics of the servo system are plotted in Figure 16. This is a plot of θ_{in}/θ_{out}, converted to db, against the frequency of the input signal. This curve shows a bandwidth of $\omega = 50$ with a flat portion out to $\omega = 18$ followed by a $5\frac{1}{2}$ db/octave rise with its peak at $\omega=33$.

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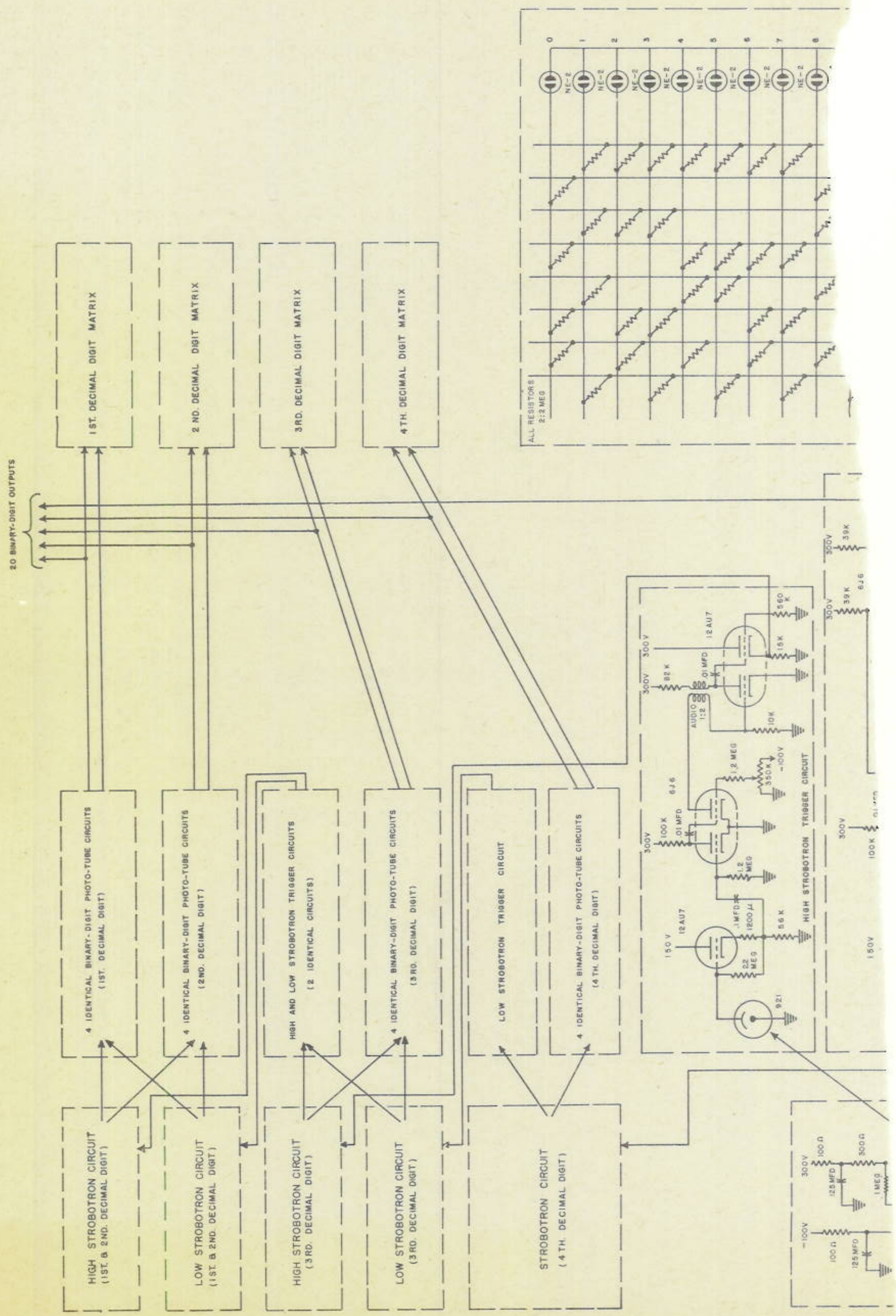


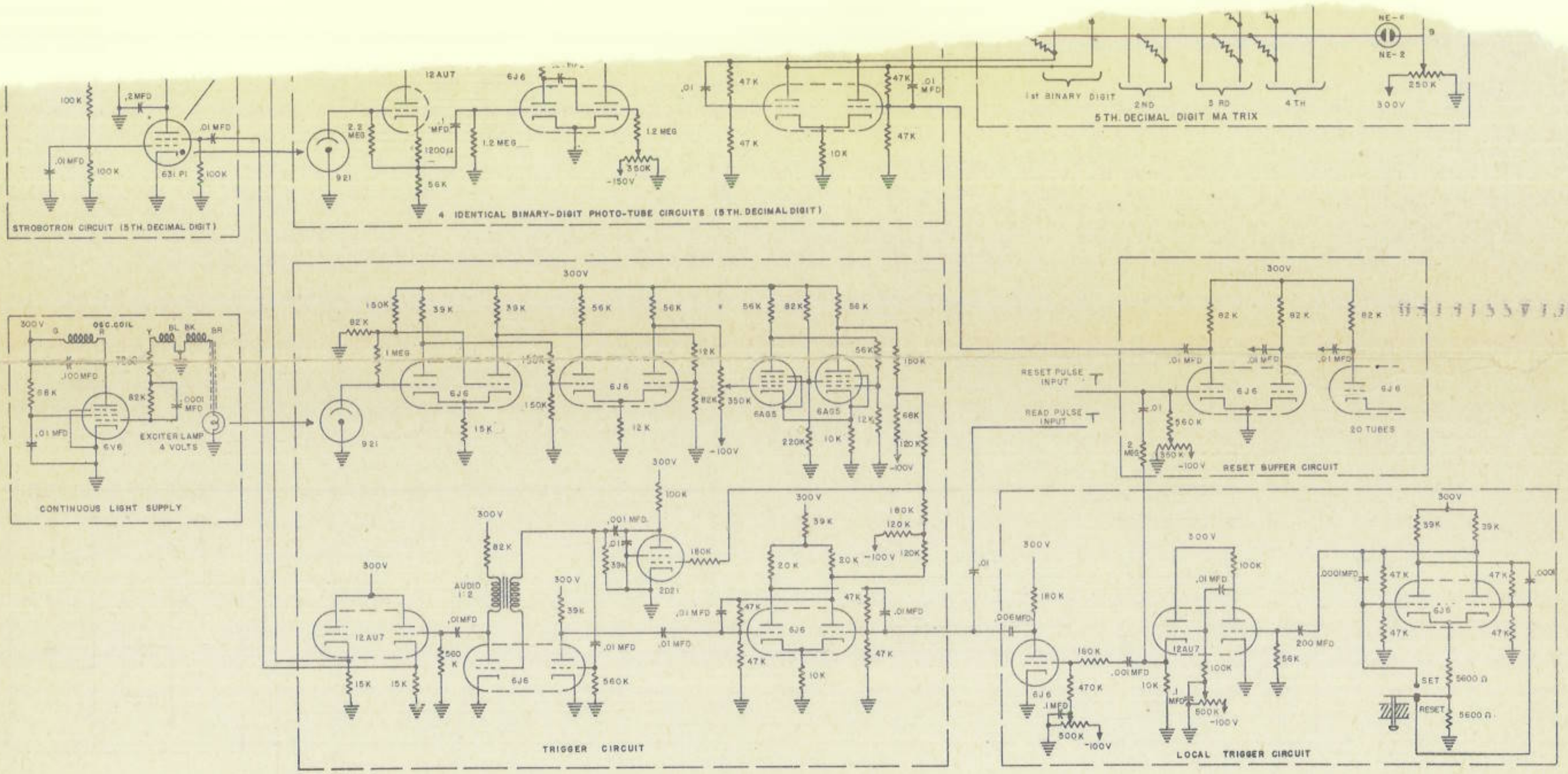


Fig. 14 - Overall Schematic of Digital Converter

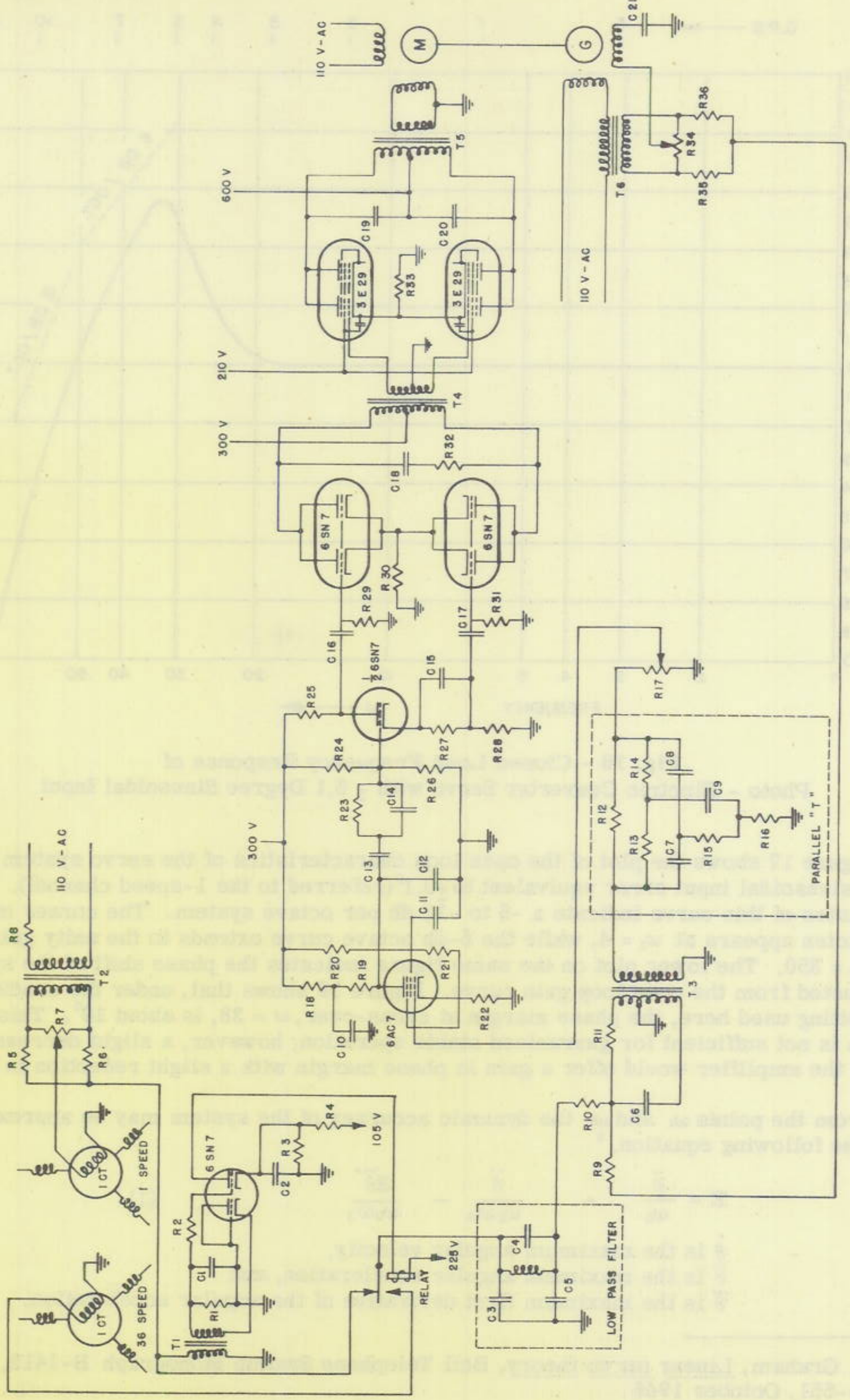


Fig. 15 - Servo Amplifier

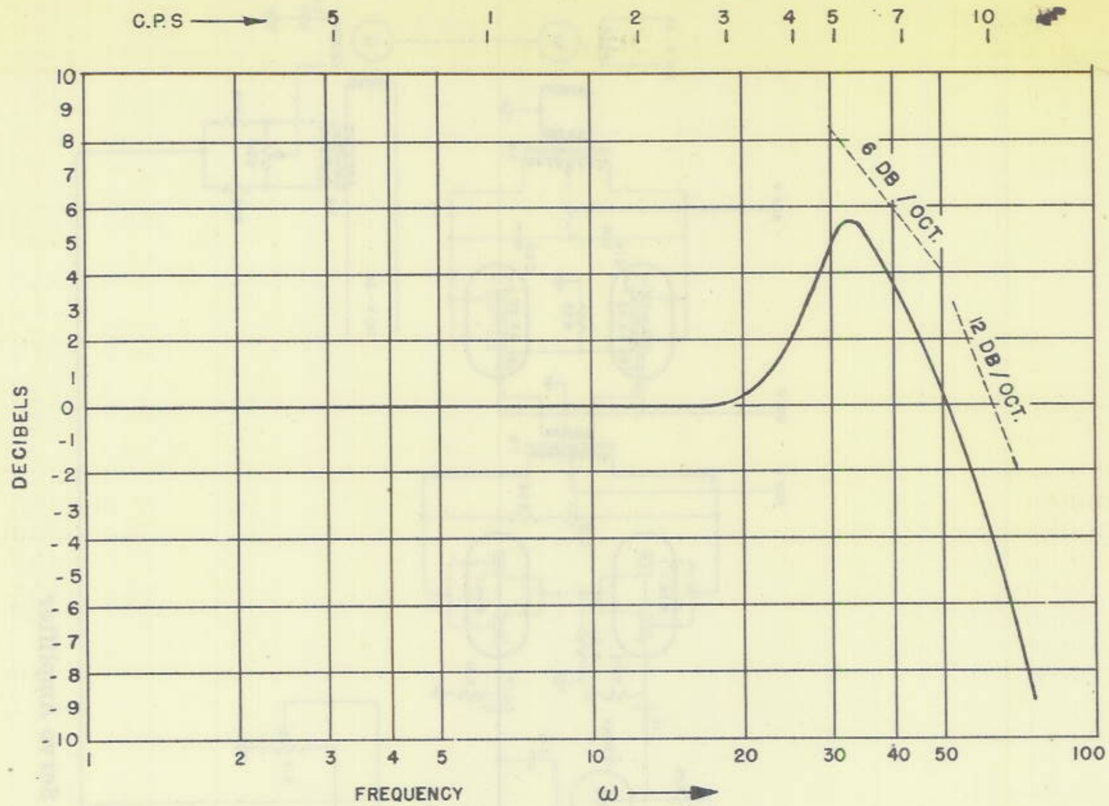


Fig. 16 - Closed Loop Frequency Response of Photo - Electric Converter Servo with ± 0.1 Degree Sinusoidal Input

Figure 17 shows the plot of the open loop characteristics of the servo system taken with a sinusoidal input error equivalent to $\pm 0.1^\circ$ (referred to the 1-speed channel). The asymptotes of this curve indicate a -6 to -12 db per octave system. The corner of the two asymptotes appears at $\omega_1 = 4$, while the 6-db octave curve extends to the unity gain line to give $\omega_0 = 350$. The lower plot on the same figure indicates the phase shift of the system as constructed from the open loop gain curve. Figure 16 shows that, under the conditions of gain setting used here, the phase margin at cross-over, $\omega = 38$, is about 10°. This phase margin is not sufficient for guaranteed stable operation; however, a slight decrease in the gain of the amplifier would offer a gain in phase margin with a slight reduction in bandwidth.

From the points ω_1 and ω_0 the dynamic accuracy of the system may be approximated from the following equation.[3]

$$E = \frac{\dot{\theta}}{\omega_0} + \frac{\ddot{\theta}}{\omega_1 \omega_0} - \frac{2\dddot{\theta}}{\omega_0 \omega_1} \quad (1)$$

where $\dot{\theta}$ is the maximum angular velocity,
$\ddot{\theta}$ is the maximum angular acceleration, and
$\dddot{\theta}$ is the maximum first derivative of the angular acceleration.

[3] R. E. Graham, Linear servo theory, Bell Telephone System Monograph B-1412, BSTS 25, 616-651, October 1946

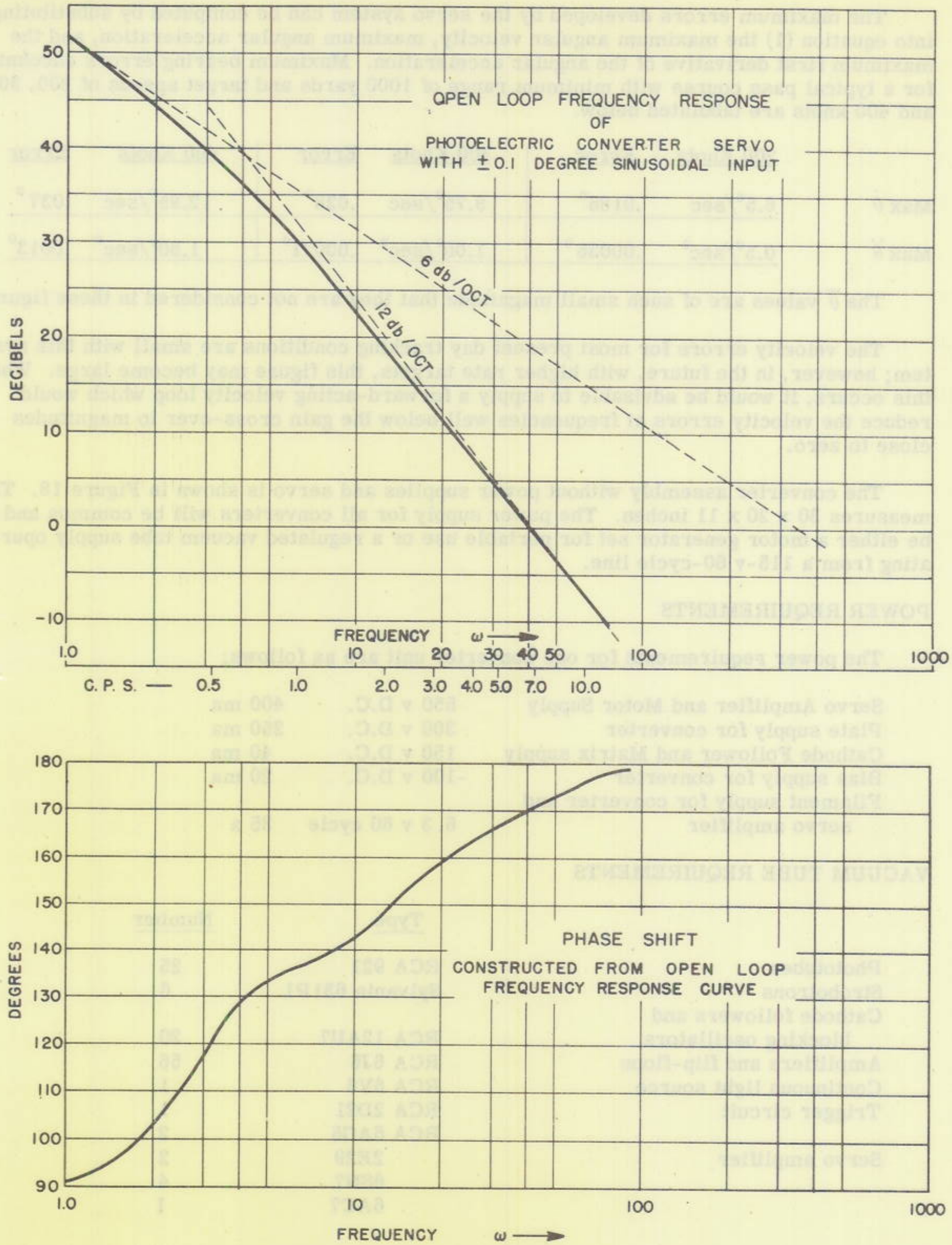


Fig. 17 - Servo Characteristics

The maximum errors developed by the servo system can be computed by substituting into equation (1) the maximum angular velocity, maximum angular acceleration, and the maximum first derivative of the angular acceleration. Maximum bearing errors encountered for a typical pass course with minimum range of 1000 yards and target speeds of 200, 300, and 400 knots are tabulated below.

	200 Knots	Error	300 Knots	Error	400 Knots	Error
Max $\dot{\theta}$	6.5°/sec	$.0186^{\circ}$	9.75°/sec	$.028^{\circ}$	12.95°/sec	$.037^{\circ}$
Max $\ddot{\theta}$	$0.5^{\circ}/sec^2$	$.00036^{\circ}$	$1.00^{\circ}/sec^2$	$.00071^{\circ}$	$1.80^{\circ}/sec^2$	$.0013^{\circ}$

The $\dddot{\theta}$ values are of such small magnitude that they are not considered in these figures.

The velocity errors for most present day tracking conditions are small with this system; however, in the future, with higher rate targets, this figure may become large. When this occurs, it would be advisable to supply a forward-acting velocity loop which would reduce the velocity errors at frequencies well below the gain cross-over to magnitudes close to zero.

The converter assembly without power supplies and servo is shown in Figure 18. This measures 30 x 20 x 11 inches. The power supply for all converters will be common and can be either a motor generator set for portable use or a regulated vacuum tube supply operating from a 115-v 60-cycle line.

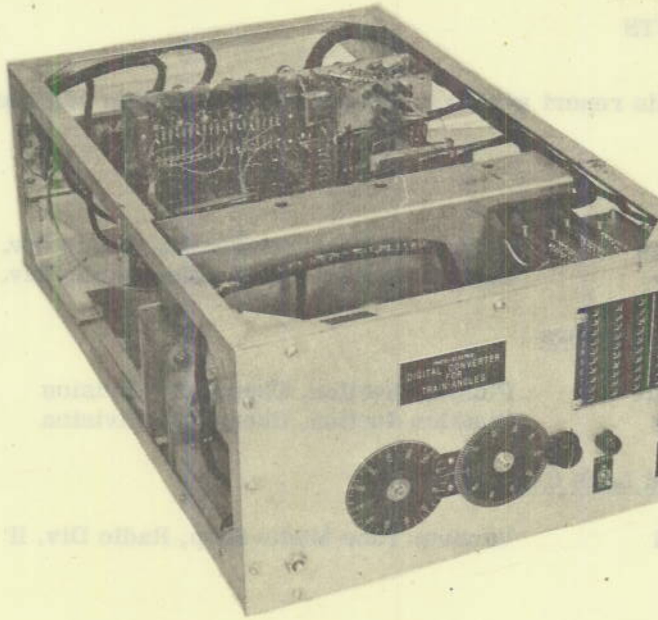
POWER REQUIREMENTS

The power requirements for one converter unit are as follows:

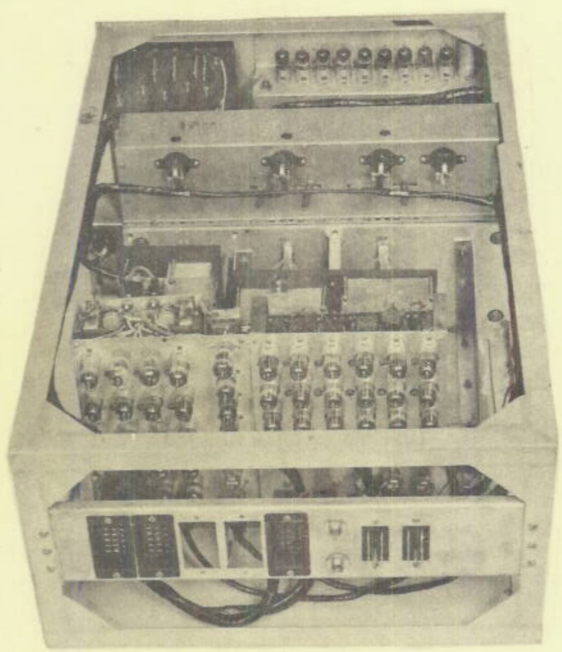
Servo Amplifier and Motor Supply	550 v D.C.	400 ma
Plate supply for converter	300 v D.C.	250 ma
Cathode Follower and Matrix supply	150 v D.C.	40 ma
Bias supply for converter	-100 v D.C.	20 ma
Filament supply for converter and servo amplifier	6.3 v 60 cycle	35 a

VACUUM TUBE REQUIREMENTS

	Type	Number
Phototubes	RCA 921	25
Strobotrons	Sylvania 631P1	6
Cathode followers and blocking oscillators	RCA 12AU7	20
Amplifiers and flip-flops	RCA 6J6	56
Continuous light source	RCA 6V6	1
Trigger circuit	RCA 2D21	1
	RCA 6AG5	2
Servo amplifier	2E29	2
	6SN7	4
	6AC7	1



FRONT VIEW



REAR VIEW

Fig. 18 - Assembled Digital Converter

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