IAS
ECP
Interim ...

FOURTH INTERIM PROGRESS REPORT ON THE PHYSICAL REALIZATION OF AN ELECTRONIC COMPUTING INSTRUMENT

By

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The Institute for Advanced Study
1 July 1948

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PREFACE

The ensuing report has been prepared in accordance with the terms of Contract W-36-034-ORD-7481 between the Research and Development Service, Ordnance Department, Department of the Army, and the Institute for Advanced Study. The express purpose of this report is to furnish contemporary advice to the Service regarding steps taken and contemplated toward the realization of an electronic computing instrument embodying the principles outlined in the following Institute for Advanced Study reports:

28 June 1946, by Burks, Goldstine, and von Neumann entitled: "Preliminary Discussion of the Logical Design of an Electronic Computing Instrument." (Hereinafter referred to as Logical Design Report No. 1.)

1 January 1947, by Bigelow, Pomerene, Slutz, and Ware entitled: "Interim Progress Report on the Physical Realization of an Electronic Computing Instrument." (Hereinafter referred to as Progress Report No. 1.)

1 April 1947, by Goldstine and von Neumann entitled: "Planning and Coding of Problems for an Electronic Computing Instrument." (Hereinafter referred to as Planning and Coding Report No. 1.)

1 July 1947, by Bigelow, Hildebrandt, Pomerene, Snyder, Slutz, and Ware entitled: "Second Interim Progress Report on the Physical Realization of an Electronic Computing Instrument." (Hereinafter referred to as Progress Report No. 2.)

1 January 1948, by Bigelow, Hildebrandt, Pomerene, Rosenberg, Slutz, and Ware entitled: "Third Interim Progress Report on the Physical Realization of an Electronic Computing Instrument." (Hereinafter referred to as Progress Report No. 3.)

15 April 1948, by Goldstine and von Neumann entitled: "Planning and Coding of Problems for an Electronic Computing Instrument." Part II, Volume II. (Hereinafter referred to as Planning and Coding Report No. 2.)

1 July 1948, by Bigelow, Panagos, Rubinoff, and Ware entitled: "First Progress Report on a Multi-Channel Magnetic Drum Inner Memory for Use in Electronic Digital Computing Instrument."

The present report on the physical realization of the computer is to be considered as a continuation of those listed above under the same title, and should be read in conjunction with them since many items referred to herein are discussed at some length in the previous reports.

This report covers the work done during the period 1 January 1948 to 1 July 1948 with the following exception: the fabrication of the Slow-Speed Drive Unit (see Section 2.10.3) took place entirely after this period. A description of this unit is included since the design of it was completed before 1 July 1948.

It should be understood that the experimental techniques, component types, schemes for synthesis of primary organs, and design philosophy all are evolutional and subject to revision as additional information emerges.

J. H. B.

T. W. H.

P. P.

J. H. P.

J. R.

R. J. S.

W. H. W.

1 July 1948

I. INTRODUCTION

The present report, covering the interval 1 January 1948 to 1 July 1948, is now long overdue. The activity of this period is particularly difficult to relate in a connected and systematic fashion since we are midway in the process of full scale construction and are continually harassed by details of compromise between theory and practicality. As the machine takes shape, the date of possible completion seems real and near to all of us, with the result that the level of individual effort and output has become unprecedentedly high. In fact, a considerable amount of will power was needed to inflict the delay necessary to report progress. As a result, the report itself is excessively detailed at some points and takes too much for granted at others, and little attention has been given to grammar and format.

Since nearly all of this machine is being constructed from basic materials by our own personnel and in our own laboratory, it was thought that some interest might attach itself to the techniques and methods of construction. These have been displayed in a series of photographs, in which each member of our construction team (both temporary and permanent) figures at least once -- with the exception of our production engineer, Richard W. Melville. After several unsuccessful attempts, the effort to photograph Melville was abandoned, as it became clear to us that the laboratory did not possess a camera having a sufficiently fast lens.

J. H. B.

II. INPUT-OUTPUT ORGANS

2.1 Summary of the Present System

Previous progress reports in this series have given considerable discussion of the over-all characteristics of the system planned for transmitting numbers and orders into and out of the machine. Thus previous reports should be consulted for any comprehensive consideration of the system; but, here we will include a brief description to serve as a background for our discussion of the equipment prepared during this latest period.

It will be remembered that our plan is to use magnetic recording on wire both as the basis of the input-output transcription and also as an auxiliary memory, an adjunct to the high-speed inner memory. This auxiliary memory function is directly achieved with the same equipment used for input and output since magnetic wire recording and reproduction are used for this latter function in order to introduce a speed change between human operations and machine operations, thus avoiding long waits by the high-speed calculating circuits while the very much slower humans transcribe new information. By definition we consider the input-output functions to include all of the data transcriptions in going from the (presumably handwritten) manuscript into one of the shifting registers of the high speed computing circuits, and in reverse going from one of the shifting registers to some form intelligible to humans, either printed or graphical.

The first data transcription in the input of information is the preparation of the manuscript information in the form of a punched paper tape. This is carried out by means of converted Teletype equipment on which a typist operates a keyboard which simultaneously punches paper

tape and prints a page proof of the information punched. The paper tape is used as a convenient means for effecting mechanical comparison of this initial transcription with a second manual transcription and so checking for errors made by the typist.

The second manual transcription results in the preparation of a "final" punched paper tape. It is carried out with much of the same type of equipment as the first transcription, with the addition of a "verifier" circuit which continuously compares the key struck by the typist with the punching produced by the first operator. If the two agree the final tape is punched accordingly, but if any difference is noticed by the verifier, the punch is blocked from operating until the typist restores coincidence between her keyboard and either the first tape or a substitution switch which she uses on each occasion that she finds the first tape to have been incorrectly punched. Thus, the second, or verifying operation produces a tape having very small probability of accidental transcription error by the operator.

The verified tape is then used to record the data on a magnetic wire. This is a relatively low-speed operation since the equipment available for handling the paper tape is only capable of reading about thirty binary digits per second. These digits can be recorded satisfactorily on magnetic wire at a spacing of fifty to a hundred digits per inch, so that during this slow-speed recording the wire moves at only about half an inch per second.

All of the steps so far described are carried out quite independently of the operation of the main part of the machine; normally the computing circuits will be working on one problem while simultaneously operators at the keyboards are preparing the information for another. From this point on the magnetic wire is associated with the high-speed circuits of the

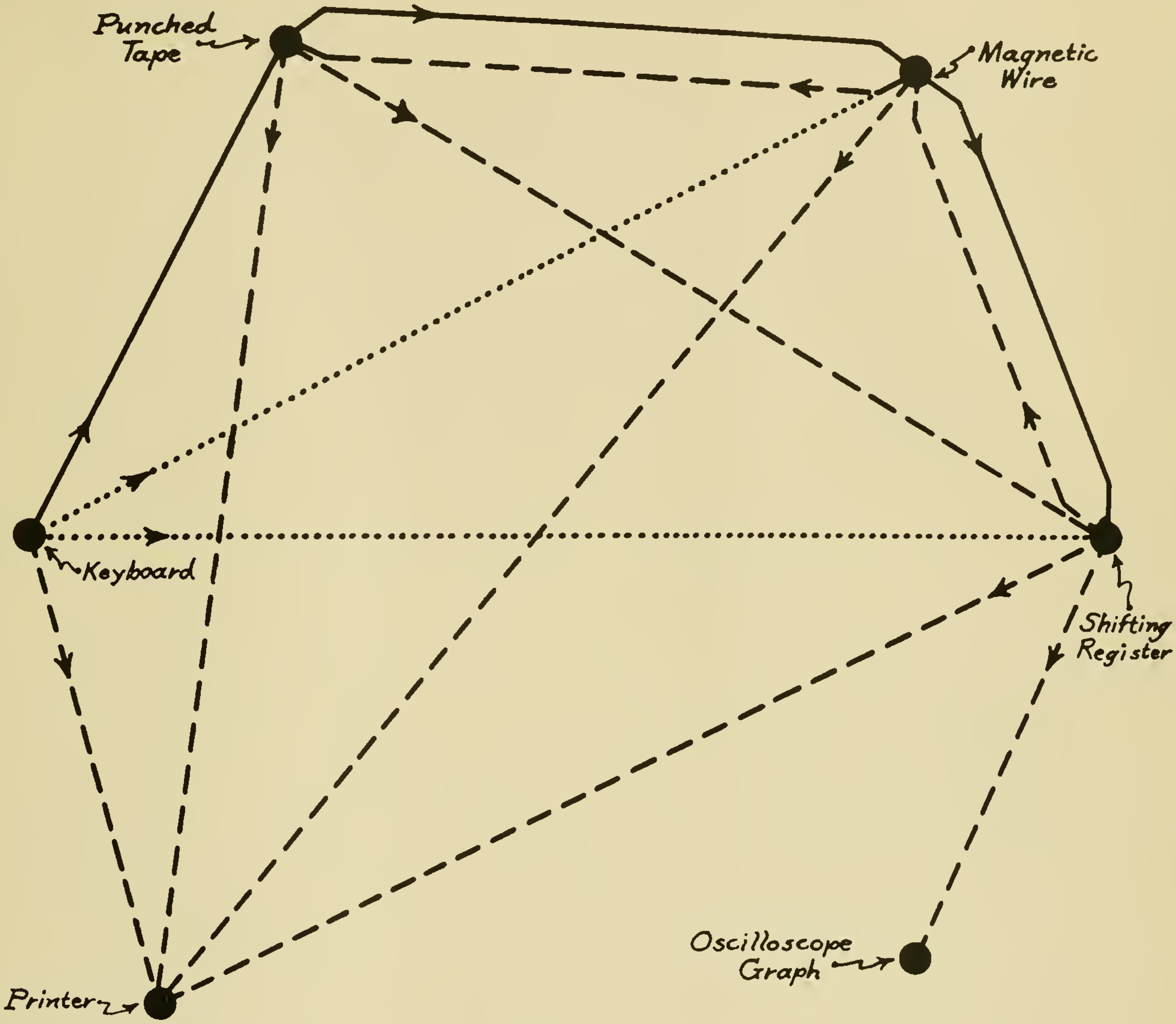
machine. The next procedure in starting computation on a new problem is to transfer the input data which so far is recorded on the wire into the internal memory of the machine. This is carried out by transmitting from the magnetic wire into one of the shifting registers of the arithmetic portion of the machine whence it is relayed into the inner memory organ. The speed of this transfer is limited only by the speed at which information can be read from the magnetic wire. Tests have shown that this can be done safely at speeds on the order of 50,000 binary pulses per second, in which case the wire speed is accordingly about 50 feet per second.

Once the data have reached the memory of the machine the arithmetic circuits carry out the operations which will result in the solution of the problem, possibly using the magnetic wire as an auxiliary memory, as already mentioned. The results of numerical computations which have been performed on the data re-enter the domain of the input-output apparatus when the problem has been completed or when some phase has reached the point when the inner memory must be replenished. This read-out sequence consists of a high-speed (50 kilocycle) operation in which the data are transferred from the inner memory via a shifting register to the magnetic wire where they may remain without impeding further computation of the machine. Once stored on a magnetic wire the data may be printed in legible form by an automatic typewriter when and if desired. The speed of the automatic typewriter is somewhat limited, and considerable electronic equipment is needed to operate it from the magnetic wire, so if a large amount of data is to be transcribed it is more efficient in the use of the electronic equipment to prepare another punched paper tape from the magnetic wire. This saving is due to the fact that the punch used is capable of operating

about three times as fast as the automatic typewriters, and so the paper tape is capable of keeping three typewriters busy. Thus the process of using punch tape is equivalent to three systems which operate directly from wire to typewriter.

The foregoing paragraphs describe in extreme brevity the system at present planned for the routine relaying data into and out from the machine. Thus a route of transcription involving more operations is justified by more efficient use of the speed-restricting elements in the chain. However, there are occasions when the more direct route will not be overloaded and where the nuisance of additional transcriptions would not be justified. For example, in certain problems it would be of considerable advantage to so program the solution that an intermediate result is presented to the mathematician who can then insert a few appropriate numbers or instructions. Similarly, in test runs it might be desirable to have prompt access to the results without having to carry through the entire chain of instructions. Accordingly there would be utility in equipment which would transcribe from some sort of a keyboard or set of switches directly into the shifting register, and conversely from a register directly to a printer.

With such cross-connections possible, it becomes a bit confusing to keep in mind all of the available transcriptions. Diagram C-5-2025 is a graphical representation convenient for indicating them. In this figure the progress of the last six months has been summarized by the different lines used. The solid lines represent transcriptions for which equipment existed six months ago; the dashed lines indicate those for which equipment has been added in the last six months; and the dotted lines indicate those which may be added in the future. The various steps in the handling of data may be discussed separately.



ELECTRONIC COMPUTER PROJECT
Institute for Advanced Study
Princeton, N.J.

INPUT-OUTPUT DATA TRANSCRIPTIONS

——— Available 31 Dec. 1947

– – – Added in last six months

········ Planned for future

C-5-2025

DATE:	DRAWN BY:	CHECKED BY:
July 1, 1948	Peter Panagos	R. J. S.

2.2 Bureau of Standards Equipment: Inscriber and Outscriber.

As part of a program on the development of computing machine components, the Bureau of Standards very kindly undertook to design and construct for the IAS computer a complete set of equipment capable of transcribing from manuscript to magnetic wire and from the magnetic wire back into printed copy. These items have been built at the Bureau by the group working under Dr. C. H. Page, with Dr. S. N. Alexander working as liaison on the project. The equipment was turned over to us in January and constitutes a very material contribution toward the realization of our machine. The two main parts have been named the "Inscriber" and the "Outscriber".

The Inscriber consists of converted Teletype equipment and of a "Verifier" which works with it. In the Teletype equipment, the type faces were altered to print from our code rather than from the regular Teletype code, the type carriage code bars were cut to permit printing of additional code combinations, and a solenoid was inserted to permit electrical rather than the original mechanical release of the keyboard transmitter clutch. Also an automatic carriage-return and line-feed were installed, and the function levers changed in their operation to suit our code. With appropriate changes in the keyboard designations, this set then is suitable for the preparation of the first punched paper tape.

In order to prepare the final paper tape, the same converted Teletype equipment is used together with the Verifier unit. This latter consists of a tape reader in which the first tape is placed, together with relay circuits comparing the first tape symbol by symbol with each keying operation of the second typist. For this purpose a set of switches were also added to the Teletype to sense the set-up of the code bars. The relay circuits proved to be relatively complicated since every effort was made to make the

circuit "fail-safe". This expression means that any failure of the equipment would cause it to indicate an excess rather than a shortage of errors; also it implies that in case the operator finds an error on the first perforated tape she must set up and check herself against a verifier switch before proceeding.

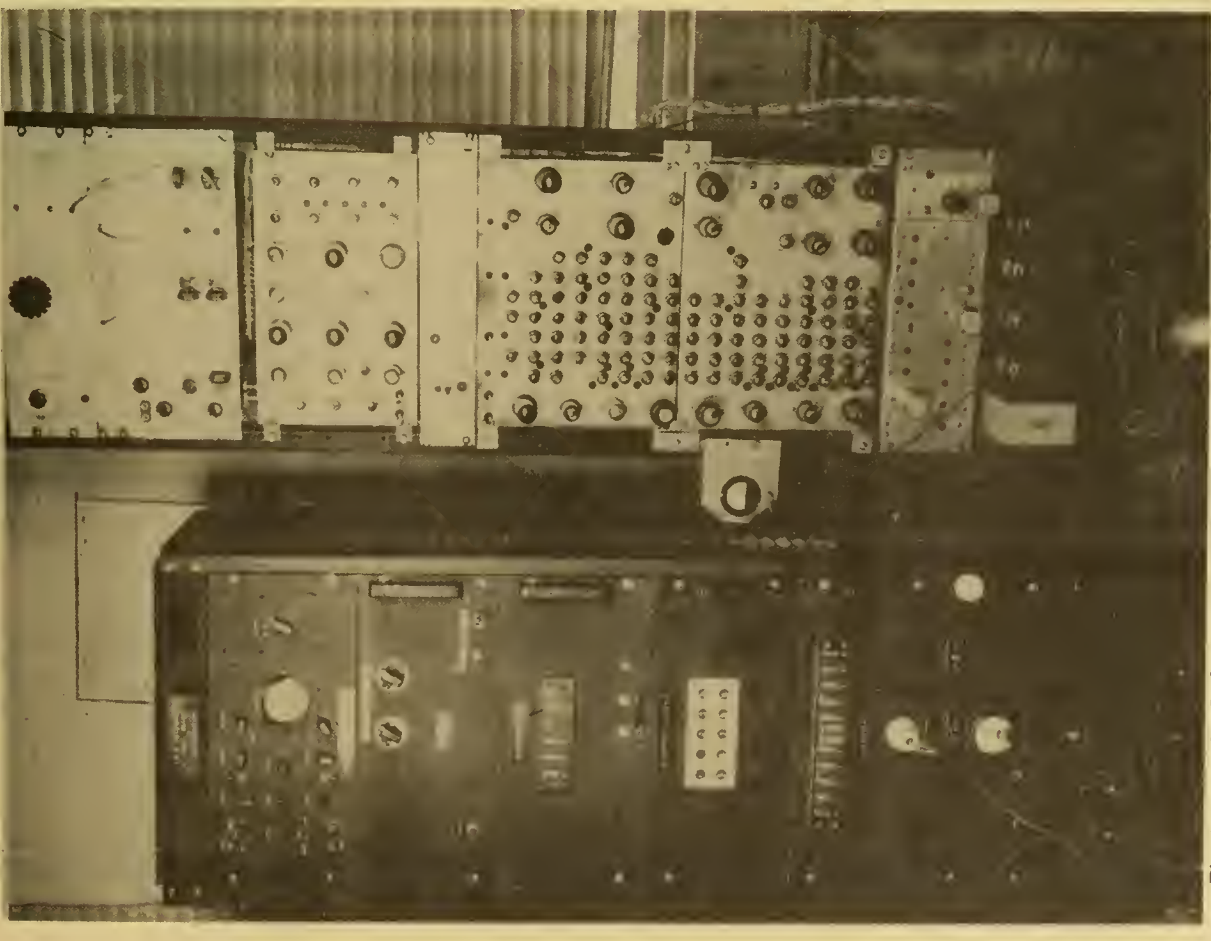
In the operation of the equipment the typist transcribes directly from the original manuscript. As long as the keys she strikes agree with the data punched on the first tape the equipment continues to operate, punching the second tape and typing a page copy. As soon, however, as the typist strikes a key which fails to agree with the data on the first tape the operation of the machine is blocked and this "error" is neither punched nor printed. Instead the whole keyboard is locked out and none of the keys are receptive. The operator must press a "release" button before she can proceed. At this point she returns to the manuscript and therefore to the first tape for a verification and decides whether the lockout was caused by her hitting the wrong key or whether it was caused by an error of the typist who prepared the first tape. If the former, she need merely strike the correct key and continue (after releasing the lockout); if the latter she must press a "Replace" button, set a selector switch to the correct digit, and then strike the same key at the keyboard as is indicated by the selector switch. The purpose of the selector switch is to provide always a double operation before recording a digit on the final tape. Normally this double operation consists of the keyboard operation of the first typist compared to the keyboard operation of the second, but in correcting the errors of the first typist the double operation consists in setting the selector switch and striking the corresponding key. It is true that both of these latter operations are performed by the same typist at approximately the same time, but it is thought that their different natures

provide sufficient protection against performing both of them correctly.

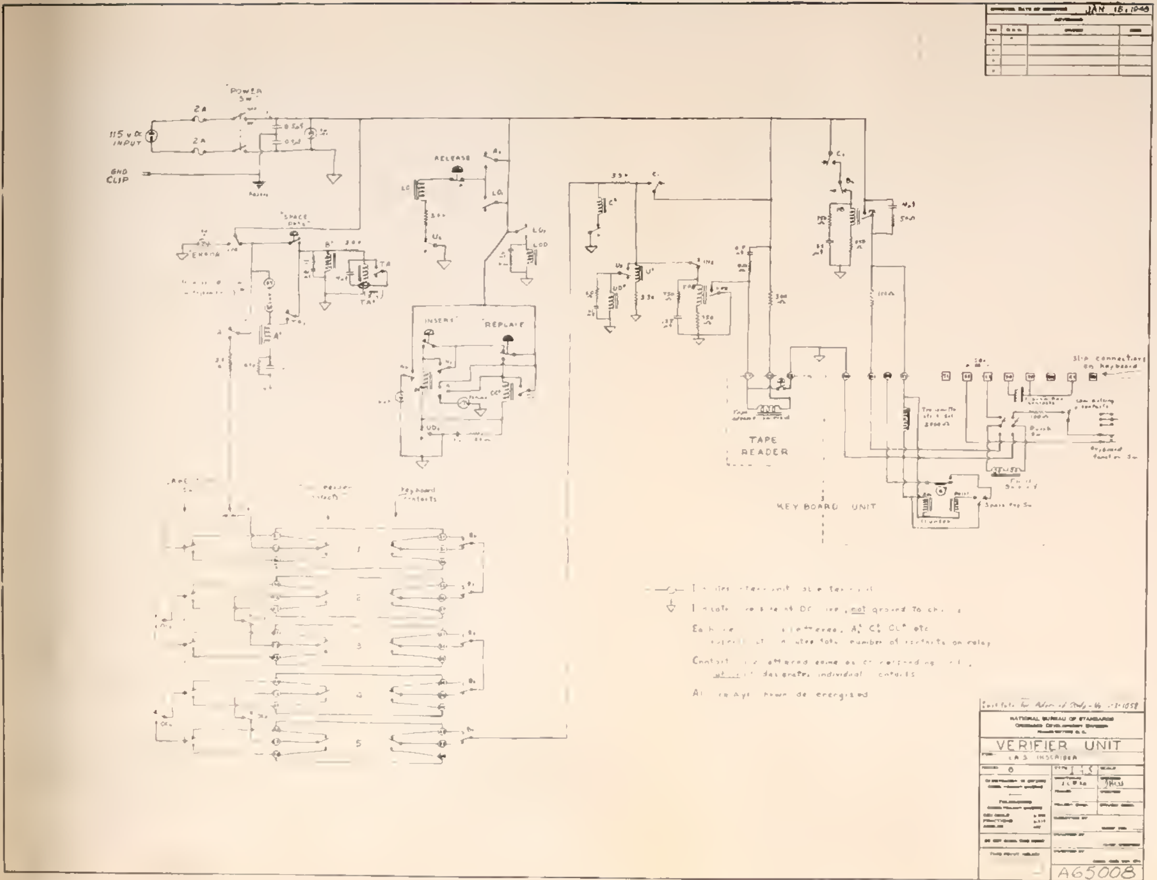
In essence, then, the "proof reading" of the first and second typings is carried out automatically and simultaneously with the second typing, and the second paper tape should have a very low probability of error of transcription. A picture of this Inscriber is given in Photograph 1-a, and a diagram of the first model of the Verifier in Drawing C-3-1058. The Bureau intends to replace the first model of the Verifier with an improved one in the near future. In the meantime the first model has operated very reliably.

The other main part of the equipment provided by the Bureau is the Outscriber. This consists of the electronic equipment and punch necessary to transcribe data from the magnetic wire into the form of punched paper tape which can then be used to operate the converted Teletype printer and record the output of the machine. Included is a high-gain amplifier having all of its stages push-pull and with high degeneration toward any signals which are not symmetric. This is used to amplify the low output of the magnetic reproducing head, and includes provision for limiting the resulting pulses in amplitude. Then there is a pulse shaping circuit which produces pulses of uniform amplitude and duration, and a ten-stage counter which together with associated gates serves to route the pulses to corresponding position in two five-stage registers. When one of these registers has received the five pulses corresponding to one printed digit, a relay circuit activates a paper tape punch, while at the same time the next five pulses are being stored in the other register. There is included in addition to this several gating circuits which serve to synchronize the counter with the incoming message, and to indicate errors, should pulse combinations not permitted in our code be received. All of this electronic equipment is

Photograph 1-a
Inscriber Verifier Equipment



Photograph 1-b
Outscriber Rack (left) and Input Indexer Rack



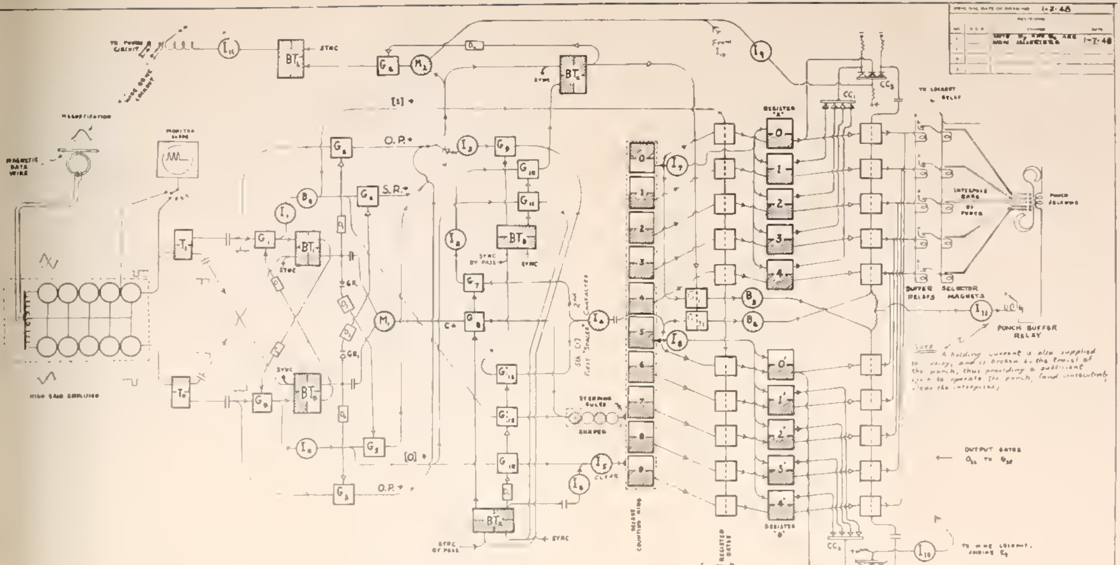
JAN 15, 1948
POWER SW
2A
2A
115 v AC INPUT
GND CLIP
RELEASE
SPACE
ERROR
INSERT
REPLACE
TAPE READER
KEY BOARD UNIT
Slip connections on keyboard
NATIONAL BUREAU OF STANDARDS
VERIFIER UNIT
A65008

assembled in a rack together with power supplies and an oscilloscope for observing operation and adjusting gain. A picture is shown in Photograph 1-b, and the Bureau's diagrams are reproduced in Drawings C-3-1057A through C-3-1057F.

Since this equipment was installed six months ago, it has been used regularly in tests and as a part of developmental work on other apparatus, and it has worked with very satisfactory reliability. Of course, as one expects with any newly designed equipment, a few small changes were found necessary. For example, it was found that at its maximum rate of operation the clearing of the two five-stage registers was marginal when a message first started; this was corrected by inserting rectifiers to effect "d-c restoration" on the clearing pulse. Also it was found that increased ventilation is needed in hot weather to avoid false operation of the error-indicating circuits. Such things are sometimes rather difficult to find but easy to correct. The only feature which has given continuing trouble is that of the mechanical adjustment of the paper tape punch, shown in Photograph 2-b. This adjustment has proven rather difficult to make and maintain. There is a good possibility though that this trouble is caused by parts of the punch being worn beyond effective adjustment, and steps are under way at the present to obtain new punch parts.

2.3 Revision of Input-Output Equipment

This equipment supplied by the Bureau of Standards has been discussed as a unit for clarity; for the discussion of the rest of the program it would perhaps be clearest to consider each of the transfers of information individually. In following this discussion then, Drawing C-5-2025 will be found useful.



WIRE-TO-TAPE TRANSFER, COMPLETE FUNCTIONAL SCHEMATIC

LEGEND

- Delay, about ½ millisec, simple RC circuit
- Buffer, cathode follower
- Inverter, simple amplifier or polarity changer (responds only to + signals)
- " " " only to − signals
- Gate requires a signal & + gate voltage
- Coincidence circuit, requiring simultaneous (−) signals
- " " , requiring (+) signals
- Simple diode rectifier, conducts (+) current → (all a germanium crystal type)
- Capacitor used as differentiator, producing sharpened pulses of about 40 μ-sec
- Mixer, separates (−) signals
- Toggle (flip-flop), state 1, outputs will flip to change sign if either a (−) pulse is applied to "a" or (+) to "b"
- Toggle, state 2, will flop to state 1 with either a (−) pulse on "b" or (+) on "a"
- Buffered Toggle, responds to (−) pulses only. State 1, a (−) pulse to "a" will reverse polarities of outputs. No response for a pulse on "b"
- State 2, a (−) pulse (reset) on "b" reverses polarities of outputs

REMARKS

- Magnetization pulse (region) on wire, is not present in circuit as a voltage. Solid line represents a "1" binary signal, and dotted line a "0"
- Amplifier (linear stages) signal for each binary pulse of magnetization on the wire
- Wave-form of above signal after clipping & differentiation. In each case only the second small pulse is utilised
- Conducting state indicated
- "SYNC" Gets (−) reset pulse from a manual switch. Readies equipment to synchronize
- SYNC BY-PASS: Pulsed from a manual switch which first provides a "sync" reset — an artificial synchronizing cycle

NOTE THAT EQUIPMENT IS SHOWN IN A "READY" CONDITION, FOR AUTOMATIC SYNCHRONIZATION ON A PULSE MESSAGE
THE COUNTER & BOTH REGISTERS ARE SHOWN CLEARED, A POSSIBLE THOUGH UNLIKELY CONDITION

NATIONAL BUREAU OF STANDARDS

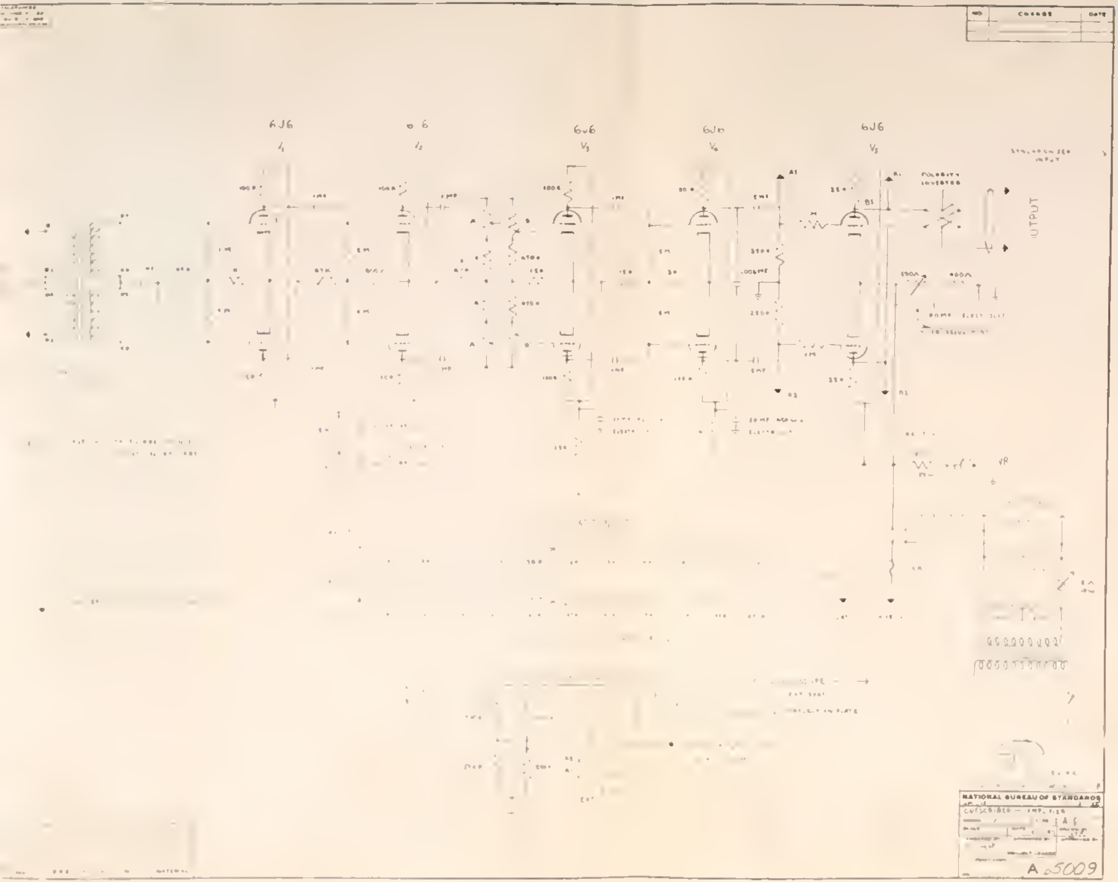
OUTSCRIBER

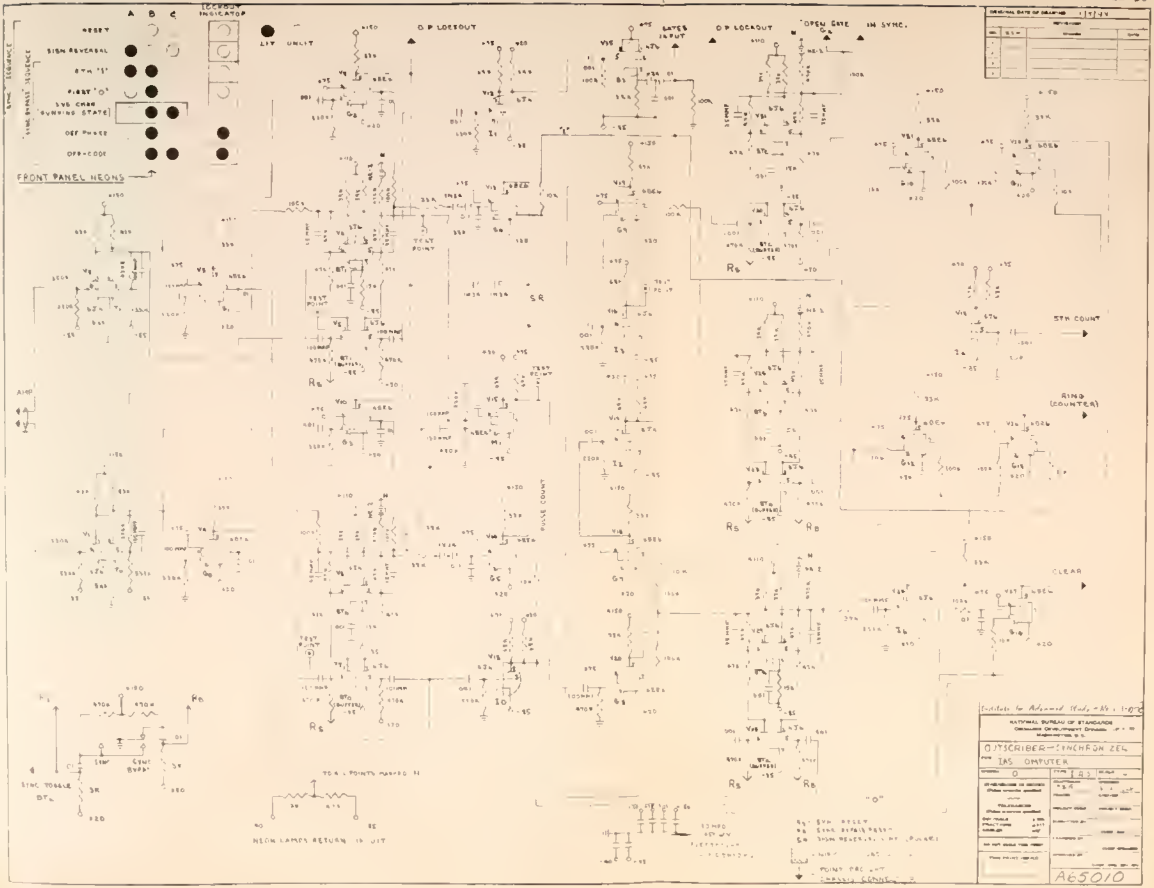
IAS COMPUTING MACHINE

O

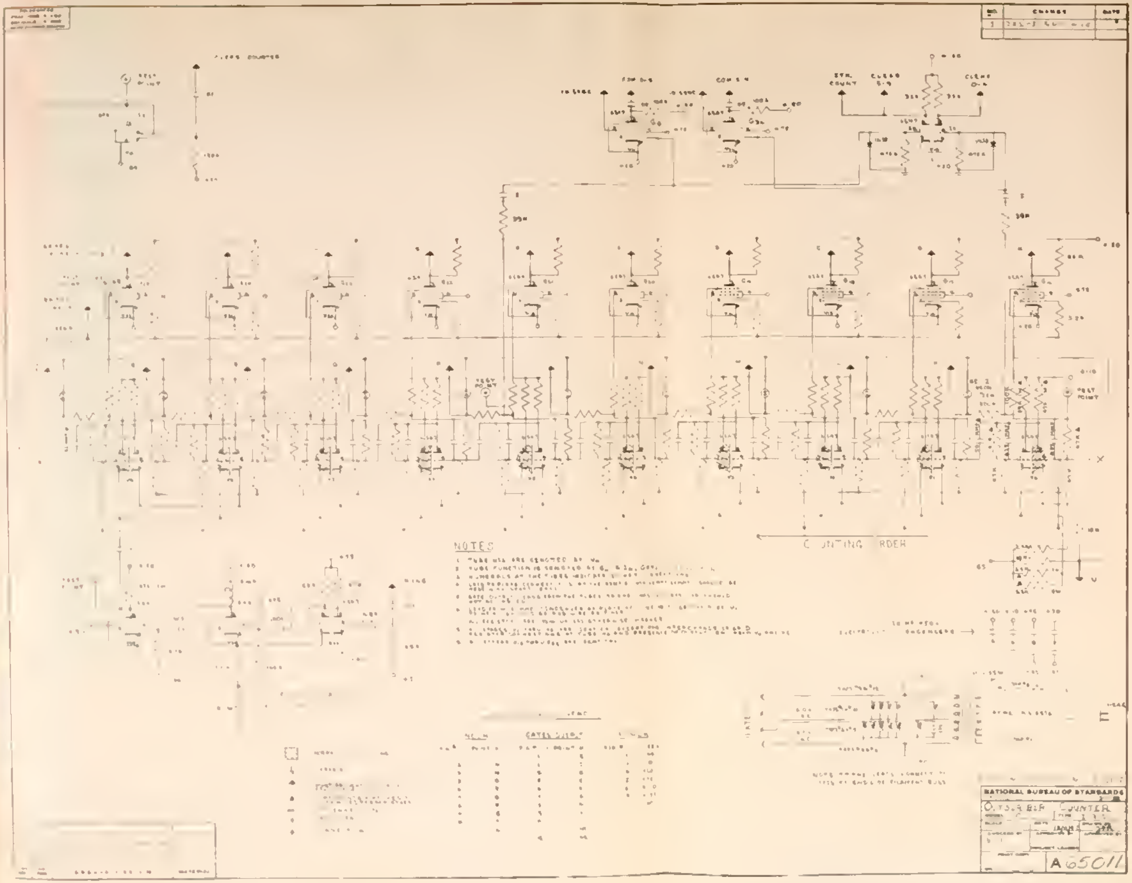
IAS

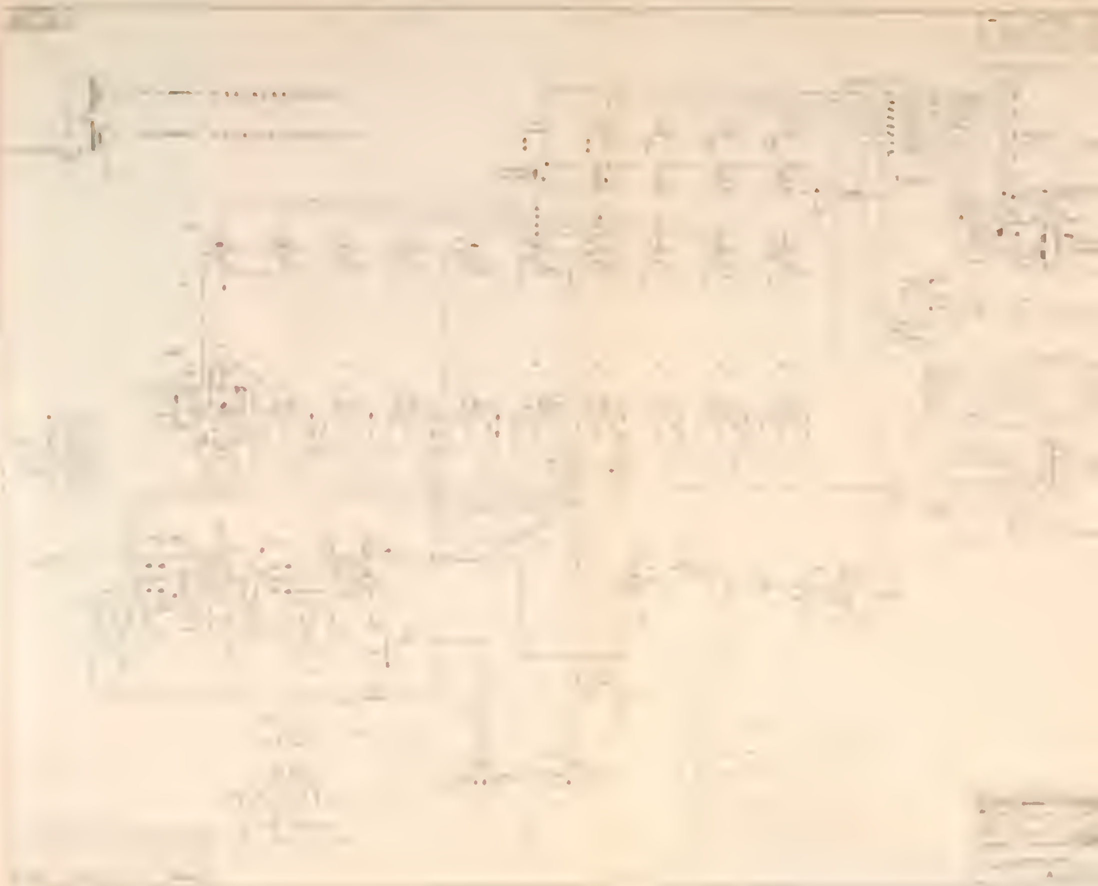
A65007

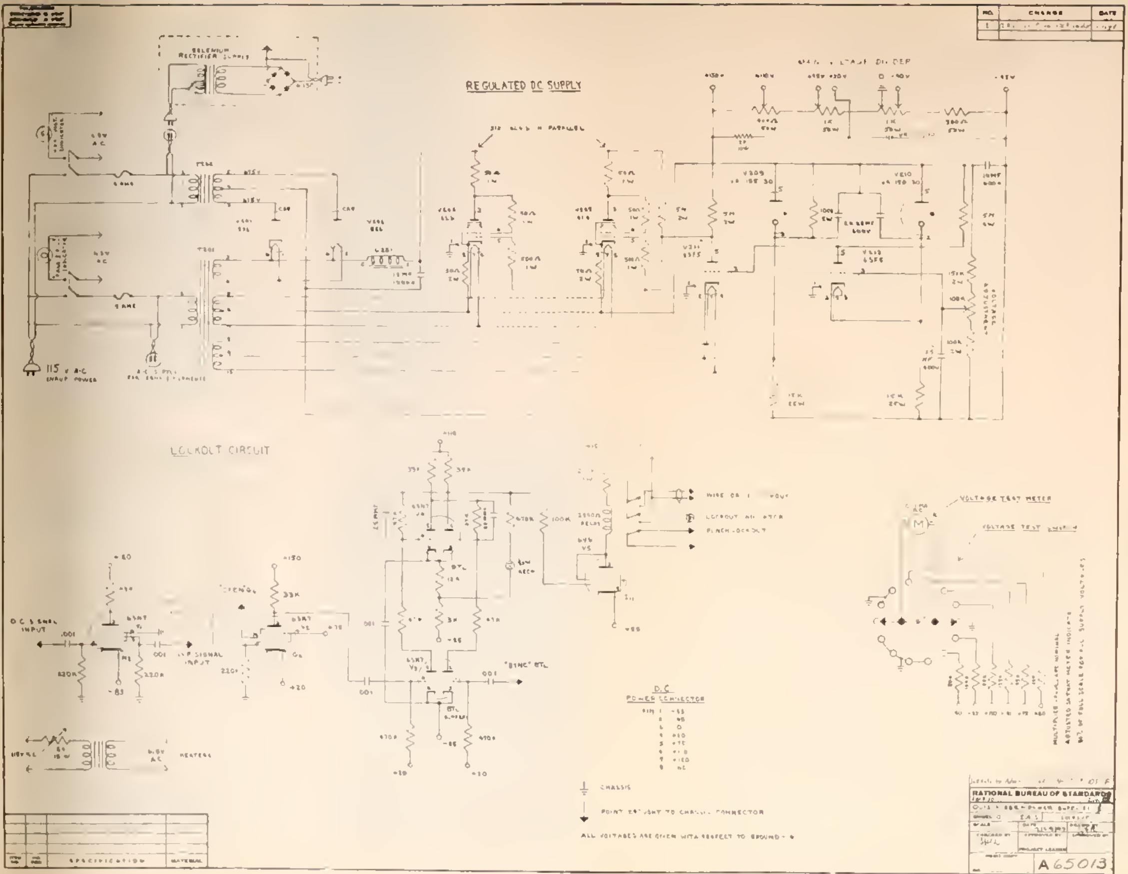

6J6
6J6
NATIONAL BUREAU OF STANDARDS
A 5009

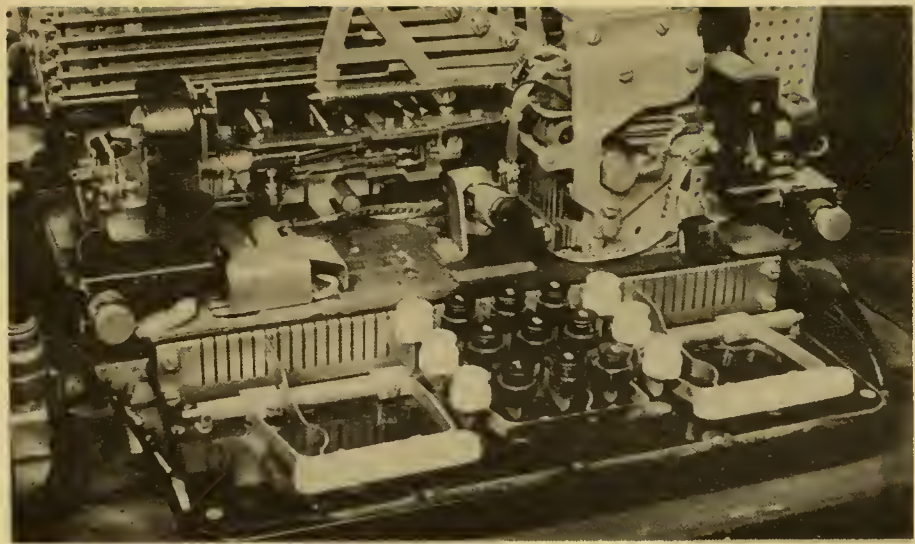


A B C
RESET
SIGN REVERSAL
FIRST '0'
FRONT PANEL NEONS
LOCKOUT INDICATOR
O P LOCKOUT
GATES INPUT
OPEN GATE
IN SYNC.
TEST POINT
SR
PULSE COUNT
5TH COUNT
RING (COUNTER)
CLEAR
SYNC TOGGLE
NEON LAMPS RETURN
"0"
NATIONAL BUREAU OF STANDARDS
OUTSCRIBER—SYNCHRONIZER
IAS COMPUTER
A65010

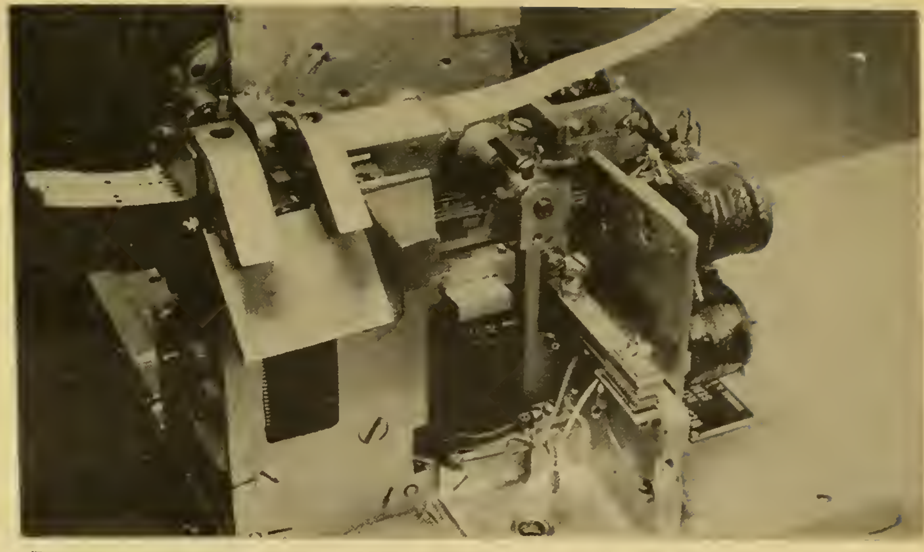

NOTES
COUNTING ORDER
NATIONAL BUREAU OF STANDARDS
COUNTER
A65011




REGULATED DC SUPPLY
SELENIUM RECTIFIER SUPPLY
115 V A-C INPUT POWER
LOCKOUT CIRCUIT
VOLTAGE TEST METER
VOLTAGE TEST SWITCH
D.C POWER CONNECTOR
CHASSIS
ALL VOLTAGES ARE GIVEN WITH RESPECT TO GROUND
NATIONAL BUREAU OF STANDARDS
A 65013



Photograph 2-a
Revised Teletype Keyboard and Automatic Carriage Return



Photograph 2-b
Paper Tape Punch

Photograph 2-c
Oscillographic Production of Letters

Photograph 2-d
$y = x$

Photograph 2-e
$y = 2x$

Photograph 2-f
$y = -x^2 + 8x - 6$

2.3.1 First Punched Tape

This is handled by the equipment which the Bureau has supplied. It was thought, however, that the added convenience of operating would warrant converting the keyboard to a new arrangement. This is a feature which was of appropriate mechanical facilities. As received by us the equipment had a keyboard on which the location of the various numbers and letters was determined by the location of the key on the original Teletype keyboard producing the required sequence of pulses. Grouping the keys together in a logical scheme required the cutting of new keyboard code bars for the machine, which we undertook. The present arrangement is shown in Photograph 2-a.

The regular Teletype automatic carriage return attachment for the printer is designed to operate always at the same length of printed line. This was accordingly adjusted so that the return occurred always on the space following the fourth printed word, and was quite satisfactory as long as the data being supplied to the printer contained no errors. If, however, a single error occurred -- which could be produced by the striking of the wrong number of keys in the initial typing, by the incorrect initial setting of the printer, or directly through a fault of the system -- then the printer would get out of register and continue so until laboriously reset by hand. Accordingly it seemed worthwhile to make this registration more automatic; particularly so in the initial period of operation of the equipment when, indeed, much of the operation is aimed at producing errors (in the sense that the aim is to determine under what conditions the equipment will fail). This was accomplished by making the operation of the automatic carriage return dependent on the reception of the code for

a space. Thus instead of the carriage's returning invariably on the 44th character of a line, it now returns when it receives the first space signal after the 33rd character of a line. With this the return occurs always at the completion of a word and registration is automatic. It was found possible to accomplish this change with a relatively minor change in the function levers of the Teletype and by the introduction of a flexible trigger lever as an actuator. This trigger lever is shown in Photograph 2-a. The new trigger lever releases the automatic carriage return function lever when the carriage passes the 33rd space, permitting the function lever to operate on the next space signal, while also permitting the carriage to move far enough to complete a normal 43 character line.

2.3.2 Final Punched Tape

This is the operation which uses the Verifier. The circuit built by the Bureau has performed very reliably; the only change that we have made was to attach counters which indicate how many times a lockout occurs and how many times the operator depresses the "Replace" or "Insert" buttons. These counters then serve to give an approximate indication of the number of errors that the typists make, and whether they are made on the first or second typings.

2.3.3. Low-speed Wire Recording

Present plans are to incorporate the mechanism of the low speed wire drive unit into the same apparatus as the high speed unit. This feature is discussed elsewhere in this report.

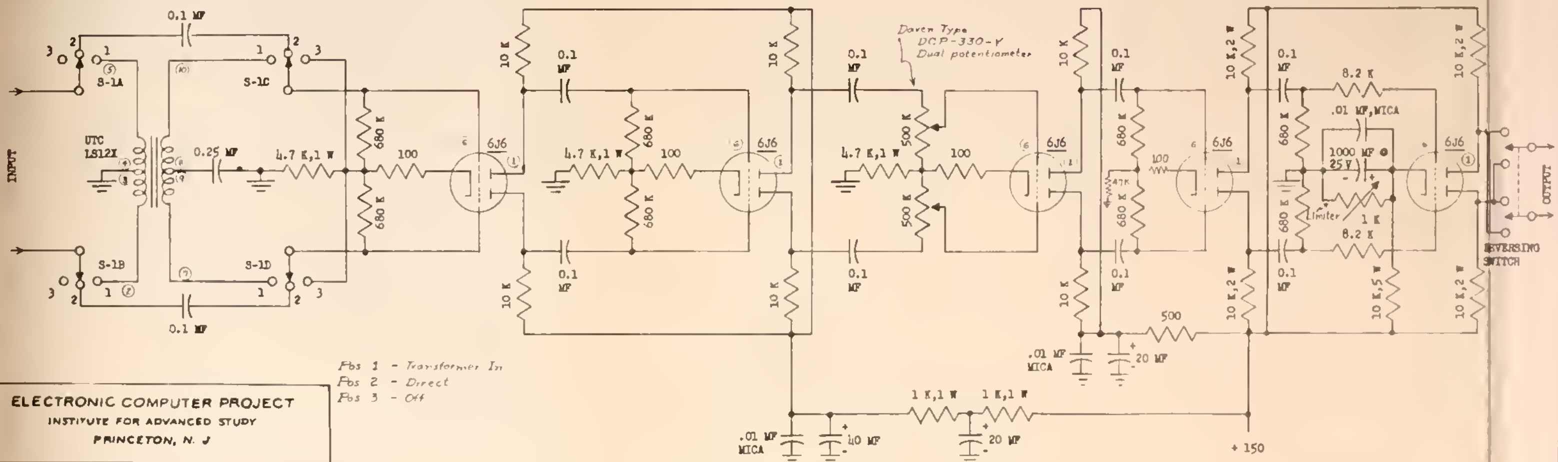
2.3.4 High-speed Wire Reading

At this time no change has been made in the basic operation of the Input Indexer (Photograph 1-b) which, as described in the previous reports, serves to maintain synchronism of the wire reading equipment with the pulses coming from the wire, check for the possibility of errors in the reproduced

message, and delete the synchronizing marker pulses before passing the remaining data pulses into a shifting register. We have, however, constructed an improved amplifier to go with this equipment and a shifting register to use with it in tests.

The previous amplifier was found to be too sensitive to transients coming in from the line, so the new one is of balanced construction throughout. This makes it relatively insensitive to line transients. A diagram is shown in Drawing C-3-1053. In this construction the limiter is included in the last stage of the amplifier rather than being separate. The limiter used separates the positive from the negative pulses, so it was necessary to build a new pulse shaper to go with it, as the former pulse shaper required that both the positive and the negative pulses be supplied on the same input. The diagram of the pulse shaper is shown in Drawing C-3-1054.

Together with this was built an experimental shifting register, Shifting Register No. 4, whose diagram is shown in Drawing C-3-1055. Each stage of this register consists of a cathode-coupled toggle and two gates to transmit the information to the next stage. The gates are 6AS6 pentodes which require that both the control grid and the suppressor be simultaneously positive before current reaches the plate. One of the gates transmits for one state of the toggle by pulling down on the plate of the next one, while the other gate operates for transmitting the other state by applying a negative pulse to the "free" grid of the next toggle. The "memory" during the shifting process is supplied by the time constants of the grid circuits of the gating tubes. For use with the magnetic wire, the maximum rate of shifting required is of the order of 50,000 shifts per second, or 20 microseconds per shift. Accordingly in this model the grids of the gate tubes are supplied through 100 K resistors and are deliberately loaded down with 50 micro-microfarads



ELECTRONIC COMPUTER PROJECT
INSTITUTE FOR ADVANCED STUDY
PRINCETON, N. J

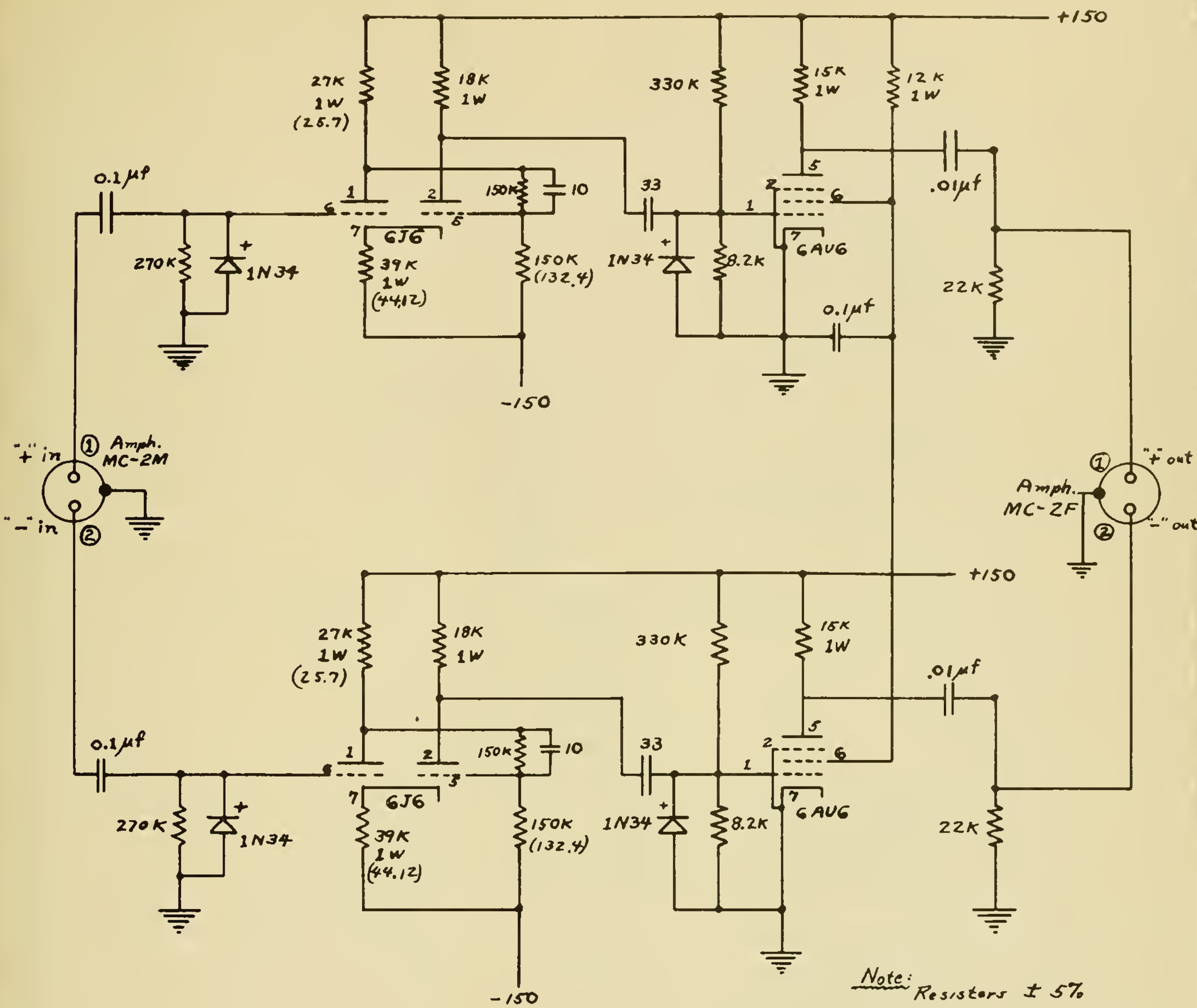
BALANCED AMPLIFIER FOR MAGNETIC WIRE
(INPUT CIRCUITS)
C-3-1053

Date:	Drawn By:	Checked By:	Initial:
April 22, 1949	H H and P Panagos		

NOTES

RESISTORS: ½-WATT UNLESS OTHERWISE SPECIFIED.

RESISTOR VALUES IN OHMS UNLESS OTHERWISE SPECIFIED

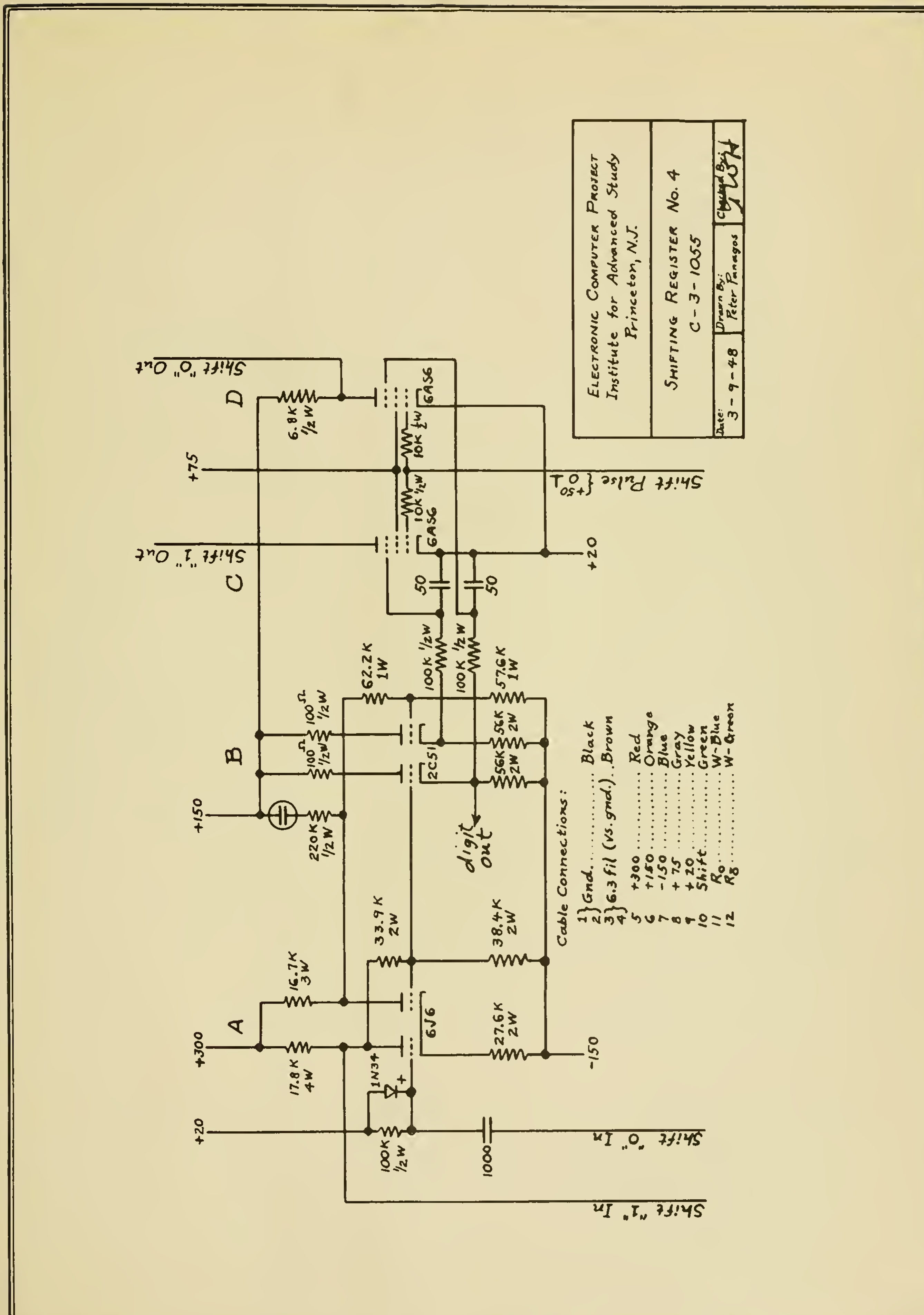


Note: Resistors ± 5%

All resistors ½ w unless otherwise indicated

All condensers in μμf unless otherwise indicated

Electronic Computer Project Institute for Advanced Study		
Pulse Shaper #2 C-3-1054		
Date: 6 - 8 - 48	Drawn By: Peter Panagos	Checked By: JWH

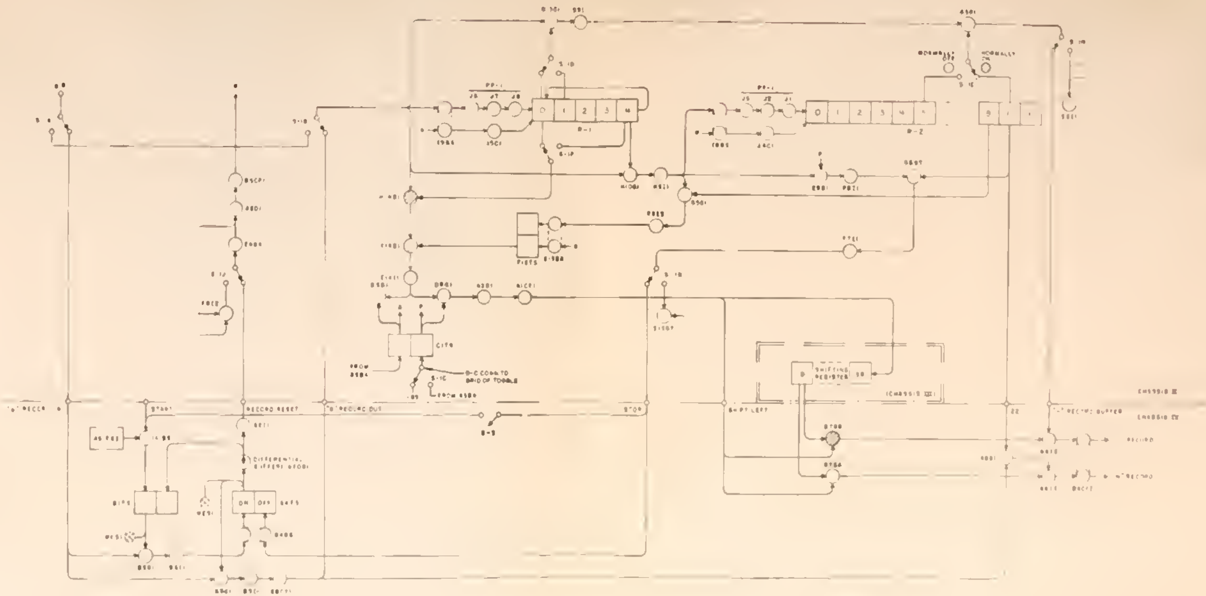

ELECTRONIC COMPUTER PROJECT
Institute for Advanced Study
Princeton, N.J.
SHIFTING REGISTER No. 4
C-3-1055
Date: 3-9-48
Drawn By: Peter Panagos
Checked By:
Cable Connections:
1 } Gnd. Black
2
3 } 6.3 fil (vs. gnd.) Brown
4
5 +300 Red
6 +150 Orange
7 -150 Blue
8 +75 Gray
9 +20 Yellow
10 Shift Green
11 R_0 W-Blue
12 R_8 W-Green
A
B
C
D
+300
+20
+150
+75
+20
-150
Shift "0" In
Shift "1" In
Shift "1" Out
Shift "0" Out
Shift Pulse {+50 0}
digit out
6J6
2C51
6AS6
6AS6
1N34
17.8K 4W
16.7K 3W
33.9K 2W
38.4K 2W
27.6K 2W
100K 1/2W
1000
220K 1/2W
100Ω 1/2W
100Ω 1/2W
62.2K 1W
56K 2W
56K 2W
57.6K 1W
100K 1/2W
100K 1/2W
50
50
10K 1/2W
10K 1/2W
6.8K 1/2W

to give a time constant of five microseconds. Under these conditions tests showed that the register would shift satisfactorily at about a seven microsecond interval. Removing the 50 micro-microfarad condenser and using the inherent grid circuit capacitance as the delay element resulted in a shiftint interval of about two microseconds.

2.3.5 High-speed Wire Recording

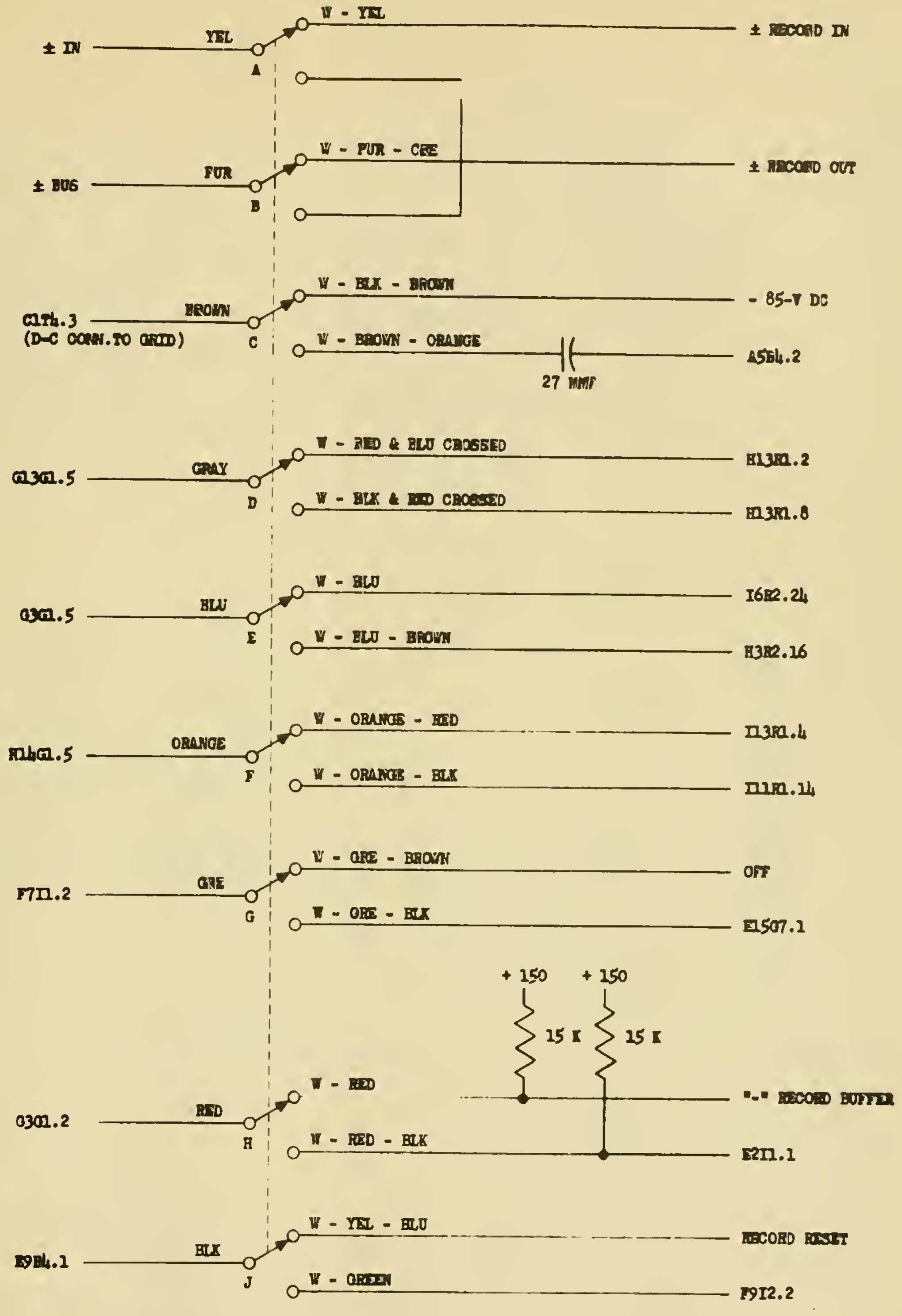
In the process of recording data from the high-speed arithmetic elements of the machine onto the magnetic wire, the need arises for counting off the 40 pulses comprising one word, and interspersing the fifteen marker pulses, thus making up the full recorded word or 55 pulses. It was found that a relatively small number of changes in the existing Indexer would serve to accomplish this, so a multi-pole switch was inserted to make the appropriate changes. The complete logical diagram of the recording circuit is shown in Drawing C-3-1053AD, while the wiring details are shown in Drawings C-3-1002R and C-3-1052DG. For this recording operation, the Indexer is supplied with a continuous chain of pulses from an oscillator, and for the first 50 pulses, the five-stage ring serves to stop the shifting register four times in a row and record the appropriate data pulses on the wire, and then without stepping the shifting register it inserts one negative marker pulse. After the 50th pulse this chain is disabled, and five positive marker pulses are inserted on the wire. With this arrangment the shifting register need be only long enough to contain the 40 data digits, and it need have sensing gates attached to only one stage.

The way this equipment relates to the rest of the machine is as follows: When the Control receives an order to record a number of words on the magnetic wire, it goes through the appropriate operations to start the wire moving at the correct place and transfers the first of the words from the internal memory to one of the shifting registers. When this has been accomplished



NOTES

ELECTRONIC COMPUTER PROJECT



NOTES

9-CIRCUIT, 2-POSITION SWITCH.

SWITCH SHOWN IN "RECORD" POSITION.

FOR CHASSIS LAYOUT BLOCK DIAGRAM OF CHASSIS II, SEE DWG. NO. C-3-1002-D-II.

SEE ALSO DWG. NO. C-3-1052-AD.

ELECTRONIC COMPUTER PROJECT
INSTITUTE FOR ADVANCED STUDY
PRINCETON, N. J.

INPUT DISTRIBUTOR
CHASSIS II
READ - RECORD SWITCH SHOWING COLOR CODE
C - 3 - 1002 - H

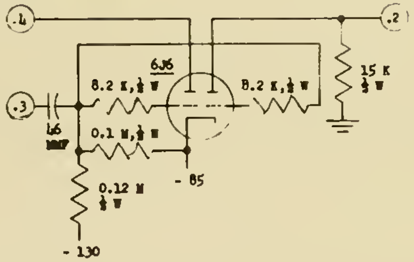
DATE	DRAWN BY	CHECKED BY	INITIAL
APR. 1, 1948	H.H.	JWH	

TUBE TYPES (CONT.)

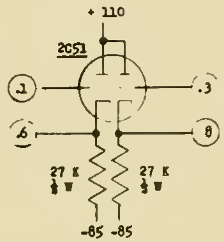
FOR OTHER TUBE TYPES SEE DWG. NO. C - 3 - 1002 - 0

INPUT DISTRIBUTOR - TABULAR SCHEMATIC: CHASSIS II

DIFFERENTIATING BUFFER
DB-1



CF-2



WIRING TABLE

A1B6.1	- START (S)	
A1B6.2	- A1B6.4	- B1T3.1
A1B6.3	- AB1PB2	
A2I1.1	- A3DB1.2	
A2I1.2	- RESET (R)	
A3DB1.3	- A4T3.2	- A5O1.5
A3DB1.4	- B1T3.3	
A4T3.1	- B4B6.2	
A4T3.3	- B4B6.4	
A5O1.1	- B2O1.1	- "±" INPUT (± IN)
A5O1.2	- B5D1.1	
A6O1.1	- B6CF1.6	- "±" OUTPUT (± OUT)
A6O1.2	- A8I2.5	
A6O1.5	- H6R2.22 OF CHASSIS II (22)	
A7O6.1	- B7O6.1	- SHIFT LEFT (S.L.)
A7O6.2	- A8I2.1	
A7O6.5	- DIGIT "1" (1)	
A8I2.2	- B9CF2.3	
B1T3.2	- B2O1.5	
B2O1.2	- B3I1.1	
B3I1.2	- B4B6.1	
B4B6.3	- STOP PULSE (STOP)	
B5D1.2	- B6CF1.1	
B7O6.2	- B8I2.1	
B7O6.5	- DIGIT "O" (O)	
B8I2.2	- B9CF2.1	
B8I2.5	- "-" RECORD BUFFER ("-" R.B)	
B9CF2.6	- (2) ON JONES S304AB ("-" RECORD)	
B9CF2.8	- (4) ON JONES S304AB ("+" RECORD)	

NOTES

HEATERS: ALL IN PARALLEL: CENTER TAP AT -40.

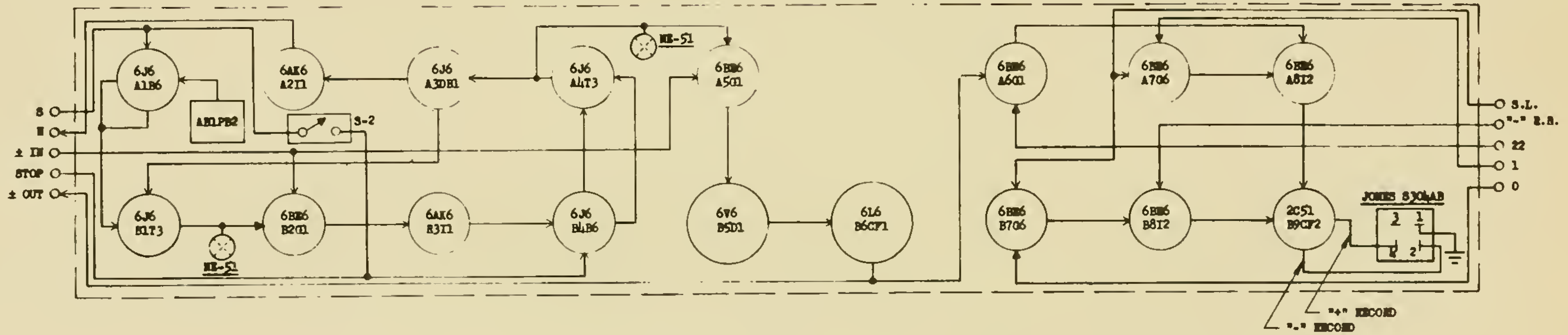
CHASSIS: 3½" x 17",
19½" OVERALL LENGTH,
TO FIT STANDARD RACK.

FOR INTERPRETATION OF WIRING TABLE, SEE NOTES, INPUT DISTRIBUTOR - TABULAR SCHEMATIC: CHASSIS II, DWG. NO. C - 3 - 1002 - 0.

FOR LOGICAL BLOCK DIAGRAM OF CHASSIS IV, SEE DWG. NO. C - 3 - 1052 - AD.

FOR CHASSIS I, II, AND III DWGS, SEE DWG. SERIES C - 3 - 1002...

SWITCH S-2 WHEN CLOSED PERMITS STOP PULSE TO RE-START RECORDING OPERATION.



CHASSIS LAYOUT BLOCK DIAGRAM

ELECTRONIC COMPUTER PROJECT INSTITUTE FOR ADVANCED STUDY PRINCETON, N. J.			
INPUT - OUTPUT DISTRIBUTOR CHASSIS LAYOUT BLOCK DIAGRAM: CHASSIS IV C - 3 - 1052 - DB			
DATE APRIL 2, 1948	DRAWN BY H. H.	CHECKED BY RWH	INITIAL

it transmits a start pulse to the Indexer equipment which takes over control. The rate of recording is determined by the oscillator driving the Indexer, which is set so that the pulses will have an appropriate spacing along the wire. This Indexer then continues until it has recorded a full word of 55 pulses, at which time it sends a pulse back to the Control. The Control then transfers the next word from the inner memory to the shifting register and sends another start pulse to the Indexer. This sequence continues until all of the desired words have been recorded, when the Control switches to the next operation.

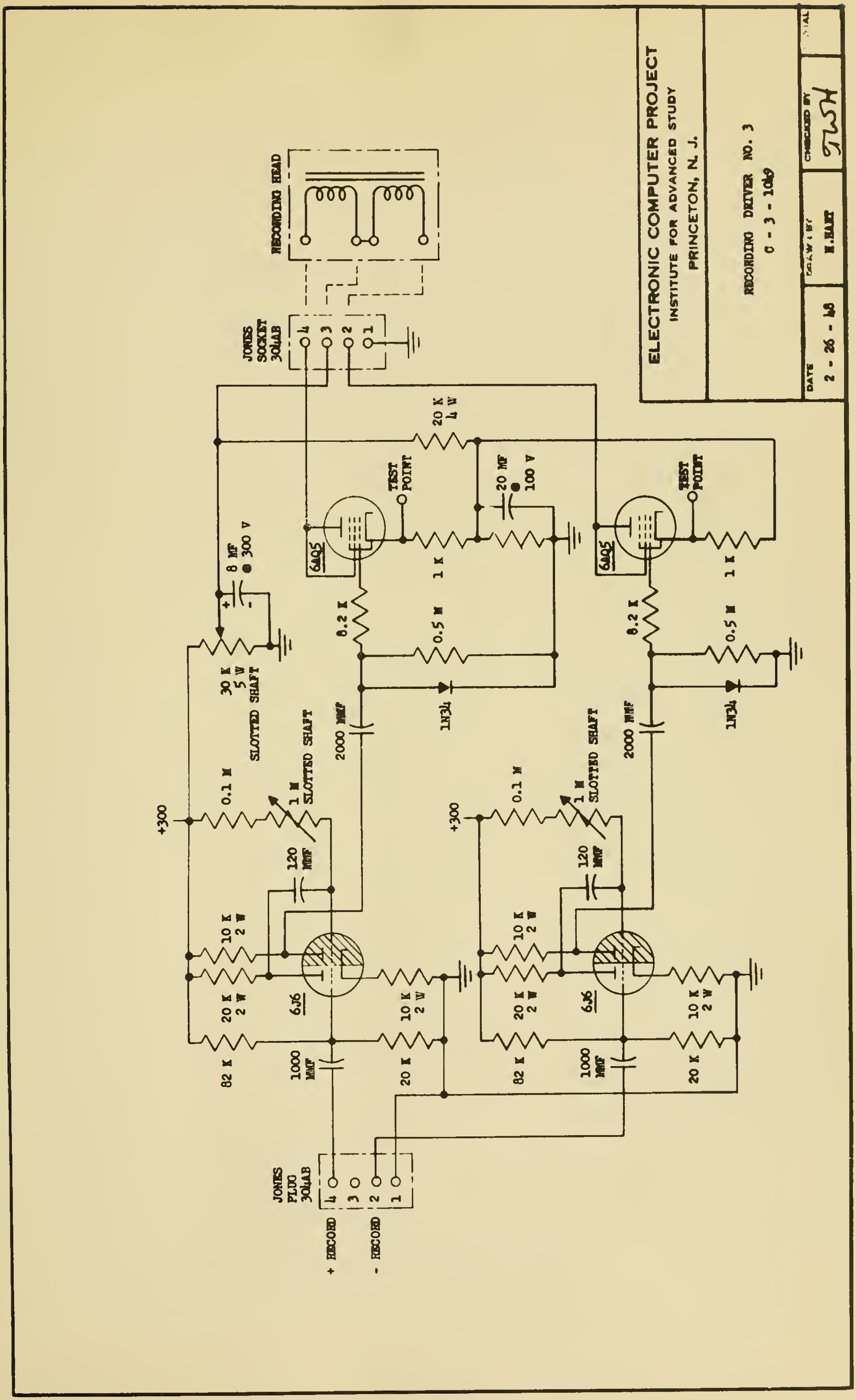
An interesting feature is that by means of which the Indexer synchronizes itself with the oscillator at the beginning of each word. If the start pulse were merely to open a gate which permitted the oscillator pulses to reach the Indexer, there would be the possibility that this gate might be in the process of opening during one of the pulses, and so transmit only a partial pulse. If this partial pulse were to reach more than one component, there is the possibility that it would be strong enough to operate one but not another. This would result in false operation. What is needed is either a pulse shaper so constructed that it will deliver from its output either a full pulse or nothing at all, or else provision that the gate which turns on the oscillator pulses should operate at a time which is synchronized with the pulses and so timed that each pulse sees the gate either fully closed or fully open. This latter method is used here. The start pulse, which may come either from the Control or from a manual pushbutton serves merely to turn on a preliminary toggle. This preliminary toggle opens a gate which permits the oscillator pulses to reach the "on" side of the on-off toggle. The first pulse strong enough to turn on the on-off toggle does so, and the output of this toggle is differentiated and used to turn off the preliminary toggle. It is the

on-off toggle which controls the gate permitting the oscillator pulses to reach the rest of the circuit, and since this toggle flips in synchronism with one of the oscillator pulses the gate it controls works in such synchronism. A small delay inserted in the gate circuit prevents it from letting through any portion of the pulse which turned on the on-off toggle, but it is fully open by the time the next oscillator pulse comes along. It will be seen that the gate controlled by the preliminary toggle has the possibility of transmitting a partial pulse, but this pulse goes to only one component -- the on-off toggle. This toggle either is or is not flipped, and so the partial pulse can cause no difficulty to the circuit.

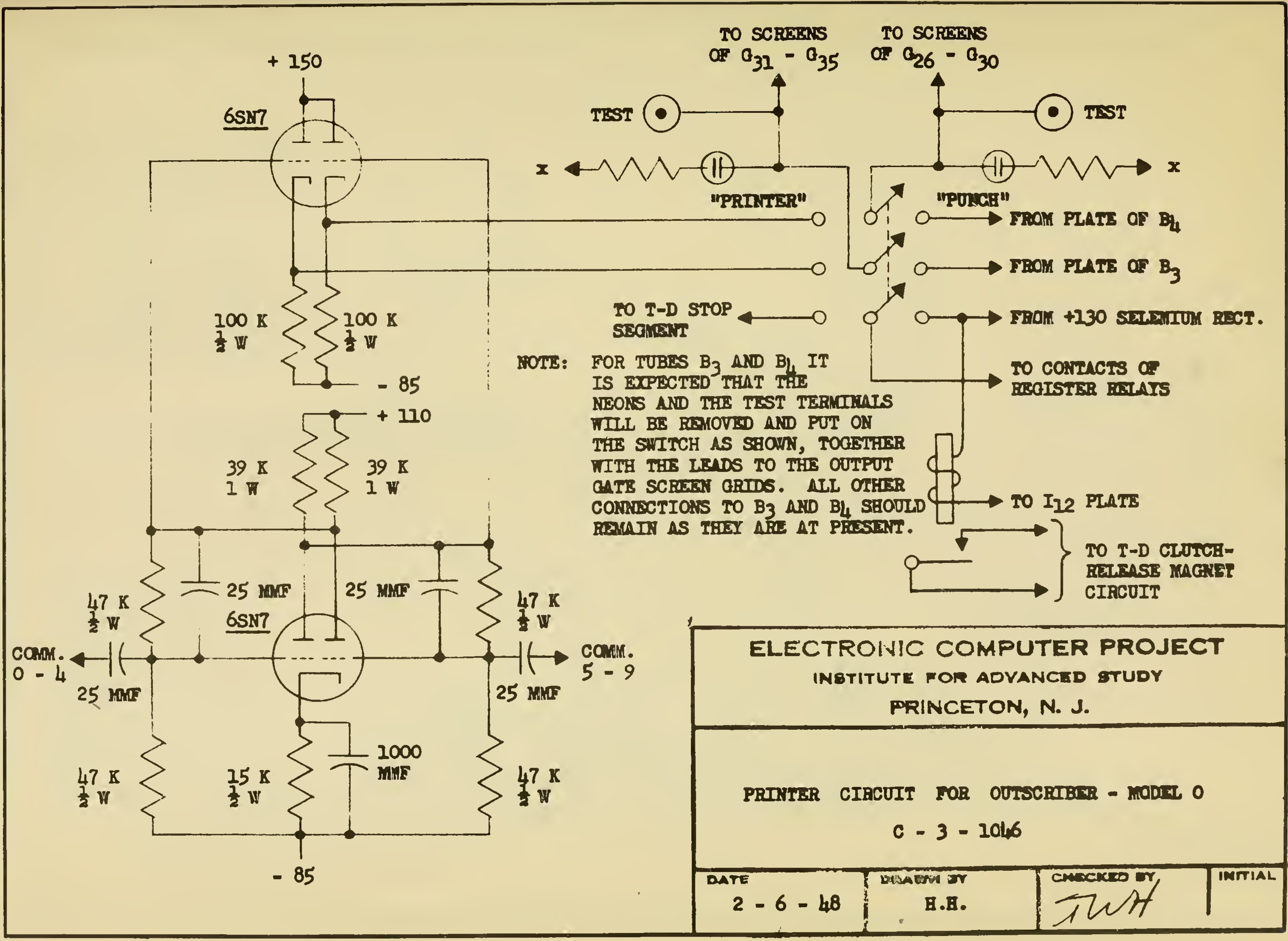
For recording with this circuit, it was necessary to construct a new driver for the recording head. The recording drivers used for low speed recording use gas-discharge tubes to form the pulse, but these tubes are not capable of operating at the high repetition rate required for this service. Accordingly Recording Driver No. 3 was constructed. Its diagram is shown in Drawing C-3-1049. Here the gated pulses from the Indexer are used to trigger one or the other of a pair of one-shot multi-vibrators. The time constants of these multivibrators determine the duration of the pulse applied to the recording head, increased power being given by pentode power amplifiers with degeneration applied. The repetition rate of this recording driver is amply fast for any high-speed recording which is anticipated.

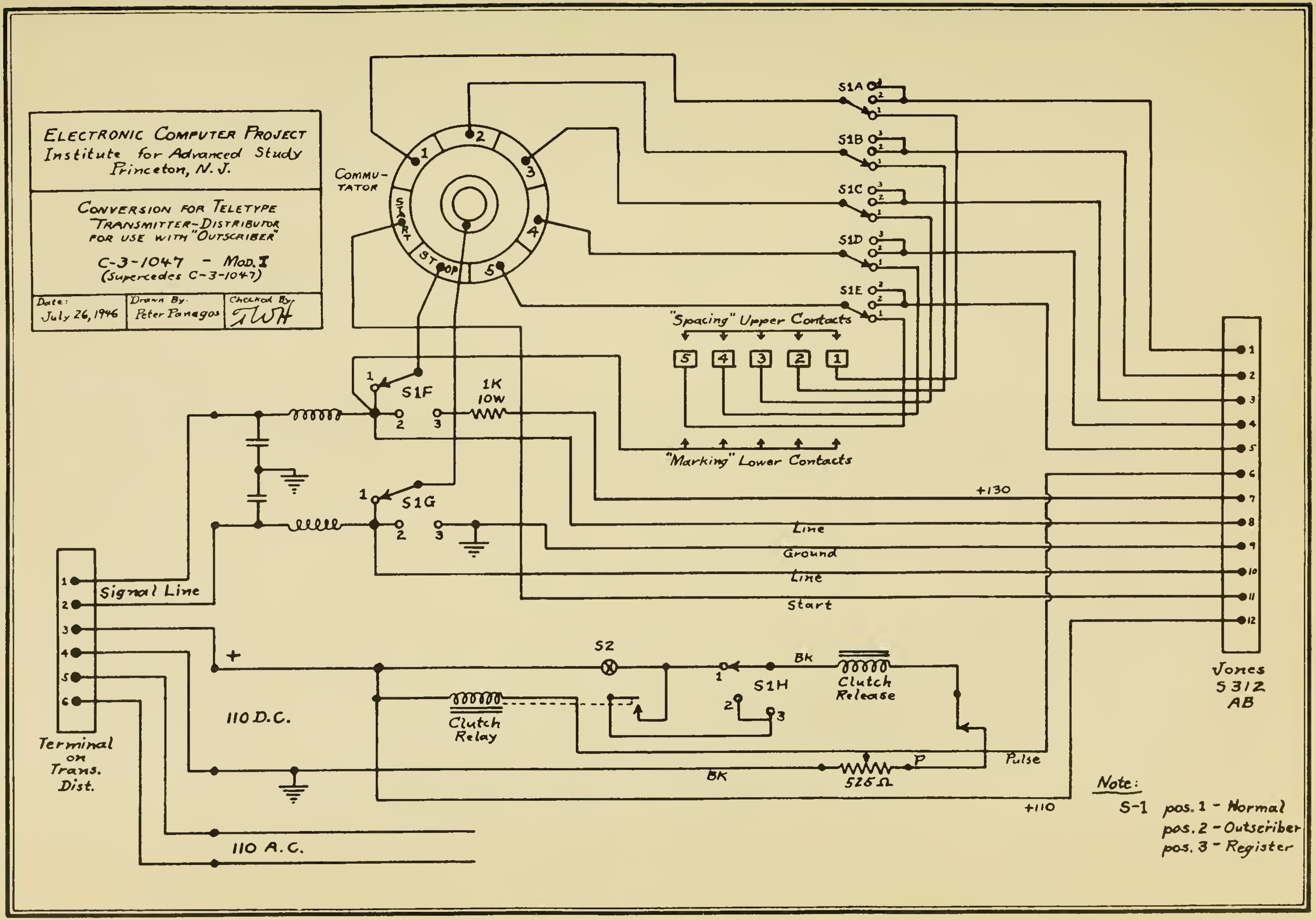
2.3.6 Low-speed Wire Reading

The Bureau of Standards equipment performs well for the low-speed reading of the magnetic wire and the resulting preparation of a punched paper tape. As has already been explained, the use of the paper tape as an intermediate step between the wire and the printer has the advantage


ELECTRONIC COMPUTER PROJECT
INSTITUTE FOR ADVANCED STUDY
PRINCETON, N. J.
RECORDING DRIVER NO. 3
C - 3 - 1049
DATE
2 - 26 - 48
N. HART
CHECKED BY
RECORDING HEAD
JONES SOCKET 304AB
JONES PLUG 304AB
+ RECORD
- RECORD
20 K 4 W
TEST POINT
20 MF
100 V
6AQ5
1 K
8.2 K
0.5 M
1N34
2000 MMF
8 MF
300 V
30 K
5 W
SLOTTED SHAFT
+300
0.1 M
1 M
SLOTTED SHAFT
120 MMF
10 K 2 W
20 K 2 W
6J6
82 K
1000 MMF
20 K

that the paper tape punch (Photograph 2-b) can operate two or three times as fast as a printer does, so the "Outscriber" equipment can be used more efficiently in this way. It was felt, however, that for smaller amounts of output data it would be advantageous to have provision for operating a printer directly from the data on the magnetic wire. Accordingly, modifications were made to the Outscriber to accomplish this function. The details are shown in Drawings C-3-1046 and C-3-1047. See also Drawing C-3-1047E. The changes consist of the insertion of a toggle to provide steady rather than pulsed outputs from the Outscriber register, and the conversion of a Teletype Transmitter-Distributor to change the simultaneous presentation of the data from the Outscriber register into the appropriate sequential presentation required by the Teletype Printer. At the same time the Transmitter-Distributor inserts the two extra pulses required by the Printer -- the "start" and the "stop" signals. In operation, the Outscriber collects the data pulses from the magnetic wire and stores the information in its register. When five stages of the register have been filled, it connects these five stages to the appropriate segments of the Transmitter-Distributor and gives out a pulse which releases the clutch of the Transmitter Distributor. The Transmitter-Distributor accordingly commutates these pulses into the Printer while at the same time the Outscriber is collecting the next five data pulses in the other half of its register. With this operation, the Transmitter-Distributor must stop after each group of five data pulses and wait until the next group is complete before its clutch is released again. Tests with this system have so far shown satisfactory operation even though the clutch of the Transmitter-Distributor was not originally intended for such frequent operation. Special clutches are, however, available, and are currently being studied for this service.


+ 150
6SN7
TO SCREENS OF G_{31} - G_{35}
TO SCREENS OF G_{26} - G_{30}
TEST
TEST
x
x
"PRINTER"
"PUNCH"
FROM PLATE OF B_4
FROM PLATE OF B_3
FROM +130 SELENIUM RECT.
TO T-D STOP SEGMENT
TO CONTACTS OF REGISTER RELAYS
100 K ½ W
100 K ½ W
- 85
+ 110
39 K 1 W
39 K 1 W
NOTE: FOR TUBES B_3 AND B_4 IT IS EXPECTED THAT THE NEONS AND THE TEST TERMINALS WILL BE REMOVED AND PUT ON THE SWITCH AS SHOWN, TOGETHER WITH THE LEADS TO THE OUTPUT GATE SCREEN GRIDS. ALL OTHER CONNECTIONS TO B_3 AND B_4 SHOULD REMAIN AS THEY ARE AT PRESENT.
TO I_{12} PLATE
TO T-D CLUTCH-RELEASE MAGNET CIRCUIT
25 MMF
25 MMF
47 K ½ W
47 K ½ W
6SN7
COMM. 0 - 4
COMM. 5 - 9
25 MMF
25 MMF
47 K ½ W
15 K ½ W
1000 MMF
47 K ½ W
- 85
ELECTRONIC COMPUTER PROJECT
INSTITUTE FOR ADVANCED STUDY
PRINCETON, N. J.
PRINTER CIRCUIT FOR OUTSCRIBER - MODEL 0
C - 3 - 1046
DATE 2 - 6 - 48
DRAWN BY H.H.
CHECKED BY
INITIAL


ELECTRONIC COMPUTER PROJECT
Institute for Advanced Study
Princeton, N.J.
CONVERSION FOR TELETYPE TRANSMITTER-DISTRIBUTOR FOR USE WITH "OUTSCRIBER"
C-3-1047 - MOD. I
(Supercedes C-3-1047)
Date: July 26, 1946
Drawn By: Peter Panagos
Checked By: TWH
COMMU-TATOR
START
STOP
S1A
S1B
S1C
S1D
S1E
S1F
S1G
S1H
S2
1K 10W
"Spacing" Upper Contacts
"Marking" Lower Contacts
+130
Line
Ground
Line
Start
Signal Line
110 D.C.
110 A.C.
Clutch Relay
Clutch Release
BK
525 Ω
P
Pulse
+110
Terminal on Trans. Dist.
Jones 5312 AB
Note:
S-1 pos. 1 - Normal
pos. 2 - Outscriber
pos. 3 - Register

In converting the second set of Teletype equipment an additional minor change was made in the function levers of the Printer, thus providing the functions of carriage-return and line-feed on one of the pulse combinations normally left unused by our code. This makes it feasible to operate the printer completely from a remote location since the carriage may be properly positioned at the beginning of a run of data without manual intervention.

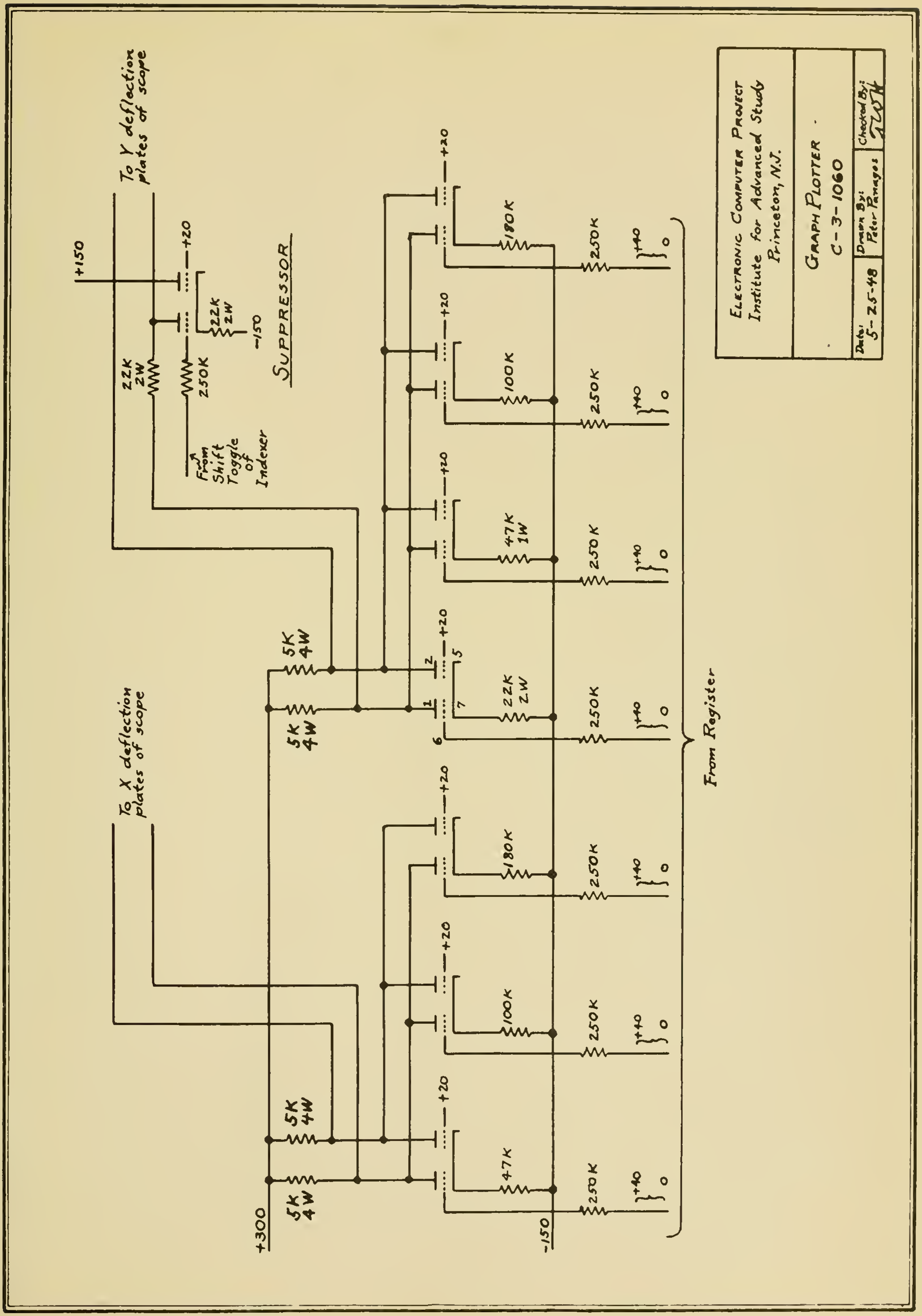
2.4 Oscilloscope Graph

The greater part of our effort on the input-output system so far has been directed toward the provision of equipment for the semi-automatic transcription of relatively large amounts of data. This will, no doubt, be the commonest input-output function. It should be remembered, however, that in addition to this routine handling of data there are also other types of operation which are desirable. These include the insertion and reading of test problems, data, and of relatively short sequence of data. Although the mathematician coding a problem will, of course, attempt to code appropriate alternatives for as many conditions as possible, there will still be cases where solution of the problem will be facilitated by prompt human observation of selected results and the appropriate insertion of changed orders or data entries. It would be relatively awkward to go through all of the customary transcription steps for this type of operation, so there is justification for providing more direct access even if it may be less efficient for the handling of large amounts of data.

One such output means which has already been discussed briefly in earlier reports, is the provision of an oscilloscope on which the machine can be instructed to plot appropriate results as they are produced. This device would take the data existing in one of the registers of the machine

and translate its binary representation in the register into an amplitude representation in the deflection of the oscilloscope spot. Suitable Control operations can then make the selection of appropriate successive numbers to give on the oscilloscope screen the desired functional representation. A model of this oscilloscope graphing device has been constructed and operated from the shifting register into which the high-speed wire reading apparatus operates. The circuits are shown in Drawing C-3-1060. In the experimental shifting register mentioned in this section only seven stages were available for the operation of the oscilloscope, so three of these seven stages were assigned to the abscissa of the plot and the remaining four stages were assigned to the ordinate. This gives only eight different abscissa positions and sixteen different ordinate positions. The problem of producing a more detailed representation is only that of having more register positions available, and it was not felt worth while at this time to build additional positions for this application. Eventually, of course, the oscilloscope would work from one of the registers existing in the arithmetic organ of the machine so there would be an adequate number of stages available.

The oscilloscope circuit is in its essence an adder very similar to that used in the high-speed arithmetic circuit. Each stage consists of a pair of triodes which are cathode-coupled and which provide a well-defined current into one of two summing resistors, depending on the state of the associated register stage. If the associated register stage is indicating "0", then the current is supplied to one of the summing resistors, but if the register indicates "1" the current is supplied entirely to the other. The value of the current supplied is determined by the size of the cathode resistor used, so since the register contains the binary representation of a number, we construct the oscilloscope adder with cathode resistors whose



To Y deflection plates of scope
+150
+20
22K 2W
250K
-150
Suppressor
From Shift Toggle of Indexer
5K 4W
5K 4W
180K
100K
47K 1W
22K 2W
250K
+40
0
From Register
To X deflection plates of scope
5K 4W
5K 4W
47K
+300
-150
Electronic Computer Project
Institute for Advanced Study
Princeton, N.J.
Graph Plotter -
C-3-1060
Date: 5-25-48
Drawn By: Peter Panagos
Checked By:

value in each stage is twice that of the stage on its left. Accordingly, the voltage change developed across each of the two summing resistors is proportional to the value of the number represented in the register. By using the two summing resistors and connecting each to one of a pair of plates on the oscilloscope tube, not only is the deflection of the spot increased for a given voltage generated, but the average potential of the pair of plates remains unchanged so the spot on the tube is not defocussed as it is deflected.

A similar circuit is applied to the other pair of plates of the oscilloscope. In the final model it is possible that only a single adder circuit would be used and switched from abscissa to ordinate with appropriate memory to give the two-dimensional representation, or else two of the registers in the arithmetic organs would be used. As described so far, the circuit would give correct representation only during the time that the number remains unchanged in the register, but while the register is shifting it would give a large number of spurious indications. Accordingly another tube was attached to the adder circuit which, during the time the register is being loaded, introduces a large deflecting voltage on one of the oscilloscope plates. This deflects the beam completely off the screen of the oscilloscope tube and so suppresses these spurious indications. When the register has been filled with its number this suppression voltage is removed and the spot appears at its appropriate location.

In Photographs 2-c through 2-f are shown samples of the operation of this circuit. Photograph 2-d gives the graph y = x, together with the $y = x^2 + 8x - 6$, respectively. It must be remembered that the experimental register used limits the fineness of detail which may be represented by the ~~grafts~~ phs. As a whim, we have included Photograph 2-c which shows the use of

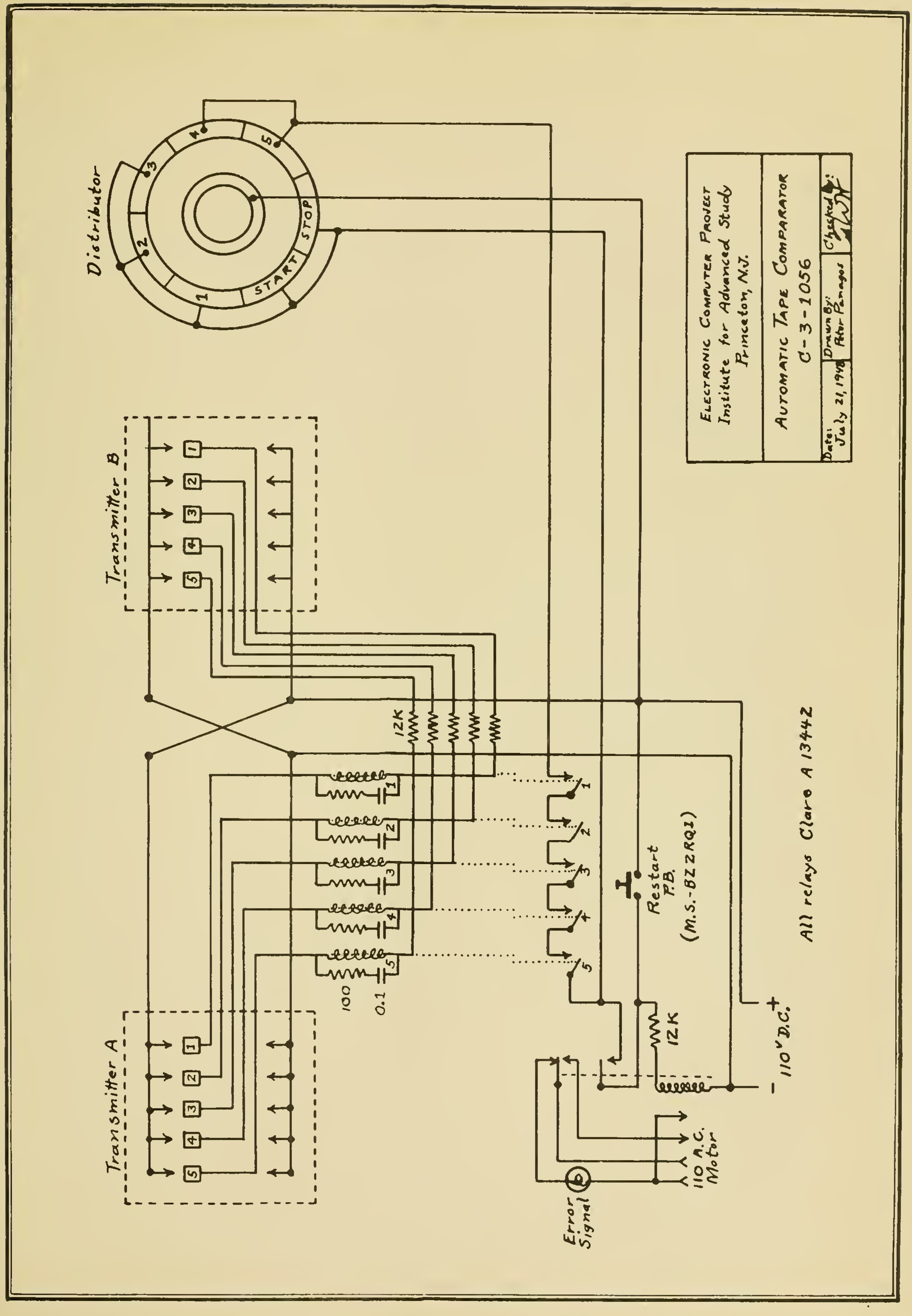
this equipment to plot not graphs but alphabetic letters. In making all of these pictures, the data were fed to the shifting register from the magnetic wire, with the wire moving at about 20 ft/sec. The numbers recorded on the wire for producing the graph y = x are as follows:

0000000000	0000000001	0000000002	0000000003
0000000004	0000000005	0000000006	0000000007
0000000008	0000000009	000000000A	000000000B
000000000C	000000000D	000000000E	000000000F
0000000010	0000000020	0000000030	0000000040
0000000050	0000000060	0000000070	0000000011
0000000022	0000000033	0000000044	0000000055
0000000066	0000000077		

The presence of all of the zeros was necessitated by the fact that the Indexer works always on the basis of a word of 40 data pulses, even though the experimental shifting register used only the last seven of these 40 pulses in generating the graph.

2.5. Tape Comparer

In order to verify the correctness of the operation of the magnetic recording and transcription, a Teletype Transmitter-Distributor was modified to check one punched paper tape against another one, indicating whenever a discrepancy is observed. The circuit of this is shown in Drawing C-3-1056. This is used mostly in testing the equipment. With it a message recorded on one tape can be transcribed onto the magnetic wire and then back again onto a second tape and the accuracy of the transcriptions checked mechanically. When an internal memory is available the transcriptions can be carried to that point and back. In constructing this unit the attempt was made to make it "fail-safe" so that if anything failed in the checking mechanism it would indicate an excess rather than too few errors. As at present constructed this is true except for the possibility of a sluggish relay late in opening


Distributor
1
2
3
4
5
START
STOP
Transmitter B
Transmitter A
12K
100
0.1
Restart
P.B.
(M.S.-BZZRQ1)
All relays Claro A 13442
110V D.C.
+
-
12K
110 A.C. Motor
Error Signal
Electronic Computer Project
Institute for Advanced Study
Princeton, N.J.
Automatic Tape Comparator
C-3-1056
Date: July 21, 1948
Drawn By: Peter Panagos
Checked by:

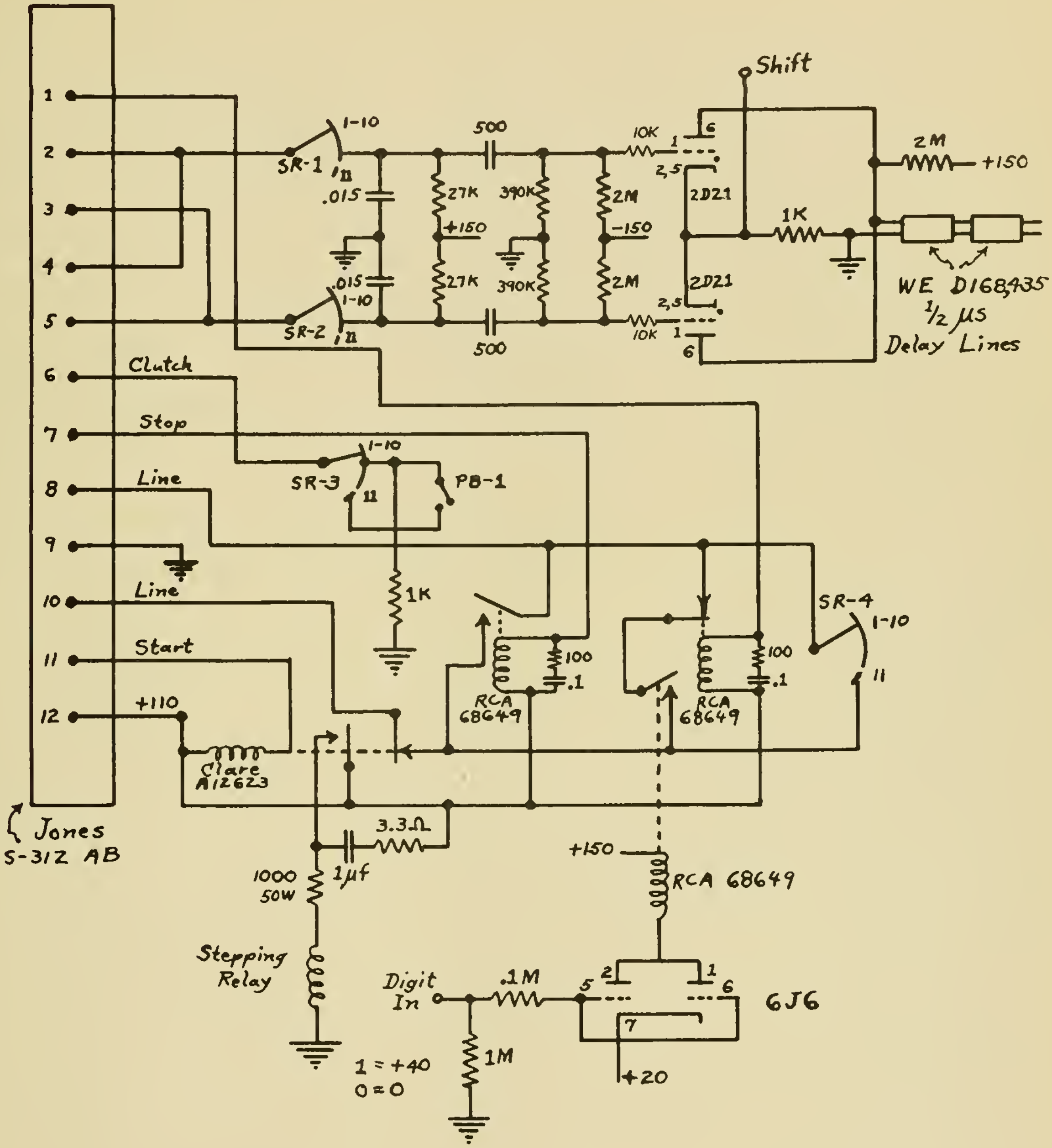
when the current is disconnected. By some modifications of the tape readers the number of relays is being reduced and the "fail-safe" feature extended over more of the circuit.

2.6 Direct Printing from Register

Equipment for operating a printer directly from a shifting register has been constructed and satisfactorily tested.

It makes use of the modified Teletype Transmitter-Distributor which is also used in conjunction with the Outscriber to provide direct printing from the magnetic wire, and can be used as well to operate a printer from the usual teletype tape. (Drawing C-3-1047, Mod I.) The three possible modes of operation are selected by the eight circuit, three position switch, S 1 A, ..., H. Direct current is conveniently supplied for the operation of the clutch magnet and its associated relay by a standard selenium rectifier built for Teletype use. The direct current is also brought out to terminals on a plug for providing direct connection to the register control unit.

The register control unit consists (Drawing C-3-1059) of a stepping relay with several sections (SR-1, ..., 4) and several line and buffer relays; a relay amplifier, which controls one of the line relays in accordance with the digit standing in the left-most stage of a register; and a pulse forming circuit, which provides the necessary pulses to step the register.



Electronic Computer Project
Institute for Advanced Study
Princeton, N.J.

Register Control Unit
for
Direct Printer Operation
C - 3 - 1059

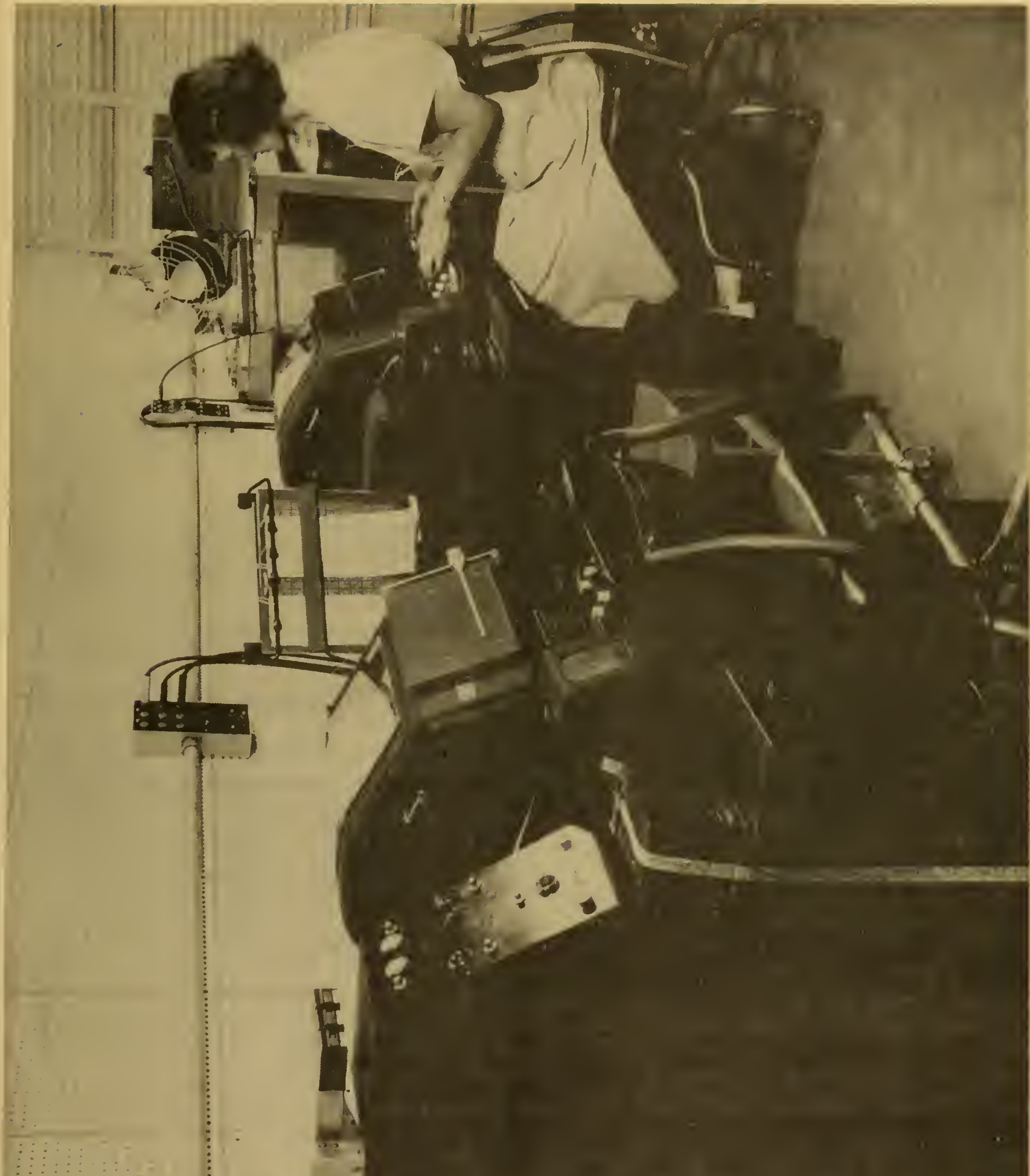
Date:	Drawn By:	Checked By:
July 26, 1948	Peter Panagos	TWH

2.7 Operating Assembly

With the completion of so many items for the input and output equipment, it has become desirable to assemble them in somewhat more nearly operating rather than laboratory form. This has been done for the Teletype equipment, as is shown in photograph 3. Provision is made at this time for the simultaneous operation of two sets of Teletype equipment. One set is complete and will carry out any of the input or output functions so far provided, while the other set is complete except for the Verifier used in the preparation of the final input paper tape.

2.8 Future Plans for Input-Output Organs

The equipment as at present constructed is capable of carrying out all of the transcriptions required for the operation of the prototype machine, and future work on it will consist in a large part of detailed testing and refinement. The largest present limitation is that erasing of data from the wire is unsatisfactory at speeds over about 15 ft/sec. This is because any frequency of signal which we can drive through the present heads with adequate power results in recording on the wire rather than erasing. So far, of course, we have been operating with standard commercial heads and avoiding any modification. It is expected that very minor modifications will remove this difficulty, and it is planned to try reducing the number of turns on the coils to reduce the high-frequency impedance of the head and also to increase the gap length so that the wire will be exposed to more cycles of the high frequency erasing signal.



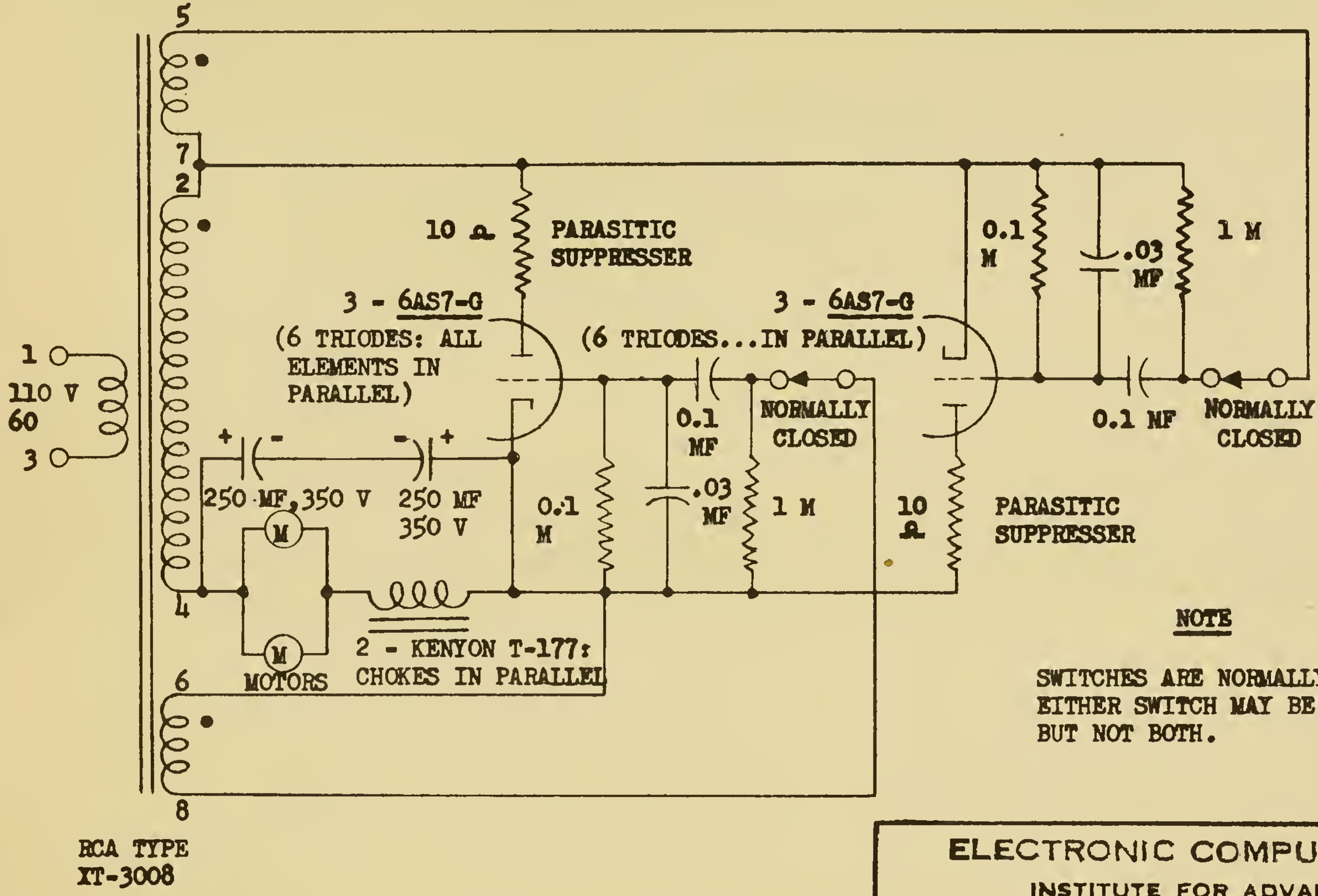
Photograph 3
Operating Position of Input Teletype Equipment

Further work that would be useful even for the "Model 0" prototype would be to provide an additional direct input for the handling of small amounts of data, as mentioned previously. In particular, means for transcribing directly from a keyboard into a shifting register are needed. This appears to be a problem of simple mechanical additions to the Teletype equipment if their keyboards are to be used, and plans for these additions have been partially worked out. Some thought is also being given to the possibility of recording data directly from the Teletype keyboard to a magnetic wire, using the arithmetic organs of the machine to compare two separate typings of the data. This would be more for the future than Model 0, as would also be the new marker system suggested previously in Progress Report No. 3.

2.9 High-speed Wire Drive No. 2

In Progress Report No. 3 it was reported that there was an interference problem when Drive No. 2 was used for reading at slow speed. Whenever the servo action took place arcing between the switch contacts produced pulses in the reading circuits of about the same amplitude as the information pulses being read from the wire. This difficulty has been eliminated by operating the servo-motors through a servo-amplifier-rectifier which is controlled by the servo switches.

The amplifier (Drawing C-3-1045) consists of two sets of triodes, connected in parallel and placed in series with the servo motors and the secondary winding of a 60 cycle transformer. One set of triodes has the cathodes connected to the motors, and the other set has the plates connected to the motors, so that when only one of the sets of triodes is in the conducting condition, rectified alternating current flows through the motors, the sense of the current depending on which of the two sets is



NOTE

SWITCHES ARE NORMALLY CLOSED.
EITHER SWITCH MAY BE OPENED,
BUT NOT BOTH.

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SERVO CONTROL - RECTIFIER
FOR WIRE DRIVE, - NO. 2 - SCHEMATIC

C - 3 - 1045

DATE	DRAWN BY	CHECKED BY	INITIAL
1 - 15 - 48	H.H.	JWH	

conducting. When no servoing action is required both sets of triodes are held in a non-conducting state by the application of properly phased 60-cycle voltages between grid and cathode; grid rectification takes place during that part of the grid cycle when the grid is more positive than the cathode, so that a d-c bias is developed across the grid coupling capacitor. When a servo action is required, the appropriate switch disconnects its set of triode grids from the a-c bias source, so that the d-c bias leaks off from the coupling and filter capacitors in the grid circuit until that set of triodes is in the conducting state. As stated before, plate rectification takes place in this set of triodes, and current is sent through the motors in the proper sense to provide the desired servoing action.

Vacuum tubes instead of thyratrons were used in this servo rectifier to avoid the possibility of high-frequency transients which usually occur when a gas tube starts to conduct. An L-C filter placed across the output of this rectifier provides more nearly pure d-c voltage for the operation of the servo motors and improves their operation considerably.

2.10 High-speed Wire Drive No. 3

At the time of Progress Report No. 3 all the mechanical elements of this high speed wire drive had been assembled and operated except for the traverse system cam and gear train (and the door upon which they mount) for level winding. This work has now been completed and the wire drive differential control circuit has been designed, constructed, and tested. In addition, design work on a slow-speed drive attachment (suitable for operation at teletype speeds) has been completed.

2.10.1 Wire Drive Differential Control

The function of the wire drive differential control is to maintain a constant loop diameter on the magnetic wire in the wire drive as it passes through the recording and pick-up head. The wire is looped around a pulley on either side of the head, each pulley being located at the end of a long lever arm which rotates about a bearing. The lever arms transfer their action to the rotor of a small selsyn, so that the position of the rotor winding with respect to the stator windings of the selsyn is controlled by the tension of the wire. The stator windings of the selsyn are supplied with a 60 cycle a-c voltage, so that the output potential of the selsyn rotor is a voltage which depends on the position of the lever arm. When the wire follow-up arms are in a neutral position the selsyn voltage output is null. When the follow-up arms are swung to either extreme the output voltage is about 20 volts and of a phase dependent on the position of the arms.

This output voltage is ultimately to control the speed and direction of rotation of a small differential motor which moves the two wire reels relatively to each other. This motor requires a three phase, 400 cycle voltage source, which consists of a generator driven by a 60 cycle motor. The reversal and speed variation of the differential motor is accomplished by controlling the amplitude and direction of the d-c field currents in the generator field. The generator has two field windings, and to reverse the direction of the differential motor the polarity of current in only one is reversed. What is required then is a circuit to transform the a-c voltage output of the selsyn rotor to a d-c voltage of proper phase for the generator fields.

Since the field currents of the generator range up to 1 ampere, vacuum tubes would have to be paralleled to handle this load. It was therefore decided to use thyratrons, four Type ELC1B thyratrons doing the work of 16 6AS7 triode tubes. The thyratrons function both as rectifying and as control elements. They are connected so as to act as a double-pole, double-throw switch, with the selsyn voltage being applied to the grids of the thyratrons and the plate outputs being supplied to the differential motor, after appropriate filtering. When the selsyn output is null no thyratrons conduct and the differential motor is at rest. With full voltage output from the selsyn rotor in one direction two of the thyratron tubes conduct, and the differential motor rotates in one direction; when the voltage output of the selsyn is in the opposite direction the other pair of thyratrons conducts and the differential motor operates in the reverse direction. No circuits are used to shift the phase of the voltage applied to the grids of the thyratrons, so that the maximum possible variation in output current which can be achieved is two-to-one. Actually, fixed negative biases of the order of 22 volts were found necessary on the grids of the thyratron tubes in order to prevent erratic and erroneous conduction due to pulses being propagated from the grids of the conducting tubes via the coupling transformers to the grids of the non-conducting tubes. As a consequence speed control is possible with the present system only over a range of field currents from 0.7 ampere to 1.0 ampere.

The wire drive has now been operated successfully with the present system over a period of three weeks without a single wire break having occurred. The circuit described above is considered a temporary expedient only; one which could be assembled from available components in the shortest possible time and which demonstrated the satisfactory operation of the system even under adverse conditions of non-proportional control.

As soon as the present critical period of construction is passed, the circuit will be revised and simplified so as to achieve the desired linear relationship.

III. ARITHMETIC REGISTERS

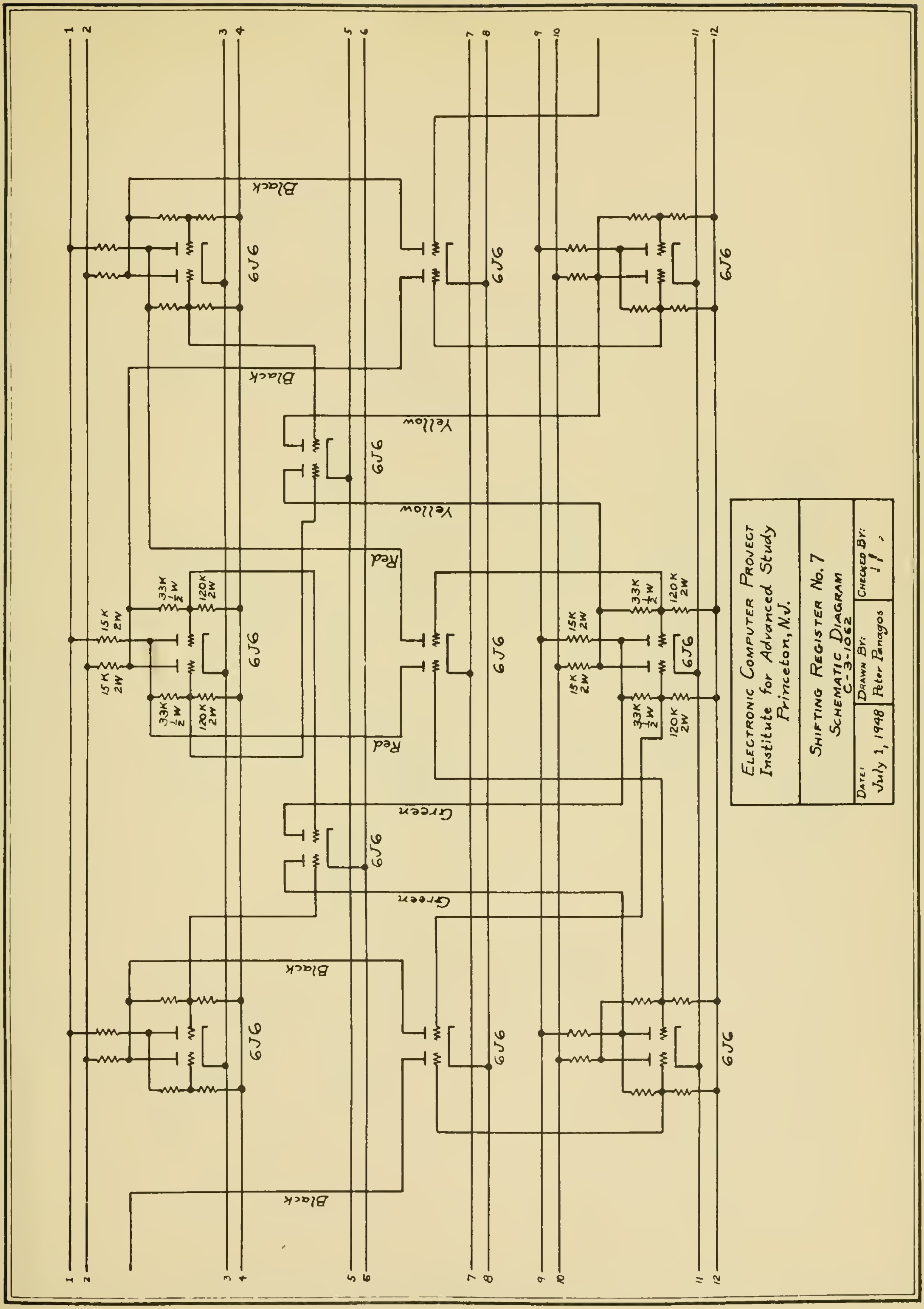
3.1 Shifting Register No. 7

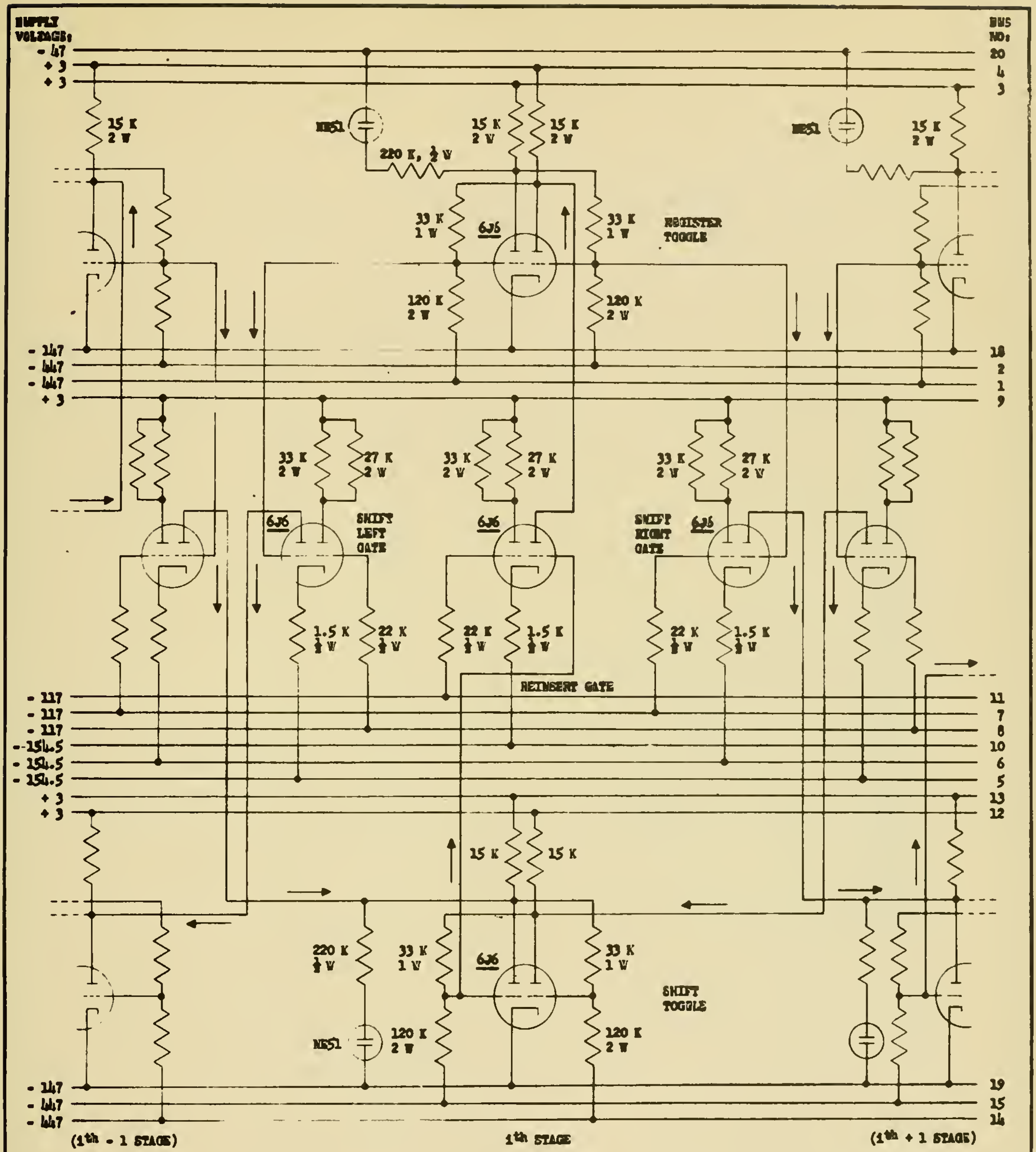
Register No. 3 was described in the last progress report. Since that time the design has proceeded through a number of stages to the final stage for the first, or laboratory, model of the computer (Model 0). This last design is called Register No. 7 and is now in production. (See Drawings C-3-1062 and C-3-1063.)

3.1.1 Circuit Design of Register No. 7

The circuit of Register No. 7 differs from that of Register No. 3 (see Drawing C-3-1021) in three fundamental respects. First, the shifting gates have been simplified so that a single triode suffices for each shift operation. In Register No. 3 a double triode with a common cathode resistor was used for each gate, the transmitting toggle being connected to the grid of one triode and the gating signal being applied to the grid of the other. In the new design the gating signal is applied to the cathode of a single triode whose grid is connected to the transmitting toggle as before. (See Drawing C-3-1064.)

Second, the shifting and clearing operations have been combined, so that a sequence of only two pulses (instead of four) is required to direct a complete shift. This was accomplished by designing the gating tubes to simultaneously transmit information from a toggle and clear that toggle. When a shift is desired the proper triode gates are pulsed on the cathodes with a negative pulse; if the transmitting toggle is in one state nothing happens, while if it is in the other state its triode gate draws sufficient


Electronic Computer Project
Institute for Advanced Study
Princeton, N.J.
Shifting Register No. 7
Schematic Diagram
C-3-1062
Date: July 1, 1948
Drawn By: Peter Panagos
Checked By:
6J6
Black
Yellow
Red
Green
15K 2W
33K 1/2W
120K 2W



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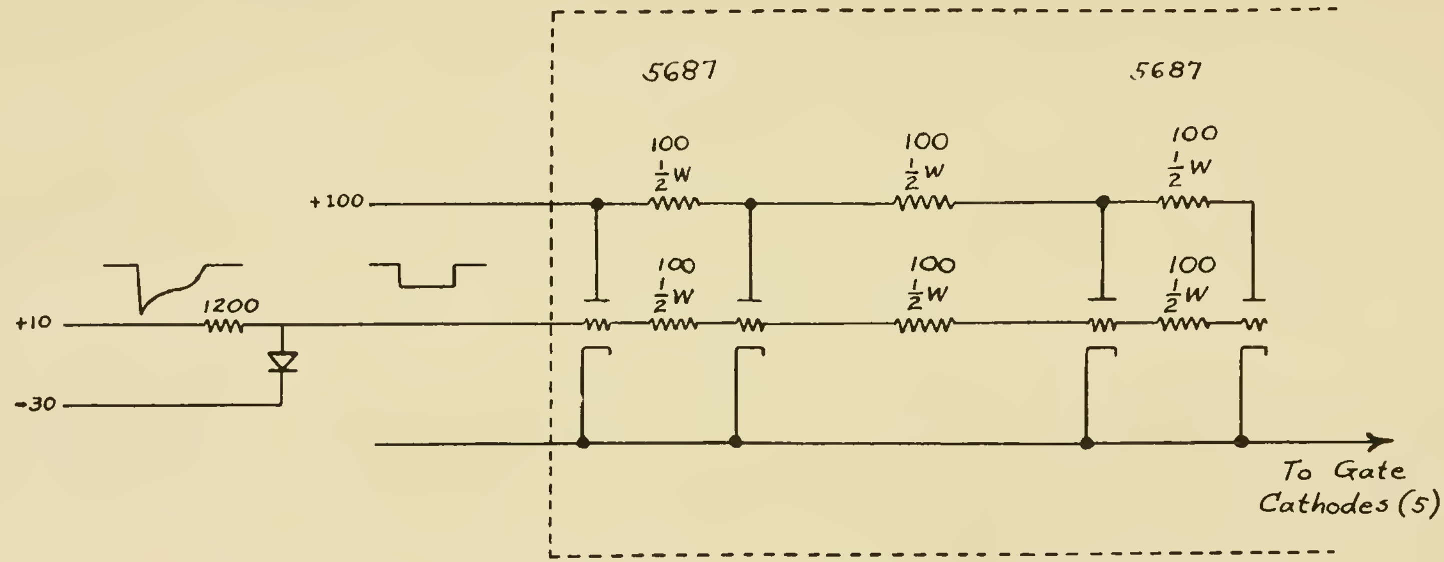
SHIFTING REGISTER NO. 3: i th STAGE

C - 3 - 1021

DATE	DRAWN BY	CHECKED BY	INITIAL
12 - 18 - 47	N.HARP	JR	



Electronic Computer Project Institute for Advanced Study Princeton, N.J.		
Shifting Register No. 7 Cathode Follower for Gate Cathodes C-3-1064		
Date: July 1, 1948	Drawn By: Peter Panagos	Checked By:

grid current to reverse the toggle and at the same time sends a pulse to the receiving toggle. It will be remembered that to make the loading effect of the gates on the toggles more symmetrical these gates are placed on both sides of the toggles, with the result that a left-shift requires clearing the toggles to one side ("0") and a right-shift requires clearing the toggles to the other side ("1"). Since in Register No. 7 the clearing may be done simultaneously with the transferring, two gates which transfer from the upper to the lower toggles at each stage are needed (instead of one, as in Register No. 3), one which clears to "0" (for a left-shift) and one which clears to "1" (for a right-shift). Thus a total of four triodes (two envelopes) per stage may be used for gating, which is a saving over Register No. 3 which used three double-triodes per stage for this function.

The operations of clearing the shift toggles and the register toggles without shifting has been simplified. Register No. 3 used a system of balanced clearing: pulses of opposite polarity were applied to the two plate-return bus lines (buses 3 and 4 for the register toggle and buses 12 and 13 for the shift toggle). A study of the clearing action of this unit showed that the positive pulse was in each case useless and could be eliminated without harming the operating characteristics of the register, so that now single bus clearing is employed. A description of the study of the clearing action follows.

The bottom or shift toggles (of Drawing C-3-1021) were set up with individual variable power supplies for busses 12 and 13. A series of static d-c tests was made to determine which bus would be able to clear most efficiently. First, bus 12 was maintained at +150 volts above cathode bus 19, with the toggles all set to 0 (left side of toggle conducting). The voltage supplied to bus 13 was gradually increased until all the toggles cleared to 1. It was found that no clearing occurred until bus

13 exceeded 300 volts and clearing was not complete until it had reached above 350 volts. Then bus 13 was set at 150 volts, and bus 12 was raised until all the toggles had been cleared back to 0. Bus 12 required 340 volts. Clearing was next attempted by downward movement of busses. With all toggles cleared to 1, bus 12 was maintained at 150 volts and bus 13 was dropped until all stages had cleared back to 0. This occurred at 110 volts. Similarly, with all toggles in the 0 condition bus 13 was maintained on 150 volts, and complete clearing back up to 1 occurred when bus 12 was dropped to 110 volts. These results indicated: a) that from a d-c standpoint the toggles were symmetrical, b) that single bus negative "dip" clearing should be practical, and c) that single bus positive deflection clearing is impractical, in fact, that the balanced clearing used heretofore included a useless positive pulse.

Dynamic single bus clearing was then attempted, and the data of the following table obtained. This shows the minimum voltage required to completely clear seven toggle stages for a given width of the clearing pulse. (The table covers the clearing of only seven toggle stages since the first toggle stage -- which has an abnormally high capacitance loading because of the "end-around" shift connection to the eighth toggle -- is not typical.)

Length of Clearing Pulse (Microseconds)	Minimum Negative Signal Needed by Bus 12 to Clear to 1 (Volts)	Minimum Negative Signal Needed by Bus 13 to Clear to 0 (Volts)
0.3	150	140
0.5	90	90
0.7	70	70

This table shows that with pulses of reasonable amplitude (e.g., 70 volts) single bus clearing can be accomplished at a fairly rapid rate (e.g., 0.7 microseconds).

A similar test was made on the top, or register, toggles. The results are given in the following table. For the shorter clearing signals the maximum voltage output of the pulser (180 volts) was not sufficient to clear all the toggles, and in these cases the number of toggles which were cleared by the signal are given.

Length of Clearing Pulse (Microseconds)	Minimum Negative Signal Needed by Bus 3 to Clear to 1 (Volts)	Minimum Negative Signal Needed by Bus 4 to Clear to 0 (Volts)
0.3	180 volt pulse clears no stages	180 volt pulse clears no stages
0.5	180 volt pulse clears two stages	180 volt pulse clears two stages
0.7	90	90

In order to determine the effect on the clearing action of the capacitance lead due to the record gates from the adder these gates were removed and the experiment repeated.

Length of Clearing Pulse (Microseconds)	Minimum Negative Signal Needed by Bus 3 to Clear to 1 (Volts)	Minimum Negative Signal Needed by Bus 4 to Clear to 0 (Volts)
0.3	180 volt pulse clears two stages	180 volt pulse clears no stages
0.5	180	150
0.7	80	80

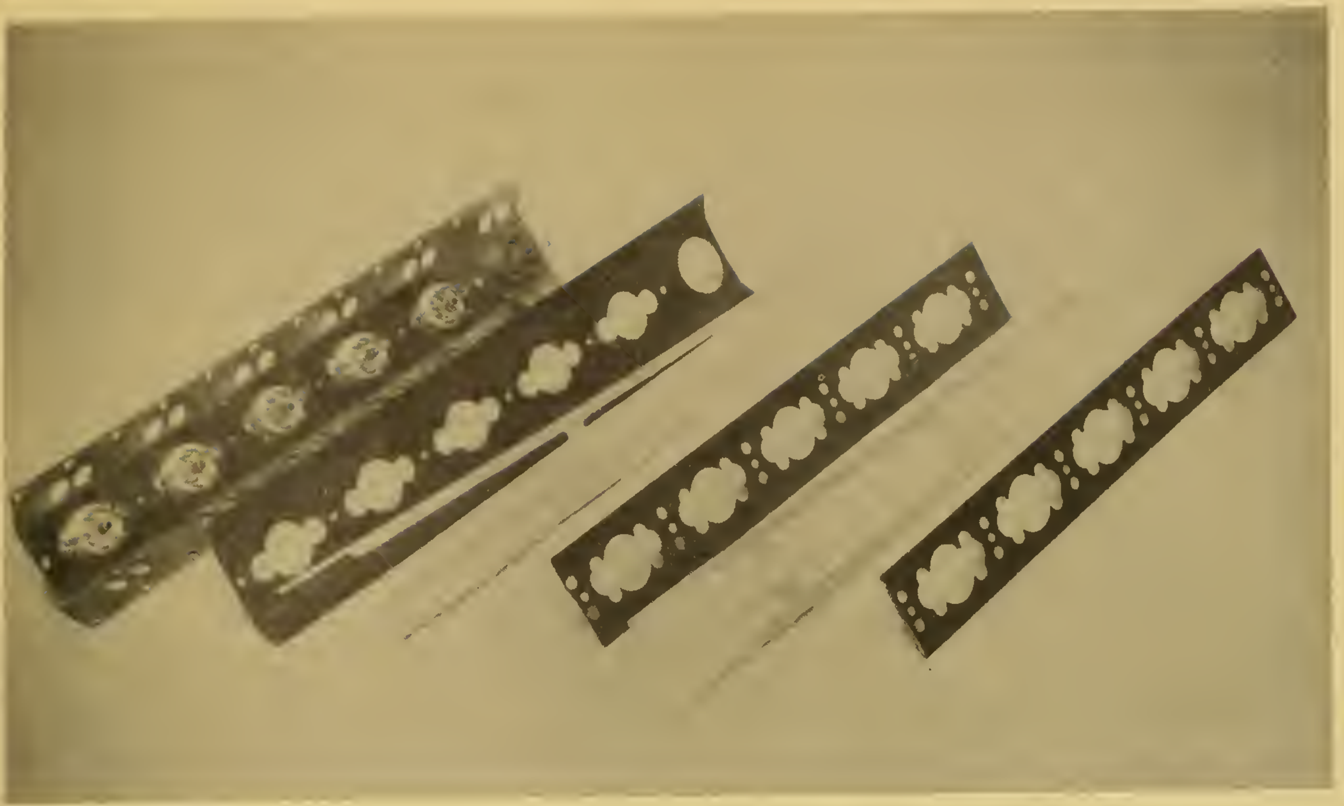
It will be noted from the above tables that somewhat different signals were required for clearing to "0" and "1". It was believed that this was due to the unsymmetrical loading of the toggles (see Drawing C-3-1021) and capacitance measurements made at various points in the circuit showed this to be the case. To indicate typical capacitance loading for this type of chassis layout and wiring we give the results of the measurements on one of the bottom (shift) toggles. Similar values were obtained for the top register. The lead going from the plate of the left-hand triode of the shift toggle to the shift left gate was disconnected from the plate; the lead was found to have a capacitance of 9 micromicrofarads, and the capacitance of the residual socket connections was found to be 17 micromicrofarads. Similar measurements for the right-hand triode gave 9.3 and 17.5 micromicrofarads respectively. The capacitance of the grid of the right-hand triode was 9 micromicrofarads. When the lead to the grid of the reinsert gate was disconnected the capacitance of the grid of the left-hand triode was 12 micromicrofarads. The lead to the reinsert gate is somewhat different from that shown in Drawing C-3-1021: a 10K resistor was inserted to prevent the grid current drawn by the reinsert gate from clearing the shift toggle, and the lead was extended on to the adder circuit. The total capacitance of this lead, measured on the side of the resistor next to the reinsert gate, was 27.5 micromicrofarads; when the lead going to the adder circuit was removed the capacitance was 9.4 micromicrofarads.

3.1.2 Design of Three-dimensional Register

Simultaneously with the electrical design of Shifting Register No. 7 work proceeded on the mechanical design of this register. The first step consisted of a study to determine how resistors could be mounted on a chassis in a way which would minimize their capacitance to ground.

Capacitance measurements were made between a 2 watt resistor and a chassis ground for various positions of the resistor around a tube socket. Measured at the tube terminal, the resistor was found to have a capacitance to ground of 3.3 micromicrofarads when parallel to the chassis and 1/16" above, while with 1/8" spacing between resistor and chassis the capacitance decreased to 2.8 micromicrofarads. When a 1/2" hole was cut in the chassis next to the tube socket, and the resistor was fed through this hole with the body of the resistor above the chassis and only the resistor wire passed through the hole, the capacity was reduced to 2.3 micromicrofarads. From several different chassis layouts, it was determined that this latter method produced the least parasitic capacitance, and it was therefore decided to build a register incorporating this scheme. It was also determined at this time that the capacity between socket terminals and socket is essentially independent of socket type.

It was decided that the new register would make an attempt to eliminate unnecessary wires from the vicinity of the grid and plate terminals of the tube sockets. Some time was therefore spent in the design of a filament bus system whereby two flat thin copper strips with long fingers are laid on an insulated chassis, one on each side of each tube, all the way down the row of tubes. The thin copper fingers are then connected to terminals 3 and 4 of the tube sockets, providing filament potentials without the sacrifice of any appreciable space around the tube sockets. It was also decided to supply power to all tube terminals which are maintained at an a-c ground potential by additional flat copper strips, each insulated from all others, and made up into sandwich layers so that the only leads supplied to the tube sockets externally are those involving pulse currents. The copper strips and the insulators are shown in Photograph 7a; in Photograph 8b they are shown assembled.



Photograph 7-a
Exploded View of Heater and Cathode Lead Sandwich

Photograph 7-b
Fabrication of Copper Strips for Sandwich

A U-shaped chassis was then designed to make it possible to wire all interconnecting leads (signal leads) between toggles and gates on a straight line; Photographs 8a and 8b show the final version of this "three-dimensional" chassis. A model register consisting of five stages of the circuit of Register No. 7 was then built. Capacitance measurements were made on the new register; they showed that a considerable improvement over the old register resulted from the new design. The following table gives the capacitance (in micro-microfarads) of a typical stage of each register, the measurements being made with the read-in and read-out lines disconnected.

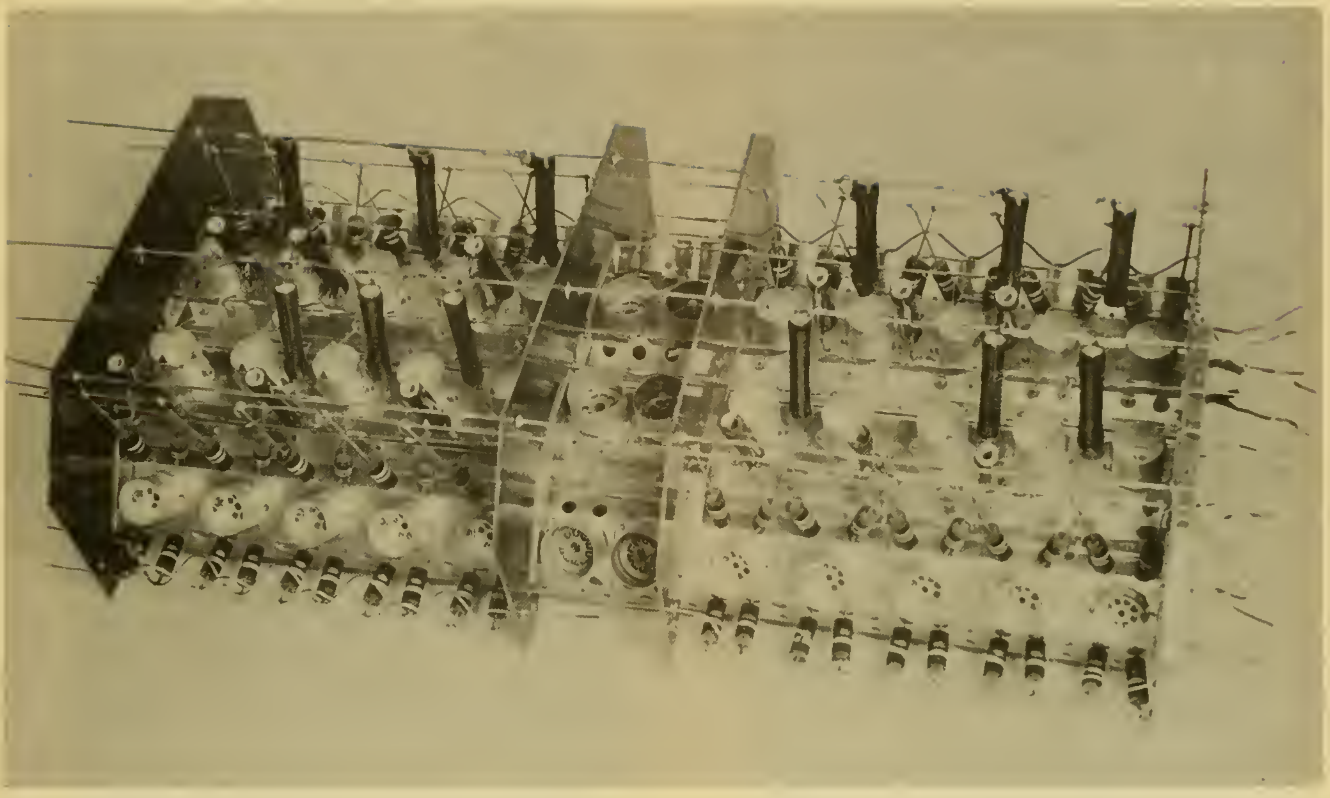
		Grid 1	Grid 2	Plate 1	Plate 2
Original register	Top toggle	9	17	9	18
	Bottom toggle	17	9	18	17
Three-dimensional register	Top toggle	7	6	10	11
	Bottom toggle	7	6	10	11

Dynamic tests of the new register showed that this reduction in parasitic capacitance had resulted in a considerable increase in register speed. It was found that a complete shift and clear could be reliably accomplished with a single pulse of 0.6 microsecond duration. (This pulse was obtained from one of the pulses described in Section 4.1.) Furthermore, the next shift and clear pulse could be slightly superimposed on the preceding pulse, so that a complete shift cycle required only 1.1 microseconds. This period is to be compared with the value of 2.5 microseconds for a complete shift in Register No. 3 under similar conditions, though it must be remembered that Register No. 3 used a four-pulse shift cycle, so

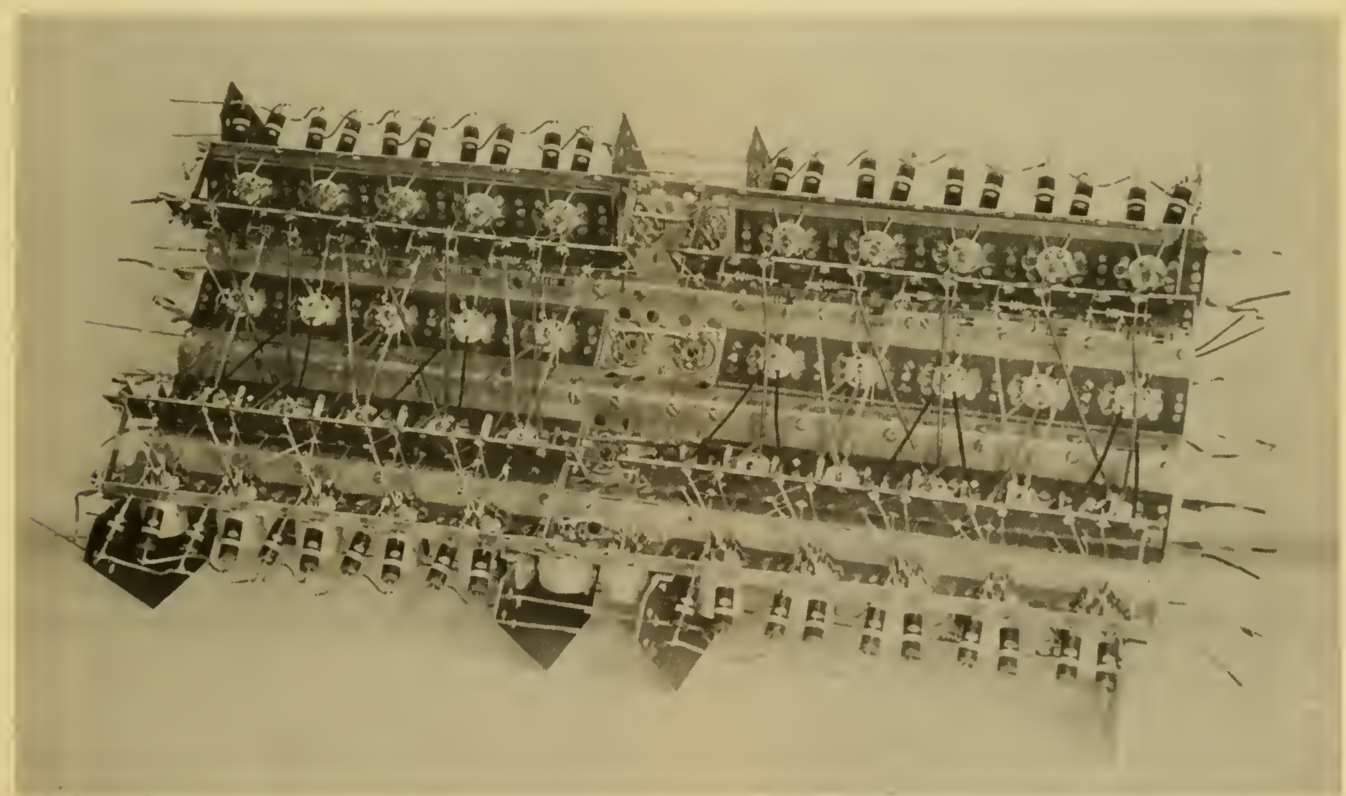
that not all of the improvement in speed is due to reduced capacitance. Another desirable feature of the new register is that all input and output leads are readily available on terminal boards above the chassis, so that read-in and read-out connections will add less additional capacitance than before.

Through an oversight the resistors initially used in this sample of the new register had not been selected to within 5% of the specified value as they should have been. This oversight resulted in a considerable variation between toggle stages; in particular, the toggle speed was affected by any assymmetry in the two 15,000 ohm plate resistors. When the faulty resistors were replaced the toggles showed a good degree of uniformity. A second model five-stage register was constructed and interconnected to the first model to make a complete ten-stage shifting register which operated satisfactorily as the arithmetic register of the ten-digit model arithmetic unit which is discussed in Section 3.2.

A considerable amount of time has been spent in refining the mechanical design of the new register, both to improve its performance and to facilitate construction, test, and maintenance. The final design is shown in Photograph 8. The unit pictured is a ten-stage register. There are five register stages at each end, with eight tubes (four for each five-stage register) in the center to supply signals to the gates. The outer strips contain the toggles, the inner strips the shift-left, shift-right, reinsert for right-shift, and reinsert for left-shift gates. Photographs 7-b, 9-a, 9-b, 9-c, and 10 show a typical ten-stage unit in construction. Several of these units are now in the process of production; a total of sixteen will be built.



Photograph 8-a
Top View of Production Model Shifting Register



Photograph 8-b
Bottom View of Production Model Shifting Register

Fabrication of Production Model Shifting Register

Photograph 9a

Photograph 9b

Photograph 9c

Photograph 9d

Photograph 10
Fabrication of Production Model of Shifting Register

IV. THE ACCUMULATOR

4.1 Operating Sequences in Arithmetic Organ

Progress Reports No.1, No. 2, and No. 3 have discussed the logical and experimental design features of several high speed binary adders and registers; in particular Report No. 3 described the d-c and simple dynamic tests on a highly reliable eight-digit accumulator. More complex dynamic measurements have been made and are briefly discussed in this section.

The present accumulator consists of a static adder and double shifting register. The static adder continuously forms the sum of the resident number (stored in the accumulator register) and incident number (stored in an external register). The process of addition consists in allowing time for the static adding circuits to reach a steady-state condition and then transferring the sum from them into the accumulator register. In multiplication and division this step is accompanied by a shift. Since a number of commands are required to effect these steps we will describe the process in some detail.

The two banks of toggles of the shifting register are called the permanent register bank and the temporary register bank. The latter is connected to the former by both shift-left and shift-right gates, while the former is connected to the latter by non-shifting gates. The permanent register supplies the resident number to the adder. Since this register bank cannot be disturbed until after the sum has been transferred out of the adding circuits, the sum is transferred first to the temporary register bank through a set of gates operated on the command of a 'record' pulse. This means that the temporary register bank must contain the original resident

number, for the digit resolving system and record gates have been designed (see Report No. 3) to operate into a register bank holding one of the numbers being summed. In other words, both register banks of the accumulator register must hold the resident number when the addition process begins.

The transferring process is as follows. The sum is transferred from the adding circuits to the temporary register bank, and from there to the permanent register bank shifted right or left. It is then transferred back to the temporary register bank. This leaves it in a shifted position in both register banks, which is what is desired when the addition is part of a multiplication or division. For a simple addition no shifting is desired so in that case the number is then transferred to the permanent register (with a shift opposite to that used on the first transfer) and back again.

The accumulator circuits require command pulses of a certain minimum duration and in a proper time sequence. Though some overlapping is permissible on most pulses (the exception is that the incident or resident digits must not be altered during any portion of the record pulse) a convenient arrangement is that in which the leading edge of the succeeding pulse is coincident with the trailing edge of the preceding one or is initiated by it.

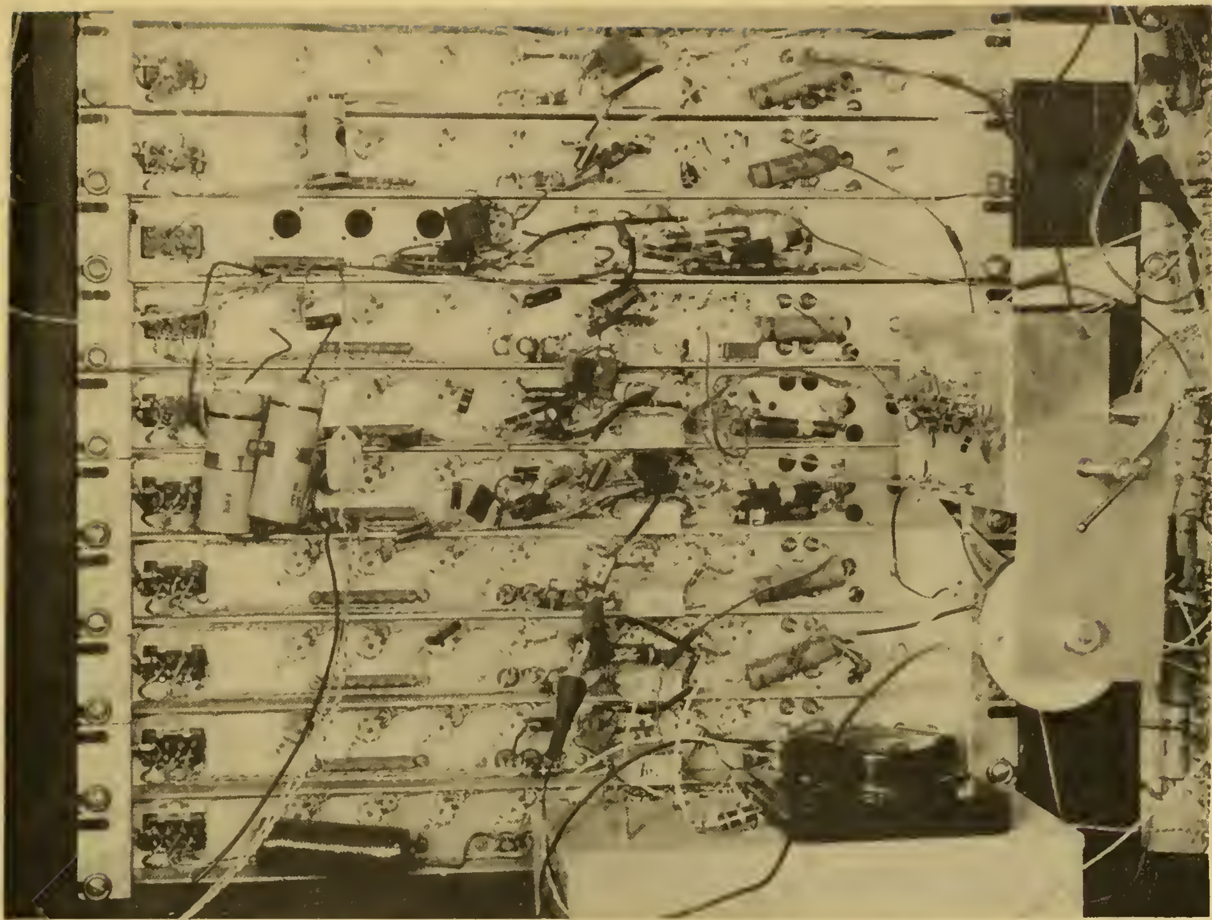
The first pulsing unit was a set of push button switches connected to the pulsing busses and hand operated in the desired sequence. Seven distinct commands were needed, but nine switches were used to permit 'add', 'shift right', and 'shift left' sequences to be performed on adjacent buttons, as shown:

Record

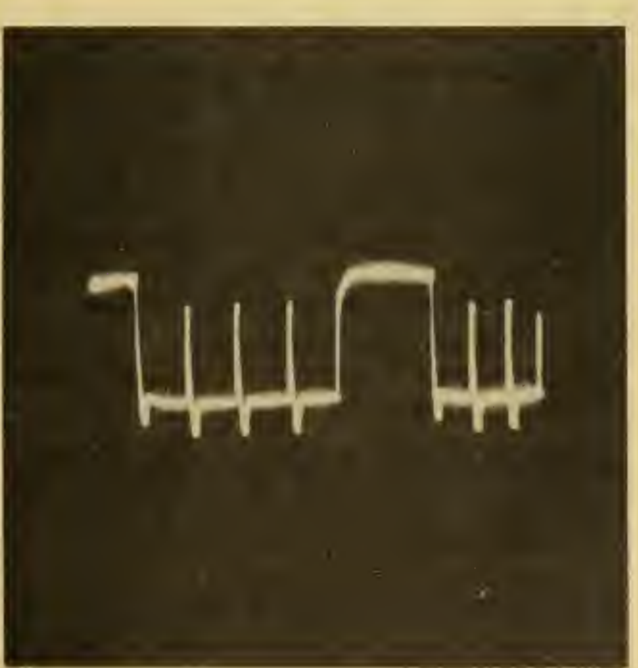
Clear permanent register to "1"	Right Shift	Add.
Shift right		
Clear temporary register to "1"		
Transfer		
Clear permanent register to "0"	Left Shift	
Shift left		
Clear temporary register to "1"		
Transfer		

The second pulsing unit consisted of the ten stage pulser described in Section 4.1 and shown in photograph 11-a, of which one stage was a spare, seven stages were logically needed, and two were added to avoid retriggering the "clear temporary register to '1'" and "transfer" pulsers within any one sequence. With proper connections between pulsers, one external pulse could be made to command an addition, shift right, or shift left quite satisfactorily.

When a new ten stage double register becomes available for test it was mounted adjacent to the accumulator. The pulsers which comprised the left-shift group were disconnected, and two of them were modified to operate the new register in a right-shift sequence. A simple gate was connected to the right-most stage of the new register which, when interrogated by an external pulse, would give an outputpulse on one wire if the stage held a "1" and on another wire if the stage held a "0". These outputs were used to trigger the "record" pulse, (whose trailing edge would then trigger the shift right group) or the shift right group respectively.



Photograph 11-a
Ten-stage Accumulator Cycling Pulser



Photograph 11-b
Multiplication Pattern with Command Pulses spaced 3000 us.

Photograph 11-c
Multiplication Pattern with Command Pulses spaced 16 us.

By using this conditional gate in connection with the new register, the accumulator, and the memory register , it was possible to perform a simple multiplication which differed from true multiplication to the extent that no counter was provided to count off the multiplier digits and terminate the multiplication when the digits were exhasuted. The multiplier was stored in the new ten-stage register, the multiplicand in the memory register, and the partial product in the accumulator register. The right shift of the multiplier was arranged to follow that of the partial product, and end-around connections were made on the ten-stage register so as not to loose the multiplier.

A number of eight-digit multiplications were effected by feeding in eight pulses from an external source and observing the product as stored in the accumulator. A more significant test was made by letting the trailing edge of the last pulse in the sequence initiate the first pulse in a new sequence giving a free running pulser system running at its maximum rate. The product could be observed as a voltage-time pattern on a plate of the right-most accumulator register toggle. (Actually one would observe the sum of the first part of one product and the latter part of the next, but the overlap can be eliminated by using a suitable multiplier and multiplicand.) Photograph 11-b shows a pattern when the command pulses arrive 3,000 microseconds apart; photograph 11-c shows a pattern when the command pulses are spaced 16 microseconds apart. The sharp pulses show the action of the toggle when it is cleared to "1" and then returns to "0", while the broad pulses show the action of the toggle when it is cleared to "1" and remains there.

The minimum time in which the complete sequence of pulses could operate was 10 microseconds. Thus an addition and a shift were accomplished in 10 microseconds, but it should be noted that this figure shows the limit of the pulsers and not of the adding and shifting circuits. The duty ratio for the pulsers was too high for prolonged operation so the total period was increased to 16 microseconds (160 microseconds for a complete multiplication), and then the multiplier was allowed to cycle for about 16 hours without trouble; during this test period over 300 million multiplications were performed without error.

It should be emphasized that the pulsing circuits and control arrangement used to carry out these robot tests proved themselves to be the limiting elements in the system both as regards speed and reliability. These pulsers and the circuit arrangement used by no means represent the performance to be anticipated in the main control of the machine in the process of construction, as they were assembled hurriedly from parts available about the laboratory.

V. CONTROL ORGANS

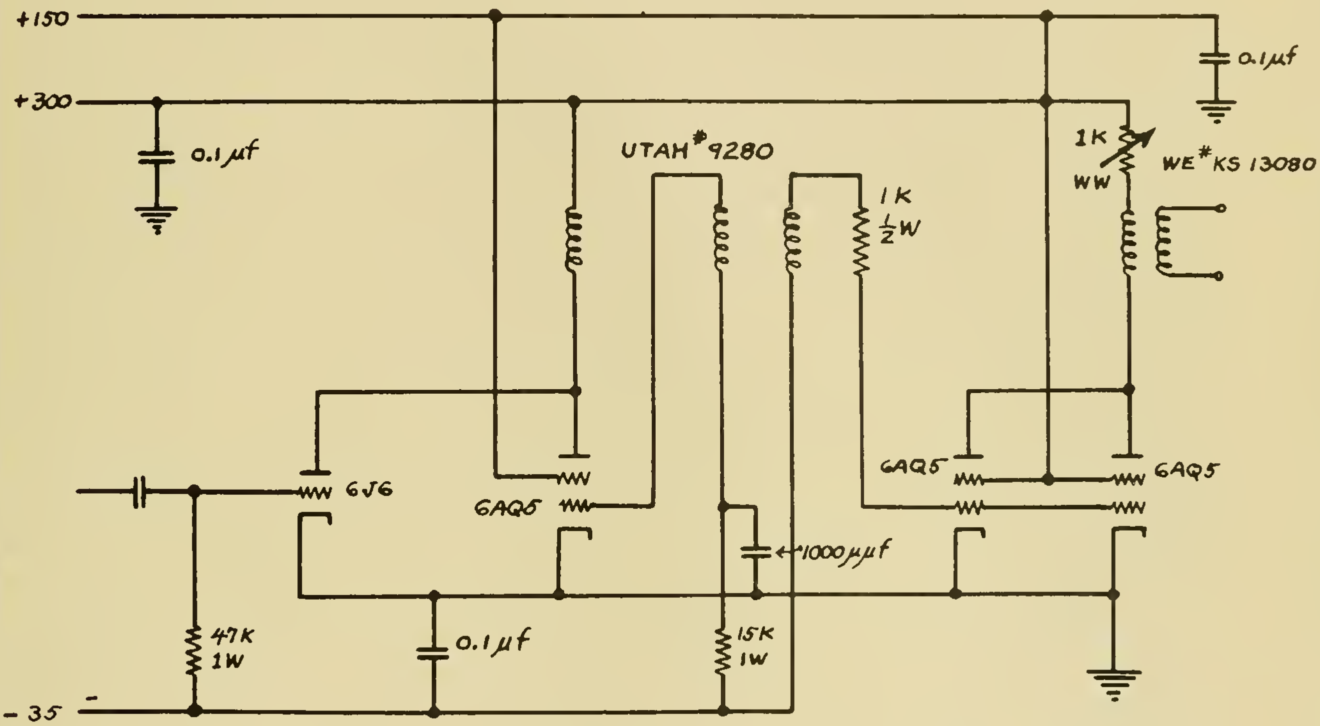
During the period covered by this report work on the control organs has been limited to the design and testing of components. Pulse generators have been built to operate the model multiplier, and the design of the two-toggles-per stage binary counter (Binary Counter No. 2) has been altered so that this counter now operates with an arbitrarily slow pulse.

5.1 Ten-Stage Pulser

To operate Accumulator No. 7 a chain of nine distinct pulses is required. (With simplifications since introduced in the register circuit -- see Section 3.1.1 -- a shorter sequence of pulses will suffice.) To allow one extra stage a ten-stage pulser was built; this is shown in Photograph 11-a. The circuit of each stage is given in Drawing C-3-1061.

Each pulser requires a trigger signal of about 20 volts. The output is taken from the secondary winding of a pulse transformer so that it can be supplied at any desired d-c level. With the plate bus of Drawing C-3-1061 at 300 volts, the screen bus at 150 volts, and the grid bias bus at -22.5 volts, a typical pulser has the following load characteristics:

Load Resistance (Ohms)	Output Signal (Volts)
4,700	220
1,000	200
470	140
220	100
100	60
10	10



ELECTRONIC COMPUTER PROJECT
Institute for Advanced Study
Princeton, N. J.

PULSER

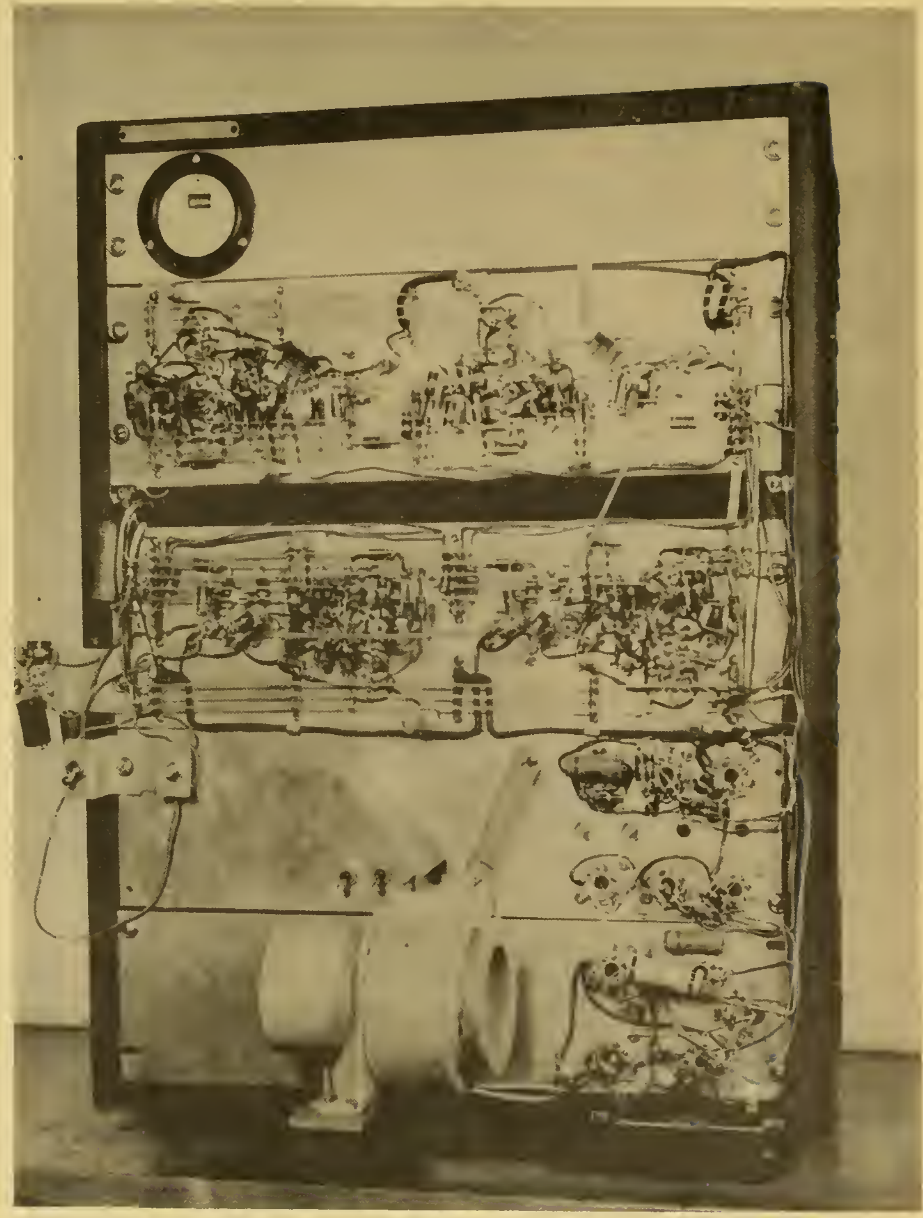
C-3-1061

DATE:	DRAWN BY:	CHECKED BY:
July 1, 1948	Peter Panagos	JR

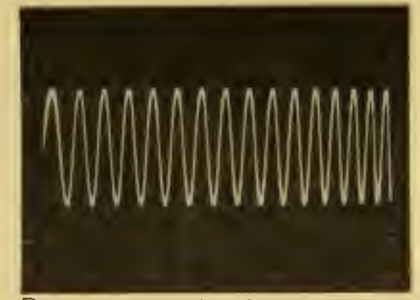
For operation of the accumulator pulses are needed on separate lines in a time sequence. This is accomplished by using the trailing edge of the pulse produced by one pulser to trigger the pulser which is to operate next. A coupling circuit consisting of a 30 micromicrofarad capacitor connected from the output of one pulser to the grid of the 6J6 trigger tube of the next pulser and a 2700 ohm grid resistor (to replace the 47,000 ohm grid resistor of Drawing C-3-1061) differentiates the output pulse and produces a positive trigger of 50 volts from its trailing edge. Nine pulsers connected sequentially operated the accumulator satisfactorily. The pulses produced were reasonably uniform, with a rise time of approximately 0.1 microsecond, a pulse width of 0.8 microsecond, and an amplitude of 200 volts across a 1000 ohm lead. When the output of stage 9 was connected to the input of stage 1, a continuous chain of nine pulses was produced at a repetition rate of 100,000 per second. It was later found desirable to increase the pulse width of several stages to 0.9 microseconds in order to produce reliable clearing of the top register.

5.2 The Counter

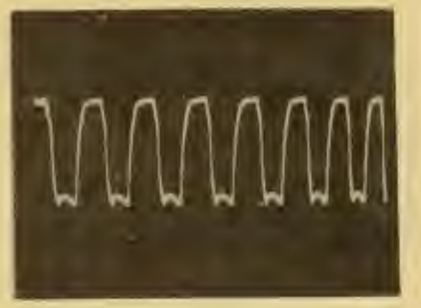
The logical development of the positive action binary counter, as well as a discussion of the evolution of the particular circuit configuration selected as suitable for construction, have been outlined in Progress Report No. 3. Small changes have been made in the circuit that was contained in that report, and the final circuit including the necessary cathode follower to supply the grid current of the gating system and the translator tube which effects a necessary d-c translation between the output of one stage and the input of the next stage is shown in Drawing C-3-1050. Photograph 12-a shows the completed counter.



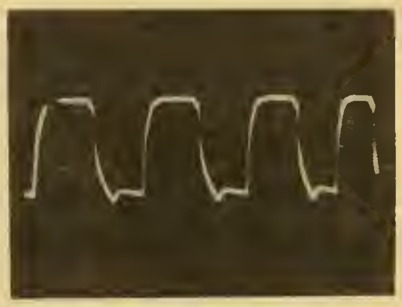
Photograph 12-a
4-stage Binary Counter



Photograph 12-b
1 mc sine wave input voltage



Photograph 12-c
Output of 1st stage



Photograph 12-d
Output of 2nd stage

Photograph 12-e
Output of 3rd stage

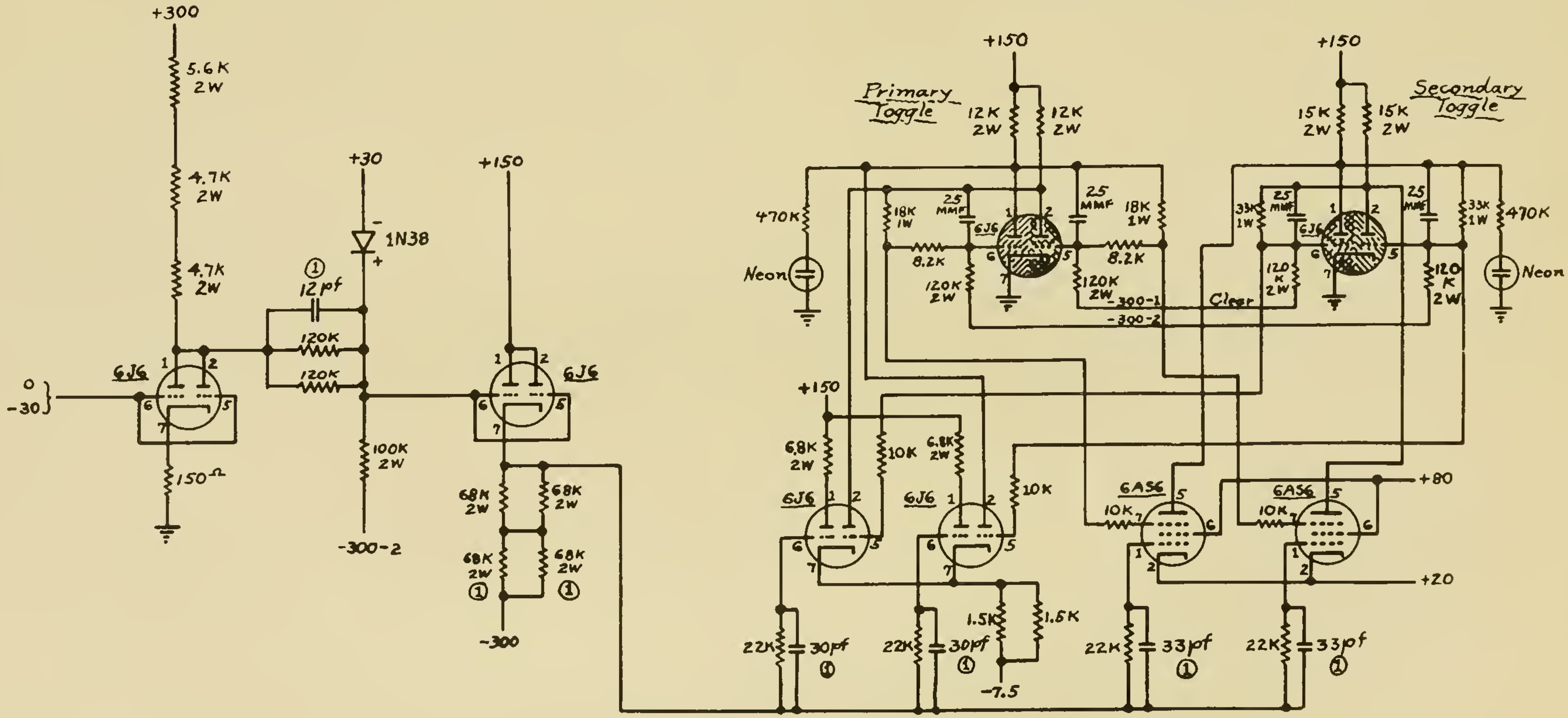
Photograph 12-f
Output of 4th stage

Primary Toggle - Flips on trailing edge of pulse.
Secondary Toggle - Flips on leading edge of pulse.

Alterations:

① Values, resistors, capacitor added 4/28/48 - W.W.

Single - Hatched Area = "0" State
Double - Hatched Area = "1" State



Electronic Computer Project Institute for Advanced Study Princeton, N.J.		
Counter WHW-348 C-3-1050 (SK) - I		
Date: 3-5-48	Drawn By: Peter Panagos	Checked By: WHWare

The unit constructed consists of four binary stages capable therefore of counting to 16. Stage 1 is in the lower strip on the left and stage 4 directly above it. The bottom-most panel contains voltage regulators which supply all voltages not contained in the laboratory distribution supply: i.e., plus 30, plus 20, plus 80, and minus 7 1/2 volts are supplied through regulators or from batteries, and plus 300, minus 300, and plus 150 volts are supplied from the laboratory system. Blowers are incorporated in front of and behind the unit to provide circulating air; an elapsed time meter in the upper left corner accumulates the total running time of the unit.

The design of the unit is such that it meets with all the stringent security requirements as outlined in Progress Report No. 3. The binary stage consists of two toggles connected through two sets of gates, so that for one condition of the gates, toggle 1 may influence toggle 2, and for a second condition of the gates, toggle 2 may influence toggle 1, but it is never possible for both conditions to exist simultaneously. The respective gates control their toggles by pulling a plate potential to the desired position, and are controlled on one grid by a grid potential from the other toggle.

The second grid of all gates is connected via the cathode follower and the translator tube to the driving voltage for the counter. The primary purpose of the cathode resistor of the translator tube is to prevent this tube from drawing grid current from its source. In all stages except the first the source is a toggle grid of the previous stage which in the present design is incapable of supplying current to a load under the worst conditions of tube and resistor variations. Secondarily, this cathode resistor makes the output of the translator relatively independent of the tube characteristics. The function of the 1N38 crystal is to limit the positive swing of

the grid of the cathode follower in order to keep the grid current drawn by the 6J6 gate tubes within a reasonable value. The value of this positive swing depends only on the five resistors in the voltage step-down circuit and must be at least 30 volts to operate the 6AS6 gate tubes reliably. Because of the tolerances allowed the values of these resistors could be such as to cause excessive grid current to flow in the 6J6 gate tubes if the crystal were not present.

Capacitors have been added in various parts of the circuit, but they in no way influence the low frequency performance of the circuit, but only maintain the sharp leading edges of the pulses at higher counting rates. The ultimate counting rate for the unit as shown in the schematic diagram is 1.25 megacycles per second, whereas the ultimate counting rate for the unit less all capacitors is approximately 0.9 megacycles per second. An input waveform of 1 megacycle per second rate is shown in Photograph 12-b, and the corresponding output waveforms of the first, second, third, and last stages are shown in Photographs 12-c, 12-d, 12-e, and 12-f respectively.

The propagation rate for the four stages is approximately two microseconds which means that if a count of 15 resides in the counter, the time from receipt of the next pulse at the first stage until the fourth stage changes state is approximately two microseconds. The minimum pulse width that will actuate the counter is of the order of 0.5 microseconds; the minimum pulse amplitude, about 45 volts. Pulse shape, rise time, and fall time are of no consequence whatsoever.

The four stages as shown in Photograph 12-a have an accumulated running time of slightly over one hundred hours at a one megacycle per second rate, and have given no trouble and no failures in this period. As a matter of interest, the tubes in the unit have been operated at a heater voltage of

6.0 in order to achieve some additional data on the life of vacuum tubes as a function of heater voltage. No special provisions for warm-up have been observed, however, other than to allow all tube heaters 30 seconds of warm-up time before applying voltages.

A revision of this circuit, both electrically and mechanically is currently in progress; it is expected that counting rates approaching two megacycles per second will be achieved.

VI. MAGNETIC WIRE DRIVE

6.1 Level Winding Unit

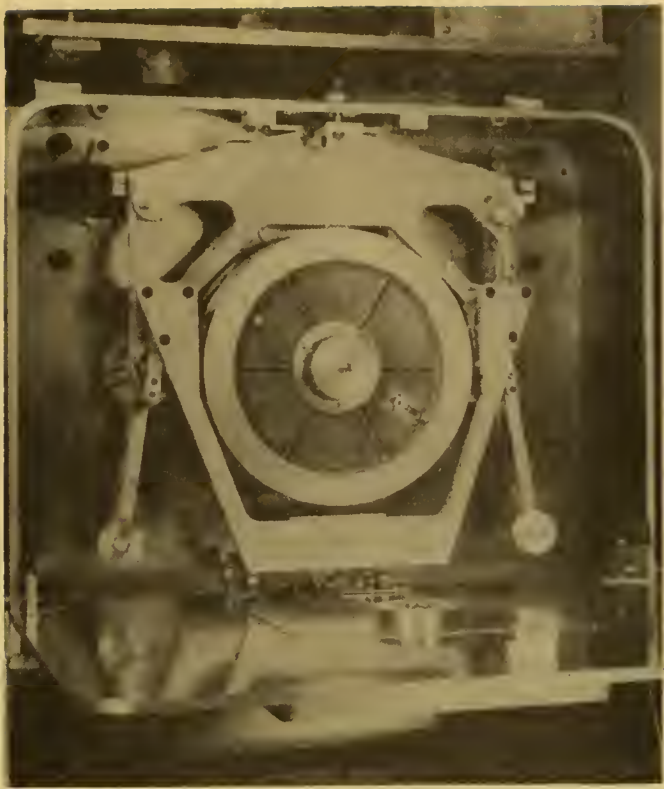
The description following deals with an essential part of the high-speed wire drive unit. The purpose of this component is to deposit the wire on the reels in an even layer. The section which accomplishes this we call the Level Winding Unit.

Note: In the photographs used in the following discussion, identical parts in different photographs are labelled with the same letter.

Photograph 4-a gives a view of the wire drive outer enclosure showing door open for access. Above the reels which are visible is a part of the level winding unit called the main mounting plate (A) which pivots at points B. Below the drive reels is the recording head mounting plate, C, which is fastened to the main mounting plate by the six screws D. Between the recording head mounting plate and the main mounting plate there is a space of about 5/8 of an inch. The recording head (seen from below in Photograph 6-c) is mounted on the lower wide section of the recording head mounting plate (in Photograph 4-a this location is on the opposite side of the plate to that shown and behind the location of the letter C). The main mounting plate bears the pulley arms and pulleys E. The path of the magnetic wire is from the inner reel, down under the left pulley, below the magnetic head which faces downward and lies below the tangent to the two pulleys, thereafter the wire passes under the right pulley and upward to the outer reel. The fact that the wire passes under the recording head prevents most of the dust from collecting in the gap since the sharp upward turns at the pulleys tend to throw off any dust particles that may be on the wire.

Photograph 4-a
Interior of Reels Chamber - Door Open

Photograph 4-b
Showing Point of Main [illegible] Drive Shaft and
Bell Crank Assembly



Photograph 4-a
Interior of Reels Chamber - Door open

Photograph 4-b
Driving Point of Main Wire Drive Shaft and Bell Crank Assembly

The entire unit, main mounting plate, recording head mounting plate, pulley arms and pulleys, recording head, etc. swings slowly back and forth in an arc about the pivot axis B-B. This unit is called the Wire Traverse Frame. Since the loop of magnetic wire passes around the pulleys and under the recording head, the back and forth arc motion of the pulleys and head is imposed on the wire loop. Thus, the loop is dragged back and forth across the face of the reels . Since the reels are rotating, this motion of the wire across the faces of the reels results in the placement of the wire on the reels in even layers.

The motion of the wire traverse frame about its pivots is caused by the gear and cam box of the level winding unit located on the door of the main enclosure. The direct connection between the wire traverse frame and the gear and cam box occurs at point F (Photograph 4-a). In order to explain how this connection is made and what causes the motion of the wire traverse frame, a discussion of the gear and cam box of the level winding unit is necessary.

In this discussion, reference will be made to the other photographs. Photograph 4-b shows the above mentioned joint (F) between the wire traverse frame and the gear and cam box. This photograph is really an enlarged and simplified version of the lower half of Photograph 4-a taken from the opposite angle. The wire drive reels and the entire wire traverse frame have been removed in Photograph 4-b. To show where the wire traverse frame would be, a dummy "broken section" of the lower left-hand corner of the recording head mounting plate (i.e., the part of the plate in which the connection with the gear and cam box is made at point F) is shown.

Photograph 5-a gives a view of the gear and cam box with the box cover removed. This view is taken from the outside of the door of the main enclosure.

Photographs 5-b, 6-a, and 6-b are exploded views of the interior of the gear and cam box. Photograph 6-c shows a view into the Inspection Mirror of the outer enclosure. The reflection in the mirror presents a view looking up into the main enclosure from below.

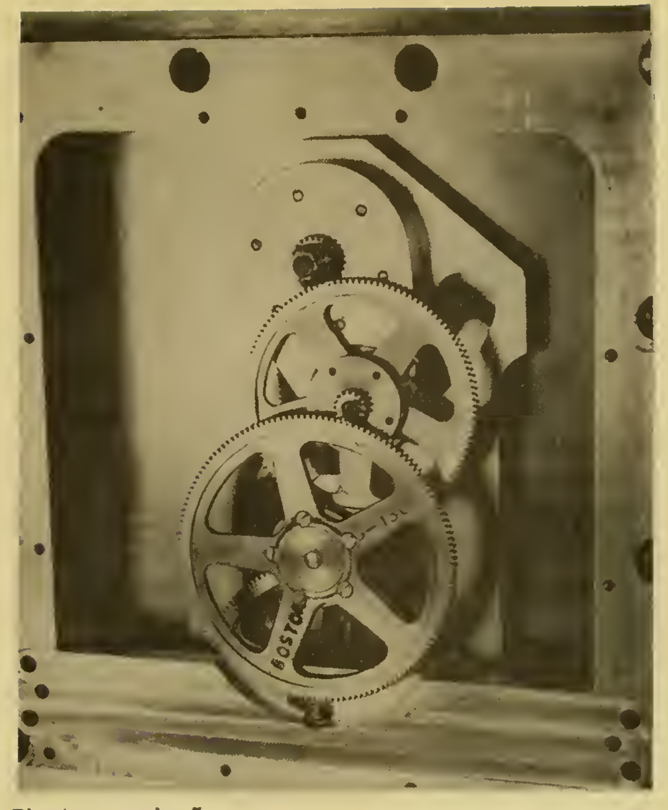
Photographs 4-a and 4-b show the door, G, of the wire drive main enclosure. The door turns on the hinges H. Because of the rectangular area cut out of the door to permit the mounting of the gear and cam box, the door is U-shaped. In this photograph we see the gear and cam mountig panel (I) which forms the rear face of the gear and cam box. The projection on the underside of the door shown in Photograph 4-a is the other side. In the above view of the door, the side which is outwards when closed, faces downward.

The motive force for the level winding unit is taken from the main wire drive motor that turns the reels at about 1750 revolutions per minute. The manner in which the motor connects with the gear and cam box of the level winding unit is shown in Photographs 4-a and 4-b. Point J is the end of the main shaft of the high speed wire drive unit. This shaft is turned by the main drive motor through a V-belt. The end J of the shaft contains two slots at right angles to each other (this is shown more clearly in Photograph 4-b). In Photographs 4-a and 4-b we also see the back of the gear and cam box (i.e.,the gear and cam mounting panel, I). At the top of this panel (in the foreground of the pictures) there is a circular projection. This projection houses the short main drive shaft for the gear and

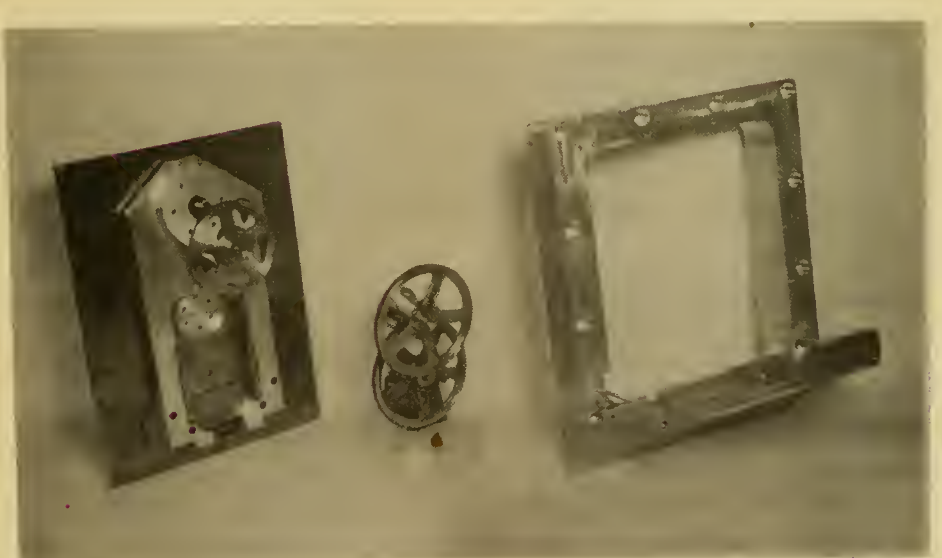
Photograph 5-a
Interior of Gear Box of Level Winding [illegible]

Photograph 5-b
Component Parts of Gear Box [illegible]

X
M
I
I
X
W
Y
M
Y
O

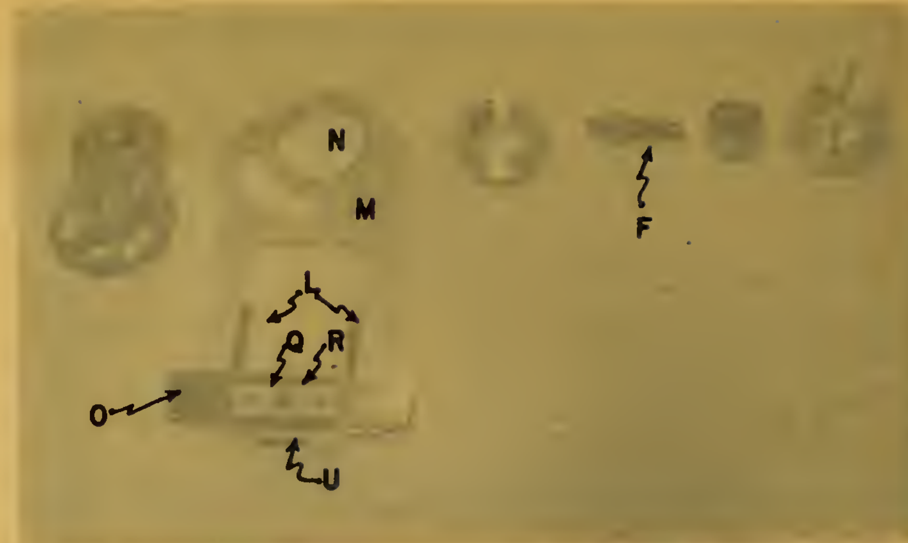


Photograph 5-a
Interior of Gear Box of Level Winding Unit



Photograph 5-b
Component Parts of Gear Box - Front View

Photograph 6-A
Component Parts of Gear Box, Rear View

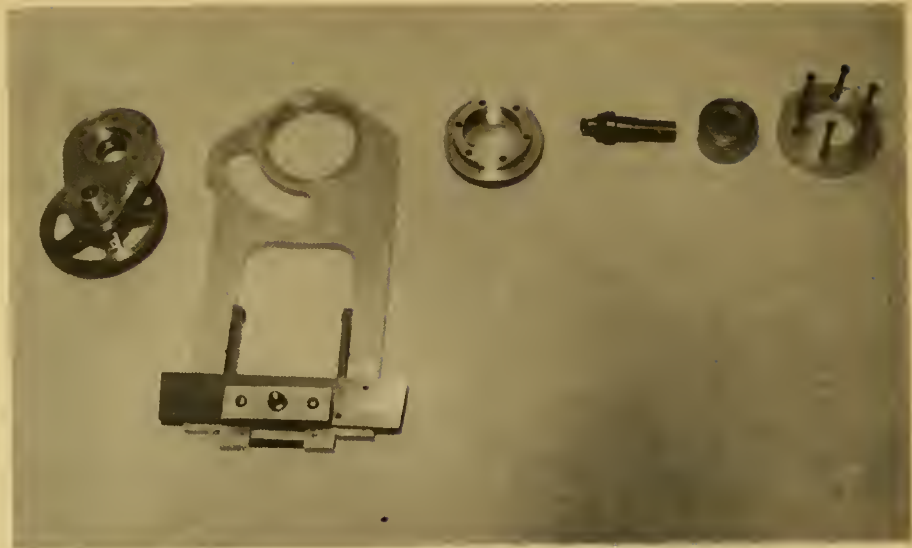


Photograph 6-B
Component Parts of First Gear Train and Cam Follower Assembly

Photograph 6-C
Interior of Reel Chamber seen via Inspection Mirror

Photograph 6-D
Wire-end Safety Shut-off Device

Photograph 6-A
Component Parts of Gear Box, Rear View



Photograph 6-B
Component Parts of First Gear Train and Cam Follower Assembly

Photograph 6-C
Interior of Reel Chamber seen via Inspection Mirror

Photograph 6-D
Wire-end Safety Shut-off Device

cam box and this shaft's principal ball bearing. This shaft has a hole part-way through it. In this hole lies a small steel tongue with a cross-section of about 1/4" wide and 1/16" thick. The tongue is pressed outwards at all times by a small spring. When the door is closed, the slotted end J of the main wire drive shaft enters the hole of the main drive shaft of the gear and cam box. The tongue carried in the shaft of the gear and cam box is forced against the slotted end of the central drive shaft carrying the reel system when the door is closed. If the slot and tongue planes do not happen to match when the door is shut, the tongue will be pushed into place by its spring as soon as the main drive motor is started and the main wire drive shaft has turned enough so that the tongue and slot planes are aligned. Thus, all that is necessary to engage and disengage the level winding unit with main drive system is to open and close the door of the main enclosure.

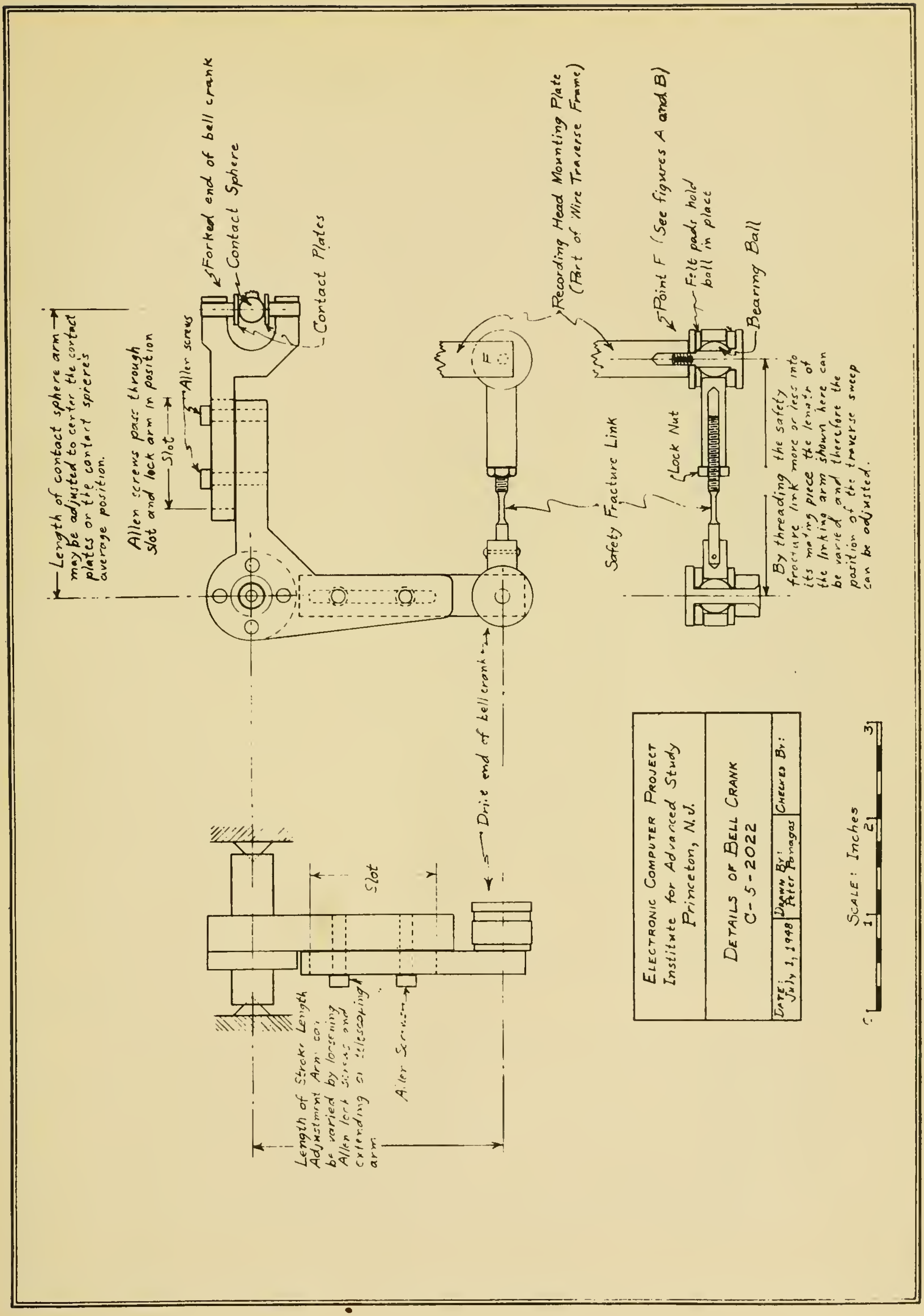
Photograph 5-a shows the gear train of the gear and cam box. The uppermost pinion is mounted on the other end of the main drive shaft of the gear and cam box. The speed of the drive pinion which rotates at the same speed as the drive shaft is reduced by the three speed reduction stages of the gear train.

The manner in which the wire traverse frame receives its slow, back and forth motion across the faces of the wire drive reels will be discussed next. Many details of the gear and cam box will be omitted here but covered later.

The speed of the drive pinion is reduced by the three speed reduction stages of the gear train. On the back of the last spur gear of the train is attached the cam, which is a slightly modified cardioid. This cam is shown most clearly at K in Photograph 6-a. The cam turns between two fixed, flat, ground steel runners (L in figure F) mounted on the cam follower plate M.

The cam follower plate is shown in Photographs 5-a, 5-b, and 6-b (most clearly in 6-b). The cam follower plate is mounted on the gear and cam mounting panel, I, by means of the large hole N shown at the top of this plate in Photograph 6-b (note that the center of the hole lies on the axis of the main drive shaft of the gear and cam box). The suspension of the cam follower plate is shown in Photograph 5-b. In this picture, the second and third gear speed reduction stages have been removed. As the cam turns slowly and pushes first on one end and then on the other runner of the cam follower plate, the plate is rocked from side to side about the center of the mounting hole N. Screwed to the bottoms of the legs of the cam follower plate is the cover and mounting bar (O in Photographs 5-b and 6-b). This bar not only helps to support the contact sphere (discussed later) but also serves to keep the radial slot in the gear and cam mounting panel (I) covered at all times (this slot, P, is best shown in Photograph 6-a). The mounting bar, O, provides a platform for mounting the contact sphere plate. This plate, with its contact sphere mounted in its center, is shown at Q in Photographs 4-a, 4-b, 6-a, 6-b. As seen, this plate Q with its contact sphere lies outside the gear box. Since the contact sphere R is rigidly connected to the cam follower plate M by means of the mounting bar O and the contact sphere plate Q, it rocks slowly back and forth in an arc about the center of the mounting hole N in the cam follower plate.

Photograph 4-b and Drawing C-5-2022 show the bell crank (S in Photograph 4-b). The bell crank pivots at T. The forked end of the bell crank encloses the contact sphere R. As this sphere moves from side to side the bell crank must follow it. The opposite or drive end of the bell crank has a similar motion imposed upon it except that its motion occurs in an arc whose chord is at right angles to the chord of the arc of the forked



Length of contact sphere arm may be adjusted to center the contact plates or the contact spheres average position.
Allen screws pass through slot and lock arm in position
Slot
Allen screws
Forked end of bell crank
Contact Sphere
Contact Plates
Recording Head Mounting Plate (Part of Wire Traverse Frame)
F
Point F (See figures A and B)
Felt pads hold ball in place
Bearing Ball
Safety Fracture Link
Lock Nut
By threading the safety fracture link more or less into its mating piece the length of the linking arm shown here can be varied and therefore the position of the traverse sweep can be adjusted.
Drive end of bellcrank
Slot
Length of Stroke Length Adjustment Arm can be varied by loosening Allen lock screws and extending or telescoping arm.
Allen Screws
Electronic Computer Project
Institute for Advanced Study
Princeton, N.J.
Details of Bell Crank
C-5-2022
Date: July 1, 1948
Drawn By: Peter Panagos
Checked By:
Scale: Inches
0
1
2
3

Figure I

end of the bell crank. The drive end of the bell crank is now moving back and forth in the same direction as the required motion of the wire traverse frame. The drive end of the bell crank is connected to the bottom edge of the wire traverse frame at F by a small link. Thus, the motion of the contact sphere and therefore the motion caused by the cam is transferred to the wire traverse frame.

By changing the gears in the gear train, it is possible to obtain many different gear reduction ratios ranging from 10:1 to 700:1. This means that it is possible to control the speed of rotation of the cam and therefore the traversing speed of the wire traverse frame. The greater the traversing speed of the frame the greater will be the distance between successive turns of wire on the faces of the reel. Thus by varying the gears in the gear box the wire traverse frame can be made to feed the wire loop across the 1-1/8" faces of the reels in 9.9 seconds which, at a main drive shaft speed of 1750 revolutions per minute, will lay adjacent turns of wire against each other (i.e., no space between turns) or the traverse time can be reduced to 1/4 of a second which will allow 1/4" of space between adjacent turns of wire. Thus, considerable variation is possible as to the manner in which the wire is placed on the reels by merely changing the gears in the gear train.

In order that the wire may be placed properly on the reels it is important that:

1. The length of the back and forth motion imparted to the wire loop by the wire traverse frame be equal to the width of the reel face;

2. The center of the traverse motion coincide with the center of the reel face, i.e., the beginning and end of the traverse sweep of the wire loop must start and end at the inner faces of the reel walls.

Adjustment of the bell crank makes it possible to meet these conditions.

Refer to Drawing C-5-2022 which consists of various views of the bell crank. Note that the contact sphere arm of the bell crank may be lengthened or shortened to insure that the contact sphere is properly enclosed by the contact plates on the forked end of this arm. The length of the wire traverse frame stroke may be increased or decreased within reasonable limits by increasing or decreasing the length of the stroke length adjustment arm of the bell crank as shown. This adjustment makes it possible to meet condition 1 given above. The positioning of the wire traverse frame stroke may be determined within limits by adjusting the length of the link joining the drive end of the bell crank with the wire traverse frame as shown in Drawing C-5-2022.

The link between the drive end of the bell crank and the wire traverse frame serves another very important function. Although the overall reduction ratio of the gear train may be varied a great number of almost uniform intervals from 10:1 to 700:1, it is most probably that the ratio used finally will be of the order of several hundreds to one. This means that a very powerful force may be exerted through the cam follower plate, contact sphere, bell crank and linkage, to the wire traverse frame. In the presence of such a large reduction ratio and consequently such a large force, the possibility must be considered that something may jam the wire traverse frame and keep it from moving (perhaps a tool or other object might carelessly be left in the main enclosure, the door shut, and the wire drive unit started). To provide for this emergency, the link between the drive end of the bell crank and the wire traverse frame is constructed partly of a piece of 1/8" diameter brass rod containing a weak fracture section as shown in Drawing C-5-2022. Any jamming of the wire traverse frame will cause this link to break before other very important parts of the level winding unit are overstressed and damaged.

At times it will be necessary to stop the operation of the wire drive unit and open the door to the reel chamber. At such times, it is desirable that the process of opening the door (which process, of course, moves the gear box mounted on the door), shall not shift the wire traverse frame thereby disturbing the position of the wire and perhaps breaking it. This motion of the wire traverse frame is prevented by locating the center of the contact sphere directly on the hinge line of the door. When the door is opened or closed, the contact sphere does not move but merely rotates about its own center. Since the process of opening and closing the door of the main enclosure does not move the contact sphere except by revolving about its own center, then the wire traverse frame is also left undisturbed. It can be seen in Photograph 4-a and Photograph 4-b that a line drawn through the door hinge centers does pass through the center of the contact sphere.

Drawing C-5-2023 shows the steel cam. As mentioned before, the cam used here is a slightly modified cardioid. It must be remembered that in a cardioid the distance across the figure measured in a straight line through its center is the same no matter which line through the center is chosen. The cardioid was slightly changed as shown in the drawing so that the distance across the cam between points of contact with two parallel planes is essentially constant; as a result the concave portion of the cardioid disappears and a slightly convex contour substituted. The result is that fixed, parallel, ground, steel runners may be used, eliminating the necessity of using a spring activated cam follower. The advantages of this cam follow system with fixed parallel runners are:

1. The pressure and therefore the wear between the dam and the cam follower is reduced to a minimum.

2. The distance between the parallel runners may be easily adjusted by slightly pulling together the legs of the follower plate by means of the adjusting screw U shown in Photograph 6-b until this distance is barely larger than the constant distance across the cam. This adjustment reduces the play between the cam and the cam follower runners (L in the photograph) to a minimum.

In order that the gear train may operate as quickly as possible, the play in the train must be reduced to a minimum. At the same time, ease of construction of the gear train is highly desirable. Also, the gear train must be so designed that the overall gear ratio may be varied very quickly by merely changing a few of the gears in the train. The method of satisfying all these conditions is described below. The gear train is composed of three individual units. Each unit is independent of the others both as to mounting and assembly.

At the left in Photograph 5-b is shown the cam and gear mounting panel. As shown, the panel contains the cam follower plate and the first gear train unit. The parts of this first gear train unit are show disassembled along the top of Photograph 6-b. Here we see the main drive shaft V of the gear train. Near the left end of this shaft is mounted the main drive pinion. This pinion is also shown in Photograph 5-a. The first gear train unit shown assembled and in place in Photograph 5-a and disassembled in Photograph 6-b contains the main drive pinion and first spur gear and (mounted on the same shaft as this first spur gear) the second pinion of the gear train.

Any one of five different main drive pinions together with their five mating spur gears may be used in the first stage of the gear reduction. Thus, the reduction ratio between the main drive pinion and the first spur gear may be varied from 5:1 to 1:1 in five steps. The position of the shaft mounting the first spur and second pinion gears may be varied a few thousandths of an inch. This adjustment is used to remove the play from between the main drive pinion and its mating spur gear.

The next gear train unit is shown partially in Photographs 5-a, 5-b, and 6-a. In Photograph 5-a the foremost and largest spur gear, seen in its entirety, is the spur gear of this second unit. In Photographs 5-b and 6-a this spur gear is the top gear in the center gear assemblies in these photographs. Photograph 6-a shows that this second spur gear is mounted on the end of a shaft which is supported in a tube that terminates in a large mounting flange. This mounting flange contains six screw clearance holes. On the cam and gear mounting panel of Photograph 5-b we see a circular, bright faced area with six tapped screw holes. This area is the face provided for securing the mounting flange of the second gear train unit. The six holes in this mounting flange are oversize clearance holes. Thus, the position of the shaft mounting this second spur gear may be varied slightly by moving the mounting flange.

The third and last pinion is mounted on the same shaft as this second spur gear. This pinion cannot be seen, however, since it is concealed in the flanged, supporting tube. This tube is partially out through so that a segment of the pinion is exposed and can contact the third and final spur gear.

The second spur gear may be replaced by larger or smaller gears. Also, the second pinion (on the first gear train unit) may be changed to any one of twenty-two gears. All that need be done when a new second pinion is used is to rotate the entire first gear unit about the main shaft center until the new second pinion contacts the second spur gear. Then the six screws are tightened, thereby locking the first gear train unit in position. It will be noted that this operation of rotating the first gear train unit until the second pinion meshes with the second spur gear practically eliminates all play from between them.

The final gear train unit appears in Photographs 5-b and 6-a as the lower spur gear of the center gear assemblies in these photographs. It is this unit that mounts the cam and the third and final spur gear. It will be noted that only in this third gear unit is the mounting shaft completely fixed. One bearing for this shaft is mounted in the gear and cam mounting panel, and the other bearing is mounted in a special bearing support bar, W, that is fastened to the side wall frame, X of the gear box. These bearings are marked Y in Photograph 5-b.

The procedure for assembling the gear train so as to eliminate the maximum amount of play is as follows:

1. Mount the third gear train unit in its fixed bearings (Y in Photograph 5-b).

2. Screw the second gear train unit in place against the gear and cam mounting panel leaving the screws loose. Move the unit by grasping its mounting flange until the third pinion is tight against the third spur gear. Holding the second unit in this position, lock it in place by tightening the six fastening screws.

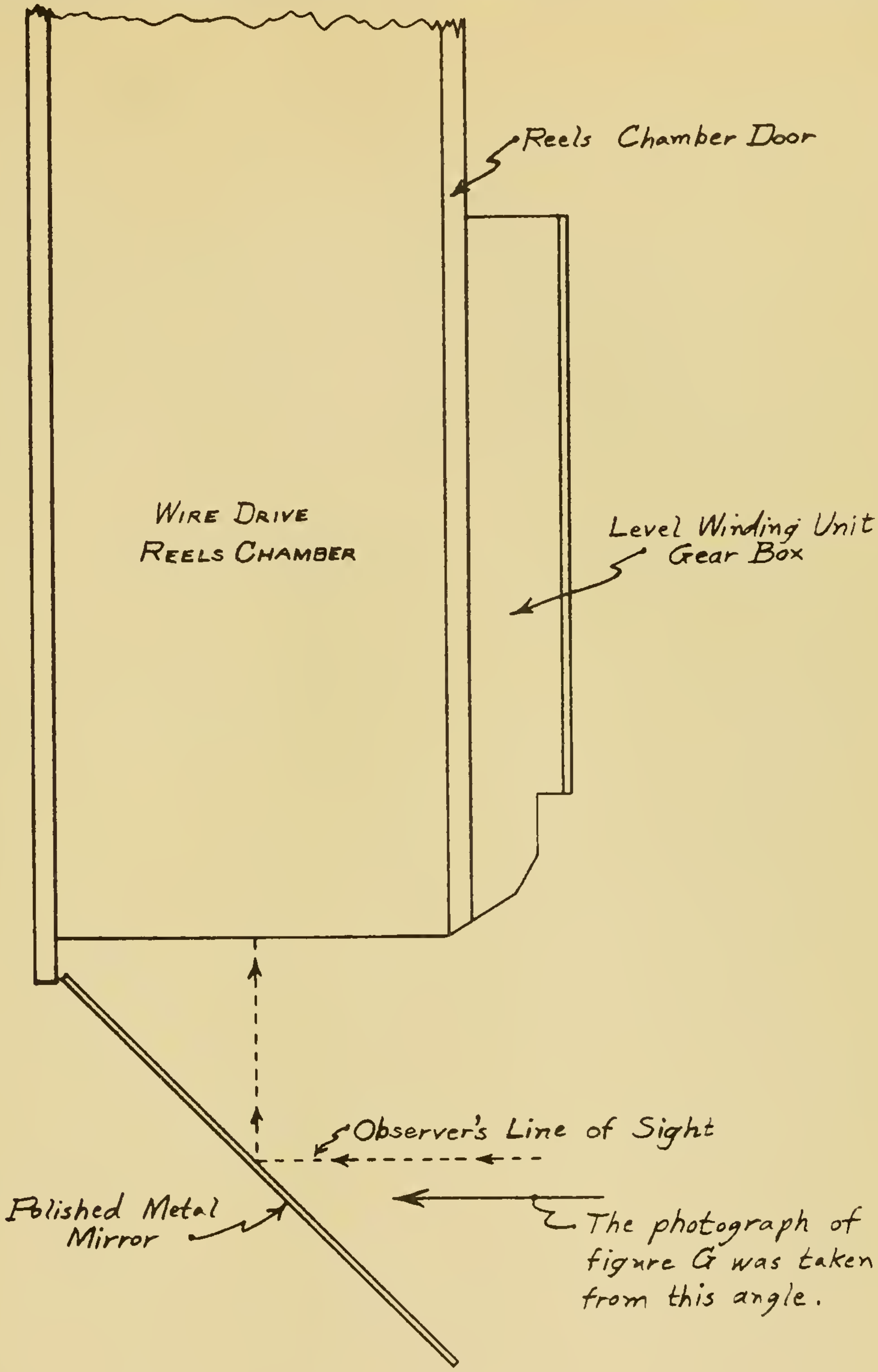
3. Adjust the position of the shaft mounting the first spur and second pinion gears until the play between the main drive pinion and the first spur gear is eliminated. Mount the first gear unit in place with the six locking screws loose. Rotate the unit until the second pinion is tight against the second spur gear and hold it in this position while tightening the six locking screws.

In this manner the gear train is assembled, and as much play is eliminated as is possible.

Photograph 6-c was taken looking into the inspection mirror. The location of this polished metal mirror is shown in Diagram C-5-2024. By looking into this mirror, one can inspect the level winding unit during operation. Note that in Photograph 6-c the following items discussed in the preceding pages may be clearly seen:

1. The recording head (block object in center) mounted on its plate.
2. The wire drive reels.
3. The bell crank with its safety fracture link.
4. The pulley arms and pulleys.

Photograph 6-d shows one of several safety features developed to automatically watch over the operation of the wire drive unit. This particular feature is for the purpose of preventing the wire drive unit from running so long in one direction as to run past the end of the wire on one of the reels. As shown, this unit consists of a slot cut in the face of the reel in which is mounted a small aluminum beam pivoted at one end. A leaf spring tends to keep the upper face of this beam projecting about 1/16" about the reel's face. On the end of this beam is fastened a small contact pin which passes through a hole in the wall of the reel. Since the leaf



Electronic Computer Project
Institute for Advanced Study
Princeton, N.J.

Location of Inspection Mirror
C-5-2024

Date:	Drawn By:	Checked By:
July 1, 1948	Peter Panagos	

spring tends to keep the beam up, it also tries to keep this pin projecting about 1/16" above the edge of the wall of the reel as shown in Photograph 6-d.

Let us assume that wire is being wound onto this reel. As strand after strand of the wire passes over the beam, it is pushed down until, when about one half of a layer of wire has been placed on the reel, the upper surface of the beam is flush with the face of the reel. This downward movement of the beam retracts the contact pin until it is completely contained within the wall of the reel.

Suppose the wire is unwound from this reel. As the last layer of wire is coming off the reel, the spring begins to slowly push the beam upwards. This upward motion of the beam pushes the contact pin out of its hole in the wall of the reel. By the time there is only one-half of a layer of wire left on the reel, the contact pin is completely exposed. As this pin rises, it begins to strike the contact leaf of a microswitch. When the pin has risen to its full height of about 1/16" above the edge of the wall of the reel (and it does this when only about one half of a layer of wire is left on the reel), it trips the microswitch,and the main drive motor is shut off.

There is one of these safety shut-off devices on each of the two reels.

6.2 Slow-speed Drive Unit

At times it is necessary to rotate very slowly the reels of the high speed wire drive unit in order that the teletypist may record the necessary information on the wire. For this recording operation, the speed of the wire must be in the neighborhood of one half to one inch per second. For such a wire speed, the reels must be turned at a speed of about one and one half to three revolutions per minute. This operation is performed by the slow drive section of the slow drive-brake unit.

When the wire drive reels are at rest, it is desirable that they be locked to keep them from turning. This will prevent the wire from "creeping". Should the reels receive a signal to stop, whether in the case of an emergency such as wire breakage or merely a routine stop order, it will be of advantage to stop the reels more rapidly than by merely turning off the power and letting them coast to a halt. The operations of locking the wire drive reels when they are at rest and stopping them rapidly when necessary are performed by the brake section of the slow drive-brake unit.

The preceding remarks are a preface to the following description of the slow drive-brake unit. This section of the High Speed Wire Drive is a unit in the true sense of the word. The slow drive-brake unit does not consist of two independent sections, one for braking and one for slow driving. Rather, these two functions of the unit are interdependent; the brake serving as a clutch for the slow drive section and the slow drive unit serving to transmit the torque from the brake to the standard relay rack which mounts the entire high speed wire drive unit.

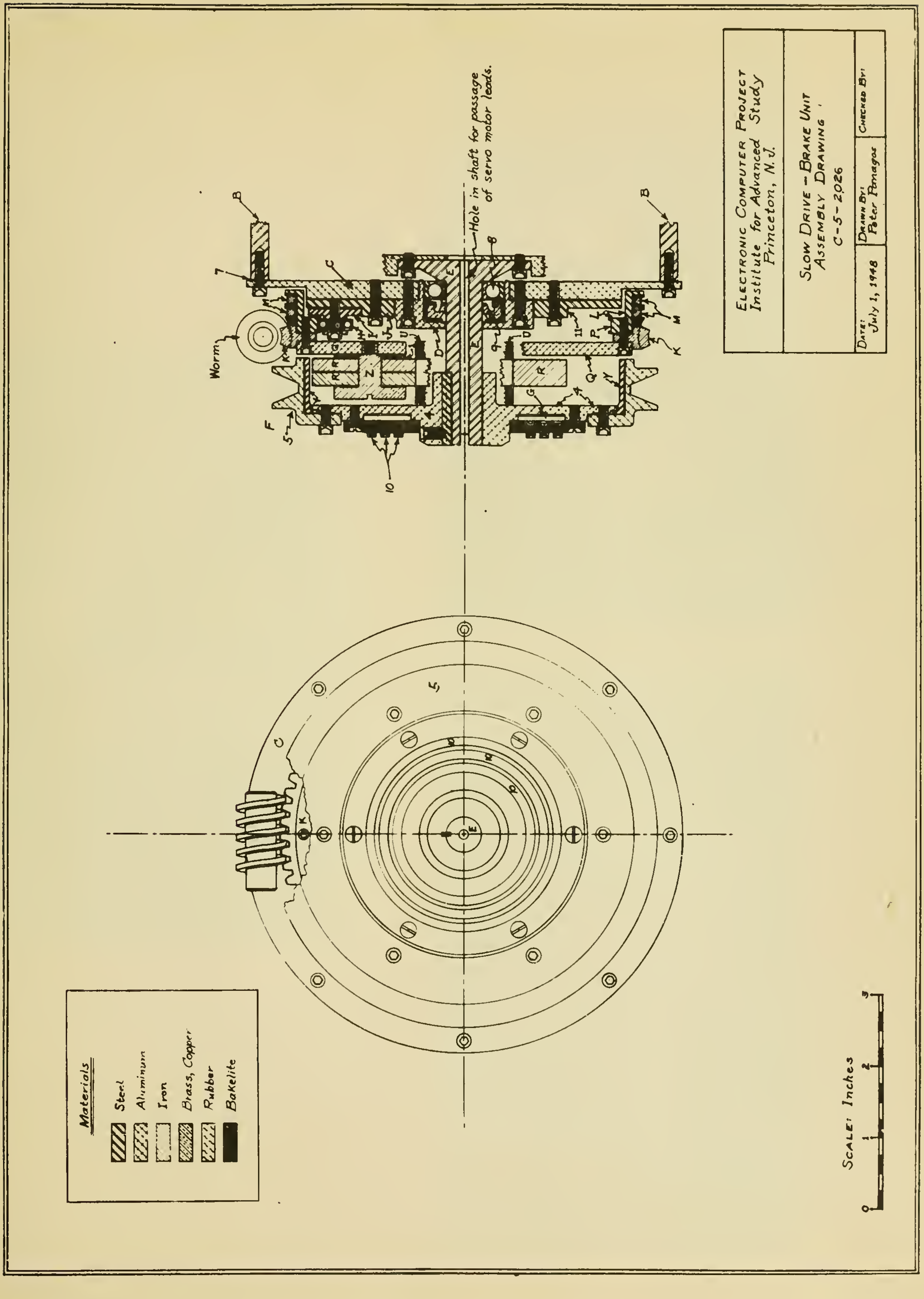
Drawing C-5-2026 is a sectional view of the slow drive-brake unit. This drawing shows the location and assembly of the various parts of this unit which will be described in the following pages. Because of the limitations of this type of drawing, only a few of the parts of the brake are shown. However, enough is shown to locate the brake. All brake parts are illustrated in later photographs.

Note that parts illustrated in more than one drawing or photograph are labelled with the same letters wherever they appear.

A glance at Drawing C-5-2026 and Photographs 13-a, b, c, will serve to locate the position of the slow drive-brake unit. Photograph 13-a shows the slow drive-brake unit completely assembled and in place. (A) is the 1/4" thick aluminum plate which mounts the entire high speed wire drive unit. This plate is screwed to a standard relay rack. These photographs are taken looking at the rear of this plate (i.e., the side opposite that on which the main enclosure lies). The steel tube (B) that encloses the servo motor (held in its square mounting shell 6) and the spur, worm, and worm gear for this motor are clearly illustrated in Photograph 13-b. This tube (B) is rigidly fastened to the main mounting plate (A). It is to the edge (7) of this tube that (Photograph 13-b) the slow drive-brake unit is screwed.

Photograph 13-c shows the circular mounting plate C screwed onto the edge (7) of the steel tube casing B. This is the mounting plate for the entire slow drive-brake unit. The circular aluminum piece B projecting from and screwed to the plate C is the cover plate and holder of the ball bearing (8) and the Garlock Klozure oil seal (9) through which the shaft E passes. The three wires seen protruding from the end of the shaft are the servo motor leads. These wires pass out radially through a slot in the hub of the V-belt pulley. This pulley F is shown in Drawing C-5-2026 and Photographs 13-a and 15-c. After passing through the radial hole in the pulley hub, the lead wires pass into the annular chamber G (C-5-2026) where each wire is fastened to its slip ring. These three slip rings (10) are shown in C-5-2026 and photograph 13-a.

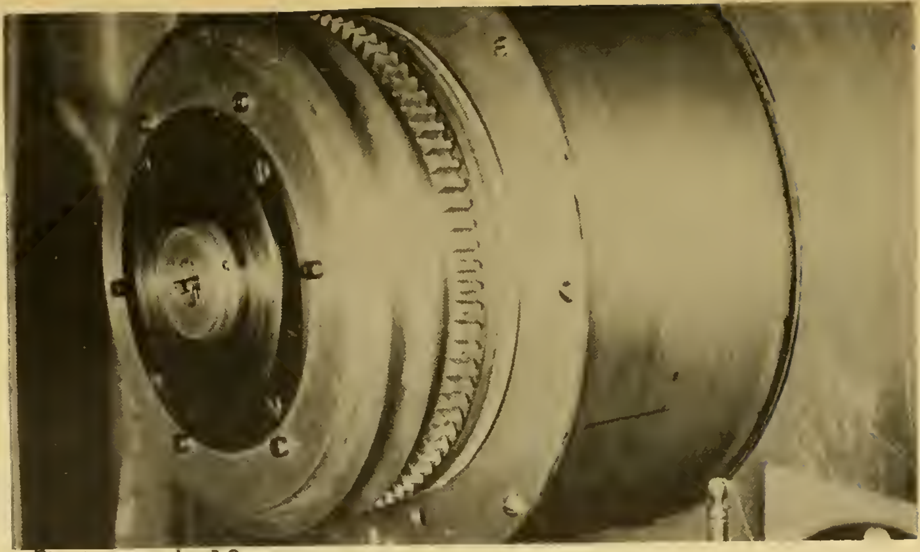
Fitted on the outside diameter of the bearing cover and mounting plate D and screwed to the main mounting plate C is the plate J (Photograph 14-a) that mounts the slow drive bearings H. Each bearing is mounted on its own small steel mounting disk (I) as shown in Photograph 14-b. The outside diameters of these steel bearing mounting disks (I) are 3/4" and contain


ELECTRONIC COMPUTER PROJECT
Institute for Advanced Study
Princeton, N.J.
SLOW DRIVE – BRAKE UNIT
ASSEMBLY DRAWING
C-5-2026
DATE: July 1, 1948
DRAWN BY: Peter Panagos
CHECKED BY:
Hole in shaft for passage of servo motor leads.
Worm
Materials
Steel
Aluminum
Iron
Brass, Copper
Rubber
Bakelite
SCALE: Inches
0
1
2
3

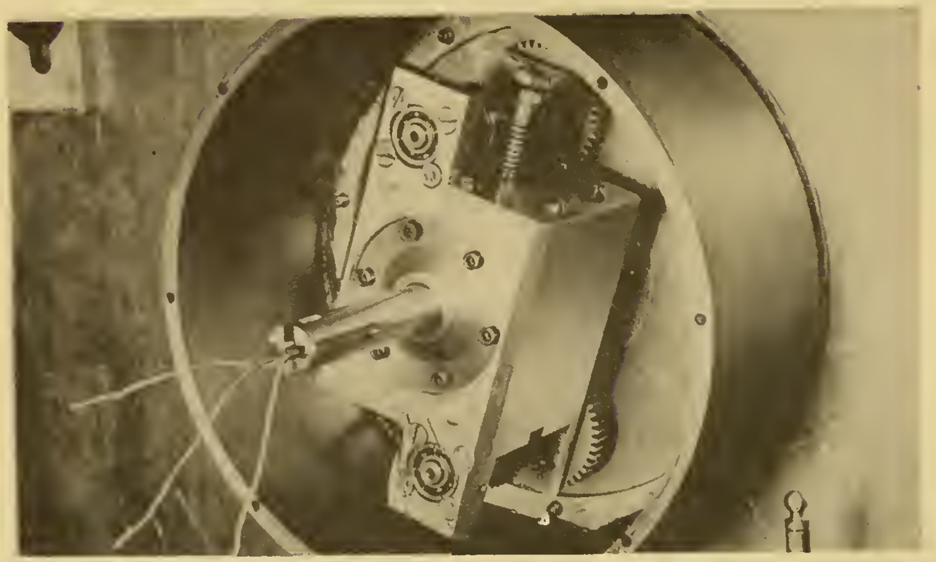
Photograph [illegible]
[illegible]

Photograph [illegible]
Servo Motor and Mechanism

Photograph [illegible]
Mounting of Slow Drive Brake Unit



Photograph 13-a
Complete Slow Drive and Brake Unit



Photograph 13-b
Servo Motor and Mechanism

Photograph 13-c
Mounting of Slow Drive Brake Unit

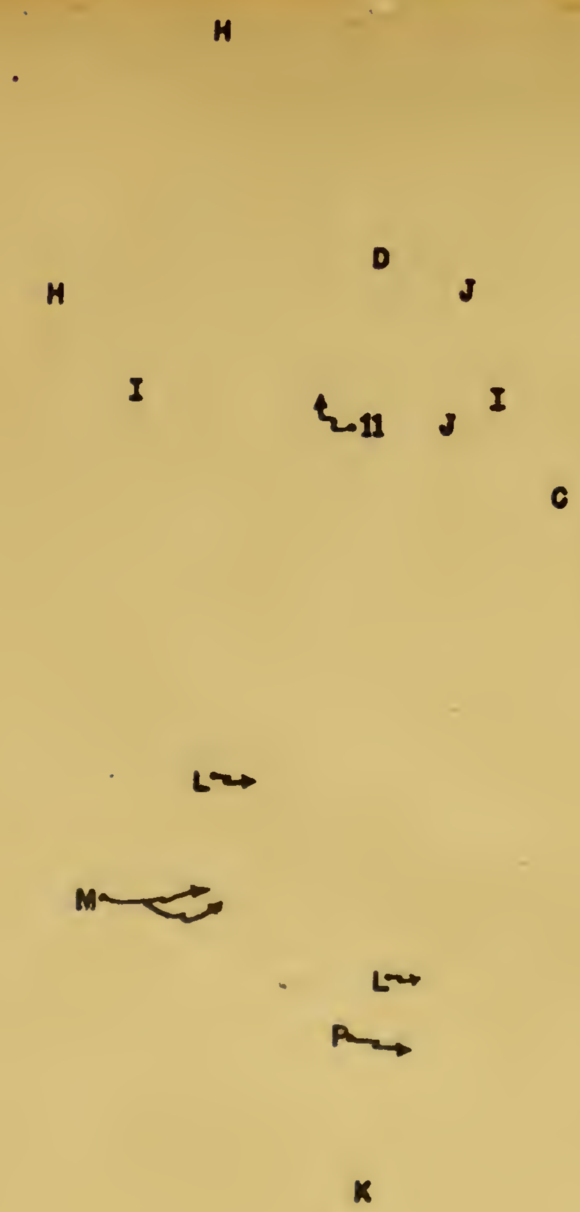
small rectangular notches so that they may be turned with a wrench or screw-driver for adjustment. The bearings have outside diameters of 1/2" and bores of 3/16". In Photograph 14-b the manner in which the bearings H are mounted on their mounting disks (I) is shown. At the left we see a bearing pressed onto the cylindrical, shaft-like projection which is an integral part of the small steel bearing mounting disk. Through this mounting "shaft" is drilled a clearance hole for a 5-40 Allen cap screw. This hole is concentric with 3/4" notched outside diameter of the mounting disk (I). As seen, the bearing mounting shaft is not concentric with the screw hole and therefore is not concentric with the outside diameter of the disk. Instead, the shaft is 1/64" off center so that the wall thickness of the shaft varies from 1/64" to 3/64". This off-center mounting of the shaft causes the mounting of the bearing on the disk to be eccentric. After the bearings and their mounts are screwed to the mounting plate J (Photograph 14-a), their positions may be adjusted as follows. Loosen the Allen cap screw; using the notches in its outside diameter, turn the bearing mounting disk (I) about the mounting screw in the desired direction. Since the bearings are mounted eccentrically with relation to these screws and the outside diameters of the steel bearing mounting disks, they may be moved radially a total of 1/32" by turning the mounting disks. It will be noticed in C-5-2026 and Photograph 14-a that the outside diameters of the mounting disks rest on the ledge (11) of the plate J. Thus, the major part of any force exerted on the bearings is not absorbed by the mounting screws, but transferred through the bearing mounting disks (I) to the main plate J. As shown in these two diagrams and again at the right of Photograph 14-b, a special steel washer is used under the head of each bearing mounting screw. This washer presses against the edge of the inner face of the bearing.

Photograph 14-a
Main Mounting Plate and Bearing Mounting Plate

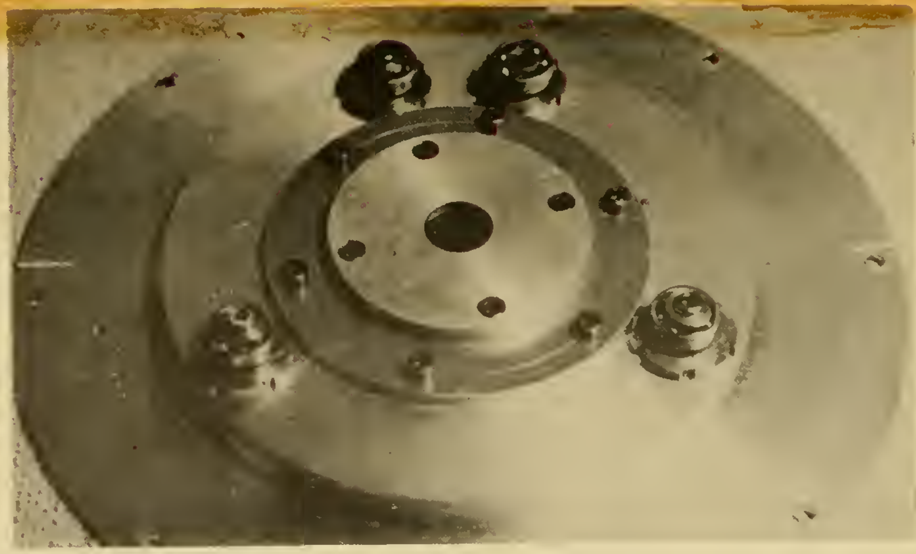
Photograph 14-b
Detail of Bearing Mounts

Photograph 14-c
Ring Gear, Steel Track, and Slip Rings of Slow Drive

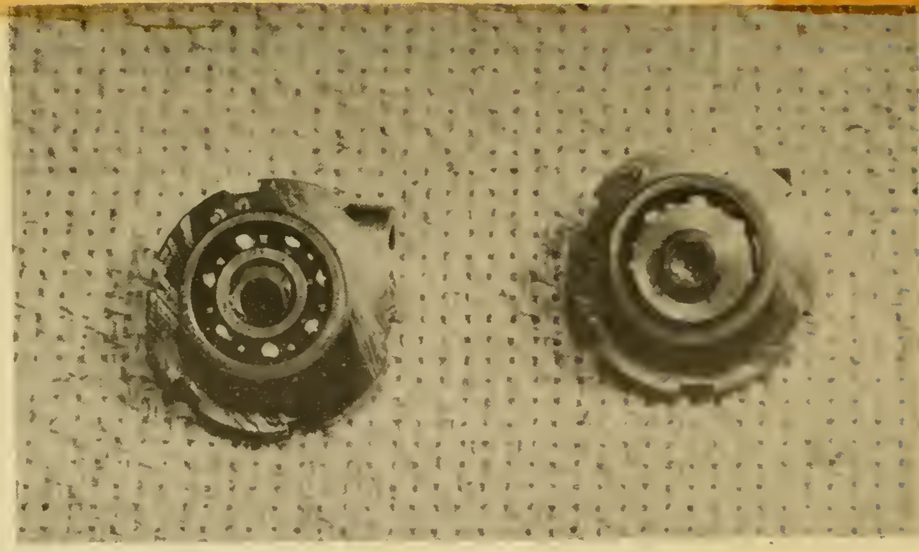
Photograph 14-d
Ring Assembly Mounted on Bearing


H
H
D
J
I
11
J
I
C
L
M
L
P
K

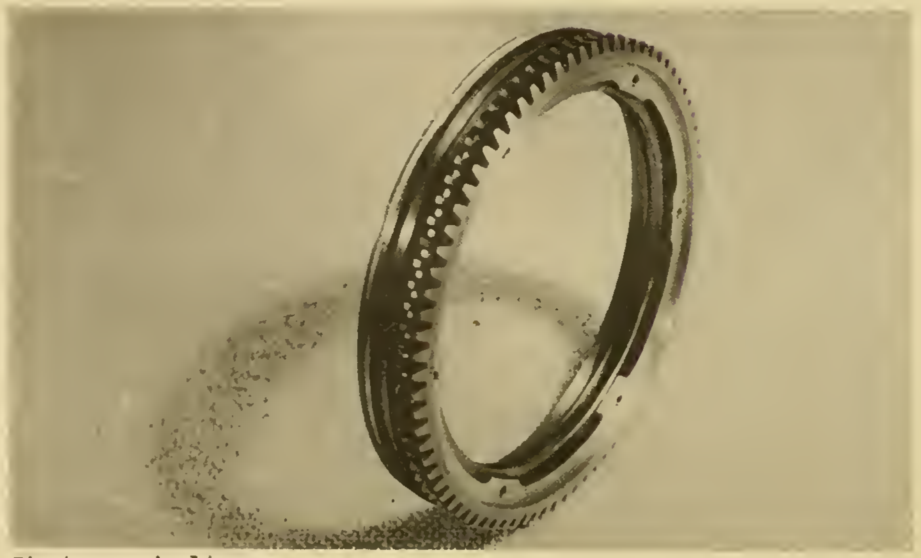

H
I
H
I
K
L
P
P
D
J
L
C



Photograph 14-a
Main Mounting Plate and Bearing Mounting Plate



Photograph 14-b
Detail of Bearing Mounts



Photograph 14-c
Worm Gear, Steel Track, and Slip Rings of Slow Drive

Photograph 14-d
Worm Assembly Mounted on Bearing

To explain the use of the slow drive bearings H we refer to Drawing C-5-2026 and photographs 14-c and 14-d. Here we see the worm gear K of the slow drive. Fitted into this gear is the steel track ring L. This ring has mounted on it two insulated copper slip rings M which serve as contacts for the brake coils, U, discussed later. These copper slip rings and their bakelite insulators are clamped between the wall of the steel track ring L and the face of the worm gear K. This is shown principally in C-5-2026 and also in Photographs 14-c, 14-d, 15-a, and 15-c. As indicated by its name, the steel track ring contains a track P. As shown in Photograph 14-d, the slow drive bearings ride in this track. Therefore, the bearings support the steel track ring and the worm gear attached to it and permit this gear to rotate without the necessity of mounting it on the main shaft E. The adjustment provided by eccentrically mounting the slow drive bearings H is used to make sure that the worm gear runs concentric with the main drive shaft E. With a jig, the worm gear is held concentric with the shaft E. Then each bearing mounting disk is rotated until its bearing contacts the track. In this position, the screw is tightened, and the bearing is locked in place.

As seen, the worm gear K is mounted at three points, 120 degrees apart. The uppermost support "point" is supplied with two bearings, and the other two support points have one bearing each. The reason for placing two bearings at the uppermost support point is that this is the place where the worm contacts the worm gear. Doubling the number of bearings at this point provides extra support to take the thrust of the worm which will be held against the worm gear under spring action to eliminate play between them.

Photograph 15-a
Detail of Brake Mounting Plate

Photograph 15-b
Disassembled Brake Unit

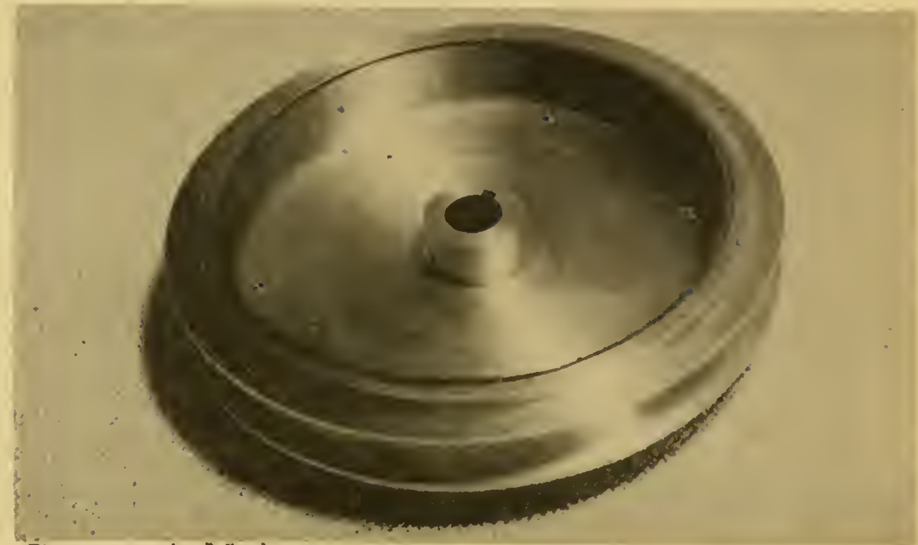
Photograph 15-c
Mounted Brake Unit

Photograph 15-d
Main Drive Pulley and Brake Drum

Photograph 15-a
Detail of Brake Mounting Plate

Photograph 15-b
Disassembled Brake Unit

Photograph 15-c
Mounted Brake Unit



Photograph 15-d
Main Drive Pulley and Brake Drum

On the other side of the worm gear is fastened the brake mounting plate Q shown in C-5-2026 and Photograph 15-a. Note that the worm gear is clamped between the brake mounting plate Q and the steel track ring L. This is best seen in C-5-2026.

Photograph 15-b shows the brake disassembled, and Photograph 15-c shows it assembled and mounted on its mounting plate Q. The brake consists partly of two iron arms R. These arms have a large cross section making the reluctance of the magnetic circuit through the iron very low. The width of the arms increases greatly at the top where they interlock and are pinned together through the holes S. Although the thickness of the arms in the pivot area is one half that at any other section, the cross sectional area of the arms is unchanged due to the more than doubled width in that area. The air gap in the magnetic circuit at the pivot area is kept very small by finishing the contact surfaces very carefully. This minimum air gap together with the large contact area serves to minimize the reluctance of the air gap. The ends of the brake arms opposite the pivot interlock in a tongue and groove manner. This is seen in Photograph 15-b in which the mating arm ends are labelled T. Photograph 15-c shows the coils U that activate the brake. These coils are wound directly on the brake arms. In Photograph 15-b one of the coils is removed to reveal the brake arm completely. Photographs 15-b and 15-c also show the brass brake shoes X. The brake lining that will be fastened to these shoes is not shown.

On the ends of the brake arms opposite the pivot are fastened two brass plates V (Photographs 15-b and 15-c). Each plate mounts a small brass post W. In assembly, as shown in Photograph 15-c, these plates cross each other in such a manner as to form an X. A spring, N, is stretched across these posts.

The pull of this spring forces the brake shoes outwards against the steel brake drum Y on the inside of the V-belt pulley (Photograph 15-d). To release the brake, the coils are energized, and the brake arms pull together thereby pulling the shoes and their linings away from the brake drum. Notice in Photograph 15-b that each of the brass plates V which mount the spring posts are fastened to the brake arms with two Allen cap screws passing through slots. These slots enable the plate positions to be adjusted thereby increasing or decreasing the distance between the spring posts. Thus, with a given spring, the spring tension can be varied by moving these plates.

Means have been provided for guidance of the brake arms so that in operation they will not tend to twist out of their proper plane. At the pivot end, the pivot shaft Z has been provided with a head of large outside diameter (Photograph 15-c). Between the brake arms and the brake mounting plate Q is a brass washer (No. 1 in C-5-2026). This washer has the same large outside diameter as the head of the pivot shaft Z. This washer keeps the brake arms from rubbing against the brake mounting plate Q and also serves to raise the brake arms enough to permit insertion of the bottom spring post mounting plate V between its brake arm and the brake mounting plate. The spring ends of the brake arms are guided by passing between the brake mounting plate Q and the brass triangular guide plate (2) as shown in Photograph 15-c.

Drawing C-5-2026 and Photographs 13-a and 15-d show the V-belt drive pulley (F). This pulley is made of three sections. One section is the disk (4) containing the hub. To the face of this disk is screwed the bakelite plate on which the servo motor slip rings (10) are mounted. Another section is the annular ring (5) which has cut into its outside diameter the V-groove for the belt. The third part of the pulley assembly is the steel lining Y of

the annular ring (5). As stated before, this steel lining forms the brake drum of the slow drive-brake unit. As seen in C-5-2026, this steel lining Y is clamped between the disk (4) and the V-belt ring (5), in addition to fitting into the V-belt ring (5) with a light press fit. The pulley is keyed to the shaft E. The keyway is seen on the shaft in Photograph 13-b and in the pulley hub in Photograph 15-d.

Now that the components of the slow drive-brake unit have been described, a few words will suffice to explain the operation of the unit. Notice that the entire brake assembly is fastened by means of the brake mounting plate Q to the worm gear K. The slip rings M are mounted on the track ring L which is also fastened to the worm gear. Thus, the slip rings rotate with the brake assembly (i.e., there is no relative motion between them), and therefore the brake coil leads need only be directly connected (screwed or soldered) to the rings to be ready to receive current to energize the coils.

Let us assume that the high speed wire drive is running, and it is necessary to stop it quickly by means of the brake. While the main drive motor is operating, the brake coils are energized, thereby keeping the brake lining clear of the drum Y. When the signal to stop the reels is received, the current in the main drive motor and the brake coils is shut off. The brake spring now takes over, pulls the brake arms out and forces the brake linings tightly against the brake drum which, of course, is part of the pulley. Thus the drive reels which are connected to the pulley through the shaft E are stopped. The torque absorbed by the brake assembly in this braking operation is transmitted by the brake shoes and arms through the pivot to the brake mounting plate Q. From this plate it passes through the worm gear to the worm. From the worm, the braking torque passes into the motor that drives the worm and thence into the main high speed wire drive mounting plate A on which this motor is mounted. Thus, the braking system of the

slow drive-brake unit is firmly connected to the mounting plate A (and therefore also to the relay rack).

Whenever it is desired to record data on the wire, a switch is thrown by the teletype operator. Throwing this switch turns off the main drive motor and cuts off the current in the brake coils thereby allowing the brake spring to force the brake linings against the steel brake drum of the pulley. Then when the teletype operator begins typing, the worm drive motor turns on. This motor drives the worm and therefore the worm gear. Since the brake assembly is rigidly fastened to the worm gear at all times, the brake rotates also. However, the brake shoes are now clamped against the steel drum of the pulley, and therefore the pulley is turned. Thus, the worm drive motor turns the pulley which in turn drives the wire reels that are connected to the pulley through the main shaft E. The worm drive motor is a gear reduction motor. This speed reduction together with the speed reduction between the worm and worm gear of the slow drive-brake unit causes the reels to be turned at the slow recording rate of from one to one-half to three revolutions per minute.

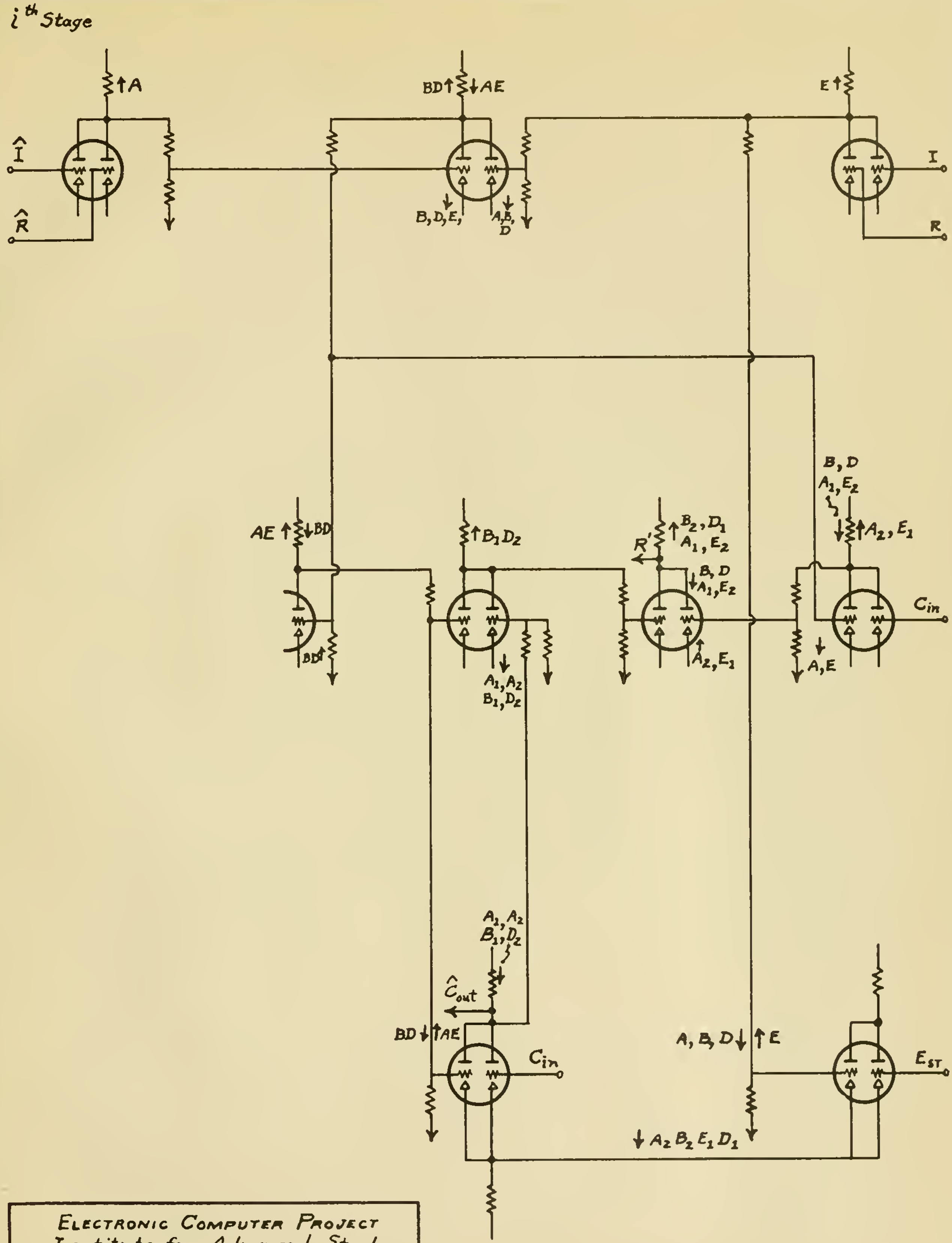
When the high speed wire drive unit is not operating, the brake coils are deenergized and therefore the brake is on. Thus, when the high speed wire drive unit is off, the reels are locked and creeping of the wire is prevented.

VII. REMARKS ON LOGICAL (NON-KIRCHOFF) ADDERS

The computing machine at present being constructed by our group utilizes an adder of "Kirchoff Law" network summation type. This adder is the culmination of a long series of experimental and schematic developments carried out from May to November 1947, all directed toward this type of analogue current-voltage adding circuit.

During the period July-August 1947, one member of our group observed that the use of Kirchoff Law current and voltage summation in an adder intended to handle binary information is certainly unnecessary, is somewhat inconsistent with the circuit componentry used elsewhere in the machine, and may be undesirable from the standpoint of speed and simplicity. A direct synthesis of logical binary gating adders by means of strictly two-level gates was proposed, and in August 1947 complete circuit details of a workable unit of this type were formulated. However, because of the advanced state of development of the work of the group on Kirchoff Law adder circuits, this technique was relegated to second priority, and it was decided as a matter of policy to continue with the construction of the first full-scale machine using the Kirchoff adder.

However, some further work was meanwhile carried out on logical "gating adders" as opposed to the analogue type, and many promising circuits of gating type were evolved. In fact, the technique of designing such circuits was clarified and simplified, and it was found that by means of a few simple types of direct-acting positive gates like those used in our latest shifting register and counter, adder circuits of many types could be directly formulated, and built directly in fast and reliable operating form immediately. Typical of the results of these techniques is the circuit C-?-1069, "Logical Binary Adder No. 3".



ELECTRONIC COMPUTER PROJECT
Institute for Advanced Study
Princeton, N.J.

LOGICAL BINARY ADDER No. 3
C-3-1069

DATE:	DRAWN BY:	CHECKED BY:
Dec. 21, 1948	Peter Panagos	

This example of the adder contains only the simplest binary gates operating so as to discriminate all signals into two classes according to whether they are "greater than" or "less than" a single standard. The schedule of gating operations is

	B		E		D		A	A
	1	2	1	2	1	2		
I (incident)	1	0	0	0	1	0	1	1
R (resident)	0	1	0	0	0	1	1	1
C (carry)	1	0	0	1	0	1	1	0
C' (new carry)	1	0	0	0	0	0	1	1
R' (new resident)	0	1	0	1	1	0	1	0

On the circuit diagram C-3-1069 the gates effecting these decisions are marked with an arrow showing a direction of voltage excursion, and the alphabetic symbols designating the categories of digits producing this excursion.

The particular circuit shown was actually constructed in experimental form during February 1948. The performance indicated by these tests was very satisfactory, carry times on the order of .1 microsecond per stage being achieved.

Many other types of logical circuit achievable by direct gating techniques have been under study, particularly in connection with the problem of central control of the arithmetic unit. It is expected to discuss these, and the technique as a whole, in a later monograph.

At some later time it is expected to replace the Kirchoff adder now being used in our first model of computing machine by a logical "gating" type, but this does not seem urgent at the present time, since both units are capable of satisfactory performance.

[illegible]