7-1-1962

Inexpensive Digital-to-Analog Converter for Curve Plotting with Small Digital Computers

G. W. Hughes
Purdue University

W. J. Eccles
Purdue University

TR-EE 62-14
NATIONAL SCIENCE F ION CONTRACT G-17754
PRF 0531

PUR UNIVERSITY
SC OF ELECTRICAL ENGINEERING

Inexpensive Digital-to-Analog Converter for Curve Plotting with Small Digital Computers

G. W. Hughes, Principal Investigator
W. J. Eccles

July, 1962
Lafayette, Indiana

PREPARED UNDER
NATIONAL SCIENCE FOUNDATION CONTRACT G-17754
PRF 0531

INEXPENSIVE DIGITAL-to-ANALOG CONVERTER FOR CURVE PLOTTING WITH SMALL DIGITAL COMPUTERS

G. W. Hughes, Principal Investigator
W. J. Eccles

NATIONAL SCIENCE FOUNDATION CONTRACT G-17754
Report TR-EE62-14
July 30, 1962

School of Electrical Engineering
Purdue University
Lafayette, Indiana

CONTENTS

LIST OF ILLUSTRATIONS

ABSTRACT

The use of the digital computer in engineering schools, with its ability to produce huge tables of results, soon causes the user to wonder if these results cannot be reduced to graphical form automatically. The equipment described here takes the numerical output of a digital computer on punched paper tape, converts the information on the tape to analog voltages, and uses these voltages to plot a point either on a common camera-equipped oscilloscope or on an available plotting table. Since the converter makes use of existing display equipment which every school has, uses low-cost relays, and works at a low speed, its cost is about $200, not including the tape reader. Complete details on design and construction are given.

Chapter 1

INTRODUCTION

Design and construction of a low-cost digital-to-analog plotter was the purpose of this project. Three principles were established at the outset in order to achieve this result. First, the plotting portion of the device would be a plotting table or an oscilloscope with a camera, since one of these two pieces of equipment would likely be available wherever the plotter was to be used. Hence the user would not have to purchase special display equipment. Second, the control circuits would make use of inexpensive relays rather than vacuum tubes or transistors, since it is still possible to build good switching circuitry using relays for a smaller cost than using electronic devices. This restriction naturally makes the operation slow, but high-speed plotting was not a design condition. Third, operation would be from paper tape, which is the common output medium for all of the small digital computers on the market today.

The circuit cost, excluding the tape reader and the labor for assembly, is about $200. This cost can be reduced by eliminating parts of the circuit which are not required, since the plotter presented here has been designed to be somewhat more general than is required in the typical application. The speed is quite low, about one point per second, but this is still quite a bit faster than a human being can plot points manually.

The description which follows begins with a synopsis of the basic design. This is followed by a detailed description of the operation of the entire system. Then there are a few notes on the construction, to bring attention to the points which may cause some question from the builder. Finally, there is a discussion of the adjustments, the display equipment, the digital computer programming required, the use of the plotter, and some of the changes which can be made to make the system less general and therefore less expensive. Complete circuit drawings and parts lists are included.

Chapter 2

DESIGN

The basic design consists of a tape reader, a relay translator to accept the information from the tape, a resistor network summer, and cathode-follower holding circuits to retain the current values of the variables. In addition, there are relay circuits to display the point and a stabilized power supply to provide the summation voltages.

2.1 - Tape Layout

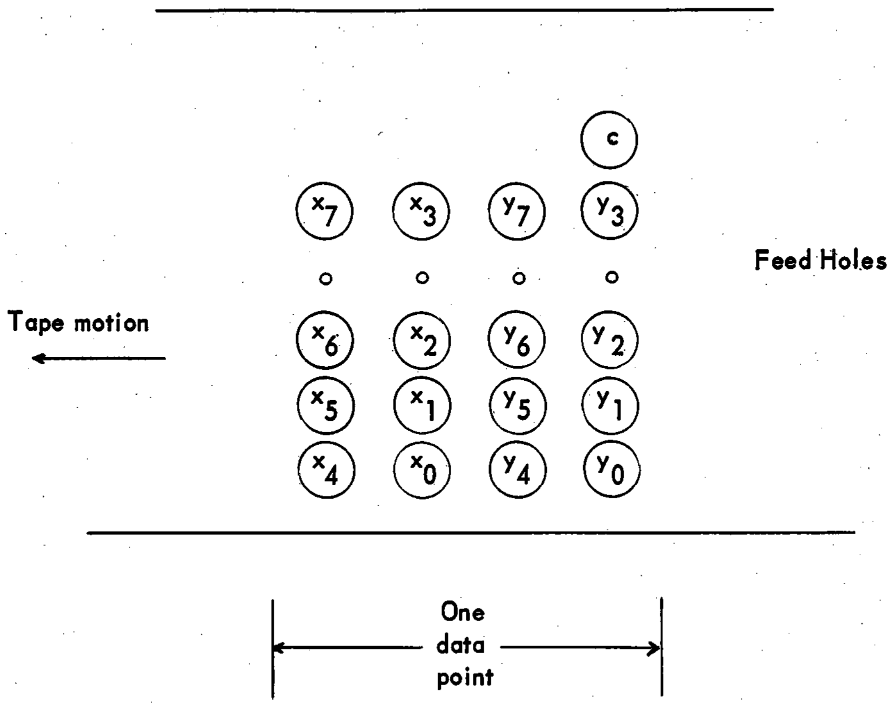
The coding of the punched tape was chosen so that the tape could be punched within the operating restrictions of most digital computers now in use. The smallest number of holes per character punched by any machine is five. Hence the code was chosen to make use of just five holes, although many machines can punch a greater number. Since one hole is needed for control of the relay circuits, only four data holes per line of tape are possible. Four bits do not give sufficient plotting precision, so two lines of tape are used to represent each of the x and y values of the datum point. (See Figure 1.) Every point has both coordinates given, first x, and then y. The control hole, which is the fifth hole on the tape, is punched along with the second half of the y value. This hole is used to insure that the relays are still synchronized with the tape reader and also to initiate the actual display of the point.

2.2 - General Operation

The signals from the various holes on the tape are routed to a relay network via a stepping switch which determines where in this network the information is to go. The first four bits of the x value are sent to the first four relays in the summation network; the second four are sent to the second four relays. The voltage representing this value of x is stored in a holding circuit. The relays are then released and the y information is stored in the same way. When the control hole is read, the point is displayed on the output device. On an oscilloscope, the point is displayed immediately. On a plotting table, the pen is not lowered until the error signals from the servo amplifiers on each axis have reached zero. After plotting one point, the tape moves on to the next set of holes and the above operation is repeated.

2.3 - Summation

Summation of voltages is done using a technique common in potentiometer construction. (See Figure 2.) Two identical strings of



x_7 is high-order bit in the value of x

x_0 is low-order bit in the value of x

y_7 is high-order bit in the value of y

y_0 is low-order bit in the value of y

c is the control bit

TAPE LAYOUT

Figure 1

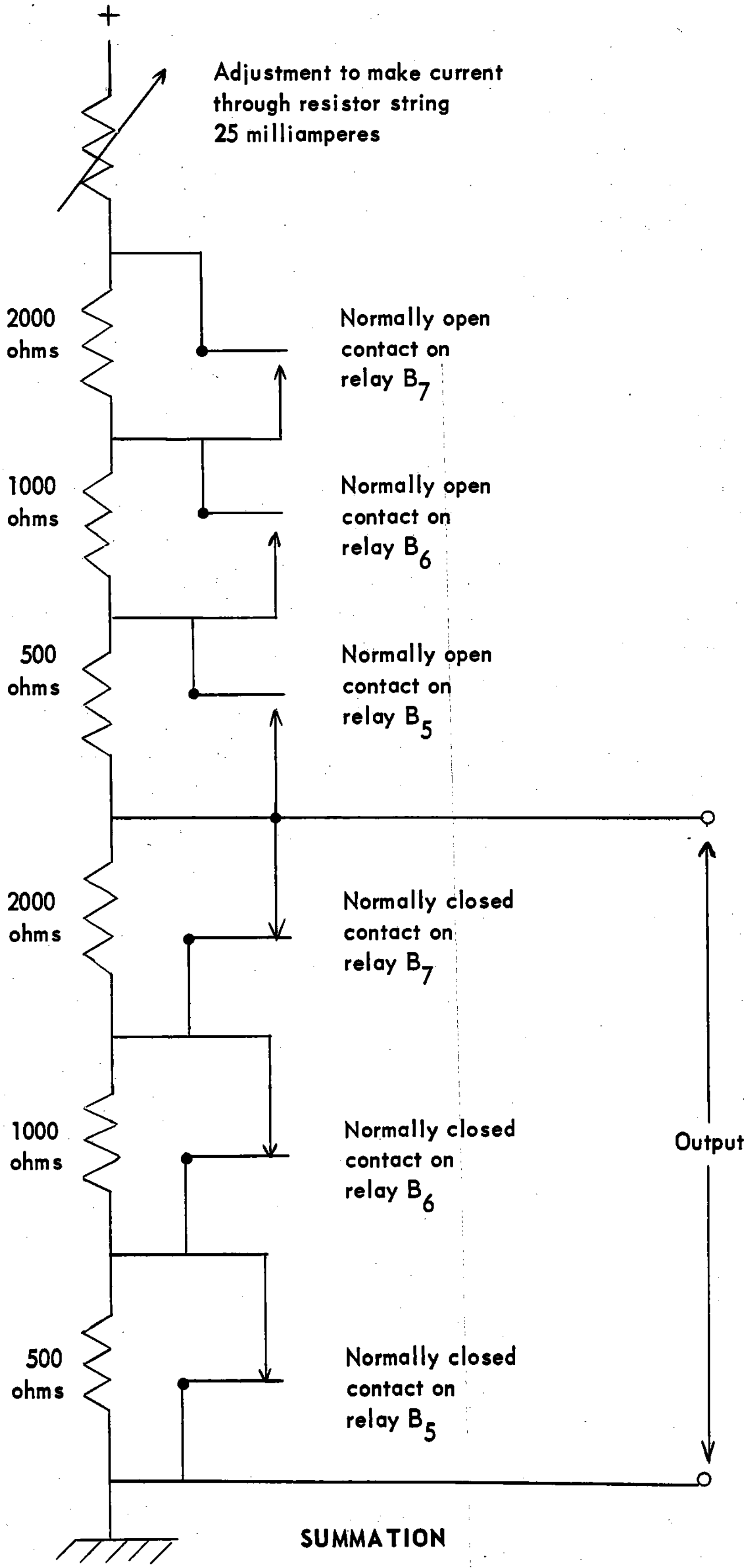
resistors are placed in series and connected to a constant voltage source. Relay contacts are placed across individual resistors in the strings so that, when one resistor is shorted out by a relay contact, the resistor's mate in the other string is unshorted by this same relay. In Figure 2, note that the 2000 ohm resistor in the lower string is shorted by a contact on the B_7 relay, while the 2000 ohm resistor in the upper string has a normally-open B_7 contact across it. The output is taken across the lower resistor string as shown.

All relays in Figure 2 are shown in their unenergized state. Hence all the lower resistors are shorted and the output voltage is zero. If relay B_7 is operated, the lower 2000 ohm resistor is placed in the circuit and the upper one is shorted out. Hence the output rises to 50 volts. If the relay B_6 is also operated, the lower 1000 ohm resistor is placed in the circuit and the upper one is shorted out. Now the output becomes 50 + 25 = 75 volts. Note that the total resistance in the string remains constant. This method of summation was chosen because it is a simple way of achieving voltage summation and does not require a closely regulated power supply, since the current remains constant.

2.4 - Display

The display signal is derived from a relay which detects the presence of the fifth hole on the tape. If a plotting table is being used, the circuit waits until both servo amplifier error signals have reached zero. Then the pen is dropped and after a short delay picked up again. Since the holding circuits retain their voltages during the entire operation, the servos do not run to zero after plotting each point.

If an oscilloscope is being used, the intensity control on the scope is turned down so that no spot appears except when a point is to be displayed. As soon as the fifth hole is detected and the reader cycle is complete, a voltage is applied to the cathode of the cathode ray tube to intensify the spot for a short time.



SUMMATION

Figure 2

Chapter 3

CIRCUIT DESCRIPTION

The circuits in the converter will be described in the order in which they function. Construction will be described briefly later.

3.1 - Reader

The functional reader circuit is shown in the drawing on Sheet 4 (Appendix I). (In a later section we will describe the signals which are necessary to make use of other types of tape readers.) The motor on the reader runs continuously. Reading action is controlled by the reader clutch which requires a -90-volt signal on wire 7 to unlatch it. About 15 milliseconds after the clutch operates, the reader pins go through the holes on the tape, closing the appropriate contacts on wires 1 through 4 (and 5 if the fifth hole is present). The reader common contact closes shortly thereafter. About 20 milliseconds after the clutch operates, the cam contact closes, applying voltage to all the reader contacts and to wire 6. About 60 milliseconds after the clutch operates, the cam contact opens, removing voltage from all contacts. Then the reader pins come back out of the tape holes and the tape advances. If no reader clutch signal is present on wire 7, the reader stops about 100 milliseconds after it has started.

3.2 - Relays

The relays shown on Sheets 2 and 3 have the following purposes:

B relays - receive the code from tape through the stepping switch. B_7 is the high-order bit, B_0 is the low-order bit. The first four bits of either the code for the <u>x</u> value or for the <u>y</u> value are stored in relays B_7 through B_4. The last four bits of either code are stored in relays B_3 through B_0. The B relays switch the appropriate resistors in the resistor string to establish the analog output voltage.

S relay - receives the cam signal, initiates advancing of the stepping switch, and delays start of the next cycle until the first cycle is finished.

I relay - is the stepping switch which determines which set of B relays receives the code and also controls operation of the X and Y relays.

H relay - holds the B relays which were energized by the first half of either code while the stepping switch advances to receive the second half of the code.

X relay - connects the resistor string output to the x-holding circuit and holds the B relays until the resistor string output has been disconnected by the S relay.

Y relay - connects the resistor string output to the y-holding circuit, holds the B relays until the resistor string output has been disconnected by the S relay, and prevents initiation of the display cycle until after the reader cycle has finished.

F relay - receives the fifth hole signal from the tape, free-runs the stepping switch to a home position if it is out of synchronization, initiates the display cycle, and prevents the reader from running again until the display cycle is finished.

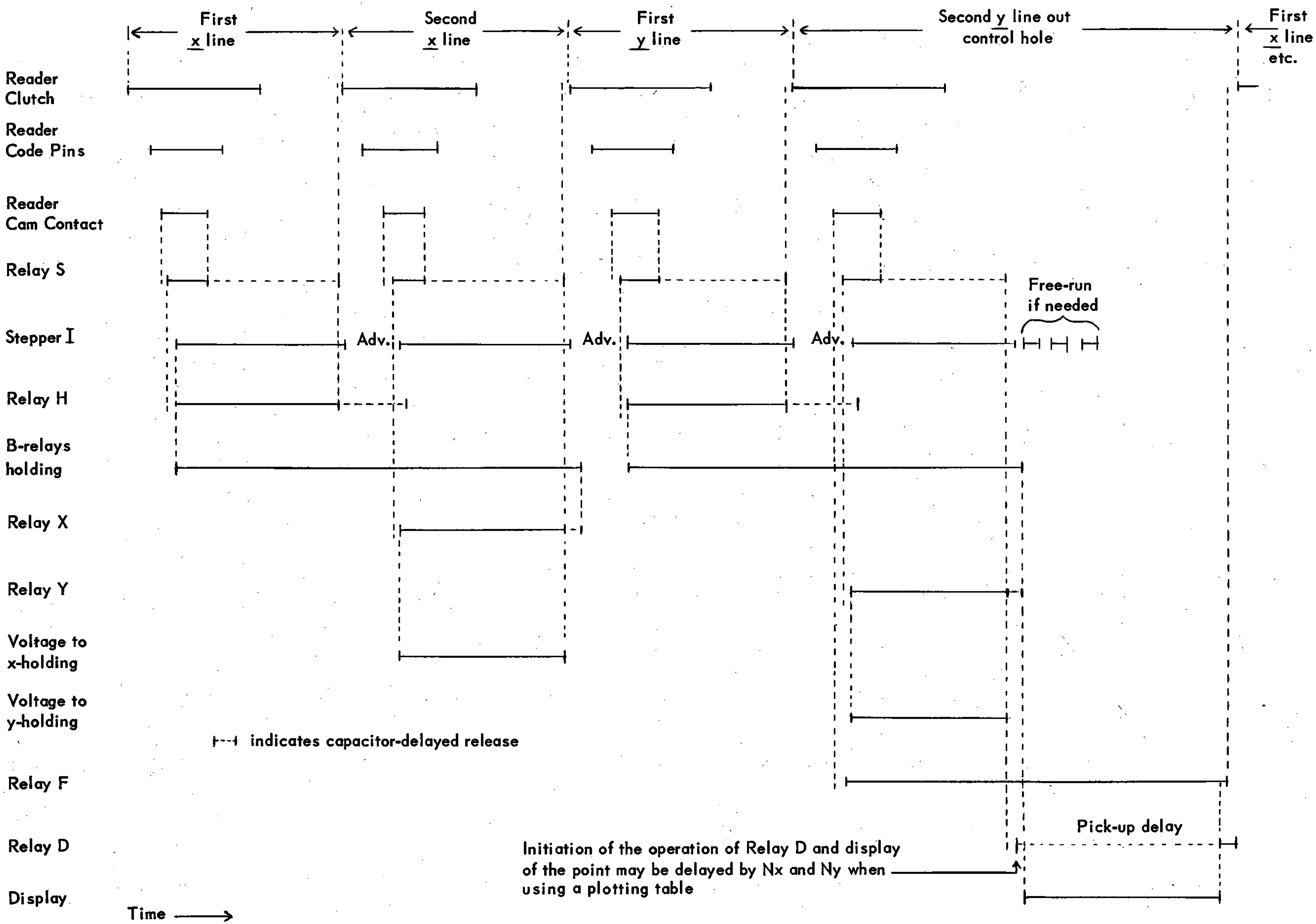
N_x relay - prevents initiation of the display cycle until the x-axis servo error signal has reached zero.

N_y relay - prevents initiation of the display cycle until the y-axis servo error signal has reached zero.

D relay - determines the length of the display cycle, and on termination of the display releases the F relay so that reading may continue.

Assume, for a description of the operation of the relay system, that the stepping switch is at point 1 (which is one of the two 'home' positions, the other being point 5). All of the relays of the circuit are released except possibly N_x and N_y. (Figure 3 is a diagram of the operating sequence which follows.) Since S is released, the reader clutch is energized and the reader starts. The line of holes about to be read is the high order half of the next x value to be plotted. The reader pins read the code holes and the cam contact closes. This operates S, which in turn energizes the magnet of the stepping switch. The switch does not move yet, because motion takes place on release of the armature. S also energizes H through point 1 on level 5 of the stepper. The information from the code holes is sent through point 1 on levels 1 through 4 of the stepper to the B relays. These relays are held up through the contact on the energized H relay.

The cam contact on the reader then opens. S, however, remains energized for some time because of the capacitor across it. This gives sufficient time for the rest of the relays to become properly operated. Since S is still operated, the clutch stops the reader. H re-



RELAY OPERATING SEQUENCE

Figure 3

mains energized throughout this time, first through S, and then after S releases because of the capacitor across H. When S releases, the stepper magnet releases, advancing the switch to point 2. The clutch on the reader is also reenergized.

The reader then reads the low-order half of the x value. The cam contact closes, energizing S and I. H has remained energized long enough, via its capacitor, to prevent the B relays from releasing. H can now drop out, however, because the X relay is energized through point 2 on level 5 of the stepper and continues to hold the B relays. The information from the code holes is sent through point 2 on levels 1 through 4 of the stepper to the B relays. Now the B relays are locked up to represent the eight bits of the binary value of x. A path from the resistor string to the x-holding circuit is provided through the S and X relays and the voltage representing x is stored in a capacitor. The cam contact then opens, and after a suitable delay S releases, disconnecting the resistor string from the holding circuit. The X relay releases slightly later than does S so that the B relays do not change state until the resistor string is disconnected from the holding circuit. The B relays release as soon as X does. The stepping switch advances to point 3 when S releases and the reader clutch is again energized.

The operation of the S, I, H, and B relays is the same for the code holes for the y value as it was for the x value, except that the Y relay instead of the X relay is energized during the second half of the code, connecting the resistor grid to the y-holding circuit. However, along with the low-order portion of the y code is the fifth hole, used for control. This code hole, when present, energizes the F relay, which holds through a contact on the D relay. The cam contact opens, and after a delay, S releases, followed by Y. However, the clutch is not reenergized because the F relay breaks this circuit. When Y releases, a path is closed to permit display of the point. This path consists of N_x and N_y released (which does not occur until the servo amplifiers are both producing zero error signals), D released, F energized, and Y released. Hence the pen is lowered and a mark is made on the paper. At the time the marking is started, the D relay begins to energize, but because of the RC delay, it does so slowly. When it finally picks up, it breaks the plotting path and releases the F relay. When F releases, the reader clutch is again energized and the next data point is processed in the same manner.

If the stepping switch did not move to one of its two home positions (points 1 or 5) after S released and when F was picked up, a contact on the F relay along with all points on level 6 of the stepper except 1 and 5 cause the switch to run freely until it reaches the next home position. This normally occurs once every other cycle, since the switch has 11 positions but only eight are used. Hence it must run over the other three. If the switch somehow got out of step, information for plotting would be improperly sent to the B relays. However, the switch would be resynchronized at the end of the cycle, although one wrong point would probably be plotted.

The use of an oscilloscope for output display requires a different marking signal. In this case, the N_x and N_y relays are bypassed and approximately 50 volt a.c. is applied to the marking line to unblank the scope.

3.3 - Resistor String

The resistor string (see the drawing on Sheet 2, Appendix I) is normally adjusted to have a current of 25 milliamperes flowing through it. Each pair of resistors in the string is adjusted to give a voltage output from the center of the string proportional to the binary value represented by the relay which shorts and unshorts it. All binary combinations from 00000000 to 11111111 are used. For example, when the code is 10000000, only relay B_7 is energized. Hence r_7 is adjusted to give one half of the maximum output voltage, or 50 volts. Therefore r_7 = 2000 ohms. Similarly, r_6 = 1000 ohms, and so on. An adjustable resistor (R_5) is used to set the maximum output to 100 volts.

3.4 - Null Detection

The null amplifiers were designed for a particular plotting table. The table used in the design is not commonly available and had been modified to some extent, but the null amplifiers should remain about the same. The circuit is shown on Sheet 6. When the voltage on the input from the servo amplifier reaches nearly zero, the relay Nx or Ny in the plate releases. The cathode resistor is used to adjust the bias to make the null point as close to zero as desired.

3.5 - Holding

The capacitor holding circuits consist of two capacitors each connected to a cathode follower. They are shown on Sheet 5. The cathode resistors are returned to -50 vdc to permit linear operation of the circuit and the plates are connected to the stabilized +200 vdc. The two controls R5 permit zero adjustment when used in connection with the 'Set Zero' switch. The control R12 permits a slight change in the gain of the cathode follower for the y-axis signal and is used only if the two cathode followers should happen to drift too far apart in their response.

Both the 'Set Zero' and 'Set Max' switches have a circuit connected to the plotting line so that the point will be marked either on the plotting table or the oscilloscope when setting the zero and full-scale points. The 'Set Zero' switch applies ground to both capacitors while the 'Set Max' switch takes the maximum voltage from the top of the resistor string and applies it to both capacitors. This permits easy adjustment of the ends of the plotting range.

3.6 - Power

Power is supplied to the system from two sources. All relays except the two in the null amplifiers operate from a 90 volt d-c source which is part of the reader. This source consists of a bridge rectifier connected directly to the power line and hence cannot be grounded to the chassis on either side. This supply is fused inside the reader cabinet and does not require additional protection.

The other power source is a transformer-operated 5Y3 circuit with appropriate zener diode stabilization. This circuit is shown on Sheet 1. Three d-c voltages are derived from this supply through a string of zener diodes. The +320 vdc supply is unregulated and is used only for the null amplifiers. The +200 vdc supply is for the resistor string and the cathode followers in the holding circuits and is stabilized by a 10 watt zener diode connected to the chassis. The -50 vdc supply is for the lower end of the cathode resistors in the holding circuits and is also stabilized by a 10 watt zener diode connected to the chassis. The 50 vac is obtained through a high resistance divider and is used only for the cathode input on the oscilloscope to intensify the point to be plotted.

Chapter 4

CONSTRUCTION AND OPERATION

4.1 - Construction

The zener diode D1, shown on Sheet 1, which stabilizes the +200 vdc supply, is screwed directly to the chassis, since it needs the chassis cooling surface to dissipate 10 watts. The diode D2 is dissipating less than its full rating of 10 watts and should be mounted on a plate which is insulated from the main chassis. Its bolt is at a potential of -50 volts with respect to the main chassis.

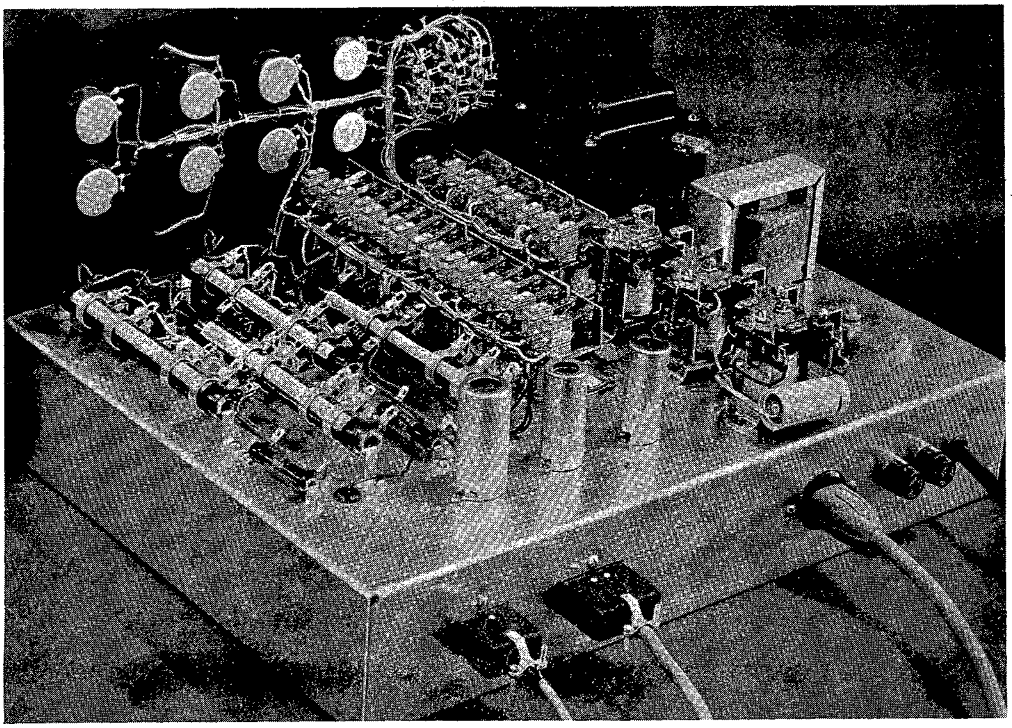
The adjustable resistors shown on Sheet 2, which are part of the resistor string, are chosen to be 75-watt resistors to get them long enough for fine adjustment. In order to get four sliders onto the resistor and have each one reasonably adjustable, it is necessary to have a resistance about 6 inches long. Other methods of obtaining the desired resistances are possible. For example, choose good quality 1-watt resistors with values a little above each required value and then use smaller high-valued resistors in parallel to achieve the final value. However, the slide-wire resistors are easier to adjust.

The relays chosen are not of very high quality. Hence the timing of the circuits has been arranged, through appropriate capacitive delays, to slow up the operation of the various parts of the circuit. Choice of finer relays with better characteristics would eliminate the need for some of the delays but would increase the cost of the circuit. With the design as given, the relay cost is about 35% of the total chassis cost, excluding the tape reader and the stepping switch.

The capacitor values given for the delays in Sheet 3 are only approximate and depend somewhat on the spring tensions of the relays. The adjustment of the springs will be discussed later.

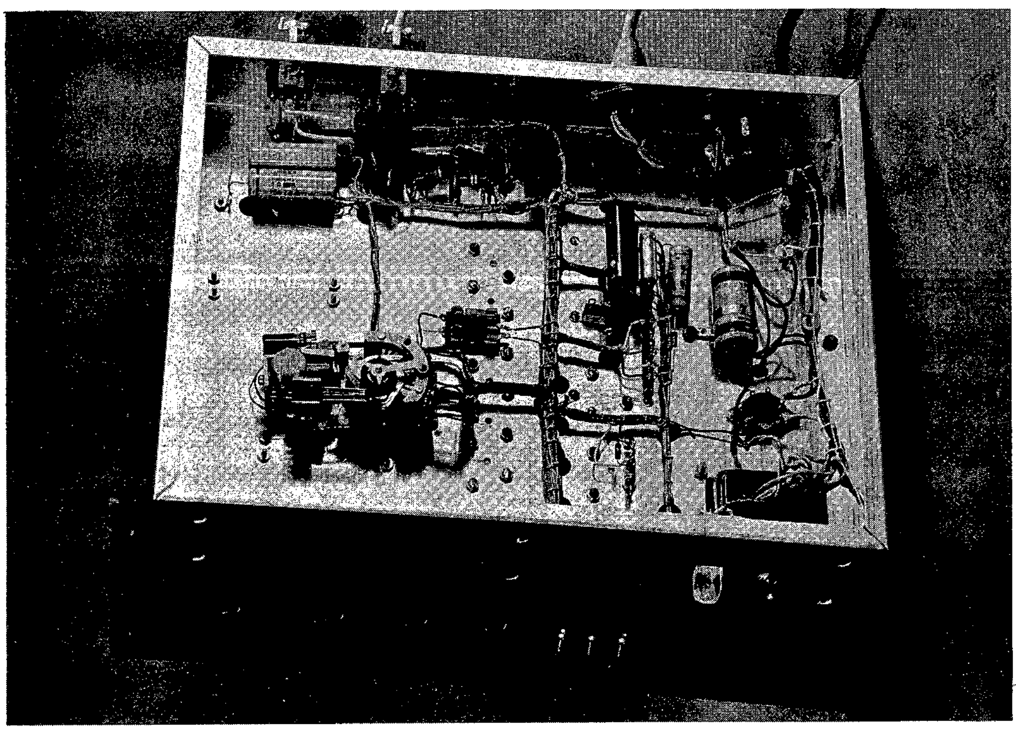
The connections to the reader are made through AMP taper-pin connectors. These can be ordered at the same time the reader is purchased. The numbers of the round terminals shown on Sheet 4 correspond to the terminal numbers given on the blue-print accompanying the reader.

The cables shown on Sheet 7 are shown for reference to indicate the pin connections which are required. The wire lengths are not critical and may be arranged as desired, since all signals are essentially d.c. The resistor R13 is placed in the x-axis lead to raise the input impedance of the x-axis of the Tektronix 515A oscilloscope and will



CHASSIS - Top View

Figure 4a



CHASSIS - Bottom View

Figure 4b

perhaps be different for other scopes. There is a discussion of the problems of input impedance in Section 4.3.

The chassis layout can be determined from the pictures in Figure 4 but there is no reason to attempt to match the layout shown. The larger parts will all fit on the top of the chassis without crowding, leaving space underneath for the stepping switch. The stepping switch is mounted on rubber shock mounts to reduce the operating noise.

4.2 - Initial Adjustments

The first step in the initial adjustment of the circuit is to get the relays working properly. Clean all contacts and insure that they are all making properly. Be sure that the contacts on the B relays which switch the resistors of the resistor string in and out are clean and have a fair amount of contact follow, so that no resistor is switched when the armature just begins to move either way. If the contacts on the B relays do not operate properly, the plotter will make errors as a result of incorrect switching.

The delay of the S and H relays must be set. The S relay delay should be enough so that the reader stops completely after each line is read. Any more delay than that is unnecessary, since the mechanical delay of the clutch mechanism adds enough to insure that all relay functions have been completed. The H relay must be adjusted so that it does not release until the X relay has picked up during the second cycle or the Y relay has picked up during the fourth cycle. Adjust the amount of delay by adjusting the spring tension on the contacts which are directly moved by the armature. More upward tension will cause the relay to release faster.

None of the other relays should require adjustment except to make certain that all contacts which are in use are operating properly. However, the stepping switch must be adjusted to run properly on the voltage from the reader. This is most easily done by connecting all points on level 6 of the switch to +90 vdc. The switch will then run freely and the tension spring can be adjusted to make the operation as smooth as possible. If the switch will function correctly when free-running, then it will operate properly with the S relay.

The values of the resistors in the resistor string must be set using a Wheatstone bridge, since carelessness in setting each of the values may cause an accumulated error which in some portions of the range will yield inaccurate plotting. Note that half of the resistors in the string can be set with the B relays unenergized while the other half have to be set with the B relays energized. The proper values for the resistor string (see Sheet 2) are:

Resistors	Value (ohms)
r_7	2000
r_6	1000
r_5	500.0
r_4	250.0
r_3	125.0
r_2	62.50
r_1	31.25
r_0	15.625

The tolerances on the values should be such that overall accuracy is held to about 1%. However, the values of resistance should be as close to the above values as they can be made to prevent accumulation of errors which would prevent obtaining all the values from the adjustable resistors used in the circuit. A reasonable tolerance is ±5 ohms. It is more important to keep the pairs of resistors as nearly equal as possible than to attempt to get the absolute values perfect. A difference between members of a pair of no more than 1 ohm is acceptable. If all the pairs are matched reasonably carefully, the current in the resistor string will be constant as the resistors are switched.

4.3 - Display Equipment

The display equipment used with this converter may be any device which meets the following conditions:

1. Zero volts on the axes plots at one extreme, 100 volts plots at the other extreme.
2. The d-c input resistance of each axis is not less than about 0.5 megohms.
3. The actual marking of the point can be done by completing a circuit or by applying a voltage.
4. If the motion of the device from point to point is not essentially instantaneous (completion of motion within ten milliseconds or so), a null signal from each axis must be available to indicate completion of motion.

The speed with which the display equipment will plot is not important, since the relay operation is already quite slow.

The conditions given above do not have to be met completely if certain changes are made in the circuits. A change of the voltage range for the plotting can be made by changing the current in the resistor string and by redesigning the cathode-follower holding circuits to operate with different voltages. The high d-c input resistance is necessary because of the cathode-follower holding circuits. Too low a resistance, below about 0.5 megohms, will cause the circuit to fail to hold the voltage long enough for plotting. If it is necessary to use a plotting device with lower input resistances, an additional stage of amplification can be added after each of the cathode followers to change the impedance level.

4.4 - Digital Computer Program

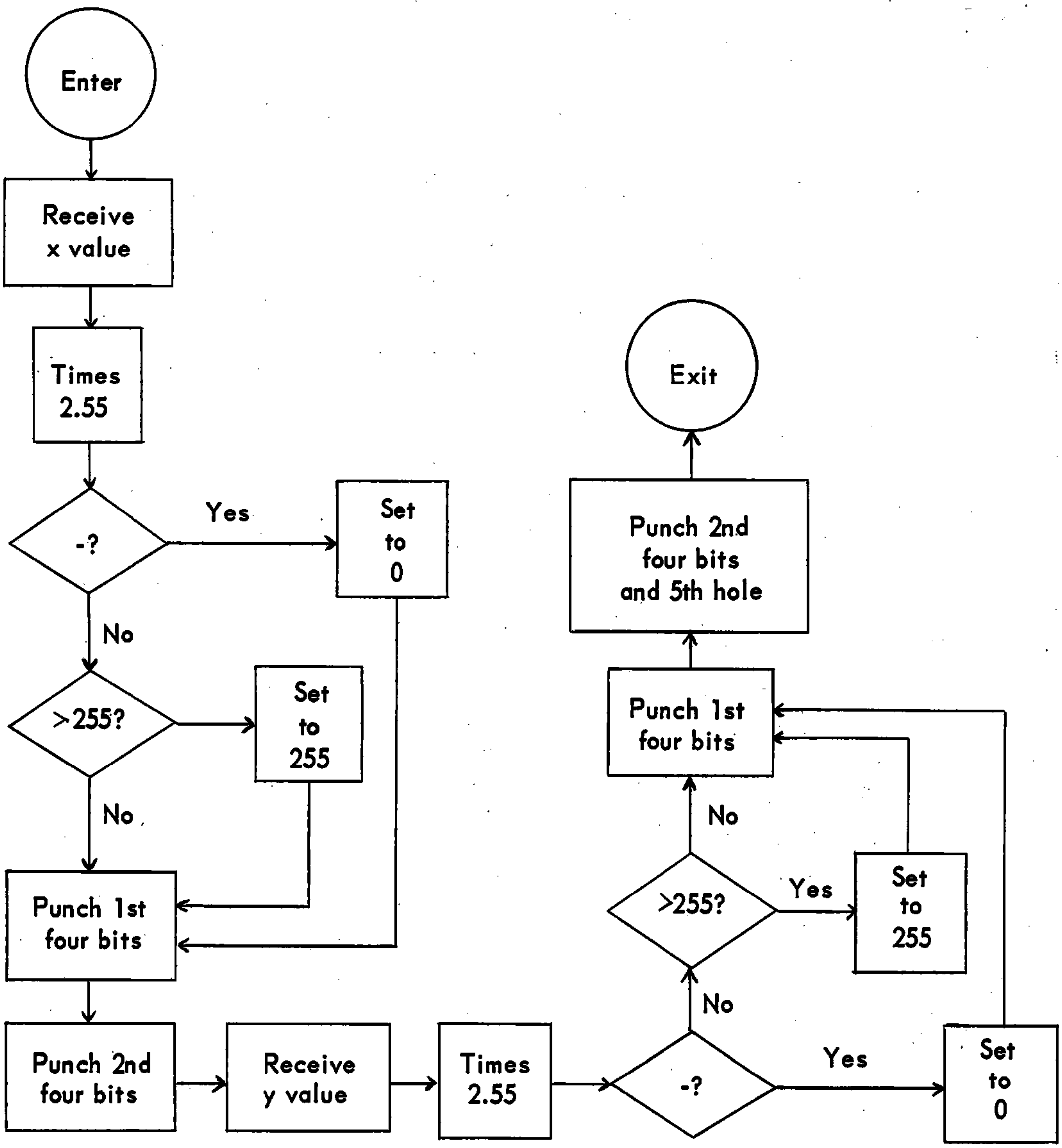
The program to convert data from the language of the particular digital computer in use to the language necessary for the converter can be stated only in general terms, since each type of computer has a different number representation and will require different programming. Basically, it is necessary to establish an allowed range for the data, as for example 0 to 100. Then this range must be converted into the range of the plotter code, which allows numbers in binary from 0 to 255. This binary representation must then be punched in the two parts required by the tape code for the plotter, first the value of $\underline{x}$ (high-order half first), then the value of $\underline{y}$ (high-order half first) with a bit in the fifth position along with the low-order half of the $\underline{y}$ value. Some oscilloscope cameras use a mirror, making it desirable to design the computer program to reverse the appropriate axis. A general flow chart is given in Figure 5.

A program for the conversion of data to the converter code has been written for the PINT system for the RPC-4000 digital computer. This program can be obtained on a request to the authors of this report.

The format for the tape is shown in Figure 6. Notice that the first character on the beginning of the tape must be a fifth control hole only. This permits the converter to synchronize with the tape in the reader.

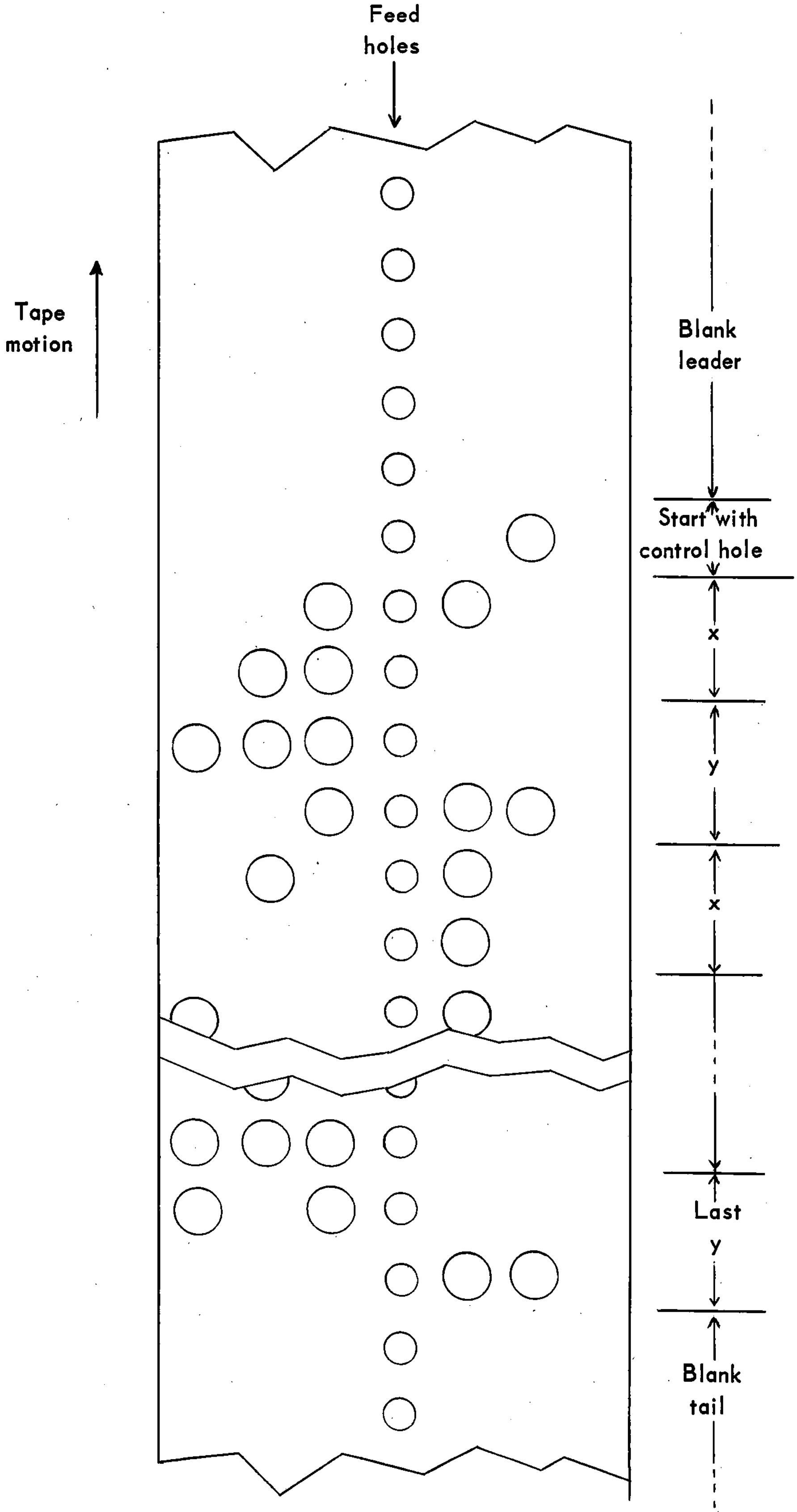
4.5 - Operation

Turn the equipment on and let the power supply and the resistors warm up for about 15 minutes or so. The plotting equipment should also be warmed up for some time to prevent drift. After the devices have warmed up, adjust the zero and the maximum values by first depressing the 'Set Zero' switch and adjusting the two potentiometers R5 (see drawing on Sheet 5) to obtain the desired zero position and then



GENERAL TAPE-PREPARATION FLOW CHART

Figure 5



TAPE FORMAT

Figure 6

depressing the 'Set Max' switch and adjusting the R5 potentiometer in the resistor string (Sheet 2) to get the desired maximum position (which should be at about 100 volts for proper operation). If the maximum point for each of the two axes is not quite the same, the potentiometer R12 in the y-axis cathode follower (Sheet 5) can be used to change the gain of that cathode follower enough to compensate for the difference.

Select either the plotter output or the scope output by using switch S3. Use a short test tape to determine the time of the display desired and adjust this time with the appropriate potentiometer R15 (Sheet 3) which controls the speed of operation of the D relay.

Insert the data tape in the tape reader, depress the 'Set Zero' switch once more, then turn on the reader. The tape should advance to the first fifth-hole code and plot the first point at x = 0, y = 0. Then it will plot the rest of the points as they are read. When the tape runs out, the reader will stop. Results of the operation of the device using an oscilloscope and three different tapes are shown in Figure 7.

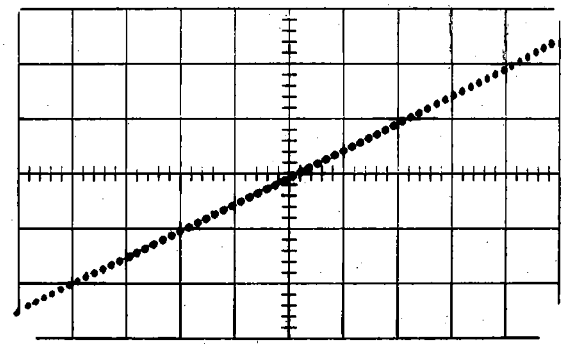
4.6 - Possible Changes

It is possible to make changes or omissions in the circuits as shown, depending on what equipment is already available. These changes can reduce the total cost of the equipment considerably, particularly if such items as the tape reader are already on hand.

The power supply (see drawing on Sheet 1) can be replaced by any reasonably well-regulated supply capable of producing about 200 vdc at 30 milliamperes, and also about -50 vdc at 5 milliamperes, in addition to unregulated 300 vdc at 5 milliamperes and 6.3vac for the three filiments. If an oscilloscope is used for display, the approximately 50 vac for unblanking can be derived from nearly any source.

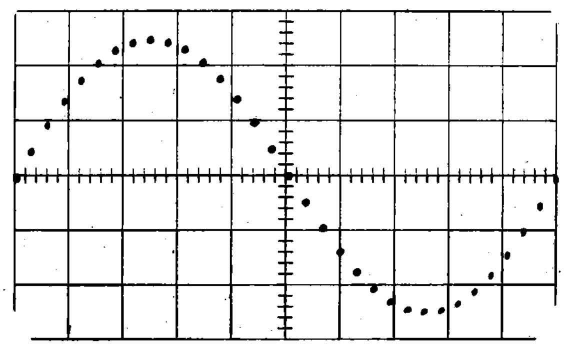
If only an oscilloscope is to be used as the display device, all of the null-amplifier circuitry (Sheet 6), including the N_x and N_y relays (Sheet 3), can be omitted, along with one of the potentiometers R15 and the switch S3 (Sheet 3). Moreover, since the zero and maximum adjustments can be made using the scope position and gain controls, all the potentiometers in the cathode-follower cathodes (Sheet 5) can be omitted and 270 kilohm, 1 watt resistors used for the cathode resistances. The potentiometer R5 in the resistor string (Sheet 2) can be replaced by a fixed 4 kilohm 5 watt resistor.

If the plotting table is used and has both position and gain controls on both axes, the controls which were omitted for the oscillo-



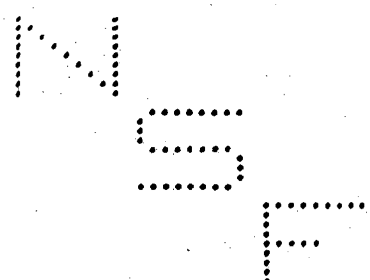
TRACE OF STRAIGHT LINE FROM (0,0) TO (100,100)

Figure 7a



TRACE OF $y = 50 + 50 \sin \frac{2\pi}{100} x$

Figure 7b



TRACE FOR FUN

Figure 7c

scope can be omitted here.

Other tape readers can be used if they meet the following conditions:

1. Read standard computer tape of at least five levels.
2. Read one line at a time on signal to the reader from the converter.
3. Provide a signal to indicate when the holes are actually being read and to initiate the advance of the stepping switch.
4. Stop after reading one line.

Considerable money can be saved if a suitable tape reader can be scrounged, since this is the most expensive single part of the converter. If another reader is used, it may be necessary to build a 90-vdc supply to provide relay power. Use a fullwave bridge rectifier directly on the 110-volt line with no filtering to provide about one ampere.

Other types of stepping switches can be used if they have at least six levels and can run from the 90-volt supply in the reader. The stepping switch circuit is designed for a switch which does not advance until the armature is released, although the relay circuits could be redesigned to use other types of switches.

Chapter 5

CONCLUSION

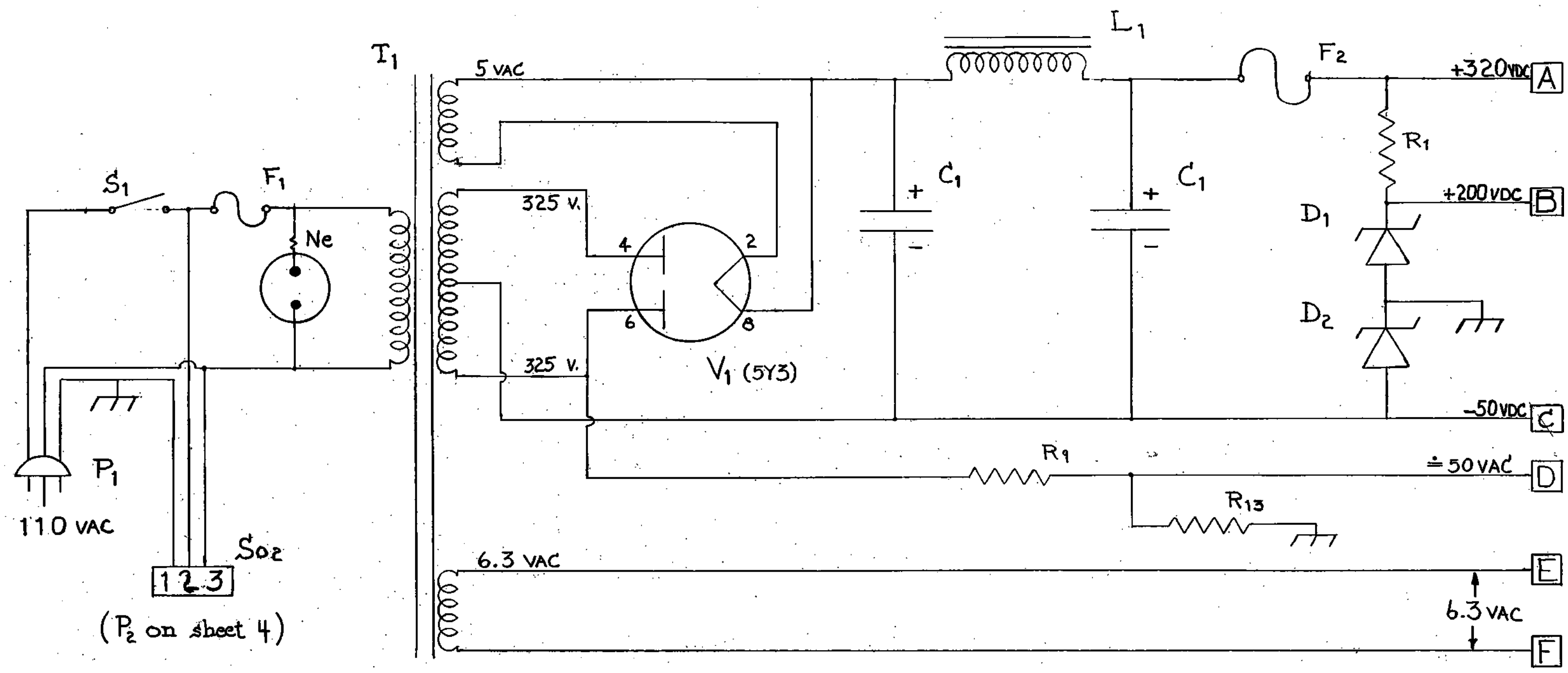
The photographs of the three curves in Figure 5 are an indication of the reliability of the plotter. Each point is correctly plotted to within the precision visible on the film. The design of the device was not aimed toward making a highly-precise instrument. Hence if the pictures are enlarged, variations in the lines will be very apparent. But the plotter can serve very well to give a graphical presentation of digital information.

The cost of the equipment was kept fairly well within bounds. The major cost is, of course, the tape reader. If a reader is already available which can meet the requirements of the plotter, then this expense can be eliminated. It is difficult to obtain a good tape reader for less than about $400. The only other cost is that of the relay chassis itself. The parts for this chassis cost, when obtained from a commercial radio supply house, about $203, including the stepping switch. There is the additional cost of labor for building the equipment, but this does not amount to more than about $50 at typical student wages.

Since the cost of this plotter has been kept well below the commercially-available plotters, mainly through use of relays and existing display devices such as oscilloscopes, it will be of value to those people who need a graphical presentation of their computer output but do not feel they can afford commercial equipment. Hence the design objectives have been met.

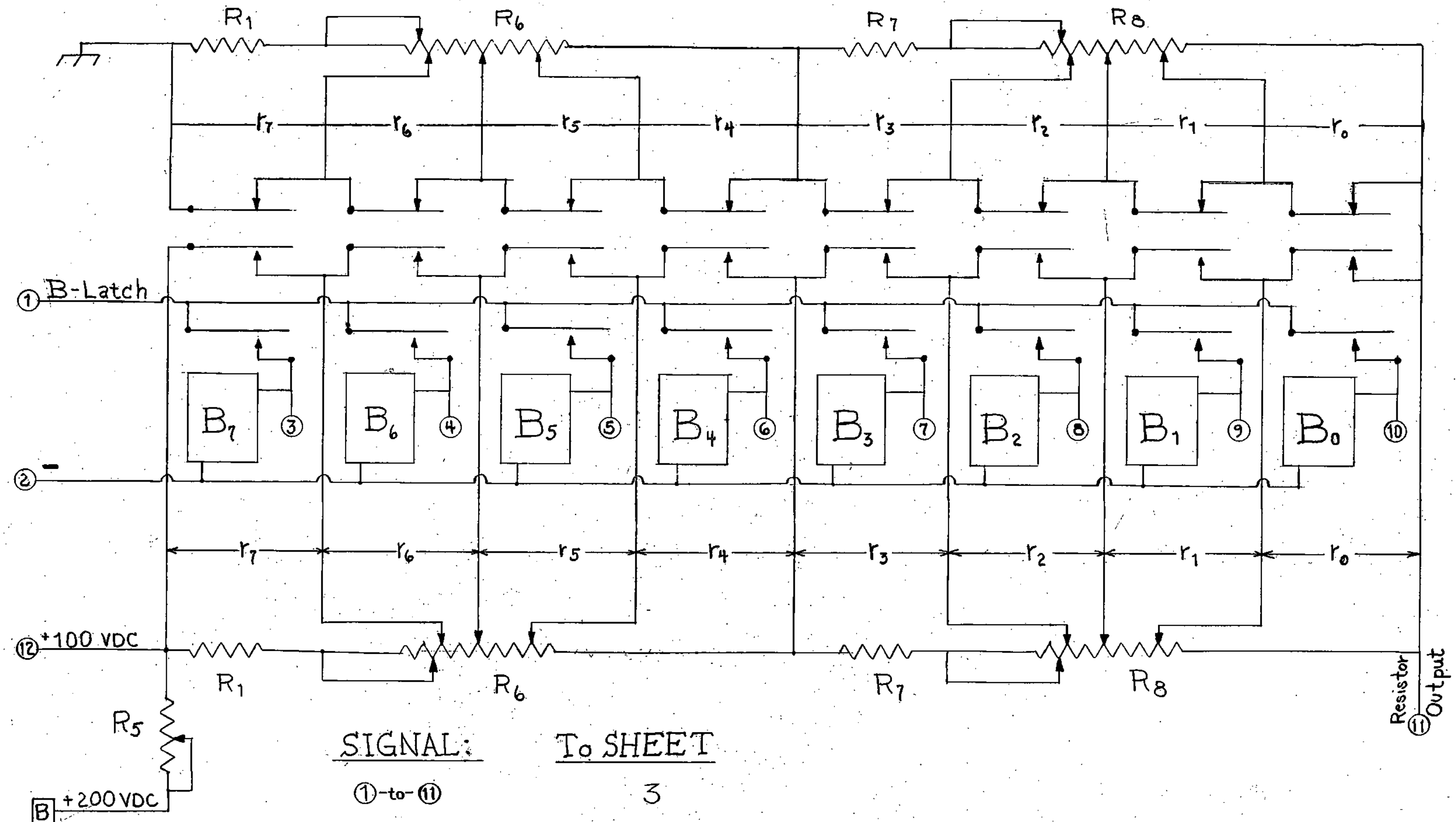
APPENDIX I

CIRCUIT DRAWINGS



Power:	Found on Sheets:
A	6
B	2, 5
C	5
D	3
E	5, 6
F	5, 6

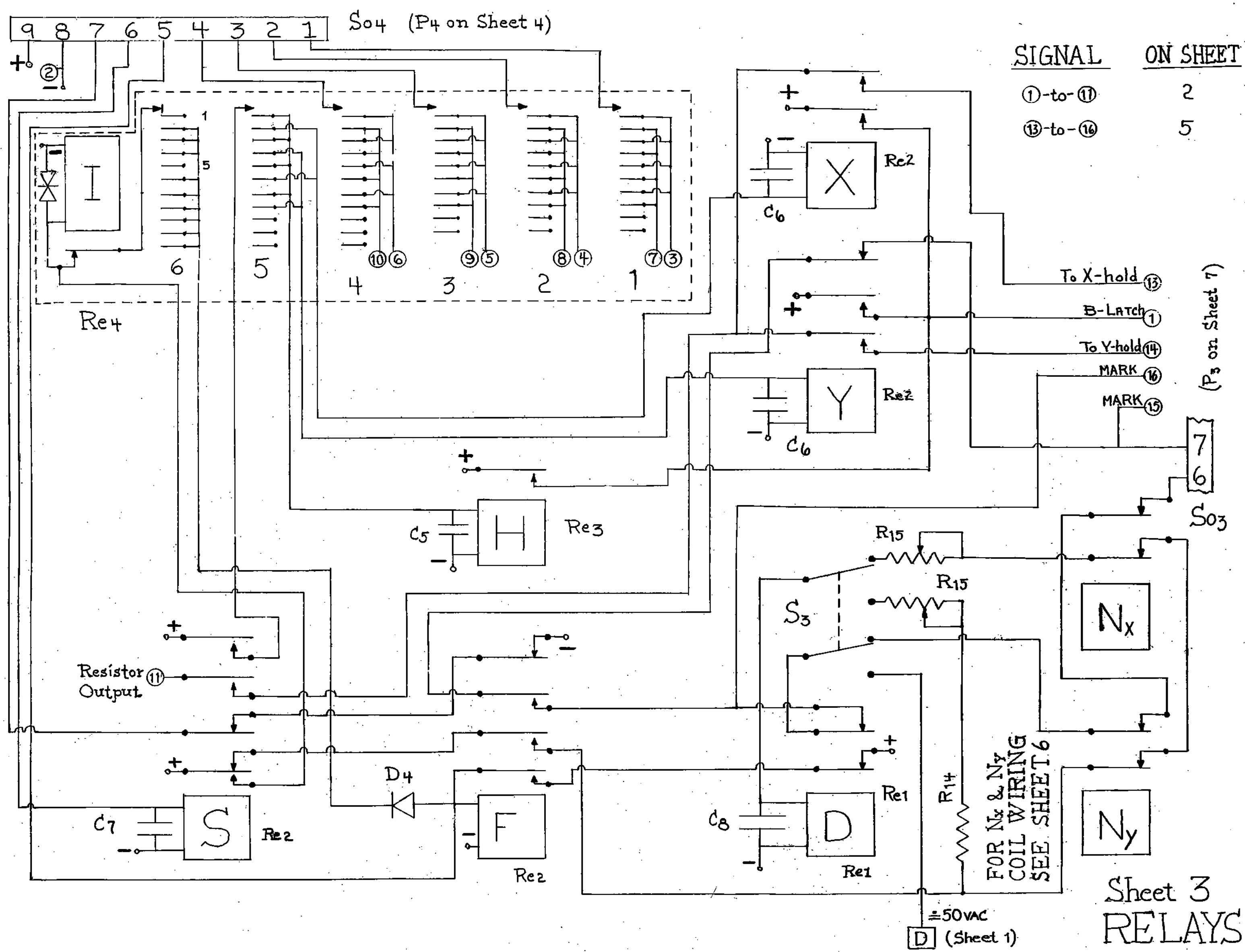
Sheet 1
POWER SUPPLY

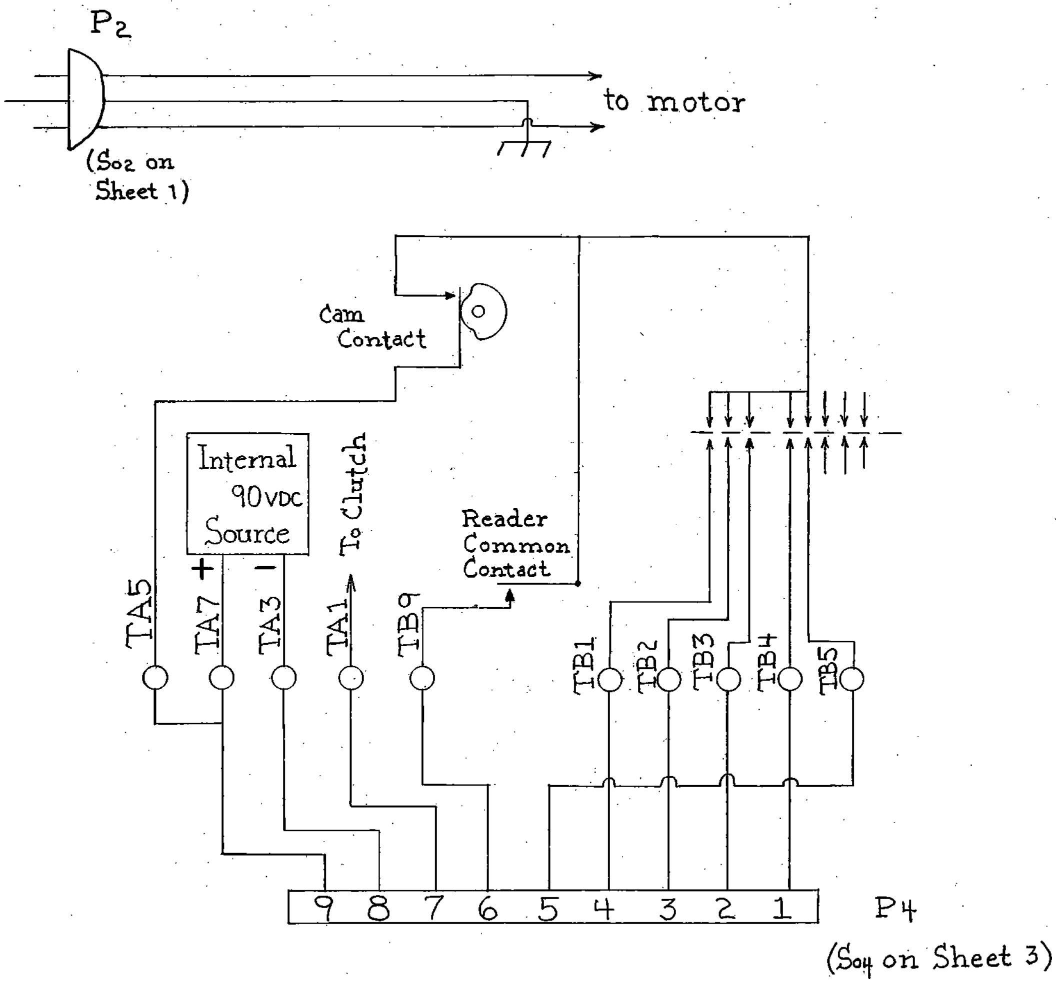


SIGNAL:	To SHEET
①-to-⑪	3
⑫	5

Sheet 2

RESISTOR SWITCHING


So4 (P4 on Sheet 4)
9 8 7 6 5 4 3 2 1
SIGNAL ON SHEET
①-to-⑪ 2
⑬-to-⑯ 5
Re4
I
6 5 4 3 2 1
⑩⑥ ⑨⑤ ⑧④ ⑦③
X
Re2
C6
Y
Re2
C6
To X-hold ⑬
B-LATCH ①
To Y-hold ⑭
MARK ⑯
MARK ⑮
(P3 on Sheet 7)
7
6
So3
H
Re3
C5
R15
R15
S3
Nx
Resistor Output ⑪
D4
S
Re2
C7
F
Re2
D
Re1
C8
R14
FOR Nx & Ny COIL WIRING SEE SHEET 6
Ny
±50VAC
D (Sheet 1)
Sheet 3
RELAYS

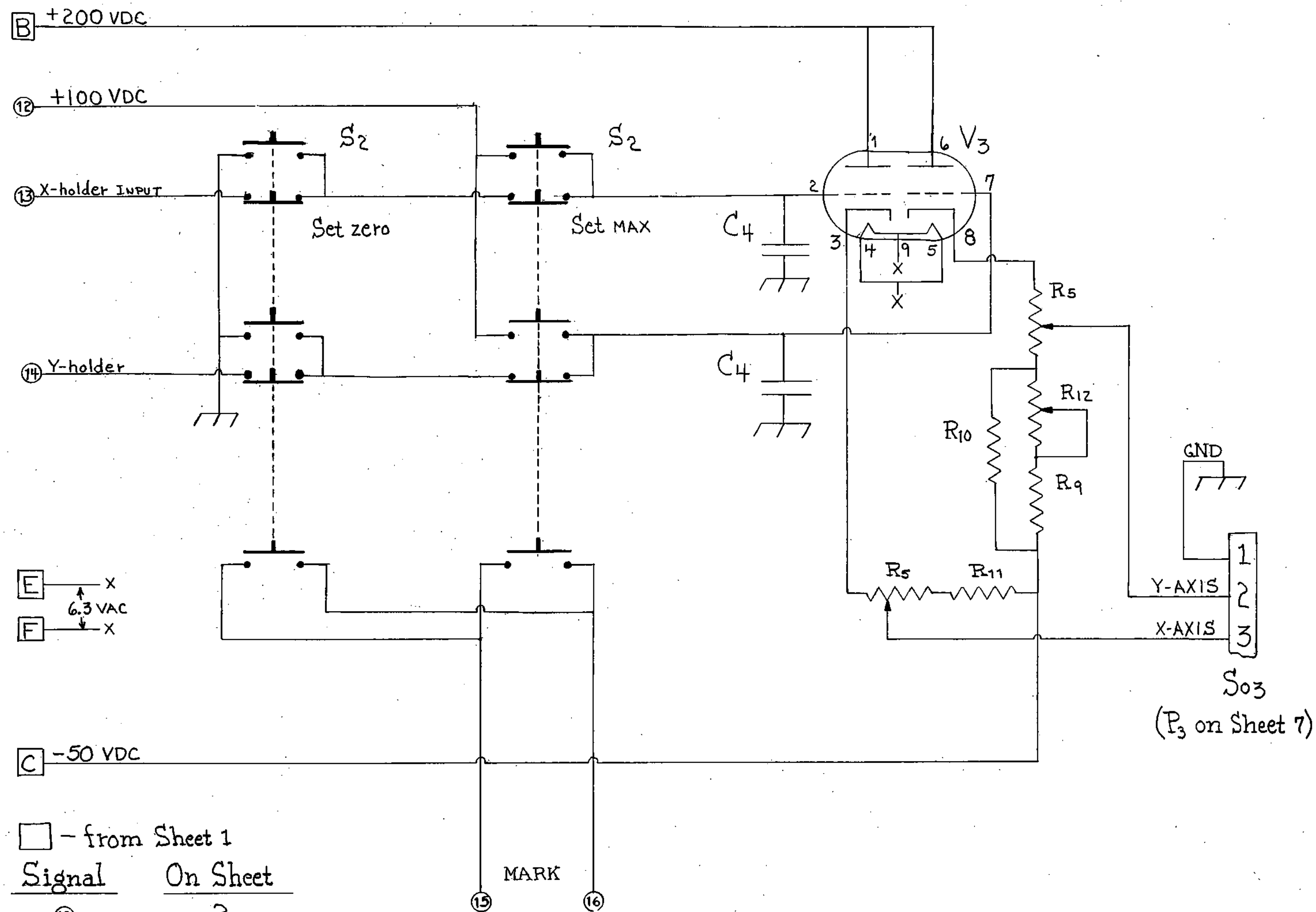


Refer to blueprint which comes with Reader for actual internal wiring

○ are taper-pin connections in reader

Sheet 4

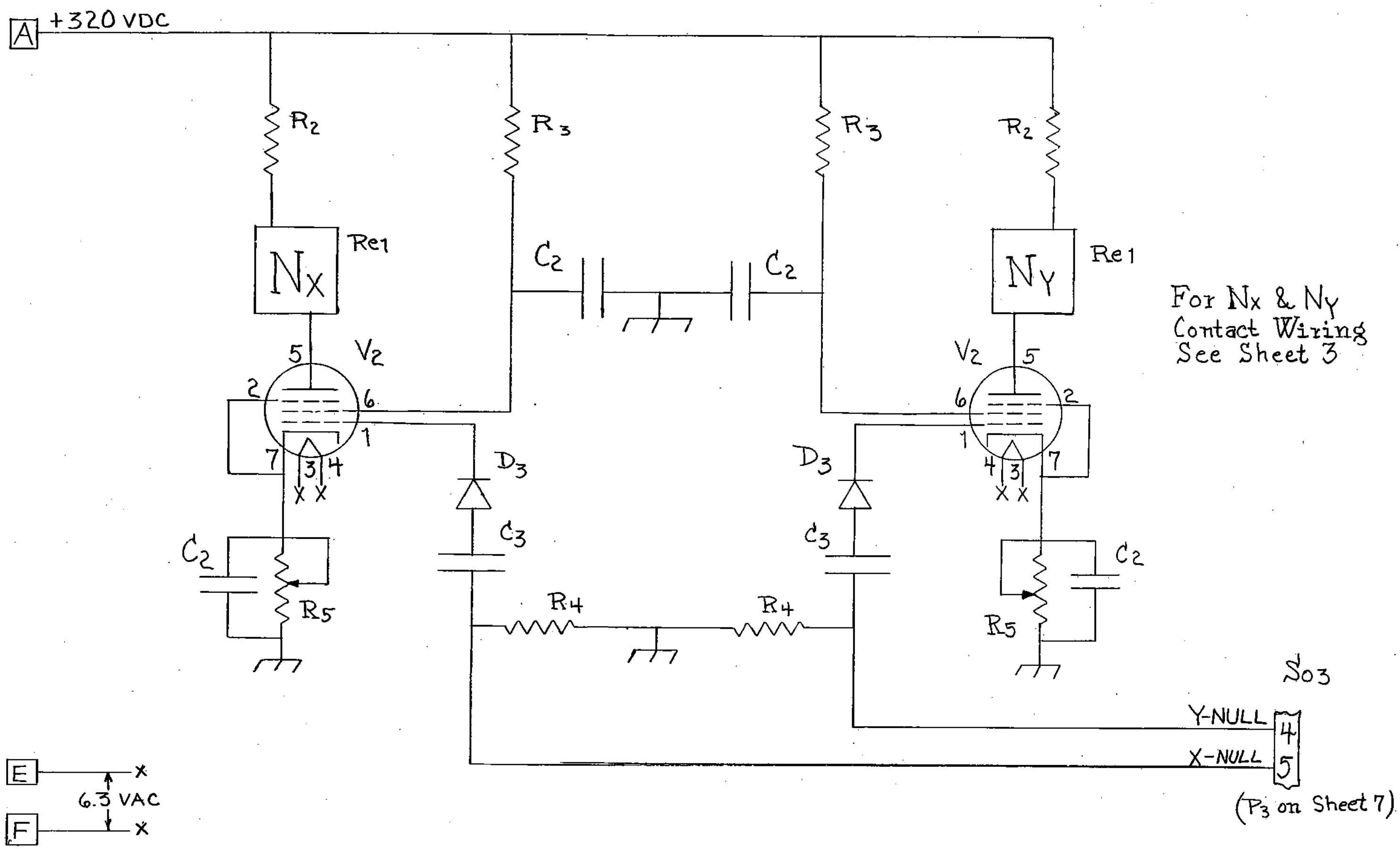
READER



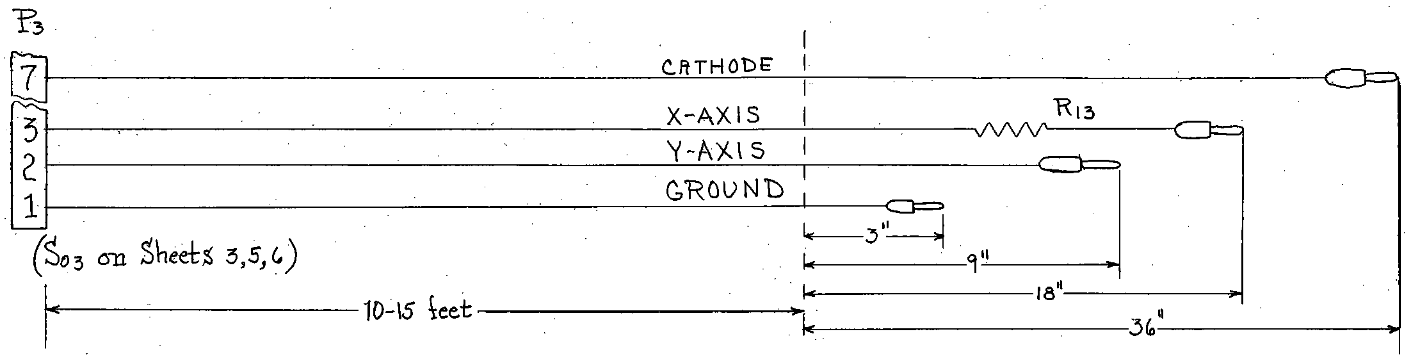
□ – from Sheet 1

Signal	On Sheet
⑫	2
⑬-to-⑯	3

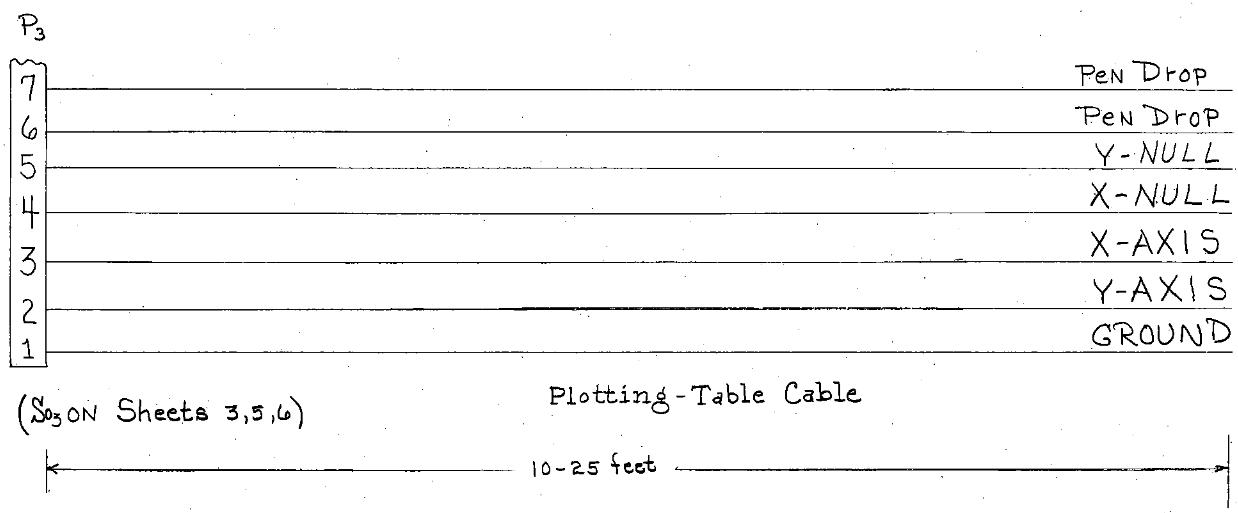
Sheet 5
HOLDING CIRCUITS



Sheet 6
NULL AMPLIFIERS



Oscilloscope Cable



Plotting-Table Cable

Sheet 7
CABLING

APPENDIX II

PARTS LIST

APPENDIX II

PARTS LIST

Capacitors

C1 - (1) Dual section 10-10 μf, 450v, electrolytic - Mallory 72
C2 - (4) 0.1 μf, 400v, paper tubular - Sprague 4TM-P10
C3 - (2) 0.05 μf, 400v, paper tubular - Sprague 4TM-S50
C4 - (2) 1 μf, 200v, mylar tubular - Cornell-Dubilier 2W1E
C5 - (1) 16 μf, 150v, electrolytic - Sprague TVA-1409
C6 - (2) 0.25 μf, 200v, paper tubular - Sprague 2TM-P25
C7 - (1) 20 μf, 150v, electrolytic - Sprague TVA-1410
C8 - (1) 40 μf, 150v, electrolytic - Sprague TVA-1413

Inductor

L1 - (1) 7h, 150ma, choke - Stancor C1710

Resistors

R1 - (3) 1500ω, 10w, wirewound - Ohmite
R2 - (2) 18kω, 2w, 10%, carbon
R3 - (2) 68kω, 2w, 10%, carbon
R4 - (2) 1 meg. 1/2w, 10% carbon
R5 - (5) 5kω, 2w, potentiometer - Clarostat 53C1
R6 - (2) 2500ω, 75w, adjustable wirewound with four sliders each - Ohmite Dividohm
R7 - (2) 100ω, 10w, wirewound - Ohmite
R8 - (2) 200ω, 75w, adjustable wirewound with four sliders each - Ohmite Dividohm
R9 - (2) 510kω, 1/2w, 10%, carbon
R10 - (1) 390kω, 1/2w, 10%, carbon
R11 - (1) 270kω, 1/2w, 10%, carbon
R12 - (1) 1 meg, 2w, potentiometer - Clarostat 53C1
R13 - (2) 100kω, 1/2w, 10%, carbon
R14 - (1) 10kω, 1/2w, 10%, carbon
R15 - (12) 10kω, 2w, potentiometer - Clarostat 53C1

Transformer

T1 - (1) Power transformer, 650vct at 150ma, 5vac, 6.3vac - Knight Type 61G471 (Allied Radio Corp., Chicago)

Diodes

D1 - (1) 1N1815 zener, 10w - Hoffman
D2 - (1) 1N1367 zener, 10w - Hoffman
D3 - (2) 1N2861 silicon rectifier - RCA
D4 - (1) M-500 silicon rectifier - Sarkes-Tarzian

Tubes and Lamps

V1 - (1) 5Y3GT
V2 - (2) 6AU6A
V3 - (1) 12AX7A
Ne - (1) Neon "Postlite" (with internal resistor)

Relays

Re1 - (3) Plate relay, 5kω, DPDT - Potter and Brumfield LM11
Re2 - (12) 110vdc, 4PDT - Guardian IR-505-GG110
Re3 - (1) 110vdc, SPST - Guardian IR-505-A110
Re4 - (1) Rotary stepping switch, 110vdc, 1 11-point bridging level, 2 11-point non-bridging levels, 3 10-point non-bridging levels, with varistor protector - Automatic Electric Type 44, piece number PW-156115-GAKC, with two RZ-46 rubber cushion mounts

Fuses

F1 - (1) 2 amp, 3AG
F2 - (1) 1/2 amp, 3AG

Switches

S1 - (1) SPST toggle switch
S2 - (2) 4PDT momentary lever switch non-shorting- Centralab 1457
S3 - (1) 4PDT latching lever switch non-shorting - Centralab 1458

Plugs and Sockets

P1 - (1) 3-wire grounding a-c power supply with 8-foot cord-Belden 17408S
P2 - part of power cord on reader
P3 - (2) 8-terminal male cable plug - Jones P-308-CCT
P4 - (1) 10-terminal male cable plug - Jones P-310-CCT
So2 - (1) grounding female power socket - Amphenol 160-2
So3 - (1) 8-terminal female chassis socket - Jones S-308-AB
So4 - (1) 10-terminal female chassis socket - Jones S-310-AB

Cables

- 15 ft, 4 conductor stranded cable - Belden 8444
- 15 ft, 7 conductor stranded cable - Belden 8447
- 15 ft, 9 conductor stranded cable - Belden 8449

Reader

- Friden Model SP-2, arranged similar to Serial No. 11-7115, Order No. 3281, with 50 AMP taper-pins

Miscellaneous Hardware

- (2) Fuseholder post, 3AG - Buss HKP
- (8) Knobs for potentiometers, 1/4 inch shaft
- (1) Mounting clip for M-500 silicon rectifier
- (2) 7-pin miniature tube socket with shield mount - Jones 7XB1
- (1) 9-pin miniature tube socket with shield mount - Jones 9XB
- (1) Octal tube socket
- (2) 7-pin tube shield, 1 3/4 inch - Jones 7S3
- (1) 9-pin tube shield, 1 15/16 inch - Jones 9S2
- Assorted grommets
- Assorted 6 and 8 machine screws and nuts
- Chassis, 13 x 17 x 3 inches deep, aluminum - Bud AC-420
- Panel, 17 x 8 3/4 inches, black wrinkle aluminum - Bud PA-1105
- (4) Banana plugs for scope input