2900-219-T

Report of Project MICHIGAN

# A SUBSYSTEM FOR THE DIGITAL CODING AND REMOTE DISPLAY OF CURVED LINES

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December 1960

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## PREFACE

Project MICHIGAN is a continuing research and development program for advancing the Army's long-range combat-surveillance and target-acquisition capabilities. The program is carried out by a full-time Institute of Science and Technology staff of specialists in the fields of physics, engineering, mathematics, and psychology, by members of the teaching faculty, by graduate students, and by other research groups and laboratories of The University of Michigan.

The emphasis of the Project is upon basic and appled research in radar, infrared, information processing and display, navigation and guidance for aerial platforms, and systems concepts. Particular attention is given to all-weather, long-range, high-resolution sensory and location techniques, and to evaluations of systems and equipments both through simulation and by means of laboratory and field tests.

Project MICHIGAN was established at The University of Michigan in 1953. It is sponsored by the U. S. Army Combat Surveillance Agency of the U. S. Army Signal Corps. The Project constitutes a major portion of the diversified program of research conducted by the Institute of Science and Technology in order to make available to government and industry the resources of The University of Michigan and to broaden the educational opportunities for students in the scientific and engineering disciplines.

Progress and results described in reports are continually reassessed by Project MICHIGAN. Comments and suggestions from readers are invited.

Robert L. Hess
Technical Director
Project MICHIGAN

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# A SUBSYSTEM FOR THE DIGITAL CODING AND REMOTE DISPLAY OF CURVED LINES


## ABSTRACT

As an outgrowth of the combat-surveillance information-processing program of Project MICHIGAN, a concept of a simple equipment for the transmission of outline drawings such as map overlays with the aid of standard teletype equipment was developed. From a communications standpoint, this concept has the advantage of a very low redundancy, and operates readily within the very narrow bandwidth of standard teletype — not a characteristic of most pictorial-data transmission systems. A compact set of lightweight equipment for two-way transmission was constructed for demonstrating the concept's technical and tactical feasibility. This report describes the equipment and gives enough details of operating technique to permit an unskilled operator to learn its use. Some notes on maintenance are included, as well as some suggested modifications for increasing its utility.


## 1
## INTRODUCTION

Project MICHIGAN, which began in the fall of 1953, immediately recognized that the large amounts of information presented to human operators from sensors or data-processing equipment created a need for visual displays of military surveillance information. The location and identification of friendly and enemy troops, equipment, and emplacements are examples of such information.

This report describes a particular subsystem that was designed and built at Willow Run Laboratories (now part of the Institute of Science and Technology) for the purpose of demonstrating and evaluating a capability for transmission and remote display of permanent pictorial information of the "line-drawing" type. The work was originally begun to satisfy a requirement for presentation of data from a digital computer, and transmission over long distances was not necessarily part of the concept. The concept of a coding, transmission, decoding, and plotting system independent of data processing in the sophisticated sense, which is perhaps dominant in this writing, developed later.

The kinds of pictorial displays which are considered as permanent include:

(a) Maps and overlays
(b) Sketches and drawings
(c) Photographs
(d) Graphs and diagrams
(e) Tracings
(f) Arbitrary signs and symbols

These displays differ mainly in the number of information bits they require for accurate transmission and reproduction. A system of transmission based on the information content of the display, as opposed to a fixed-scan type such as facsimile, would allow the transmission of all these kinds of displays except photographs in far less time than it does with current methods. The information in these displays is usually of two distinct types: first, the alphanumerics, which are more easily represented and transmitted in digital code and can be reproduced by printing; and second, the curved or irregular lines which are more readily represented and transmitted in analog form and can be reproduced by an automatic plotter. However, a combined analog and digital transmission system to handle these types of data would be unduly complex. A digital transmission system, on the other hand, has the advantage of being far less subject to interference and easier to encrypt. Thus, a means of converting analog line information to digital form is desirable to make possible the digital transmission of all the information in these military displays.

A top limit on the rate at which data can be received is imposed by the response of the plotting mechanism. There is no advantage in using a higher data-transmission rate than that which will drive the display at its maximum rate unless complex buffer storage equipment is added to the display equipment. Teletype was selected as the transmission medium for this system because of its widespread use for commercial and military communications and because its data rate is generally compatible with the operating speeds of most plotting equipments. Figure 1 is a reproduction of a map overlay which after being coded on perforated tape was automatically reproduced in four minutes. The Decoder Unit which is part of this subsystem can be adjusted to follow higher transmission rates if faster response plotters become available; however, as mentioned before, the limiting factor in this case is the response of the particular plotter used in this subsystem.

A combination of this subsystem with a standard teletype network can provide the added capability of transmitting pictorial information such as overlays or sketch maps between selected line- or radio-teletype stations or to a number of stations simultaneously. This added capability permits the prompt transmission and automatic reproduction of:

Surveillance Information

In the display presentation, teletype-coded reports can automatically trace unit and equipment symbols, outline critical areas, and show directions of advance, as the reports are received, without the aid of an operator.

Situation Summaries

Periodic pictorial reports of the military situation at a specified time can be reproduced automatically and simultaneously at a number of stations.

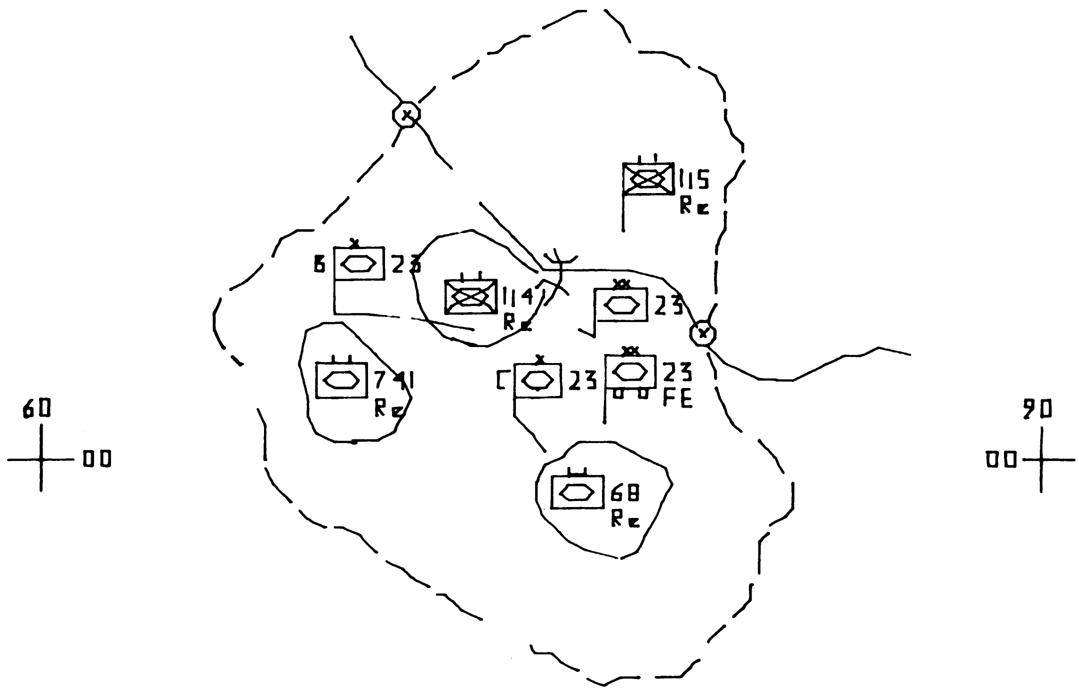



FIGURE 1. MAP OVERLAY REPRODUCED FROM TAPE

Field-Order Supplements

The sketch maps which often supplement combat orders can be sent with them on teletype by automatically switching between the page printer and this subsystem. An identifying code printed on the map and the printed orders assures their correct matching.

Weather Maps

The line information on weather maps showing moving and stationary fronts, high- and low-pressure areas, isotherms, etc., can be quickly transmitted to a number of stations.

Fallout Radiation-Level Contours

The transmission of predicted radiation levels in a fallout area downwind from an atomic explosion would be useful in both military and civil-defense situations. Safe and dangerous areas can be distinguished, and the degree of protection required for rescue workers can be estimated.

Tracing Path of Tracked Vehicle

Any vehicle for which changes in position can be teletype-coded as increments in rectangular coordinates and transmitted to headquarters can be tracked as a permanent record on this subsystem. Thus a reconnaissance vehicle on patrol equipped with radio teletype, an odometer for land navigation, and a coder, can keep headquarters informed of its position with brief periodic transmissions. Similarly, tracking by radar and coding the position changes for transmission provide a means of monitoring the position of an aircraft on patrol or approaching an airstrip.

## 2
## RESULTS of TESTS on PROTOTYPE SUBSYSTEM

A compact prototype subsystem was built to check the details and the reliability of operation. The components used were selected for small size and reliability, so they could be used in portable field models. After thorough tests of the prototype to demonstrate its accuracy, freedom from drift, independence of line-voltage variations, and reliability, two models for field demonstrations were built. These models were designed with plug-in components wherever possible for simple and rapid maintenance.

Tests on these units, using a Moseley X-Y Recorder as the display, demonstrated the following operating characteristics:

(a) When the fine pen which draws a line approximately 1/100 inch in width is used, and the line voltage is constant, it is not possible to detect a widening of the lines when a picture or pattern is traced the second time from the same teletype tape.

(b) There are no misses or errors in the operation when the line voltage is varied from 100 volts to 130 volts a-c, 60 cps. (The teletype will operate with a line-voltage variation from 105 volts to 125 volts.)

(c) When a picture or pattern is traced with the line voltage set at 105 volts and the same teletype tape is repeated with the voltage at 125 volts, the maximum error introduced at the outer edges of the plotter table is approximately two line widths, or 1/50 inch. This is one-fifth of the least count of 0.1 inch and is acceptable for a demonstration unit. Better regulation of the voltage for the ladder network in the digital-to-analog converter can be provided when higher independence from line-voltage variations is required.

The portable prototype, shock-mounted in its case, weighs 40 pounds and is 23 inches wide, 18 inches deep, and 8 1/4 inches high. It is shown in Figure 2. For a more compact unit without shock mounting, the rack for the chassis alone is 18 inches wide, 15 inches deep, and 7 inches high. Thus portability approximating that of a plotter and of a teletype unit has been achieved. The construction of the four chassis with the plug-in relays and counter modules is shown in Figures 3 and 4. An extension cable is provided so that any one of the chassis can be operated outside the rack for testing and adjustment. There are adjustments in the signal-distributor and power-supply chassis only.

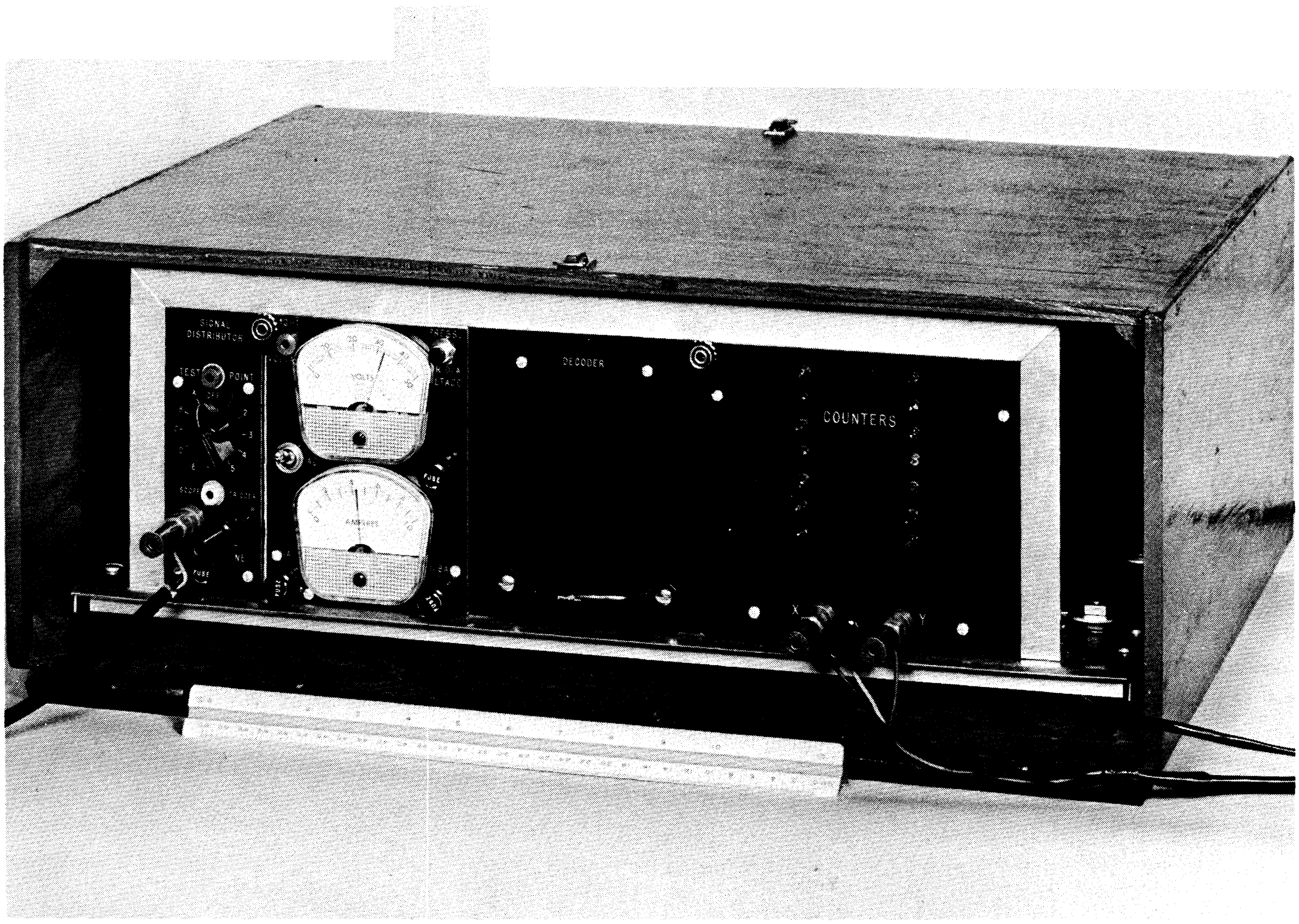



FIGURE 2. PROTOTYPE EQUIPMENT SHOCK-MOUNTED IN CASE

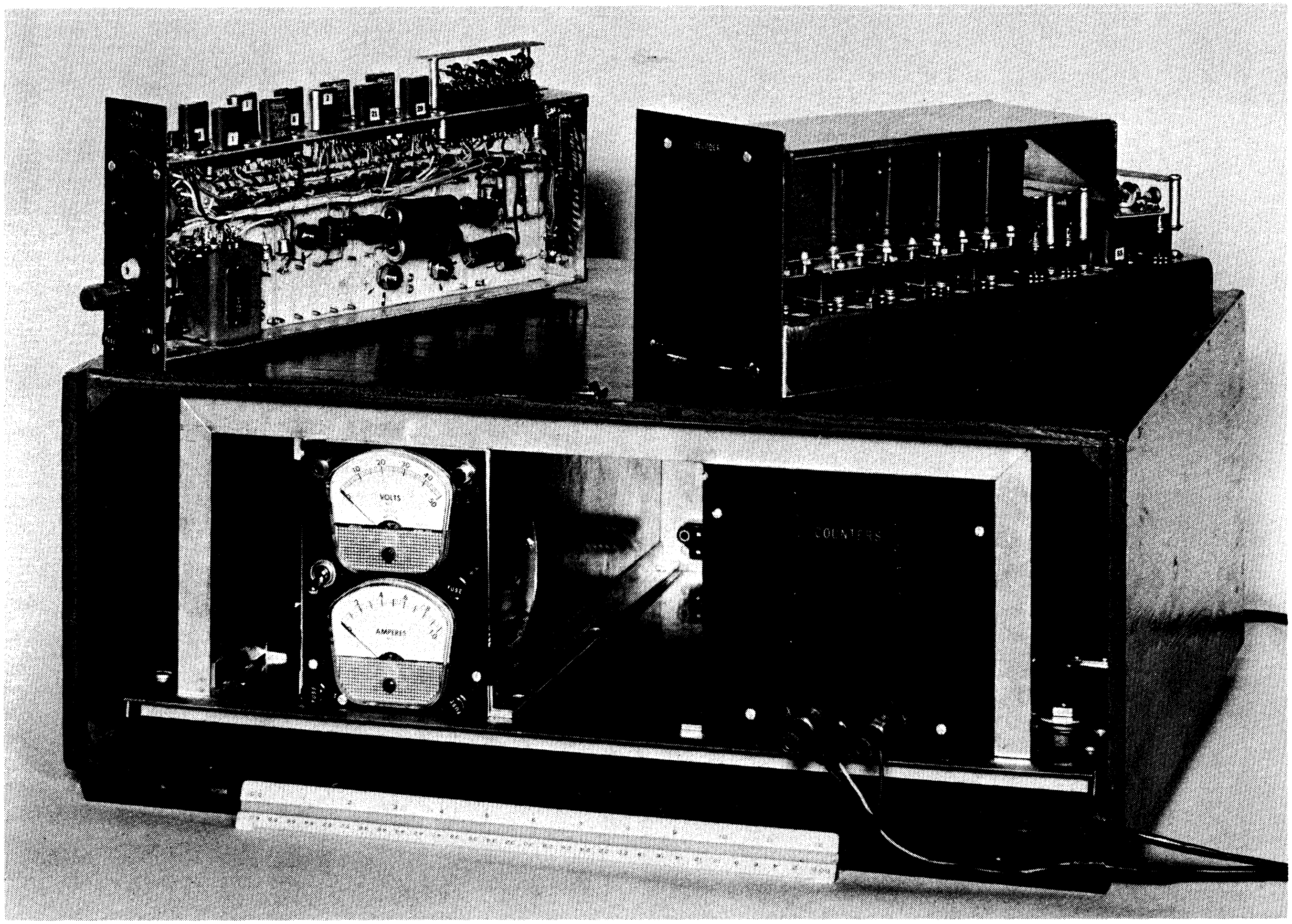



FIGURE 3. PROTOTYPE EQUIPMENT SHOWING THE SIGNAL-DISTRIBUTOR AND DECODER CHASSIS

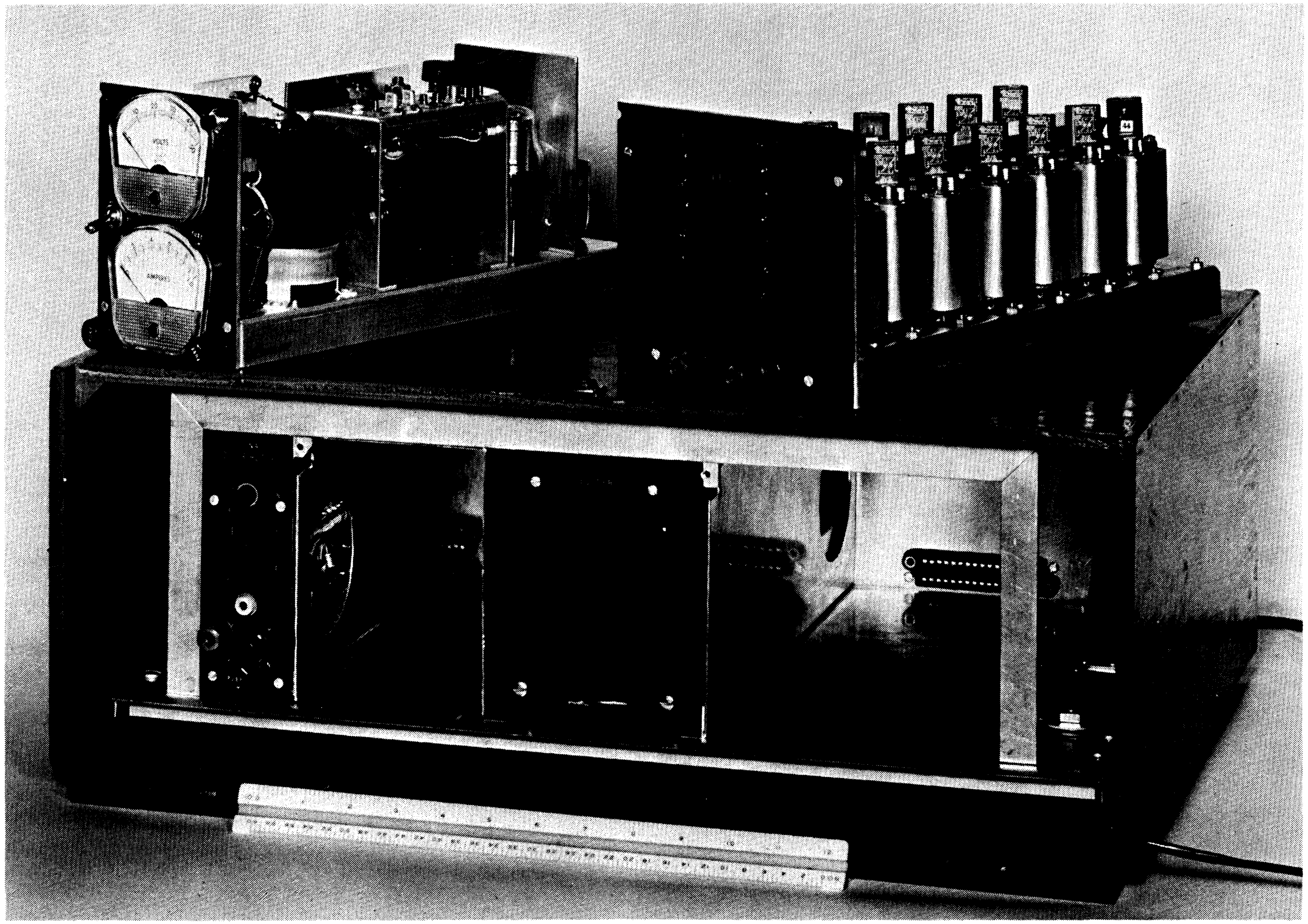


FIGURE 4. PROTOTYPE EQUIPMENT SHOWING THE POWER-SUPPLY AND COUNTER CHASSIS

## 3
## CONCLUSIONS

With the demonstration of the reliable digital transmission of continuous or interrupted, curved or irregular, lines for map overlays and other simple pictorial displays, the feasibility of sending map overlays and similar display material entirely in digital form has been proven. The digital coding of letter, number, and symbol information is fairly straightforward and has been used in a number of applications. Printing heads for printing such information in digitally designated positions on large automatic plotting boards are commercially available. The Benson-Lehner Model S Geophysical Plotter is one example.

For simple pictures of the line-drawing type, the speed of transmission is far superior to facsimile, since no time is spent in sending blank space. In addition, no adjusting and synchronizing time is required. The overlay shown in Figure 1 was transmitted in 4 minutes at a 60-words-per-minute teletype rate and traced directly from tape reception. With a faster plotter, this reception speed can be increased. By transmitting from tape and receiving on tape, this subsystem can be made even more independent of the teletype system and transmission can be made at a still higher rate.

The small size and portability of the prototype unit described herein also demonstrates the feasibility of using map-overlay transmission to and from small military units in which teletype is available. In the smallest military units where portability is of paramount importance a tracing plotter without a printing head might be preferable. If so, abbreviated alphanumerics and symbols can be traced on the plotter.

With the variety of sizes and types of plotters commercially available, it is feasible to build a fast and efficient printer-plotter for use at any of several command levels to transmit and reproduce map overlays from information transmitted in teletype. Given the detailed specifications for a single application in terms of overlay size, symbol size and types, and accuracy and repeatability requirements, a printer-plotter can be built which will satisfy these specifications. The prototype unit might be used to test applications at different command levels to aid in determining these requirements by varying the least-count size as the factor controlling the accuracy, and the capacity of the counters which controls the size of the plotting area.

The model described herein uses a relatively simple, but slow, method of encoding the line data. Faster methods for encoding have been developed, requiring somewhat greater equipment complexity. Proposed applications of systems of this type can, therefore, trade off speed of encoding for simplicity, if desired.

# 4
# GENERAL DESCRIPTION of OPERATION

The operation of the subsystem can best be described in terms of the function diagram in Figure 5, which represents the single special unit required for a map-overlay reproducer. The four separate boxes represent the four subchassis in the unit. Information flow is to the right through the three upper boxes. The teletype follower is connected in series with the teletype line, which nominally carries 60 ma at 115 volts d-c and transmits the information in a 5-bit sequential code. The presence or absence of 60 ma of current in pulse intervals 22 ms (milliseconds) long indicates ones or zeroes in the binary-coded teletype information.

The teletype follower merely reproduces the current pulses in the teletype line as identical voltage pulses to the signal distributor. This places no extra load on the line since the impedance of the teletype follower matches the input impedance of a teletype page printer and can be interchanged with it in the series line. In the signal distributor, the pattern of pulses in sequence is converted into a corresponding pattern of pulses in parallel in the five channels leading to the Decoding Network. Five multicontact relays in the Decoding Network are operated in the same

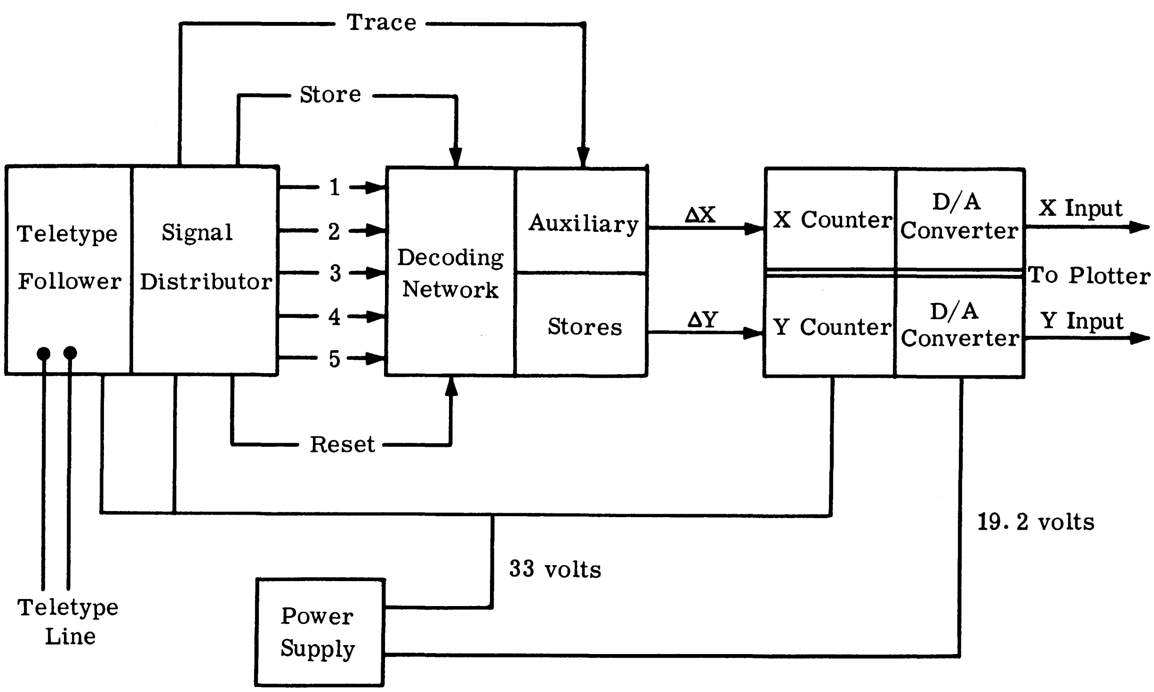



FIGURE 5. FUNCTION DIAGRAM OF THE PROTOTYPE EQUIPMENT

pattern and close a circuit corresponding to the information in the decoded teletype symbol. The Store pulse then transfers the information through this circuit to one of the auxiliary stores just before the Reset pulse returns the Decoding Network to normal for the next teletype symbol.

The information in the tape is coded in terms of the $\Delta X$ and $\Delta Y$ components of a sequence of straight-line segments which, when traced in order, will reproduce the desired lines. In order to trace a diagonal line on a plotter, the changes in the X and the Y voltages must be fed to the inputs simultaneously even though they are transmitted by teletype in sequence. This second conversion, one from sequential to simultaneous, depends on the auxiliary stores. The $\Delta X$ magnitude is stored in the upper store, and the $\Delta Y$ magnitude is stored in the lower store. Immediately after the $\Delta Y$ is stored, the Trace pulse sends the two increment values simultaneously to the X and Y counters. These counters maintain an algebraic sum of the increments sent to them and control digital-to-analog converters, which have a voltage output proportional to the sum in the corresponding counter. This digital-to-analog conversion is the third conversion required in the subsystem and provides changing voltages to the X-Y recorder or plotter, which will reproduce the lines coded in the tape. Thus, the reproduction of map overlays from teletype signals or from tape is entirely automatic.

The coding of the map-overlay information can be done in a number of ways. The one requiring the least equipment will be described first. In this method, only two pieces of equipment are required: a teletype punch, and a transparent grid as large as the overlay, having line spacing equal to the required least count. The overlay is traced with grease pencil on the transparency using only lines which join intersections on the grid and have components in the X and Y directions of 0, 1, 2, 4, or 8 least-count units. This limited selection is required by the binary X and Y counters in this subsystem.[1] After the overlay has been reproduced on the transparency as accurately as possible within the limitations set by the available line segments, the X and Y incremental values of the line segments are listed in sequence in the teletype code, including the symbols for raising and lowering the pen at the beginning and end of each discontinuity in the line. When this list of symbols is punched into tape, the overlay is ready for transmission to another station. Although this method requires little equipment, it is so subject to human error that it would be advisable to reproduce the overlay locally as a check before transmission. The omission of a pen-raise or pen-lower symbol would probably be the most frequent error, but the inclusion of unacceptable segments in the original tracking would also be likely to occur.

[1]Although this selection requires choices to be made by the operator, it provides a means of sending long line segments to represent lines in the drawing having only slight curvature. The alternative is to count the least-count units in each X and Y increment, and transmit the numbers, as would be done with a stylus-controlled analog-to-digital converter in both X and Y. This would be far less efficient in both coding and in transmission.

The second coding method takes advantage of the fact that in a two-way system there must be a plotter at each end of the communication link. Thus, the plotter normally used for reproducing a drawing being received may also be used in the coding operation. For this purpose, the pen on the plotter is replaced by a transparent coding grid shown in Figure 6. In addition, the use of the unit shown in Figure 2 and a teletype tape perforator are required. The plotter with the grid and the teletype tape perforator are arranged for coding as shown in Figure 7. The grid is designed so that the magnitude and sign of the X or Y component can both be expressed by a single teletype symbol. The lines are arranged to limit the components to the 0, 1, 2, 4, and 8 values mentioned before. On the grid there are 80 line segments (from the origin at the center to any of the other intersections) which can be selected in the coding and can be represented by two letters in the teletype code. By use of the subsystem Decoding Unit, the plotter will follow the progress of the coding operation; i. e., after a segment is punched the plotter moves the center origin of the coding grid over the terminal end of the segment just punched. The complete coding loop is shown in diagram form in Figure 8. The switch shows that the identical subsystem equipment is used for both receiving and coding overlays with only the pen on the plotter replaced by the grid.

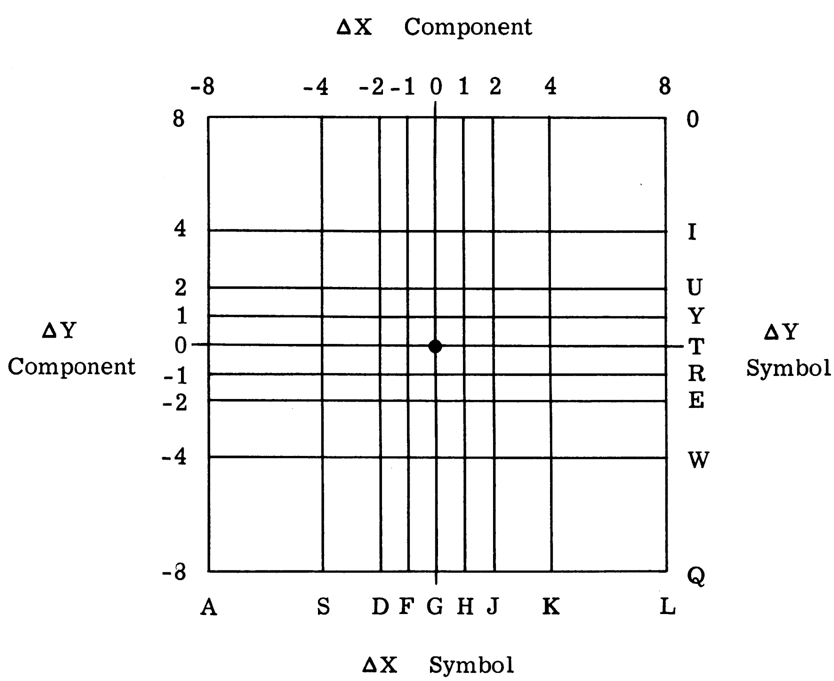



FIGURE 6. CODING GRID

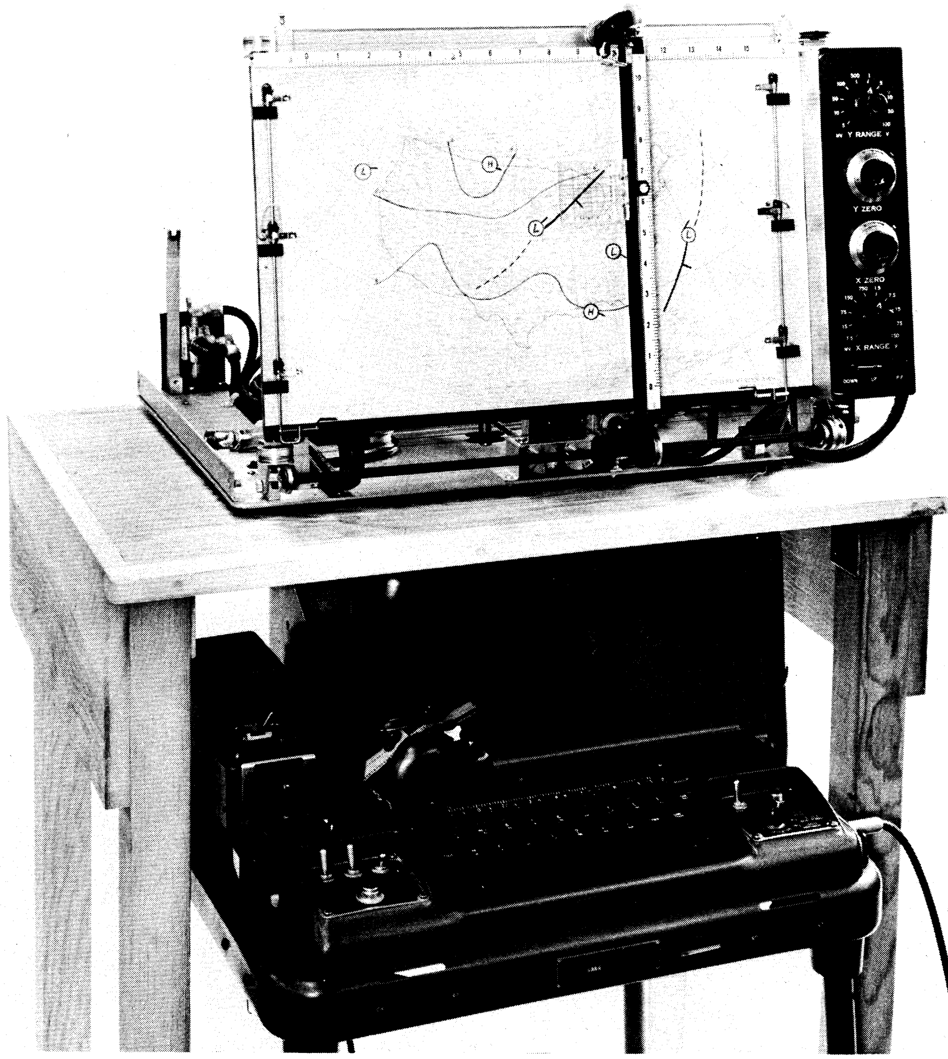


FIGURE 7. CODING EQUIPMENT FOR WEATHER-MAP TRANSMISSION

This method has the advantage of showing the operator directly on the grid the available selection of line segments at each point in the coding and of providing him with an instantaneous and continuous check on the coding of each line segment. In addition, errors in coding can be corrected immediately.

A third coding method, which has been proposed but not tested, requires a special device similar to a drafting machine. This method, which is described in Appendix B, has several

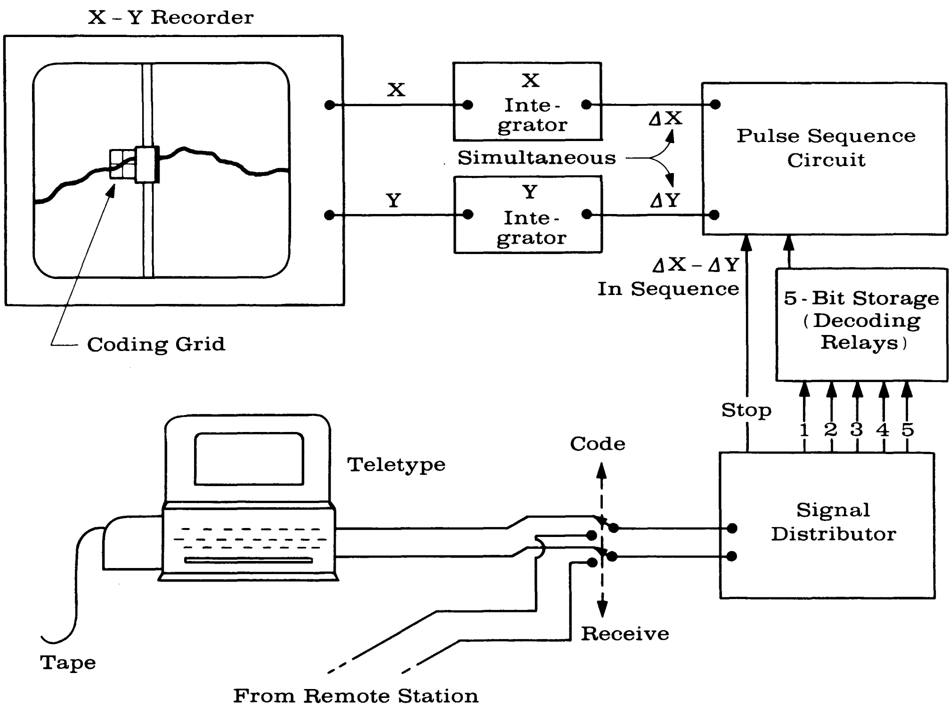



FIGURE 8. DIAGRAM OF CODING LOOP

advantages. The translation from a selected line segment to the ΔX and ΔY symbols is done almost automatically and therefore does not require a skilled teletype operator. The coding is done with a stylus and a grid which limits the selection of lines to the same 80 segments, but the operator is not required to think of them in terms of a teletype code.

A fourth method, which requires still more equipment, would use a computer program and its storage to code the line in terms of the selected set of line segments. The same type of least-increment counter as used in the third method would be required, but the stylus in this case is used simply to follow the line. The computer is required to store not only the count of the X and Y increments beyond 8, but the rate of change of Y with respect to X. Only in this way can the program select the longest acceptable line segment to code in the tape. However, this sytem would require so much additional equipment that the advantages of simplicity and portability would be completely lost.

Obviously, variations and combinations of these methods are also possible.

# 5
# OPERATOR INSTRUCTIONS

## 5.1. EQUIPMENT LAYOUT

The AN/GGC-3 teletypewriter set used in this subsystem is first unpacked, set up, and connected to a line unit and local d-c line supply. This part of the system should be functioning as a regular teletypewriter station before the remaining equipment is connected. A Moseley X-Y Recorder and the Decoder Unit are all that remain to be added to this teletypewriter station in order to complete this subsystem.

The recorder is preferably placed on a table immediately above and slightly to the rear of the teletype keyboard. The recorder surface is elevated so that it can be easily seen by the operator sitting at the teletypewriter (Figure 7). The power cord is then plugged into a 115-volt, a-c, 60-cycle outlet and the power switch turned on.

The Decoder Unit, or conversion unit, is placed so that the operator may see the neon lights on the counter chassis and possibly the power-supply meters. The three terminals on the counter chassis are connected by a three-conductor cable to the X, Y, and ground input terminals on the recorder. The pen-lift phone plug is inserted in the symbol head or pen jack on the recorder. The power cord of the Decoder Unit is then plugged into the 115-volt, a-c, 60-cycle power outlet. The 115-volt, d-c, 60-ma teletype line connections are made to the two terminals on the signal-distributor chassis. The red terminal is connected to the positive side of the current supply, which may be a line unit or special interconnection box. This interconnection box contains local-distant and teletype-plotter switches and maintains proper polarity of current supply during local coding or distant reception operations. Essentially, this box is a looping switchpanel which allows several units to be interconnected.

The power switch is then turned on and the voltages checked in the Decoder Unit power supply chassis. The voltmeter should read 33 volts. When the D/A voltage pushbutton is depressed, the voltmeter should read 19.2 volts. Some of the neon lights on the counter chassis should be illuminated at this time. If none of them are lighted, the light voltage should be measured at the plug on the power-supply chassis labelled light voltage. When the whole subsystem is correctly interconnected, the operator can depress the Z key on the teletype keyboard and the top two lights on the counter chassis will be lighted. This is the zero or reset position of the counter. The recorder servo switch may now be turned on and the coding grid centered over the pictorial display by means of the X and Y zero controls. The equipment should now be ready to operate. If any malfunction is noted, the detailed operational procedure should be consulted.

Occasionally when the Decoder Unit is first switched on, one of the relays will oscillate or buzz. If this occurs, the teletype break button should be pushed or the line interrupted memen-tarily and the oscillation will stop. If it does not stop, the signal distributor is not adjusted correctly and needs to be checked (Appendix A).

## 5.2. CODING PROCEDURE

The coding of a permanent pictorial display such as the map overlay shown in Figure 1 will be described and the necessary coding steps for method two will be outlined in this section.

5.2.1. MOUNTING. The selected overlay is placed on the recorder surface under the hold-down clips and the vacuum switch is turned on. This vacuum will hold the paper perfectly flat against the surface and will not distort the overlay. Moreover, the coding grid, which is attached to the recording crossarm, will not catch on the overlay and tear it when the vacuum is holding it perfectly flat.

5.2.2. CENTERING. With the coding grid in position on the recorder crossarm, the Z key on the teletype keyboard is depressed to reset the counters, and the X and Y zero potentiometers on the recorder are adjusted until the coding grid centers on the pictorial display to be coded. Since the capacity of the X counter in this prototype is not adequate for the full horizontal range of the plotter, the position selected for a center should not be so close to the edge of the recorder surface that the maximum counter limits are reached when the recorder arm moves to the opposite edge of the plotting board.

5.2.3. CODING GRID AND KEYBOARD. The teletype keyboard is very similar to the standard typewriter keyboard. It has three rows of keys, and the letters and numerals are in the same order. The teletype keyboard does not have a shift key, but instead has two keys called LETTERS and FIGURES which perform a similar function. There is another key called CARRIAGE RETURN whose function is self-explanatory.

The coding scheme used with this system utilizes only the middle and top rows of keys. The middle row contains the $\Delta X$ positions and the top row the $\Delta Y$ positions. When a line segment is coded, the $\Delta X$ key in the middle row is always punched first; and then the $\Delta Y$ key in the top row is punched, completing the operation. The two characters alone are enough to transmit a line segment.

The grid used for coding is shown in Figure 6. The line segments which can be coded are the lines radiating from the origin, or center, of the grid (GT) and extending to any other intersection of horizontal and vertical lines. Each line is designated by the coordinates of its distal end, as shown on the top and left side of the grid. The corresponding teletype symbols are shown on the right side and bottom of the grid. The X coordinate symbol found along the bottom is typed first on the keyboard, and then the Y coordinate symbol found along the right side is typed. Figure 9 shows all the available line segments divided into four groups according to length and labelled with the correct letter code. Although the standard coding grid is simpler and more compact (Figure 6), the information in Figure 9, if memorized, might aid the operator in coding.

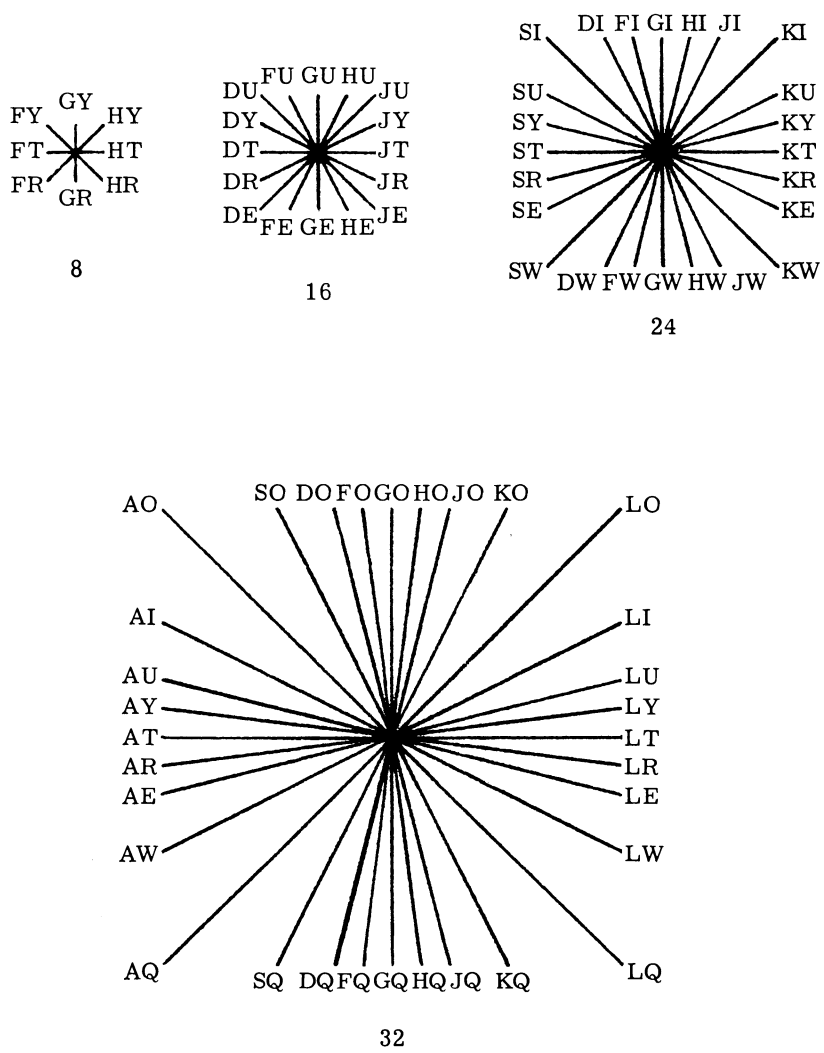



FIGURE 9. LINE SEGMENTS, GROUPED AND CODED

The operator now determines where to begin coding the map overlay. First, he must determine the direction in which the grid must be moved from the center position to begin coding the first line segment. In the case of the overlay shown in Figure 1, the operator should move the grid straight to the left and begin on the outer boundary, as indicated in Figure 10. After feeding out a length of blank tape, the operator strikes the Z key several times to insure that the receiving recorder will be properly centered before receiving the overlay. He also may strike the C

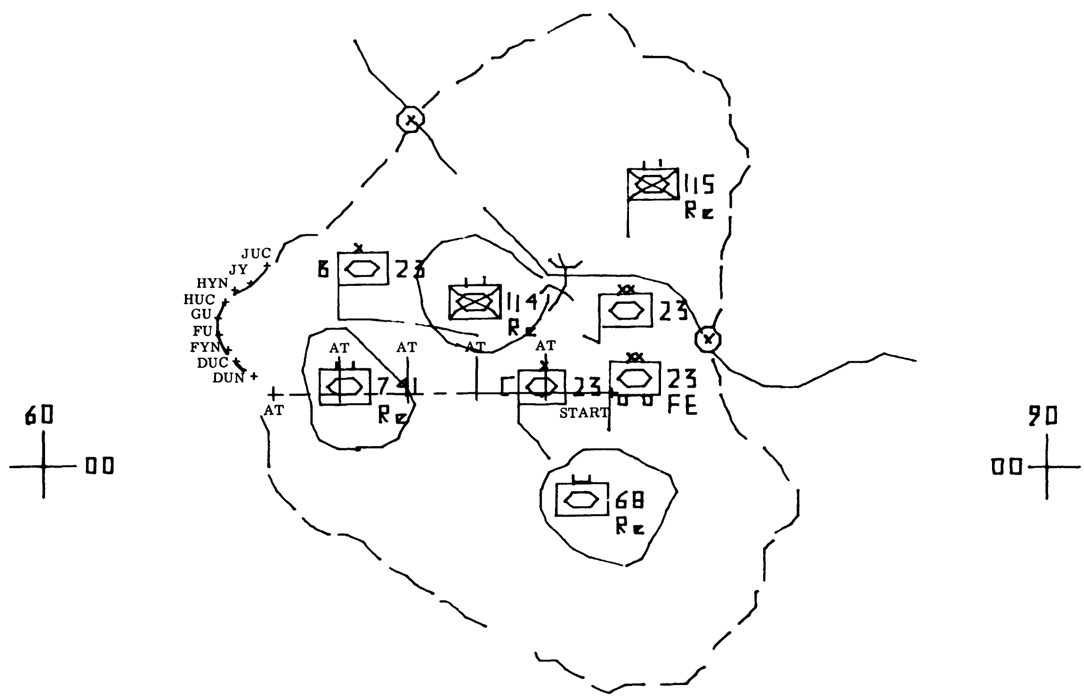


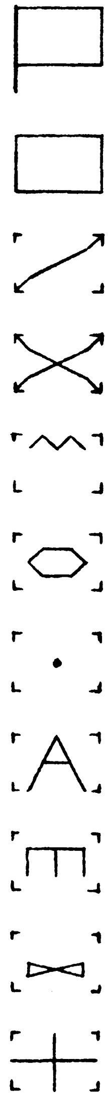

FIGURE 10. DETAILED CODING STEPS OF OVERLAY FOR FIGURE 1

key (raises the pen) and the N key (lowers the pen) alternately, which will leave a dot at the center position of the receiving recorder for reference. The pen is left in the raised position while the series of moves are being made from the center to the starting point on the boundary. To move directly to the left, the operator strikes the AT keys, which will then move the grid the longest segment in the -X direction. Since the grid has not yet reached the outer boundary, the AT keys are depressed again, moving the grid another segment toward the left boundary. The AT keys are struck twice more, which will bring the grid close to the boundary but still short of the starting point. The next move must be 45$^{o}$ in the upper-left direction, which is coded using the characters DU. Now the starting point has been reached and the pen is lowered with an N character. The first line segment is in the same direction as the previous move and for the same distance, so the DU keys are struck again. Since the boundary is an interrupted curved line, the pen is raised at this point by depressing the C key, and a space equal to the line segment FY is punched, after which the pen is lowered with an N. Continuing along the boundary, the code will read something like this: FU, GU, HU, C (pen raised), HY, N (pen lowered), JY, JU, C (pen raised). The coding is continued in much the same fashion until the entire overlay is coded.

This system was originally designed to transmit only curved and irregular lines. The military symbols and alphanumerics were to be printed by a special printing head on the recorder. Since the printing head is not part of the present system, the recording pen must trace any symbols and alphanumerics that are used. The method of tracing these is not efficient if many alphanumerics are used because several teletype characters are required to trace each letter or number. However, for abbreviated alphanumerics and symbols, the tracing scheme may be very useful. Several military map symbols selected from those most likely to be found in forward combat areas are shown in Figure 11, along with the code for the line segments required to trace the symbol. The spaces between the teletype characters in Figure 11 are included for ease of reading and should not be included in the tape. The command-post symbol is coded as though the pen were in position at the base of the staff and raised from the paper. The first teletype character is the letter N, which lowers the pen.[2] After the command-post symbol is traced, the pen is raised at the lower left corner of the flag by striking the C key. The command-post identification is then traced, starting from this point. In the same fashion, the remaining symbols start at the lower-left corner of the flag and are returned to the lower-left corner so that a number of symbols can be superimposed in a given unit identification (see the Armored Infantry symbol in Figure 1). Obviously, this list can be added to and standarized to accommodate additional or changing size and proportion requirements.

5.2.4. ERROR CHECKING. There are several ways in which an operator may check the coding of these pictorial displays. First, the coding operator may check the display he has just coded by locally reproducing the overlay on a new sheet of paper from the tape he has just coded, and comparing this overlay with the original. The overlays when superimposed should match perfectly. On the receiving end, the operator can determine whether a transmission is correct if the coding operator, while coding the overlay, periodically returns the grid to the zero-zero

[2]However, if the last motion of the plotter before lowering the pen is equal to one of the longer time segments, it is advisable to strike the letter G before striking the letter N in order to allow the plotter time to reach its final position (see C. P. and Unit symbols, Figure 11).



| | | |
|---|---|---|
| C. P. | G N U I KT JT GW ST DT C | 15 |
| UNIT | G N I KT JT GW ST DT C | 13 |
| CAV | N HY KU HY C SW DT | 12 |
| INF | N HY KU HY C W G N FY SY FY C W | 19 |
| ABN | HI R GN HY HR HY HR C SR FR | 18 |
| ARMOR | HU N HY JT HR FR DT FY C FE | 18 |
| ARTY | JU HT N C DE FT | 10 |
| AAA | HT N JI JW FU DT C DE | 14 |
| ENGR | HY N U JT GE U JT GE C SR FT | 18 |
| AIR | HY N Y KR GY SR C FR | 13 |
| MED | U G N KT JT C DY FY N GW C DT FT | 20 |

FIGURE 11. MILITARY SYMBOLS WITH THE CODE FOR TRACING

position or Z origin and moves it back again to the point where he left off. If this is done several times during the coding of a given overlay or display, the receiving operator can note the point to which the pen returns from the origin and can thus check the transmission accuracy.

Another means of error-checking the transmission makes use of the closed loops that naturally occur in a display. Wherever a boundary or loop is closed (Figure 1), the point of closure is checked and if there is a deviation of more than a least count, an error has been made or there is drift in the circuits. Each military map symbol, each battalion area of influence, each regimental area, etc., is a closed loop. Therefore, they represent possible error checks for the operator.

5.2.5. ERROR CORRECTING. If an incorrect $\Delta X$ is typed, it is corrected by hitting the SPACE bar. This resets the $\Delta X$ auxiliary store in the coding loop and in any receiving subsystem. If an incorrect line segment is typed ($\Delta X$, $\Delta Y$), the code symbols for an equal line segment in the opposite direction are typed in the tape. This brings the plotter back to the last correct position. The tape is then backed four symbol spaces and the LETTERS key is struck four times. This eliminates both the incorrect line and its correction from the tape. A receiving subsystem will merely pause while these four symbols are being received.

## 5.3. DECODING PROCEDURE

The decoding or receiving process is entirely automatic, since the recorder and the Decoder Unit may be connected directly to the incoming teletype line. Consequently, the operator's function in the reception of a pictorial display is only to stand by and watch the overlay as it is received. Even this is not necessary, although desirable in order to check for errors promptly.

## 5.4. CONCLUSIONS

The information given as instructions to the operator should be sufficient for any teletype operator to run this equipment. The equipment layout, decoding, and coding have been described without delving unnecessarily into the electronic details. This subsystem has the capability of transmitting while the operator is coding, since transmission requires only the use of the tape-transmitter distributor and preperforated tapes, and since only the reperforator and keyboard are used in the coding operation. When a pictorial display is being received, however, the operator can use the teletype machine for transmission from either the keyboard or tape-transmitter distributor provided full duplex operation is maintained. The received pictorial display may also be reperforated while the operator is transmitting on another line.

This present subsystem makes very few demands on the teletype operator other than his regular function. Although coding involves some extra work, depending upon the amount of information on the pictorial display, the reception or decoding is entirely automatic and does not impose on the operator.

The chief limitation of this subsystem is that the teletype machine is only partially useful on the line while the pictorial information is being coded. The alternate coding equipment mentioned in Appendix B would allow the teletype machine to be used for regular teletype communications during the coding operation. Moreover, this new coder would also eliminate the requirement for a skilled operator.

## Appendix A
## DETAILED CIRCUIT OPERATION

The purpose of this appendix is to furnish a more detailed explanation of the operation of the circuitry, with brief adjusting and maintenance instructions. A broad description of the function of each chassis has already been given above in terms of Figure 5.

The first chassis, the signal distributor, is shown in Figure 12. There are two types of miniature relays used in this circuit. Both are plug in and the same size, but they have different characteristics. The MV Relays have a single coil with double-pole, double-throw contacts, and are standard in operation, closing the lower contacts only when current flows in the coil. The SL Relays also have double-pole, double-throw contacts, but are magnetic latching and have two coils. A sketch of the coils and contacts of an SL Relay, with the terminal numbers, is shown in the upper-right corner of Figure 12. This sketch shows the terminal arrangement for all eight SL Relays in the circuit. The terminal numbers are given in each case for the two MV Relays on the diagram.

The SL, or latching, Relays require only a 3- or 4-ms pulse of 24 volts applied to the operate coil (9, 3) to transfer from the upper to the lower contacts. The relay will hold in this position without current until a like pulse is applied to the release coil (2, 8). The contacts will then return to the upper position and hold without voltage being applied.

Since the signal-distributor circuit must be adjusted to synchronize with the incoming teletype signals, the timing intervals of the signals must be matched in the circuit. The teletype signal is shown at the top of Figure 13 and is marked TT SIG-A. The 22-ms intervals are always constant. The teletype signal for a single character always starts with a 22-ms interval of no current, followed by five 22-ms intervals in which 60-ma current pulses may or may not appear. For each different character, a different pattern of pulses occurs. The only change in current which occurs in every symbol signal is the drop in current from 60 ma to zero at the end of the STOP pulse, which is also the beginning of the START interval. The 31 ms given as the duration of the STOP pulse is the minimum. The maximum STOP pulse duration could reach infinity if a character was never transmitted. The 163-ms period between START intervals is for transmission from tape at 60 words per minute. For transmission from a keyboard, these values are both increased because the STOP interval increases.

The second signal in Figure 13 is marked TT $\overline{\text{SIG}}$. It is produced by the teletype follower circuit, and is the opposite or inverse of the teletype signal, i.e., the spacing and working

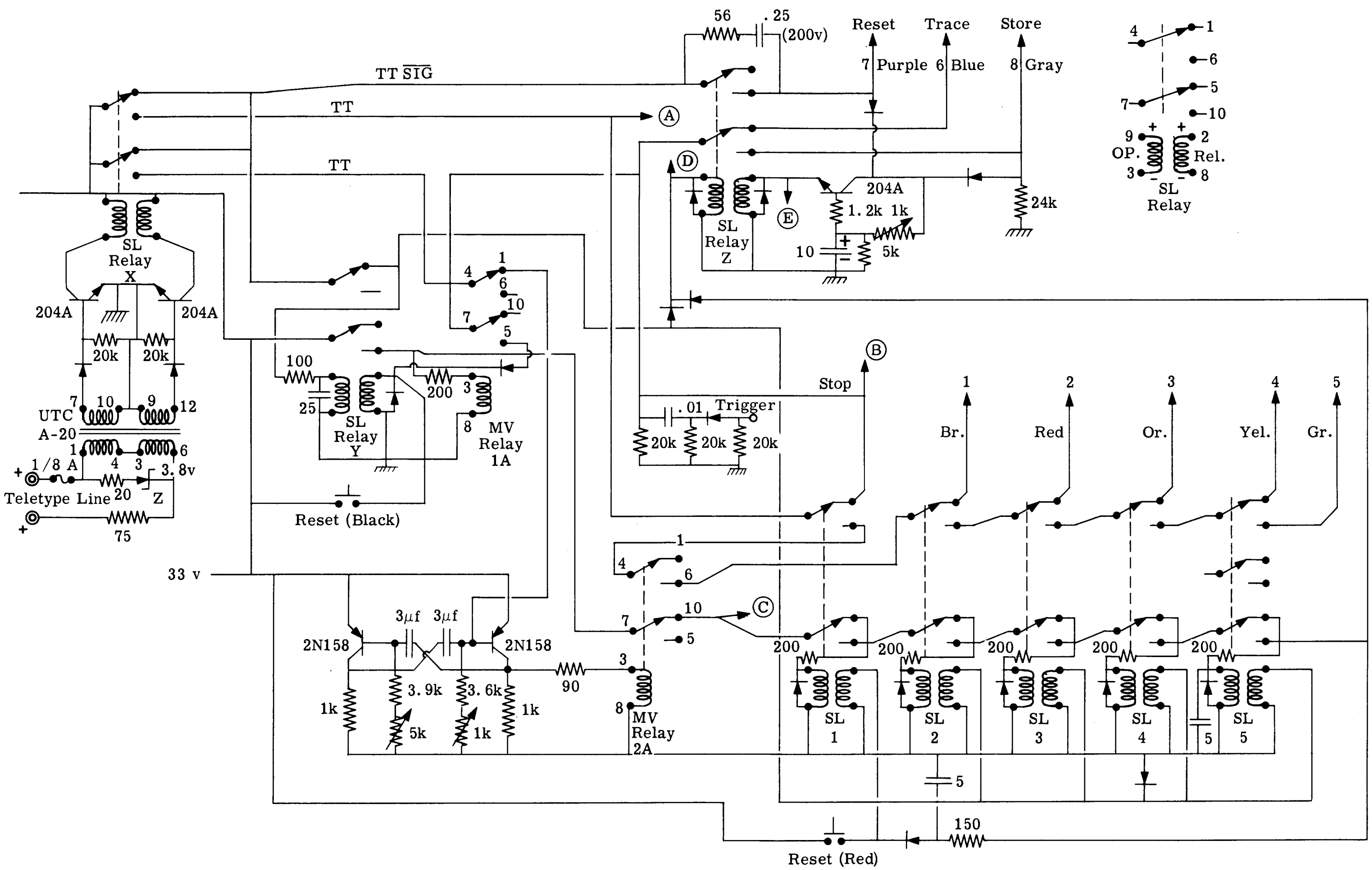



FIGURE 12. SIGNAL-DISTRIBUTOR CIRCUIT

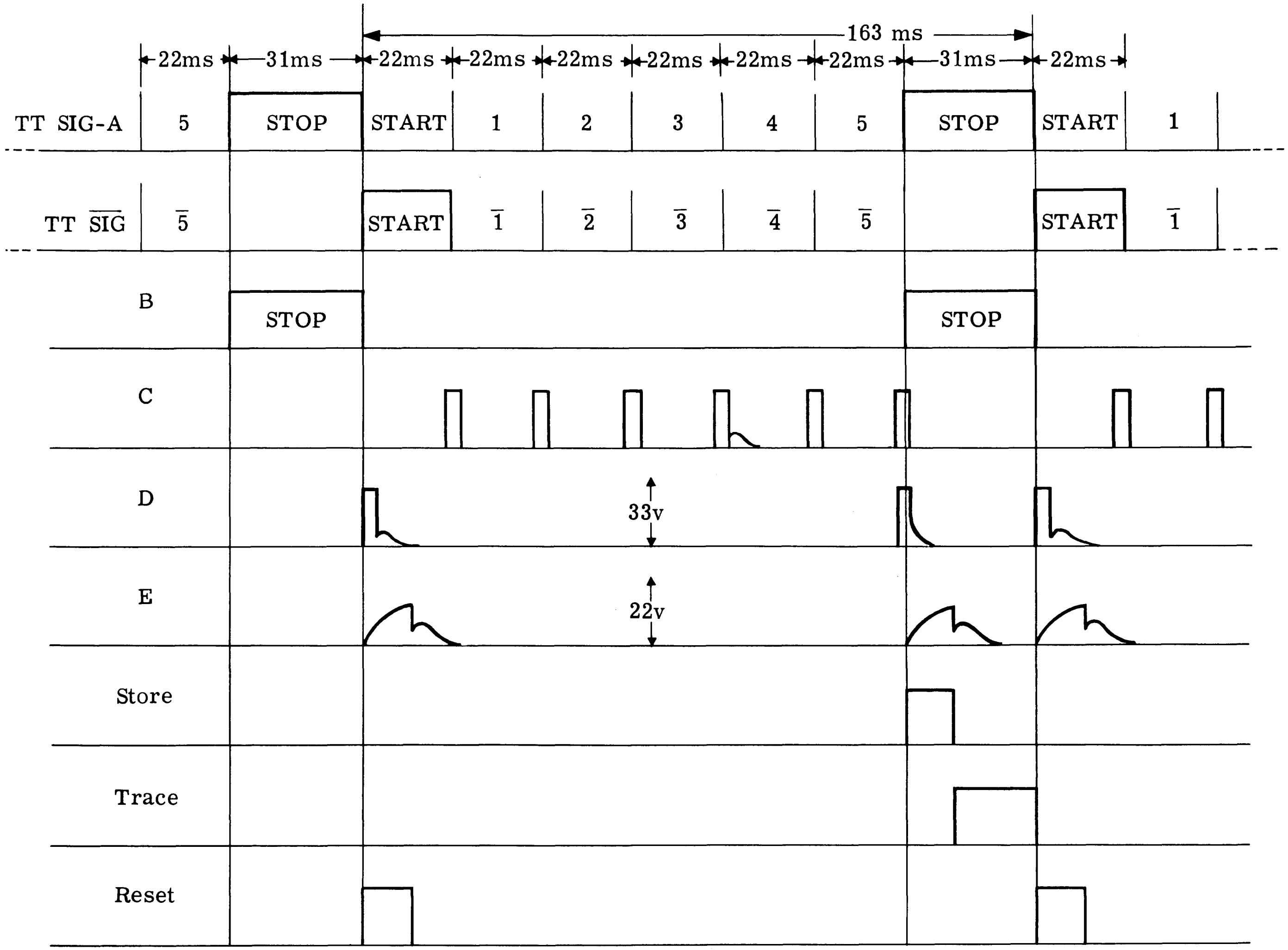



FIGURE 13. SIGNAL-DISTRIBUTOR TIMING

impulses are interchanged. During the STOP interval no voltage pulse occurs, during the START interval a voltage pulse always occurs, and the pattern of pulses that follows is the inverse of any teletype signal received. This pattern does not influence the circuit since it is always switched out by the START pulse.

The input circuit on the left of Figure 12, the teletype follower circuit, depends on the characteristics of the transformer, the transistors, and the magnetic latching relay. The teletype line current passes through the primary of the transformer, which produces pulses in the secondary for each rapid change in line current. With the center tap of the secondary (9 and 10) grounded, a positive pulse appears at 7 for a rise in line current and a positive pulse appears at 12 for a drop in current. These pulses are amplified by the 204A transistors which are connected with grounded emitters to drive the coils of SL Relay X. The secondary pulses are short compared to the 22-ms intervals, but the latching relay holds its position until the next pulse. In this way the current pulses in the teletype line are duplicated as voltage pulses on terminals 6 and 10 of SL Relay X. Since the teletype follower circuit operates only on changes in line current, it will follow signals of either polar or neutral types without circuit adjustment.

Relay X is shown in the position in which no teletype line current is flowing. As soon as the line is connected and the STOP current flows, the operate coil of the relay is pulsed and the contacts transfer to the lower positions. The 33 volts from the power supply appear only at the A and B test points and the Trace output. Except for the X Relay, all the relays are shown in this standby and ready-to-receive-a-signal position. In fact, all relays except X must be in the positions shown or the signal distributor will not operate. The two reset push-button switches are provided to permit resetting SL Relays Y and 1 during adjustment of the circuit timing. If the timing is not correct, these two relays will not be reset at the end of a character. It is then necessary to reset them manually to try another adjustment. The timing in the signal distributor is not especially critical, but it can be upset sometimes by changing or reversing certain relays.

The unbalanced transistor multivibrator at the lower left provides the timing which keeps the circuit synchronized with the incoming signals. It is blocked in the standby position by the 33 volts applied to the base of the 2N158 transistor on the right. The collector current of this transistor is cut off and MV Relay 2A is not energized. When the circuit from the base of the 2N158 to the 33-volt supply is broken, the multivibrator operates. After a delay of approximately 19 ms the contacts of MV Relay 2A are transferred to the lower position for approximately 3 ms. This cycle is repeated until 33 volts is again applied to the base of the 2N158 transistor to hold it cut off. The 5k and 1k potentiometers in the multivibrator are the adjustments for these two intervals. The multivibrator is free-running during each character cycle of 132 ms and must stay synchronized with the incoming teletype pulses.

When the line current drops to zero at the start of a character, the contacts of Relay X are transferred to the upper position, removing the 33 volts from the base of the 2N158 transistor and starting the multivibrator. At the same time, the STOP voltage is also removed from test points A and B and the START pulse is applied through an RC delay circuit to the operate coil of SL Relay Y. Ignoring for the present the other function of contact 1, the operation of this relay merely removes the START pulse from its own operate coil and applies 33 volts to the coil of MV Relay 1A and to terminal 7 of MV Relay 2A. The operation of the multivibrator has already energized MV Relay 2A so the voltage at terminal 7 does not appear at terminal 10 and test point C. No voltage is applied at terminal 7 of MV Relay 1A because it is during the START interval of a TT signal. The shape of the voltage pulses at the lettered test points are shown in Figure 13.

After approximately 19 ms, Relay 2A is released for 3 ms. The resulting voltage pulse on the operate coil of SL Relay 1 transfers its contacts to the lower position. The operation of the relay occurs at the correct time to prevent any of the pulse in the first interval from appearing at the STOP test point B, but does cause it to appear at output 1 on SL Relay 2. The next four 3-ms pulses, which appear at test point C at 22-ms intervals, operate SL Relays 2, 3, 4, and 5 in synchronism with the incoming signal pulses, so that any pulses in the second, third, fourth, and fifth intervals appear at the corresponding 2, 3, 4, and 5 outputs. This completes the major function of the circuit. The remaining pulses, contacts, and relays serve to reset the circuit for the next character and to provide timing and control pulses for the circuits which follow.

The sixth 3-ms pulse at test point C resets SL Relay 1 and operates SL Relay Z. Resetting Relay 1 returns the TT signal to test point B which is now in the STOP interval. The STOP voltage is therefore applied to terminal 7 of Relay 1A which was energized earlier in the character cycle. The application of the STOP voltage to the release coil of Relay Y resets the relay and removes the 33 volts from the coil of Relay 1A and from terminal 7 of Relay 2A. The resetting of Relay Y also returns the TT $\overline{\text{SIG}}$ to terminal 1 of Relay Y so that the START pulse of the next character will reset Relays 2, 3, 4, and 5. The release of Relay 1A clips off the pulse to the release coil of Relay Y and returns the 33 volts to the base of the 2N158 transistor, stopping the multivibrator. The circuit is now ready for the next character cycle.

The circuit of Relay Z provides timing and control pulses required in the other chassis. This relay is doing double duty and operates twice during a character cycle. The operate and release voltages of Relay Z are shown as D and E in Figure 13. The first pulse to the operate coil of Relay Z, shown at test point D (Figure 1), occurs at the beginning of the START interval and is the same pulse that operates Relay Y. The discharge trail-off, shown in the first pulse of D in Figure 13, is caused by the RC delay in the operate coil circuit of Relay Y. The second pulse at the beginning of the STOP pulse is the sixth 3-ms pulse in C. These two pulses are fed to test point D through a diode OR-gate to prevent each from influencing the other's circuit. The 204A transistor, which drives the release coil at test point E, is connected as an emitter follower. The transistor driver permits the use of an RC delay circuit of reasonable values in the base circuit of the 204A. It is doubtful that an electrolytic capacitor of any reasonable size would provide the 8- to 10-ms delay required when connected across the release coil of Relay Z.

The first pulse in D (Figure 13) occurs at the beginning of the START interval. Hence, the START pulse is applied through terminals 4 and 6 and through a diode OR-gate to the collector and to the delay in the base circuit of the 204A transistor. Through the same contacts, the reset circuit of the decoder is pulsed. The delay determines the release time of Relay Z and the length of the Reset pulse.

The second pulse in D occurs at the beginning of the STOP interval. Hence, the STOP pulse is applied through a diode OR-gate to the collector and to the base of the 204A transistor through terminals 7 and 10. Through these same contacts the Store circuit is pulsed. Because the same delay is used, the Store pulse is the same length as the Reset pulse. The adjustment for this pulse duration is controlled by the 1k potentiometer in the 204A base circuit. The length of the Trace pulse is the length of the STOP pulse with the Store pulse subtracted. Since the STOP pulse can be of any length, this is also true of the Trace pulse. The Trace pulse is clipped to a few milliseconds in length in the auxiliary store circuit on another chassis.

When the signal distributor is connected to the teletype line, and no character is being sent, the power-supply voltage appears at the test points A and B and at the Trace output. When testing and adjusting the circuit, special care must be taken to avoid shorting these circuits to ground. To reduce the chance of this occurring when a trigger circuit is connected to the monitor oscilloscope, a differentiating circuit was connected to the STOP circuit to provide a sharp negative pulse at the end of the STOP pulse to synchronize the scope sweep. Pulse patterns C, D, E, (Store, Trace, and Reset of Figure 13) are shown as they would appear on an oscilloscope synchronized to start sweeping at the end of the first STOP pulse.

The outputs of the signal-distributor circuit are the five outputs numbered 1 through 5, which carry the corresponding pulses of the character, and the Store, Trace, and Reset control pulses. As shown in Figure 5, these signals all go to the Decoding Network and the Auxiliary Stores.

A. 1. ADJUSTMENT OF THE SIGNAL DISTRIBUTOR

The timing adjustment of the signal distributor requires an oscilloscope to show the waveform at each of the lettered test points shown in Figure 12. If the waveform at each of these points matches that shown in Figure 13, satisfactory operation is almost assured. The best teletype characters for adjustment are a series of Y's or R's or both read from a tape, since these characters have alternate 1's and 0's to clearly mark the 22-ms intervals. The sweep of the oscilloscope should be adjusted to show all six intervals on the screen. If the waveform at A is correct and matches the character transmitted, the teletype follower circuit is operating correctly. If it is not, consult the description of the teletype follower above and check the waveforms at different points in its circuit to find the component failure. The test extension cable must be used as shown in Figure 14 to make the controls accessible.

Initially, adjust the three potentiometers so that the black end of the screwdriver slot coincides with the darker mark on the mounting board (Figure 14). The pencil marks indicate

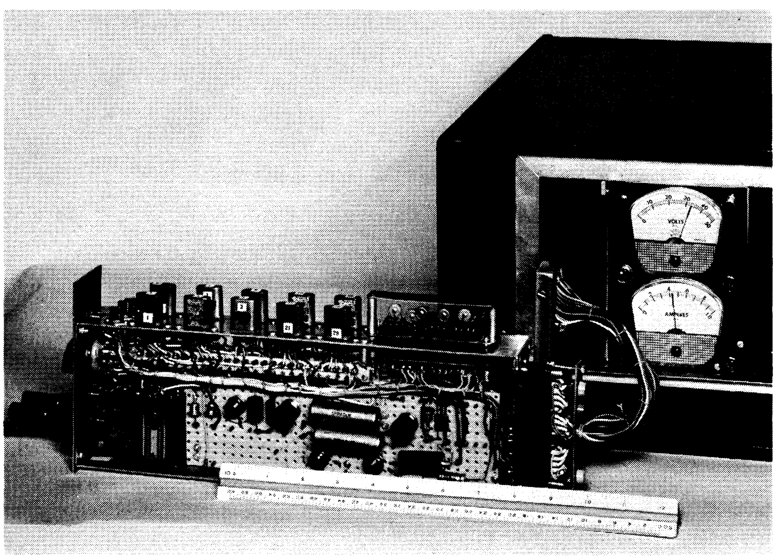


FIGURE 14. SIGNAL DISTRIBUTOR SHOWING CONTROLS

the approximate range for satisfactory operation. The two potentiometers at the lower right are in the transistor multivibrator. The 5k potentiometer is on the right above the 4-inch mark, and the 1k potentiometer above the 2 1/2-inch mark on the scale. These two potentiometers control the pulse width or duration and the pulse spacing of the signals at C. The pulse duration must be long enough to operate one of the SL 1, 2, 3, 4, or 5 sequence relays, but not long enough to operate a second one through the first. The sum of the duration and the spacing must equal the 22-ms-bit interval of the teletype characters. The two reset pushbuttons are also shown in Figure 14. The red one, above the 5-inch mark on the scale, resets SL Relay 1. The black one, above the 1 1/2-inch mark, resets SL Relay Y. The third control, above the 0-inch mark, is the 1k potentiometer reset delay circuit of the SL Relay Z. It controls the duration of the Store and Reset pulses. Test points for the Store, Trace, and Reset pulses are brought out and marked on the back of the female connector in the test extension cable. The Store pulse must be approximately 10 ms long to assure the operation of the plus- and minus-sign relays in the counters before the Trace pulse is received.

The Decoding Network has no adjustments and should require very little attention after satisfactory operation has been attained. The six-pole relay contacts should last indefinitely since they never make or break current. The diodes can be unplugged and quickly tested, as a set, in a diode tester.

The operation of the counter is easily monitored by the lights on the front panel. The individual modules can be checked in a module tester by varying the supply voltage from 31 to 36 volts to reveal marginal operation.

The power supply has three regulated voltage outputs (Figure 4) with a plainly marked control for each. The main supply is set at 33 volts even though the unit will operate with a variation of ±2 volts from this value. It has been operated with the line voltage varied from 100 volts to 130 volts. The regulator holds the output voltage to within 0.2 volt of 33 volts over this range.

The second regulator is set at 19.2 volts output. The actual value is not as critical as the regulation. The combination of the output changes from the ladder network, and the sensitivity of the plotter must give a change of position of 0.1 inch on the plotter for each 1-count change in the counter. A change in the 19.2 volts will change both X and Y, while the X and Y plotter sensitivities can be adjusted separately.

The third voltage level of 86 volts is not critical and has proved adequate to light the count indicator lights consistently.

A. 2. POWER-SUPPLY CHASSIS

The power supply shown in Figure 15 uses semiconductors throughout for rectification and regulation except for a single OA3 voltage-regulator tube. There are three regulated voltages from the power supply. The main supply at the upper left uses a bridge of four 1N2104 silicon diodes and a transistor regulator to provide 33 volts to operate the relays. This voltage is further regulated by transistors to provide the 19.2 volts for the ladder network digital-to-analog converter. The panel meter normally indicates the voltage of the main supply, but a pushbutton permits a check of the 19.2 volts. Zener diodes are used in each of the regulators as a reference to aid in holding the voltages constant.

The regulated 86 volts for the lights is obtained in the supply shown in the lower part of Figure 15. This supply has a built-in ripple to aid in firing and extinguishing the neon lights with a smaller change in reference voltage. The lower-left part which supplies 70 volts regulated by the OA3 is quite orthodox. The small middle center-tapped winding provides an added full-wave rectified voltage through the 200-ohm resistor to the output. The half-wave voltage doubler furnishes additional voltage to the transistor regulator which sets the clipping level on the full-wave rectified ripple. This regulation is provided so that clipping will be at the same level regardless of changes in the line voltage.

The fan and heat sink for the 2N441 are mounted so that they are not at chassis ground.

A. 3. DECODER CIRCUIT

The full teletype code is not used in this data-conversion system. The LETTERS-FIGURES shift, for example, has no meaning in the decoding. However, most of the letters are used, and the remaining ones might be useful in any extension of the system. The pulse groups for each teletype character are shown in Figure 16. This code must be referred to in order to understand how a different output is obtained for each teletype character used in the transmission.

Five 6-pole, double-throw relays are used in the Decoding Network, shown on the left in Figure 17. They are magnetic latching relays like the SL Relays in the signal-distributor circuit. They are operated in numerical sequence by the pulses in the character groups from the signal distributor. The ON-OFF pattern of these relays is set by the pulses in the teletype character. Being latching relays, they hold this pattern until the Reset pulse is applied to the release coils of all five relays. The network is then ready for the next character.

The up, or nonoperated, position of the relay contacts results from a no-current or clear (Spacing) interval in the code of Figure 16. The lower, or operated, portion of the contacts

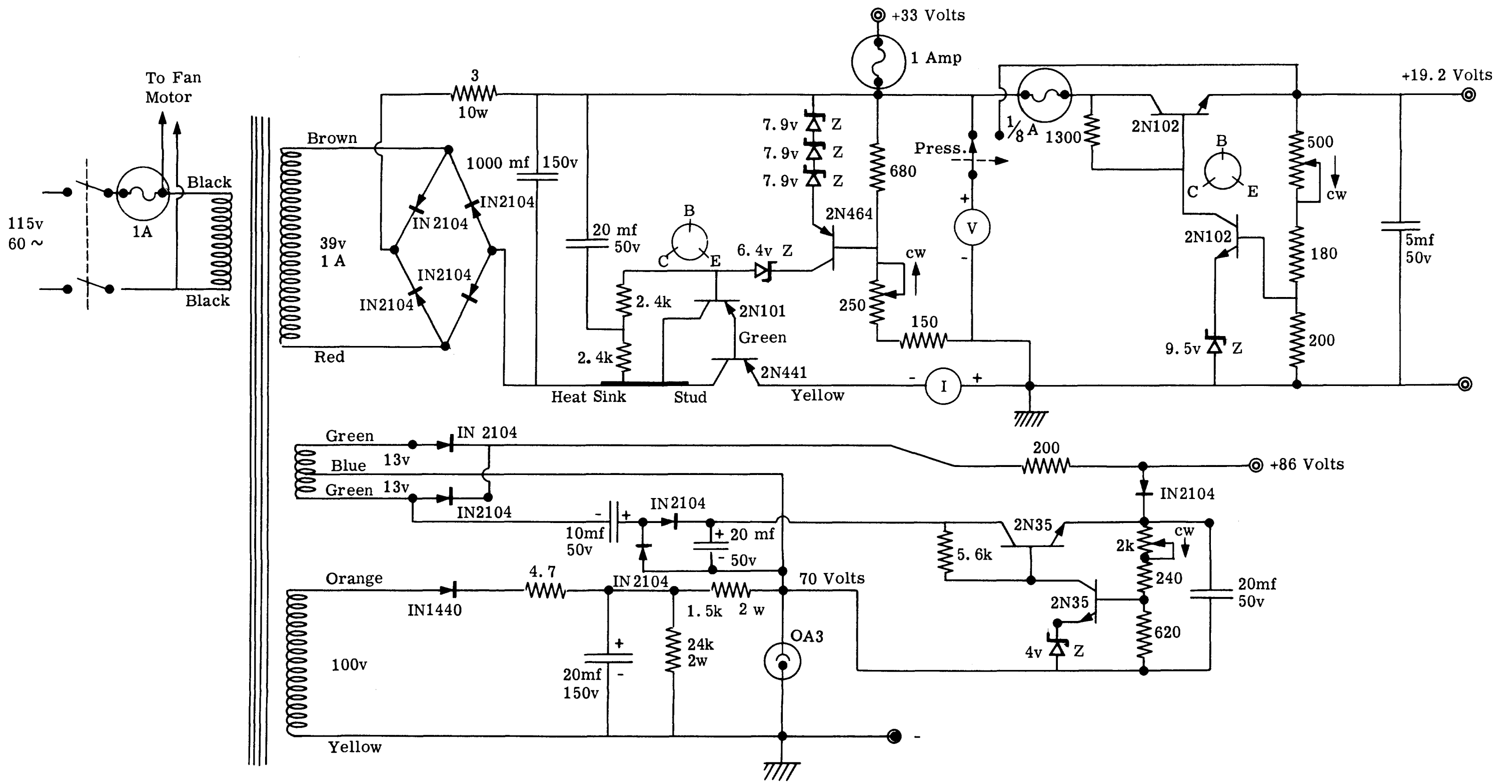



FIGURE 15. POWER-SUPPLY CIRCUIT

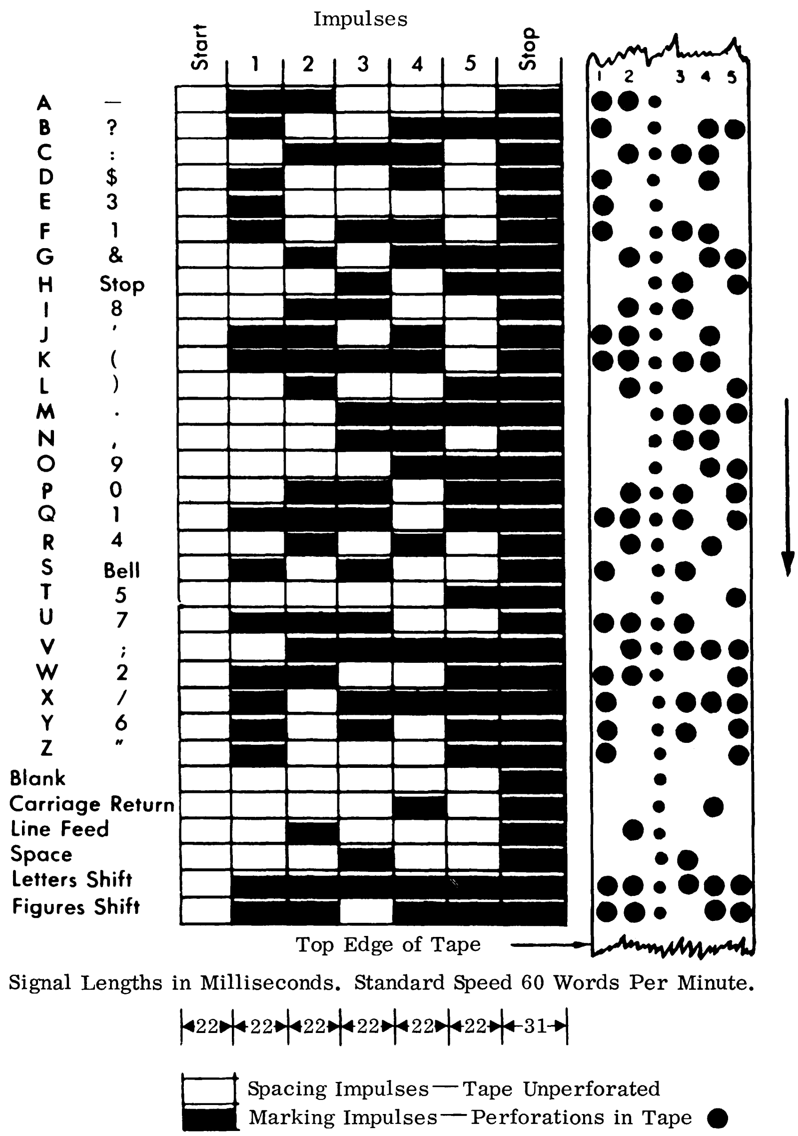



FIGURE 16. TELETYPEWRITER CODE

results from a current pulse or black (Marking) interval in the code. It should be noted that the relays are not arranged in the same sequence as the pulse intervals they represent. The wiring was simplified by this rearrangement.

The input signal to the Decoding Network, the Store pulse, enters at the lower contacts of Relays 3 and 4. Each indicated output can be traced back through the network to one of these

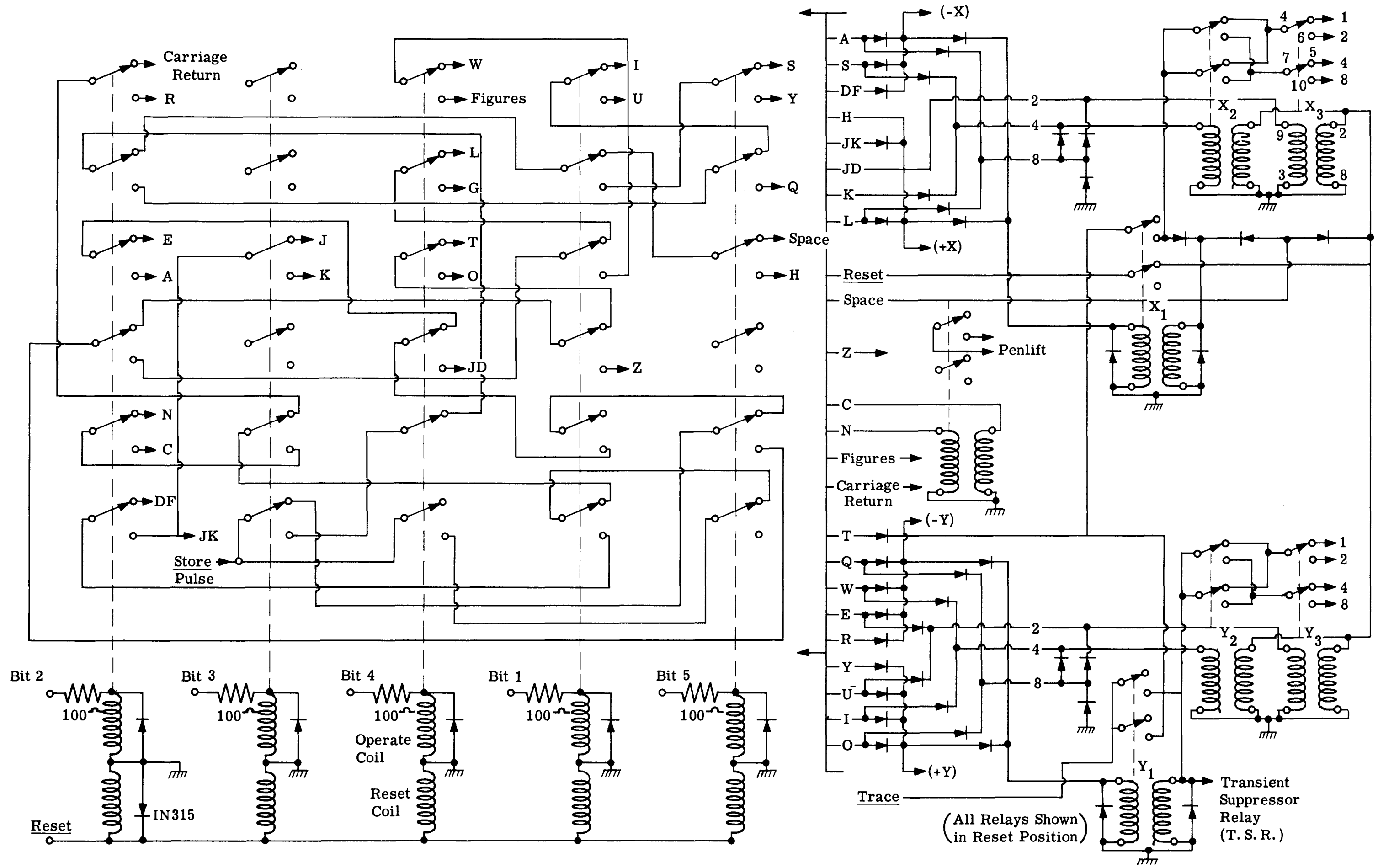



FIGURE 17. AUXILIARY STORAGE AND DECODING NETWORK

inputs as a check on the circuit. For example, to trace the E-character output from relay 2 in the 0 position, the remaining contacts are: Relay 4 at 0, Relay 1 at 1, Relay 5 at 0, and Relay 3 at 0. This is the (1, 0, 0, 0, 0) code for E in Figure 16. The Y-character output requires that Relays 1, 3, and 5 be operated, and Relays 2 and 4 not be operated. Thus the code is (1, 0, 1, 0, 1) as shown in Figure 16.

Some of the outputs are shown as two letters (Figure 17), due to the fact that these two letters need not be distinguished. J and D both indicate a magnitude of 2 and the letters D and F both indicate a negative sign. By leaving them together, fewer diodes are required in the OR-gates which follow. The outputs of the decoding relay network are not shown drawn to the OR-gates, since it would greatly complicate the diagram. Instead, they are labelled as a column near the middle of the diagram. The circuit marked Reset in this column is the only circuit which is not an output of the relay network. The Reset pulse is from the signal distributor and is the same pulse which resets the five decoding relays. The FIGURES and CARRIAGE RETURN characters are not used, but are available for added functions. The letter N is used to lower the pen on the plotter, and C is used to raise the pen. The letter Z is used to reset the counters to the mid-scale value, which is the starting point for each independent part of the outline picture transmitted. The SPACE character is used to reset the X store if an incorrect X increment is recognized before the Y increment is typed and the line segment traced. The LETTER character is rejected in the Decoding Network and does not appear as an output in the Decoding Network.

The remaining letters indicate increment values in X and Y. Since the inputs to the counters are sign (plus or minus) and magnitude (1, 2, 4, or 8), the outputs of the decoder must be in this form. Furthermore, the sign signal must precede the magnitude signal by an interval long enough to allow the six-pole latching relays to operate before the Trace pulse sends the magnitude signal. For this reason, the sign signal is the Store pulse sent through diode OR-gates to set the sign relays in the counters. The A, S, and DF are combined in an OR-gate to get the minus-sign signal for X. The H, JK, and L are combined to get the plus-sign signal. There are four magnitude values, 1, 2, 4, and 8, which can be held in an auxiliary store with two relays, $X_2$ and $X_3$. The need for including a zero magnitude for some line segments appears to complicate things. However, this difficulty is solved by using another relay, $X_1$, to allow the Trace pulse through only when $\Delta X$ has one of the four magnitudes. The reset position is the 1 position, therefore 1's need not be stored. Any one of the $\Delta X$ values shown will operate the $X_1$ relay and permit the Trace pulse through the $Y_1$ relay to carry the stored X information to the X counter. The letter G which signifies zero magnitude in X is not brought out to the diode networks.

The diode OR-gates for Y operate in exactly the same way, except that the letter T which signifies zero in Y must be used. It does not operate any part of the Y store circuits, but merely replaces the Store pulse to assure that the stored X increment will be transferred to the X counter. The release times of the $X_1$ and $Y_1$ relays serve to clip the Trace pulse to approximately 3 ms as input pulses to the counters. The only other output is this same clipped pulse from the other contact of Relay Y. This output operates the Transient Suppressor Relay, which is located in the counter chassis and will be explained later.

## A. 4. COUNTER CHASSIS

This chassis comprises two 7-bit binary counters with six-pole, double-throw latching sign relays and two ladder-type resistor networks which serve as digital-to-analog converters for both X and Y. The ladder networks supply a voltage proportional to the number in the counter, in this case, 0. 1 volt for each count. With a range in the counter of 0 to 127, the output voltage range is 0 to 12. 7 volts. In addition, neon lights on the front panel indicate the binary count in both the X and Y counters.

The circuit in Figure 18 shows the wiring of the X counter and indicates that the counter elements are plug-in units or modules which fit 11-pin sockets. The 2k and 4k resistors at the top are the ladder network which converts the digital count to an analog voltage. The 130k resistors at the bottom are the dropping resistors for the neon lights which indicate the count. A single module is shown schematically in the center or 8-bit socket. The SL Relay and its driving transistor flip-flop are shown simply as a flip-flop with DPDT contacts. This module is shown in the zero position. The sign relay, which is shown in the Add position, is a six-pole relay shown between the ladder network and the module sockets. The operation will be described in terms of an 8 input. The 1N2104 diode is to prevent an input from affecting lower-count modules.

It should be noted that the $2^6$, or 64, module socket is wired differently from the rest. It was desired to reset the counter to 64 with a Z signal from the decoder. Thus, the same pulse must set the 64 module to 1 and the others to 0. It is always advantageous to have all the plug-in modules identical. This can be done by having the position which represents a 0 in the other six modules represent a 1 in the $2^6$ module. The light is connected to the other side of the flip-flop, and terminals 5 and 6 to the ladder network are interchanged.

If it is assumed that the counter is in the reset or 64 position and the sign relay is in the Add position as shown, an 8 input will simply cause the 8 module to flip to the 1 position, changing the count from 1000000 to 1001000. The input pulse encounters an open circuit at

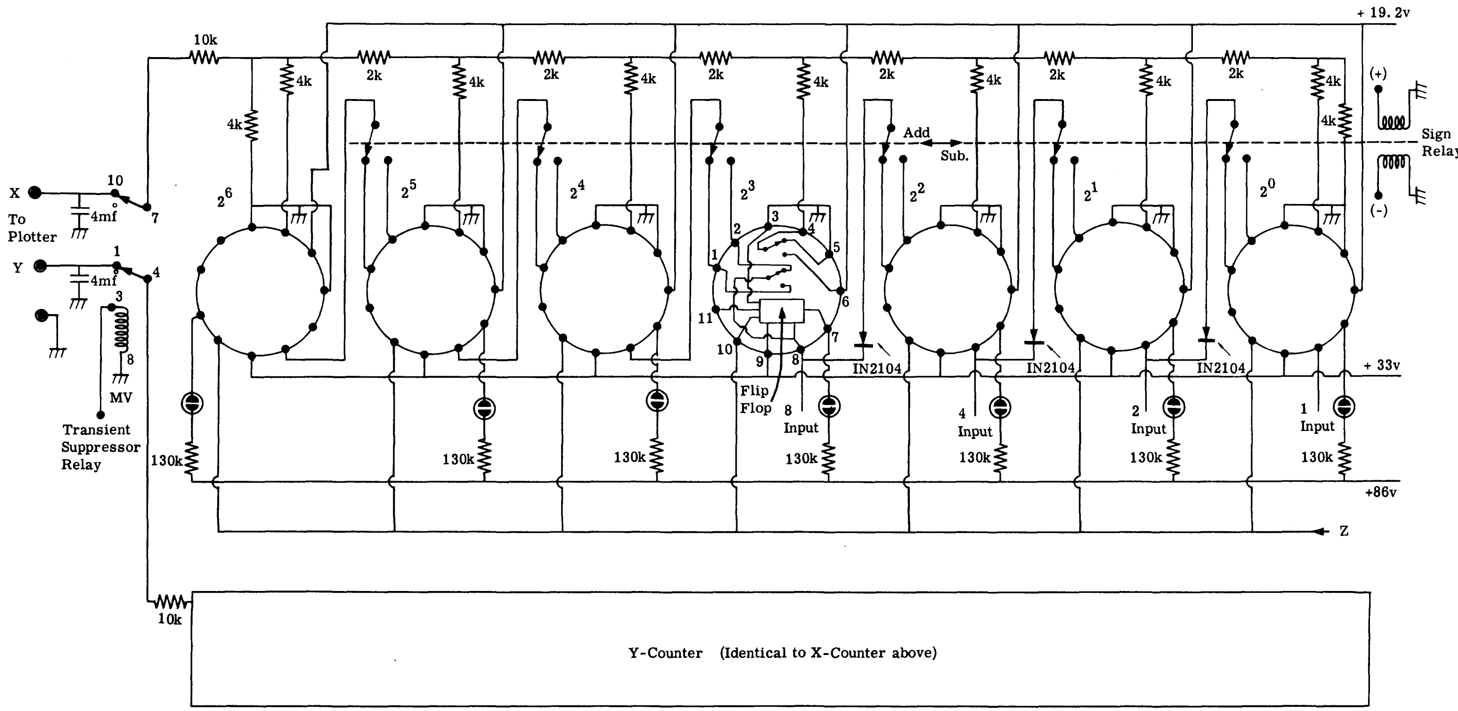



FIGURE 18. COUNTER-CHASSIS CIRCUIT

terminal 2 and does not carry. However, the next input to 8 finds the relay in the down position, so that it not only returns the 8 module to the 0 position, but carries through terminal 1 to flip the 16 module to the 1 position. The count is changed to 1010000. In this way, a carry will continue up a line of 1's changing them to 0's and stop at the first 0 it can change to a 1.

If the counter is reset to 64 and the sign relay is in the (-) or subtract position, an 8 input will not only flip the $2^3$ module to 1, but it will also borrow through terminal 2 so that modules $2^4$ and $2^5$ will flip to 1 and module $2^6$ will flip to 0. Another 8 input will flip the $2^3$ module from 1 to 0, subtracting without a borrow. The operation with 1 inputs is identical except that the carries and borrows can go farther up tht line.

The outputs of the X and Y counters are integrated in the RC circuit of 10k and 4 mf before reaching the plotter inputs. This smooths out the steps in the network outputs and makes the X and Y inputs to the plotter change at the same rates. When the count changes from 64 to 63, it is not merely a drop in 0.1 volt at the output. Actually, the count goes very rapidly from 64 up to 128, then drops back to 63. This causes a brief but sharp transient in the input to the integrators and causes a jump in the plotter. A like transient occurs whenever many borrows are required in a subtraction, but at 64 it is most serious. The transient suppressor relay reduces this problem by opening the circuit to the integrators during the switching transient.

The lights are a great aid in checking the operation of the counters. If the counter is filled and a 1 is added, all the lights will go out. If a 1 is then subtracted, all the lights will go on. This provides an excellent check on the modules and the sign relays.

The details of the module circuit are shown in Figure 19. This circuit is merely a transistor flip-flop which reverses the SL Relay with each input pulse. The pulses can be very short, which makes it possible to drive them more reliably than if the relays were driven directly. The Reset pulse (Z) applied to pin 10 on all modules will always return the module to the 0 position. The lights are operated by the change in voltage on the transistor collectors as the flip-flop changes state.

## Appendix B
## PROPOSED CODING UNIT

Coding for the previously described subsystem is simply the selection of line segments that, when put in code and transmitted, will properly display the curved line or picture. A separate coding unit has not been built, although considerable thought has been given to the

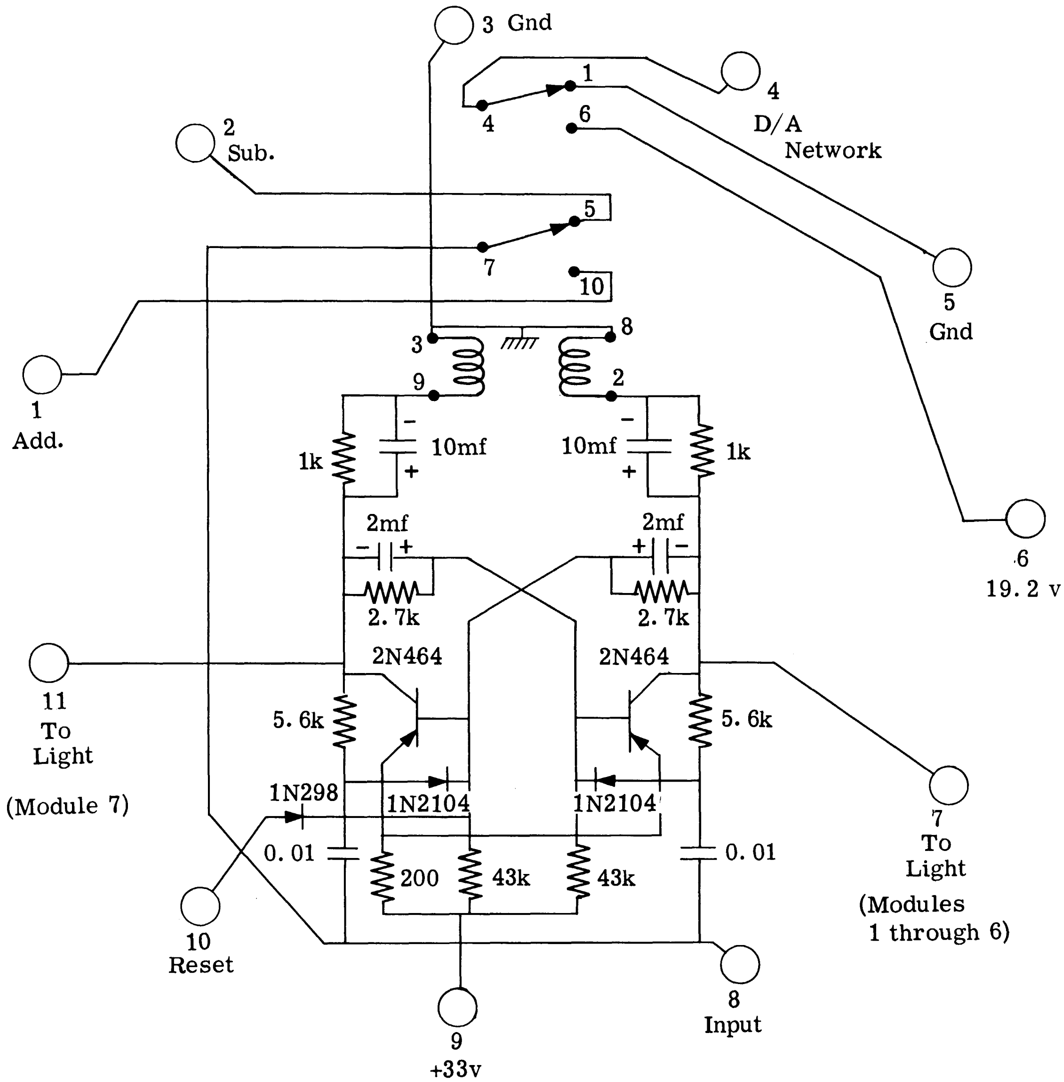



FIGURE 19. WIRING OF THE FLIP-FLOP MODULE. Bottom view of 11-pin plug.

question of how coding might be made simpler for the operators. The coding equipment suggested in this appendix would have the following advantages over previous methods:

(1) It would not require a skilled teletype operator.

(2) It would not require simultaneous decoding and plotting for the coding operation.

(3) The entire subsystem could be remote from on-line teletype equipment.

(4) It would not require a standard teletype machine for operation.

The Coding Unit as it is visualized will consist of a 2-foot x 3-foot surface with a crossarm and moving grid coupled to pickoffs to register least-count increments of $\Delta X$ and $\Delta Y$ when the coding grid is moved in any direction (Figure 20). The magnitude and direction ($\pm X$ or $\pm Y$) for any line segment will be determined automatically when the operator places the stylus (Figure 21) at a marked intersection (shown as a black dot) on the line interval extension from the center of the coding grid that most nearly corresponds to the curved line being coded. The slots and marked intersections on the coding grid represent all the line-segment magnitudes and directions that can be produced using this guide. The origin or reference point of the grid is at the intersection of the center lines represented by teletype code symbols $\Delta X$ = G, $\Delta Y$ = T on the standard grid presently in use. With 9 horizontal and 9 vertical lines in the standard system, there are 81 intersections, the origin included. To cover these 81 intersections in the proposed system, a total of 32 slots radiating from the origin is required. Using these 32 slots, any one of the 80 different lines can be traced from the origin. These make up the assortment of lines from which the operator may select. A stylus is used to mark the point and guide the grid during the movement along the selected line segment. With the stylus held firmly as a guide pin, the operator moves the coding grid toward the stylus, coming to rest at the center of the grid. The direction sign (+ or -) and magnitude ($\Sigma\Delta X$ and $\Sigma\Delta Y$) are then fed into step

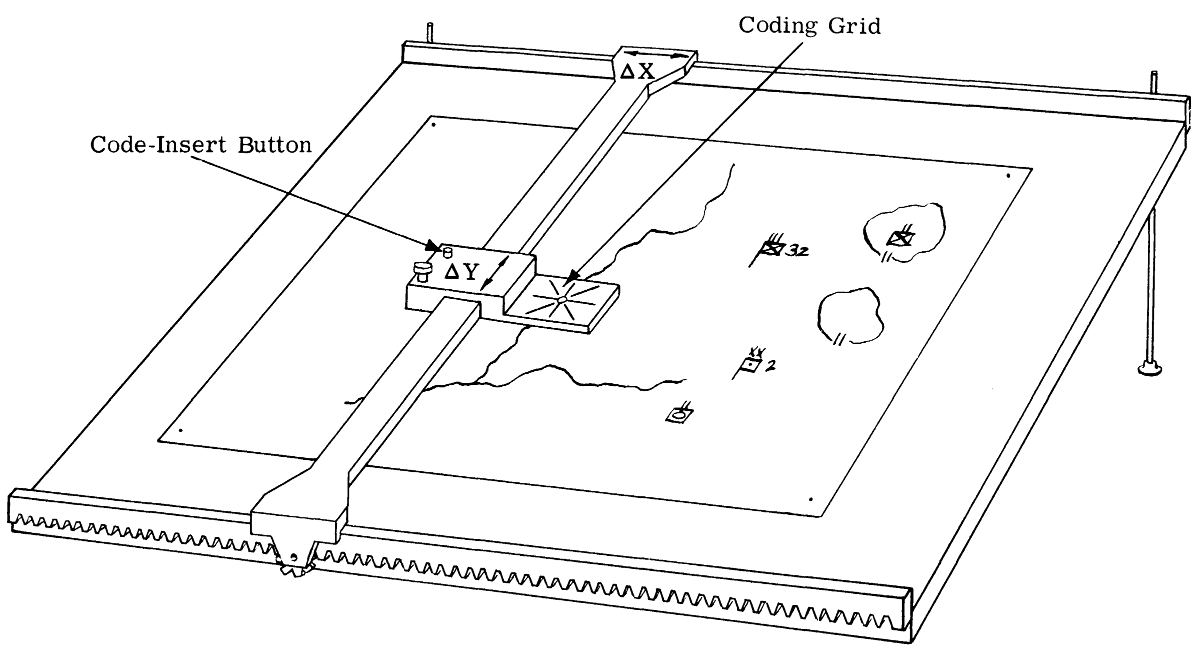



FIGURE 20. CODING BOARD

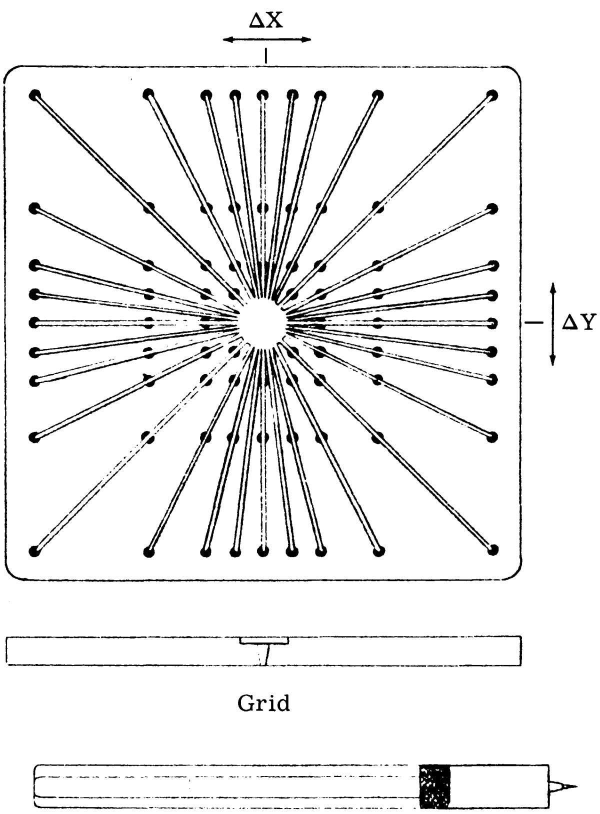



FIGURE 21. CODING GRID AND STYLUS

counters that register and store the magnitude of X and Y in binary form. When the operator pushes the code-insert button, the X and Y magnitudes, along with their direction signs (±X and ±Y), are fed to the Decoding Network that selects the proper teletype code for the X and then the Y increment just coded and feeds this in parallel to a teletype tape perforator for punching. After the tape is punched, it is indexed one step and the counters are reset for the next line segment. This completes the coding of one line segment. The operator then selects the next segment and the operation is repeated until the entire curved line or picture is coded. Any one teletype symbol will represent the magnitude and direction of X or Y. Thus each line segment will be coded as two teletype symbols; the first representing ±X, and the second, ±Y.

A function diagram of this Coding Unit is shown in Figure 22.

The entire unit shown in Figure 22 would weigh about 30 pounds and occupy a volume of 2 feet x 3 feet x 1/2 foot, or 3 cubic feet.

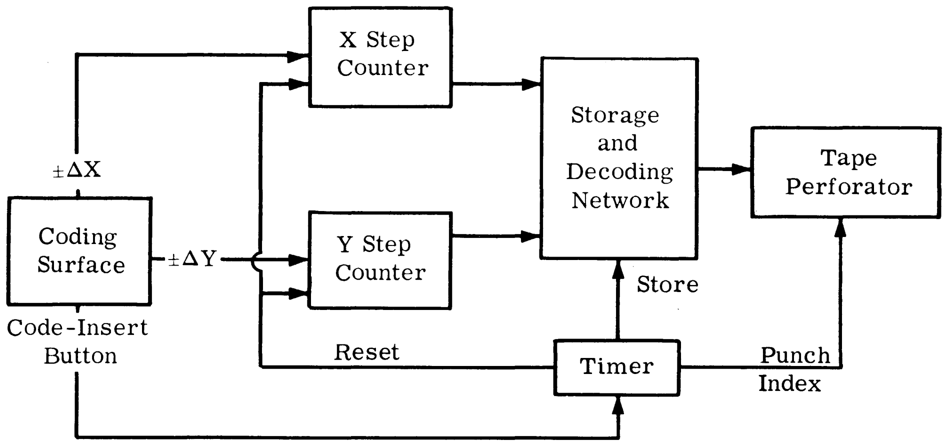



FIGURE 22. FUNCTION DIAGRAM OF PROPOSED CODING UNIT

A complete remote, off-line, sending and receiving subsystem would be packaged in three units: plotter, Coding Unit, and Decoder Unit. Each package would weigh 30 pounds and be about 3 cubic feet. A function diagram of this subsystem is shown in Figure 23. The Decoder Unit would be the same as the one presently in use and would consist of a signal distributor, a

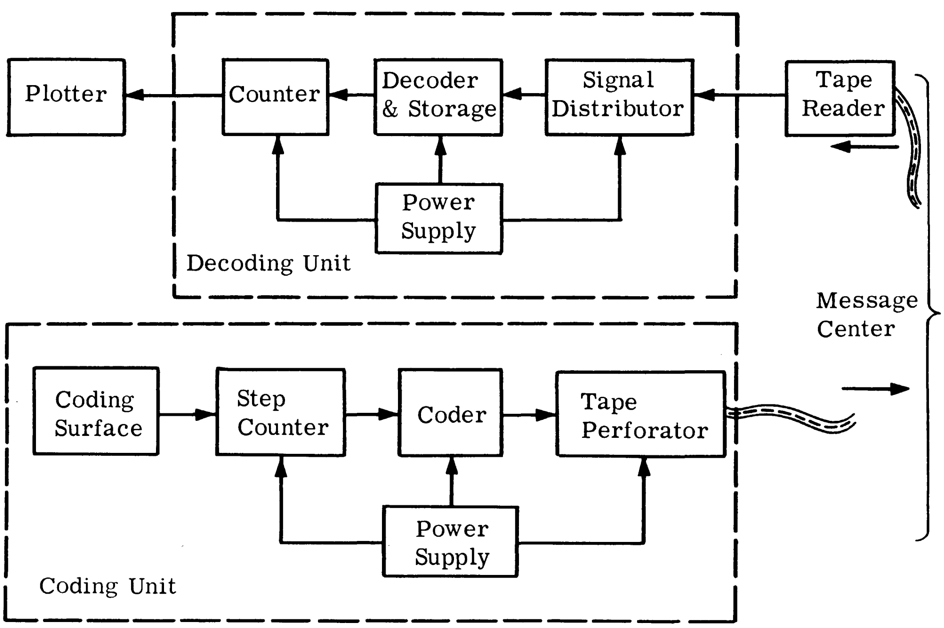



FIGURE 23. FUNCTION DIAGRAM OF COMPLETE OFF-LINE SUBSYSTEM. The tape reader may be omitted if a direct teletype line is brought in from a communication center.

decoder and storage, and a counter-integrator. This Decoder Unit would provide the input to a plotter which might be any one of several commercially available. The unit proposed here would add to this a Coding Unit consisting of a coding surface, a step counter, a coder, and a tape perforator. Addition of a tape reader to this subsystem would provide it with a complete off-line capability and make it useful for remote installations where information is handled through message or cryptographic centers. In this case, perforated teletype tape would be handled like any other message.

The Decoder Unit and plotter might be used alone, i.e., without normal teletype equipment, on any teletype line where only permanent pictorial information is to be received and where there is no requirement for transmission.

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As an outgrowth of the combat-surveillance information-processing program of Project MICHIGAN, a concept of a simple equipment for the transmission of outline drawings such as map overlays with the aid of standard teletype equipment was developed. From a communications standpoint, this concept has the advantage of a very low redundancy, and operates readily within the very narrow bandwidth of standard teletype—not a characteristic of most pictorial-data transmission systems. A compact set of lightweight equipment for two-way transmission was constructed for demonstrating the concept's technical and tactical feasibility. This (over)

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1. Computers—Coding
2. Communication Systems—Display systems
3. Teletype—Teletype systems

I. Title: Project MICHIGAN
II. Brown, John, and Wagner, Donald
III. U. S. Army Signal Corps
IV. Contract DA-36-039 SC SC-78801

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report describes the equipment and gives enough details of operating technique to permit an unskilled operator to learn its use. Some notes on maintenance are included, as well as some suggested modifications for increasing its utility.

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