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METHODS OF GENERATING IFF REPLY SYMBOLS

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METHODS OF GENERATING IFF REPLY SYMBOLS

W. M. Furlow, Jr.

June 8, 1949

Approved by:

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DEPARTMENT OF THE NAVY OFFICE OF NAVAL RESEARCH

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ABSTRACT

NRL Report R-2980, "A Method of Coding and Displaying IFF Reply Symbols," described a pulse-pattern coder for transponders which used a mechanical commutating and switching arrangement to control the composition of successive pulse groups. These groups, when presented on an unmodified conventional indicator such as a PPI, form distinctive symbols designating the individual identity of the vehicle carrying the transponder. Different methods of obtaining the same result were investigated and two are described in this report.

An electromechanical coder which utilizes a disc composed of transparent and opaque elements revolving between a light source and photoelectric tubes is first described. The commutated light beam causes the photosensitive circuits to produce corresponding gates to control the generation of a pulse pattern.

The electronic coder described in the second section of this report utilizes a flying-spot type of scanner to produce a pulse-pattern controlled by a mask interposed between a cathode-ray tube screen and a photoelectric pickup.

Comparisons made of the mechanical, the electromechanical, and the electronic systems in the third section of the report indicate that, with suggested modifications, the mechanical system is best suited for aircraft service. For shipboard use, where more weight can be tolerated, the electronic system yields superior results.

PROBLEM STATUS

This is the concluding report on this phase of the IFF development program. Further investigation is not contemplated unless requested. Work on the main problem is continuing.

AUTHORIZATION

NRL Problem No. R03-06R (BuShips S1234X-5)

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METHODS OF GENERATING IFF REPLY SYMBOLS

INTRODUCTION

NRL Report R-2980, "A Method of Coding and Displaying IFF Reply Symbols," described a pulse pattern coder which used a mechanical commutating and switching arrangement to control the composition of successive pulse groups. In an effort to develop an improved method of accomplishing this type of pulse-pattern coding, other coders have been constructed and tested, two of which are described in this report together with a comparative analysis of these systems.

The pulse-pattern coder is intended to be part of a transpondor with the function of controlling the transmitter modulation so that various pulse groups will be transmitted in response to interrogating signals. These pulse groups, when received by the responsor and displayed on a PPI or type-B indicator, form readable letters or other characters to give individual identity to the replying target.

ELECTROMECHANICAL PULSE-PATTERN CODER

The electromechanical pulse-pattern coder differs from the coder described in NRL Report R-2980 only in respect to the method of controlling the pulse-group composition, control being effected without the use of mechanical contacts. A beam of light is interrupted by opaque elements contained in a moving assembly. The absence or presence of this commutated light operates a photosensitive circuit which controls a gate tube to cause the absence or presence of a pulse at its output at a particular time. Availability of a small photoelectric tube, type 1P42, allows such a system of practical size to be constructed.

Figure 1 illustrates the system which was first put into operation together with voltage levels at various points. The gate tube is in the on condition when light is incident on the photo tube; hence this is called the "bright" system. Direct coupling is used between stages in order to avoid long-time-constant coupling capacitors and d-c restorer circuits. Another system, illustrated in Figure 2, keeps the gate circuit on during the period when no light is incident on the phototube, and is consequently called the "dark" system. In both systems light is directed through a rotating disc and a fixed aperture to the sensitive surface of the phototube.

Design Parameters

The distance from the center of the disc to the center line between the aperture and light source is defined as r and the diameter of the aperture as d. An element on the disc at a radius r from the center must have an arc length at least equal to d in order to

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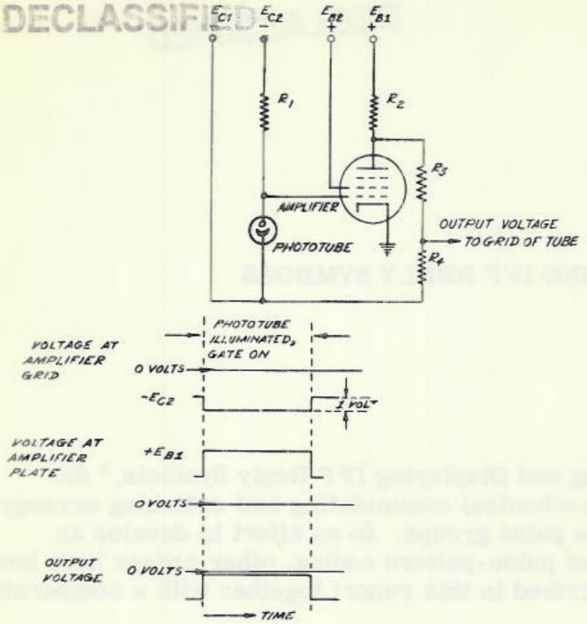


Fig. 1 - Bright system, schematic diagram and voltage levels.

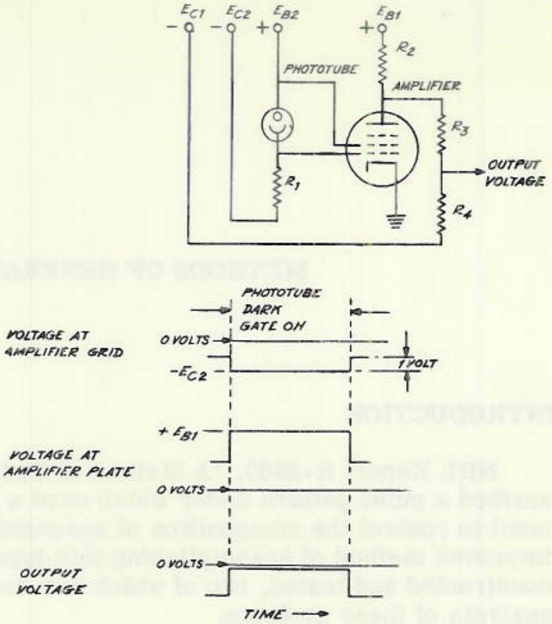


Fig. 2 - Dark system, schematic diagram and voltage levels.

cause the phototube output to change from one extreme to the other and return as the disc rotates. The arc length or width of the smallest resolvable element is therefore

$$W = d \text{ inches} \tag{1a}$$

or

$$W = \frac{d}{r} \cdot \frac{360}{2\pi} \text{ degrees} \tag{1b}$$

and, conversely, the maximum number of resolvable elements for specified values of r and d is

$$N = \frac{2\pi r}{d} \tag{2}$$

If the effect of any dispersion of the light beam is neglected, the time required for the light to be commutated from minimum to maximum is the time required for a point on the disc at radius r to move a distance d,

$$T = \frac{d}{r} \cdot \frac{1}{\text{RPM}} \cdot \frac{60}{2\pi} \text{ seconds} \tag{3}$$

where

RPM = Disc revolutions per minute.

In the absence of dispersion effects, measurements of phototube output rise and decay times should give results predicted by equation (3). This was found to be the case, indicating that equations (1) through (3) may be used without modification.

A pattern as illustrated in Figure 3A is defined as one group of letters or other characters, including spacing, which is produced by one revolution of the coding disc. The horizontal rows are defined as lines and each line is subdivided into elements representing "on" and "off" times during which a given pulse can or cannot be transmitted in reply to interrogations. Experience has shown that a readable pattern is obtained when the spacing between adjacent letters is half the width of a letter and the spacing between letter groups is the full width of a letter. This establishes the relation

$$M = \frac{n}{2}(3m + 1) \qquad (4)$$

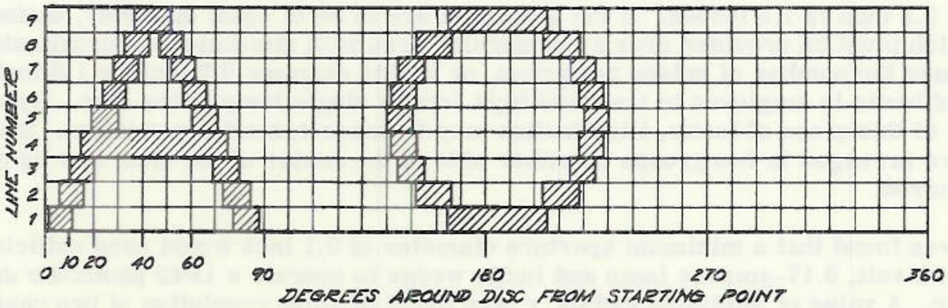
where

M is the maximum number of elements comprising a single line of the pattern,

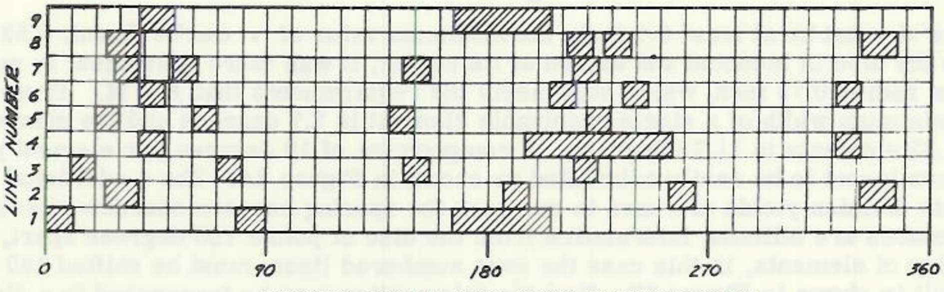
m is the number of letters or other characters contained in the pattern, and

n is the maximum number of elements to be used in forming a single line of one letter.

It follows that N from equation (2) must be equal to or greater than the value found for M. The dimensions of the disc and aperture are thus related to the composition of the characters to be transmitted.



A- LETTER ELEMENTS, INITIAL LAYOUT



B-LETTER ELEMENTS, EVEN NUMBERED LINES SHIFTED 180°

Figure 3.

So far mention has been made only of one set of elements appearing on the disc at a radius r, which would control only one pulse. Other circles of elements may be placed on the same disc at radii $r_1, r_2, r_3 \ldots r_n$, each associated with a corresponding aperture of diameter $d_1, d_2 \ldots d_n$ and phototube. The spacing, D, between adjacent radii is a factor in determining the over-all disc diameter. If all the phototubes are arranged on the same radial line side by side, the minimum spacing between adjacent tubes of the 1P42 type is about 0.4 inch; hence the spacing between adjacent circles of elements is $D = 0.4$ inch. If, however, the phototubes are arranged on the same diametrical line, with phototubes which take information from adjacent radii arranged on opposite sides of the center, the effective spacing between radii may be reduced to 0.2 inch. The spacing between adjacent radii may be reduced to the diameter of the fixed aperture by judicious positioning of the phototubes.

If it is desired to resolve M elements for each line, as r increases d must also increase. A change in d varies the light reaching the phototube from a constant source proportional to the second power of d; hence, in order to maintain a constant output level for all phototubes, the illumination must have a gradient inversely proportional to d^2. If the aperture were a slit of constant radial length and a width along the arc equal to d, the gradient would be inversely proportional to d. On the other hand, if it is specified that M elements are the minimum which must be resolved, then a value for d may be found to satisfy the relation $N \geqq M$ for the case of the shortest radius used. With d being held constant at the different radii, N increases as the radius increases and the illumination required along the diametrical line is uniform.

The distance between the inner and outer radii in the case where 9 pulses are used and $D = 0.2$ inch is 1.6 inches. If the apertures are to be of equal diameter, uniform illumination must be provided over a rectangular area with dimensions approximately D by D times the number of pulses per group, or in this example 0.2 inch by 1.8 inches. A wedge of lucite is employed to transmit light from a single lamp to the disc. By proper shaping of this piece of lucite, illumination may be made essentially uniform. Since phototubes are arranged in two groups on either side of the center of the disc, two light sources are required.

It was found that a minimum aperture diameter of 0.1 inch would pass sufficient light from a 24-volt, 0.17-ampere lamp and lucite wedge to operate a 1P42 phototube satisfactorily. A value of minimum radius r was found to allow resolution of two characters each consisting of nine pulse groups. From equation (4), M may be found to be 32. N, as given in equation (2), must be equal to or greater than M; hence

$$\frac{2\pi r}{d} \geqq 32$$

and since d must be at least 0.1 inch, the minimum value of r can be found, 0.52 inch. Because the disc is mounted and driven at its center, it was more convenient to make the minimum radius 0.75 inch, which still meets the requirements that $N \geqq M$. From equation (1) the minimum width of a single resolvable element is 5.7 degrees and the maximum width to allow 32 elements is 11.25 degrees. A compromise of 10 degrees per element permits the pattern layout to be easily calculated as shown in Figure 3A. The 4 additional elements which this division yields are used to increase the spacing between character groups. Since the phototubes are utilizing information from the disc at points 180 degrees apart, appropriate circles of elements, in this case the even numbered lines, must be shifted 180 degrees. The result is shown in Figure 3B. Now the information may be transposed to a disc which when finished will appear as in Figure 4. This disc is designed to work with the dark system.

Factors Affecting Voltage Level of the Gate

The voltage at the gate-tube grid during the on period must be no more than the voltage required to reduce the plate current of the tube to zero, but it may be slightly more negative, permitting a range of allowable grid voltage dependent to some extent on the amplitude of the signal pulse to be passed. An analysis of the factors which may affect this voltage in the circuits of Figures 1 and 2 follows.

Light intensity variations can be expected since the brilliance of a lamp changes rapidly with voltage variations. The bright system is susceptible to brilliance variations, which have a direct effect on the gate voltage. During the on period, the dark system has no illumination on the phototube; hence the gate voltage is not affected by lamp brilliance. Should the lamp be energized by alternating current, ripple at twice the line-voltage frequency will be present on a gate obtained from the bright system but not on the gate from the dark system.

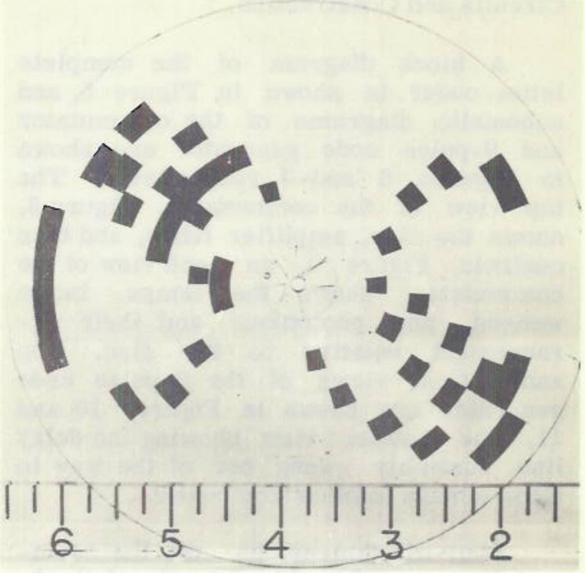


Fig. 4 - Disc for producing letters AO.

The average dark current of the 1P42 phototube is given as 0.003 microampere, which will develop 6.6 millivolts across a 2.2-megohm load resistor. If the net amplification to the grid of the gate tube is 50, this represents a voltage of 0.33 volts. The dark current can vary from the average value by a comparatively large factor without affecting the operation of the dark system. No great deviation in the sensitivity of the phototube can be tolerated in the bright system, however, and some means must be provided for equalizing the effective sensitivity of all the phototubes.

Changing characteristics of the amplifier tube will affect both systems, though in different ways. A change in transconductance only will not affect the dark system since the amplifier is operating at plate-current cutoff. The bright system is directly affected, since with a given grid bias on the amplifier, the plate voltage is a function of transconductance. Any variation in the amplifier grid voltage necessary for plate-current cutoff will change the operating point and, hence, the output voltage of the amplifier in the bright system; the dark system is affected only if the change tends to increase the negative bias necessary for cutoff. These changes could be caused by screen-grid voltage fluctuations; thus a requirement for a regulated screen-grid voltage supply is established.

If E_{B1} and E_{C1} are obtained from the same power supply, it may be assumed that a change in one will be accompanied by the same percentage change in the other. These voltages can be selected with respect to the voltage during the on period of the gate so that they may vary over a moderate range with no deleterious effects. The resistors which make up the voltage-dividing network between the amplifier and gate tube can be allowed to vary only if the percentage variation is the same for each. Temperature changes therefore should not affect the voltage-division ratio. From a consideration of this analysis, the dark system is the more stable, a conclusion which has been verified by tests made on experimental models of the two systems.

Circuits and Construction

A block diagram of the complete letter coder is shown in Figure 5, and schematic diagrams of the commutator and 9-pulse code generator are shown in Figures 6 and 7 respectively. The top view of the commutator, Figure 8, shows the disc, amplifier tubes, and bias controls. Figure 9, an end view of the commutator, shows the lamps, lucite wedges, and phototubes and their arrangement relative to the disc. Top and bottom views of the 9-pulse code generator are shown in Figures 10 and 11, the bottom view showing the delay line assembly swung out of the way to allow access to other components.

Over-all dimensions of the commutator are 9″ x 6″ x 5″ and of the 9-pulse generator 7″ x 7″ x 4″, exclusive of power supplies. The size of the commutator may be reduced to 6″ x 6″ x 2½″ with no sacrifice of performance. Power is to be supplied by the transpondor with which the letter coder is associated. The requirements are listed below:

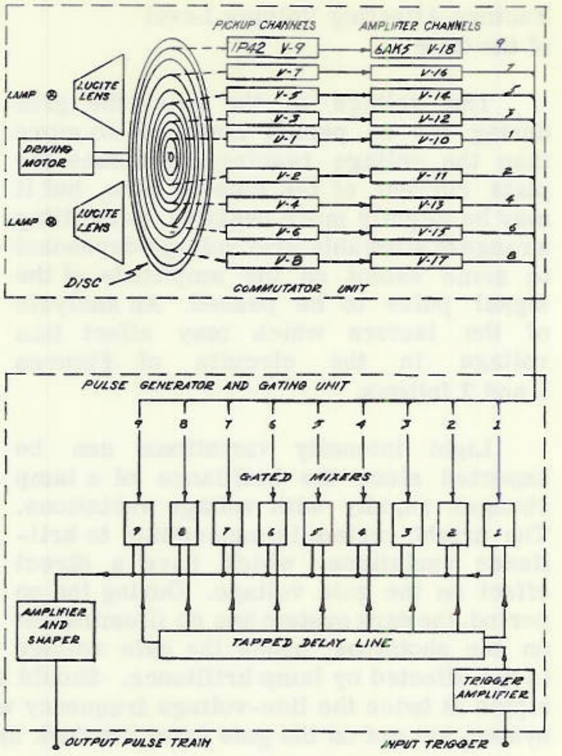


Fig. 5 - Block diagram, electromechanical system.

	Commutator	9-Pulse Code Generator
Heater Supply	18 watts	18 watts
+150 Volts (regulated)	2 watts	2 watts
+300 Volts (unregulated)	4 watts	5 watts
-150 Volts (regulated)	2 watts	3 watts
-300 Volts (unregulated)	3 watts	--
Total	29 watts	28 watts

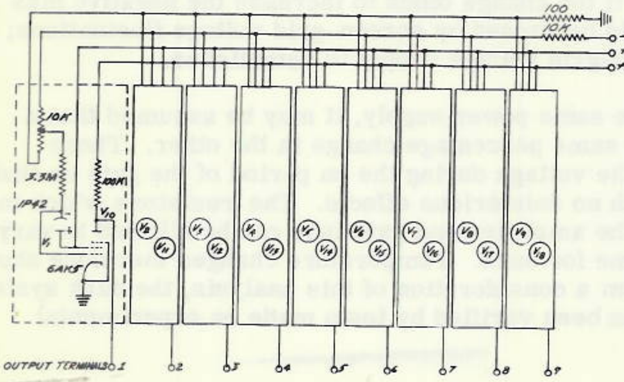


Fig. 6 - Nine-channel electromechanical commutator, dark system.

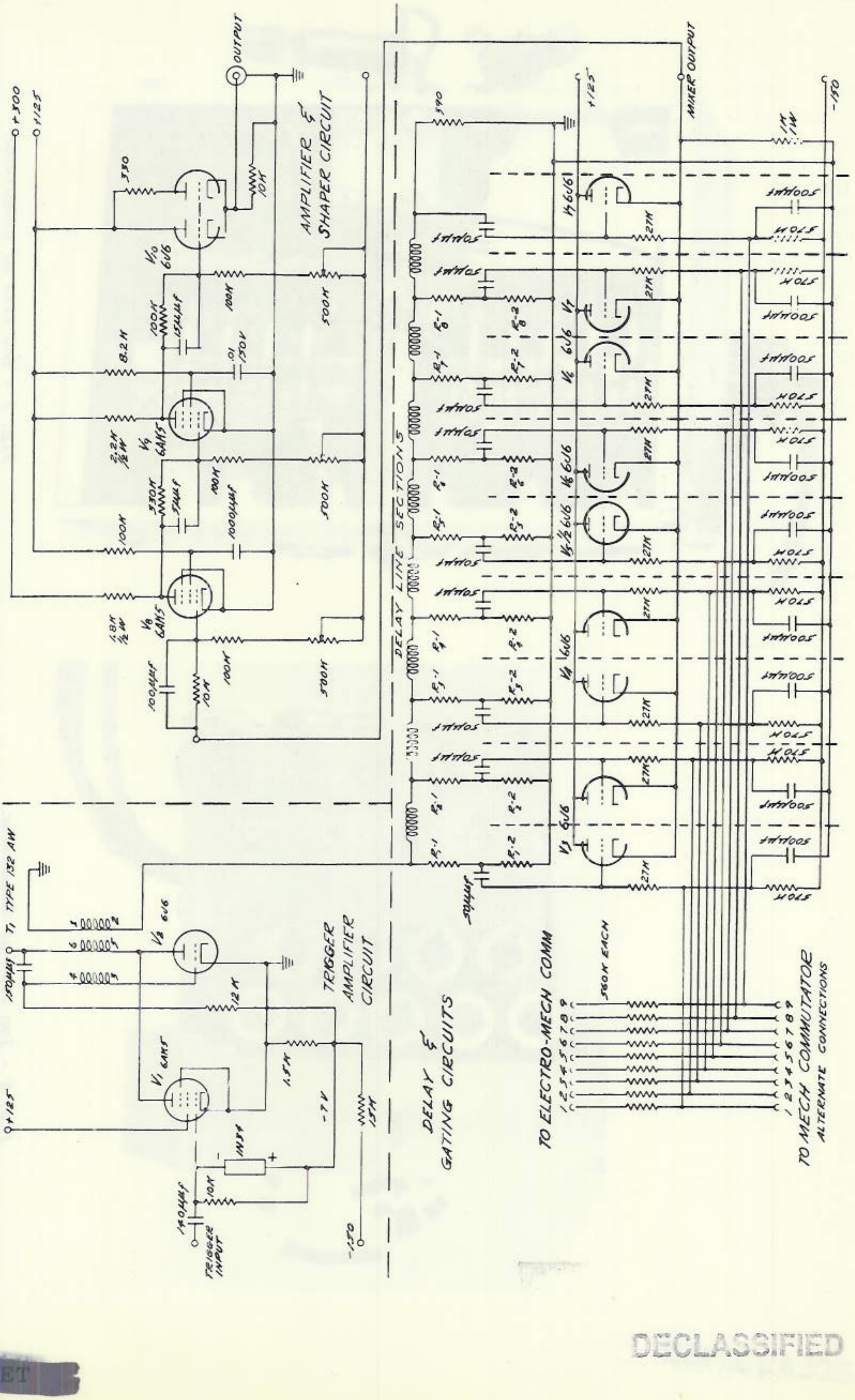


Fig. 7 - Pulse generator and gate circuit.

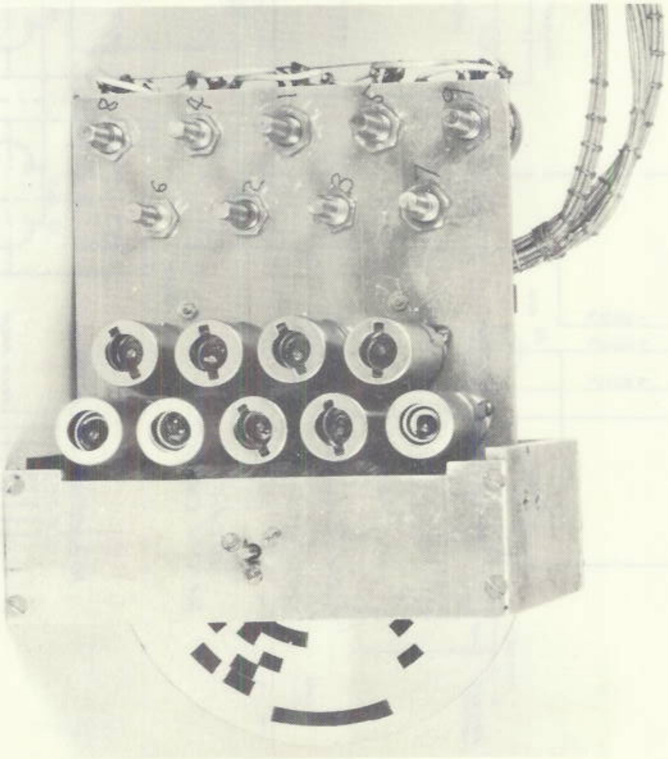


Fig. 8 - Top view of commutator.

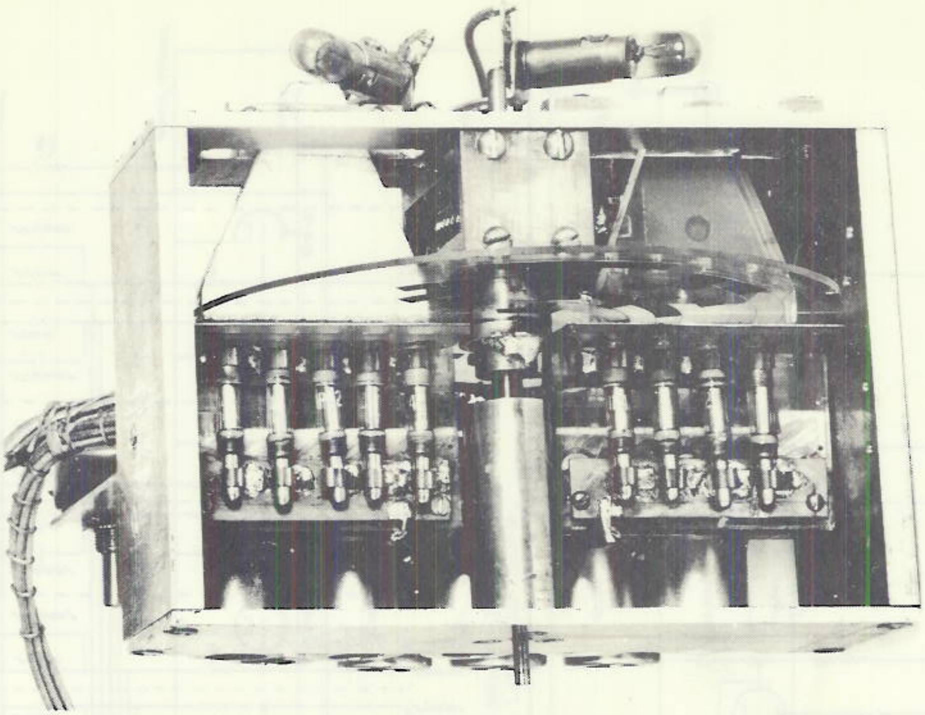


Fig. 9 - End view of commutator.

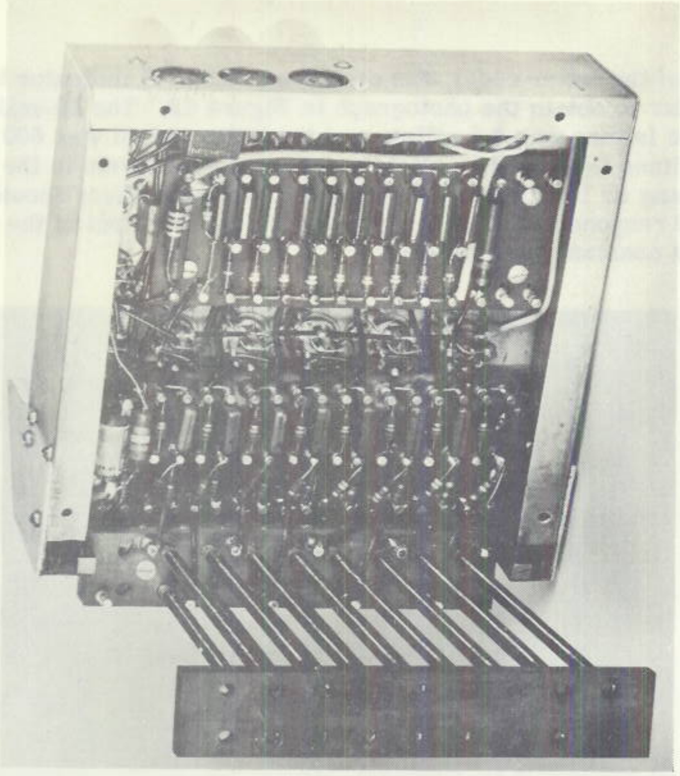


Fig. 11 - Bottom view of 9-pulse generator.

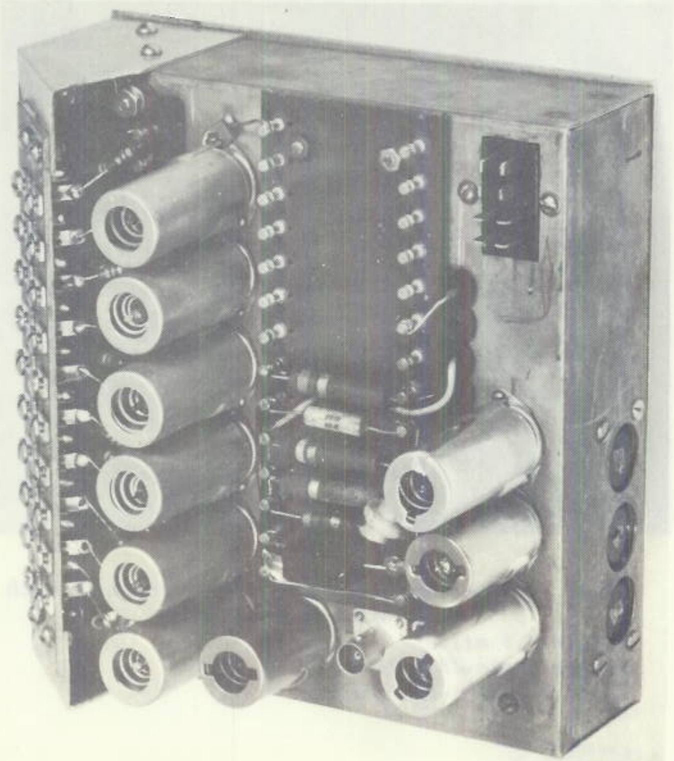


Fig. 10 - Top view of 9-pulse generator.

Results

The output of the letter coder was displayed on the VJ indicator together with signals from the SG radar to obtain the photograph in Figure 12. The 10-mile range scale was in use; range to the letters was 6.5 miles, and the letter height was 600 yards. The unevennes of the letter outlines is caused by slightly different gate levels in the commutator and the absence of clipping or limiting in the indicator. No such effect should be observed if a transpondor and responsor are used since the r-f pulse output of the transpondor would be of essentially constant amplitude.

Fig. 12 - Letters displayed of VJ indicator with radar data from SG radar.
Range–6.5 miles
Range scale–10 miles
Letter height–600 yards

ELECTRONIC PULSE-PATTERN CODER

There are no mechanically moving parts in this system, all of the pulse forming functions being carried out by vacuum tubes; hence the name electronic pulse-pattern coder. Fundamentally, a sensitive photoelectric cell is used to convert pulses of light into electrical pulses. The light pulses are produced as the spot on a cathode-ray tube is made to move across a mask of alternate opaque and transparent areas placed on the external face of the tube. Light from the moving spot reaches the photoelectric tube only when the spot is in a predetermined and desired position, that is, when it is traversing the transparent area of the mask which has the shape of the character to be displayed on the radar indicator in response to interrogation.

If no interrogating signals are being received by the transpondor and therefore no trigger pulses being fed into the coder, the spot on the cathode-ray tube will move horizontally slightly below the pattern mask from position A to N (Figure 13) in a time T_S, and then return to point A in a negligible time. The cycle is then repeated. Should a trigger arrive at the coder input when the spot is at position B, the spot will be deflected vertically to point B′ in a time T_F and return to point B in a negligible time, the time T_S being much greater than the time T_F.

Successive interrogations arriving as the beam reaches points C, D, E, etc. will cause the beam to be deflected to points C′, D′, E′, and return as before. In this manner the entire mask is scanned when interrogating signals are present. To insure against stray light being picked up, the beam is intensified only during the time, T_F, in which it is being deflected upward.

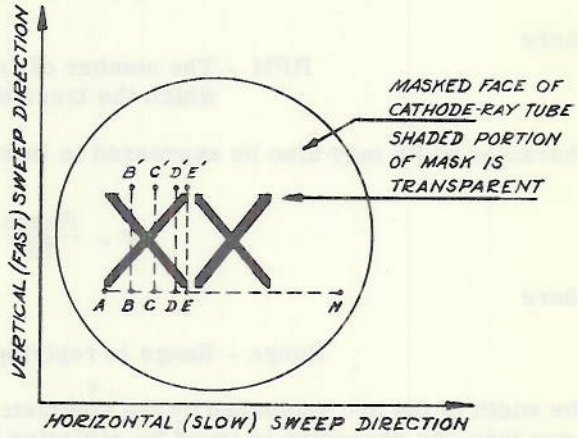


Fig. 13 - Path traveled by CRT spot.

Characteristics of Characters

The readability of the letters or other characters when displayed on an indicator screen is determined by their size and proportions. Although the following discussion is concerned specifically with the electronic pulse-pattern coder, the remarks pertaining to displayed character size and shape are also applicable to the electromechanical coder previously described.

Relations between the parameters T_F and T_S of the coder and the physical dimensions of the character displayed on the radar indicator are easily determined. The three quantities involved in the pattern coder are:

T_F - Time required for the cathode-ray spot to traverse the pattern mask in a vertical direction in microseconds.

T_S - Time in seconds required for the cathode-ray spot to sweep the pattern horizontally.

kT_S - Time in seconds required for the cathode-ray spot to sweep horizontally across a single character when the mask consists of more than one character.

The displayed character height in nautical miles is

$$\frac{T_F}{12.37} \text{ miles.}$$

The height of the characters in inches when displayed on a PPI indicator is

$$H = \frac{T_F}{12.37} \times \frac{L}{RS} \text{ inches} \qquad (5)$$

where

L – Length of the trace on the indicator, inches.

RS - Range scale in use, nautical miles.

The width of a single character, expressed in degrees, is

$$W_\theta = kT_S \times 6 \times \text{RPM degrees} \qquad (6)$$

where

RPM - The number of revolutions per minute through which the trace on the PPI rotates.

Character width may also be expressed in inches.

$$W = \frac{\text{Range}}{RS} \times L \times \frac{W_\theta}{57.3} \text{ inches} \qquad (7)$$

where

Range - Range to replying target, nautical miles.

The width of the arc subtended by the complete group of characters when a mask contains more than one character is found by replacing kT_S by T_S in the above expressions.

In general, characters of the ordinary English alphabet of printed capital letters are most easily readable when the ratio of their height to width is about unity. The expressions found for character height and width may be put in the form of a ratio

$$\frac{H}{W} = \frac{T_F}{kT_S}\left(0.772\right)\left(\frac{1}{\text{Range}}\right)\left(\frac{1}{\text{RPM}}\right). \qquad (8)$$

The factors affecting the height-to-width ratio can be easily seen. From experience, limits may be placed to define the range of acceptable readability as

$$0.4 < \frac{H}{W} < 2.5 \qquad (9)$$

During operation there is only one quantity which is expected to vary — the range to the target. If the other factors remain constant, the characters will be readable while the target changes its range by a factor of about 6.25. This is independent of the range scale in use so long as the character height is sufficient to permit accurate resolution on the indicator. A minimum height of 1/8 inch is allowable with indicators available for these tests; therefore a second limitation may be written

$$H > 1/8 \text{ inch.} \tag{10}$$

Equations 9 and 10 now specify the coder parameters.

In addition, two limitations must be placed on the interrogating system. To insure that the character group is read correctly regardless of the starting point of the display, the group should be transmitted completely a minimum of two times while the interrogator responsor antenna is scanning through the azimuth of the target. The minimum antenna beam width required thus becomes

$$\text{Min. Ant. Beam Width} = T_S \times \text{RPM} \times 12 \text{ degrees.} \tag{11}$$

A single transmission of each of the pulse groups which constitute a character element is insufficient to produce a clear display, particularly when noise and nonsynchronous pulses are present. An arbitrary minimum number of repetitions may be set at three, with the possibility that this may be modified as more data is gathered. If each character is to have a resolution of 9 lines, the minimum repetition rate of effective interrogations is

$$\text{Min. PRF} = \frac{27}{kT_S} \text{ interrogations per second.} \tag{12}$$

When the characters are displayed on an expanded type-B indicator such as the P^3I of the VF, the character height and the height-to-width ratio become independent of range to the target. With the dimensions of the B-scope presentation 20 degrees in azimuth and 2 nautical miles in range, as is the case with the VF indicator, relatively short times may be used for T_F and T_S. It may be desired to make T_F as short as one microsecond.

Circuits and Construction

Since short sweep times are contemplated, it is apparent that the coder cathode-ray tube must have an extremely short persistence screen. Such a tube was obtained from Dumont with the 3JP type construction. The photoelectric tube must be capable of responding to short light pulses and of delivering short electrical pulses. These requirements together with the low-light intensity expected led to the choice of a photomultiplier tube, type 931-A, for the first trial. It was found to operate satisfactorily.

A block diagram of the system is shown in Figure 14. Both the fast- and slow-sweep circuits are designed to allow variation in T_F and T_S without changing the length of the trace on the cathode-ray tube, and are shown schematically in Figures 15 and 16 respectively. The intensifying gate circuit was incorporated in the fast-sweep circuit. No wiring diagram of the video amplifier is included, since the one used provided much greater bandwidth than was necessary. An amplifier with a frequency response extending to 4 megacycles and a gain in the order of 100 is all that is required in conjunction with the cathode-ray tube used. Figure 17 shows the circuit used for the cathode-ray tube control, the photomultiplier tube, and the preamplifier.

A section of steel tubing closed at one end was used to house the cathode-ray tube with the photomultiplier tube and preamplifier built into a similar section of tubing of such diameter that the open ends of the two tubes could be telescoped together. This placed the photomultiplier tube about two inches in front of the cathode-ray tube, and the whole in a light-tight chamber. All voltage controls for the circuit were mounted on one chassis together with the housing; and the slow-sweep, fast-sweep, and video-amplifier circuits were built on individual small chassis.

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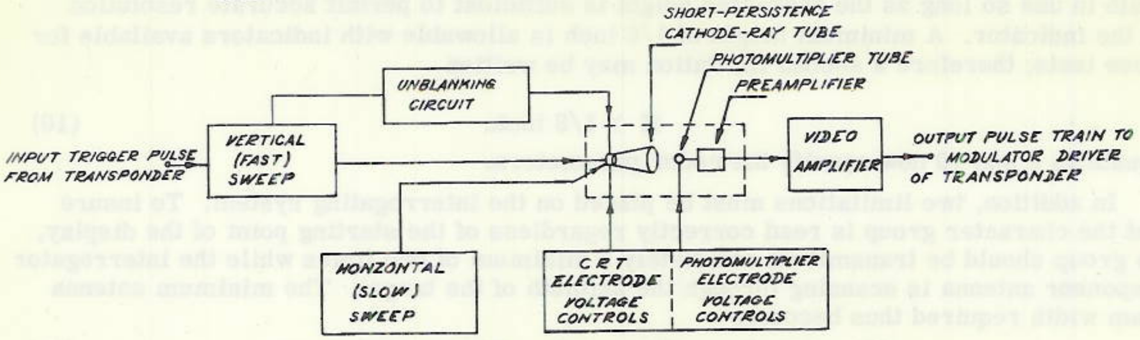

Fig. 14 - Block diagram, electronic pulse pattern coder.

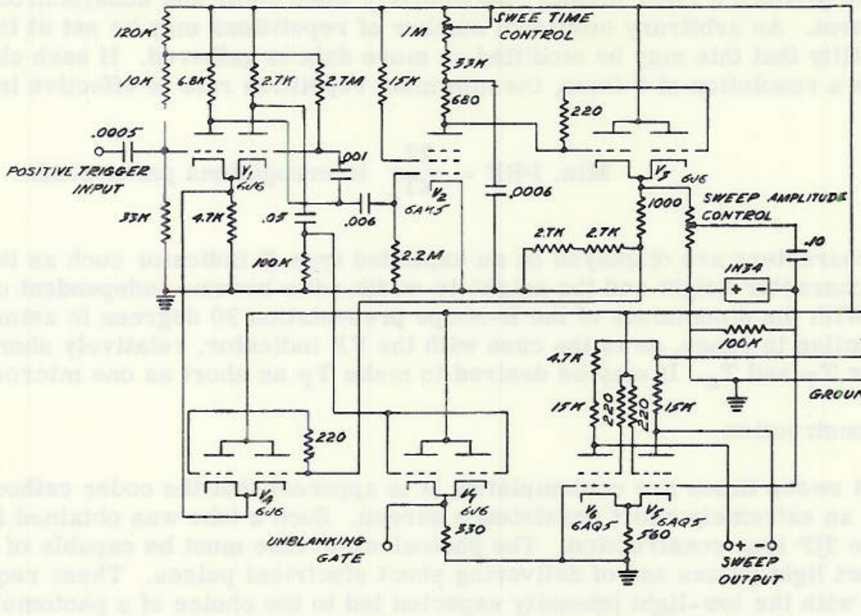

Fig. 15 - Vertical (fast) sweep and unblanking circuit.

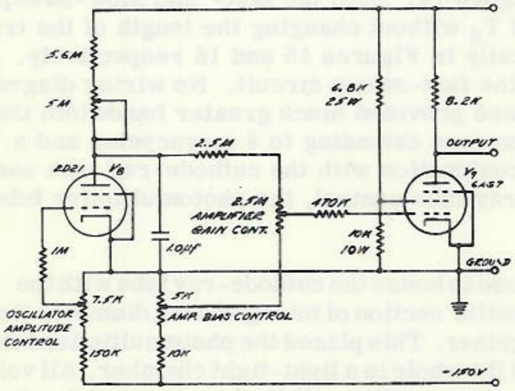

Fig. 16 - Horizontal (slow) sweep circuit.

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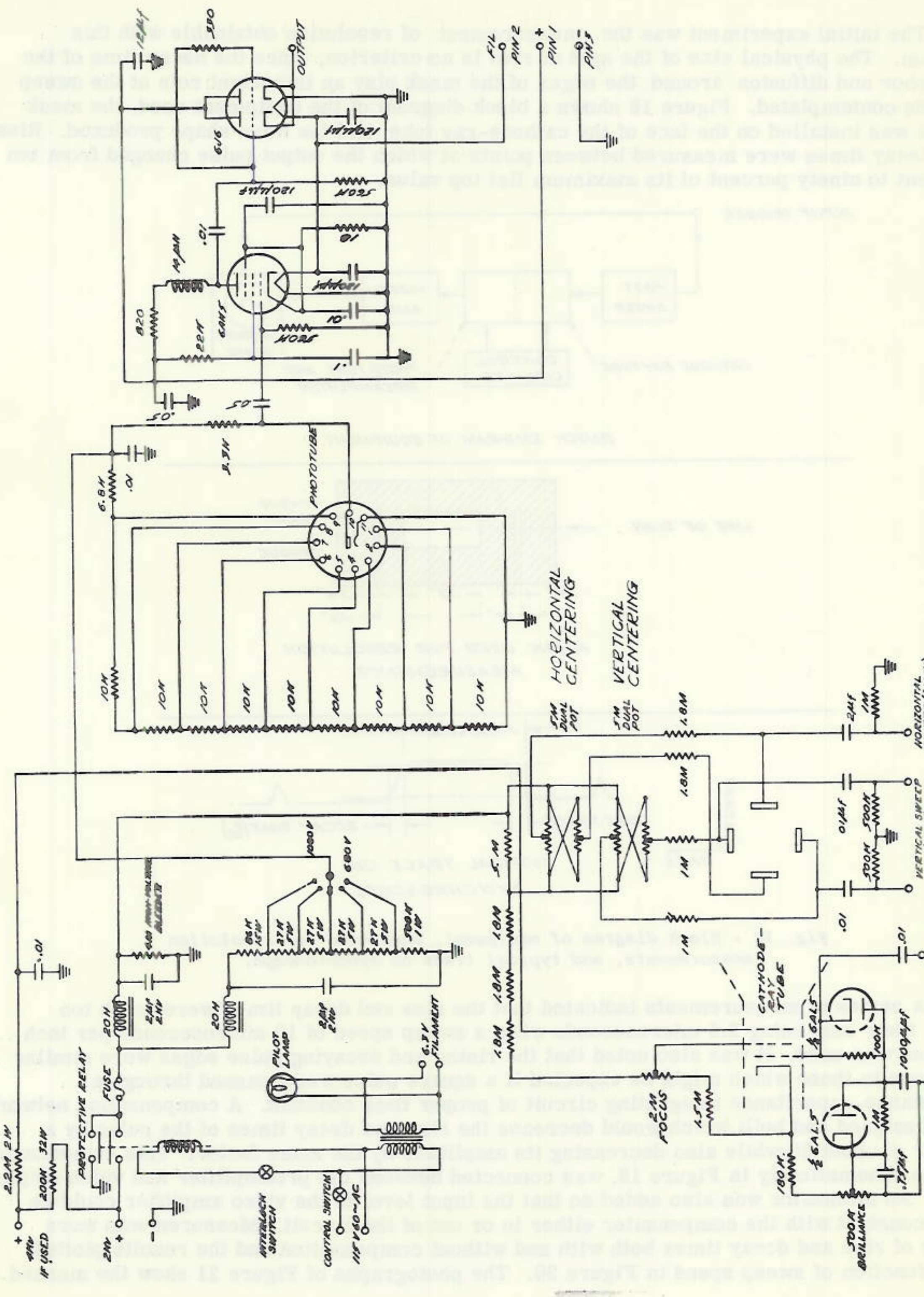

Fig. 17 - Circuit for cathode-ray tube, photomultiplier, and preamplifier.

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Measurement of Resolution

The initial experiment was the measurement of resolution obtainable with this system. The physical size of the spot at rest is no criterion, since the decay time of the phosphor and diffusion around the edges of the mask play an important role at the sweep speeds contemplated. Figure 18 shows a block diagram of the equipment used, the mask which was installed on the face of the cathode-ray tube, and the wave shape produced. Rise and decay times were measured between points at which the output pulse changed from ten percent to ninety percent of its maximum flat top value.

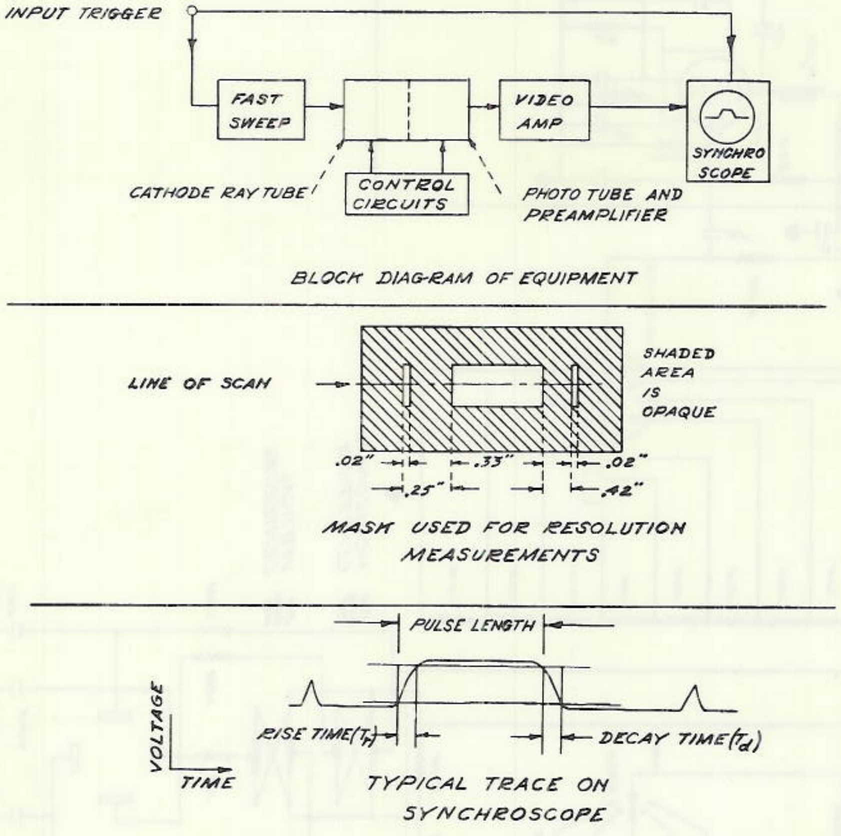


Fig. 18 - Block diagram of equipment, mask used for resolution measurements, and typical trace on synchroscope.

A series of measurements indicated that the rise and decay times were much too long, their sum being 2.5 microseconds when a sweep speed of 10 microseconds per inch or less was used. It was also noted that the rising and decaying pulse edges were similar in shape to those which might be expected if a square pulse were passed through a resistance-capacitance integrating circuit of proper time constant. A compensating network was designed and built which would decrease the rise and decay times of the pulse by a factor of about 20 while also decreasing its amplitude by the same factor. This compensator, shown schematically in Figure 19, was connected between the preamplifier and video amplifier. An attenuator was also added so that the input level to the video amplifier could be held constant with the compensator either in or out of the circuit. Measurements were made of rise and decay times both with and without compensation and the results plotted as a function of sweep speed in Figure 20. The photographs of Figure 21 show the marked improvement in pulse shape obtained through the use of the compensating circuit.

Minimum resolvable line width was defined as that which would allow the output pulse to rise from ten percent to ninety percent of its maximum amplitude and decay back to ten percent before the next rise started. This means that the sum of the rise and decay times determines the minimum time spacing between successive lines.

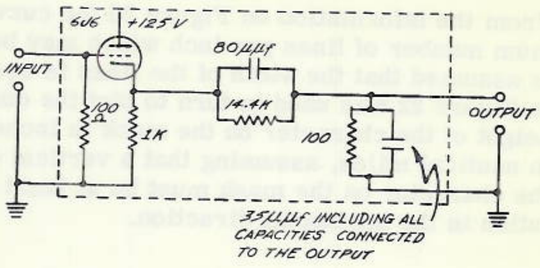


Fig. 19 - Compensation circuit.

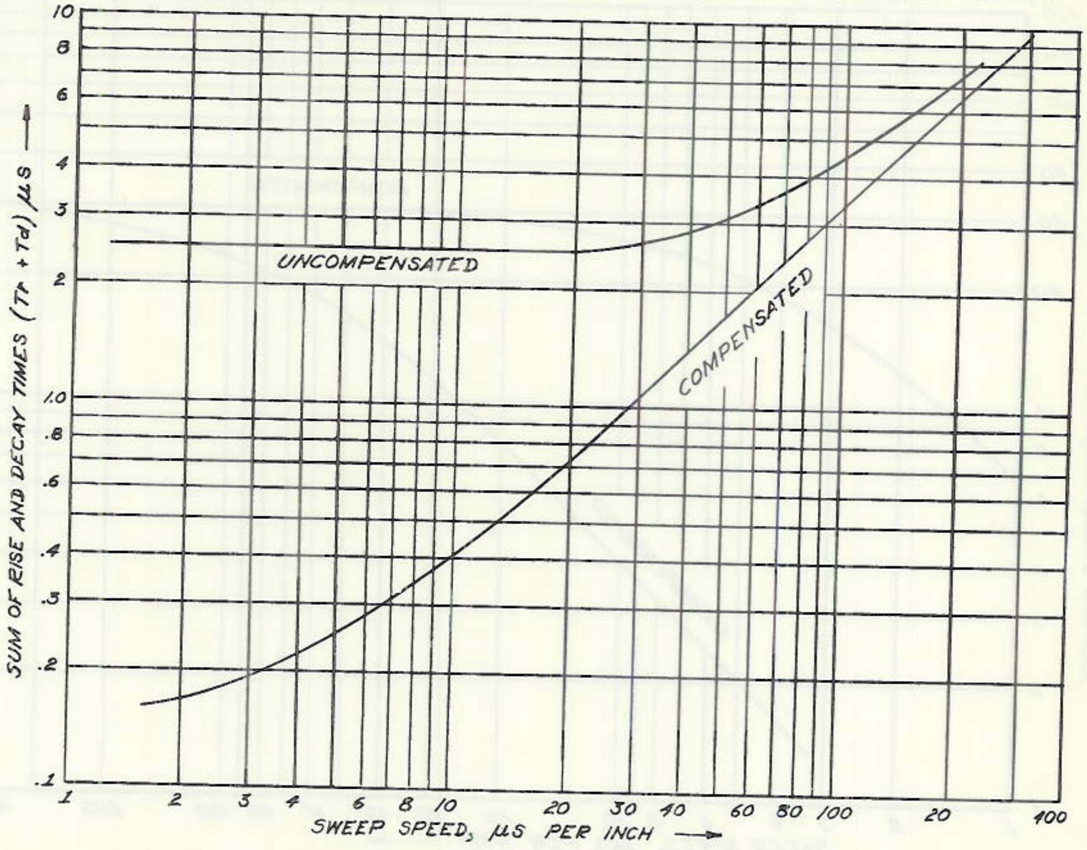
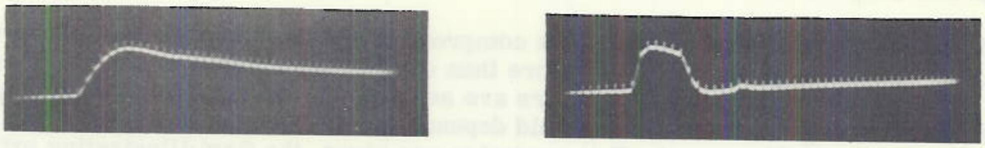


Fig. 20 - Sum of rise and decay times as a function of sweep speed.



Uncompensated pulse shape *Compensated pulse shape*

Note: Markers appear at 0.1 microsecond intervals.
Figure 21.

From the information on Figure 20 the curve of Figure 22 was plotted to show the maximum number of lines per inch which may be resolved as a function of sweep speed. It is assumed that the width of the lines is equal to the space between lines. The information in Figure 22 was used in turn to plot the curve in Figure 23 which shows the minimum height of the character on the mask in inches as a function of the displayed character height in nautical miles, assuming that a vertical definition of 9 lines is required. The width of the character on the mask must be at least 0.3 inch to secure a minimum of 9 lines resolution in the horizontal direction.

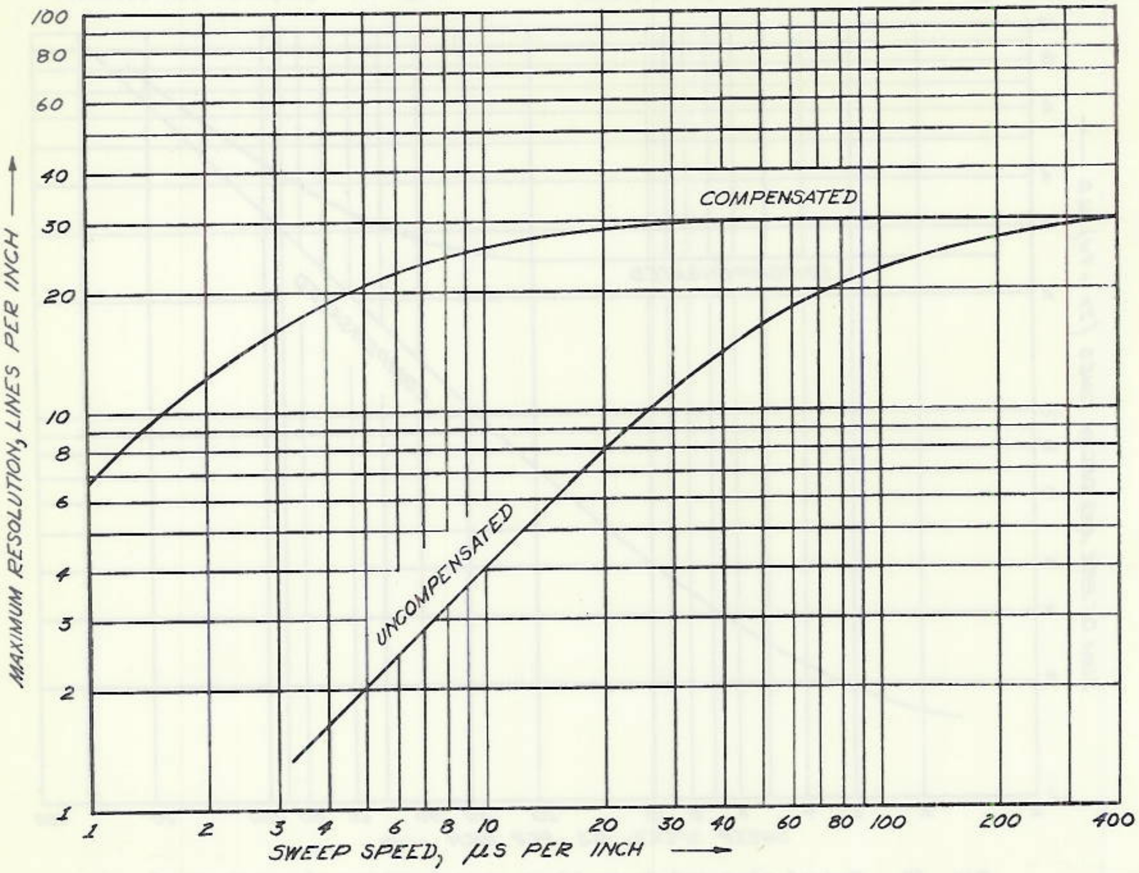


Fig. 22 - Maximum resolution lines per inch as a function of sweep speed.

Design and Construction of a Pattern Mask

Although it is possible to determine a compromise set of values for T_F and T_S which will allow satisfactory readability on more than one indicator range scale, optimum results may be obtained if these parameters are selected for use with a specific range scale. The particular range scale selected would depend on tactical considerations which are beyond the scope of this report. Two examples are given, the first illustrating extreme conditions when the transmission time of a pulse train is abnormally long and the second a more practical case.

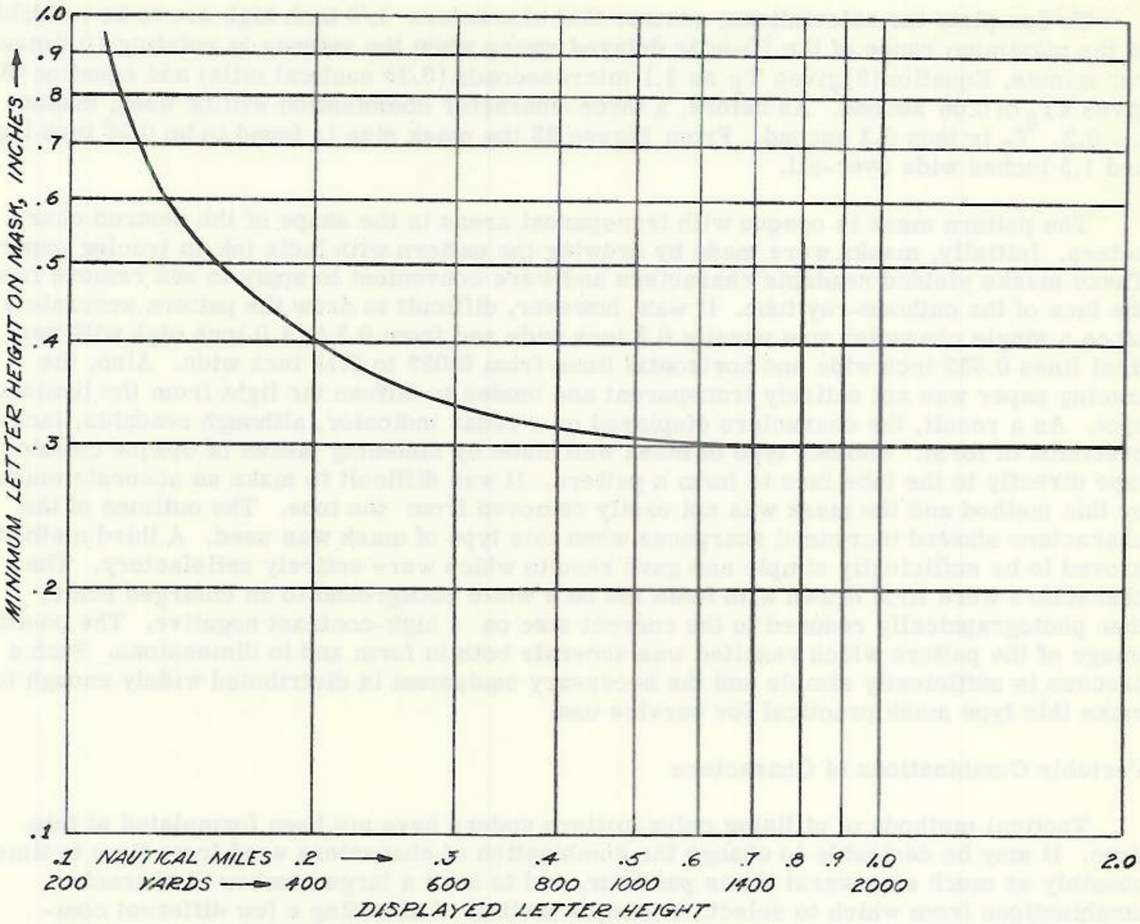


Fig. 23 - Minimum letter height on mask as a function of displayed height.

If it is desired to display characters 1/8 inch high on the 80-mile range scale of a 7-inch PPI indicator, the required vertical sweep time, T_F, may be found from equation (5) to be 35 microseconds (2.83 nautical miles). In order to maintain a readable height-to-width ratio up to 80 miles, equation (9) yields a slow sweep time, kT_S, of 0.14 second per character with an antenna rotation rate of 6 RPM. Allowing for a three character combination, k will be about 0.2, making T_S equal to 0.7 second. A height-to-width ratio of unity will exist when the characters are displayed at a range of 32 miles and they will be readable from 13 to 80 miles. Figure 23 may be used to determine the size of the mask necessary to permit resolution of a character and from this figure a size 0.3 inch high and 0.3 inch wide is found. The over-all size of the mask will be 0.3 inch high and 1.5 inches wide including spacing between characters.

The foregoing method of calculation will also be applicable to an indicator with an expanded range scale such as the VJ. For instance, if the 10-mile delayed sweep is to be used in reading the characters, calculations may be made as though a PPI with a 10-mile range scale were in use. Thus a readable H/W ratio may be maintained from 1.6 to 10 miles with a H/W ratio of unity at 4 miles. When the start of the VJ sweep is delayed M miles, the characters will have a readable H/W ratio from M + 1.6 miles to M + 10 miles.

To complete the calculations, assume that characters 1/8 inch high are to be readable at the maximum range of the 10-mile delayed sweep when the antenna is rotating 10 times per minute. Equation (5) gives T_F as 3.1 microseconds (0.25 nautical mile) and equation (8) gives kT_S of 0.06 second. As before, a three-character combination will be used, making $k = 0.2$. T_S is then 0.3 second. From Figure 23 the mask size is found to be 0.36 inch high and 1.5 inches wide over-all.

The pattern mask is opaque with transparent areas in the shape of the desired characters. Initially, masks were made by drawing the pattern with India ink on tracing paper. These masks yielded readable characters and were convenient to apply to and remove from the face of the cathode-ray tube. It was, however, difficult to draw the pattern accurately since a single character was usually 0.3 inch wide and from 0.3 to 1.0 inch high with vertical lines 0.033 inch wide and horizontal lines from 0.033 to 0.11 inch wide. Also, the tracing paper was not entirely transparent and tended to diffuse the light from the luminous spot. As a result, the characters displayed on a radar indicator, although readable, lacked precision of form. Another type of mask was made by fastening pieces of opaque cellulose tape directly to the tube face to form a pattern. It was difficult to make an accurate mask by this method and the mask was not easily removed from the tube. The outlines of the characters showed increased sharpness when this type of mask was used. A third method proved to be sufficiently simple and gave results which were entirely satisfactory. The characters were first drawn with India ink on a white background to an enlarged scale, then photographically reduced to the correct size on a high-contrast negative. The positive image of the pattern which resulted was accurate both in form and in dimensions. Such a process is sufficiently simple and the necessary equipment is distributed widely enough to make this type mask practical for service use.

Variable Combinations of Characters

Tactical methods of utilizing pulse-pattern coders have not been formulated at this time. It may be desirable to change the combination of characters used from time to time, possibly as much as several times per hour, and to have a large number of character combinations from which to select. A simple method of affording a few different combinations requires a mask containing several characters so arranged that by changing either the horizontal or vertical centering voltages of the scope, or both, different combinations of characters will be scanned. The tube face must be large enough to accommodate the extra characters; a three-inch scope with eight characters on the mask allows four combinations of three characters each if there are two centering positions for both the horizontal and the vertical deflection.

A greater number of character groups may be made available by the use of a strip containing several masks and mechanically operated to place the selected mask in front of the scope face. This would not be easy, because the mask must be in contact with the curved tube face in order to secure satisfactory resolution. Manufacture of the strip of masks itself would be simple if the photographic process is used. Use of a lens system in conjunction with a 2-inch cathode-ray tube would greatly simplify the moving-mask-strip method of changing characters by deleting the requirement that the mask be in contact with the tube face, and at the same time would probably improve resolution. Standard 35-mm film with 16 frames per foot could be used with a simple mechanism for changing masks. One hundred different combinations would occupy 6.25 feet of film, a small and easily handled amount. Operation could be made either manual or completely automatic.

Discussion of Results

Originally a tentative goal was the resolution of lines representing 0.1 microsecond width with 0.1 microsecond spacing between lines. From Figure 20 it may be seen that the minimum sum of rise time and decay time of the output pulse is 0.3 microsecond. This then establishes the minimum line width at 0.15 microsecond with 0.15-microsecond spacing. Past experience indicated that each character should be broken down into a mosaic containing at least nine elements on each side. It follows that the minimum value for T_F is 2.15 microseconds, corresponding to a character height of 0.2 nautical mile (400 yards) and requiring a mask 1 inch high on the face of the cathode-ray tube.

The resolution of this system expressed in lines per inch is rather poor compared to that obtained with more elaborate flying-spot scanners for television and teleran use, but is still sufficient for this application. Phosphor rise and decay times are among the limiting factors at high sweep speeds. A five-inch cathode-ray tube, 5WP15, which has an extremely short persistence has recently been announced by the Radio Corporation of America, the claim being made that a rise and decay time of 0.05 microsecond can be obtained. If such a tube were used, diffusion of light around the edges of the pattern because of the fact that the pattern and screen are separated by the glass face of the tube would have to be taken into account in order to utilize the full resolving power available. A lens system would allow the mask to be placed effectively in the plane of the phosphor, but the resolution would be increased at the expense of added size, bulk, and complexity. Operation of this particular tube requires a very high accelerating potential, 25 kilovolts, which, plus the fact that the tube is made only in a 5-inch size at present, limits the desirability of using it.

The bulk and weight of the experimental pattern coder are prohibitive for use in aircraft, but several ways of reducing it to practical size are available. A production model would not have the features of variable fast- and slow-sweep speeds, and would have a video amplifier sufficient only to do the job at hand. Use of a radio-frequency high-voltage power supply would further economize on space and weight. The possibility of using a smaller cathode-ray tube depends on the character height and on the number of characters necessary. As was pointed out, the total mask size for a three-character combination with characters 0.25 nautical mile high is 0.36 inch high and 1.5 inches wide. If a tube with slightly better focusing characteristics and a faster phosphor could be obtained, a 2-inch cathode-ray tube would be sufficient.

No attempt was made to flight-test this equipment, as several technical difficulties presented themselves. The size and weight of the experimental coder are too great when the present power supplies are included. Had 800-cycle power supplies been available, it would have been entirely practical to fly the equipment, but the AN/APX-6 transpondor is not capable of being modulated by a closely spaced group of short pulses without major redesign of the modulator and transmitter. Flight tests made with an earlier model coder have supplied information as to the workability of the system and a guide to the results which may be expected. Further flight tests were not considered essential at the time.

Photographs of the letters displayed on the VE indicator were made under simulated operating conditions with the output of the video amplifier feeding the video input of the indicator. Figure 24 is a photograph of the indicator screen showing letters 0.8 mile high at a range of 11 miles on the 20-mile range scale.

A COMPARISON OF THREE SYSTEMS

Three different methods of obtaining a suitable pulse-pattern code have been described and discussed. For convenience in making comparisons they will be given designations as follows:

System I	Mechanical Commutator and Letter-Selector Unit described in NRL Report R-2980
System II	Electromechanical Commutator described in the first section of this report
System III	Electronic Commutator described in the second section of this report.

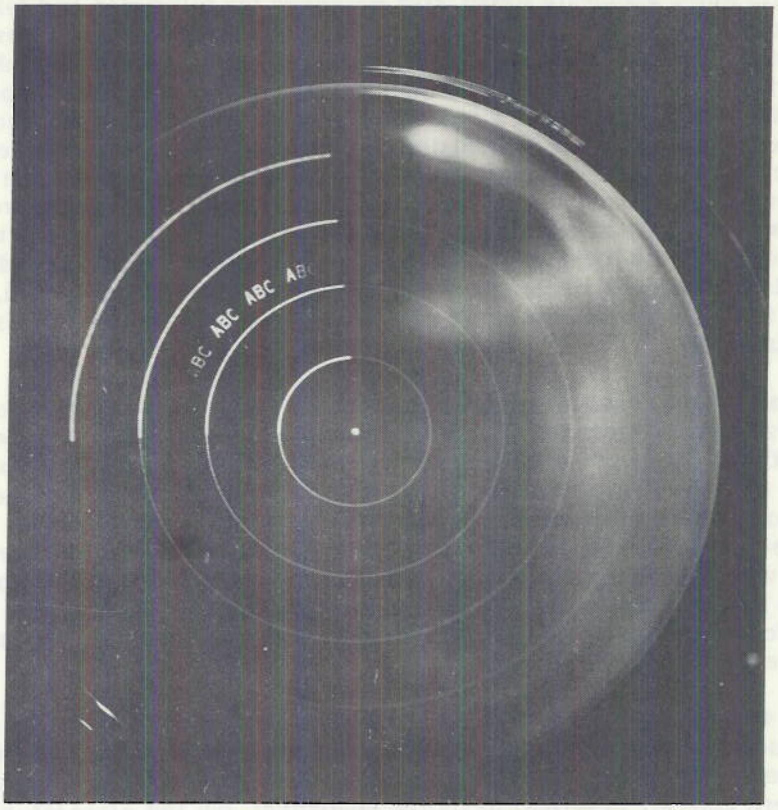


Fig. 24 - Letters displayed on VE indicator.
Range-11 miles Range scale-20 miles
Letter height-0.8 miles.

A list may be made of the necessary features of a pulse-pattern coder and the three systems may be evaluated with respect to their conformance to each requirement. The requirements may be subdivided into two groups, those of primary importance and those of secondary importance. Each of the primary requirements is assigned a weight of 4 as compared to a weight of 2 for each secondary requirement, and a proportionate value is given to each system depending on how nearly the system fulfills the requirement. The total for each system permits an over-all comparison to be made.

Table 1 indicates the relative practicability of the three systems as they now exist. In order to obtain a more accurate evaluation, the effect of developments in the foreseeable future must be taken into account. An analysis is therefore made of each requirement and some possible changes for each system.

TABLE 1
Evaluation of the Systems

Requirements	System Designation I	 II	 III
Primary			
1. The size and weight must be small	2	4	0
2. The total power requirements must be small	4	2	0
3. Displayed characters must be easily readable	2	4	4
4. Operation must be stable under normal changes in supply voltages and circuit parameters	4	2	2
5. Life in service must be long	0	2	3
Secondary			
6. A large selection of codes must be contained as an integral part of the coder	2	0	0
7. No tools must be needed in order to change codes	2	2	2
8. Installation, adjustment, and maintenance must be simple	2	1	0
9. The coder must be suitable for installation in single-place aircraft	1	2	0
10. A practical design should be available which could be used as a basis for a preproduction model	0	2	2
11. Cost of manufacture must not be excessive	2	1	0
TOTAL	21	22	13

1. The size and weight must be small.

System 1. The size of the commutator, letter selector unit, and their connecting cables in the earlier model was too great. Since then the space required for these components has been reduced from more than 725 cubic inches to 18 cubic inches. Miniaturization of the units permits them to be mounted together and eliminates the complex connecting cable. A modification was made in the operation of the letter-selector unit; instead of having a large group of push-button switches which must be operated individually to set up a pattern, the miniature unit has a single plug for each letter, insertion of the plug performing all necessary switching functions.

A preferable modification would be the elimination of the commutator and letter selector, replacing them with a group of cam-operated switches. There would be one cam and switch for each pulse in the group (9 pulses suggested), one set of cams producing one group of letters. It would be necessary to change cam sets in order to alter the letters.

Reduction in size of the pulse generator has also been achieved, the present unit being 7″ x 7″ x 5″, exclusive of power supply.

System II. The mimimum practical size of the commutator unit is about 6″ x 6″ x 2 5/8″, about half the size of the unit described. The pulse generator and gating unit used is the same as for System I.

System III. This system requires a cathode-ray tube, a photomultiplier tube, sweep circuits, a video amplifier, and associated power supplies. Reducing the size of any one component will have little effect on the total bulk. A unit about the size of the AN/APX-6 transpondor represents the minimum size considered likely to be obtained.

2. The total power requirements must be small.

There is small probability that any appreciable reduction in power consumption may be realized for any of the systems.

3. Displayed characters must be easily readable.

System I. A considerable improvement may be made by the use of a greater number of pulses in forming the characters. A nine-pulse code appears to be adequate.

Systems II and III. No improvement is needed until the resolution of cathode-ray tubes used in indicators is improved.

4. Operation must be stable under normal changes in supply voltages and system parameters.

System I. This system is considered to be sufficiently stable.

System II. Uniformity in tubes and photocells can be improved and more stable circuit elements may be found to improve the over-all stability of the system.

System III. Better voltage regulation by simple means is required to improve stability. Beneficial results will also be derived from the availability of tubes with more uniform characteristics.

5. Life in service must be long.

System I. The original model did not meet this requirement because of rapid wear of the commutator and brushes. Investigations were continued in an effort to develop a suitable commutator but no satisfactory model has been produced up to this time. Abandonment of the commutator and letter-selector unit in favor of cam-operated switches would eliminate the source of the difficulty. Various switches for use with cams have been tested and at least one satisfactory unit has been found. Microswitches are not suitable because of excessive contact bounce.

System II. This system has been operated for approximately 1,000 hours and apparently is good for many more. Life of the simple motor and gear train used to turn the disc should be ample and tube life under the operating conditions should be good.

System III. The number of vacuum tubes employed make this system more vulnerable to tube failure or changing characteristics.

6. A large selection of codes must be contained as an integral part of the coder.

System I. The miniaturization of the unit to comply with requirement 1 would eliminate the letter-selector unit and thus this requirement is no longer met. There appears to be little possibility of meeting this requirement without sacrificing size and weight.

System II. This system seems to be limited to one character group unless the size is doubled.

System III. With a relatively small percentage of increase in size, several character groups may be made available for selection. This can be accomplished by making several masks on a strip of film and changing the mask on the face of the cathode-ray tube by means similar to that used to change frames in a microfilm viewer.

7. No tools must be needed in order to change codes.

All systems meet this requirement now and can be designed to conform in the future.

8. Installation, adjustment, and maintenance must be simple.

Only System I meets this requirement at present but all three systems can be so designed as to reduce maintenance problems to a minimum.

9. The coder must be suitable for installation in single-place aircraft.

System I. The existing model is too large and in addition a pilot would have difficulty setting up a character group in flight. Miniaturization as proposed under requirement 1 would render this system suitable for such use.

System II. No improvement is necessary since a pilot would have to perform no operations in addition to those required by the transpondor alone.

System III. There is little likelihood that this system can be adopted for such use.

10. A practical design should be available which could be used as a basis for a preproduction model.

System I. Preliminary investigations have been made of the improved system and one experimental model has been tested. However a satisfactory prototype is not in existence.

Systems II and III. Sufficiently complete designs have been made and all components are available.

11. Cost of manufacture must not be excessive.

System I. A simple system of this type requires production of precision parts for the commutator and a simple electronic circuit. Present production techniques are believed to be adequate to produce units at a reasonable cost.

System II. Moulded plastic parts can be used to minimize the cost of this system; also printed circuits might be utilized to make the cost reasonable.

System III. Almost entirely an electronic circuit with little mechanical precision required in manufacture, this system could be produced by any factory now making television sets. The cost would probably be high because of the amount of wiring and number of tubes required.

A revision of Table 1 may now be made for comparison on the basis of future developments.

TABLE 2
Re-evaluation of Systems

Requirement	System Designation		
	I	II	III
1	4	4	0
2	4	2	0
3	4	4	4
4	4	4	2
5	4	4	3
6	0	0	2
7	2	2	2
8	2	2	2
9	2	2	0
10	0	2	2
11	2	1	1
TOTAL	28	27	18

CONCLUSIONS

Of the three systems built and tested, Systems I and II appear to be equally practicable and both preferable to System III, particularly for airborne use. The effect of proposed modifications will not appreciably alter their relative standings. For shipboard or shore installations, where weight requirements can be relaxed, the flexibility of System III may make it the most desirable.

RECOMMENDATIONS

Further work on this phase of the IFF problem is not contemplated unless requested by a cognizant agency. In that event, it is recommended that System I be modified according to the suggestions made in this report.

It is recommended also that the basic methods of letter coding be considered for Air Traffic Control and Aircraft Interception purposes.

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