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ELECTROSTATIC DEFLECTION SYSTEMS FOR PLAN POSITION INDICATORS-II

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ABSTRACT

This report discusses factors affecting the performance of an electrostatic Plan Position Indicator (PPI) and methods of compensating for various errors in presentation.

It includes descriptions of various systems for obtaining PPI traces by purely electronic means. One system eliminates the selsyn follower mechanism at the indicator by obtaining the antenna-position information from a sine potentiometer or Autosyn resolver phase-amplitude detector in such form that it can directly actuate the sweep generator.

PROBLEM STATUS

This is a second interim report on one phase of a continuing problem on radar display.

AUTHORIZATION

NRL Problem R07-16R (BuShips S1228)

ELECTROSTATIC DEFLECTION SYSTEMS FOR PLAN POSITION INDICATORS-II

INTRODUCTION

A plan position indicator (PPI) using a cathode-ray tube with electrostatic deflection affords advantages in size, weight, and power consumption compared with a magnetic-deflection tube.[1]

The purpose of this report is: (a) To compile a list of the various factors affecting the performance of a plan position indicator using a standard two-coordinate electrostatic-deflection cathode-ray tube, (b) to indicate the relative importance of each of the factors, (c) to mention methods used by the investigator to compensate for each type of error in presentation, and (d) to indicate the results obtained using various deflection generator systems.

The primary units of an electrostatic-deflection system to be considered are the cathode-ray tube (crt) itself and the sweep generator. The ideal sweep generator would deliver four perfectly linear sweep voltages, the magnitude of each varying as the sine or cosine of the angular rotation of the radar antenna.

The ideal crt would receive the voltages from the sweep generator and give a perfect PPI display with no angular or amplitude error and no defocusing over the face of the tube.

FACTORS AFFECTING THE PERFORMANCE OF AN ELECTROSTATIC PLAN POSITION INDICATOR

Errors Caused by the Cathode-Ray Tube

a) Skewed deflection plates.

b) Interference between deflection plates.

c) Astigmatism.

d) Variation in deflection sensitivity over the face of the scope.

e) Different deflection sensitivity on horizontal and vertical plates.

f) Defocusing due to beam modulation.

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[1]A general discussion of electrostatic deflection systems, as well as a detailed description of the push-pull sine-condenser method of producing a PPI trace on an electrostatic-deflection cathode-ray tube, may be found in the first of this series of reports—"Electrostatic Deflection Systems for PPI," by E. V. Phillips, NRL Report No. R-3161, August 22, 1947.

Errors Caused by the Sweep Generator

a) Amplitude errors.

b) Angular errors.

c) Nonlinear sweep voltages.

d) Poor clamping.

CONSIDERATION OF FACTORS AFFECTING THE CRT PERFORMANCE

Skewed Deflection Plates

Specifications for the 5CP7 state that the angle between the trace produced by one pair of deflection plates and the trace produced by the other pair shall be 90 ± 3 degrees. Assuming that a tube was at the tolerance limit of 3 degrees, there would be a maximum angular error of 3 degrees and a maximum amplitude error of 2.6 percent in the display. The equations for this condition are as follows:

$$|D_R| = 2\,|D| \sqrt{1 + (\sin 2\theta)\ (\sin\phi)}$$

$$\beta = \operatorname{Tan}^{-1} \frac{(\cos\theta)\ (\cos\phi)}{\sin\theta + (\cos\theta)\ (\sin\phi)}$$

where:

$|D_R|$ = Magnitude of total resultant displacement.

$|D|$ = Magnitude of displacement due to single deflection plate.

θ = Angular position of antenna.

ϕ = Angle by which one pair of deflection plates deviates from the 90-degree relationship to the other plates.

β = Angular direction of D_R.

Thus it can be seen that the angular accuracy and amplitude accuracy are directly dependent on the alignment of the plates. In order to meet the present-day tolerances of ± 0.5 degrees in PPI display, it is evident that tubes with much smaller alignment tolerances will be required.

Interference Between Deflection Plates

With the high accelerating voltages used to excite the P-7 screen properly, it has been found that push-pull deflection voltages are a necessity in order to avoid the distortion produced by the electrostatic fields generated when the deflection voltage is applied solely to one plate. This distortion is of small magnitude, and is of academic interest only.

Astigmatism

When the electron beam is deflected from the center toward the edge of the tube, a lengthening of the spot occurs in the direction of the deflection. On several 5-inch tubes measured, the spot tripled in size along the radial dimension at 2 inches from the center.[2] This is a serious limitation on the ultimate resolution of the PPI indicator, and it is imperative that this condition be improved.

Variation in Deflection Sensitivity Over the Face of the Cathode-Ray Tube

The deflection sensitivity of most cathode-ray tubes decreases slightly as the beam is moved toward the edge. This effect is not uniform at all positions on the tube face, and could produce some rather peculiar distortions if it were of a large magnitude. Fortunately, the change is small and has not been noticeable in any of the units developed in this Section.

Variation of Deflection Sensitivity Between Pairs of Deflection Plates

Since one pair of deflection plates is mounted closer to the electron gun than the other, there is a difference in the deflection sensitivity of the two pairs. The pair mounted nearest the gun usually has about 1.35 times the sensitivity of the other pair, a condition which must be considered in designing the sweep generator. Fortunately all that is required is that the sweep voltage for the less sensitive pair be 1.35 times the voltage for the other pair.

Defocusing Due to Beam Modulation

The spot size varies almost directly with beam current. With the beam current adjusted to what was considered to be an average operating level, the spot was approximately 3/64 inch in diameter. This large spot size is sufficient to limit severely the resolving power of a PPI. The spot size obtained was approximately twice that of a magnetic (focus and deflection) crt at the same light intensity level.

FACTORS CONSIDERED IN DESIGNING THE SWEEP GENERATOR

Angular Errors

The manner in which the amplitude of each sweep voltage varies with antenna rotation determines the angular accuracy. Ideally the sweep amplitude on each plate should follow sine or cosine curves as the antenna is rotated, and be spaced exactly 90 degrees from each other. Except in a few special cases, any digression from this condition results in both angular and amplitude error in the resultant sweep.

Amplitude Errors

Even though the angular relationship of the sweep voltage is perfect, if the amplitudes on all four plates are not correctly matched (including allowance for differences in deflection sensitivity) there will be both amplitude and angular errors in the sweep.

The general equations for determining the accuracy of the sweep generator were derived as follows:

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[2] See reports by National Union Radio Corporation on "Electrostatic Cathode-Ray Tube For PPI" under contract No. NObsr-39149.

Let

$|E_R|$ = Magnitude of resultant sweep voltage.

k_1, k_2, k_3, k_4 = Magnitude of maximum sweep voltage on deflection plates DJ-1, DJ-3, DJ-2, DJ-4 respectively.

$\phi_1, \phi_2, \phi_3, \phi_4$ = Angle by which each deflection voltage varies from being a function of θ alone.

θ = Angular position of antenna.

β = Angular direction of E_R.

The voltage applied to each deflection plate is then:

$$E_{DJ-1} = k_1 \sin(\theta+\phi_1)$$

$$E_{DJ-2} = -k_3 \sin(\theta+\phi_3)$$

$$E_{DJ-3} = k_2 \cos(\theta+\phi_2)$$

$$E_{DJ-4} = -k_4 \cos(\theta+\phi_4)$$

The component of E_R on the pair DJ-1 and DJ-2 is then:

$$E_{1+2} = E_{DJ-1} - E_{DJ-2} = k_1 \sin(\theta+\phi_1) + k_3 \sin(\theta+\phi_3)$$

The component of E_R on the pair DJ-3 and DJ-4 is then:

$$E_{3+4} = E_{DJ-2} - E_{DJ-4} = k_2 \cos(\theta+\phi_2) + k_4 \cos(\theta+\phi_4)$$

The resultant deflection voltage acting on the electron beam is then the vector sum of E_{1+2} and E_{3+4} and is E_R.

$$E_R| = \sqrt{[k_1 \sin(\theta+\phi_1) + k_3 \sin(\theta+\phi_3)]^2 + [k_2 \cos(\theta+\phi_2) + k_4 \cos(\theta+\phi_4)]^2}$$

$$\beta = \mathrm{Tan}^{-1}\left[\frac{k_2 \cos(\theta+\phi_2) + k_4 \cos(\theta+\phi_4)}{k_1 \sin(\theta+\phi_1) + k_3 \cos(\theta+\phi_3)}\right]$$

β may also be expressed in the following manner:

$$\beta = \mathrm{Tan}^{-1}\left[\frac{(k_2+k_4)\cos 1/2\,(2\theta+\phi_2+\phi_4)\cos 1/2\,(\phi_2-\phi_4) + (k_4-k_2)\sin 1/2\,(2\theta+\phi_2+\phi_4)\sin 1/2\,(\phi_2-\phi_4)}{(k_3+k_1)\sin 1/2\,(2\theta+\phi_1+\phi_3)\cos 1/2\,(\phi_1-\phi_3) + (k_1-k_3)\cos 1/2\,(2\theta+\phi_1+\phi_3)\sin 1/2\,(\phi_1-\phi_3)}\right]$$

Nonlinear Sweep Voltages

If the sweep voltages are uniformly nonlinear, i.e., each deflection voltage having the same degree of nonlinearity, the only error produced will be nonuniform spacing of the range rings; there will be no angular error, nor will the range rings be noncircular.

If the four deflection voltages do not have the same degree of nonlinearity there will be errors in range; amplitude errors causing distortion of the range rings; and angular errors, which are evidenced by bending of each trace.

One of the major difficulties encountered so far is the nonlinearity of vacuum tubes for large deflection voltages required for an electrostatic system. The most objectionable distortion is due to the vacuum tubes having a higher percentage of nonlinearity at high voltage amplitudes than at low. This produces the same type of distortion as that noted in the paragraph above.

The most satisfactory method that the investigator has found is to have the basic sweep generators work at the voltage amplitudes needed for full deflection of the trace so that no further amplification is necessary. The output of the sweep generators is then fed to cathode followers and the output of the cathode followers applied to the crt deflection plates.

Poor Clamping

Considerable difficulty has been experienced in attempting to clamp properly the voltages of the electrostatic PPI. Each type of sweep generator tried has its own peculiar form of unclamped voltages. So far the best method found is to provide clamping in the sweep generator unit itself rather than to attempt clamping after the generator. This requires that any subsequent amplifiers be direct-coupled if clamping is to be maintained.

ELECTRONIC SWEEP GENERATORS INVESTIGATED

Four methods of generating the electronic sweep were investigated. Three proved unsatisfactory; the fourth, though not without certain disadvantages, was by far the most practical.

Sweep Voltage Applied to Sine Potentiometer

This method consists of applying a sweep voltage to a sine-pot and feeding the four resultant output voltages to the crt deflection plates. This method proved unsatisfactory because of inductance in the sine-pot winding and distributed capacitances in the wiring and deflection plates. The output varied in waveshape at various positions of the sine-pot and the output did not follow a sinusoidal variation with antenna rotation.

Sweep Voltage Applied to Autosyn Resolver

In this method the sweep voltage is applied to an Autosyn resolver and the four outputs attached to the crt deflection plates. This method is limited to extremely low voltage outputs and to fast sweep speeds because of saturation of the iron in the resolver. Tests of this circuit proved that it was incapable of providing a satisfactory PPI display.

PPI Sweep Generated by Varying the Gain of Four Sweep Amplifiers

This method consists of applying four d-c voltages which vary as the sine or cosine of the antenna position to the grids of four sweep amplifier tubes to cause the gain of each tube to vary so that the sweep output from each amplifier follows a sine or cosine variation with antenna position. It is extremely nonlinear, the point of zero gain on the tubes cannot be approached, nor can sweeps of both positive and negative polarity be obtained with any degree of linearity.

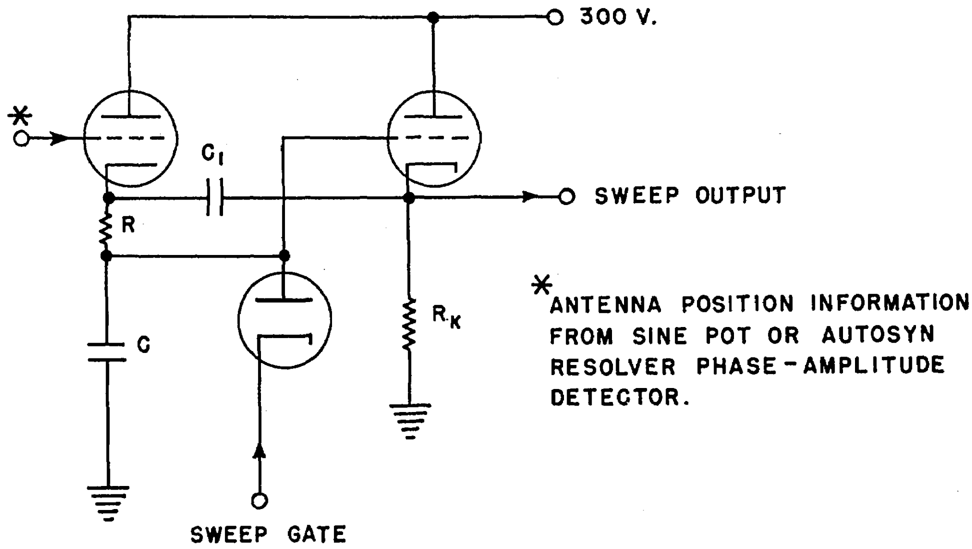

Fig. 1 - Basic Sweep Generator

PPI Sweeps Generated by Varying the Supply Voltage to Four Sweep Generators

The system finally adopted as being the most practical uses four d-c voltages, which vary as the sine or cosine of the antenna position, to power separate sweep generators. The sweep generator itself is capable of delivering an effective sweep voltage of 250 volts with an angular accuracy of 2 degrees and an accuracy in the resultant PPI vector of one percent. (The basic sweep circuit is shown in Figure 1.) There are four of these generators, one for each deflection plate, fed with the four d-c antenna-information voltages.

This circuit delivers sweeps of only positive polarity, a feature which has the advantage of avoiding the difficulty of clamping both positively and negatively in the same circuit. The system does have the disadvantage that the resultant driving voltage is the difference of two voltages instead of the sum as in push-pull systems. An additional drawback of this circuit is the change, during each sweep, in the average voltage at the deflection plate system which causes some astigmatism in the crt.

The complete sweep generator is shown in Figure 2. This is of the bootstrap variety with cathode-follower disconnect on the B supply. It will be noted that a 6D4 thyratron is used to gate the clamping diodes. This was done so that it would not be necessary to build a pulse amplifier which would deliver positive pulses of a magnitude larger than the sweep amplitude, and to insure a constant clamping potential of low impedance.

The four d-c antenna-information voltages are connected to the grids of four cathode followers in order that no current will be drawn from the antenna-information circuit and so that the impedance of the circuit charging the feedback capacitors will be decreased. This prevents crosstalk back in the antenna-information circuit and requires the least recovery time between sweeps. There is no tendency for any change in the d-c antenna-information voltage to affect the sweep after the sweep has started.

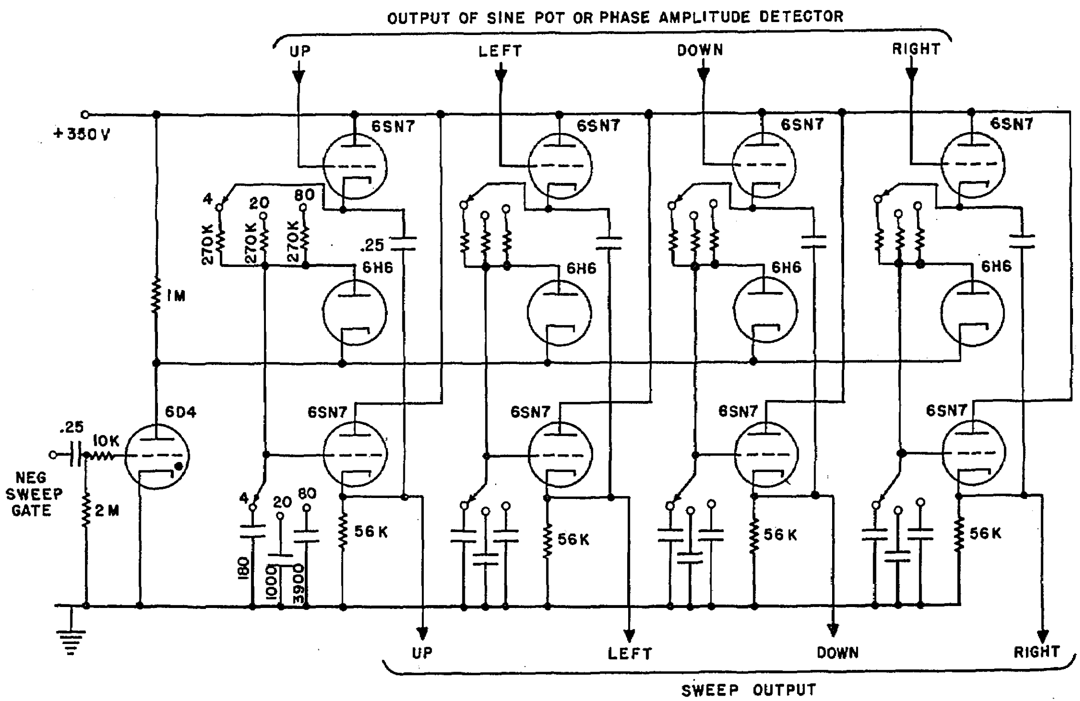

Fig. 2 - Sweep Generator For Electrostatic PPI

METHODS OF OBTAINING THE D-C ANTENNA AZIMUTH INFORMATION VOLTAGES

For obtaining the four voltages which are proportional to plus or minus the sine and plus or minus the cosine of the antenna azimuth the investigator used two methods. One utilized a sine-potentiometer; and the other, a phase-amplitude detector on the output of an Autosyn resolver which is being rotated in synchronism with the antenna.

Sine Potentiometer

The simplest method for obtaining the d-c antenna-azimuth information is from a sine potentiometer. The sine-pot (RL-14) output has an angular accuracy of ± 0.5 degrees, and an accuracy in the magnitude of the resultant PPI vector of 0.65 percent. It may be of interest to note that the specifications state that a maximum of 330 volts may be placed across the resistance winding of the sine-pot; that the maximum recommended speed of rotation is 30 rpm, with an absolute maximum of 120 rpm; and that the life of the sine-pot is in excess of 5,000,000 revolutions.

The main disadvantages of the use of a sine-pot for this purpose are its limited life and the fact that there is some electrical noise generated in it by brush commutation over the wires. Its main application would be for use with low antenna-rotation speeds.

Autosyn Resolver Phase-Amplitude Detector

A more difficult method of obtaining the d-c antenna azimuth-information voltages is by means of an Autosyn resolver rotated in synchronism with the antenna and followed by a phase-amplitude detector for converting the a-c output of the resolver to the four d-c

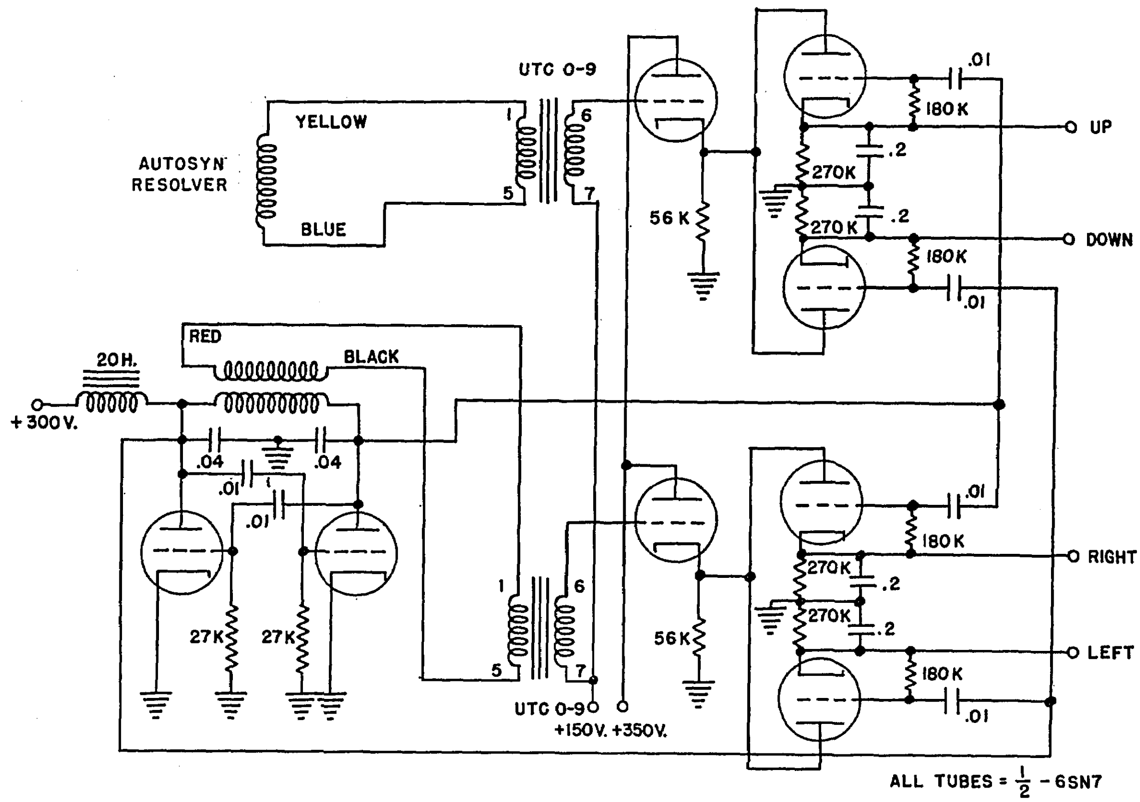

Fig. 3 - Phase-Amplitude Detector

voltages desired. The method used by the investigator consisted of applying a 3-kc voltage to one of the rotor windings of an Autosyn resolver and feeding the output of the two stator windings into a phase-amplitude detector which in turn delivers four d-c output voltages that vary as the sine or cosine of the antenna position angle. The circuit used is shown in Figure 3. An accuracy in the magnitude of the resultant PPI vector of ± one percent at 200 volts maximum d-c output has been obtained with this system.

The advantage of the resolver system over the sine-pot method is the long life of the resolver and the high rotation speeds allowable. Both of these methods allow the sensing device (sine-pot or resolver phase-amplitude detector) to be mounted at the antenna, thereby eliminating the synchro system in radars designed for continuous antenna rotation. The antenna azimuth-information is now transmitted as four d-c voltages. This d-c method of transmitting the antenna position could be adopted between any radar indicator and any remote indicators eliminating the bulky synchro follower usually associated with remote indicators.

CONCLUSIONS

It is possible to build electronic sweep generators that are capable of performance exceeding that of the cathode-ray tubes available at present. The greatest needs are for improvement in spot size, for reduction of astigmatism, and for improved alignment of the deflection plates in the cathode-ray tubes.

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