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THE CONICAL SCAN RADAR TARGET SIMULATOR

Technical Report No. 73

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ABSTRACT

A target simulator is discussed which permits extensive laboratory investigation of the dynamic response of conical scan radars, such as the AN/MPQ-10A mortar tracking radar, to typical mortar trajectories under a variety of test conditions. A predetermined trajectory is generated by three mechanical cams representing the variations of azimuth, elevation and slant range of the simulated target. These quantities are electrically compared by means of synchros to the corresponding quantities in the radar, and result in the generation of error signals. The azimuth and elevation errors are combined, and converted by means of an optical device, which also compensates for the antenna beam shape. The converted error signal is used to produce a pulsed echo signal at the IF frequency of the radar, which is modulated in the same manner as the echo signal from a true target with the corresponding pointing error. This signal is fed to the input terminal of the radar IF amplifier. Range information is introduced by means of a variable delay pulse generator, controlled by the range cam. The simulator is easily adapted to types of conical scan radars other than the AN/MPQ-10A. A quick-change feature facilitates interchangeability of cam sets, which correspond to various typical trajectories.

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THE CONICAL SCAN RADAR TARGET SIMULATOR

1. INTRODUCTION

In conical scan radars the antenna radiation pattern is a narrow lobed beam. The beam axis scans about the antenna axis forming a cone. Scanning occurs continuously at a fixed rate, while the antenna axis moves only during tracking. Radars of the conical scan type are designed specifically for missile and/or projectile tracking applications.

The interest of this countermeasures group in this type of radar is, at present, centered primarily on the susceptibility to jamming of the conical scan tracking radar adapted to mortar tracking. One of the main problems encountered in an investigation of susceptibility to jamming of this type of radar is that of generating targets for the radar within a laboratory environment (Ref. 1).

To establish a simulated field environment for the radar within the laboratory, this group has designed and built a radar target simulator which is the subject of this report.

The Simulator was built to fit the AN/MPQ-10A Mortar Tracking Radar but can be easily adapted to other conical scan tracking radar sets. A photograph of the Simulator is shown in Fig. 1. A general description of the Simulator, shown in the block diagram in Fig. 2, is given in Section 2, and a more detailed description of the design and operation of the component units is given in Section 3.

2. GENERAL DESCRIPTION OF SIMULATOR

The Simulator consists of five basic units. These are:

(1) Trajectory generator (i.e., cams and followers);

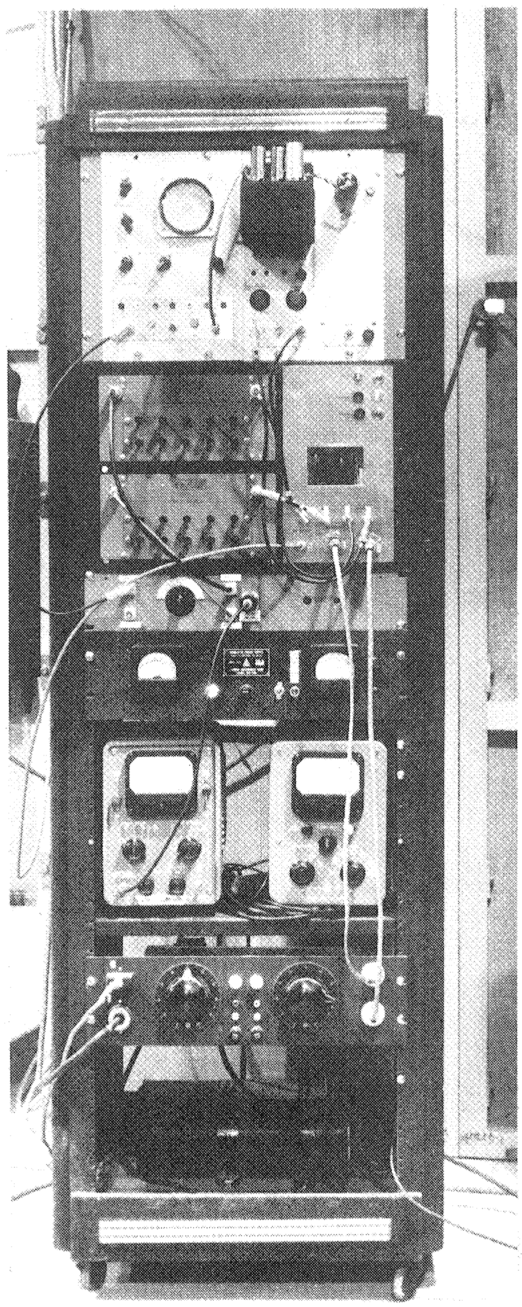

FIG. 1. PHOTOGRAPH OF CONICAL SCAN RADAR TARGET SIMULATOR.

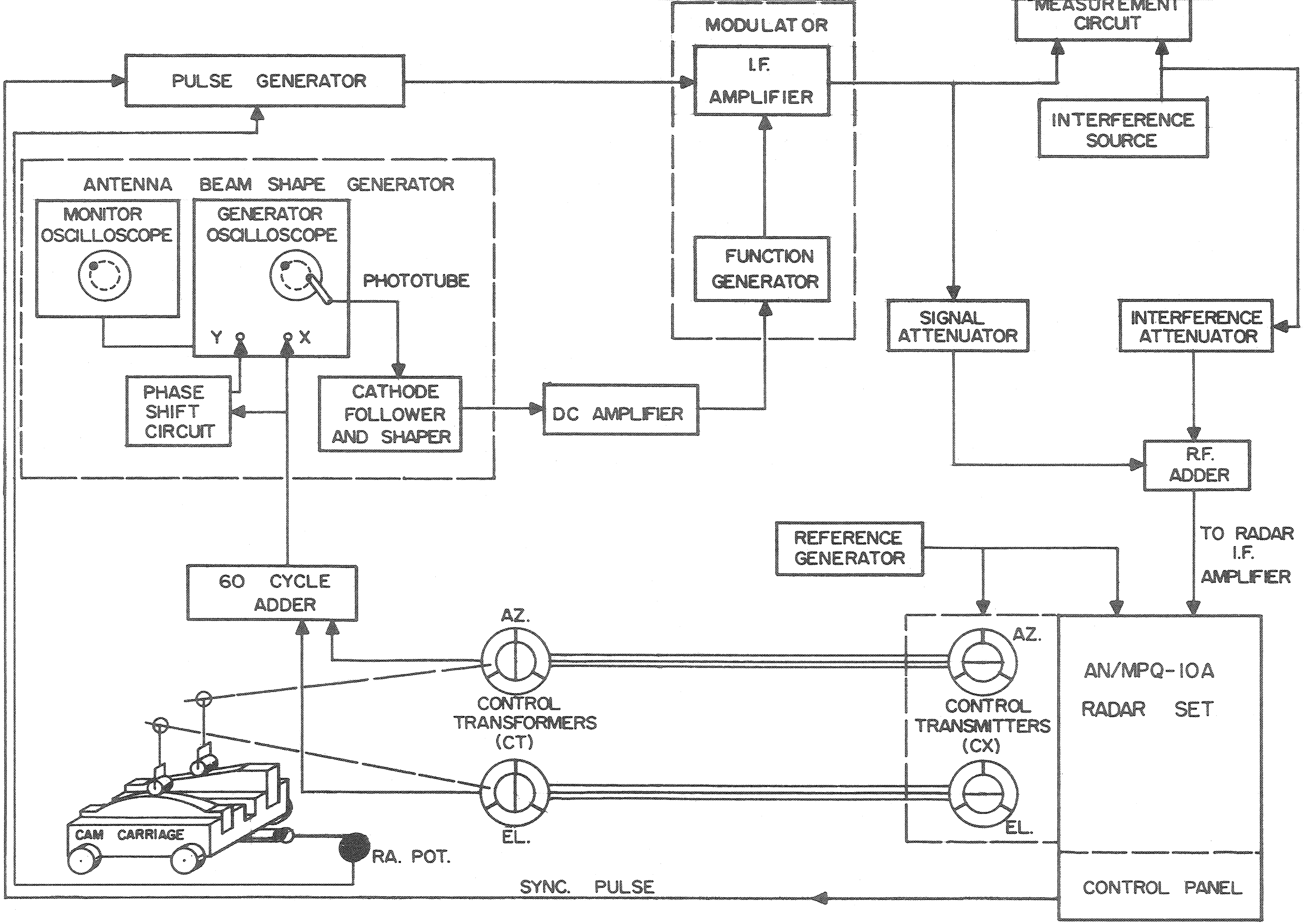

FIG. 2. CONICAL SCAN RADAR TARGET SIMULATOR BLOCK DIAGRAM.

(2) Electrical Comparator;

(3) Beam-Shape Generator;

(4) Pulse Generator Unit;

(5) Modulator Unit.

The basic operations performed when tracking a simulated target are as follows:

(1) A predetermined trajectory is generated by the motions of three (replaceable) mechanical cams, representing the azimuth, elevation and slant range motions of the particular target to be simulated.

(2) These mechanical motions are converted to electrical signals which are compared with the position of the radar, giving rise to a set of error signals.

(3) The error signals in azimuth and elevation are combined in a suitable manner and fed to the Antenna Beam-Shape Generator. This unit converts the simulated pointing error signal into an electrical signal (having DC and 60 cycle components) which corresponds to the antenna echo response during the action of conical scanning of the actual radar beam under field conditions.

(4) A delay pulse generator produces pulses at the radar IF frequency (30 MC) of 0.8 microseconds duration, and at a repetition rate determined by the synchronizing pulse output of the radar which normally controls the transmitted pulse. The IF pulses are delayed by an amount determined by the position of the range cam; this delay corresponds to the slant range of the simulated target.

(5) The IF pulses are further modulated in a variable gain IF amplifier, called the Modulator, by the converted error signal from the Beam-Shape Generator. After suitable attenuation, the modulated IF pulses are fed to the input of the IF amplifier in the radar set.

When the Simulator is used, the radar microwave circuits are not operated, and the investigation is carried out at the IF frequency. In the automatic tracking mode, the radar set senses the errors in azimuth and elevation, and moves the turret to reduce these errors. The error in range is also sensed by the radar, and the position of its range notch is adjusted to track the simulated range input.

To understand how these operations are performed, consider the block diagram in Fig. 2. A reference generator is used to furnish two 60 cycle voltages in time quadrature. These are called the Azimuth and Elevation Reference voltages. These voltages are fed to the radar phase-sensing detectors, and also to the rotor windings of the Azimuth and Elevation Control Transmitters (CX's). These control transmitters are mounted on the radar turret and coupled in a manner which furnishes the Simulator with azimuth and elevation signals, determined by the radar position.

The control transformers (CT's) are located in the Simulator and their rotors are mechanically linked to the cam carriage. During tracking, the target information derived from the cams controls the CT rotors. The voltage at the rotor of the CT is an error signal which represents the angle of error between the antenna and the target. The Simulator cams (Azimuth, Elevation, and Range) represent a typical target trajectory for the radar set to track. During operation of the Simulator the desired action is to have the radar set follow or track this target. In doing so, the 60 cycle error voltage from both of the CT's should remain near zero.

The error signals from the azimuth and elevation CT's are combined in the 60 Cycle Adder. Each signal contains information in its amplitude and phase, and, because of the quadrature relationship of the voltages, all of the error information is combined in a single 60 Cycle Error Signal.[1]

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[1] When this information is received by the radar set, the servo amplifiers are able to separate the error into the proper channels by means of phase comparator circuits.

The response of the radar echo signal during the conical scanning is such as to produce a 60 Cycle Error Signal which increases as the pointing error increases only for small pointing errors, and then begins to decrease for larger pointing errors. The error voltage from the adder (referred to above) will increase linearly with pointing error angle, and must therefore be converted into an error signal which corresponds with the actual radar echo response. In addition, the particular shape of the main lobe of the antenna is involved, as well as the angle of conical scan. In order to convert the 60 Cycle Error Signal to suitable form, it is fed to the Antenna Beam-Shape Generator.

This single 60 Cycle Error Signal is used to form a circle on the Generator Oscilloscope. This is accomplished by applying the signal directly to the X (horizontal) input and shifting the signal 90° before applying it to the Y (vertical) input of the oscilloscope. The amplitude of the error signal determines the diameter of the circle, and the phase of the error signal determines the spot position at any given instant of time. This circular error signal is concentric to the position of the zero-error spot.

A phototube is placed in front of the face of the Generator Scope. The axis of the phototube is displaced laterally from the zero-error spot. This displacement represents the vertex angle formed by the beam axis and the radar antenna axis. The output of the phototube represents the relation between the antenna orientation and the target position. The output of the phototube is fed to Cathode Follower and Shaper circuit which shapes it to the radar antenna response curve. A DC amplifier is used to amplify the signal and to retain the DC component of the Modulation Signal. This Modulation Signal is one of the inputs to the Modulator. The Modulator amplitude-modulates a train of RF pulses. The RF pulse train, which is the other input to the Modulator, is derived from a Pulse Generator.

A timing pulse (or sync) is one of the references obtained from the radar set. This reference triggers the Pulse Generator which, after a prescribed delay, forms a pulse of the same width as the radar set uses. This delay, which is variable, determines the range of the simulated target. During operation of the Simulator, the delay potentiometer is controlled by the mechanical linkage to the range cam on the Cam Carriage. The short duration pulse is used to gate a ringing circuit. The frequency of this circuit is the same as that of the radar IF.

The Modulator unit consists of an IF Amplifier and a Function Generator. This IF Amplifier has a modified AGC circuit. The DC modulating signal is applied to the AGC circuit and thereby changes the gain of the amplifier as a function of the instantaneous signal level. The gain of the amplifier is <u>not</u> a linear function of the DC level of the signal voltage. To correct this non-linearity, a Function Generator is used which has a response that is the inverse of the gain function of the IF Amplifier. This combination produces linear modulation of the pulse train.

After passing through the Modulator, the pulses are attenuated and then added to an interference signal in the RF Adder. The output of the RF Adder is matched to the input of the IF Amplifier on the radar set. This signal, plus interference into the radar set IF Amplifier, is the same as the signal which would normally come from the RF section of the radar set under field conditions.

3. SIMULATOR COMPONENTS

The operation of the individual simulator component units, and some of the design considerations, are discussed in this section.

3.1 Target Selection and Generation

The criteria used in selecting the mortar trajectories and the methods used in generating targets are discussed in the following three sub-sections.

<u>3.1.1 Selection of Trajectories.</u> The trajectories were chosen

arbitrarily. However, an attempt was made to choose typical values of shell size, shell charge and firing angle. An 81 mm shell was selected. A firing angle of 63.4° (arctan 2) was selected because it gave a trajectory whose peak height (h) was equal to one-half the range of the shell (r) (Figure 3). For trajectory A a charge 6 was used, and for trajectory B a charge 3 was used. These charges yield the values given in Table I.

Traj.	r(yds)	h(yds)	ϕ(deg)	time(sec)
A	4060	2030	63.4	39
B	2140	1070	63.4	28.7

Table I Trajectory Information

Three different ground paths were chosen for these two mortar trajectories, as shown in Figure 4. The peak of the trajectory for each ground path passes over Point "X", 5000 yards from the radar set, at zero azimuth.

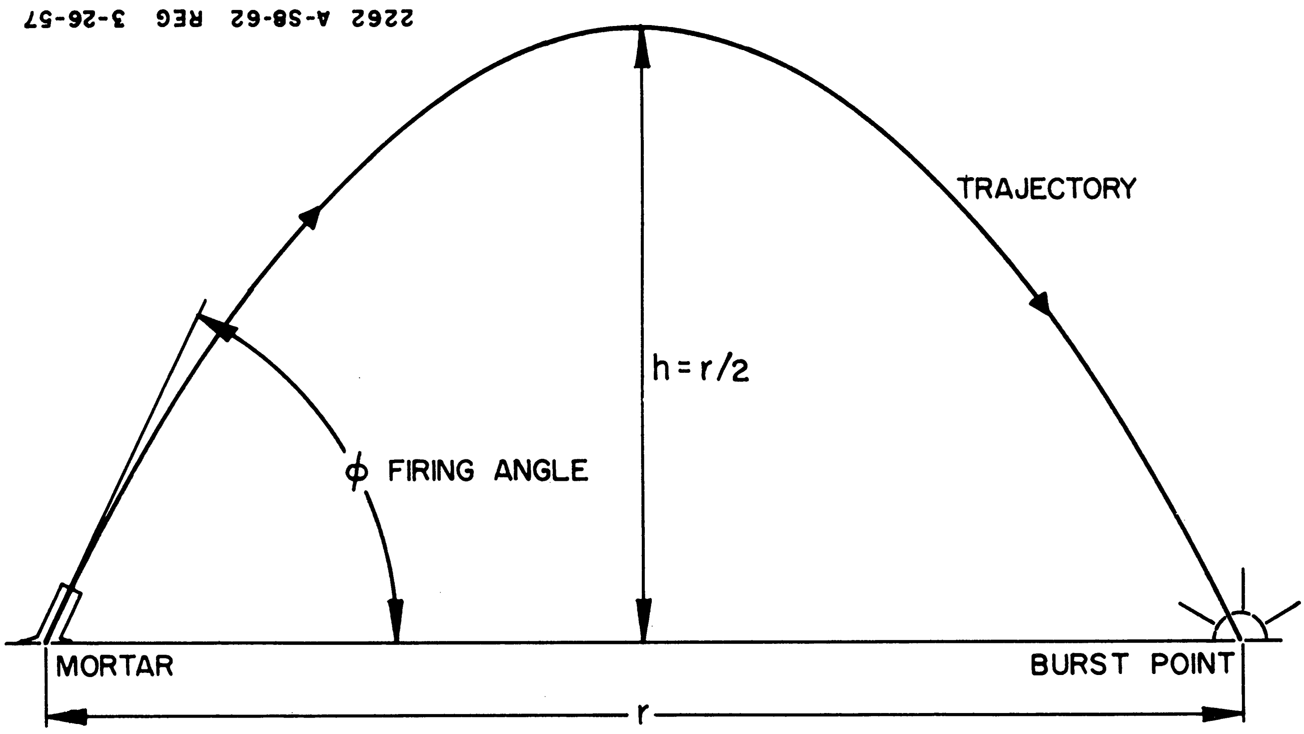

FIG. 3. ELEVATION VIEW OF TRAJECTORIES A AND B.

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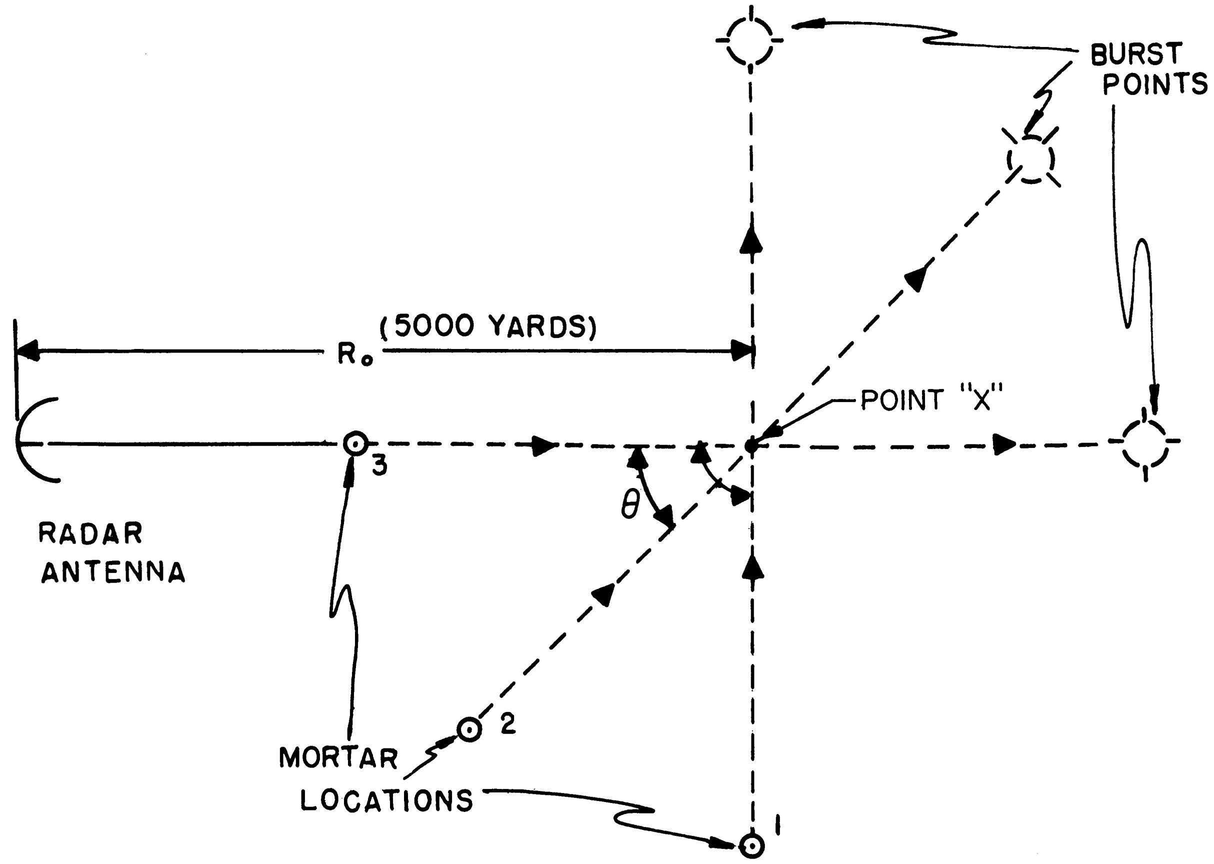

FIG. 4. PLAN VIEW OF TRAJECTORIES 1, 2, & 3.

Cams were prepared for an aspect angle, θ, having values of 90°, 45°, and 0° which are called 1, 2, and 3 respectively. Thus, there are six sets of cams corresponding to the 3 aspect angles and two charges A and B.

The target information needed is the elevation angle (E), the azimuth angle (A), and the slant range (R_s), all as functions of time. This information was computed for one-second intervals over the trajectories and was used to make the three cams (A, E, and R) for each trajectory and aspect angle.

<u>3.1.2 Trajectory Cams</u>. In deriving the cams, the points computed from the trajectories are plotted and a curve drawn to an enlarged scale. This drawing is photographed, reduced to the correct size, and the negative used to photo-engrave the curve on a strip of 16 gauge sheet steel. This gives an etched line for a machinist to follow in machining the cam. The cams thus obtained are

accurate to ± 0.0025 inch. The processing of the cams is described in detail in Reference 2.

Each trajectory requires three sets of computations, drawings, photographs, etchings and machining. The scales for the cams were chosen as follows: Azimuth, 100° per inch; elevation, 100° per inch; range 10,000 yards per inch; cam speed, 0.1 inch per second. Having chosen these cam scales the cam followers and linkages were constructed to provide the proper motion of the CT's and the potentiometers. The limitations on the various trajectories are imposed by the mechanical linkages involved in the mechanism.

Figure 5 is a picture of the cam carriage assembly before completion of all three channels. There are two cams (AZ and EL) in place on the cam carriage.

3.1.3 Cam Carriage Assembly and Linkage. As shown in Figure 5, the cam carriage is supported by four precision ball bearings which roll on two steel rails. Its horizontal velocity is constant, being controlled by a constant speed motor and an instrument chain. A typewriter spring is used to maintain tension in the chain (see Figure 6). When the motor has pulled the carriage to the end of its travel, a limit switch changes the direction of the motor rotation. The spring then pulls the carriage back along the rails as the motor pulley unwinds the instrument chain. A second limit switch again reverses the motor rotation when the carriage reaches the other end of its travel. The motor circuit is shown in the schematic of Figure A-7.

The cam follower rides against the cam as the carriage travels back and forth. It is held against the cam by the tension in the instrument chain, as translated by the multiplier arm. When the cams are made, the radius of the follower roller is taken into account so that the axis of the roller has the desired motion. The cam follower is restricted so that it can move only vertically. A pin in the follower moves the multiplier arm which enlarges the

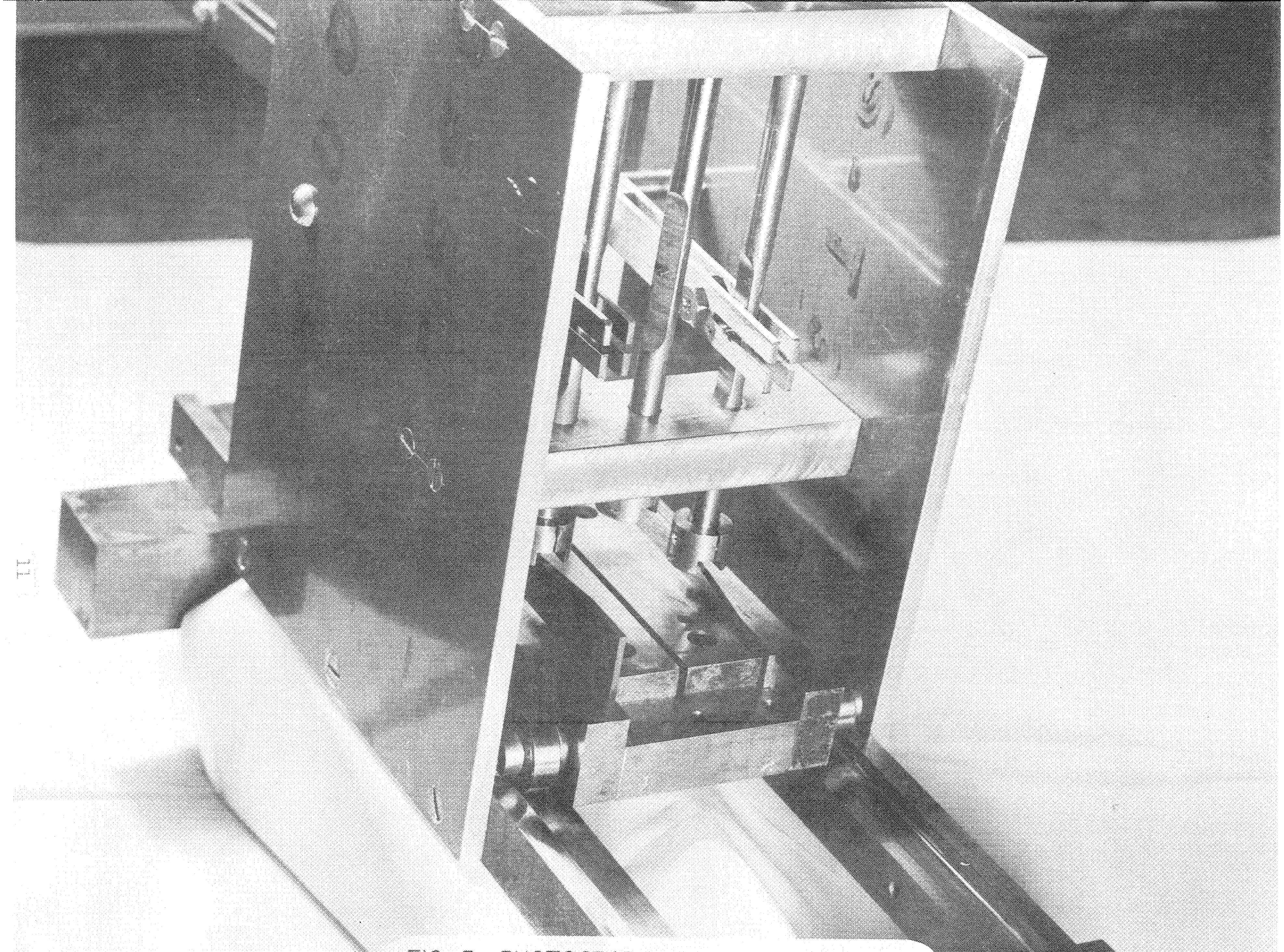

FIG. 5. PHOTOGRAPH OF CAM CARRIAGE.

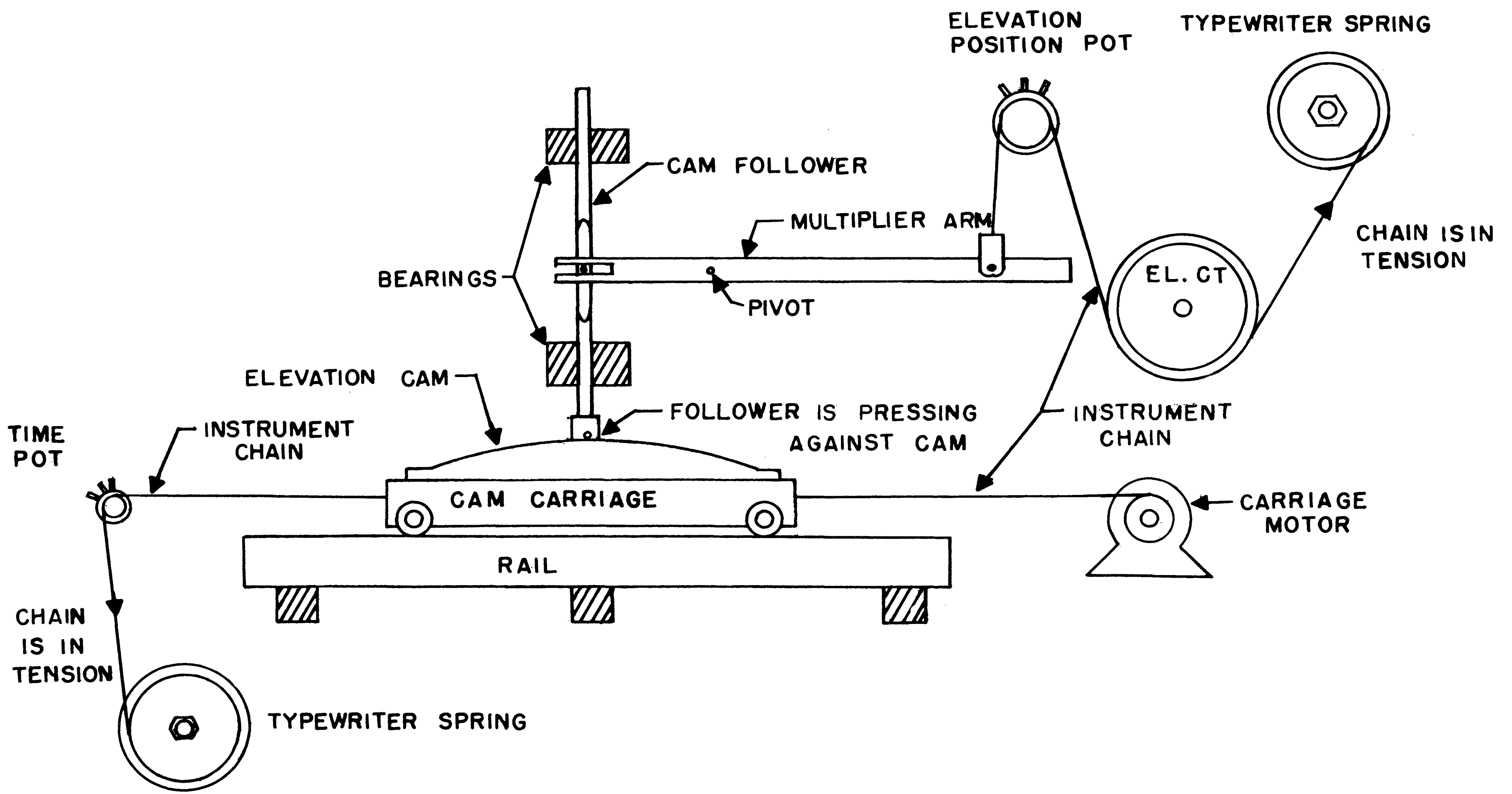

FIG. 6.

CAM LINKAGE FOR ELEVATION CHANNEL

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motion taken from the cam.

The vertical motion of the follower is small compared to the length of the multiplier arm. Thus, the error due to the change in the arm length is smaller than that due to the inaccuracy of the cams, and can be neglected.

The instrument chain moves with the multiplier arm and causes rotation of the Elevation CT and the Elevation Position Potentiometer as shown in Figure 6. The diameters of the pulleys on the CT and the potentiometer are calculated to give the correct rotation of their respective shafts. The information for the instantaneous azimuth and elevation angles of the target is fed to the azimuth and elevation CT's in the form of a rotation of their respective shafts. This information is necessary to form the 60 cycle error signals described in Section 3.2.2.

The instrument chain in the range cam linkage drives the shaft of low-torque potentiometer which controls the time delay in the pulse generator and thus changes the range of the target.

The position information from AZ, EL, RA, and Time is fed to the monitor scope selector switches as shown in Figure 18 and in the schematic of Figure A-6.

The physical limits of the Cam Carriage are: maximum change of 50° in azimuth and elevation; a maximum change of 5000 yards in range; and a maximum time of flight of 40 seconds. These limits could be changed by a redesign of the cam carriage assembly and linkage.

3.2 Generation of 60 Cycle Error Signal

The 60 Cycle Error Signal described in this section, represents the antenna position error in both azimuth and elevation. The units involved in the generation of the Error Signal are: (1) Reference Generator, (2) Position Indicators, (3) Cosine Transformer, and (4) 60 Cycle Adder.

3.2.1 Reference Generator. Normally the radar set uses a reference

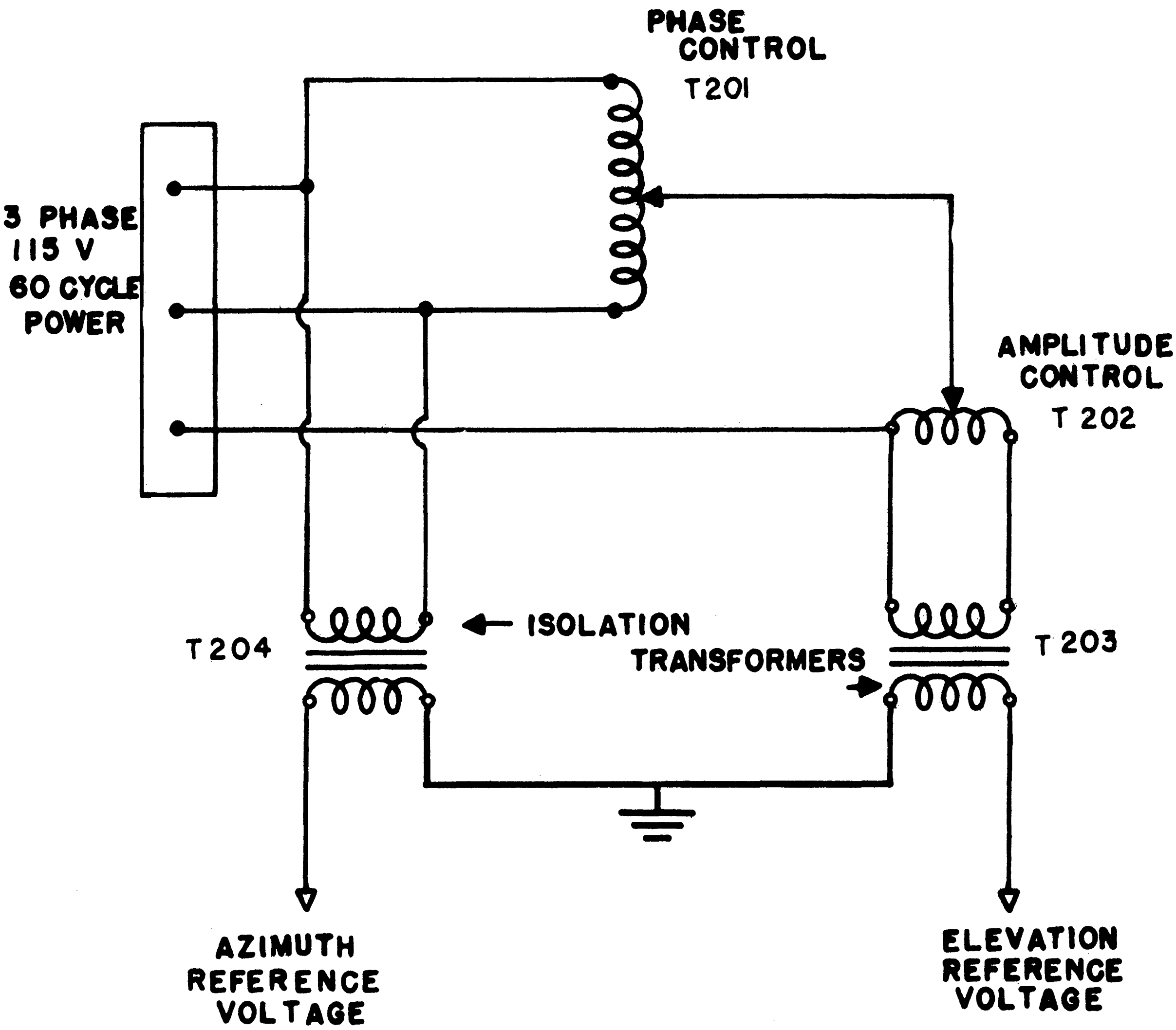

FIG. 7.

REFERENCE GENERATOR CIRCUIT

generator, mounted on the spin axis of the antenna, to provide reference voltages to the comparator circuits in the Azimuth and Elevation servo amplifiers. Antenna position information for the Simulator required the use of synchros whose excitation had to come from the reference generator. For ease of operation, and to prevent excessive loading of the radar set reference generator, a two-phase reference voltage was derived from line power. This was possible because the spin frequency of the AN/MPQ-10A radar set is 60 cycles per second.

The Reference Generator circuit, shown in Figure 7, provides controls for adjusting the amplitude and phase angle between the two reference voltages. The reference voltages are used to excite the two CX's and to supply reference to the phase comparators in the azimuth and elevation servo amplifiers of the radar set.

3.2.2 Position Indicators. A CX and a CT are used to indicate the antenna azimuth position, and a second set is used for elevation position.

For elevation, the CX is mounted on an auxiliary bracket and its rotor is connected to a shaft on the elevation gear case. This shaft is geared in a 1:1 ratio, with the antenna elevation angle. Thus the relative position of the CX rotor to the stator varies directly with the elevation angle. When the CT is connected electrically to the CX, and they are zeroed properly, the voltage at the rotor of the CT will vary with the elevation position. Figure 8 shows the electrical and mechanical connections for elevation.

The rotor of the CT is mechanically connected to the linkage from the elevation cam. The relative position of the CT rotor to the stator represents the target's elevation angle. The linkage is connected so the voltage at the CT rotor is a function of the difference between the antenna position and the target position. This error voltage represents the error in the antenna elevation and is proportional to it for small angles. In normal operation the radar set senses

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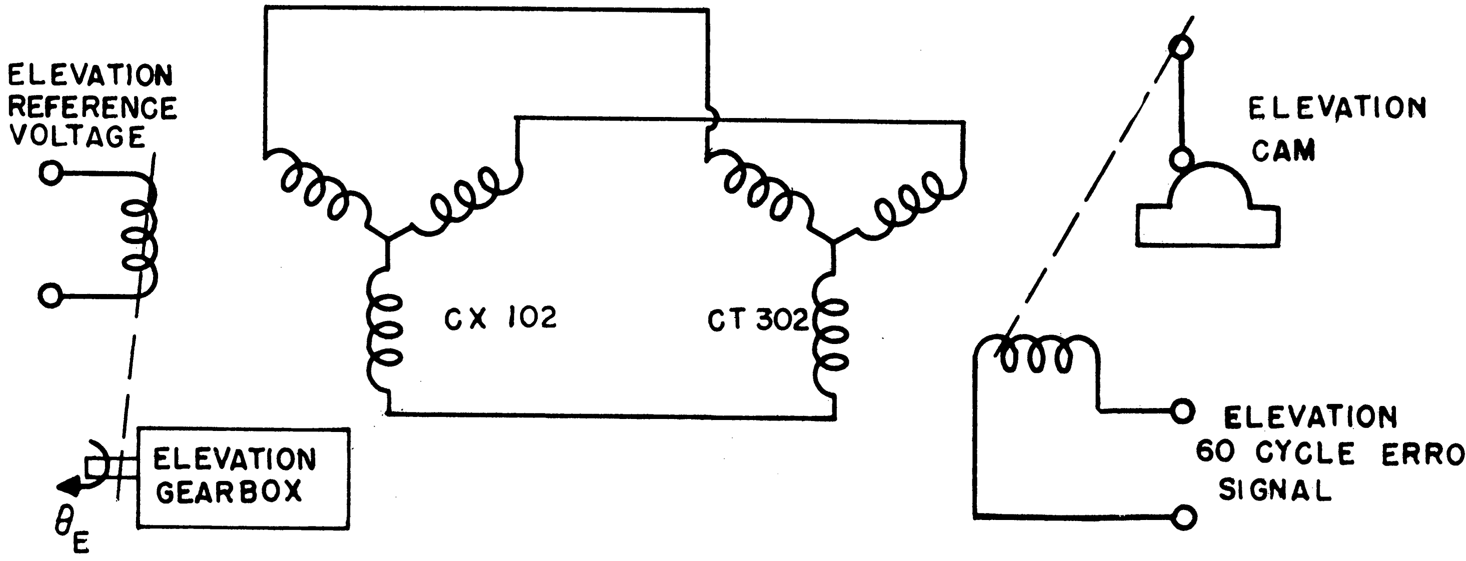

FIG. 8.

ELEVATION CX AND CT CIRCUIT

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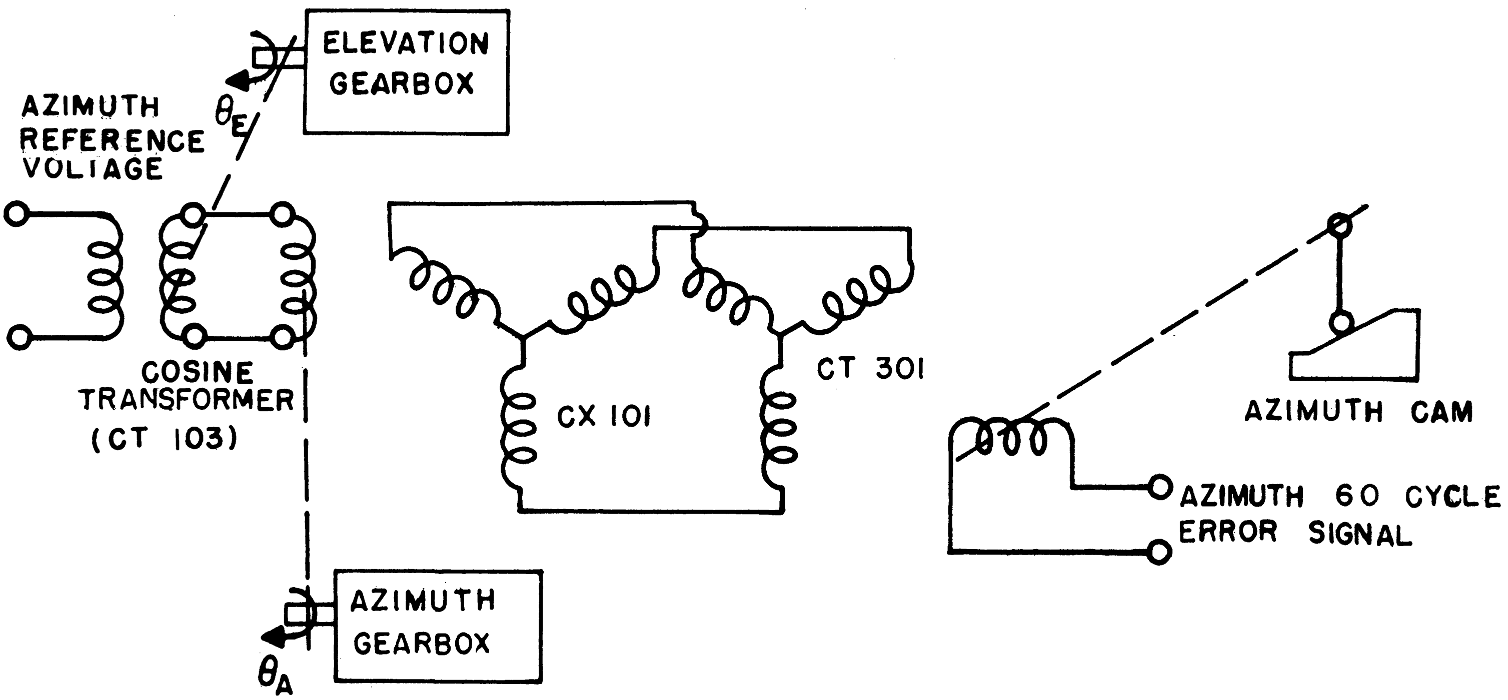

FIG. 9.

AZIMUTH CX, CT, AND COSINE TRANSFORMER

the error and attempts to reduce it to zero.

The azimuth CX and CT function in the same way. The rotor of the azimuth CX is connected to the azimuth gear box and the rotor of the azimuth CT is driven by the linkage from the azimuth cam.

3.2.3 Cosine Transformer. Because of the space relationships between elevation and azimuth angles, the radar set changes the gain of the azimuth servo amplifier by the secant of the elevation angle.

To compensate for this correction by the radar set, the simulator must change the size of the azimuth error by the cosine of the elevation angle. This can be done by using a synchro as a variable transformer to reduce the amplitude of the azimuth reference voltage which excites the azimuth CX.

The rotor of this cosine transformer moves with the elevation position of the radar set. When the elevation angle is zero (horizontally oriented) the transformer gives maximum excitation to the azimuth CX. When the elevation angle is 90°, the excitation voltage is zero. The circuit is shown in Figure 9.

The output of the azimuth CT represents the difference between the antenna azimuth angle (θ_A) and the azimuth target position (τ_A) multiplied by the cosine of the elevation angle ($\cos \theta_E$); i.e., $(\tau_A - \theta_A)(\cos \theta_E)$.

3.2.4 60 Cycle Adder. The outputs of the two CT's are added together by the 60 Cycle Adder whose circuit is shown in Figure 10. Each input is attenuated and the relative output amplitudes are equalized by adjusting the gain controls. The signal developed across the 1K resistor becomes the combined 60 Cycle Error Signal. This signal is fed to the Antenna Beam-Shape Generator.

3.3 Antenna Beam-Shape Generator

The theory and operation of the Antenna Beam-Shape Generator are described in this section. This part of the Simulator takes the 60 Cycle Error Signal and converts it into the Modulation Signal. This operation simulates the

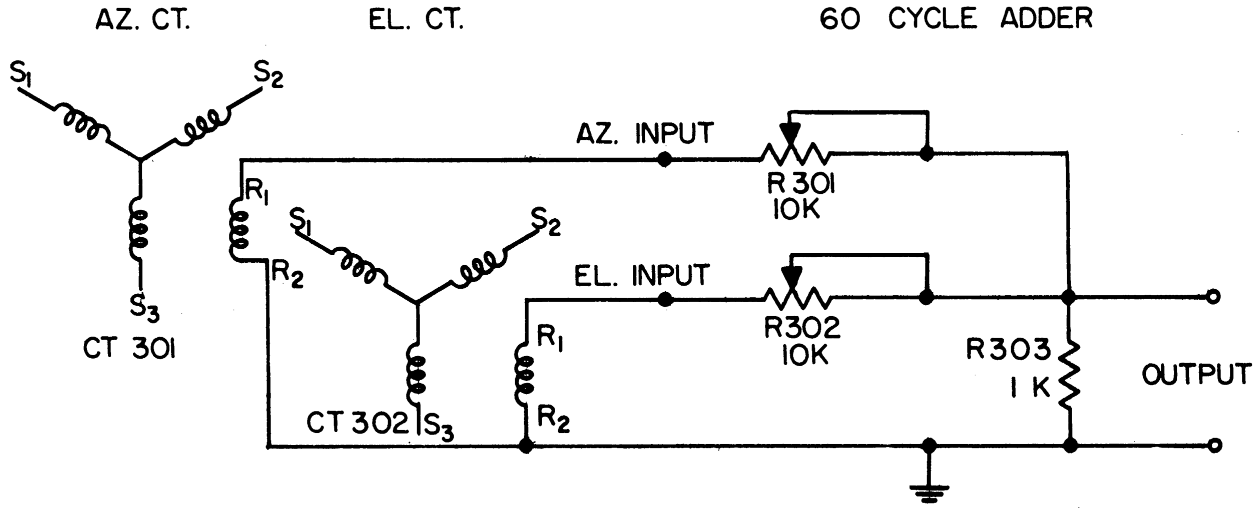

FIG. 10. SIXTY CYCLE ADDER CIRCUIT.

antenna response pattern and the space relationships involved in conical scanning. All of the information required for simulation is contained in the Modulation Envelope.

3.3.1 Introduction. A brief description of the conical scanning action of the radar is necessary before examining the principles of the Beam-Shape Generator and its reaction to the 60 cycle error signal.

The AN/MPQ-10A Radar set has a beam shape which is a figure of revolution. In the plane of the target, the electric field from the radar antenna falls off with the angle Θ from the beam axis according to the law

$$E_\Theta = E_o \frac{\sin k\Theta}{k\Theta} \qquad (1)$$

where E_o is the field on the beam axis, and k is a constant* such that when $\Theta = 2.5^o$ the field is reduced by 3 db (the half-power point).

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* When Θ is expressed in radians, k = 31.8.

The received voltage at the antenna due to target reflection is affected again by the beam shape. Therefore this received voltage (V_θ) will be of the form

$$V_\theta = V_o \frac{\sin^2 k\theta}{(k\theta)^2} \qquad (2)$$

where V_o is the voltage received when the target is located on the beam axis. Since k has the same value in both Equation (1) and Equation (2), the received voltage will be 6 db down at $\theta = 2.5^\circ$ (the half-voltage point). The curve in Figure 11 (b) shows a plot of the relative voltage response, with $X = K\theta$.

In conical scanning, the beam axis moves at uniform angular velocity about a right circular cone, with a vertex angle between the beam axis and the antenna (cone) axis. For the AN/MPQ-10A radar set the vertex angle is 1.5°. If a target, T, is located on the radar axis, the beam axis rotates about T forming the vertex angle, and thus the received signal is not modulated.

However, if the radar axis is displaced one degree off target, as in Figure 11 (a) for example, the angle θ will vary between 0.5° and 2.5°, modulating the received signal in a manner illustrated in Figure 11. In the target plane, the point T in Figure 11 (a) represents the target location, while the point R represents the position of the radar antenna axis. Thus, the distance TR represents the pointing error of one degree. P represents the instantaneous position of the beam axis, which rotates at constant angular velocity about the point R, and successively assumes position A, B, C and D in the course of scanning. The changing angle θ, represented by the length of the vector TP, successively takes on values TA, TB, TC, etc., in the course of scanning.

To obtain the resulting amplitude modulation of the received voltage, the angles TA, TB, etc. are interpolated on the antenna response curve (see Figure 11 (b)). The result is shown in Figure 11 (c). This curve indicates the instantaneous carrier level as a function of time, for a pointing error of 1°.

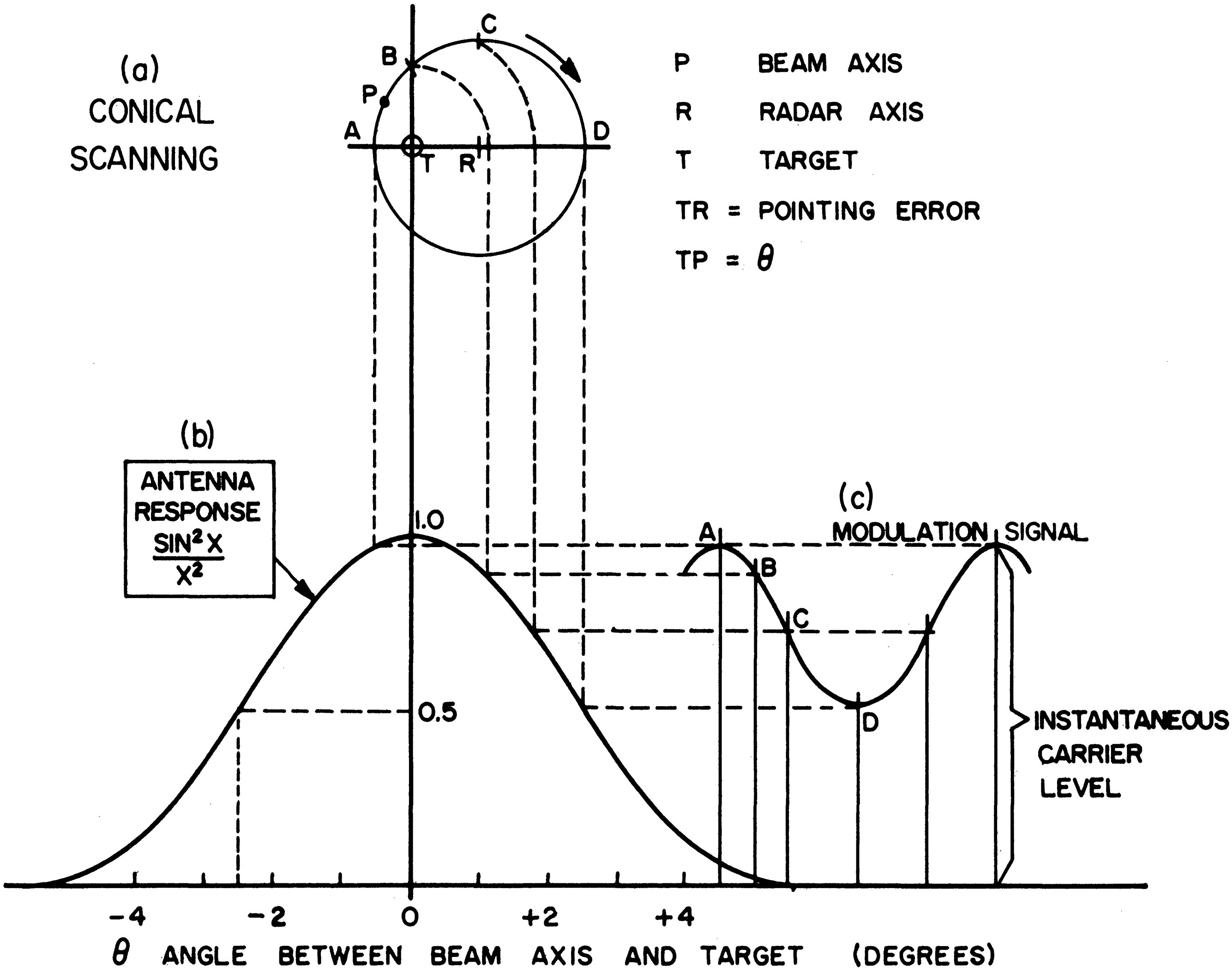

FIG. 11. SIGNAL MODULATION DUE TO CONICAL SCANNING ONE DEGREE OFF TARGET

To simulate this action of the radar beam, the Antenna Beam-Shape Generator is used. This unit consists of a flat-faced cathode-ray tube and a phototube as shown in Figure 12 (b). The luminous spot has a cosine radiation pattern, while the light entering the phototube through a plane aperture parallel to the CRT face will also vary as cos ϕ. In addition, the intensity of light at the phototube varies as the inverse square of the distance. Combining these effects, the light flux entering the phototube as the spot is moved may be expressed as:

$$L_x = k_1 \frac{1}{x^2 + d^2} \cos^2\phi, \tag{3}$$

where x is the off-axis spot displacement, d is the distance of the phototube aperture from the CR tube face, ϕ is the incident angle (given by tan $\phi = x/d$), and k_1 is a constant.

If $\cos^2\phi$ is replaced by $\frac{d^2}{x^2 + d^2}$, and k_1 by ($L_o = k_1/d^2$), Equation (3) may be written:

$$L_x = L_o \frac{1}{(x^2/d^2 + 1)^2} \tag{4}$$

where L_o is the light flux when x = 0. When a vacuum phototube is used at low light levels, the response will be linear and hence have the form of Equation (4), as illustrated in Figure 12 (a). By removing the lower portion of the phototube response curve, the remaining portions can be fitted closely to the desired antenna response curve shown in Figures 11 (b) and 13. The lower portion of the phototube curve is removed by establishing a new reference level (Figure 12 (a)) which is higher than the minimum voltage output of the phototube. If the reference level is chosen at 0.25 of the maximum phototube response, the theoretical match, after scale normalization at the match point, is shown in Figure 13. It is seen that a good match is obtained at all points except at the low end, where the

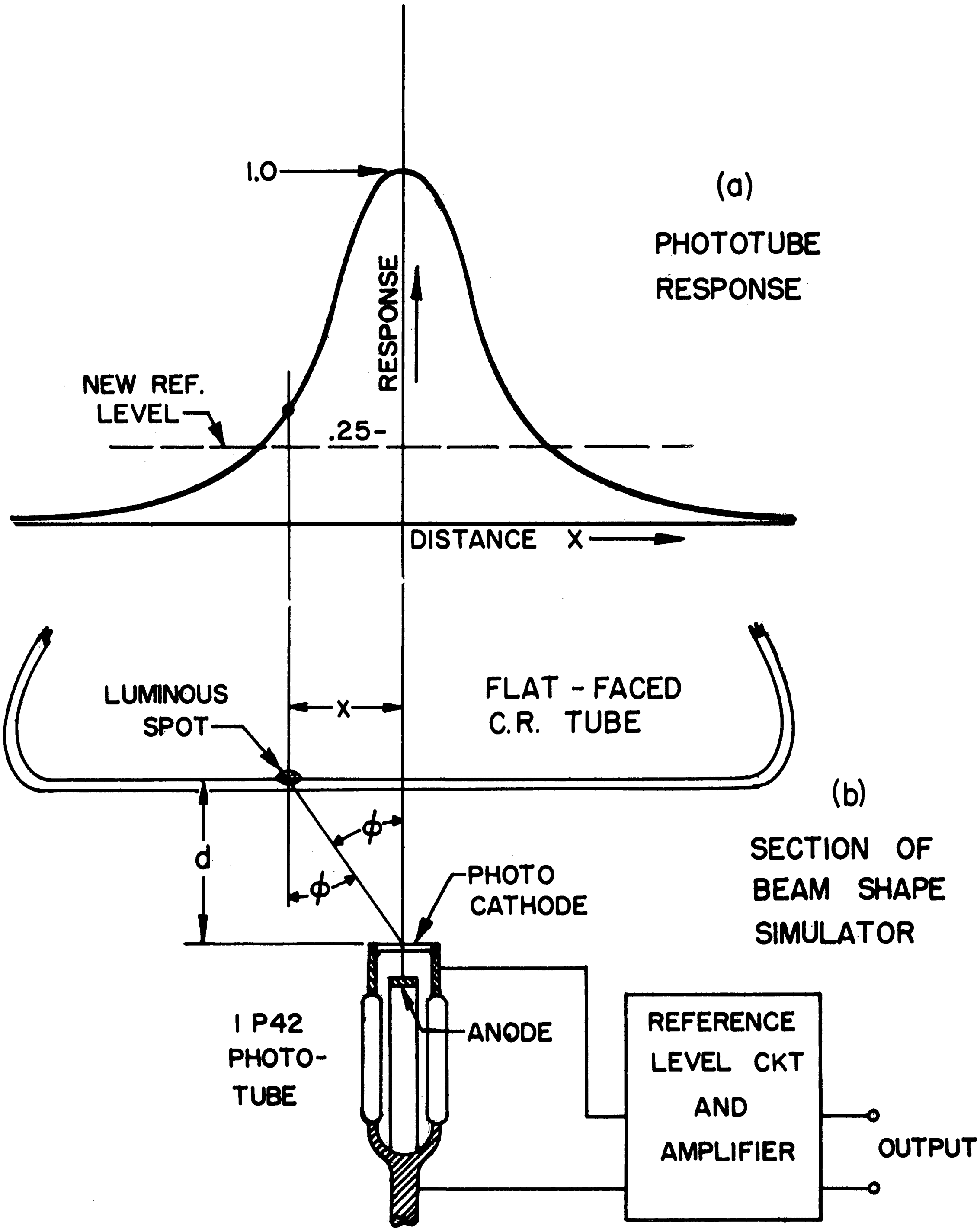

FIG. 12. PRINCIPLE OF BEAM SHAPE SIMULATOR

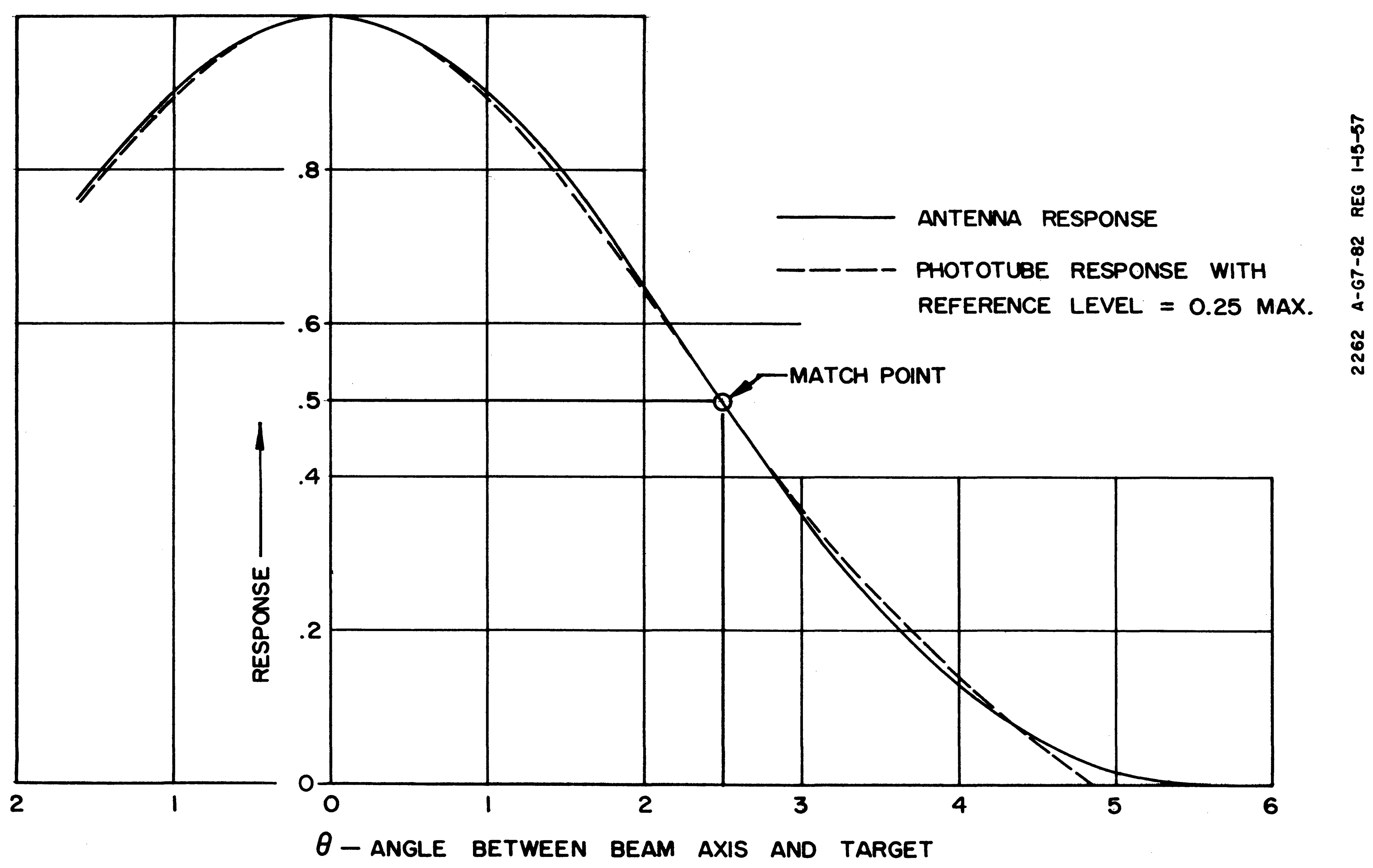

FIG. 13. THEORETICAL MATCH POSSIBLE WITH BEAM SIMULATOR

phototube response curve breaks sharply at zero, and does not extend far enough to the right. In practice, however, the shaping circuit following the phototube has a tapered characteristic as it approaches cut-off. This rounds out the response of the system at this point so that a good match is obtained over the entire dynamic range of operation.

The overall system response departs slightly from the dashed curve in Figure 13 because of slight nonuniformities in the phosphor response over the face of the CRT.

When a pointing error exists, a motion of the cathode spot must be produced so that the output of the Beam-Shape Generator will furnish the same modulation envelope as the antenna would produce on the RF pulses. This is accomplished by causing the cathode spot to move in a circle whose radius is proportional to the pointing error, and to have the same angular velocity as the conical scanning rate (i.e., 60 cps). When the phototube is displaced from the center of this circle by an amount corresponding to 1.5°, or the vertex angle, the phototube output will correspond to the envelope of the radar signal at any given pointing error.

The radar pointing error consists of the vector sum of the angular errors in azimuth and elevation, which are in space quadrature. In the simulator two CT's generate voltages which are proportional to the azimuth and elevation errors respectively. These two voltages are in time quadrature, and are added vectorially to produce the 60 Cycle Error Signal. The magnitude of this signal corresponds to the radar pointing error, and the phase angle corresponds to the space angle of the pointing error.

This error signal is applied directly to the horizontal input of the oscilloscope, and shifted 90° lagging by a phase shift network before being applied to the vertical input of the scope. By suitable adjustments of the horizontal and vertical gains, a circular spot motion having a radius porportional to the pointing error is obtained.

For example, an error voltage arising from a pointing error of 1.5 degrees should produce a circular scan corresponding to 1.5 degrees on the scope face, and thus pass directly under the phototube at one point in the orbit.

3.3.2 Description of Component Units. Several circuits are necessary to obtain the correct modulation signal from the information contained in the 60 Cycle Error Signal. The circuits include a phase shift circuit, an oscilloscope, a phototube and its associated cathode follower and shaper, and, finally, an added CRT used for monitoring purposes.

3.3.2.1 Phase Shift Circuit. The 60 Cycle Error Signal must produce a circular trace on the Generator Scope. This requires that one of the inputs to the scope be shifted in phase by 90°. The 60 Cycle Error Signal is applied directly to the X input of the scope and also goes into the Phase Shift Circuit. The shifted output voltage is applied to the Y input of the scope.

The circuit shown in Figure 14 is a low pass filter which has a total phase shift of 90 degrees at a frequency of 60 cycles. If necessary, a phase adjustment can be made to improve the shape of the circle.

The low pass filter was chosen because of the higher attenuation of any harmonics which might be present in the 60 Cycle Error Signal. If the line power had an undesirable harmonic content, an additional low pass filter could be added in series with the 60 Cycle Error Signal to reduce the effect of the harmonics.

3.3.2.2 Generator Scope. A Tektronics Model 360 Oscilloscope was chosen for the Generator Scope because it seemed to best meet the requirements of the Simulator. It contains a flat face CRT, a high-voltage supply, and is compact in size with provision for rack mounting.

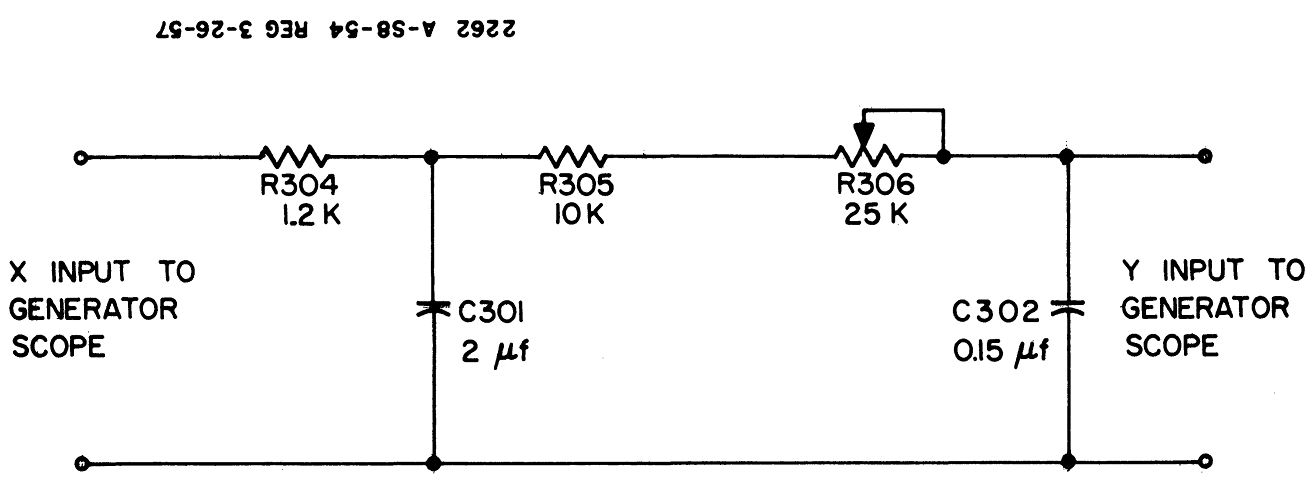

FIG. 14. PHASE SHIFT CIRCUIT.

A P-11 blue phosphor tube was chosen because its light output matched well with the S-9 response of the 1P42 phototube. The P-11 phosphor also has a fast response and a high-density saturation.

Original plans called for no modifications of the Model 360 scope, but it was soon discovered that the 60 Cycle Error Signal was too small for direct application to the horizontal deflection plates; therefore, an EECO (No. 8762) Plug-in Amplifier was added between the X input and the horizontal deflection plates.

With a 60 Cycle Error Signal present, a circle can be obtained on the face of the CRT by adjusting the vertical gain and phase shift controls. The methods used in calibrating this circle are discussed in greater detail in the Calibration Section (Appendix B).

The display on the face of the CRT is a spot which moves along a circular path at a rate of 60 cycles per second. The radius of the circle is proportional to the amplitude of the 60 Cycle Error Signal. The output of the phototube is used as a modulating signal as explained in Section 3.3.1.

3.3.2.3 Phototube. The 1P42 phototube is mounted on the front of the Generator Scope and located so that its axis is near the center of the CRT. The distance from the phototube cathode to the CRT face ("d" in Figure 12 (b)) may be varied.

The phototube is mounted inside a brass tube which is used as an electrostatic shield. This brass tube fits into a bushing which has a set screw to hold the tube in place (see Figure 15). The bushing is fastened to a box which is used as a light shield. The box is fastened to the front of the Generator Scope. The inside of the box is painted with a flat black paint to reduce the reflection of the light emitted by the spot. The box itself shields the phototube from any room light which has the 60 cycle variation. To keep the leads from the phototube short, the Cathode Follower and Shaper Circuit is on a chassis which fastens on the bushing used to hold the brass tube.

3.3.2.4 Cathode Follower and Shaper. The phototube acts as a current generator, and, to provide usable signal, must work into a high impedance. A Cathode Follower stage is used to furnish this and to get the signal to a lower impedance level. The tube used in this Cathode Follower circuit (Figure 16) was chosen for its low grid-current characteristics. The bias level at which the net grid current was equal to zero was found experimentally, and the input triode circuit designed to operate at this point. The grid-to-cathode voltage of the tube for signals up to 10 volts DC grid-to-ground is very small because the cathode resistor is returned to a negative voltage. The cathode circuit consists of a 68K resistor paralleled by a diode in series with a 470K resistor.

If the Cathode Follower were allowed to operate by itself, the

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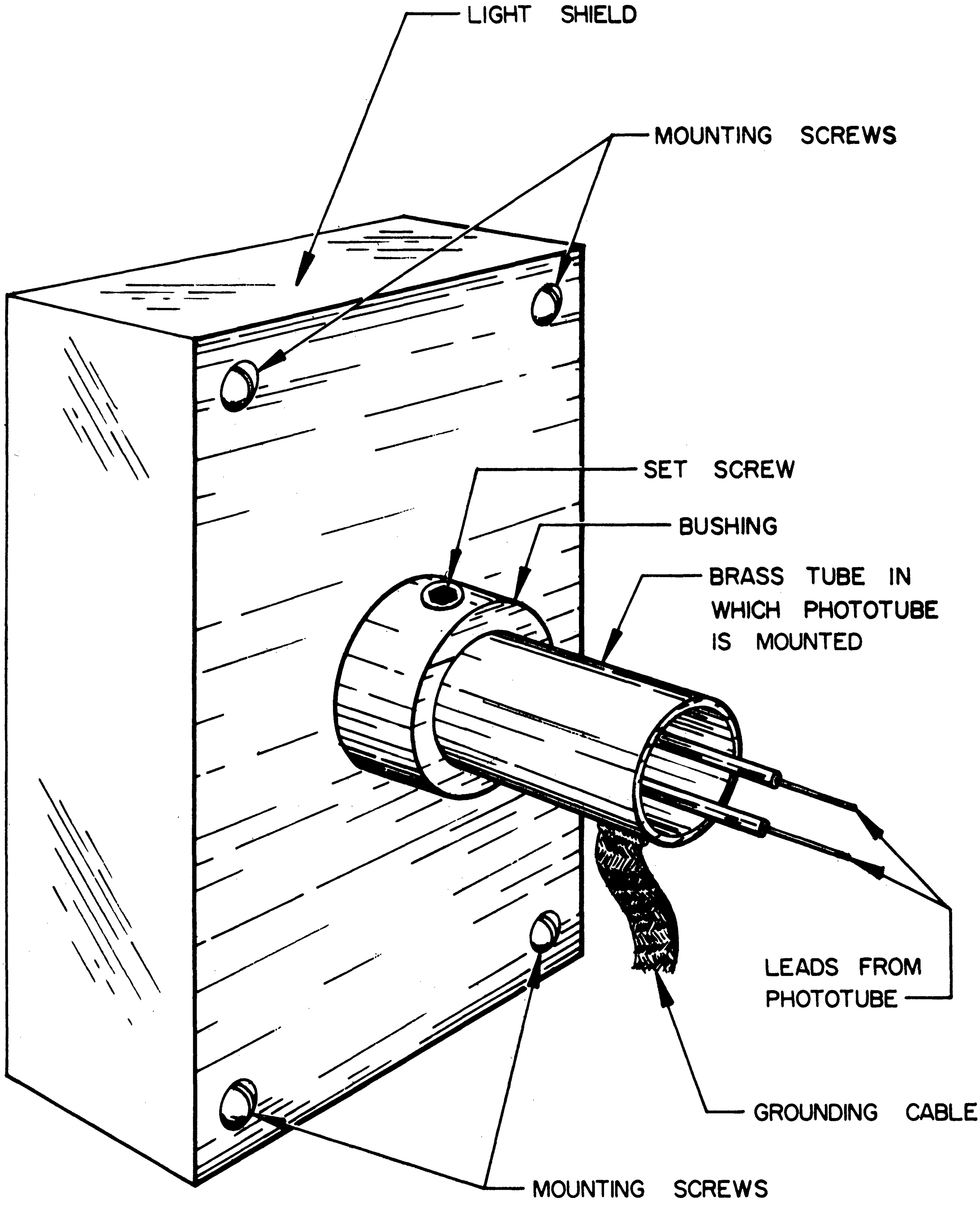

FIG. 15. PHOTOTUBE MOUNT.

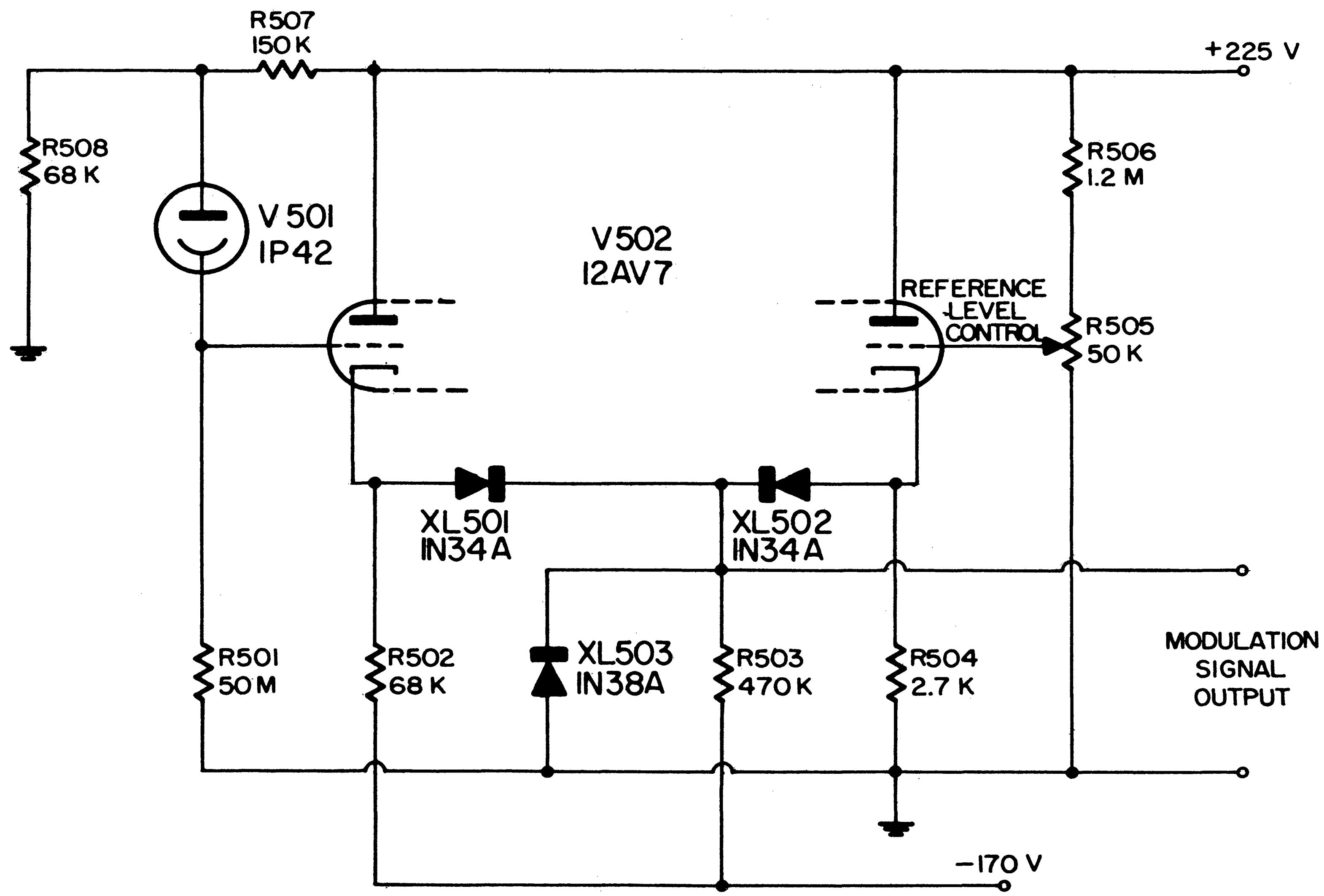

FIG. 16. CATHODE FOLLOWER AND SHAPER CIRCUIT.

output voltage would be essentially the same as the cathode voltage, since the voltage drop across the diode (XL 501) is small. This would make the output proportional to the response curve shown in Figure 11 (a). To establish the reference level (explained in 3.3.1), the Shaper circuit is used. This circuit consists of a triode whose grid is held at a fixed potential. The tube operates at quiescent point determined by the self bias from the cathode resistor. When the output of the Cathode Follower tries to go below the cathode voltage of the Shaper, the IN34A diode (XL 502) conducts. The current which flows through the diode will be sufficient to maintain the reference level voltage at the output.

The output of the Antenna Beam-Shape Generator now fits the actual radar antenna response curve, except for the proper gain and angle settings, which are described in Appendix B. Figure 17 shows a relationship between the 60 Cycle Error Signal, the Modulation Signal, and the RF Signal for a 1.5 degree error in tracking. Note that the minimum output for the Modulation Signal is equal to the cathode voltage of the Shaper circuit (Figure 16) rather than ground potential.

<u>3.3.2.5 Monitor Scope</u>. The Monitor Scope is used because the face of the Generator Scope is enclosed by the light shield for the phototube. The deflection plates of the CRT in the Generator Scope are connected directly to the deflection plates in the Monitor Scope CRT. Thus, because of the same deflection sensitivities of the two CRT's, the display on the monitor scope will be identical with that which is on the generator scope and unavailable to the operator.

The negative high voltage for the Monitor Scope CRT is obtained from a voltage tripler circuit shown in Figure 18. The output of the tripler is -1100 volts at 1 MA for an input of 520 volts AC from the center-tapped high voltage windings of the power transformer.

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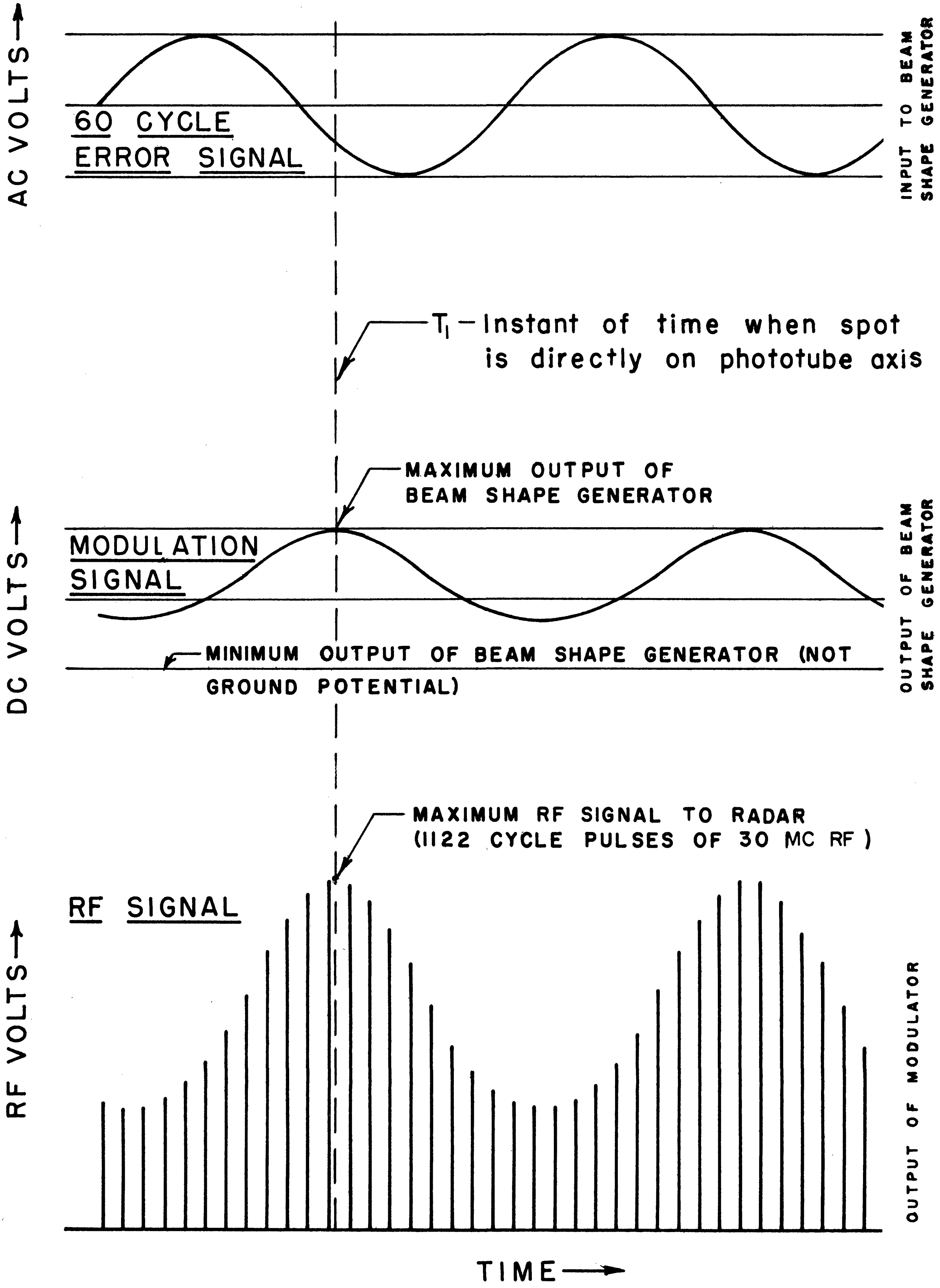

DIAGRAM OF SIMULATOR SIGNALS FOR 1.5 DEGREE ERROR

FIG. 17.

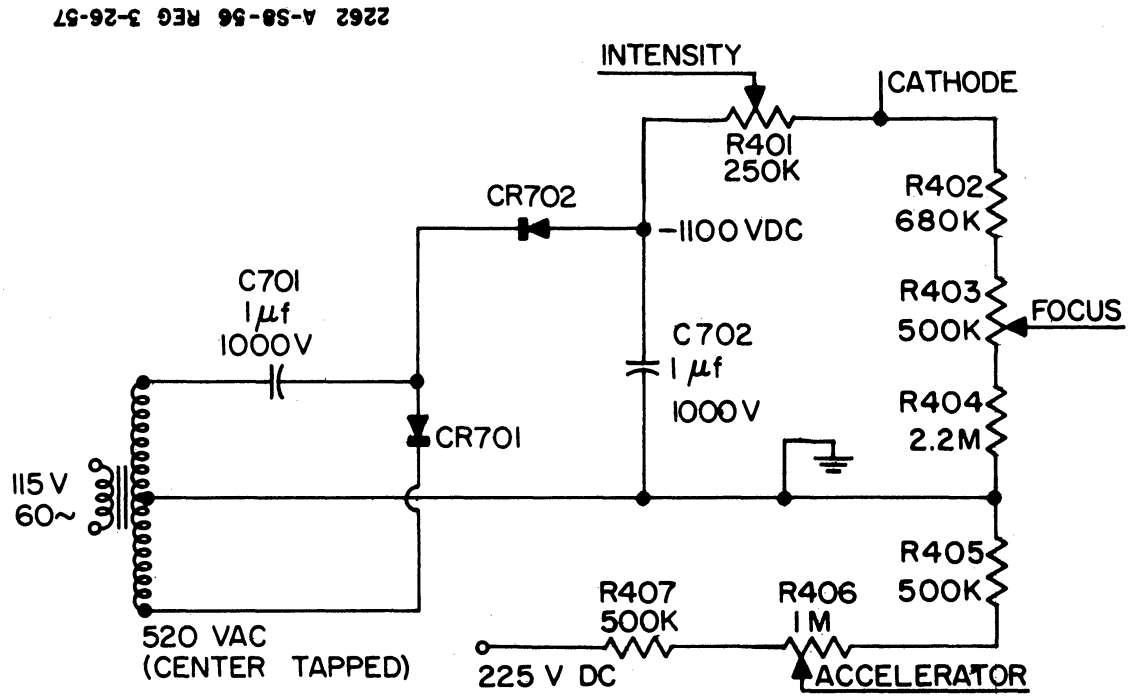

FIG. 18. CIRCUIT OF VOLTAGE TRIPLER AND MONITOR CRT VOLTAGE DIVIDER.

This high voltage supplies the cathode voltage for the 3RP1-A CRT in the Monitor Scope. The accelerator voltage is obtained from the +225 volt DC supply, as shown above.

This set-up provides the same deflection signals to both scopes with individual controls for focus and intensity. This is desirable since the phototube responds best to a de-focused low intensity spot, whereas the spot on the monitor scope should be focused to aid in accurate positioning.

A selector switch on the Monitor Scope allows two distinct presentations on the face of the CRT; (1) the error signal circle and (2) the target position.

In the "error" position the deflection plates of the two CRT's are tied together and the presentation on the Monitor Scope is identical (except for focus and intensity) to that on the Generator Scope. Thus, the operator knows the position of the spot and the size of the 60 cycle error signal.

In the "target" position, two amplifiers are connected to the deflection plates. The input to one amplifier is the signal from a "Y" selector switch and the other from an "X" selector switch. The voltages at these selector switches represent the positions of the target being tracked, as shown in Figure 19. These voltages come from the low-torque potentiometers which are linked with the trajectory cams (Figure 6).

The Monitor Scope gives the operator information about the simulator which helps him in the calibrations which must be made. Also, the error circle on the scope indicates how the system is behaving during operation and, in addition, provides a quick visual check on the output signal (i.e., Modulation Signal) from the Antenna Beam-Shape Generator.

3.4 DC Amplifier

The minimum output of the modulation signal (Figure 17) must be shifted to a negative DC voltage which corresponds to the cut-off (AGC) potential of the IF amplifier, and must be amplified because of the attenuation in the Function Generator. The low gain DC Amplifier (Figure 20) is used to perform these two operations on the Modulation Signal. Its input circuit is a common differential amplifier type with a high impedance, common-cathode circuit provided by a degenerative pentode. Gain variation is accomplished by adjusting feedback to one grid of the differential amplifier pair. The output level is varied by adjusting the common-cathode bias of the pentode in the amplifier pair. The gain adjustment affects the output voltage level to a slight extent, and it is necessary to readjust the output voltage level after changing the gain.

3.5 Modulator

The two circuits used in the modulator (i.e., the IF Amplifier and the Function Generator) are described below.

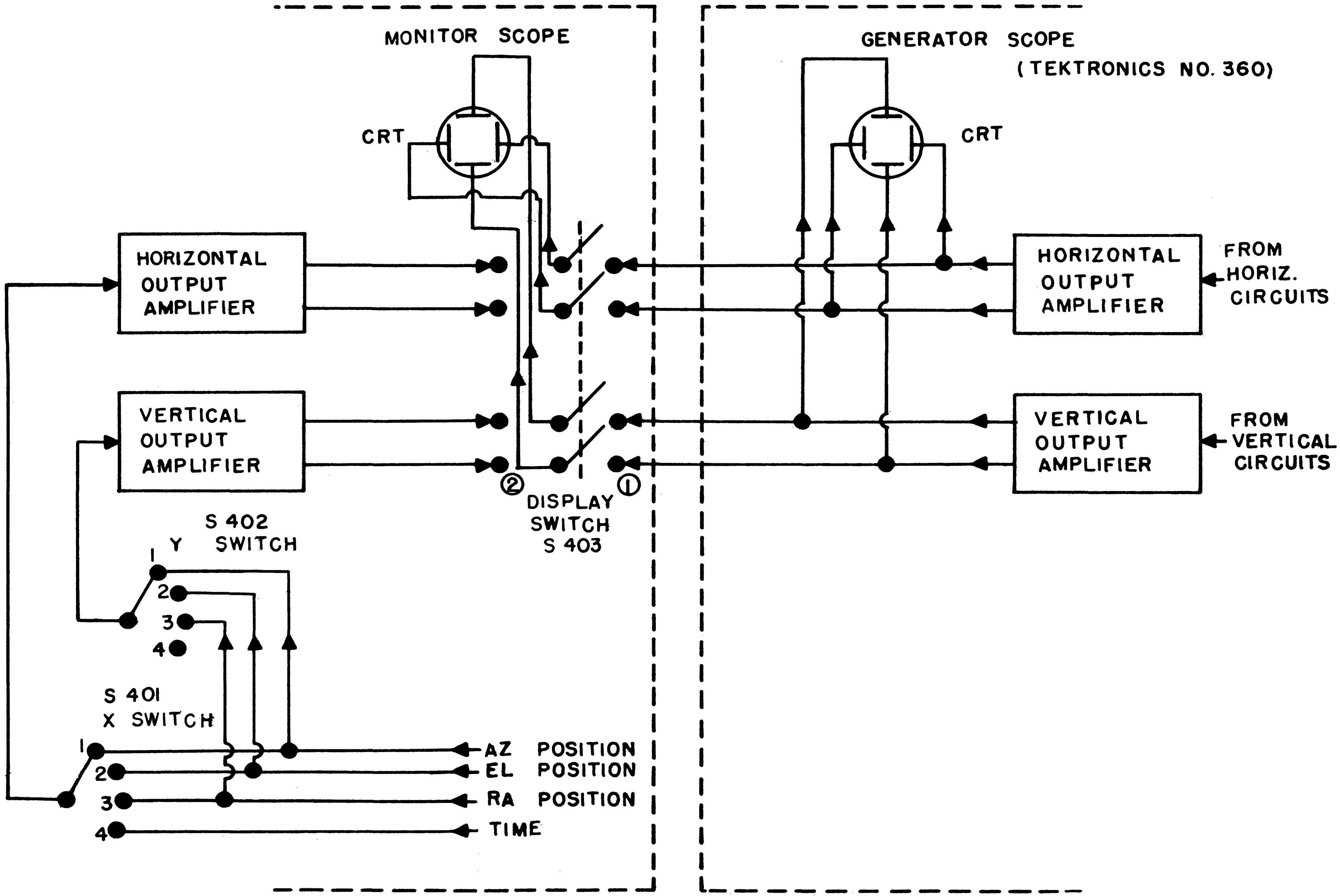

FIG. 19.

MONITOR SCOPE DEFLECTION SIGNALS

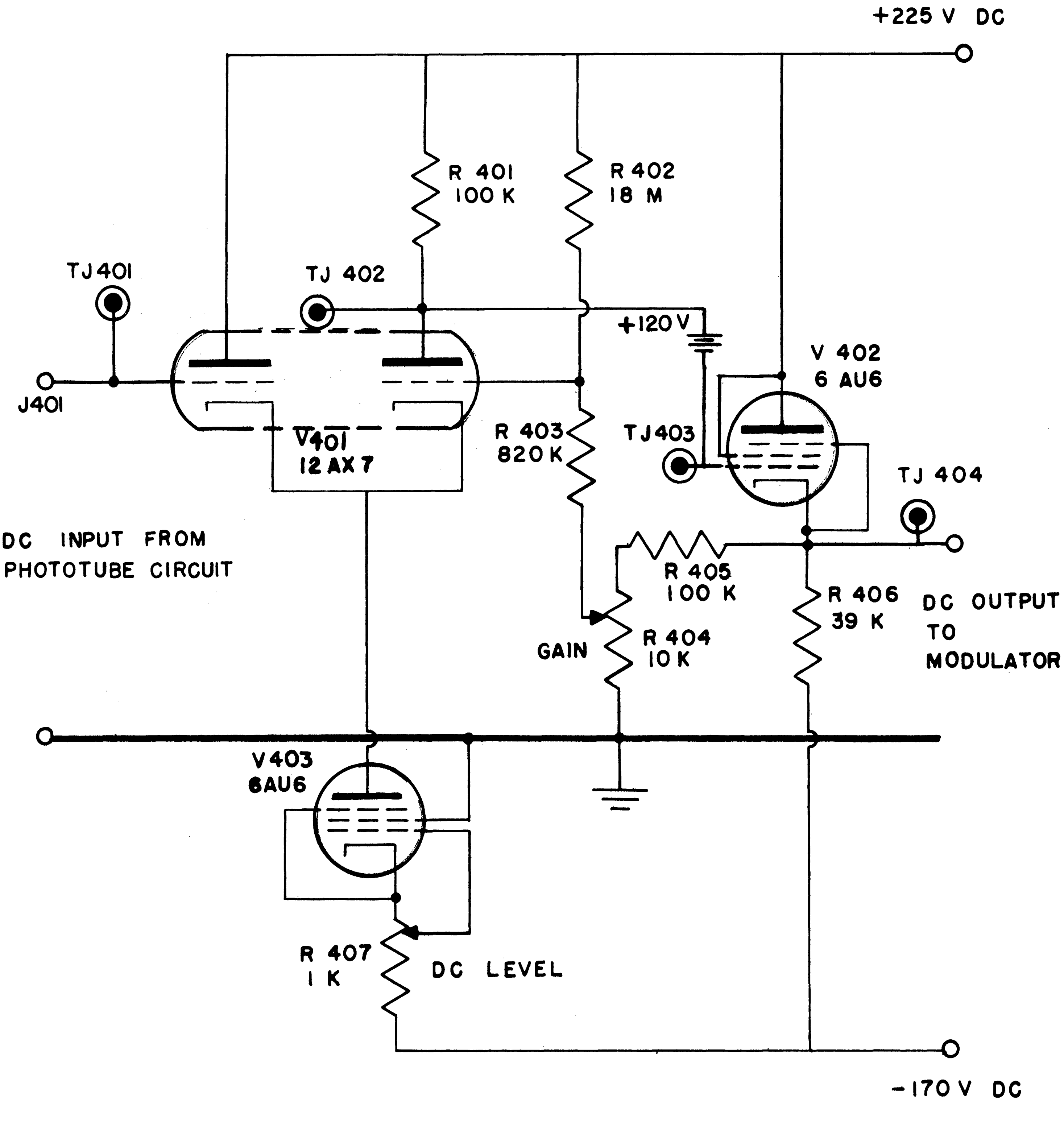

FIG. 20.

DC AMPLIFIER CIRCUIT DIAGRAM

The Modulator linearly amplitude modulates a train of RF pulses. The modulated pulses are shown in Figure 17 (c).

3.5.1 IF Amplifier. A four stage IF amplifier (Figure A.5) with a modified AGC circuit is used to amplify the RF pulses. The bias (AGC) voltage changes the operating point of the second and third stages, thus changing the gain of the amplifier.

The IF amplifier is tuned so that the shape and bandwidth remain almost constant for bias voltages from 0 to -6 volts DC. The bandwidth is about 6.5 MC for the given range of bias voltages.

A characteristic curve of the gain versus bias for the IF amplifier is shown in Figure 21. The curve is not linear at either extreme (i.e., near cut-off or near zero bias); therefore, an input signal would not produce a modulating envelope of exactly the same shape. A function generator is used to linearize this curve.

3.5.2 Function Generator. The Function Generator has an input-output curve which is the inverse of the characteristic curve for the IF Amplifier. By plotting the input on the ordinate and output on the abcissa, a curve is obtained which has essentially the same shape as the characteristic curve. A given voltage input to the Function Generator (Figure 21) will give an output which can be projected up to the IF Amplifier curve. This voltage biases the IF Amplifier, and, since the RF voltage increments are precisely linear, the gain of the IF Amplifier is now a linear function of the DC input (the Modulating signal) to the Modulator.

The Function Generator circuit is shown in Figure 22. The diodes used in the circuit will not conduct until the output voltage rises to a DC potential which is more positive than the voltage on their cathodes (bias levels). The attenuation of the circuit is unity for input voltages up to V_1 volts. For

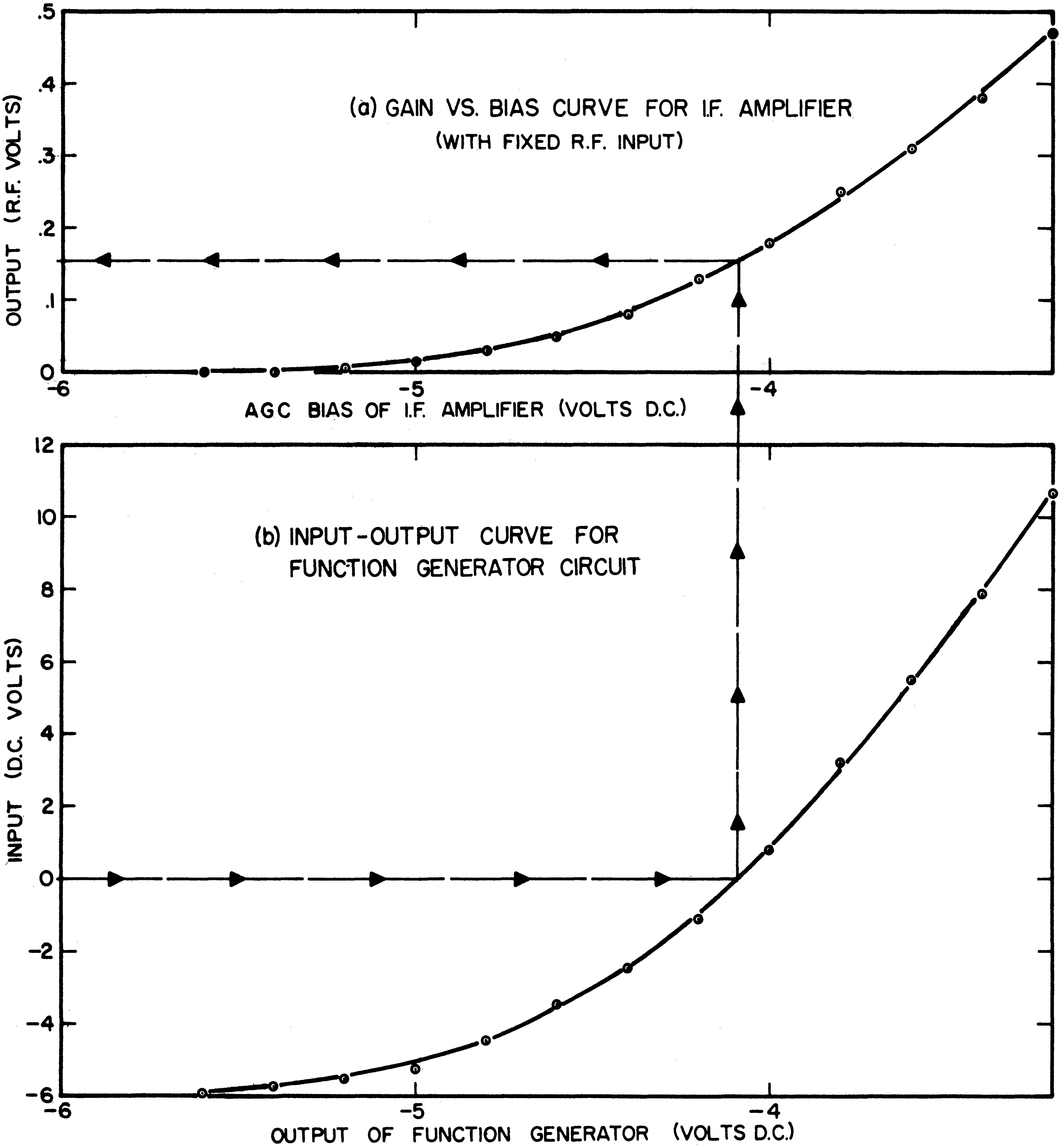

FIG. 21. RESPONSE OF MODULATOR CIRCUITS

inputs between V_1 and V_2 the attenuation is determined by the values of R_{410} and R_{411} and is equal to $\frac{R_{410} + R_{411}}{R_{411}}$. For inputs greater than V_2, R_{411} and R_{412} are parallel $\left(R_p = \frac{R_{411}\, R_{412}}{R_{411} + R_{412}}\right)$ and the attenuation is equal to $\frac{R_p + R_{410}}{R_p}$. The slopes of the curve shown in Figure 21 (b) are the result of the proper selection of R_{411}, R_{412} and R_{410}, and the points at which the slopes change are determined by the bias levels V_1 and V_2. In the Simulator, the bias levels are obtained from the DC filament supply (shown in Figure A.3).

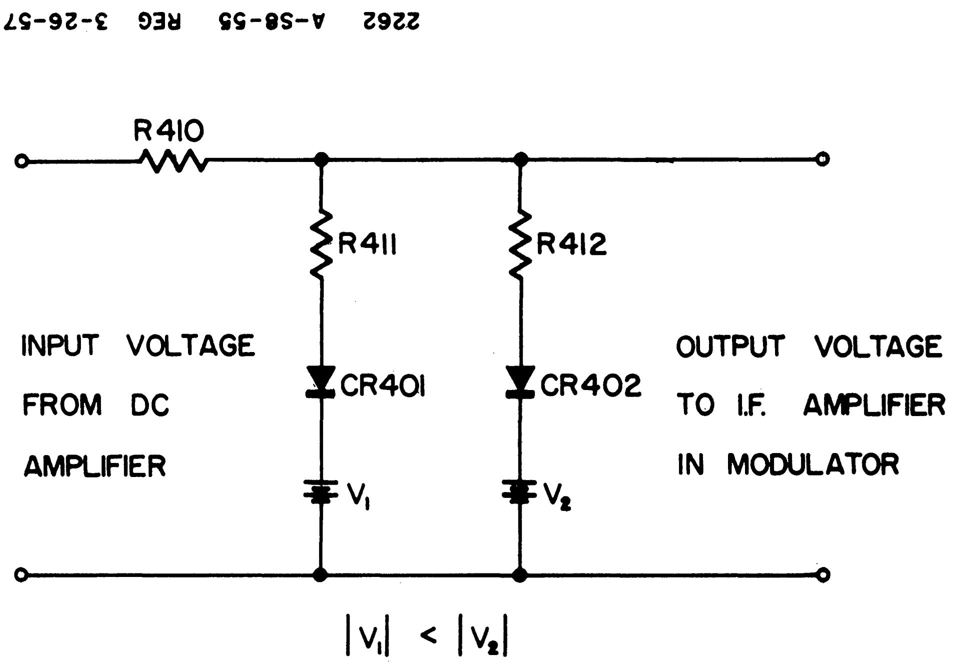

FIG. 22. FUNCTION GENERATOR CIRCUIT.

The RF pulses from the pulse generator and oscillator circuit are fed into the Modulator and are of constant amplitude. The amplitude of the output pulses thus vary directly with the instantaneous DC level of the Modulating Signal. This is the desired output RF signal.

3.6 Pulse Generator

The equipment for simulating the target signal includes a pulse echo multivibrator and a 30 MC ringing circuit. The Pulse Generator provides an 0.8 micro-second pulse which is delayed according to the simulated range of the target. The frequency and pulse-width requirements of this signal are determined by the radar. The Modulator amplitude modulates the pulse from the generator at a 60 cycle rate according to azimuth and elevation error information. The resulting simulated target echo signal is introduced to the radar IF amplifier input through an attenuator.

The pulse generator has the following principal features:

(1) The radar timing pulse initiates the pulse generator at 1122 cps repetition rate.

(2) A phantastron circuit generates a pulse with a delay proportional to voltage. This delay voltage is determined by the position of the range cam.

(3) The output pulse is 0.06 volts RMS into 50 ohm. The low pulse amplitude and shielding and isolation assure very low leakage to the radar. Thus the echo signal can be attenuated below the noise level of the radar IF.

The schematic is shown in Figure A.4. A block diagram of the Pulse Generator, together with output waveforms, is shown in Figure 23. The positive pulse from the radar is inverted and used to initiate the phantastron cycle. The initial plate voltage of the phantastron is determined by a cathode follower controlled by the range potentiometer giving a range of 2000 to 8000 yards. This initial voltage thus determines the delay introduced by the phantastron, which corresponds to the range of the simulated target. The phantastron output is differentiated, with the positive pulse in the output marking the end of the delay interval. This pulse is inverted again and triggers a monostable multivibrator, which produces a rectangular 0.8 micro-second gating pulse.

Some care was taken to make the 0.8 micro-second pulse rectangular and

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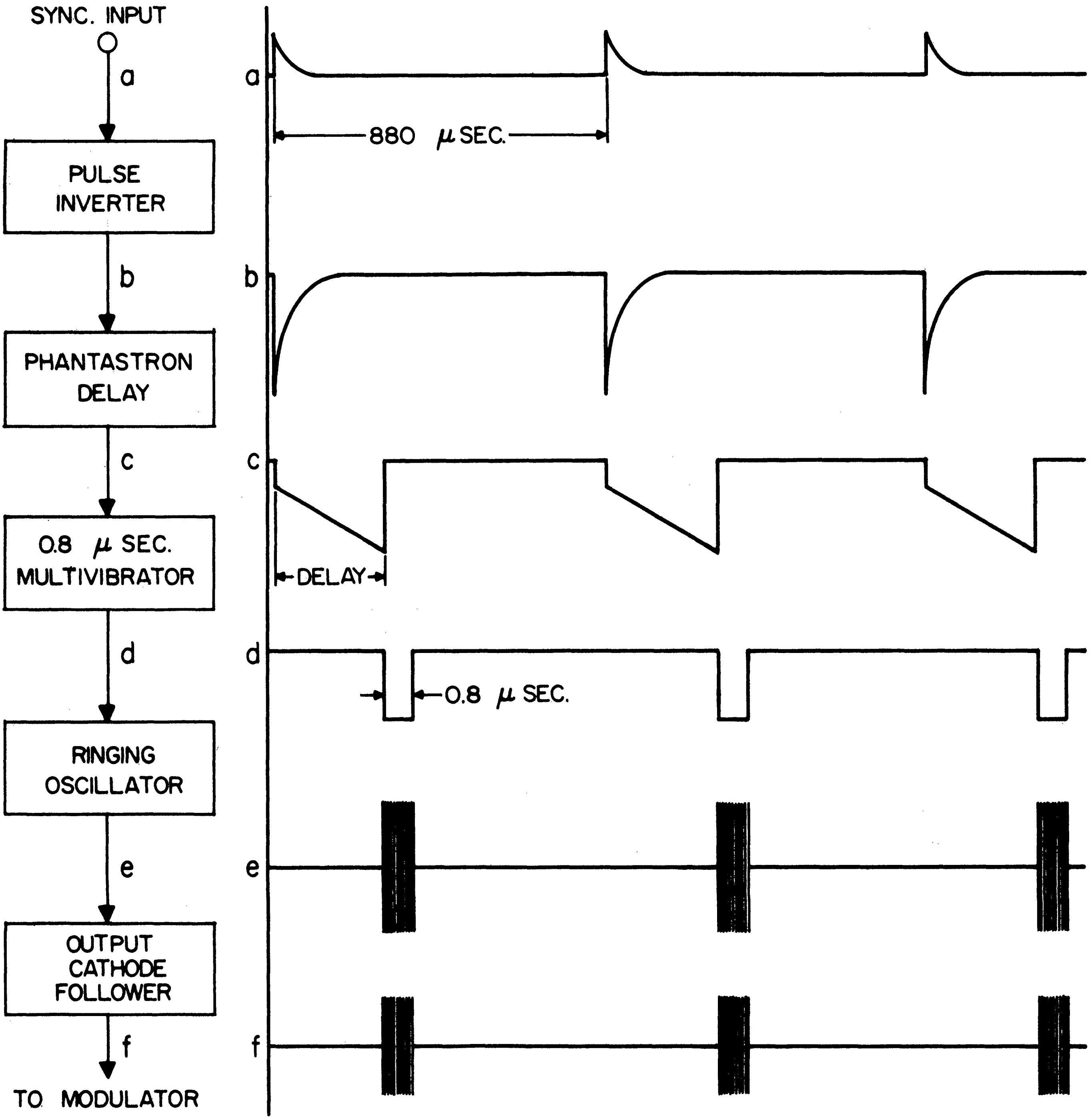

FIG. 23. BLOCK DIAGRAM AND WAVESHAPES OF PULSE GENERATOR AND OSCILLATOR.

fast so as to be effective for actuating the 30 MC ringing circuit. If the pulse is not rectangular and fast, it is possible for the 0.8 micro-second pulse to carry into the output undesirable overshoot of the same order of amplitude as the ringing circuit output. A cathode follower provides isolation of the timing and ringing circuits while a diode clipper enhances the rectangular qualities of the pulse applied to the ringing circuit.

It is necessary to provide feedback to maintain the 30 MC transient of the ringing circuit at its initial amplitude; this is provided by a cathode follower. A second cathode follower drives the 50 ohm output line. Two cathode followers are necessary in order to provide ringing circuit feedback independent of output line impedance.

Care must be taken in the construction of the pulse generator, particularly the 30 MC circuits, to prevent radiation and coupling to the radar IF. It is essential that one ground must be closely located to each loop circuit and that all loops be as compact as possible. No current paths can be allowed to pass through the chassis.

3.7 Attenuators and RF Adder

The Simulator RF signal from the Modulator must be attenuated since it is too large for the radar set. A Daven RF attenuator is used for this purpose.

An attenuated interference signal is added to the Simulator RF signal in the RF adder. The RF adder is a resistive network which matches the two 50 ohm inputs to a 90 ohm output. The total attenuation of the adder for one of the signals is 14.55 db. The 90 ohm line to the radar set is required to match the input to the radar IF amplifier. After some investigation it was discovered that the radar IF amplifier actually looked back into a 300 ohm impedance when receiving a signal from the radar RF mixer. Another resistive network was placed at the radar IF amplifier input to change the 90 ohm to a 300 ohm impedance with an attenuation of 11.54 db.

A selector switch was added to facilitate measuring the power of the signal and of the noise. The circuit is shown in Figure 24.

3.8 Power Supply

The DC and filament voltages for the simulator are supplied by a Tektronix Model 160 power supply. This supply furnishes the proper voltages for the Model 360 oscilloscope, and the other circuitry in the simulator was designed to operate with these voltages. The load which the simulator presents is within the maximum limits of the supply. Three modifications were made in the supply: (1) a filter was added to the +300 unregulated voltage; (2) a high voltage supply was added for the Monitor Scope CRT; and (3) a magnetic shield was placed around the fan motor in order to limit the magnetic field in the CRT.

The filter used to minimize the 120 cycle intensity-modulation of the spot on the Generator Scope is an L-type with a series coil of 20 henrys at 50 MA and a parallel capacitor of 125 μf at 300 volts.

The voltage tripler shown in Figure 18 supplies -1100 volts DC to the monitor scope CRT.

4. SUMMARY

A target simulator for use with conical scan tracking radars has been described. It permits extensive laboratory investigation of the dynamic response of the radar to typical target paths under a variety of test conditions. A predetermined path of the shell trajectory type was set up by means of three mechanical cams representing the variations of azimuth, elevation and slant range of the simulated target. These quantities were electrically compared by means of synchros to the corresponding quantities in the radar set and resulted in the generation of error signals. The azimuth and elevation errors were combined

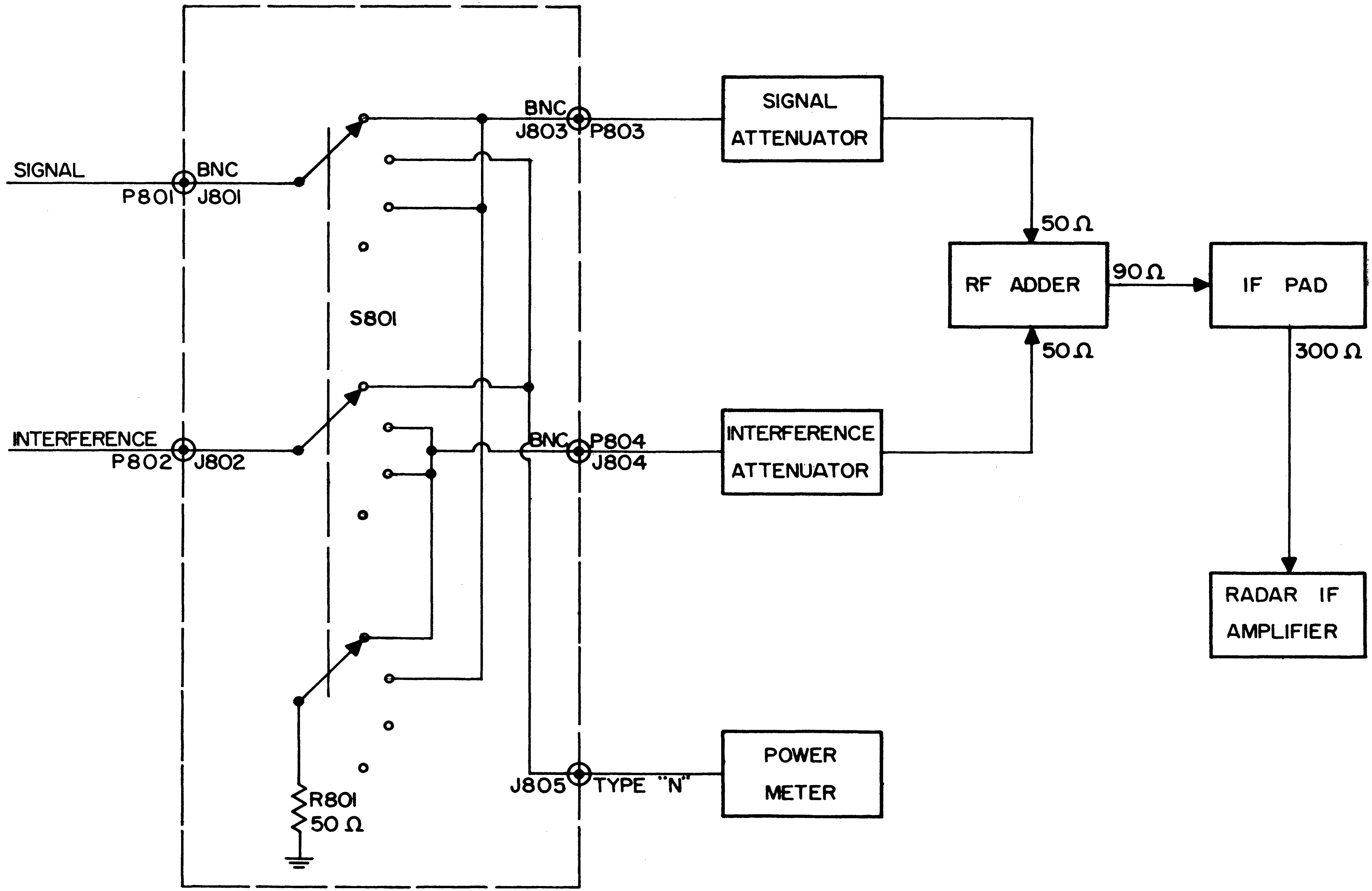

FIG. 24. POWER MEASUREMENT SELECTOR BOX.

and converted by means of an optical arrangement which takes into account the antenna beam shape. The converted error signal was used to produce a pulsed echo signal at the intermediate frequency of the radar, the echo signal being modulated in the same manner as the echo signal from a true target with the corresponding pointing error. This signal was fed to the input of the radar IF Amplifier. Range information was introduced by means of a variable delay pulse generator, controlled by a range cam. The simulator can be easily adapted to types of conical scan radars other than the AN/MPQ-10A for which the described unit was designed. A quick-change cam feature permits the use of different sets of cams corresponding to other target paths.

APPENDIX A

The following detailed circuit schematics and interconnection diagrams are included for reference in servicing the equipment.

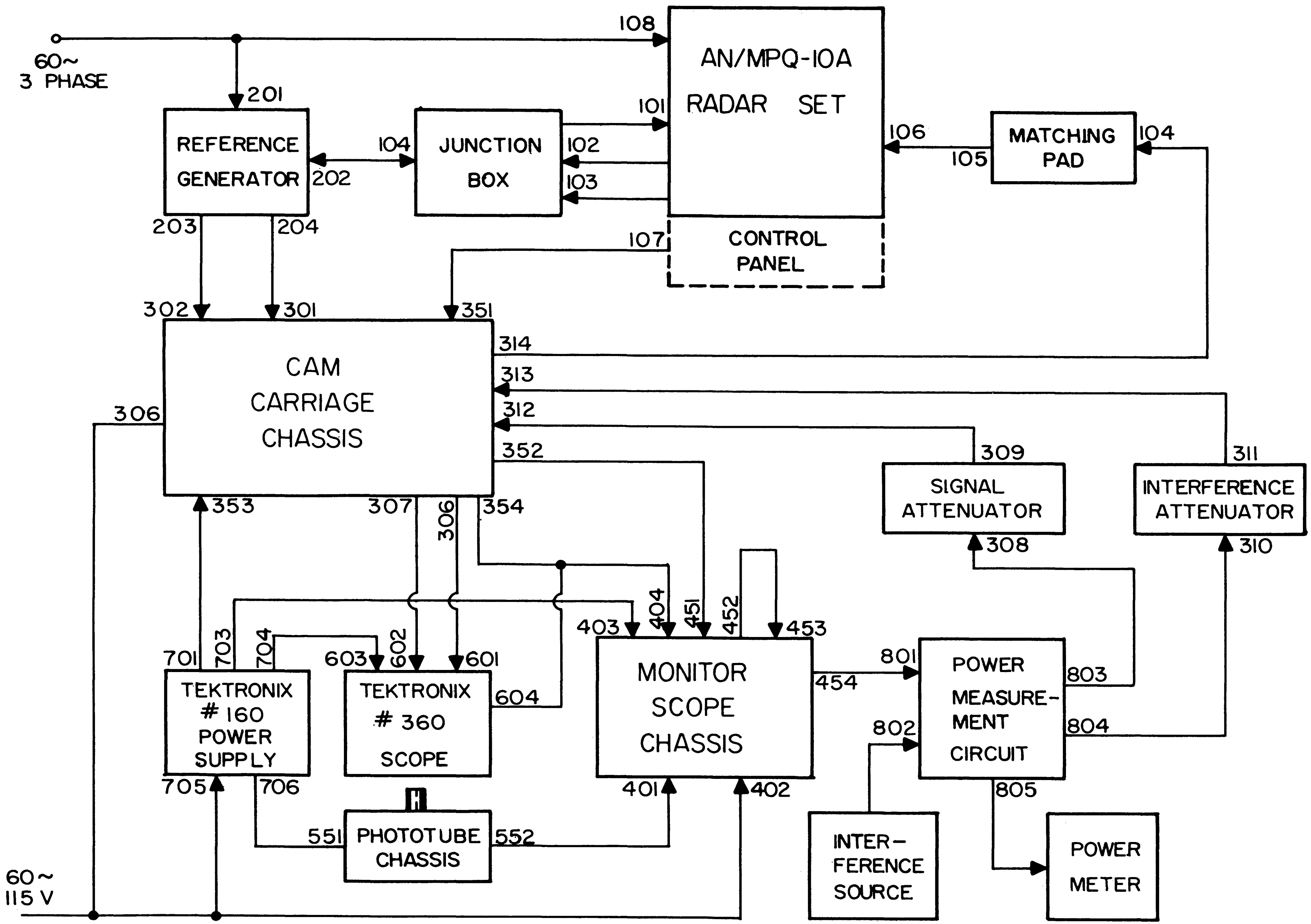

FIG. A-1. CABLING DIAGRAM OF TARGET SIMULATOR.

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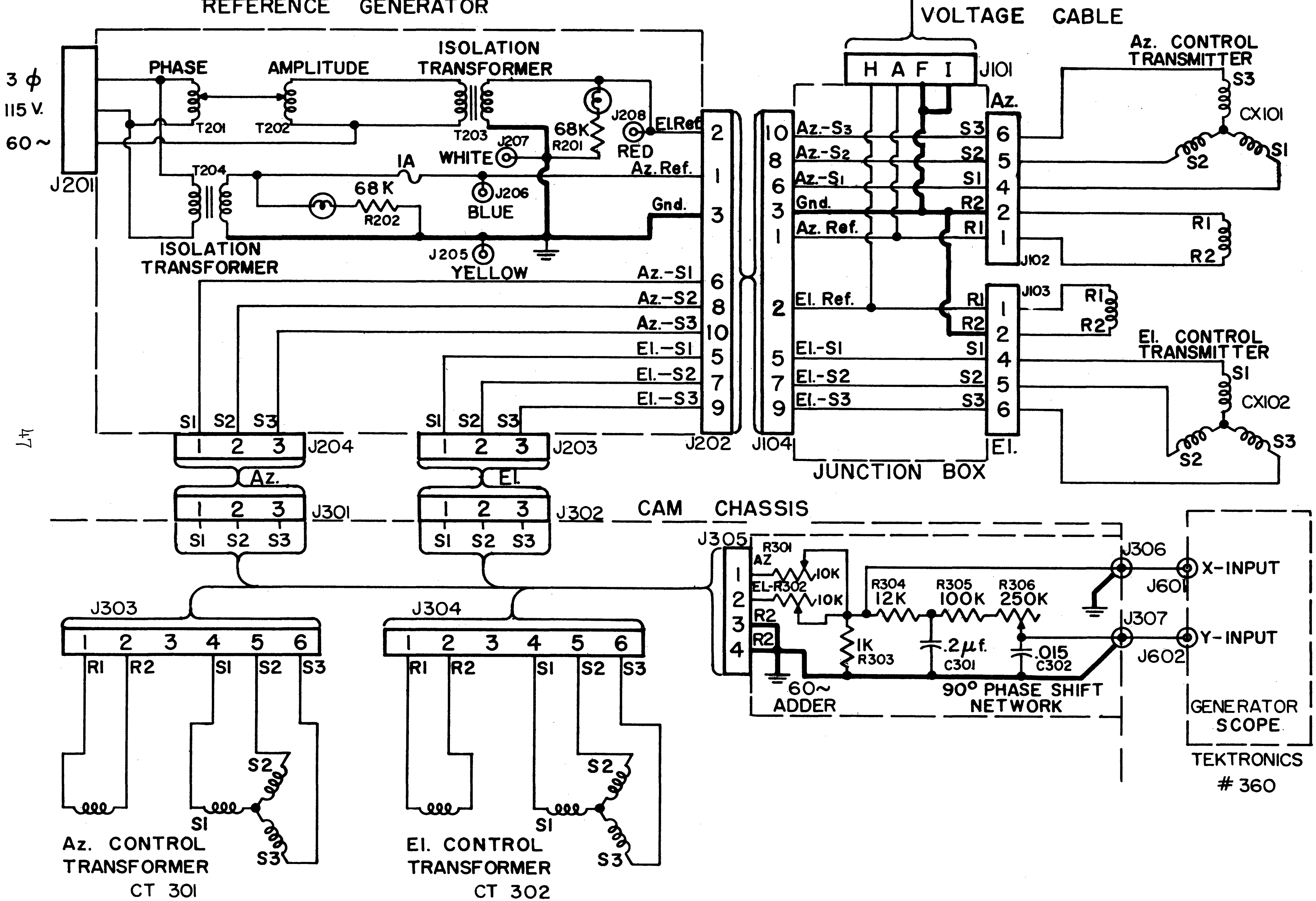

FIG. A-2. 60~ ERROR SIGNAL SCHEMATIC OF TARGET SIMULATOR.

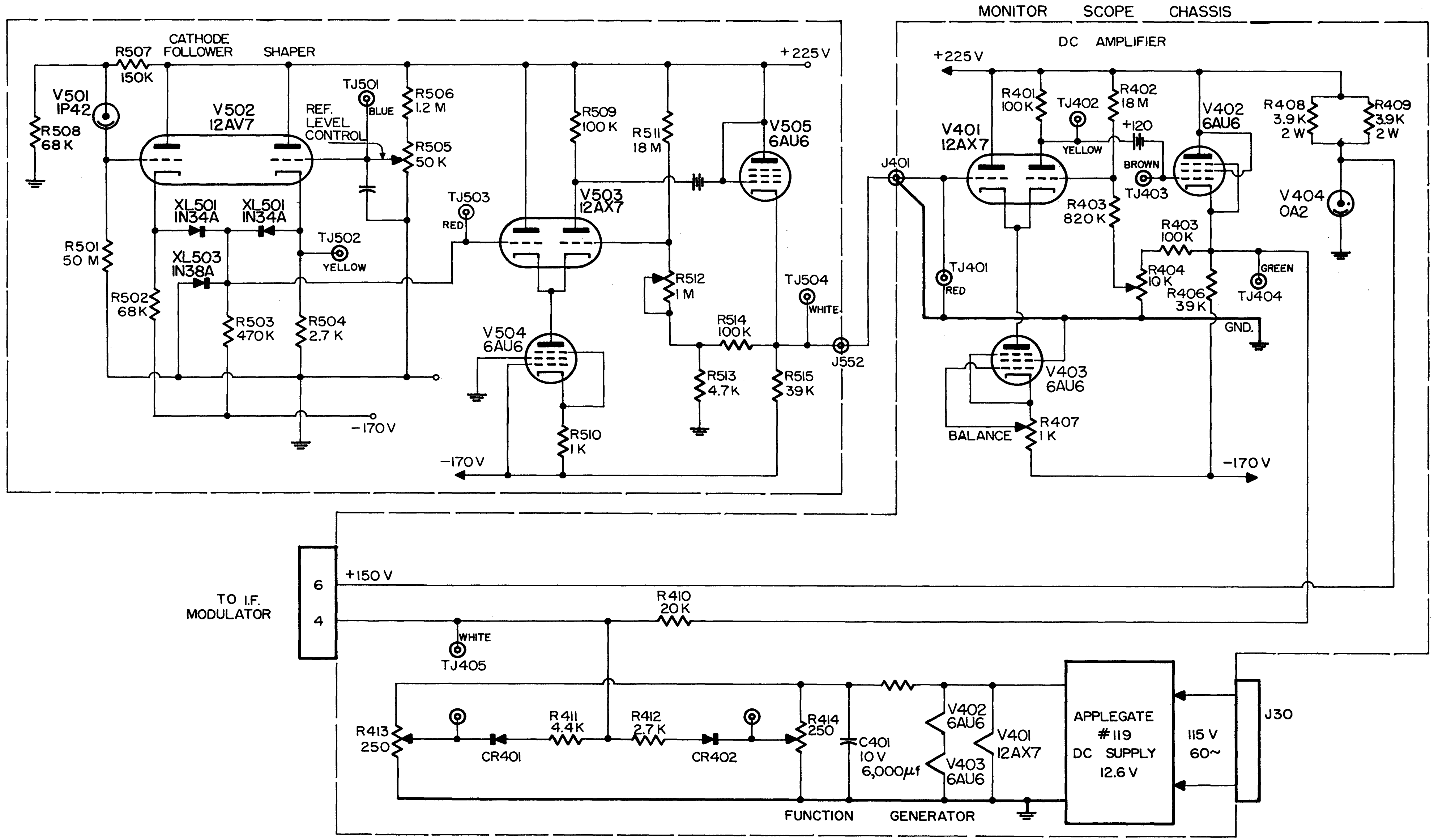

FIG. A-3. MODULATING SIGNAL SCHEMATIC OF TARGET SIMULATOR

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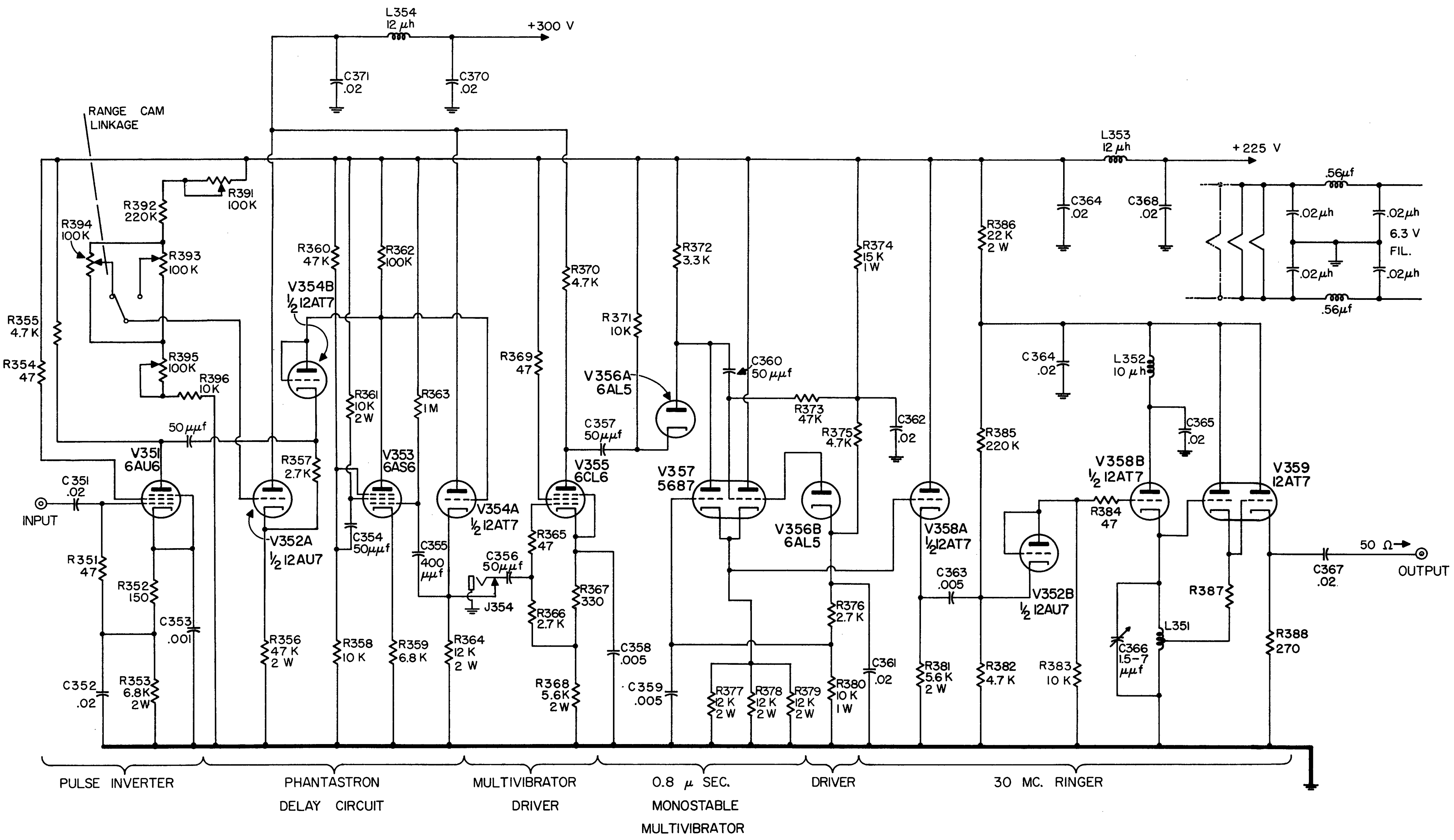

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FIG. A-4. SCHEMATIC DIAGRAM OF PULSE GENERATOR AND OSCILLATOR.

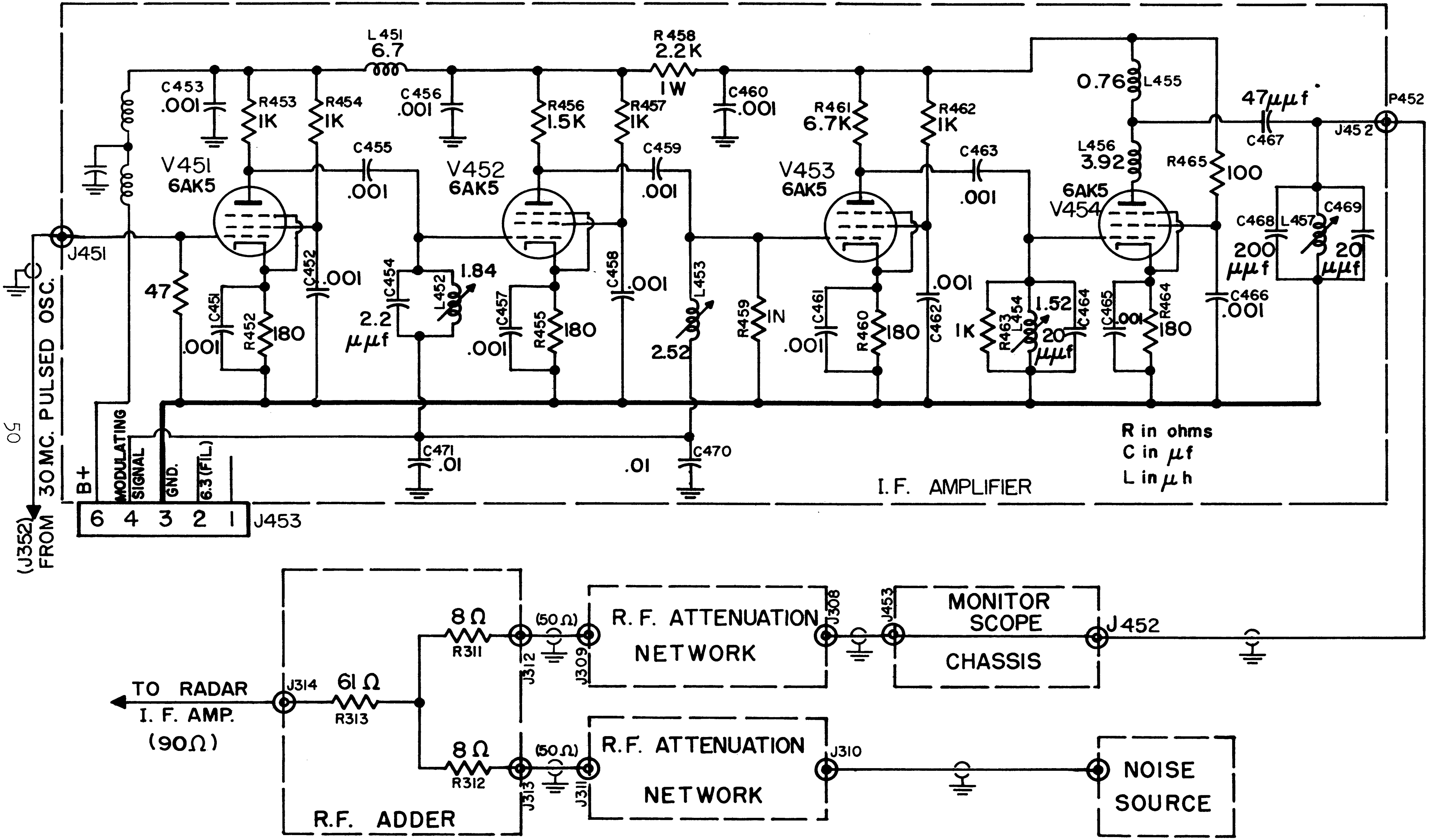

FIG. A-5. R. F. SIGNAL SCHEMATIC OF TARGET SIMULATOR.

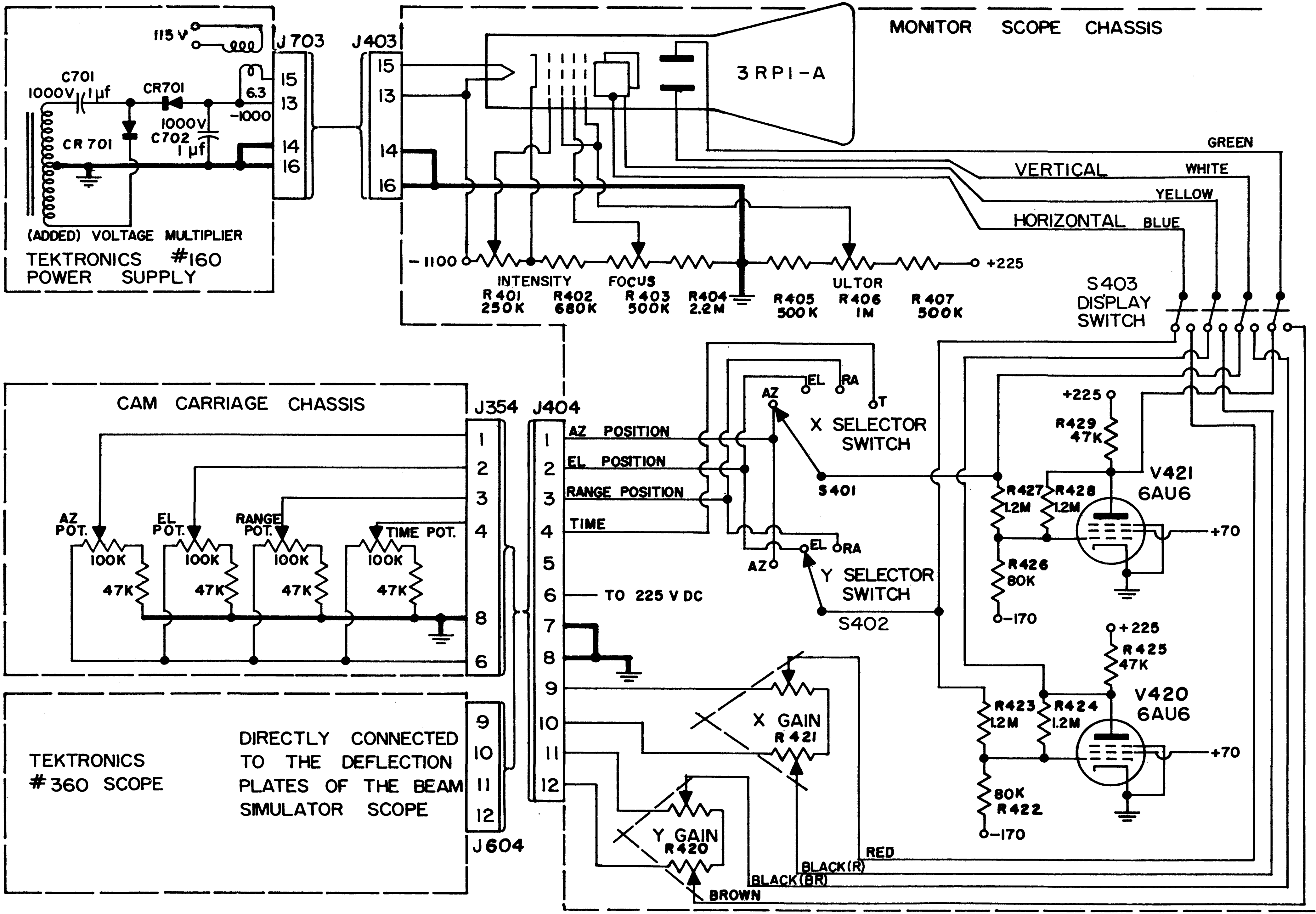

FIG. A-6. MONITOR SCOPE CHASSIS OF TARGET SIMULATOR.

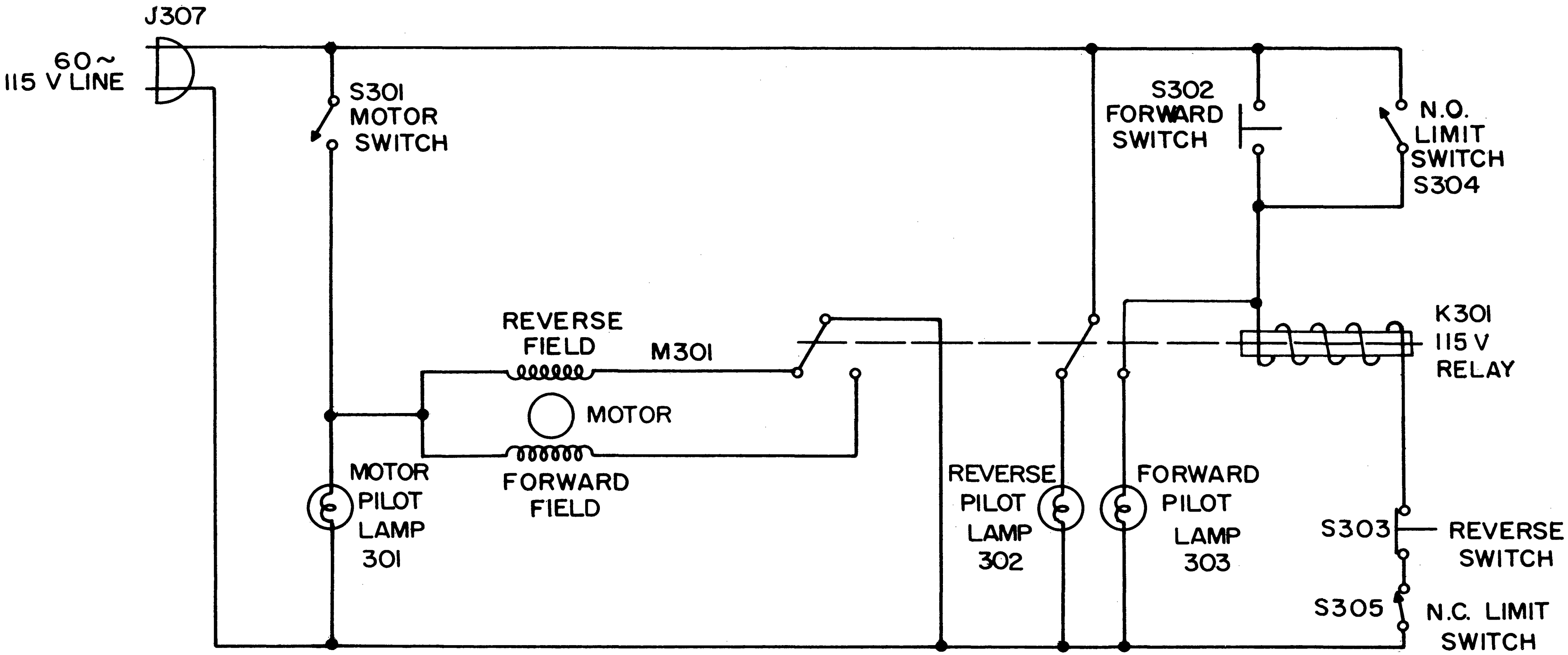

FIG. A-7. CAM MOTOR CIRCUIT OF TARGET SIMULATOR.

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APPENDIX B

CALIBRATION

B.1 Introduction

The calibration procedures for the Conical Scan Radar Target Simulator are given in this appendix. The theory and operation of this equipment is given in the body of the report. The purpose of this appendix is to aid in the operation and maintenance of the Simulator.

There are several checks which must be performed before the Simulator will operate properly. In general these tests are made on each of the component units shown in the block diagram in Figure 2. The tests are listed below in the order presented.

- B.2 Reference Voltages
- B.3 Synchro Position
- B.4 Beam-Shape Generator
  - B.4.1 Error Circle Shape
  - B.4.2 Phototube Axis
  - B.4.3 Azimuth and Elevation Gain
  - B.4.4 Phototube Response
- B.5 Function Generator
- B.6 Signal Phase
- B.7 Range Delay
- B.8 Cams and Linkages
- B.9 RF Signal Level

Two aspects of each test will be presented. First a general discussion of the test, followed by a detailed step-by-step procedure for performing each test.

The test equipment required is listed below with suggested models.

VTVM (Hewlett-Packard 410B)
OSCILLOSCOPE (Dumont 304A)
ELECTRONIC COUNTER (Hewlett-Packard 522B)
POWER METER (Hewlett-Packard 430C)
TRANSPARENCIES

1. Circle Guide (Concentric Circles 3/16, 3/8, 9/16, 3/4 inch radius).
2. Antenna Response Guide $\left(\text{Plot of } \frac{\sin^2 X}{X^2}\right)$.

B.2 Reference Voltages

The output of the reference generator must be determined in both amplitude and phase. The amplitudes must be equal and the phase between Az and El reference must be 90°.

Procedure

Step 1: Measure AC voltage between jacks J 205 (yellow) and J 206 (blue) and record this reading. This voltage is constant and can only be changed by adjusting the 3-phase supply. It should have a nominal value of 115 V AC (RMS).

Step 2: Measure AC voltage between jacks J 207 (white) and J 208 (red). This should be the same value as recorded in step 1. If not, the amplitude variac, T-202, should be adjusted to make the two reference voltages equal in amplitude.

Step 3: Connect the two reference voltages, using one to start trigger and the other to stop trigger. The time for one complete cycle is 16,667 micro-seconds. The phase adjustment should be set to obtain a time between reference voltages of either 1/4 or 3/4 of this period (i.e., 4,167 or 12,500 micro-seconds). The two reference voltages are now in quadrature. CAUTION - Do not exceed the maximum input voltage to the counter.

Step 4: Check the amplitude again as in step 1 and 2.

B.3 Synchro Position

There are five synchros to be positioned. Three are mounted on the radar set: (1) the azimuth CX, (2) the elevation CX and (3) the cosine transformer. The two remaining synchros (i.e., the azimuth and elevation CT's) are on the cam carriage chassis.

The azimuth CX and CT have their stators connected together electrically, as do the elevation CX and CT. Thus, for each channel, the zero position of the synchros could be accomplished by rotating either the CX or the CT.

The construction of the Simulator makes it easier to rotate the CT's, which are located in the rack.

When the CT's are at their zero positions the stators are clamped so that they cannot move from this setting.

Procedure

Step 1: Connect a voltmeter to S-1 and S-2 on the cosine transformer.

Step 2: Apply Reference voltages to the radar set from the Reference Generator and set the elevation angle to 0.

Step 3: Rotate the cosine transformer until the voltmeter reads a maximum.

Step 4: Check this maximum by reading the voltages with the elevation angle at +100 and -100 mils. When these two readings are the same value the cosine transformer is positioned properly and should be fastened securely.

Step 5: Set the elevation angle to zero and azimuth angle to some arbitrary reference point.

Step 6: Set the cam carriage so that it is at either limit of travel.

Step 7: Remove plug P-302 from the cam chassis panel. This disconnects the elevation CX and CT stators.

Step 8: Rotate the azimuth CT until the output of the 60 cycle adder is zero volts (or until the circle on the Monitor Scope reduces to a spot). Secure the azimuth CT in this position.

Step 9: Replace plug P-302 and remove plug P-301. This restores the elevation stators and disconnects the azimuth stators.

Step 10: Rotate the elevation CT until the output of the 60 cycle adder is zero (a spot on the Monitor Scope). Secure the CT in this position.

Step 11: Replace plug P-301. The synchros are now positioned properly. For the final positioning see test 8 in Section

B.4 Beam-Shape Generator

The calibration of the Beam-Shape Generator is broken up into four separate tests. These tests, given below, are presented in the same manner as other tests, i.e. general description and procedure.

Two transparencies are used throughout these tests: (1) a circle guide, and (2) an antenna response guide. The circle guide has four concentric circles, representing errors of 1.5, 3.0, 4.5 and 6.0 degrees. For the Monitor Scope a calibration scale was chosen so that each 1/8 inch of circle radius represents one degree of error. The antenna response guide is a curve plotted from the equation $R = \frac{\sin^2 X}{X^2}$.

B.4.1 Error Circle Shape. The shape of the error circle can be changed by two adjustments; that is, by the vertical gain of the Generator Scope and the total phase shift of the Phase Shift Circuit.

The shape of the error circle is checked visually against the circle guide over the face of the Monitor Scope.

Procedure

Step 1: Place the circle guide over the face of the Monitor Scope.

Step 2: With the Radar Set in manual control move the azimuth and/or elevation dial to create a small error signal whose display fills about half of the CRT face.

Step 3: If the error presentation is an ellipse, with its major axis vertical or horizontal, the shape can be made more circular by adjusting the vertical gain control of the Generator Scope. Set the total vertical swing equal to the total horizontal swing of the display. NOTE: Check the DC balance of the

Generator Scope.

Step 4: If the error presentation is still ellipical (with a tilted axis), the shape can be adjusted by varying R-306 in the Phase Shift Network. Changing R-306 will change the amplitude of the "Y" input to the generator scope; therefore, the vertical gain control must be varied to obtain a circular display.

A third harmonic in the two reference voltages will cause the circle to be distorted toward a hexagon shape.

B.4.2 Phototube Axis. The display on the Monitor Scope is the same size and shape and has the same relative position as the display on the Generator Scope. The point chosen as reference is the location of the phototube axis. An error circle is centered about the phototube on the Generator Scope. The center of this circle on the Monitor Scope is used as a reference point for future positioning of the error circle. This test also gives a further opportunity to check on the shape of the error circle.

Procedure

Step 1: Connect the output of the phototube circuit, (J-652) to the Wave Analyzer and Test Oscilloscope.

Step 2: Position the error circle (Generator Scope position controls) to obtain a 60 cycle null for all circle sizes from 0° to 6° error. Examine the display on the oscilloscope to see that the track is almost flat for all sizes of error circles.

Step 3: The position for 60 cycle null is considered to be the effective phototube axis on the Generator Scope. The circle guide is centered at this point on the Monitor Scope face and will remain in this position.

Step 4: Check for 120 cycle component in the Phototube Circuit output. This is a good measure of the shape of the circle. If the circle is ellipical there will be a 120 cycle component on the output. There may be some 120 cycle pickup caused by intensity-modulation of the electron beam in the Generator Scope. Obtaining a null at 120 cycles, by changing the circle shape, (see B.4.1 Step 3) yields a circular display on the Generator Scope.

Step 5: Check the output for other harmonic content. Any excessive amount should be eliminated.

B.4.3 Azimuth and Elevation Gain. The size of the circle on the Monitor Scope must be set so that an error will cause the radius to equal the scale chosen for the Circle guide. This must be done for azimuth and elevation channels separately. The two will then work properly together, because of the quadrature relationship involved in forming the error and the 90° phase difference of the two reference voltages.

The gain potentiometers (R-301 and R-302) are located in the 60 Cycle Adder.

Procedure

Step 1: Put the antenna in its zero position. This should give a "zero error" spot on the Monitor Scope.

Step 2: Move the antenna 80 mils (4.5°) in azimuth and adjust R-301 to make the circle radius 9/16 inch (same size as next to largest circle on the Circle Guide (4.5°).

Step 3: Return antenna to zero in azimuth and displace it in elevation 80 mils.

Step 4: Adjust R-302 to obtain a 4.5° error circle.

Step 5: Because of the interdependence of these two adjustments, repeat steps 1 thru 4 several times displacing the antenna in both positive and negative directions for each channel. NOTE: When reading the position of the antenna use the indicators located on the radar set and not those on the control panel.

B.4.4 Phototube Response. In this test the phototube circuit output is fitted to the antenna response guide. There are several variables which affect the output. They are: (1) distance of the phototube from the face of the Generator Scope; (2) the reference level of the Shaper Circuit; (3) the focus of the Generator Scope; and (4) the intensity of the Generator Scope. The settings of the focus and intensity are limited due to physical considerations; i.e., the focus at maximum de-focus and intensity at minimum. To obtain a display which can be compared to the Antenna Response Guide it is necessary to determine the instantaneous spot position and compare this with the instantaneous output of the photocell circuit. This can be done by using the 60 Cycle Error Signal (X input to Generator Scope) as a horizontal deflection signal to the test oscilloscope and using the phototube output as the vertical deflection signal. This will present a loop display on the test oscilloscope. The Beam-Shape Generator output must now be adjusted to make the test oscilloscope presentation fit the Antenna Response Guide. The end point of the loops formed for various size error signals should be tangent to the curve on the Guide.

Procedure

Step 1: Apply the 60 Cycle Error Signal (X input to Generator Scope) to the horizontal input of the test oscilloscope and the output of the phototube circuit (the red test jack) to the vertical input of the test oscilloscope.

Step 2: Set the distance of the phototube from the face of the CRT to approximately 3/8 inch.

Step 3: Set the focus on the Generator Scope to obtain a large defocused spot. This will be one of the limits of the focus control.

Step 4: Set the intensity of the Generator Scope to make a faint spot. There is a peep hole on the right side of the light shield to allow viewing while doing this.

Step 5: Set the "zero error" spot on the 1.5 degree circle on the Monitor Scope. The exact point on this circle should be when the loop forms a "figure eight" pattern.

Step 6: Set the error to 6 degrees (1-1/2" diameter). The display on the test oscilloscope should be a flat line. As the error is decreased one end of the trace should begin to rise immediately, showing that the phototube can "see" the spot at slightly less than 6 degrees. The X and Y gain and position controls of the test oscilloscope must be continually adjusted to keep the display on the CRT so that it can be compared to the Antenna Response Guide which is over the face of the test oscilloscope. The bias control, R-505 in the Shaper Circuit, determines the amount the phototube can "see".

Step 7: The final setting of the adjustments should produce an output of the first DC amplifier of zero to +1.2 volts DC for the error from 6° to zero error. Along with these limits in amplitude the loop should be tangent to the Antenna Response Guide, and the spot which appears for zero error should fall at the 1.5° point on the curve.

Step 8: The DC level of the first DC amplifier should be set so that its output for a 6° error is zero volts DC.

Step 9: The gain and level controls of the second DC amplifier should now be set. The output for 6° error should be -6 volts DC. The output for zero error should be approximately +19 volts DC. The output can be measured at J-404.

B.5 Function Generator

The Function Generator bias levels must be set in order that its input-output curve be the inverse to the modulation curve of the IF Amplifier.

Procedure

Step 1: Connect the VTVM to test J-406 and adjust R-413 to obtain -5.0 volts DC.

Step 2: Connect the VTVM to test J-407 and adjust R-414 to obtain -4.2 volts DC.

B.6 Signal Phase

The modulation of the RF pulses to the radar set has been accomplished. Now the phasing of these signals with the reference voltages supplied to the phase comparitors in the servo amplifiers must be checked. This is accomplished by finding the correct position of the "zero error" spot on the 1.5° circle. Each channel is adjusted individually.

Procedure

Step 1: Remove J-302 and turn the radar elevation servo switch to "OFF"

Step 2: Obtain a "zero error" spot by adjusting the radar manually in azimuth. Also, the target must be in the range gate on the J-scope.

Step 3: Put the radar set in automatic track. Check to see if the radar set will lock-on the target with the spot in this position. If not, try 45° further around on the 1.5° circle. Continue this process until the lock-on region is located. Because the phototube is located off center of the CRT, it is desirable to have the lock-on position located as close to the center as possible. If the lock-on position determined in this step is on the opposite side of the 1.5° circle from the center, the azimuth CT should be rotated 180°.

Step 4: Replace J-302 and remove J-301.

Step 5: Turn elevation servo switch to "ON" and azimuth servo switch to "OFF".

Step 6: Place the "zero error" spot at the trial lock-on position determined in step 3.

Step 7: Put the radar set in automatic track and see if the elevation will lock-on or be driven off. If it is driven off, rotate the elevation CT 180 degrees.

Step 8: Replace J-301 and turn azimuth servo switch "ON".

Step 9: When the radar is put on automatic track the radar set should lock-on in azimuth and elevation, although there may be some "crosstalk" between the two channels causing "hunting" of the antenna.

Step 10: With the radar in automatic, position the spot to obtain the least amount of "crosstalk". The antenna should not hunt very much. If it does, and there is not an optimum position, check to see that the sensitivity adjustments on the radar servos are not set too high. The optimum operating point is a function of: (a) the spot position, and (b) the sensitivity adjustments of the radar servos.

B.7 Range Delay

The range channel adjustments require only that the delay time be correct for the position of the range linkage. This adjustment is performed as part of the next test on calibrating a set of cams.

B.8 Cams and Linkages

Whenever new cams are put in the cam carriage they must be calibrated with the radar set so that the desired trajectory is presented. Five pieces of information have been computed for some points on each trajectory. These are: (1) slant range (R_s); (2) horizontal range (Do); (3) height (Ho); (4) azimuth angle (A); and (5) elevation angle (E). The points chosen are convenient to locate on the trajectories, such as the end points and the point for maximum height (center of cams).

The cam carriage is positioned so that the followers are in the center of the cams (maximum height). The radar set is positioned manually to the computed values for the trajectory. The azimuth and elevation CT's are rotated to bring the error circle to a spot, and the range linkage is adjusted to place the target in the narrow gate on the J-scope. At the end points on the cams the computed values are checked against the radar set position since there might be a slight error in the machining of the cams.

Procedure

Step 1: Place the cam in their respective slots, making sure that they are down to the bed plate and that they are tight against the stop.

Step 2: Position the cam carriage so the followers are in the center of the cams. This can best be done by setting the radar set to track the target automatically and check the output of the radar computer for the point where maximum height occurs (not necessarily maximum elevation angle).

Step 3: With the radar set in manual track, position the radar set to the values given in Table I, using the values for the trajectory cams being calibrated. Use the dials located on the radar set, not those on the control panel.

Step 4: Rotate the azimuth and elevation CT's to obtain a "zero error" spot on the Monitor Scope.

Step 5: Rotate the Range Delay pulley (RA) to put the target pulse into the narrow gate on the J-Scope.

Step 6: Put the radar set in automatic track, leaving the cam carriage in the position located in step 2.

Step 7: Compare the radar position to the values in the Table I. If the radar set has moved from the computed position, repeat steps 3 through 7.

Step 8: Put the radar in automatic track. Move the cam carriage to one end of the cams. Stop the carriage at the limit of travel.

Step 9: Record the position of the radar at this end of the trajectory.

Step 10: Move the cam carriage to the other limit of travel and record the position of the radar at this point.

Step 11: Check the values recorded in steps 9 and 10 with those in Table I to see if these points agree with the calibration made at maximum height. This check might be used to see if the maximum height position was correct. If there is a wide variation in readings check to see that the cams are free from dirt in the slot and that the cams are down flat against the carriage bed.

CAM	TIME (Sec)	R_s (Yards)	E (Mils)	A (Mils)	Do (Yards)	Ho (Yards)
	0	5396	0	+393	5396	0
IA	19.5	5396	393	0	5000	2030
	39	5396	0	-393	5396	0
	0	6594	0	+224	6594	0
IB	19.5	5396	393	0	5000	2030
	39	3842	0	-389	3842	0
	0	7030	0	0	7030	0
IC	19.5	5396	393	0	5000	2030
	39	2970	0	0	2970	0
	0	5113	0	+215	5113	0
2A	14.35	5113	215	0	5000	1070
	28.7	5113	0	-215	5113	0
	0	5806	0	+133	5806	0
2B	14.35	5113	215	0	5000	1070
	28.7	4310	0	-180	4310	0
	0	6070	0	0	6070	0
2C	14.35	5113	215	0	5000	1070
	28.7	3930	0	0	3930	0

Table I

B.9 RF Signal Level

The average power output from the IF Amplifier is measured when the error circle is a spot. This gives the maximum average RF power received from the target. If the output of the IF Amplifier is too low to be measured accurately, the repetition rate of the signal can be increased by triggering the Pulse Generator with an external trigger.

Procedure

Step 1: Position the radar to obtain a "zero error" spot on the Monitor Scope.

Step 2: Set the power measurement selector switch to "signal" position and measure the average power with the power meter.

Step 3: To measure the average power of the interference signal set the selector switch to "noise" position.

Step 4: Return the selector switch to "operate" position.

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1. G. S. Cohen, "Evaluation of Susceptibility of Conical Scan Tracking Radars," Electronic Defense Group Technical Memorandum in preparation.

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