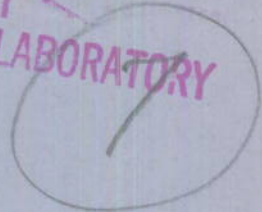


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REPORT

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30 November 1942

THE PLAN POSITION INDICATOR

By
James J. Fleming
Millard S. McVay

Report No. R-1948

FR-1948

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BuShips Problem W5-2S
and X4-13S

NAVY DEPARTMENT

Report on

The Plan Position Indicator

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AUTHORIZATION

1. The research work done on the plan position indicator is authorized by Bureau of Ships Problem No. W5-2S as covered by Bureau of Ships letter of 1/21/31, and No. X4-13S as covered by Bureau of Ships letter S-S67/36(485) Serial 1667 of 11/5/42.

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INTRODUCTION

2. In the spring of 1939 it was realized that the use of radar would be greatly facilitated by employing indicators which would present a polar coordinate map (in terms of range and bearing) of all objects "visible" to the radar system. This type of indication can be produced through the use of a radial sweep on a cathode-ray tube. In particular, an electron beam is made to sweep from the center to the outside edge of a long-persistence fluorescent screen deposited on the inside face of the cathode-ray tube. To have radial distance on the face of the cathode-ray tube represent the range of an object, it is necessary to have the sweep start at the same time that a radio-frequency pulse is radiated from the directional radar antenna. To have an angle measured on the face of the cathode-ray tube represent the bearing of an object, the radial sweep is made to rotate about the center of the fluorescent screen in synchronism with the radar antenna, so that the sweep is always in a direction corresponding directly to that in which the antenna is pointing.

3. When the radio frequency pulse from the radar transmitter strikes an object, it is partially reflected and if the energy of the reflected pulse is sufficiently great, a distinguishable signal, or echo, is received from that object. These signals are applied to the grid of the cathode-ray tube to produce a brightening of the cathode-ray trace for each echo received. This is called intensity modulation and it results in the echoes appearing as bright spots in the form of circular arcs on the fluorescent screen. The position of such a bright spot on the cathode-ray screen gives directly a measure of the range and bearing of the object producing the echo. For obtaining target bearing readings a scale in degrees is generally marked around the edge of the cathode-ray tube screen with 0° at the top (see plate 1). For determining the range of an echo some form of range scale is also provided. For a better understanding of the type of pattern actually received a glance ahead at Plates 22 and 23 should suffice.

4. The name originally given to this apparatus was Radial Sweep since it is descriptive of the method used to produce the required result. After some time the name Plan Position Indicator (abbreviated as PPI) was adopted as more suggestive of the end accomplished. Henceforth the apparatus will be simply referred to as PPI.

5. Plan Position Indicators are intended to give rapidly the bearing and range of any number of targets and so are used in conjunction with other types of radar indicators which are built to furnish more accurate readings of these quantities. Since they provide a polar plot of the positions of all objects, they are not limited to searching for targets but can also be used on ships as an aid to navigation.

THEORY

6. The rotating radial sweep necessary for PPI can be generated by an electron beam moving (1) through two perpendicular fields both making a right angle with the beam, or (2) through a single mechanically rotated field which always makes a right angle with the beam. In the first case, either electric or magnetic fields may be used, but, in the second case, only the use of a magnetic field has proved practical.

7. In general the following holds true for both cases (See Plate 2). The point at which the electron beam strikes the fluorescent screen, which is assumed to be flat, is determined by the coordinates r (range) and θ (bearing). For the sweep to be linear the electron beam must move radially with time according to the function r illustrated graphically in Plate 2. This means that equal segments of the radial trace will represent equal differences of range. At the instant the pulse leaves the radar antenna, the electron beam starts moving away from the center ($r = 0$) of the PPI screen. It continues to move radially outward until it reaches the edge ($r = r_{\max}$) of the fluorescent screen when it quickly returns to rest at the center. It remains at the center until another pulse is radiated when the cycle described above begins again. From the time the beam reaches the edge of the screen until it starts another sweep, it is blanked out so that it is not visible to the observer.

8. The maximum range reached by the electron beam depends on the length of time for the sweep to be completed; the value of r_{\max} is unchanged but the slope of the inclined line (see Plate 2) is changed. Thus plan position indicators can have several ranges available for use but it must be remembered that each change of range necessitates a change of range scale on the face of the tube.

9. For the consideration of case (1) it will again be necessary to refer to Plate 2. It can be shown that, under certain simplifying assumptions which are generally justified in practical cases, the deflection r of the electron beam is directly proportional to the voltage applied between the deflecting plates of an electrostatic deflection type cathode-ray tube. Furthermore, for the purpose of this discussion, it will be assumed that both the vertical and horizontal plates have equal deflection sensitivities. If, then, such a cathode-ray tube is oriented so that the vertical deflecting plates are perpendicular to the $0^\circ - 180^\circ$ line, the voltages to be applied to the vertical and horizontal plates respectively should have the form

$$V_v = K r \cos \theta \quad (1)$$

$$V_h = K r \sin \theta \quad (2)$$

where K is a proportionality constant, r is the function shown graphically in Plate 2, and θ is the angle between an arbitrary direction and the direction in which the antenna is pointed. This angle θ can be made to correspond either to relative or true bearing. These equations hold for a single-sided connection to the deflection plates, that is, one of the horizontal and

one of the vertical plates are grounded while the voltages of equations (1) and (2) are applied to the opposite plates.

6. If a balanced connection with respect to ground is used so that the deflection plates are operated push-pull, the voltages to be applied to the upper and lower vertical plates should have the form

$$(V_v)_1 = K' r \cos \theta \quad (3)$$

$$(V_v)_2 = -K' r \cos \theta \quad (4)$$

and the voltages to be applied to the right and left horizontal plates should have the form

$$(V_h)_1 = K' r \sin \theta \quad (5)$$

$$(V_h)_2 = -K' r \sin \theta \quad (6)$$

7. Another arrangement that can be used to give a resultant field like that of equations (1) and (2) is to operate each deflecting plate independently. The voltage wave forms for the vertical plates are then

$$(V_v)_1 = K'' r (k + \cos \theta) \quad (7)$$

$$(V_v)_2 = K'' r (k - \cos \theta) \quad (8)$$

and for the horizontal plates

$$(V_h)_1 = K'' r (k + \sin \theta) \quad (9)$$

$$(V_h)_2 = K'' r (k - \sin \theta) \quad (10)$$

where k is always greater than unity. Here it can be seen that equation (8) subtracted from equation (7) gives essentially equation (1). Likewise, equation (10) subtracted from equation (9) results in equation (2). The saw-tooth voltage wave forms on the deflecting plates are never of zero amplitude but, for certain values of θ , the horizontal or vertical deflection of the beam is zero.

8. Also under case (1) is classified the cathode-ray tube of magnetic deflection type when a fixed pair of deflection yokes is used. Since an electron beam moving through a magnetic field perpendicular to its direction of motion experiences a force which is perpendicular both to the field and to its direction of motion, the deflection yokes are mounted so that their axes make a right angle with the axis of the cathode-ray tube. Both the horizontal and vertical yokes often consist merely of a pair of air-core coils so wound that the magnetic field in the region traversed by the electron beam is very nearly uniform. After certain justifiable assumptions are made, it can be shown that the deflection r of the electron beam is directly proportional to the current passed through properly designed air-core deflection yokes. Thus, if the vertical deflection yoke is mounted with its axis perpendicular to the $0^\circ - 180^\circ$ line and the horizontal yoke has its axis parallel

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to this line, the currents to be passed through the vertical and horizontal yokes respectively should have the form

$$I_v = C r \cos \theta \quad (11)$$

$$I_h = C r \sin \theta \quad (12)$$

where C is a proportionality constant and both r and θ are defined as before. Obviously equations giving the current necessary for magnetic deflection can also be written to correspond to the electrostatic cases of equations (3) through (10) but they are not included here.

9. Up to this point, the method described for obtaining a sweep directed in correspondence to the angular position of the antenna has consisted essentially of an effectively rotating field, either electric or magnetic. This has necessitated the use of voltage or current wave forms which are not as simple as they can be made if the field is actually rotated by mechanical means.

10. This fact naturally leads to a discussion of case (2). Obviously, it would be impractical to rotate the deflecting electrodes of a cathode-ray tube since, to be able to direct the motion of the electron beam properly, they have to be mounted inside the tube in a high vacuum. But it is a relatively simple matter to rotate in synchronism with the antenna a single deflection yoke which is placed around the outside of the neck of the cathode-ray tube. Now the current to be passed through this yoke is

$$I = C r \quad (13)$$

where C and r have been previously defined. The automatic mechanical follow-up system eliminates the introduction of a function of θ into the current wave form.

11. Magnetic deflection yokes have both resistance and inductance and can be considered electrically as a series combination of the two. To produce a saw-tooth current in a resistance R alone, a saw-tooth voltage is applied; to produce a saw-tooth current in a pure inductance L , a square wave of voltage is applied. Thus, to obtain a saw-tooth current wave form (as in equations (11), (12) or (13)) in a deflection yoke, it is necessary to apply a voltage wave form consisting of a square wave with a saw-tooth wave superimposed on it. This fact is illustrated in Plate 3.

DEVELOPMENT OF PPI

12. The first experimental method for producing a radial sweep made use of the electrostatic deflection type cathode-ray tube. The form of the voltages that need to be generated in this case has been given in equations (3) through (6). The output of a push-pull saw-tooth generator is applied to the control grids of four triodes, operated push-pull in pairs. By means of a sine wave generator geared to the antenna, the bias on the control grids of these tubes is varied sinusoidally as a function of the antenna

position so that their outputs are saw-tooth voltages whose maxima also vary sinusoidally in the same way. These voltages are amplified in two stages and then applied to the deflecting electrodes of the cathode-ray tube. So that the sweep will rotate with the proper end at the center of the tube, a sinusoidal voltage likewise dependent on antenna position is placed on the control grids of the output tubes which are directly coupled to the deflecting electrodes. Thus, the average bias of these tubes is automatically adjusted to keep the sweep properly centered as it rotates on the fluorescent screen.

13. Another scheme using electrostatic deflection, but only requiring one sine wave generator was tried. The forms of the voltages to be generated in this case have been given in equations (7) through (10). Four individual saw-tooth generators are directly coupled to the horizontal and vertical deflecting electrodes. Through the use of a sine wave generator geared to the antenna, the plate voltages of these saw-tooth generators are varied sinusoidally with the position of the antenna. The saw-tooth voltage starts at ground potential on all four deflecting plates so that a special bias supply is not necessary to keep the sweep rotating properly about the center of the tube.

14. Various types of sine wave generators have been employed. Direct-current potentiometer arrangements introduce into the circuits objectionable brush noise which cannot be completely eliminated. A synchro generator geared to the antenna can be made to furnish a sinusoidally varying potential through the use of appropriate rectifying and filter circuits and this seems to be the best method for obtaining such a potential.

15. Several modifications of these circuits for electrostatic cathode-ray tubes tried but they all were fairly complicated. The idea then occurred to use a magnetic deflection type tube so that the field producing the radial sweep could be rotated mechanically in synchronism with the radar antenna. Accordingly, rotatable magnetic deflection yokes were constructed and used with both a projection-type television cathode-ray tube arrangement and a television cathode-ray tube having a fluorescent screen 12 inches in diameter.

16. In the cathode-ray projection-tube type PPI, the cathode-ray tube was mounted vertically with the fluorescent screen facing a spherical mirror so that the pattern appearing on the screen was focused on an 18 x 18" ground glass screen mounted as a table-top. If a permanent record of the successive positions of moving objects was desired, the ground glass screen could be replaced by a sheet of plain glass covered with tracing paper so that as the echoes appeared their outlines could be traced on the paper. The persistence of the fluorescent screen was not sufficient to permit the whole pattern to be viewed at any time, the intensity of the echoes diminishing very quickly after the sweep passed by them. The horizontal yoke of this PPI was driven mechanically so that its sweep rotated in synchronism with the directional antenna. To permit the expansion of any given sector of the pattern over the whole face of the tube, a vertical yoke was also used, thus providing a manual adjustment for moving the center of rotation of the sweep

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to any point at the edge of the fluorescent screen. As is evident from these statements, the horizontal yoke is defined as the one through which the sweep current is passed. By passing direct current through it, the vertical yoke is used for positioning the center of the PPI pattern.

17. This PPI had either 1-mile, 5-mile or 25-mile markers or any combination of them applied to the cathode-ray grid to produce bright range circles, by means of which the range of an object could be quickly estimated. In addition, the sweep line was brightened up every 10° to give radial azimuth markers to aid in determining the bearing of the object.

18. Since this type of tube could not be made with a screen of sufficiently long persistence and since a projection tube is not sensitive enough to give the proper contrast for viewing weak signals, this method was abandoned in favor of using a large cathode-ray tube and observing the screen directly.

19. At the same time that the projection type PPI was being tried and even for a while before, a PPI using a 12-inch cathode-ray tube was built. The same system of range and bearing markers as well as the same arrangement of deflection yokes was used. This apparatus, however, was open to the same objection as the projection type, namely, that the fluorescent screens available were not of long enough persistence.

20. Finally the greatly needed long-persistence screen was developed. The persistence of this new double-coated fluorescent screen was such that an echo would remain distinctly visible on the fluorescent screen for at least 12 seconds. When the repetition rate of the transmitter is 60 cycles per second, it becomes necessary to keep the speed of rotation of the antenna at or below 5 revolutions per minute (r.p.m.), since individual sweep lines are visible on the fluorescent screen if the antenna is rotated any faster. Since it is expedient to view all targets in 360° as quickly as possible, the antenna is generally rotated at 5 r.p.m. so that the PPI pattern is renewed once every 12 seconds. By using the long-persistence screen the whole 360° pattern is then continuously visible to the observer.

21. Experiments were then conducted to determine the best type of markers to be used on plan position indicators. It was decided that having bright range circles and bright radial bearing markers every 10° on the fluorescent screen interfered with viewing the echoes received. Thus a marker system was tried whereby 2 bright circular arcs about 4 miles apart and 9° wide could be adjusted to any range and bearing on the face of the tube by simply rotating two dials. After centering an echo between this pair of markers, the range is read directly from one dial (used to adjust the radial distance of the markers) and the bearing from another (used to adjust the position of the markers in azimuth). The objection to a system of this type is one which arises from the loss in time in properly setting the markers. This is especially serious when it is necessary to rotate the antenna slowly (5 r.p.m.) as is always the case with 60-cycle-per-second repetition rates.

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22. An adjustable marker consisting of a single bright circular arc and a marker consisting of a blank arc in a bright circle were also tried. Both of these systems, although they are capable of producing accurate readings of range and bearing, are open to the same objection as the 2-marker method described above.

23. Because of the difficulty in obtaining a quick and at the same time accurate adjustment of the marker both for range and bearing, it was decided to dispense with the electrical type of marker. By engraving a hair-line and appropriate scale divisions on a rotatable disc and mounting this disc above the face of the cathode-ray tube together with a fixed disc engraved with a scale of degrees, a suitable system is provided for determining both the range and bearing of an echo with sufficient accuracy as well as with the requisite speed.

PPI MODEL RA 55 ACN

24. In November 1941, the Bureau of Ships established problem X4-13S, authorizing the construction of two (2) units of the latest PPI developed at NRL to be used in connection with SC-1 equipment. With this combination of apparatus, the search for objects is accomplished by viewing the PPI fluorescent screen while rotating the antenna at a constant speed (5 r.p.m.). Whenever an echo appears, its approximate bearing may be obtained very quickly by rotating a Lucite disc so that the radial line engraved on it is centered on the echo. The bearing can then be read from the angular scale engraved around the circumference of a fixed Lucite disc. Both discs are edge-lighted to make all engraving visible to the operator without interfering with the observation of any echoes. The range can be estimated by using the linear scale engraved along the hair-line used for finding the bearing. If a more accurate range and bearing determination is desired, the operator can stop the antenna so that it is pointing directly at the object and use the SC-1 for such readings.

Mechanical Construction

25. This model of the PPI has been designated as NRL Model I-4 and Bureau of Ships Model RA 55 ACN. Two PPI Units, marked Serial #101 and #102, have been constructed under Problem Number X4-13S. They are each 570 pounds in weight and have a power input of 60 cycles, single phase, 115 volts, 5.5 amperes and 500 watts. The cabinet for this model (Plates 6 and 7) is of steel construction finished with Navy gray enamel and the panels have a Navy gray wrinkle finish on their exposed surfaces. Its dimensions are 38 inches (high) by 36 inches (wide) by 21 inches (deep), plus a sloping bay which comes to a peak at 27 inches above the base, the depth of the cabinet at this peak being 33 inches. The bay is at the front of the cabinet and placed between the top and a point 20 inches above the base to provide leg room for the observer. The cabinet is designed expressly for mounting the type SC-1 receiver-indicator and control units on its top since the PPI and SC-1 are intended to be used by one and the same operator. The two SC-1 units are equipped with rubber shock mounts which are retained when these units are

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bolted to the top of the cabinet. The cabinet itself is vibration mounted at its base and the component units in the cabinet are individually shock mounted.

26. The cathode-ray tube is held in a separately shock-mounted cradle so that the fluorescent screen is in an inclined plane to make viewing by a seated operator easier. Also mounted on this cradle are the magnetic focusing coil, the rotating yoke (magnetic deflection coils), and the driving system for rotating the yoke. (See Plates 7 through 10).

27. All front panels are fastened in by thumbscrews, the power being disconnected by interlock switches whenever one of these panels is removed. All power, signal, and other cables are brought in at the rear of the cabinet to terminal board TB-7 (See Plate 10). This terminal board contains four female Jones connectors to which are brought four 3/8 inch flexible coaxial lines, one to carry signal from the recognition receiver, and the other three to carry the synchronizing pulse, receiver signal, and marker signal from the SC-1.

Signal and Sweep Unit

28. The signal and sweep circuits are contained in chassis TB-4 (see Plates 4, 17 and 18) mounted behind the left-hand control panel. A positive keying pulse synchronized with the transmitter pulse is brought into this chassis over 3/8 inch 75-ohm flexible coaxial line to Jones plug A (see the circuit diagram in Plate 21). This pulse is fed through one half of V-8 which serves as a keyer for the multi-vibrator tube V-9. The grid circuit constants of V-9 can be given three different values resulting in square waves of three different widths, but all having the same repetition rate (60 cycles per second). The range, or the total time taken for the electron beam to sweep from the center to the edge of the fluorescent screen, is determined by the width of this square wave so that three possible ranges are provided. Serial #101 of Model RA 55 ACN has 20, 50 and 100 mile ranges while Serial #102 of Model RA 55 ACN has 20, 100 and 300 mile ranges. Any one of these ranges can be selected through the use of the three-position rotary switch marked RANGE MILES. A variable potentiometer marked SWEEP VERNIER is in series with the grid resistors on one half of the multivibrator; it can produce a small change in width of the square wave corresponding to about 10 miles of range.

29. The positive square wave generated by this multivibrator is amplified in one half of V-10 to give a negative square wave which is applied to the grid of the other half of V-10, blocking it for a small part of a cycle. While the tube is blocked, a combination of saw-tooth and square wave (due to the particular resistance-capacity circuit used) is impressed upon the grids of V-11 and V-12 in parallel. This tube (V-10) is used to generate a voltage of the shape needed to give a saw-tooth current through the electro-magnetic deflection coils present in the plate circuit of V-11 and V-12. This saw-tooth current through the deflection coils will produce a linear sweep on the fluorescent screen, that is, equal distances will be swept in equal times.

To vary the amplitude of the sweep, the plate voltage of the second half of V-10 is varied by changing the position of the potentiometer marked SWEEP AMPLITUDE on the control panel.

30. The positive video signal coming from the SC-1 receiver is fed into the cathode follower tube V-1 (see Plates 19, 20 and 21). The cathode of this tube is connected through a resistor to a 75-ohm 3/8 inch flexible coaxial line which is terminated in the PPI video chassis by a 75-ohm potentiometer. The movable arm of this potentiometer is connected to the grid of V-3 through a resistance-capacitance coupling circuit. The position of this movable arm determines the voltage of the signal applied to the PPI video channel and is thus called the SIGNAL AMPLITUDE control. The positive video signal on the grid of V-3 is amplified to give a negative video signal applied to V-4. The saturated peaks of the negative video signal coming into V-4 may be clipped off by adjusting the grid bias on this tube, that is, by adjusting the SIGNAL LIMITER control. The strong signals can be made to drive the tube beyond cut-off and thus be cut down in amplitude so that weak signals will have comparable strength. This will prevent saturated signals from overdriving the grid of the cathode-ray tube (which would result in brilliant fluorescence and defocusing of the electron beam) and by thus reducing the contrast between strong and weak signals will make it easier for the operator to detect weak signals. Tube V-4 shares its plate load with V-5 so that the positive square wave coming from V-5 is mixed with the video signal and then applied to the cathode-ray tube grid. Since the multivibrator V-9 supplies V-5 with a negative square wave whose width depends upon the range being used on the PPI, the electron beam is cut off except when it is sweeping across the face of the tube. This is accomplished by adjusting the grid bias on the cathode-ray tube by means of the control marked INTENSITY.

31. The electron beam is focused electromagnetically by adjusting the current passing through a coil whose axis coincides with that of the cathode-ray tube. This control is marked FOCUS.

32. To measure range in the SC-1 indicator, a step wave is employed which can be moved to coincide with an echo at any point within the range being used. This step wave is taken off the cathode of V-703 in the SC-1 through a small condenser and carried through a flexible coaxial line to the video chassis of the PPI. By amplification through four stages and by using short time constants the step is changed into a pulse marker which is put onto the grid of the PPI cathode-ray tube. This marker may be switched on or off by using the toggle switch labeled MARKER. The position of the marker on the face of the PPI cathode-ray tube depends on the position of the step wave in the SC-1.

33. The ranges on the PPI can thus be calibrated by setting the SC-1 marker on the maximum range of the PPI sweep to be used and adjusting the SWEEP AMPLITUDE control until the marker coincides with the last scale division engraved on the PPI Lucite disc.

Power Supplies

34. The power supplies are of conventional design, the high voltage supply for the cathode-ray tube employing a voltage doubler circuit (see Plates 15, 16 and 21) while all others employ full wave rectifier and choke condenser filter circuits (see Plates 11, 12, 13 and 14).

Deflection Yoke Follow-up System

35. The mechanism used to keep the magnetic deflection yoke turning in synchronism with the antenna consists of two electromagnetic slip clutches operating on a common shaft (see Plates 5, 8, 10 and 21). The two outer members of the clutch mechanism are driven in opposite directions by a 1/12 h.p. 1725 r.p.m. alternating-current motor coupled to them by bevel gears. The two inner members are bipolar armatures which are placed in the plate circuits of tubes V-13 and V-14. When the antenna is rotated, the resulting voltage from the secondary of a 5 CT synchro control transformer (E-2 in Plates 9 and 10) geared 1:1 to the deflection yoke appears across the primary of transformer T-4. One end of each of the secondaries of T-4 is connected to one grid of V-15 and the secondaries are phased so that when one grid is driven positive the other grid is driven negative. Let us assume for the moment that the 5 CT is in a position that causes the right hand grid of V-15 to be positive and that at the same time the voltage applied to the plates of V-13, V-14, and V-15 is positive. Under these conditions the right hand half of V-15 will be conducting causing a voltage drop across plate resistor R-65. This voltage drop is sufficient to block V-14 nearly to cut-off. At the same time the left half of V-15 is blocked; hence there is no voltage drop across plate resistor R-64 and V-13 draws heavy current. This current passes through the corresponding electromagnetic clutch which, due to the action of induced eddy currents, tends to rotate the 5 CT toward the null (zero voltage output) position, that is, tends to rotate the deflection yoke to correspond to the position of the antenna. On the next half cycle V-13, V-14 and V-15 have negative voltage on their plates causing no effect. If the 5 CT is out of position on the other side of the null position V-14 will draw heavy current tending to rotate the system in the opposite direction and bring the 5 CT to the null position. Thus the output of the synchro generator in the antenna pedestal changes as the antenna rotates, which in turn causes the output of the 5 CT to change and the system tends to follow the rotation of the antenna.

36. To prevent the system from hunting, two circuits are included. An adjustable resistor is connected between the plates of V-13 and V-14; it can be set with a screwdriver from the front of chassis TB2 after the lower front panel of the cabinet has been removed. This resistance tends to damp out oscillations but should not be made too small or it will result in a large angular lag in the system. Further a small direct-current generator E-3 (Plate 8) is geared up from the yoke in the ratio of about 100:1. The output of this generator is amplified in V-17 which is in turn coupled to the grids of V-15. The coupling is such that only a change in the output of the generator (corresponding to a change in its angular velocity) will be

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transmitted to V-15. This change in voltage is introduced as a voltage bucking that of the 5 CT so that high accelerations of the follow-up mechanism are reduced and as a result hunting is reduced.

37. By setting the two angular control dials (see the upper left and upper right section of the PPI control panel in Plate 6) on the PPI, the antenna can be made to rotate back and forth through any given sector. The minimum possible sector that can be scanned is approximately 30 degrees and the maximum practical sector is 180 degrees. If sectors greater than 180 degrees need to be observed it is more efficient to allow the antenna to rotate continuously through 360 degrees. By limiting the scan of the radar system to some comparatively small sector, the pattern in that sector is repeated more frequently than would be so if the antenna were allowed to continue through the complete 360 degrees. Thus sector scanning enhances closer observation of a particular sector but it does not prevent the observer from allowing the antenna to rotate through 360 degrees every few minutes or so to check up on targets in other directions. For turning this sector scanning on or off a toggle switch marked ANGULAR SWEEP is provided on the control panel.

Performance

38. From data taken at NRL on several fixed landscape echoes the following statements can be made concerning the accuracy of measurements made using PPI Model RA 55 ACN. At its operating speed of 5 revolutions per minute the PPI sweep lags behind the rotating antenna by very nearly $1/2$ degree. After an operator has had some experience in observing PPI patterns, he can determine the bearing of most echoes with a probable error of plus or minus 1 degree of arc, while range readings can be made with a probable error of plus or minus $1/10$ of a scale division. There are 10 scale divisions engraved on the rotatable Lucite disc so the value of a scale division will, of course, be different for each range.

39. The angle subtended by an echo depends on the beam width of the radar antenna. It is generally somewhat greater than 20 degrees for echoes received using the SC-1 and around 18 degrees for those received using the XAR-1 at NRL. Of course the angular width of an echo also depends upon the power radiated by the radar transmitter, the width increasing with increasing power. The photographs (Plates 22 and 23) taken of the fluorescent screen of Model RA 55 ACN Serial #102 using a 12-inch General Electric tube Type ZP477 show the pattern received when the XAR-1 transmitter was operating at 100 KW peak power. These photographs show all the fixed landscape echoes and 6 airplanes at various ranges up to 20 miles. The airplanes appearing in Plate 23 have been drawn in Plate 1 where their ranges and bearings have been listed. The PPI pattern given on a PPI aboard ship at sea would be similar to the diagram of Plate 1, rather than Plate 22 or 23, in which saturated echoes from buildings and landscape give a continuous brightening of the fluorescent screen to a distance of 7 miles or more.

CONCLUSIONS

40. At the present time the magnetic deflection type plan position

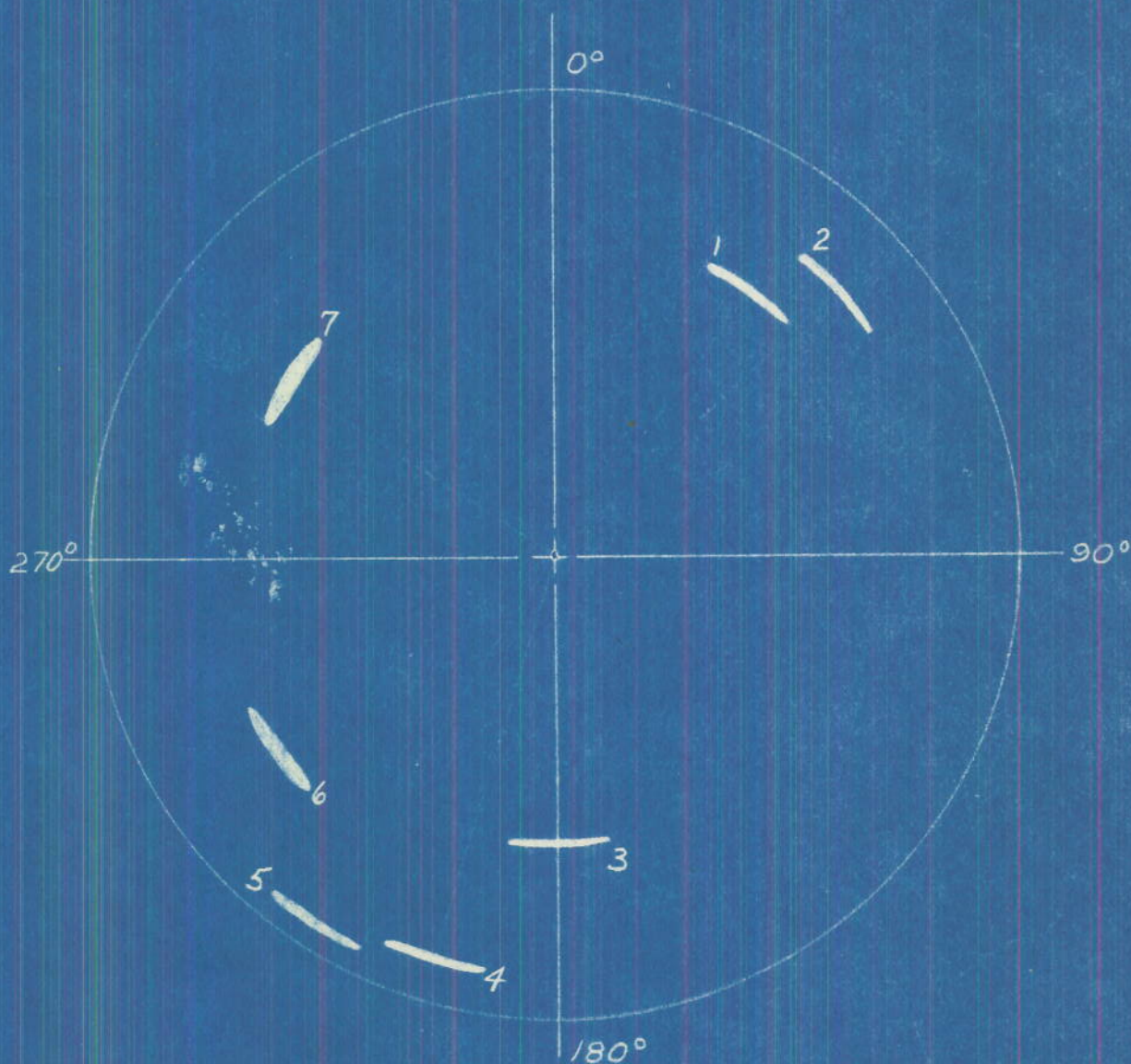
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indicator using a mechanically rotated deflection yoke is still the most accurate of all the types of such indicators. A satisfactory PPI of this type has been developed to a point where a model has been built for use aboard ship and to serve as a prototype for a manufactured product. Plan position indicators will undoubtedly become an indispensable adjunct to the radar systems now being used in the Fleet.

41. It is to be hoped that this will not be the end of the project since more research work should still be performed so that a more simple and accurate type of PPI can be built.

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DIAGRAM OF ECHOES APPEARING ON FLUORESCENT SCREEN OF PLAN POSITION INDICATOR



	RANGE (NAUTICAL MILES)	BEARING (DEGREES)
ECHO #1	10.0	36°
ECHO #2	17.6	47°
ECHO #3	13.8	180°
ECHO #4	19.2	197°
ECHO #5	20.0	214°
ECHO #6	15.4	235°
ECHO #7	14.2	304°
MAXIMUM RANGE = 20 MILES		

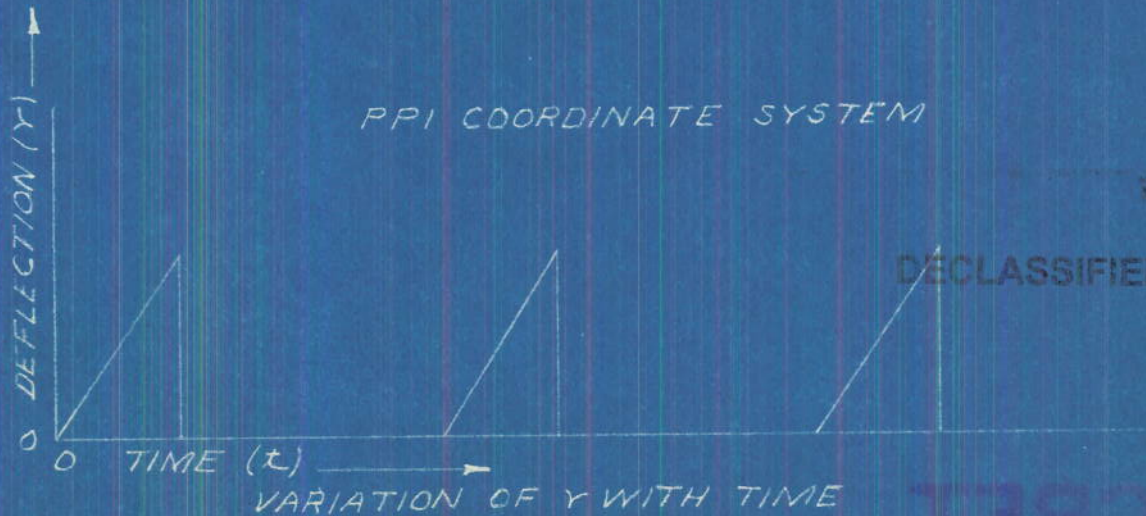
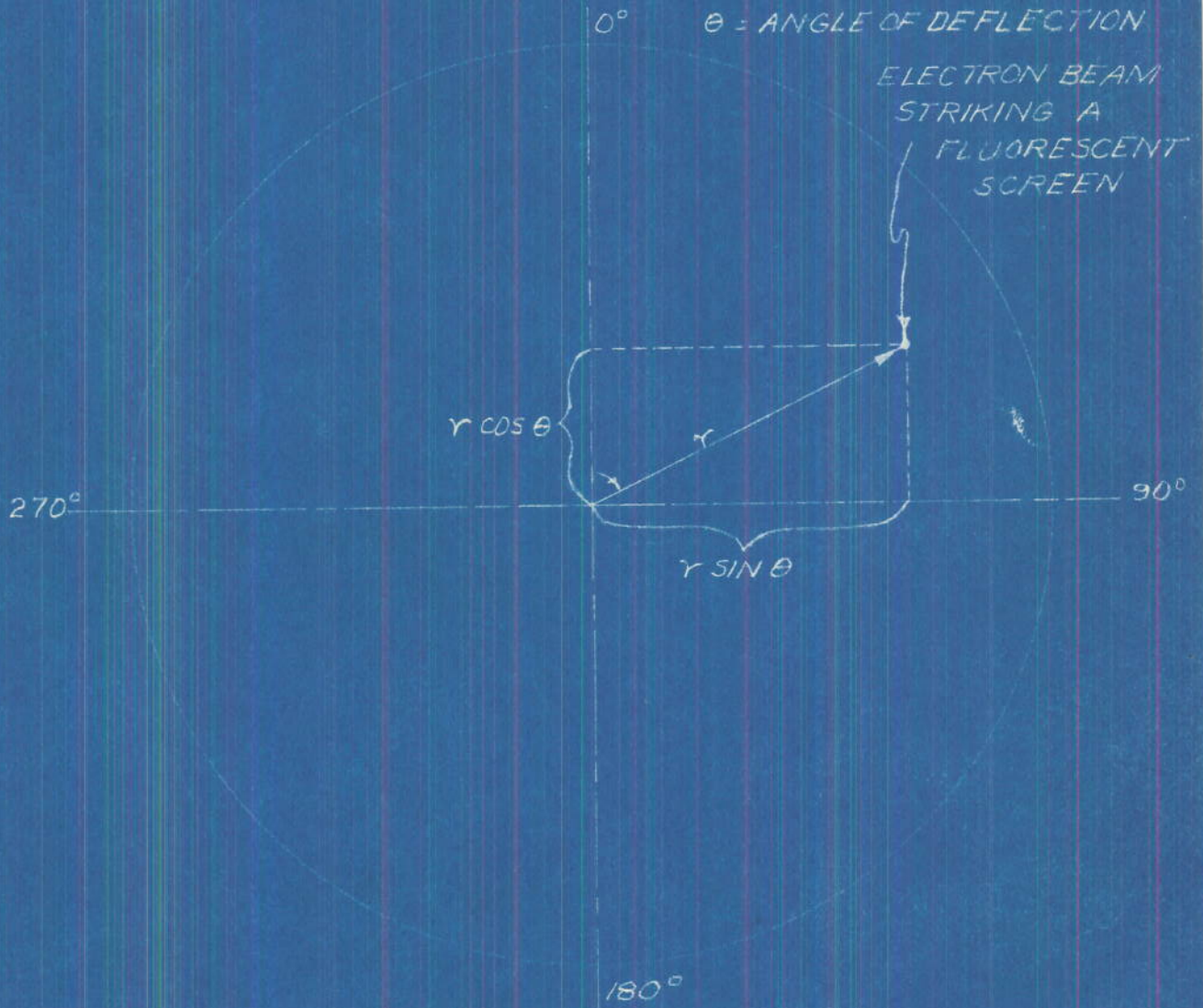
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PLATE I

DIAGRAM OF SWEEP USED ON PLAN POSITION INDICATOR

γ - DEFLECTION OF ELECTRON BEAM.

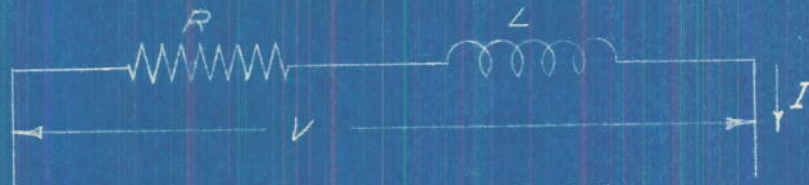
θ - ANGLE OF DEFLECTION



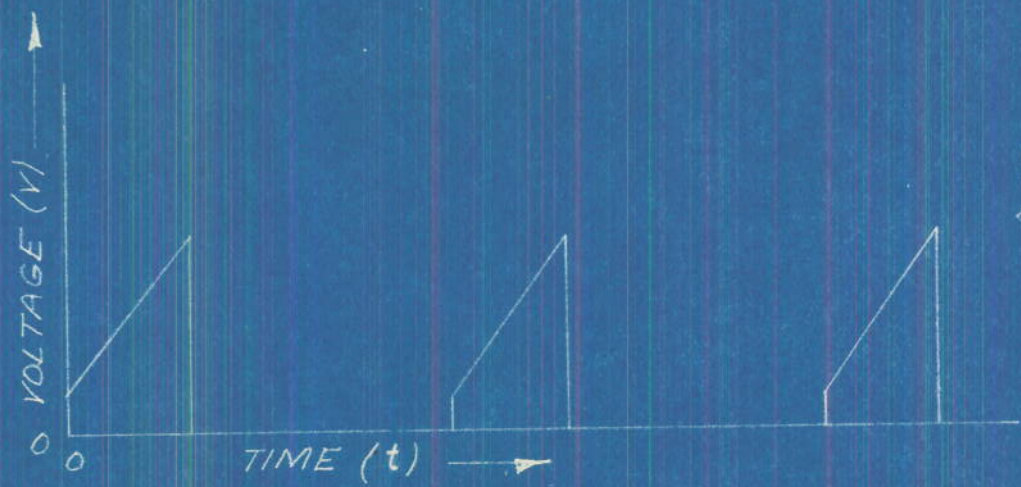
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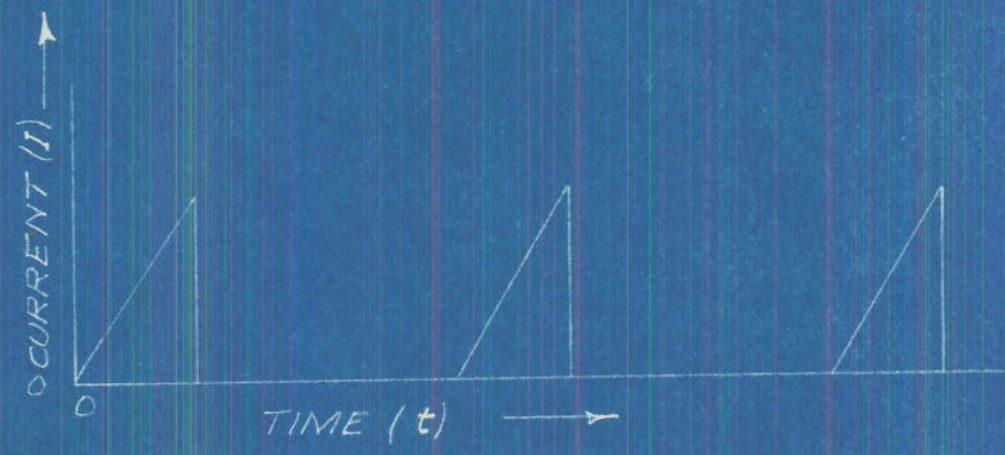
WAVE FORMS PRESENT IN MAGNETIC DEFLECTION YOKE



EQUIVALENT CIRCUIT OF MAGNETIC DEFLECTION YOKE



VOLTAGE WAVE APPLIED TO YOKE

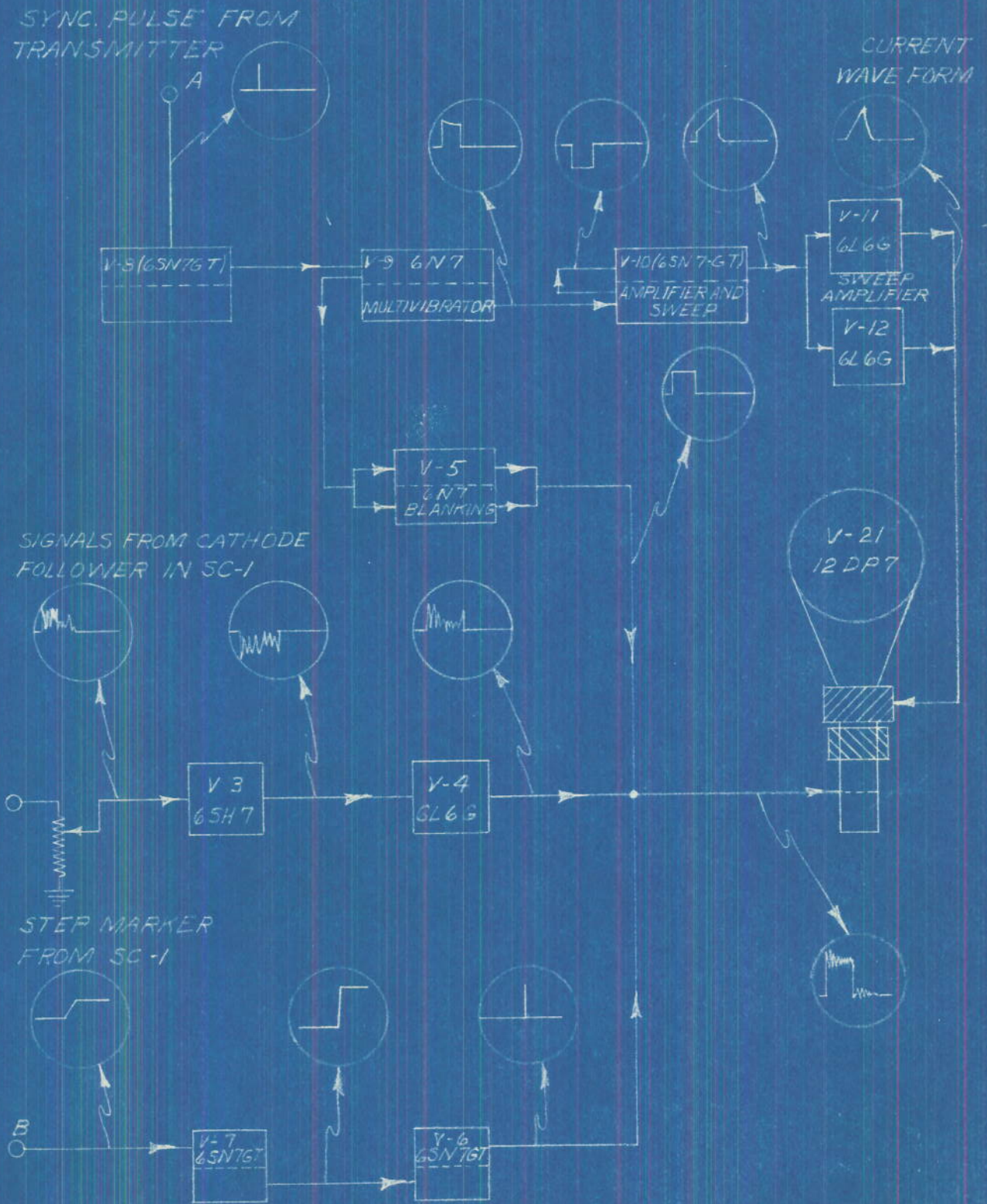


SAWTOOTH WAVE OF CURRENT THROUGH YOKE

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PLATE 3

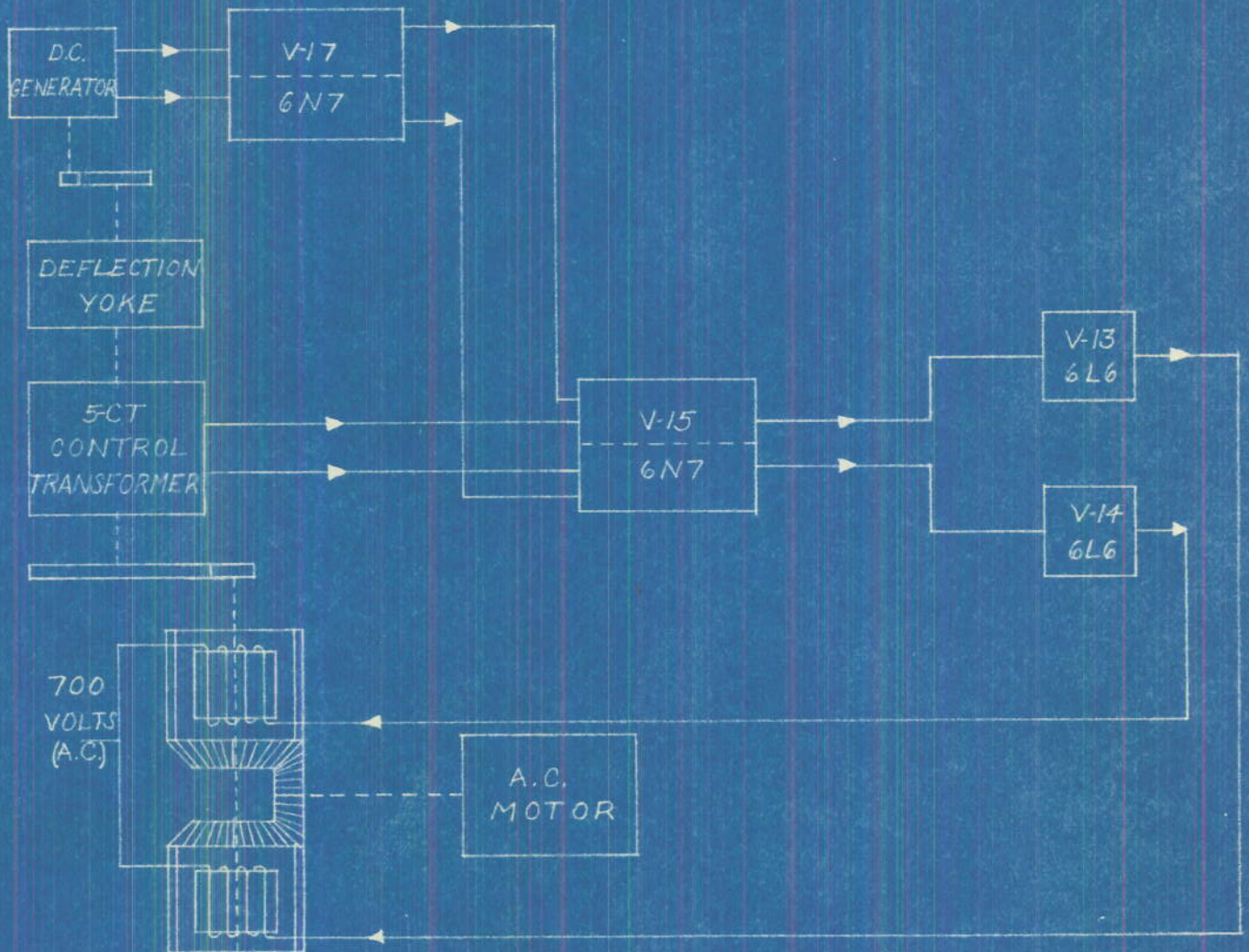
BLOCK DIAGRAM OF VIDEO AND SWEEP CIRCUITS



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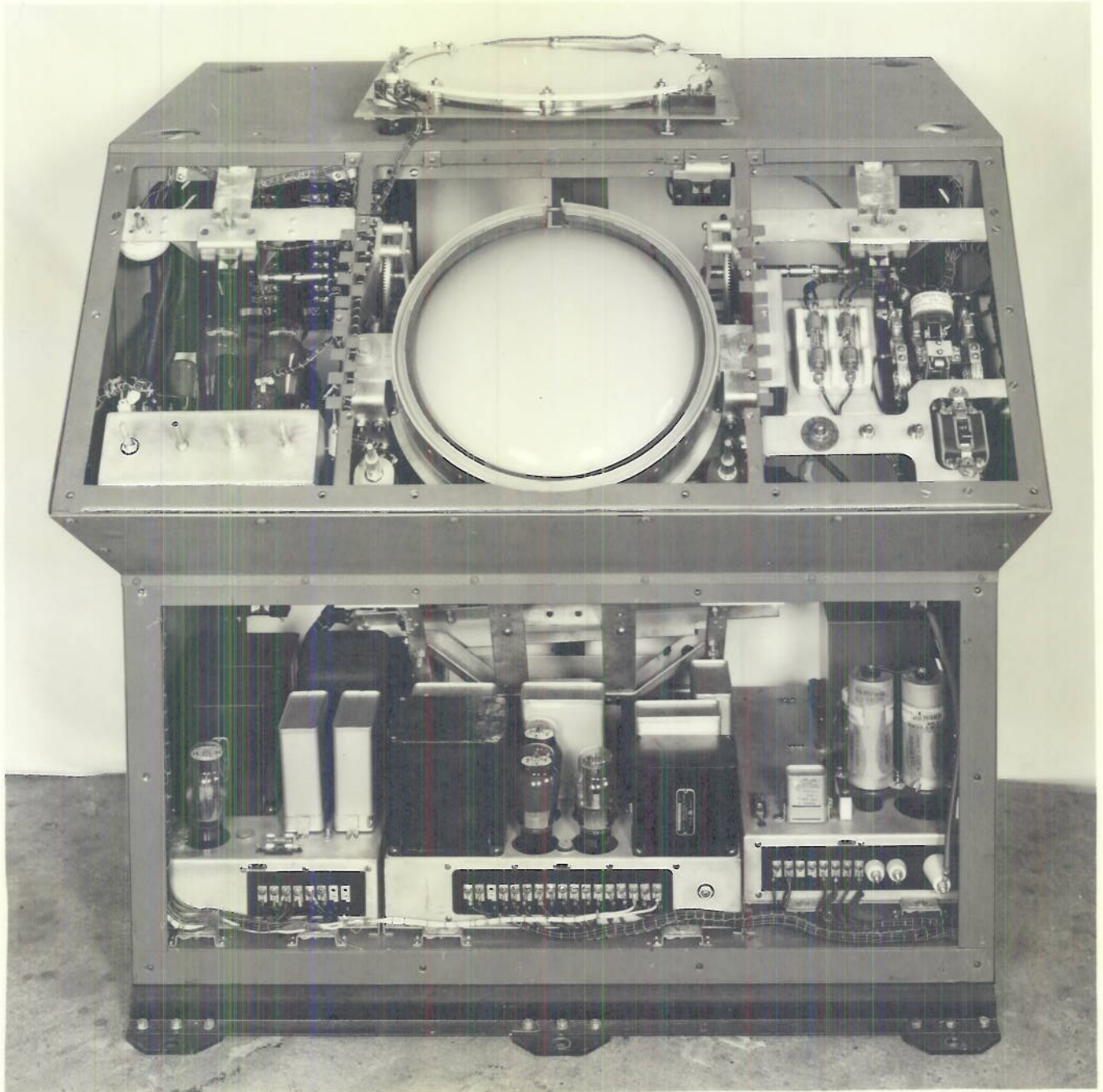
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BLOCK DIAGRAM OF
DEFLECTION YOKE FOLLOW-UP SYSTEM



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PLATE 5.

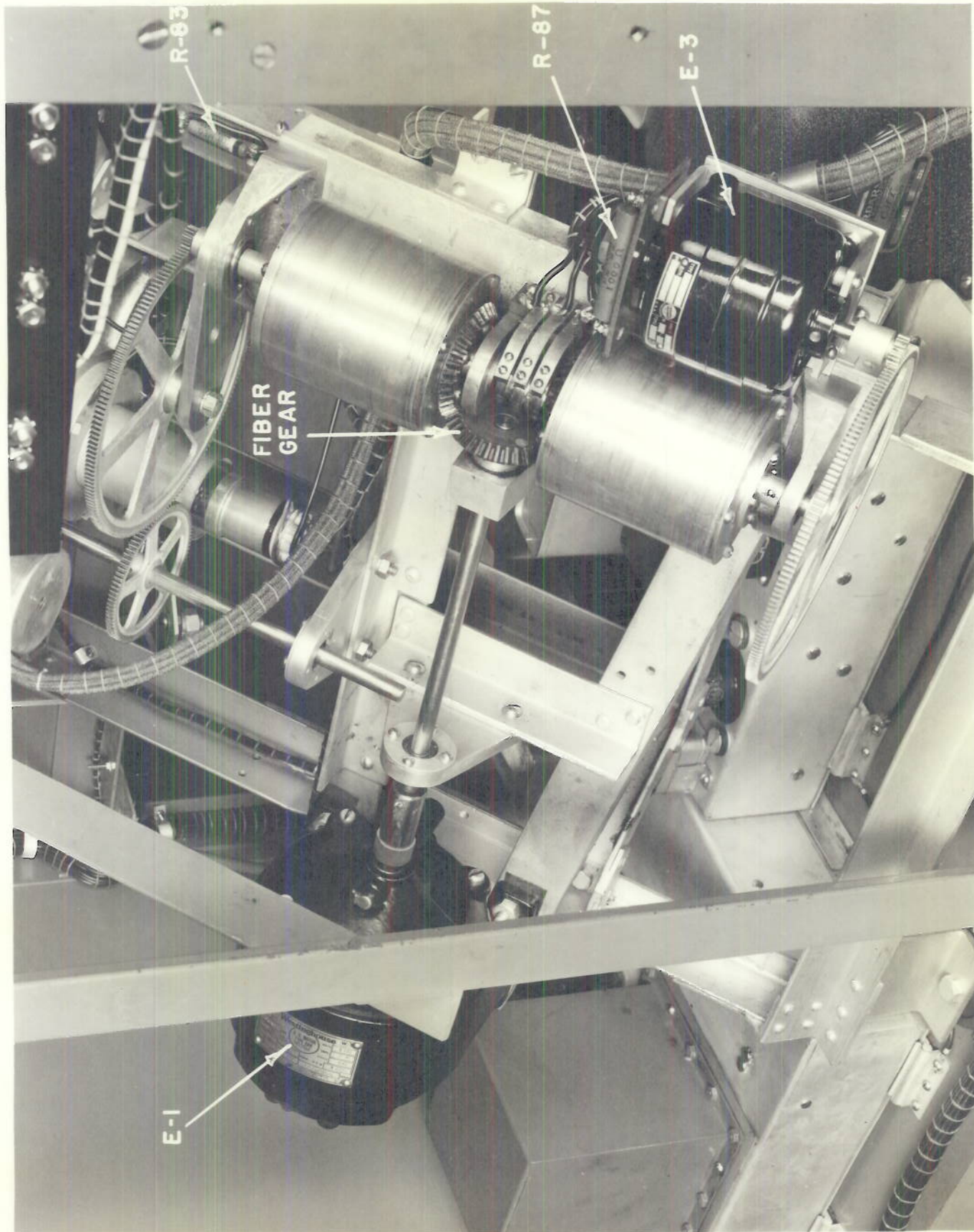


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PLATE 7



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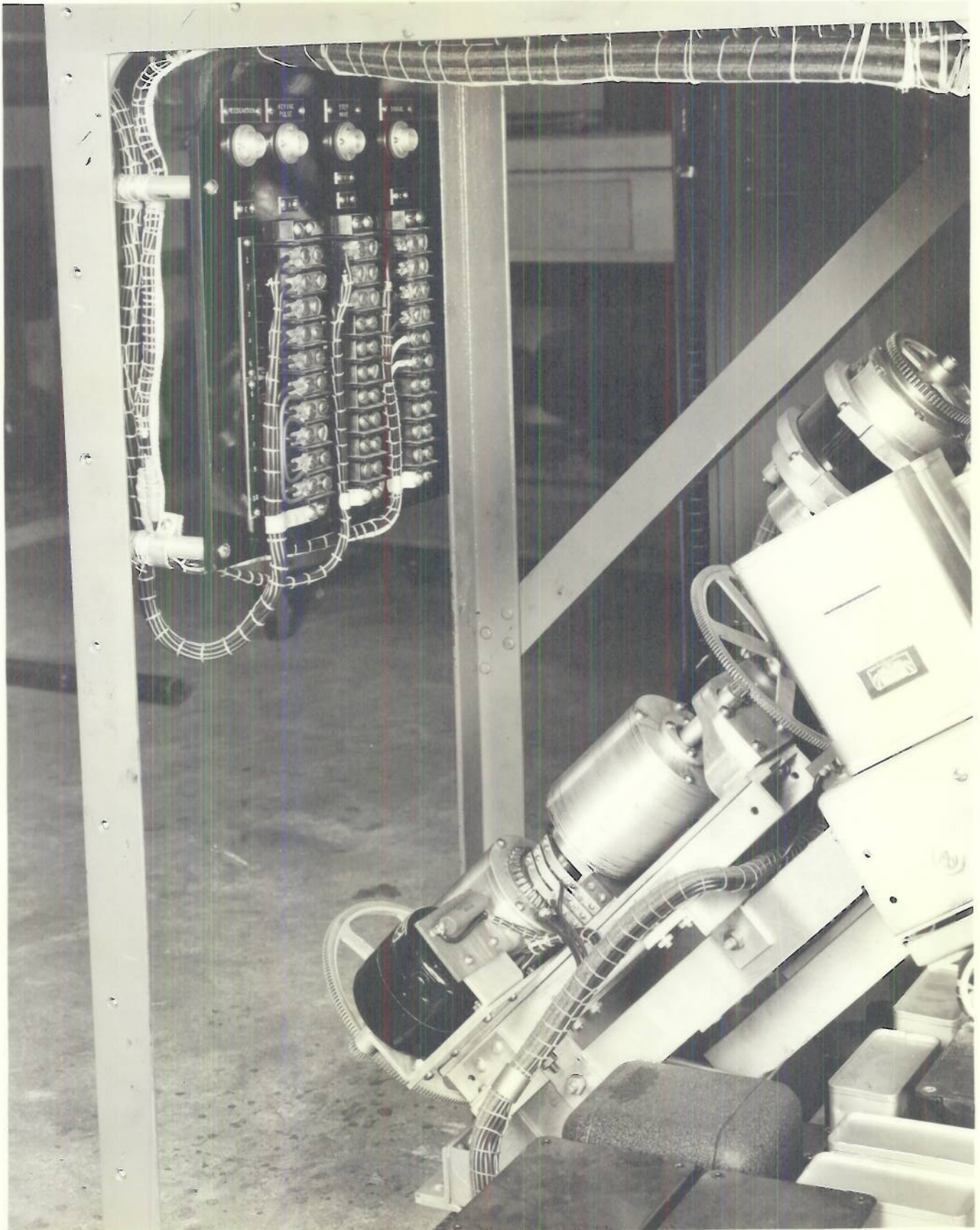
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PLATE 8



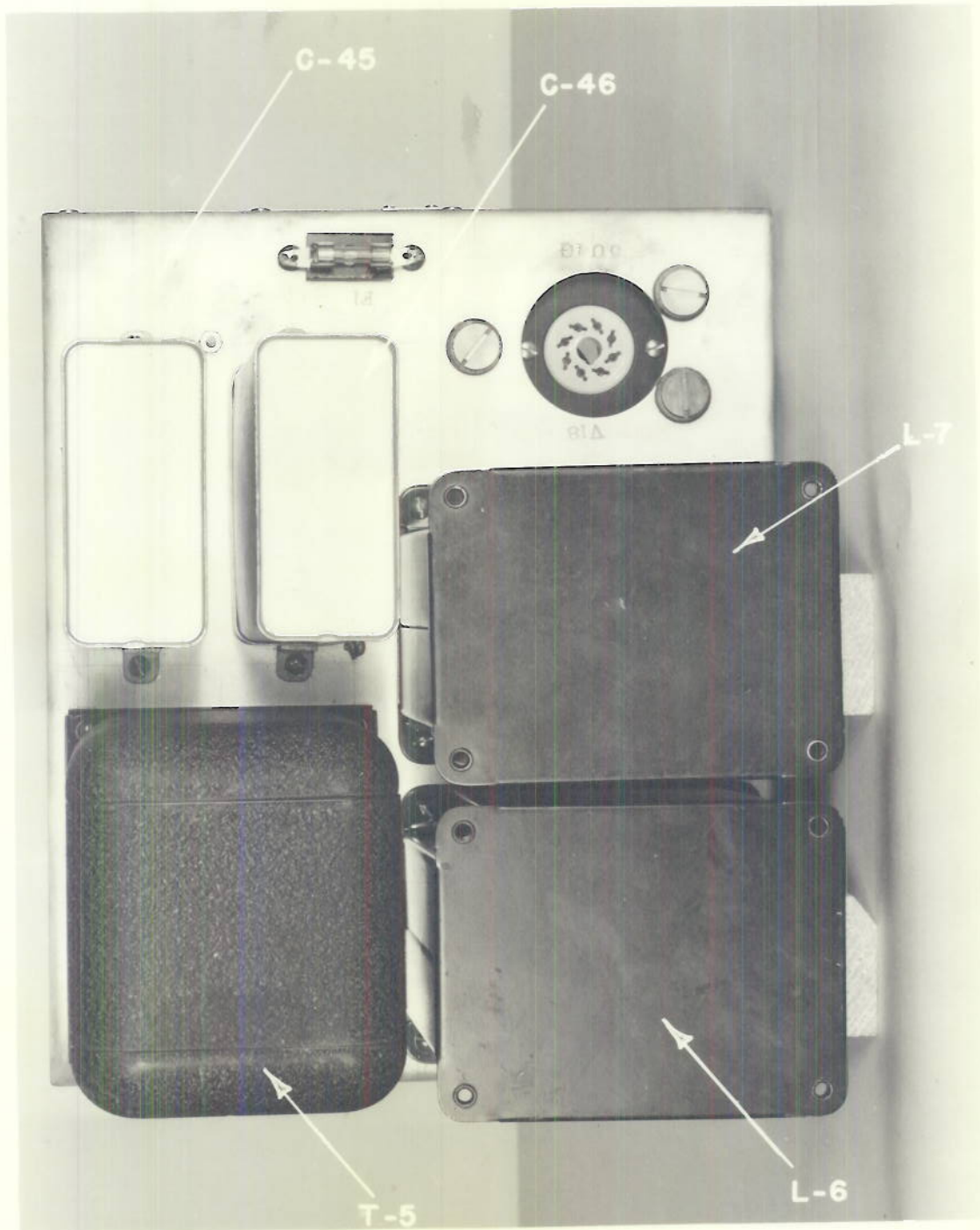
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PLATE 9



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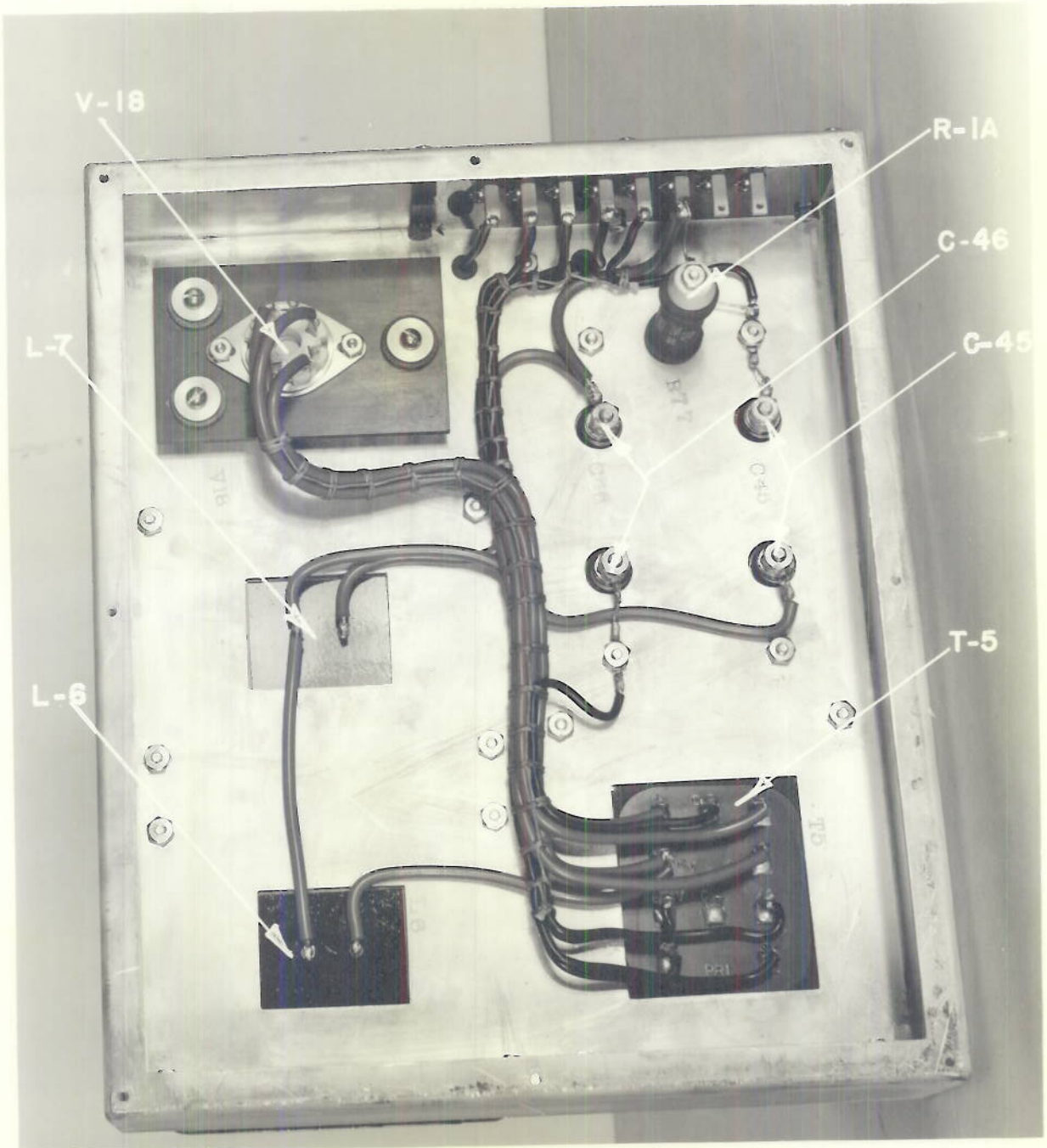
PLATE 10



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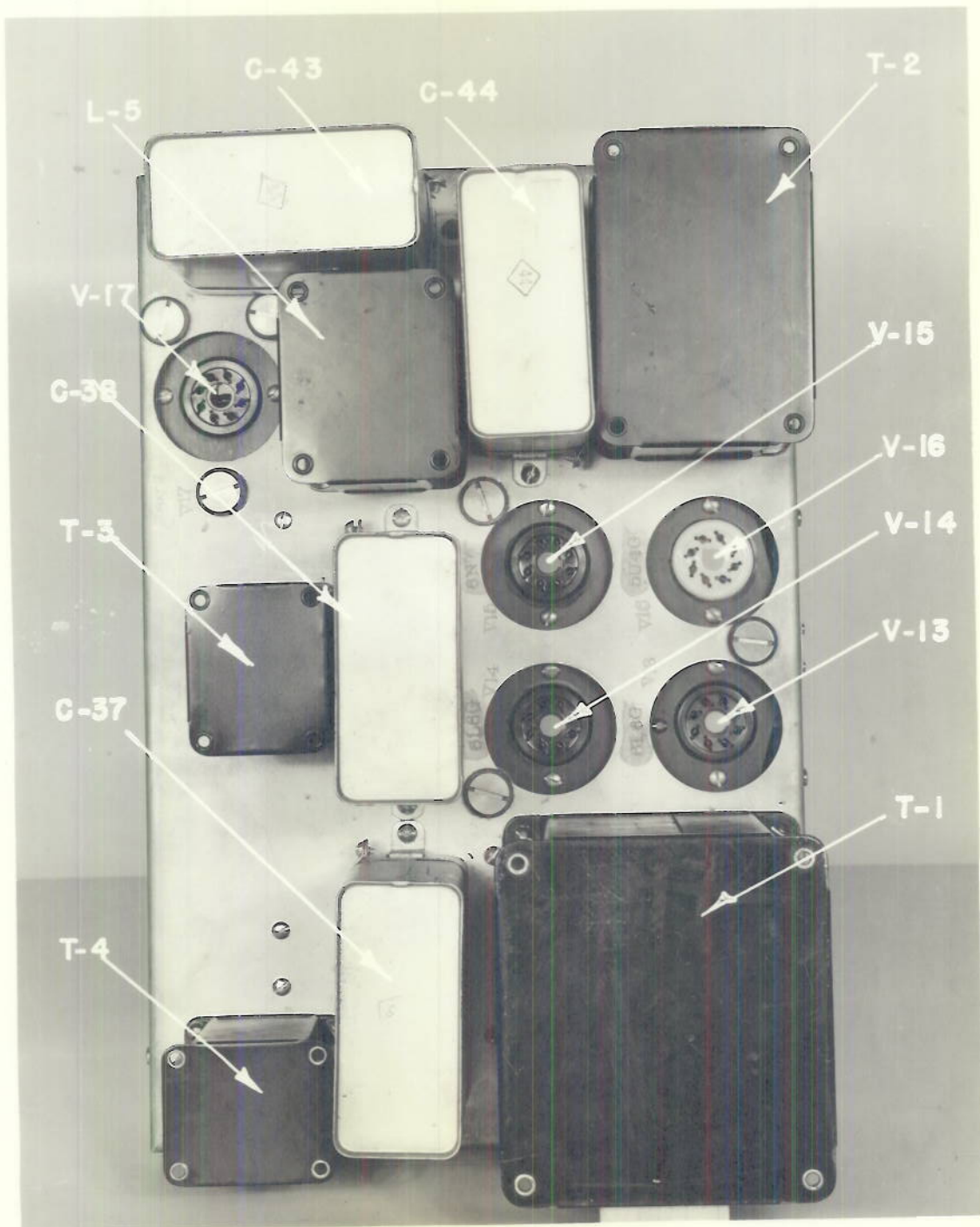
PLATE II



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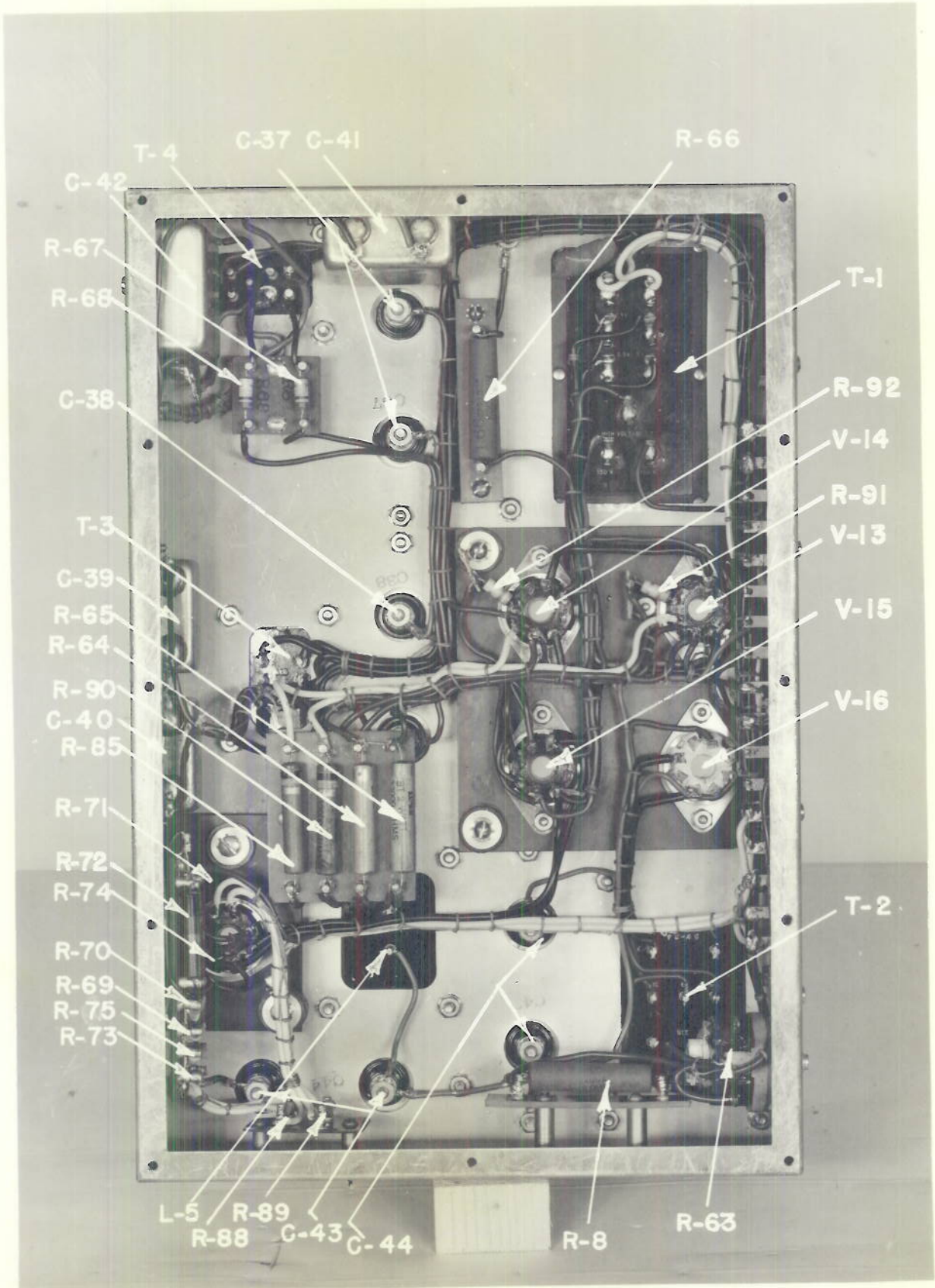
PLATE 12

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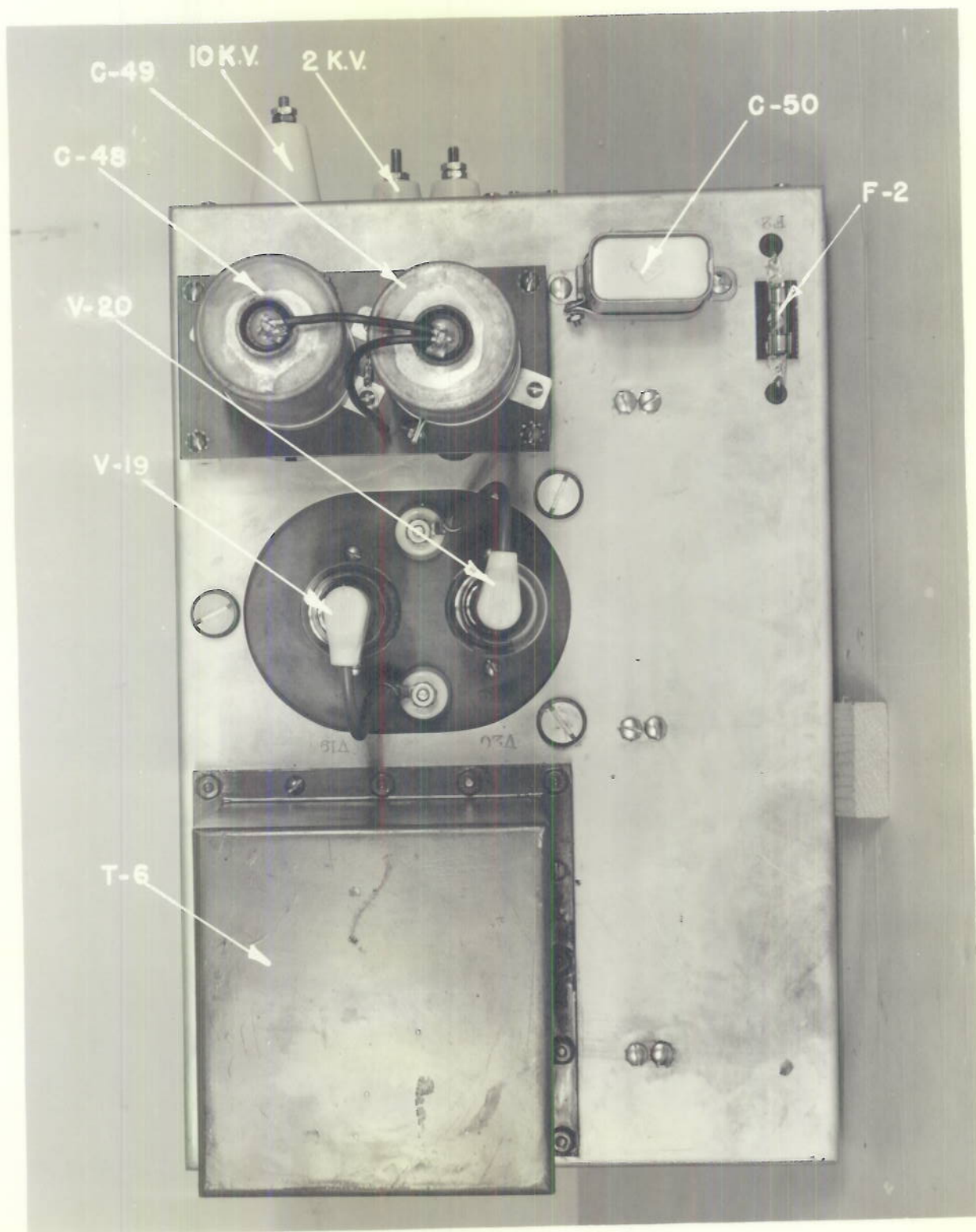
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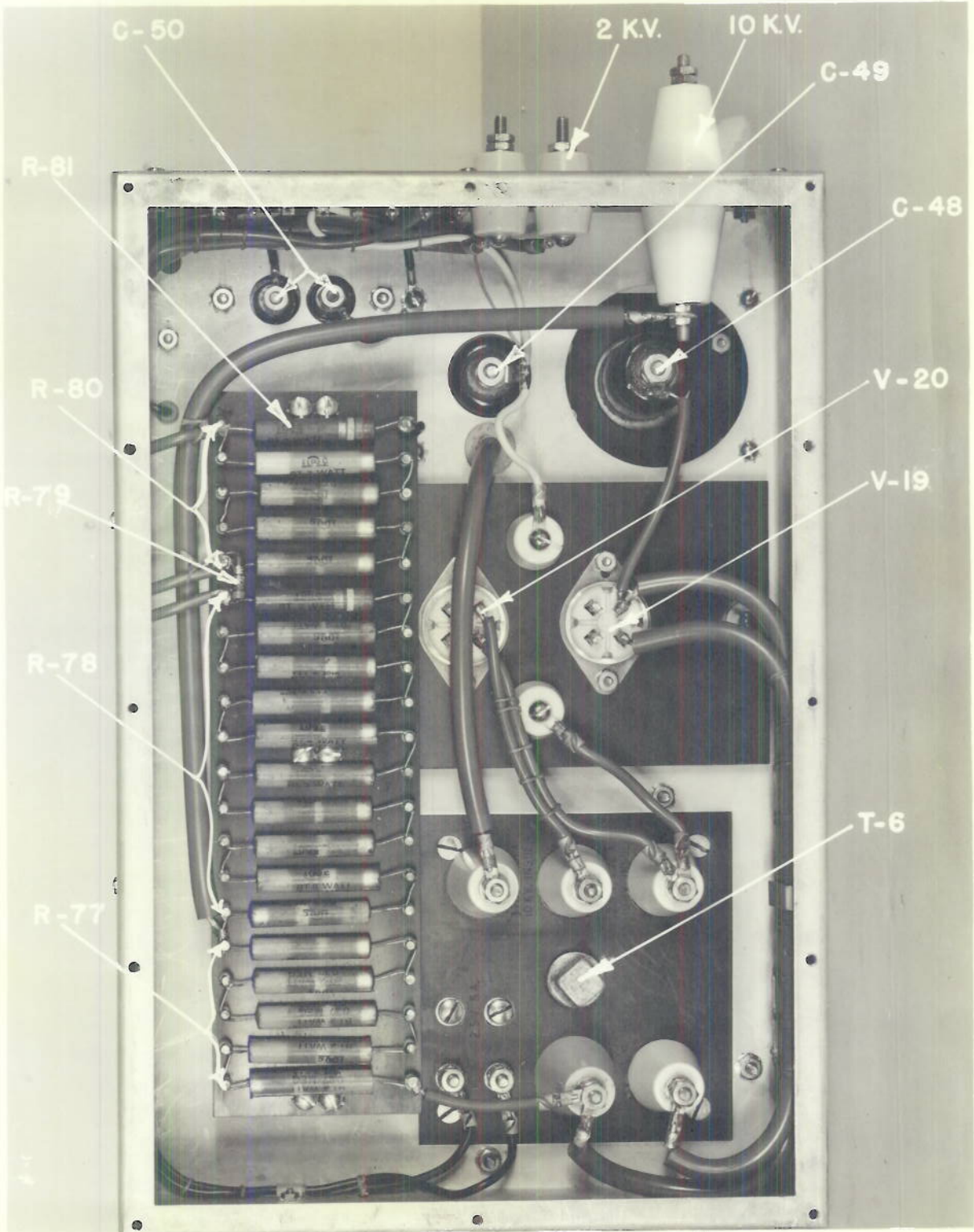
PLATE 14



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PLATE 15

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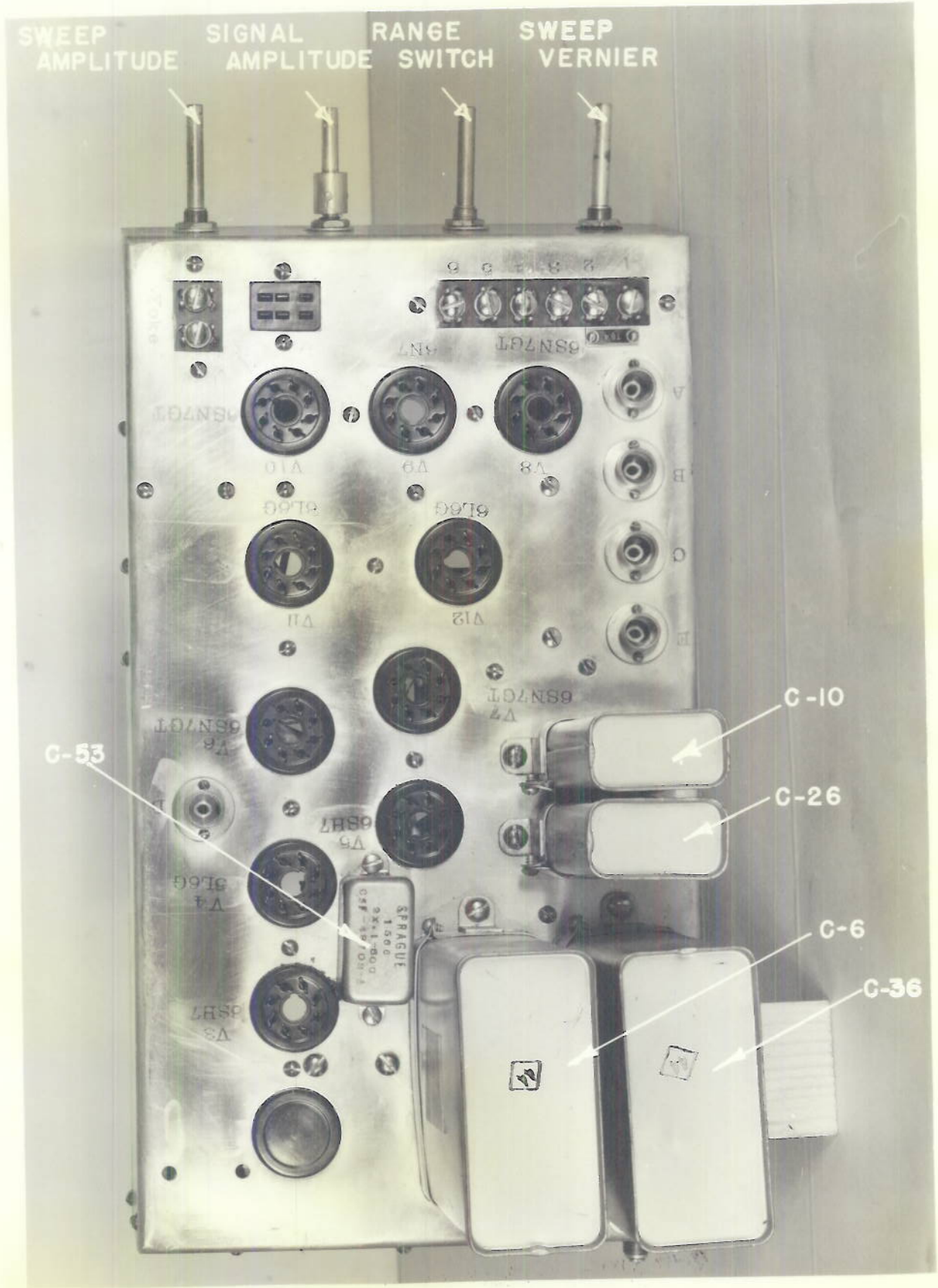
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SWEEP
AMPLITUDE

SIGNAL
AMPLITUDE

RANGE
SWITCH

SWEEP
VERNIER



C-53

C-10

C-26

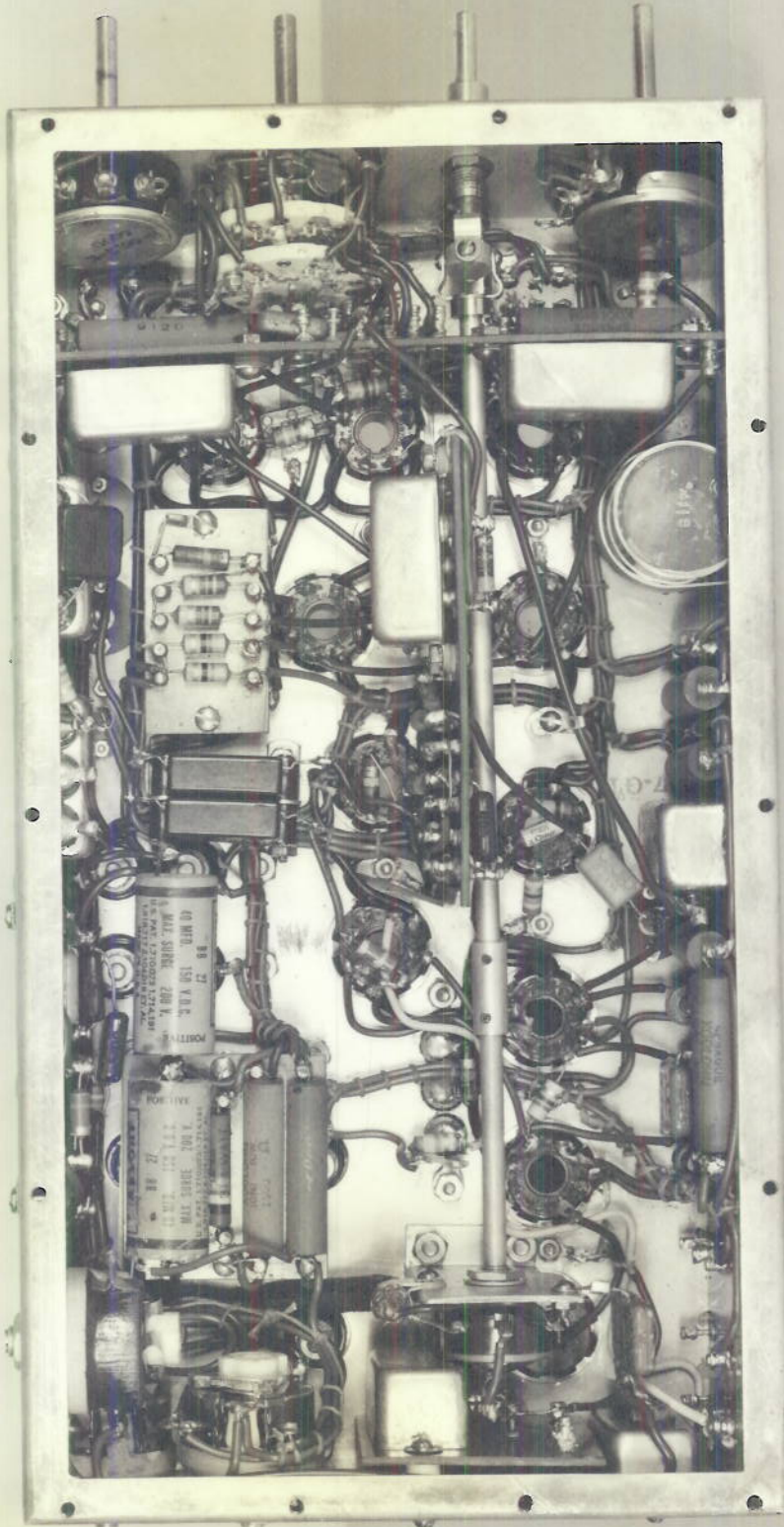
C-6

C-36

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PLATE 17

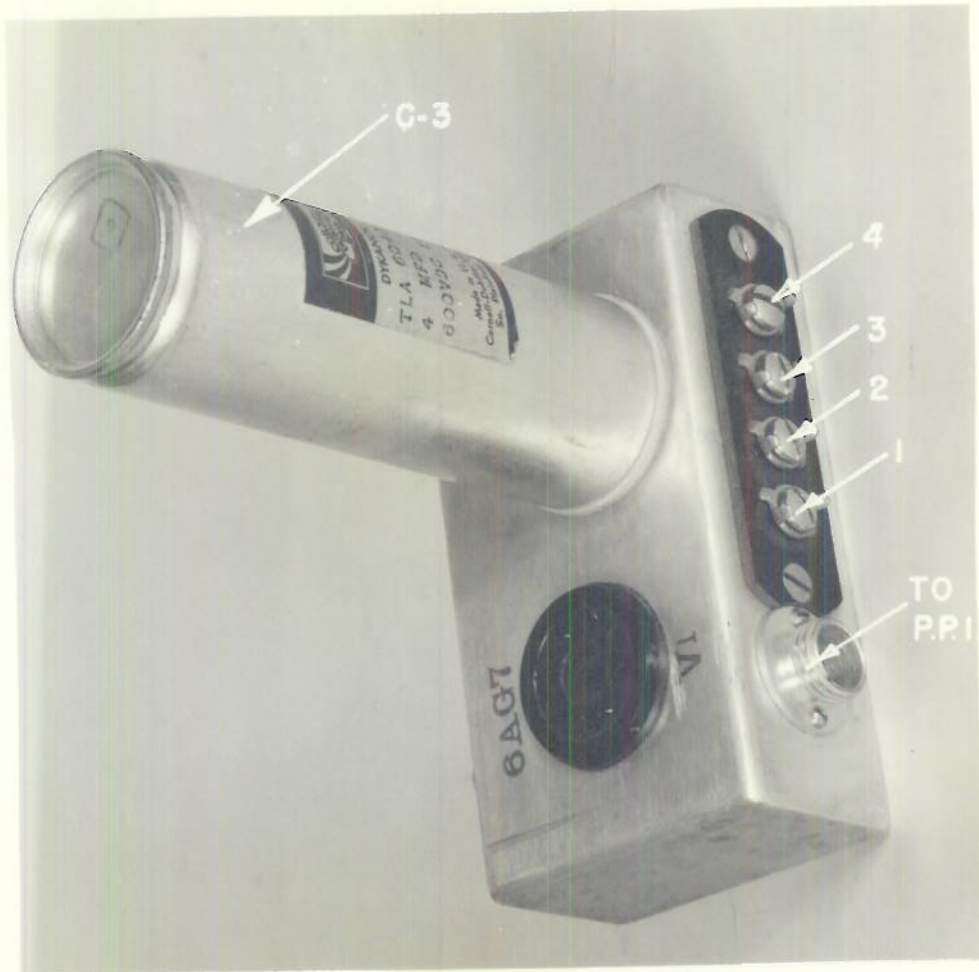
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PLATE 18

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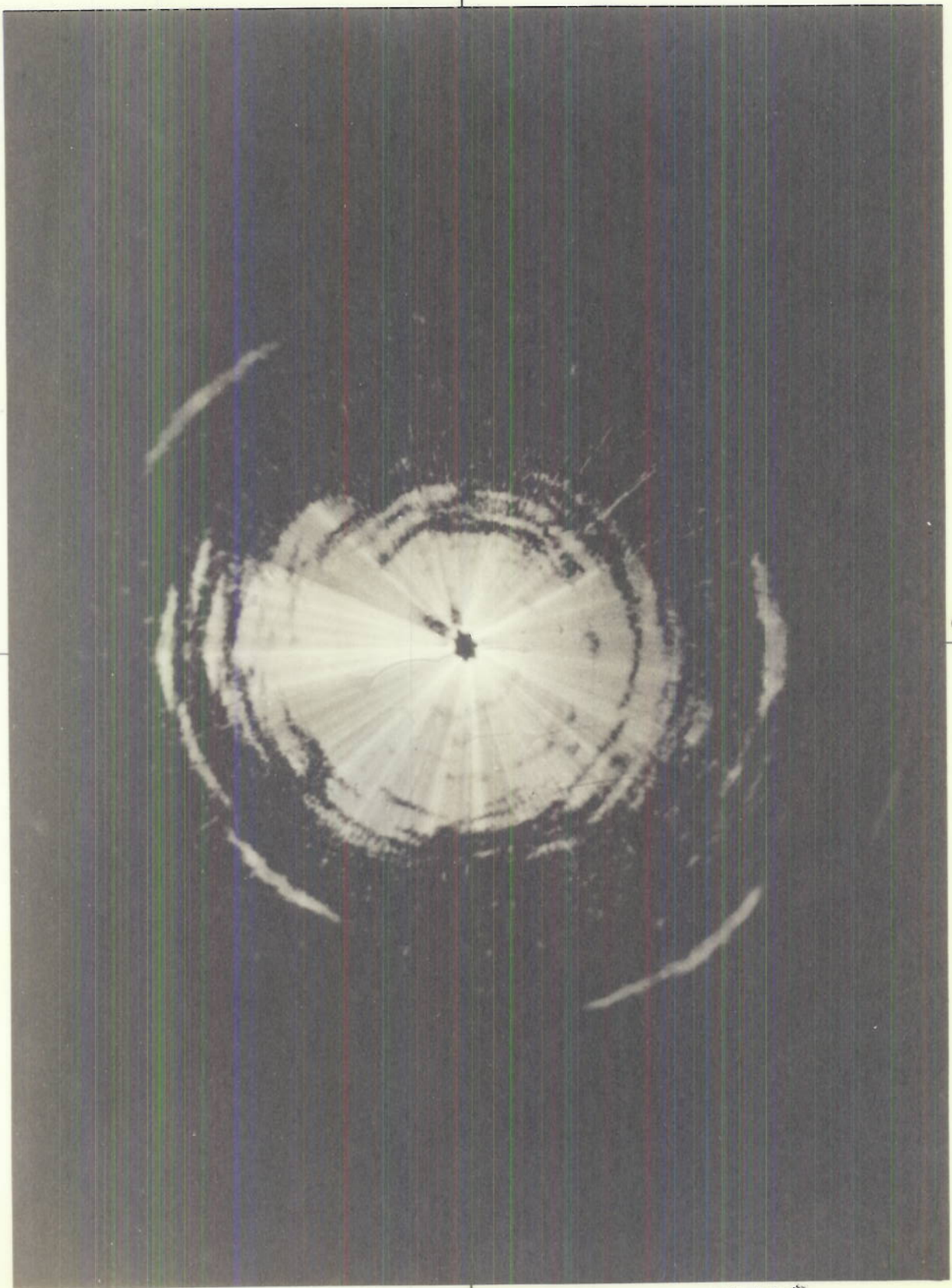


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PLATE 19

NORTH

E



S

W

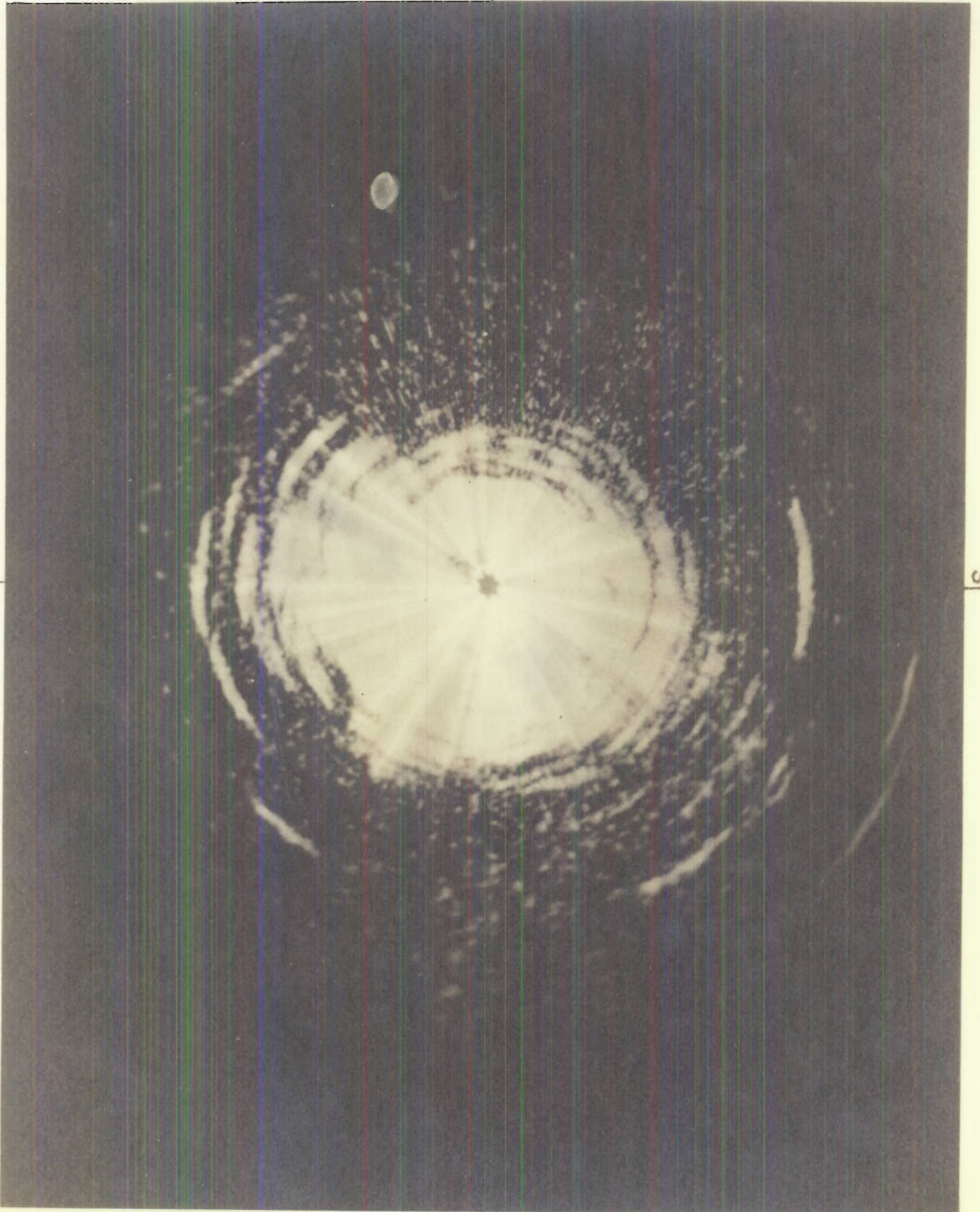
PLATE 22

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E



NORTH

S

W

PLATE 23

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