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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/21274419
Report (National Research Council of Canada. Radio and Electrical Engineering Division : ERB), 1963-12

ERB-658

UNCLASSIFIED

NATIONAL RESEARCH COUNCIL OF CANADA
RADIO AND ELECTRICAL ENGINEERING DIVISION

A TRANSISTORIZED MARINE RADAR

A. D. HOOD, H. R. SMYTH, W. WYSLOUZIL

OTTAWA

DECEMBER 1963

ABSTRACT

A compact battery-powered marine navigational radar is described. The general design was dictated by the requirements of the small boat owner and of fishing vessels operating on inland and coastal waters. Power consumption is kept to a minimum by the use of solid state components whereever practical and economically possible. Ranges of 1, 6, and 15 miles are available on a 10-inch cathode-ray tube, with associated range rings of 500, 2000, and 4000 yards. The maximum range is ample for coastal navigation, and the minimum range is sufficiently short for navigation in restricted waterways. Power is supplied to the radar by a 12-volt storage battery driving a transistor converter, and consequently the radar can be produced to operate from any practical primary power source.

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A TRANSISTORIZED MARINE RADAR

- A.D. Hood, H.R. Smyth, W. Wyslouzil -

INTRODUCTION

The radar system to be described was designed to bring the benefits of radar navigation to the small boat owner, and particularly to the commercial fisherman. Basic requirements were minimum size and weight, and low power consumption from power sources that are practical for small craft. Filament power is required only by the magnetron, klystron, thyratron, and cathode-ray tube. Solid state devices are available to replace the klystron and thyratron, but the cost is prohibitive for a radar of this type. Primary power is supplied by a 12-volt storage battery, and a transistor converter generates the required d-c voltages. Filtering problems are minimized by synchronizing the pulse recurrence frequency from the transistor converter.

The radar was constructed as a three-package unit, with interconnecting cables, consisting of the indicator, modulator, and antenna (Fig. 1). This type of construction is more adaptable to a small wheelhouse where space is normally at a premium. The indicator may be clamped in any desired position by an adjustable bracket and may be mounted on a bulkhead, shelf, or overhead, if desired. The

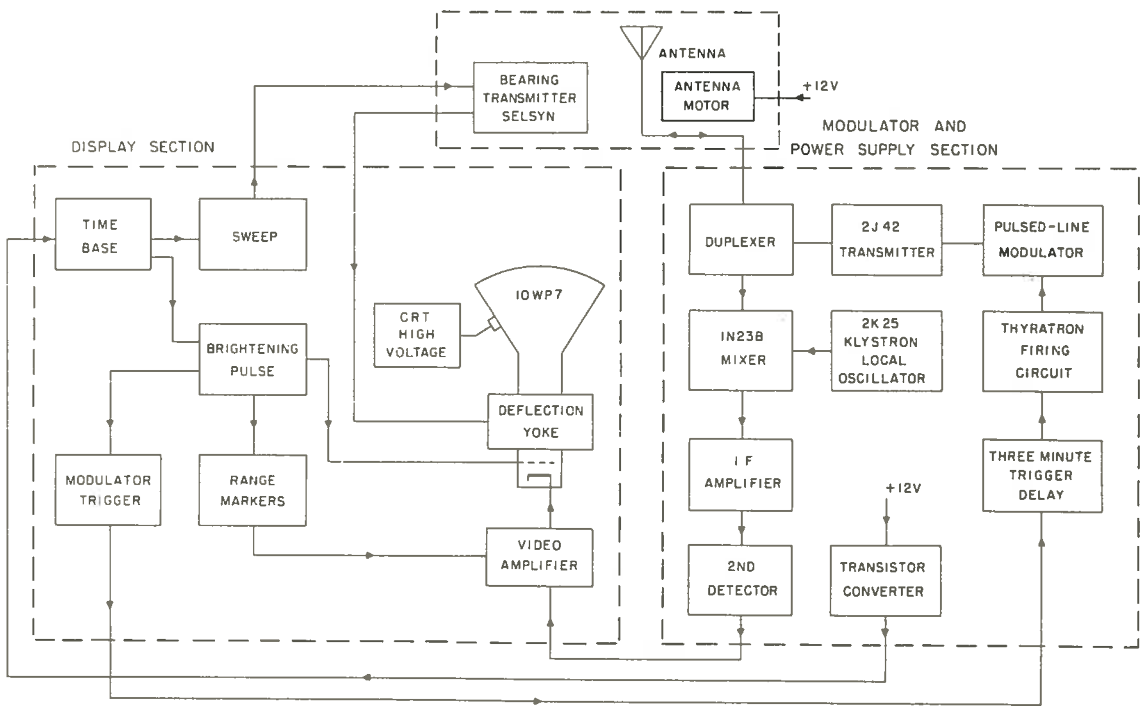


Fig. 1 Block diagram of transistorized marine radar

modulator may be placed in any location that will simplify the waveguide run and still leave the pull-out chassis available for service. In Plates I and II the radar is shown as a complete unit, but the cabling between the indicator and modulator may be extended to 20 feet, or more, to comply with the installation. Ventilation is not required in the indicator chassis, but owing to klystron, magnetron, and thyratron heating in the modulator case, louvered panels are necessary for operation in high ambient temperatures. The radar may be used with any X-band marine antenna and is adaptable to either single or dual arrays. A light-weight slotted-guide antenna in a Fiberglas radome is available commercially, and has been redesigned to take the appropriate drive motor and selsyn. This antenna will be used by the manufacturer on the production model.

DESCRIPTION

a) Indicator The indicator (Plates III and IV) includes the PPI display and all operating controls for power-on-off, receiver gain, intensity, local oscillator tuning, range and range marks, range mark amplitude, centre-out, heading-marker, and cursor lights. A meter is also included for monitoring the primary voltage supply. The total weight of the indicator chassis and case, complete with mounting bracket, is 33 pounds. Case dimensions are dictated by the physical size of the type-10WP7 cathode-ray tube, and only a small amount of the available space is utilized. The indicator circuitry is confined to three plug-in boards, built as complete sub-assemblies and adaptable to printed-circuit techniques. The main board contains the time base, sweep, brightening pulse, and range mark circuits. This circuit board is connected through the chassis plug to the range switch and the associated front panel control. The cathode-ray tube high-voltage supply is developed from the output of a transistorized ringing-choke converter and a voltage-multiplier circuit. The sub-assembly is self-contained, and an 8-kv tap is taken from the circuit board to the CRT anode. The third sub-assembly contains the four-stage video amplifier, and is mounted in a shielded case beneath the indicator chassis. The range selector switch on the front panel is a five-deck three-position switch controlling the time base, brightening pulse delay, sweep speed and length. Pre-set controls for the start of the brightening pulse, range marks, and sweep are mounted on the sub-assembly. Range marks are generated by a pulsed tunnel-diode oscillator. Pre-tuned tank circuits are switched into the oscillator circuit in conjunction with the associated time base. The on-off centre-out control is for radial displacement of the centre, and is used for close-in navigation on the one-mile range only. The heading-marker circuit is triggered from a ball-contact switch on the antenna mount and is pushbutton-operated from the front panel. A rotating cursor with a variable illumination control is provided for azimuth readings.

b) Modulator The modulator case contains the 0.2-microsecond pulse-line modulator, magnetron, thyratron, and trigger amplifier, duplexer, receiver, and transistor converter power supply (Plates V and VI). The complete unit weighs 35 pounds and the dimensions of 14" × 15" × 10" are minimum for component size and heat dissipation. A side-panel door provides access to the klystron and crystal-current meter. The case may be removed from the chassis without decoupling the waveguide. The pulse-line modulator is of conventional design using d-c resonant charging from a 1300-volt supply. A low-amplitude pulse from the display chassis is used to trigger a 4-layer diode switch for firing the thyratron. All voltages, with the exception of the CRT high voltage, are generated in the various secondary windings of the transformer-coupled converter. The converter transistors are mounted on a heat sink on the chassis panel outside the modulator case. This provides adequate ventilation and the case-grounded transistors require no additional shielding. The receiver was built as a sub-assembly in a shielded case and mounted on the modulator chassis. It consists of 6 stages of 30 mc/s i-f amplification and the second detector. Video output is fed through BNC connectors and shielded cable to the video amplifier in the indicator chassis. Receiver gain is controlled by varying the emitter voltage on the first three i-f stages.

SPECIFICATIONS

Power requirements:	12 volts d-c, at 6.5 amperes, antenna motor excluded. Operation in accordance with specifications under ±10% voltage variation.
Transmitter frequency:	9375 mc/s
Pulse duration:	0.2 microseconds
Peak transmitter power:	7 kw
Repetition rate:	1800±10%, pps
Range accuracy:	±2% on 1-mile range
Minimum range:	30 yards
Bearing accuracy:	±1°, by mechanical cursor
Range scales:	a) 1 mile b) 6 miles c) 15 miles
Range rings:	a) 500 yards b) 2000 yards c) 4000 yards

Antenna rotation:	20 rpm	
Weight:	Modulator unit, 35 pounds Indicator unit, 31 pounds	
Indicator:	PPI tube	type-10WP7
	Focus	electrostatic
	Deflection	magnetic
	Panel controls	Power On/Off Range Scale/Range Rings Range Ring Amplitude Intensity Local Osc. Tuning Receiver Gain Heading Marker Centre Out Cursor Lights Bearing Position
Receiver:	I-F bandwidth	- 7 mc/s at centre frequency (30 mc/s)
	Video bandwidth	- 5 mc/s
	Noise figure	- 10 db
	Receiver gain	- 100 db

TECHNICAL DESCRIPTION

Display Chassis

a) Time-Base Generator

The time-base generator consists of a monostable multivibrator, employing a unijunction transistor, synchronized with the transistor converter power supply frequency. The 6.3 a-c square wave is differentiated and the positive trigger is applied to the emitter of Q_1 (Fig. 2) through a type-1N2071 diode. The conduction time of Q_1 is controlled by the resistance switched into the circuit by the range switch, and a negative pulse of appropriate duration is generated at base 2 of Q_1. This negative pulse is amplified in Q_2 and Q_3, giving a positive pulse at the emitter of Q_3 for the brightening pulse circuit and a negative pulse at the collector for the sweep circuit.

b) Sweep Generator

Linear deflection of the cathode-ray tube sweep is directly dependent on the

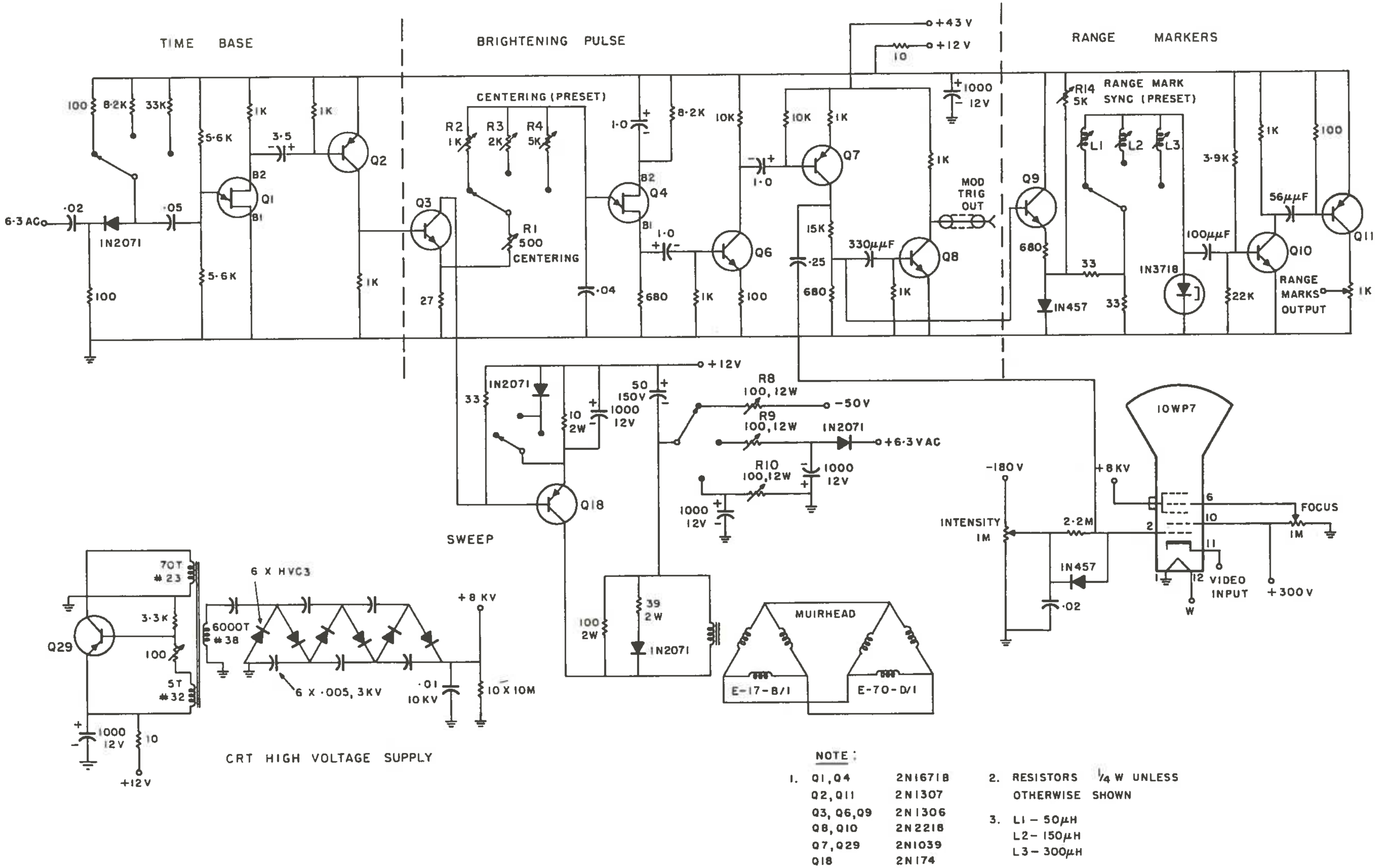


Fig. 2 Circuit diagram of indicator and CRT high-voltage supply

linearity of the current waveform generated in the rotor of the bearing transmitter selsyn. The selsyn used in this circuit has low internal resistance, and consequently behaves very nearly like a pure inductance, so that a square-wave voltage applied across the rotor results in a linear rise of current through it. The negative pulse from the collector of Q_3 is applied directly to the base of the power transistor Q_{18}, driving it into saturation for the duration of the pulse and thus applying a square-wave voltage across the selsyn rotor in the collector circuit. The rate of rise of current through the rotor is proportional to the amplitude of the applied voltage, and the required sweep speeds are obtained by applying the appropriate amplitude of square-wave voltage as determined by the position of the range switch and the pre-set values of R_8, R_9, and R_{10}. The pulse durations of the time-base generator are adjusted for the individual sweeps. To ensure positive switch-off of Q_{18}, back bias is applied on the short range with a heavily by-passed emitter resistor. On the two longer ranges, with lower voltage, a diode in series with the emitter serves the same purpose. The 39-ohm resistor in series with a type-1N2071 diode dissipates the energy stored in the rotor on termination of the sweep. The 100-ohm resistor in parallel with the rotor helps to dampen oscillations at the beginning of the sweep when voltage is suddenly applied across the rotor inductance.

The sweep voltage waveform is applied to the cathode-ray tube through a rotating transformer and does not contain a d-c component. Consequently, the sawtooth waveform of current in the deflection stator coil has an average value of approximately zero, and the beam starts deflecting somewhat off centre, moving through centre to the edge of the screen. It is the function of the brightening pulse circuit to intensify the trace from the instant it crosses the centre of the display screen.

c) Brightening-Pulse Circuit

To initiate the brightening pulse as the sweep crosses the centre of the screen, a controlled delay is introduced between the leading edge of the sweep wave and the leading edge of the brightening pulse. The positive pulse from the time-base generator is fed through an RC circuit to the emitter of unijunction transistor Q_4. Fixed delays for the short, medium, and long sweeps are pre-set by adjusting the charging resistors R_2, R_3, and R_4, respectively. R_1 is a series control for minor centring adjustments, and provides a means of expanding the centre for close-in navigation on the short range. At the end of the pre-set delay the emitter of Q_4 reaches its peak voltage and fires, resulting in a positive voltage waveform at base 1. With the termination of the input timing pulse Q_4 is cut off, returning base 1 to its quiescent voltage. The positive square wave at base 1 is amplified in Q_6 and Q_7. The brightening pulse is taken from the collector of Q_7 as a positive square wave of 40 volts amplitude and is applied to the grid of the cathode-ray tube. A portion of the brightening pulse is differentiated and amplified in Q_8 to produce a short negative pulse at the collector for the modulator trigger circuit.

d) Range-Mark Generator

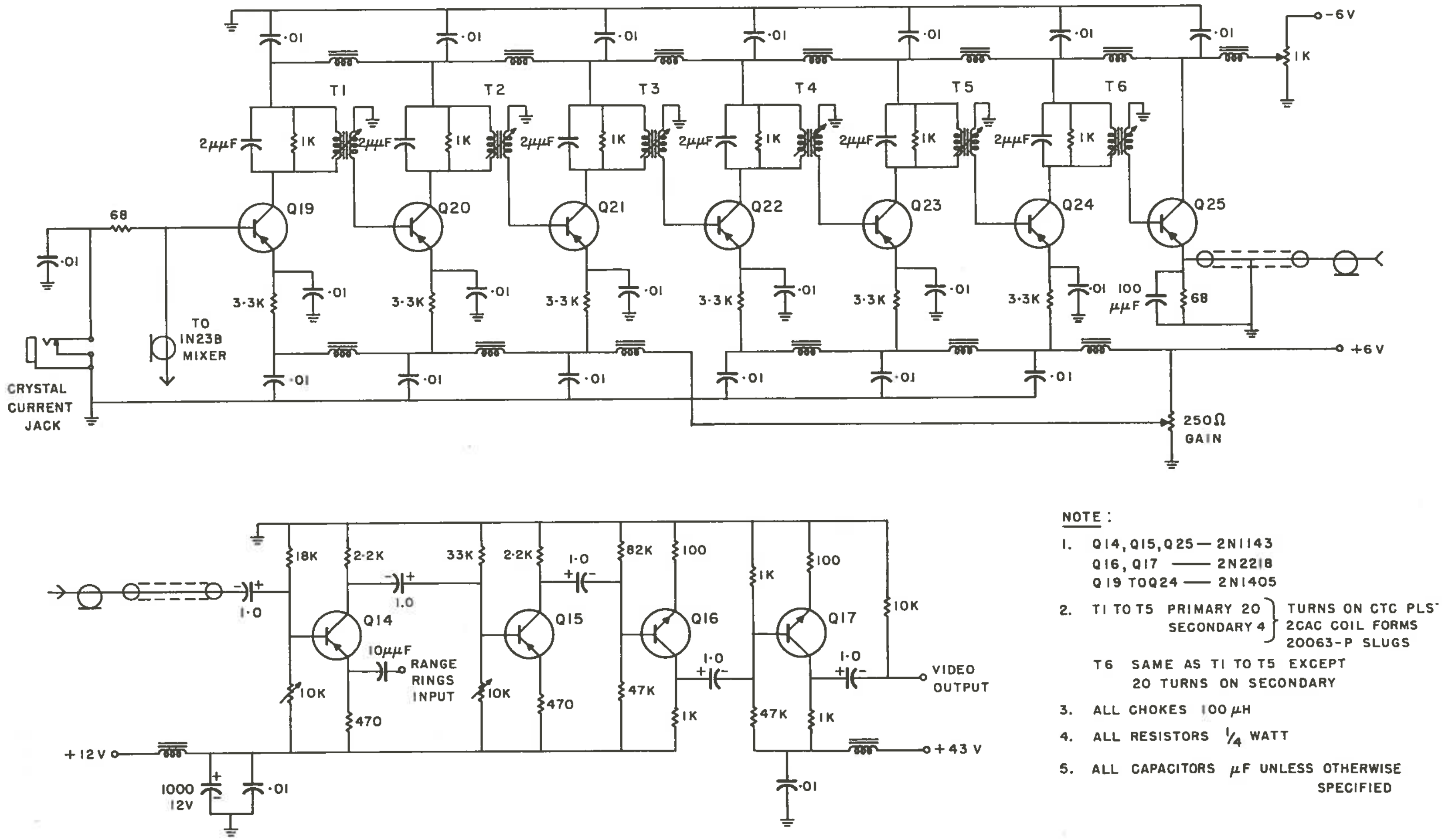
The range-mark generator is a gated tunnel-diode relaxation oscillator whose frequency is controlled by the value of inductances (L_1, L_2, L_3) switched into the circuit. A portion of the brightening pulse from the collector circuit of Q_7 is used as a gate to turn on emitter follower Q_9. The voltage-dividing network in the emitter circuit applies the correct driving voltage to the tunnel-diode oscillator for the period of the brightening pulse. The forward voltage drop across the type-1N457 diode stabilizes the driving voltage. The first range mark is produced when the peak voltage is reached across the tunnel diode. Since the series inductance has to be charged through a 33-ohm resistance, a time delay is introduced between the leading edge of the brightening pulse and the first range ring. This delay is controlled by applying some forward bias across the diode by means of the pre-set control R_{14}, and the first range marker is adjusted to be coincident with the transmitter pulse. Q_{10} and Q_{11} peak and amplify the marker pulses, and the 1 K potentiometer in the collector circuit of Q_{11} is the range mark amplitude control.

e) Video Amplifier

Video signals from the second detector in the modulator chassis are fed to the display chassis through shielded cable. The video amplifier (Fig. 3) is a four-stage (Q_{14} to Q_{17}) RC-coupled common-emitter amplifier. The negative video output from the collector of Q_{17} has a peak amplitude of 25 volts and is coupled directly to the cathode of the cathode-ray tube. Video amplifier gain can be controlled by adjusting the bias of Q_{15} and is pre-set for optimum performance. The range marks from Q_{11} are coupled through a 10-pf capacitor to the emitter of Q_{14} where they are mixed with the video signals.

f) CRT High-Voltage Supply

The type-10WP7 cathode-ray tube (Fig. 2) requires a potential of 8 kv at the anode for specified definition and brilliance. This voltage is supplied by a ringing-choke converter. The secondary-to-primary turns ratio of the transformer is limited by stray capacitance, coupling, and insulation, so that a voltage multiplier network was required to raise the converter output to 8 kv. The 3.3 K resistor from the base of Q_{29} to ground provides sufficient forward bias to insure reliable starting of the oscillator when power is applied. The 100-ohm potentiometer in series with the base winding



NOTE :

1. Q14, Q15, Q25 — 2N1143
   Q16, Q17 — 2N2218
   Q19 TO Q24 — 2N1405
2. T1 TO T5 PRIMARY 20 / SECONDARY 4 } TURNS ON CTC PLS-2CAC COIL FORMS 20063-P SLUGS

   T6 SAME AS T1 TO T5 EXCEPT 20 TURNS ON SECONDARY
3. ALL CHOKES 100 μH
4. ALL RESISTORS 1/4 WATT
5. ALL CAPACITORS μF UNLESS OTHERWISE SPECIFIED

Fig. 3 Circuit diagram of IF and video amplifiers

provides limited control over the output voltage, with increased resistance resulting in decreased voltage.

Modulator Chassis

a) Pulse-Line Modulator

The modulator chassis contains all the components associated with the generation of the type-2J42 magnetron pulse, including the thyratron trigger circuit (Fig. 4). The modulator is a "line type pulser", using a 0.20-microsecond pulse line and employing d-c resonant charging. The charging choke of 33 henries is larger than the minimum required for a pulse recurrence frequency of 2000, but it eliminates the use of a hold-off diode and allows a reasonable variation in the pulse recurrence frequency due to converter frequency change at low primary voltage.

The d-c supply of 1300 volts from the converter to the charging choke allows the delay line to be charged to 2400 volts. When the type-3C45 thyratron conducts, the charge on the delay line is dissipated. This pulse-forming discharge appears across the primary of the pulse transformer and is stepped up to a high negative value (-6000 volts) in the secondary and applied to the cathode of the magnetron.

b) Thyratron Trigger Circuit

The thyratron trigger pulse is synchronized with the leading edge of the brightening pulse. The negative synchronizing pulse of -40 volts amplitude, from the collector of Q_8 in the display chassis is fed to the modulator trigger circuit through shielded cable. To obtain the fast-rise-time positive pulse required at the thyratron grid a Shockley 4-layer type-4G200 diode was used. When voltage is applied, the 0.01 capacitor in the anode circuit of the diode is charged to 150 volts through the 33 K resistor. Since the switching voltage varies from 180 to 200 volts, a negative pulse of -30 to -50 volts is required at the cathode for reliable breakdown. The type-1N2071 rectifier diode in the cathode circuit allows the negative synchronizing pulse from the display to appear at the cathode, causing avalanche breakdown. The dynamic resistance of the 4-layer diode is less than 0.3 ohms, so that the 0.01 capacitor is effectively short-circuited to ground, through the 68-ohm resistor providing a positive pulse of 150 volts with a rise time of 0.1 microseconds.

c) Modulator Time Delay

A pre-heating time of three minutes is required for the magnetron and thyratron filaments before trigger pulses are applied to the thyratron grid.

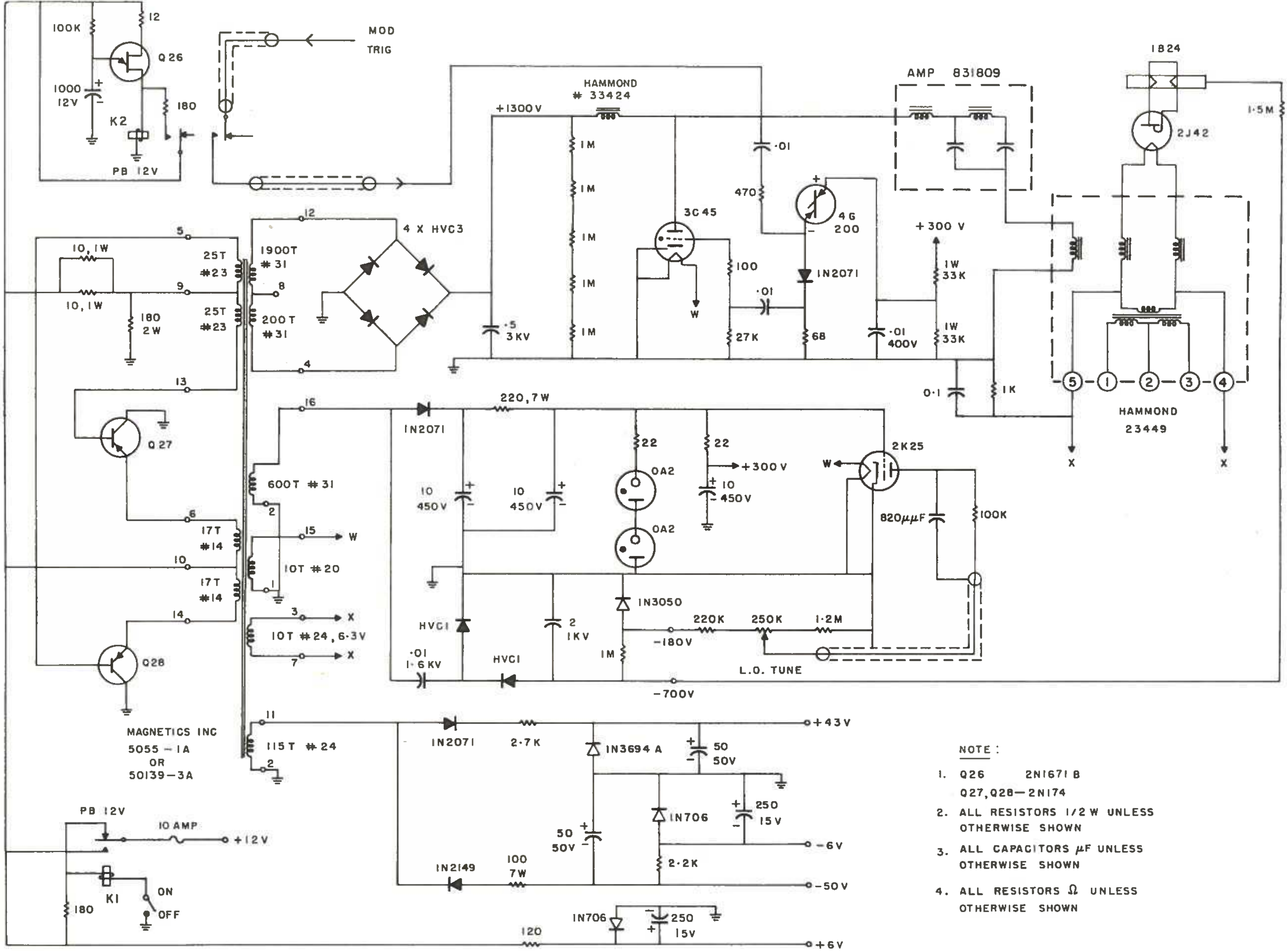


Fig. 4 Circuit diagram of modulator and power supply

To obtain this delay a unijunction transistor Q_{26} (Fig. 4) is used. When voltage is applied, the 1000-mfd capacitor in the emitter circuit is charged through a 100 K resistor until the peak point voltage is reached and the transistor fires. This charge time is approximately three minutes. The capacitor discharges through the transistor and K2, closing the relay. One set of contacts holds the relay closed by by-passing the transistor through 180 ohms to 12 volts. The other set of contacts applies negative synchronizing pulses from the display to the thyratron trigger circuit.

d) Transistor-Converter Power Supply

All voltages, with the exception of the positive 12 volts supplied directly from the battery, are generated in the secondary windings of the transformer-coupled converter (Fig. 4). The power transistors Q_{27} and Q_{28} are switched into saturation alternately by voltages applied to the bases from the feedback winding, so that the input voltage is applied to each half-primary in turn. Forward bias on the bases assures reliable starting. Power is applied to the converter through relay K1, which is controlled by the ON-OFF switch located on the front panel. Transformer winding data and output voltages are shown on the power supply schematic. The high-voltage winding (terminals 4, 8, and 12 on the transformer) is tapped at 200 turns, and this feature may be used to reduce the line charging voltage.

e) I-F Amplifier and Second Detector

The 30-mc/s intermediate-frequency output from the mixer is amplified in a 6-stage single-tuned common-emitter amplifier (Fig. 3). The interstage coupling transformers are designed to match the input and output impedances of the stages with the primary inductance tuned to 30 mc/s by a 2-pf capacitor and the stray capacitance to ground. Resistive loading of the tank circuit, with 1 K resistors. increases the bandwidth to 7 mc/s at the 3-db points. This bandwidth is achieved at the expense of gain, but it eliminates the necessity for neutralization and reduces the possibility of oscillations. The 2-pf capacitive loading in the tank circuit is employed to reduce the sensitivity to temperature and bias drift. Receiver gain is controlled by varying the emitter voltage on the first three stages. Output from the last intermediate-frequency stage is coupled to the second detector through T6. a 1:1 transformer. Q_{25} operates as an amplitude detector, and is normally at cutoff, so that only negative-going signals appear across the 68-ohm emitter resistor. Video output is fed to the video amplifier in the display chassis through shielded cable.

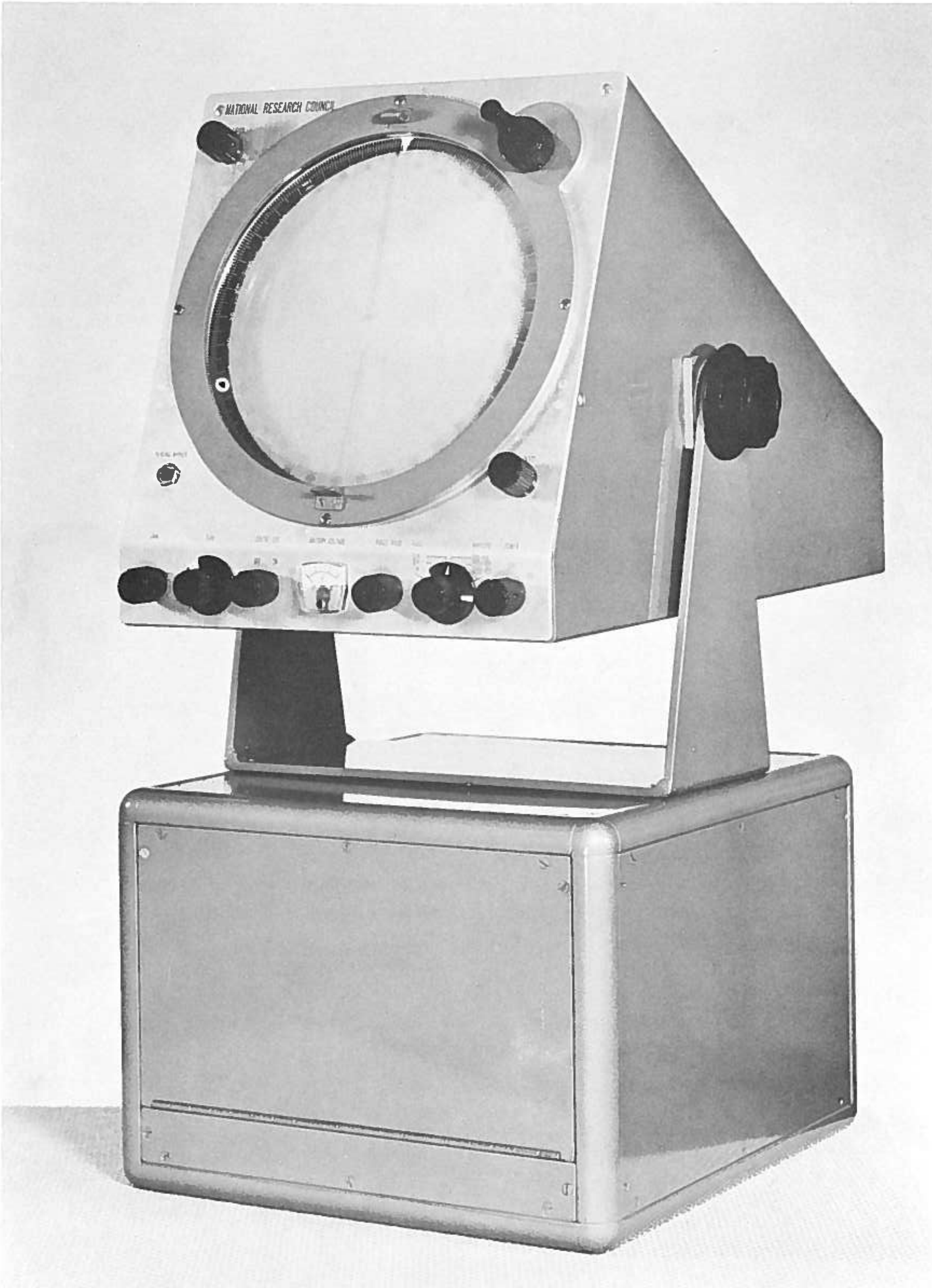


Plate I — Indicator and modulator — front view

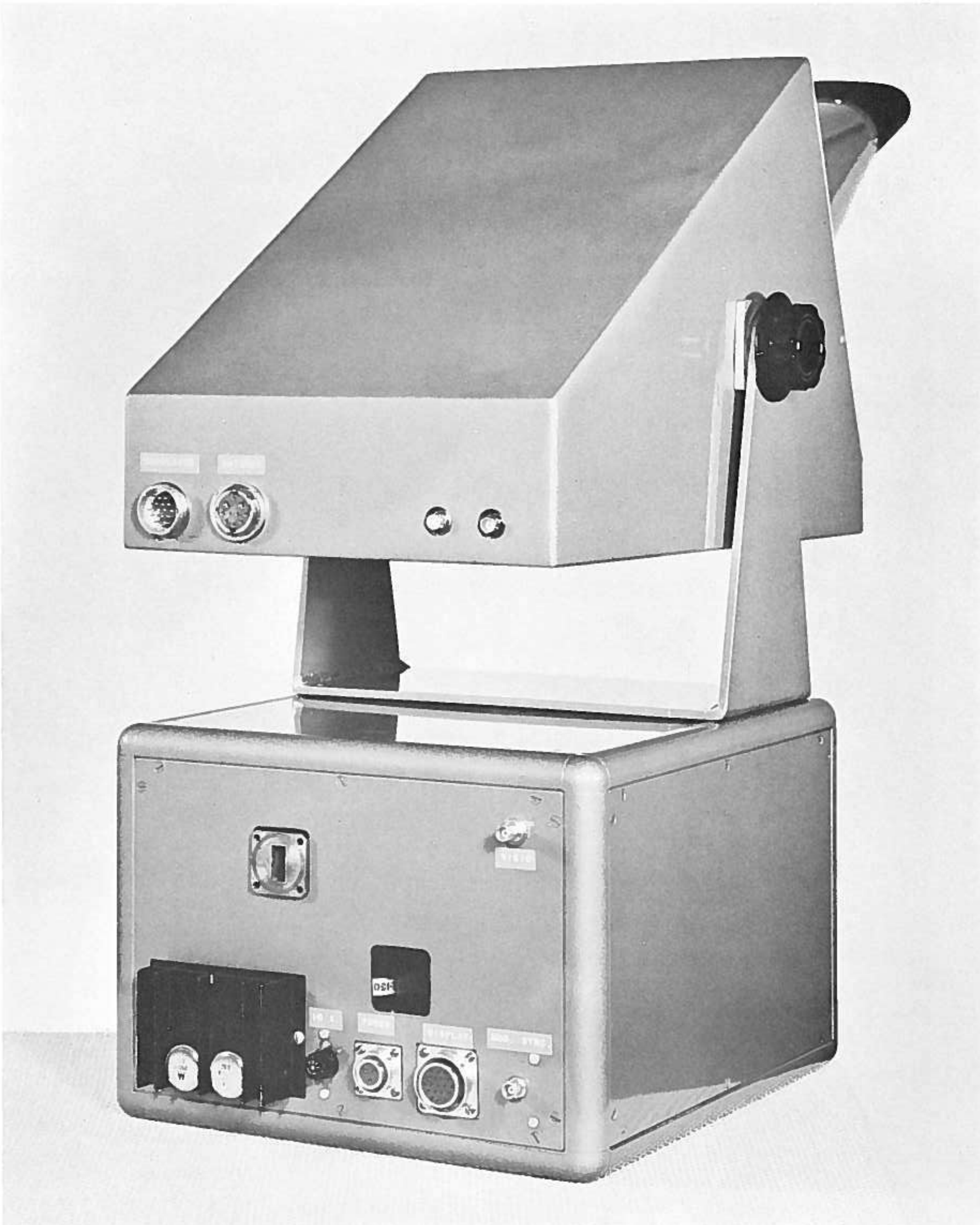


Plate II — Indicator and modulator — back view

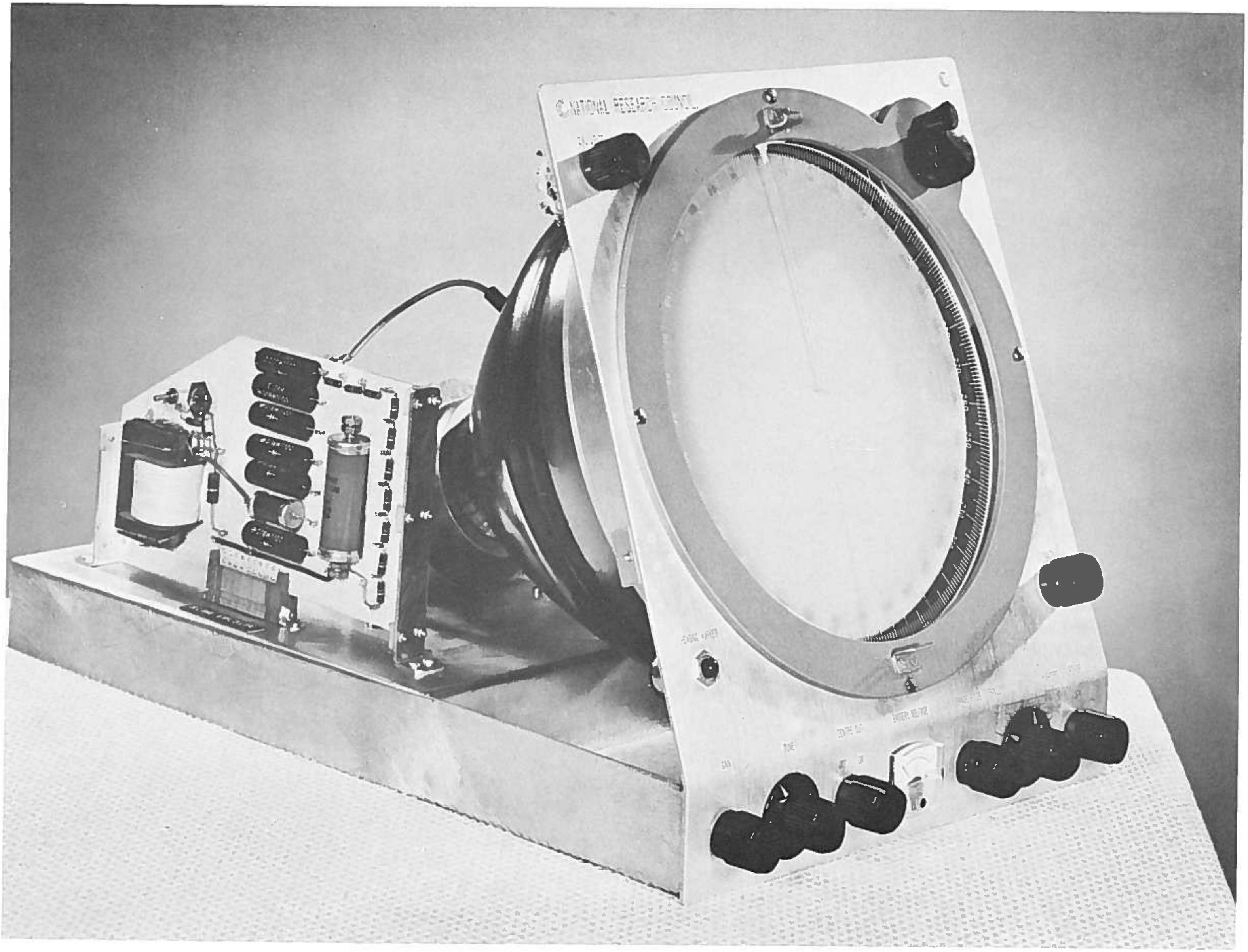


Plate III — Indicator from left side

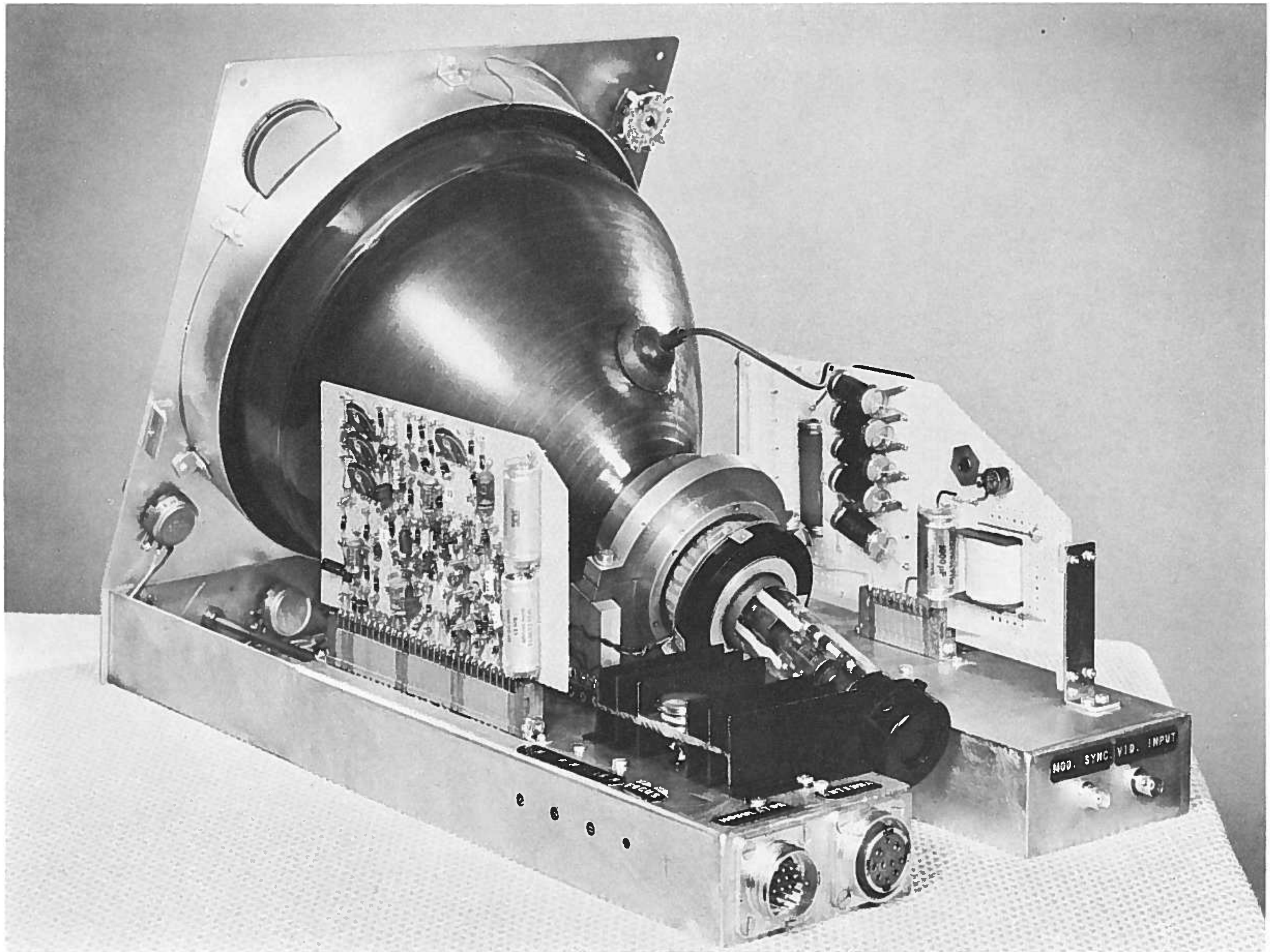


Plate IV — Indicator from right side

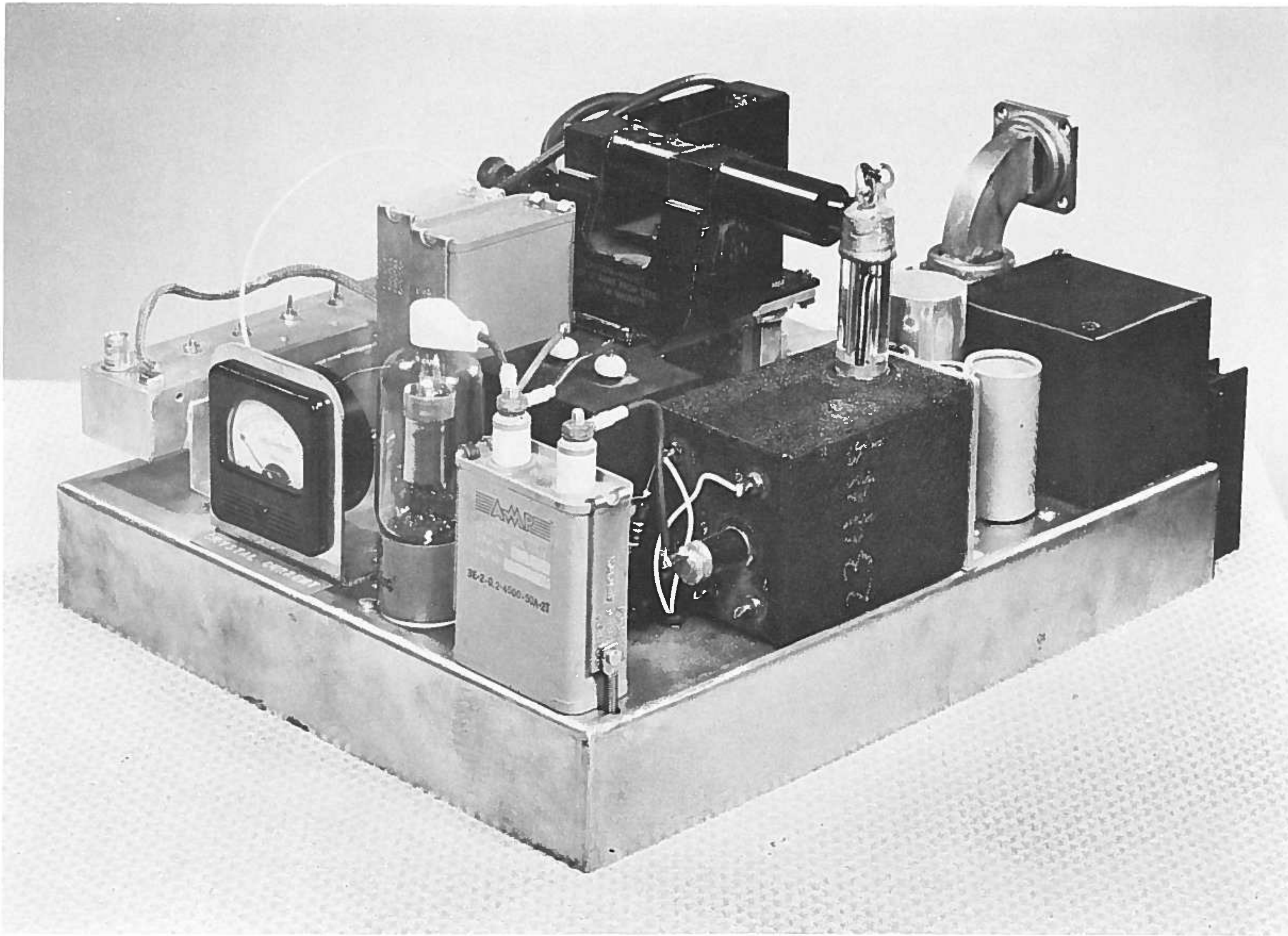


Plate V — Modulator chassis — top view

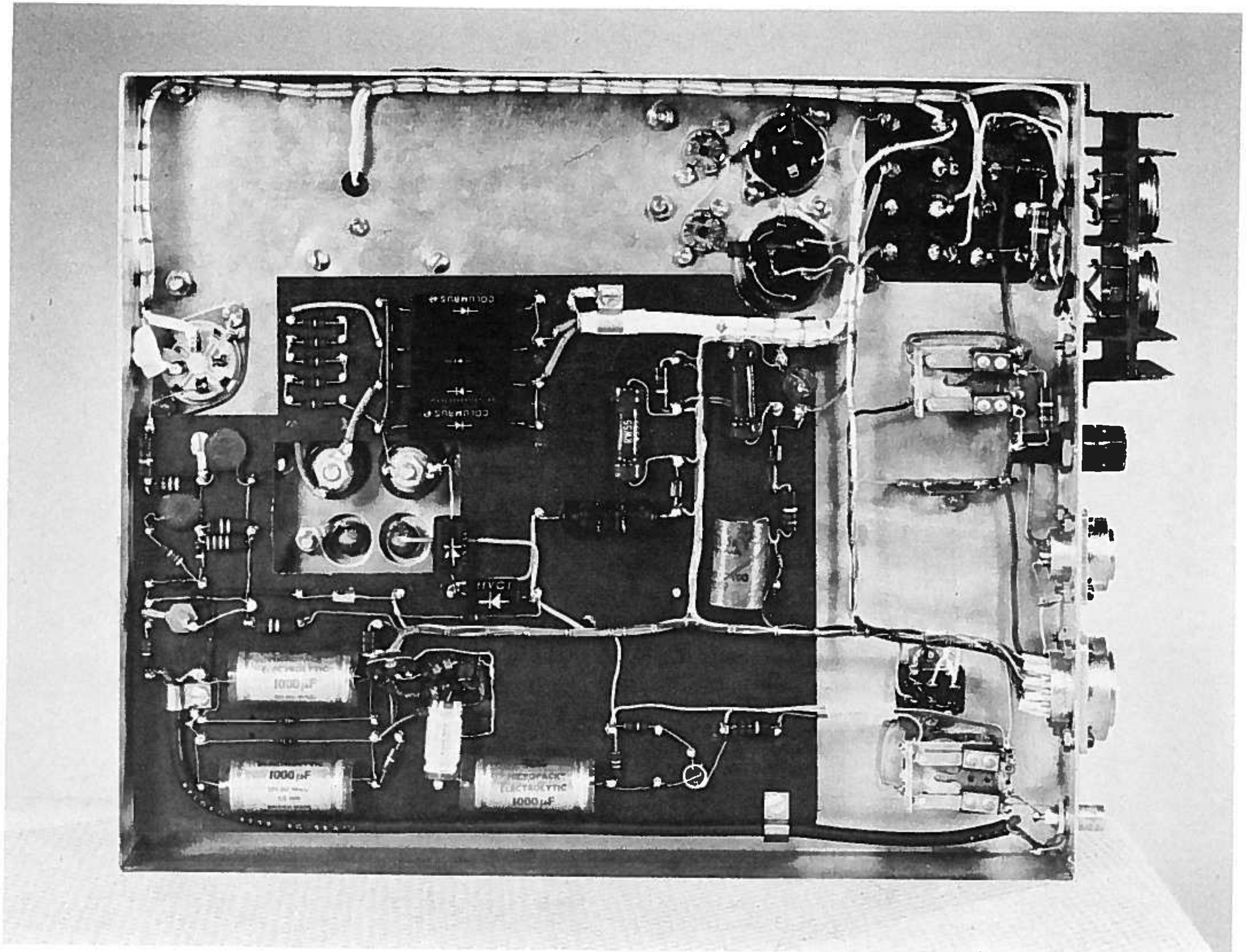


Plate VI — Modulator chassis — bottom view

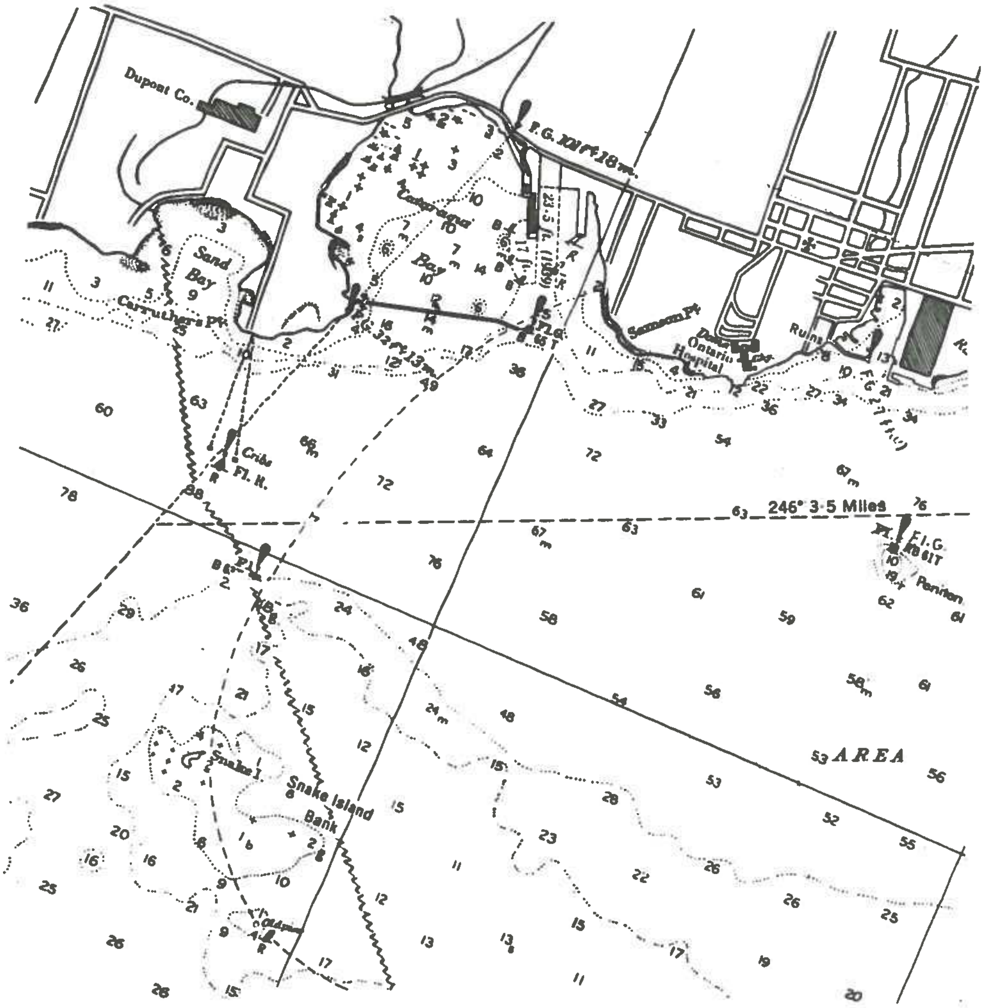

Dupont Co.
Sand Bay
Carruthers Pt.
Cataraqui Bay
Samson Pt.
Ontario Hospital
Ruins
Cribs
Fl. R.
246° 3·5 Miles
Fl. G.
Snake I.
Snake Island Bank
AREA

Plate VII — Radar display of approaches to harbour at Kingston, Ont.