NATIONAL RADIO ASTRONOMY OBSERVATORY
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18 CM RECEIVER
IF ELECTRICAL POLARIMETER
FOR DUAL LINEAR FEED

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18 CM RECEIVER IF ELECTRICAL POLARIMETER FOR DUAL LINEAR FEED

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18 CM RECEIVER IF ELECTRICAL POLARIMETER FOR DUAL LINEAR FEED

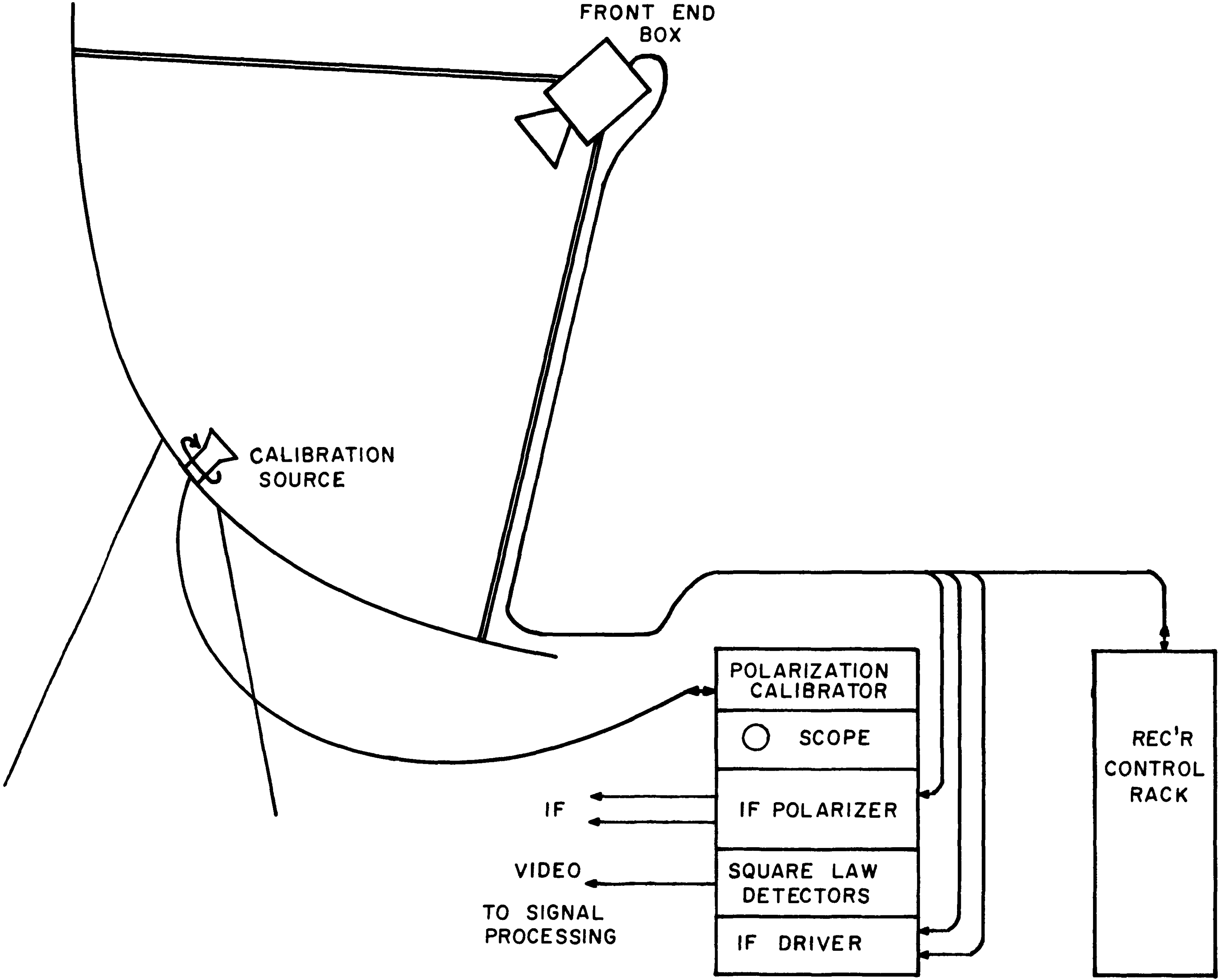
I. General Description

This equipment is intended to produce circular polarization (right and left) and orthogonal linear polarizations rotated 45° with respect to the parent linear polarization which is produced by a dual linear feed system. The resulting six polarizations are available simultaneously or can be switched out in various formats.

The signal combining necessary to produce the polarizations is done at IF (150 MHz, 20 MHz maximum 3 dB bandwidth). The amplitude equalization prior to signal combining is also done at IF, but the phase equalization is done at the LO frequency. The phase shifter is located in the 18 cm receiver front-end box, while all the IF components are located in a 19-inch rack located in the telescope control room. For accurate polarimetery at wide bandwidths the two IF cables from the focal point to the polarimeter should be equal in length. This will insure identical phase slope (delay) and thus preserve the phase equalization across the IF bandwidth.

The phase and amplitude equalization of the two receiver channels is accomplished with a calibration signal transmitted from the vertex of the 140-foot telescope. In this manner the entire receiver system, including the feed horn, is equalized. The calibration signal consists of broadband noise which is transmitted by a linear polarized horn antenna rotating at approximately 300 rpm about the main beam axis. The resulting signal produces AM modulation in both IF channels of the dual linearly-polarized receiver. The modulation in either of the circularly polarized outputs is nulled-out to achieve amplitude and phase balance.

A typical installation is shown in the pictorial diagram, Figure 1.



18 cm IF POLARIMETER

FIG. 1

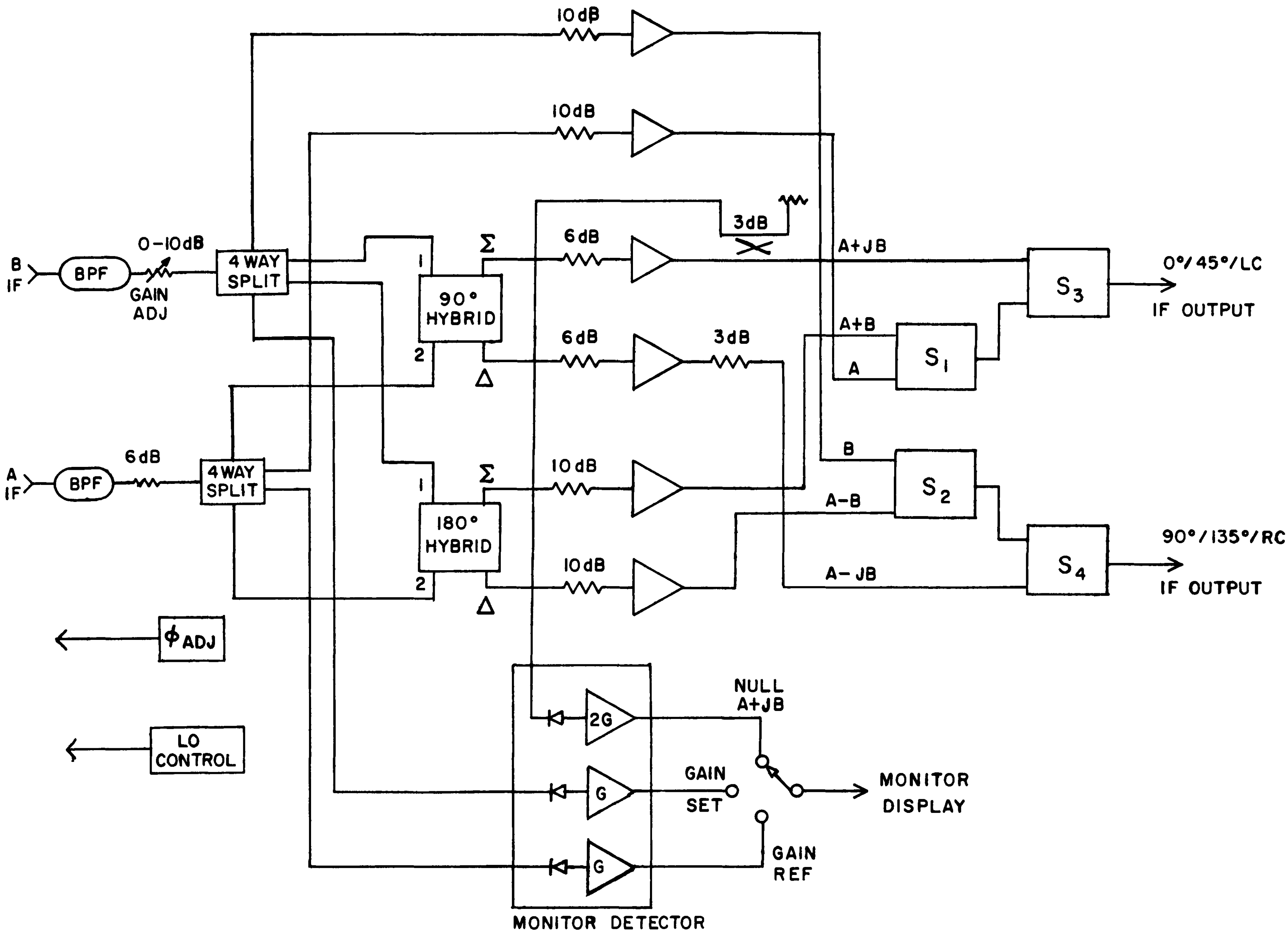
II. Operational Description

A. IF Polarizer

The block diagram of the polarizer drawer is shown in Figure 2. This unit is intended to be operated with a dual-linear polarization feed system. Each IF channel contains AM noise modulated at twice the rotational speed of the calibration signal horn and 180° out of phase with the other channel. The 10 Hz AM signal of one channel appears on an oscilloscope with the display switch in the Gain Ref position. The Gain Set position displays the other channel, and the variable attenuator is adjusted for an amplitude equal to the previously displayed channel. With a common LO and the display switch in the Null position (A + jB), the phase and amplitude difference of the two channels can be adjusted for a null in the displayed 10 Hz sine wave. At this point the two channels are balanced and circular polarization of opposite senses will appear at the output ports of the 90° hybrid, while linear polarization rotated 45° with respect to the polarization produced by the feed system appears at the output ports of the 180° hybrid. IF amplifiers are included on each output to provide 0 dB insertion loss through the unit and isolation of the various hybrids and power splitters from load impedance variations. IF switches are also provided which can be programmed with a remote switching function to accommodate various polarization formats. Selection of the LO source and control of the channel phase difference is provided in this drawer, but the actual functions are performed in the front-end box.

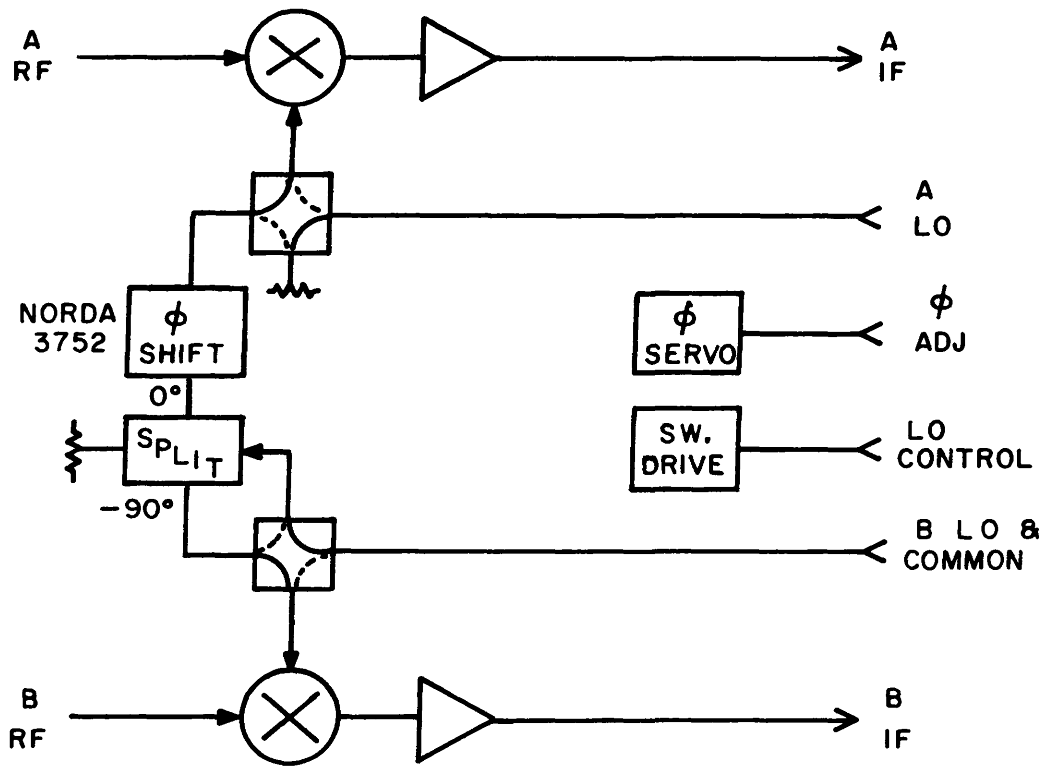
B. Front-End Box LO Control

A block diagram of this circuitry is shown in Figure 3. Mechanical transfer switches are mounted in the front-end box to select a common or separate LO for the two receiver channels. Channel phase difference is adjusted with a common LO by a servo-controlled, air-line phase shifter in the LO line to one channel. Phase adjust is done at the LO, rather than the IF, to negate the variation of phase shift across the IF signal bandwidth.



150 MHz IF POLARIZER

FIG. 2



LO CONTROL CIRCUITRY
18cm FRONT END

FIG. 3

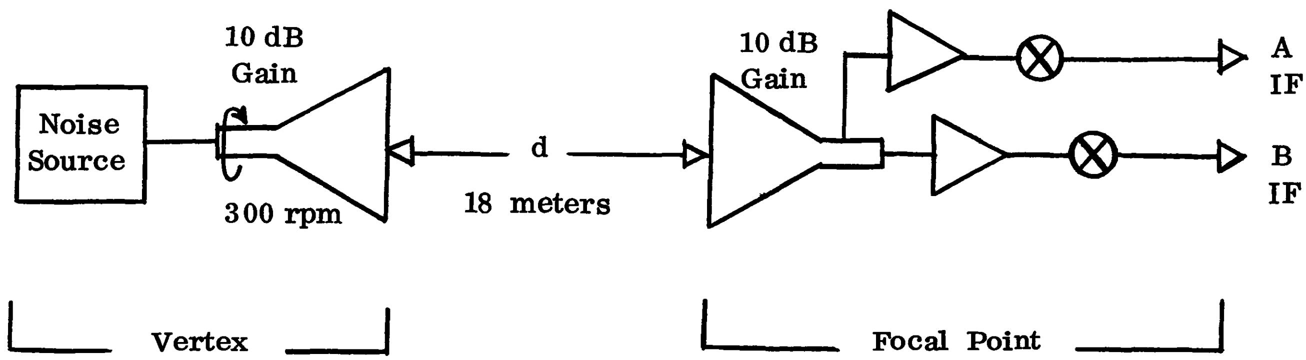
C. Vertex Calibration Source

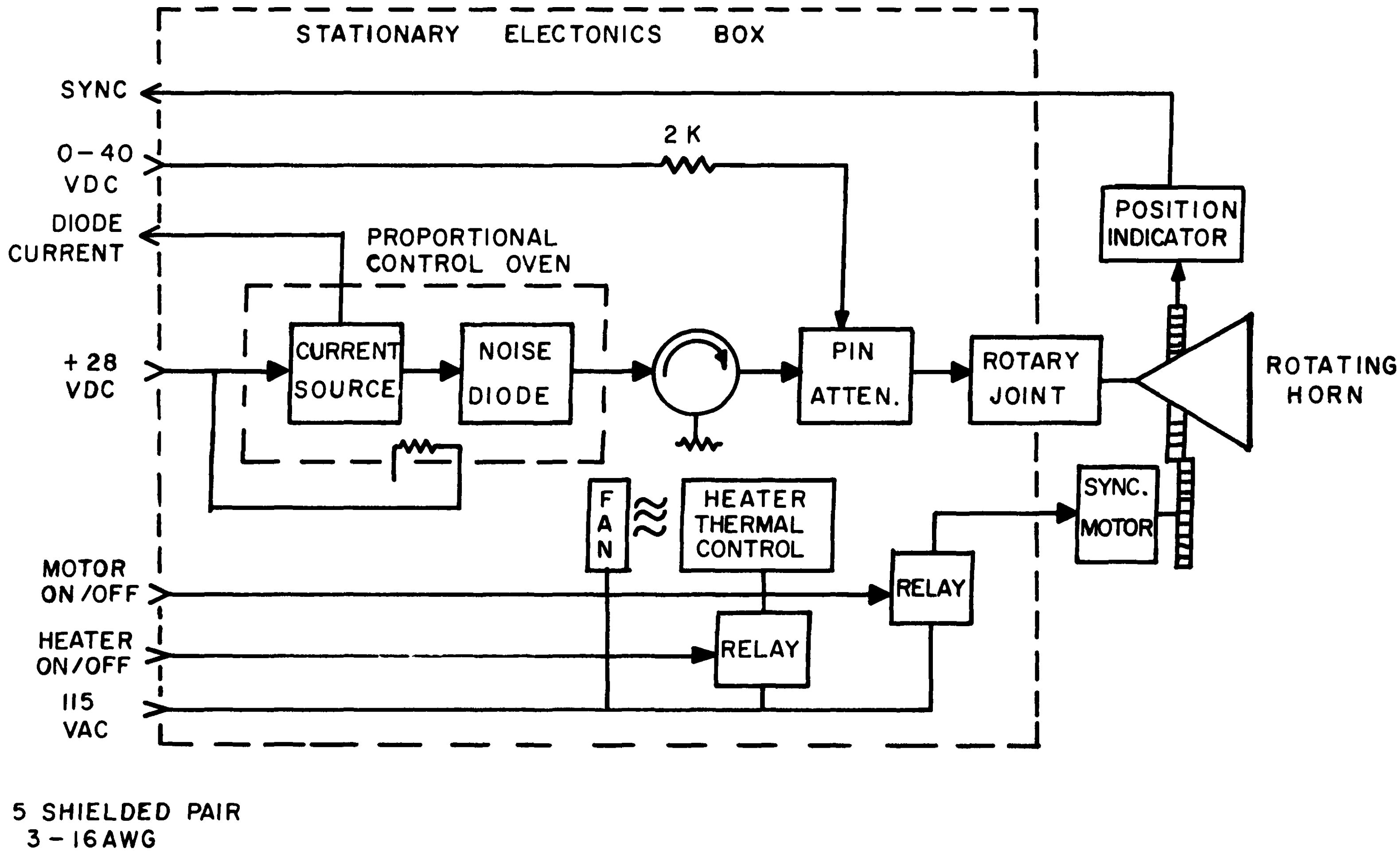
A block diagram of this unit is shown in Figure 4. The calibration signal consists of a noise source and rotating linear polarized feed horn located at the vertex of the telescope reflector. The horn rotation generates AM test noise in each receiver channel. The test signal is generated by a 1-2 GHz noise diode and coupled to the rotating horn through a coaxial rotary joint. The noise diode and associated current source are housed in a proportional control component oven which holds the internal temperature to within ± 0.1 °C. The oven and other components are housed in an insulated box which is heated by a snap-action, thermostatically controlled AC heater to 60 °F. An AC heater is used to eliminate the need for high current DC wires up to the telescope vertex. The heater can be turned off when the box temperature reaches 60 °F to eliminate the thermostat noise. No power supplies or complex electronic circuits are included in the box. This was done because of the difficulty in servicing a unit at the telescope vertex. Two cable runs are required to the vertex, a 3-conductor, 16 AWG AC power cable and a 6, No. 22 shielded pair control cable.

A fractional horsepower DC motor is used to rotate the feed horn at about 300 rpm. Since the motor will not permit accurate fixed positioning of the horn, a magnet actuated reed switch is employed for a dynamic position indication. The horn is connected to the electronics box through a length of RG-14/U coaxial cable so that the horn aperture can clear the vertex cone while the electronics box is mounted on the instrument mount behind the reflector surface. This unit should be capable of intermittent operation without maintenance for a period of one year or more.

III. Theoretical Analysis

Figure 5 — Calibration Signal Propagation Link





VERTEX CALIBRATION SOURCE
18 cm IF POLARIMETER

FIG. 4

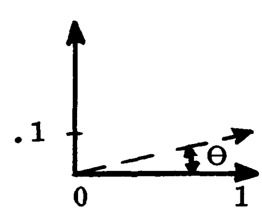
A. Power Budget

Xmit Noise	=	35 dB	=	9.5×10^5 °K		
Xmit Ant Gain	=	10 dB				
Isotropic Path Loss	=	62 dB	=	$\frac{\lambda^2}{(4\pi d)^2}$	=	$\left(\frac{.18}{4\pi 18}\right)^2$
Receiver Ant Gain	=	10 dB				
Received Power	=	-7 dB	=	60 °K		
System Noise				70 °K		
Feed Spillover				11 °K		
Sky Temperature				7 °K		
Total Noise				88 °K		

The 300 rpm amplitude = 118° ± 30 °K ≃ 50% peak-to-peak of 10 Hz AM on either IF channel total power.

B. Phase and Amplitude Error

For axial ratio of $0.82 = \frac{0.9}{1.1} \Longrightarrow$ 10% voltage error. Thus, the two IF channels must be matched vectorially (phase and amplitude) to within 10% in voltage.



$\sin \Theta = .1 \Longrightarrow \Theta = 5.7°$

$\cos 5.7° = .99$

Thus, total ϕ unbalance must be less than 6° and total amplitude unbalance less than 0.8 dB.

Referring to IF block diagram:

			ΔG	$\Delta\phi$
3-way splitter	Merrimac	PD-30-20	0.2 dB	1.0°
90° hybrid	"	QA-3-160	0.3 dB	± 2 °
180° hybrid	"	HJ-200	0.2 dB max.	± 1 °
			0.7 dB max.	4 ° max.

Selection of splitter ports reduced unbalance to within 0.1 dB and 1.4°. Cable lengths were made equal to within 5/16", for RG-188 = 2.40° error. All ports are well matched (VSWR ≈ 1.1).

C. Sensitivity

The predetection IF bandwidth is determined by the IF bandpass filter, or the RF bandwidth of 30 MHz, whichever is smaller. For a 10 MHz, 3 dB bandwidth IF filter and a post-detection time constant of 17.5 milliseconds (20 Hz, 3 dB video bandwidth) the sensitivity is:

$$\Delta T = \frac{1.4\ T_S}{\sqrt{B\tau}} = \frac{1.4 \times 118}{\sqrt{10^7 \times 17.5 \times 10^{-3}}} = 0.39\ ^\circ K$$

This represents the peak value of the minimum detectable 10 Hz modulation in the null condition, which is 37 dB below the 30 °K maximum peak unnulled value, and assures resolution of a 10% voltage error (20 dB null) corresponding to an axial ratio of 0.82 in the circular polarization output. A narrower IF bandwidth will result in less sensitivity and thus a larger error in the resulting circular polarization. Further bandwidth limiting after the polarimeter is much more desirable, as it does not affect the resolution of the phase and amplitude null.

IV. Experimental Performance

The following data was taken with the 18 cm cooled receiver at 1666 MHz on the NRAO 140-foot telescope. The measurements were made on October 27, 1970 with the 18 cm variable polarization feed. The polarization dial setting of 750 was arrived at after several iterations of phase nulling on right and left circular polarization. See Figure 6.

A. Vertex Calibration Noise Level

Telescope at stow, IF channels balanced, vertex source stationary, rotate the front-end box for maximum total power on any linear polarization output (used A output).

$$\text{Excess Noise} = \frac{V_{on} - V_{off}}{V_{off}} = 105\% = 73.5\ ^\circ K \text{ based on } 70^\circ\ T_{sys}.$$

[redacted]

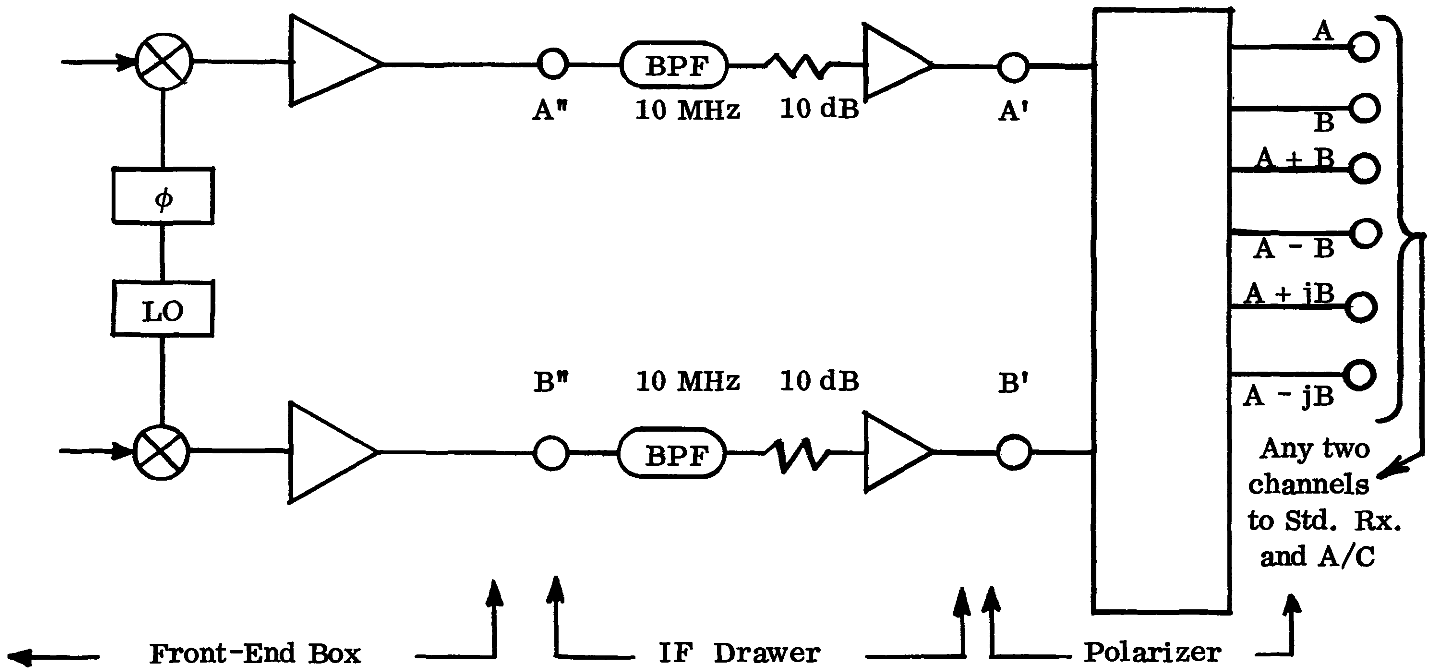


Figure 6 — Experimental Test Set-Up

B. Null Depth

Telescope at stow, vertex source rotating:

Null Depth = 2.5 V peak-peak unbalanced / .05 V peak-peak balanced

= 34 dB of 10 Hz modulation.

C. Axial Ratio and Orthogonality — Feed Polarization = 750

Telescope at stow, vertex source stationary, rotate front-end box for maximum and minimum total power, IF channels balanced:

Circular Outputs			Right (A-jB)	Left (A+jB) Null Channel
Total power - vertex noise off		=	.415 V	.500 V
Total power maximum	vertex noise on	=	.632 V	.760 V
Total power minimum		=	.610 V	.750 V
Axial Ratio = $\frac{V_{min} - V_{off}}{V_{max} - V_{off}}$		=	0.90	0.96

Linear Outputs

	0° (A)	90° (B)	45° (A + B)	135° (A - B)
Box position at max. total power	270°	180°	135°	228°
Box position at min. total power	180°	270°	226°	135°
Estimated resolution of max. min.	± 1°	± 1°	± 1°	± 1°

Signal Levels

Telescope at stow, IF channels balanced, vertex source off:

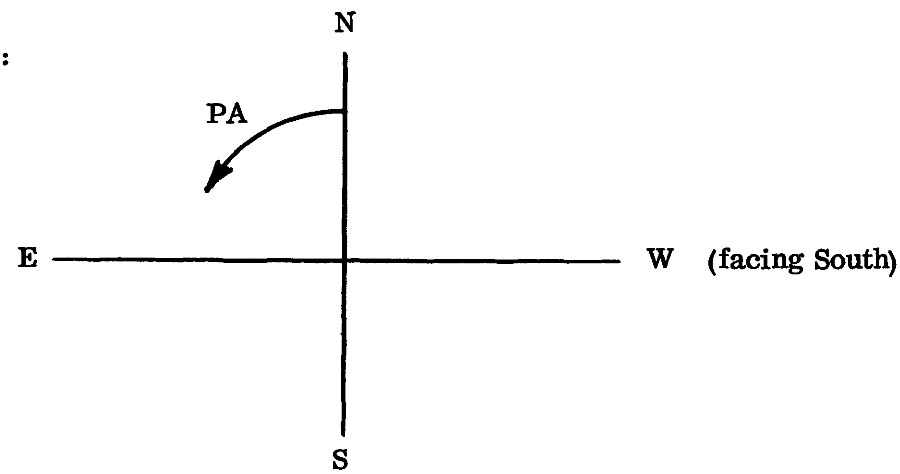
Test Point		Total Power Level into 50 ohms				Output at 1 dB Gain Compression	
	A"	5.6 mV	=	-32	dBm		
	B"	3.5	=	-36			
	A'	17.8	=	-22			
	B'	15.0	=	-23.5			
0°	A	33.0	=	-16.5		+2	dBm
90°	B	20.0	=	-21		0	
45°	A + B	26.0	=	-18.5		+3	
135°	A - B	28.0	=	-18		-3	
LC	A + jB	23.8	=	-19.5		-2	
RC	A - jB	20.0	=	-21		-2.5	

APPENDIX I

Polarization Nomenclature

The following nomenclature is used for labeling the outputs from this IF polarimeter when the receiver feed is located at prime focus.

Beam on sky:



PA = Position Angle (positive counterclockwise from North to East on sky)

Six polarization outputs are labeled:

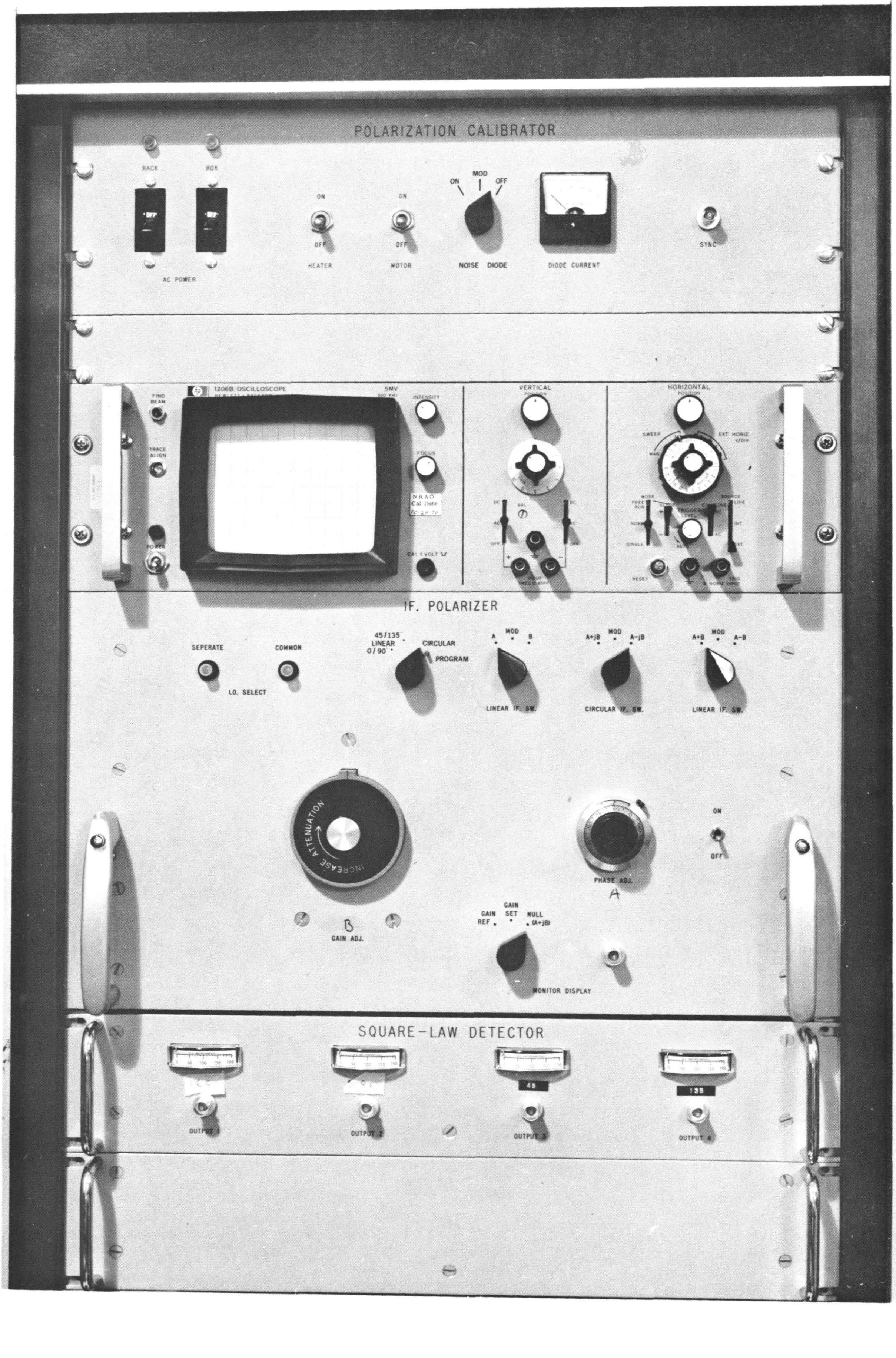
0	Position angle as received from the sky.
45	" " " " " " "
90	" " " " " " "
135	" " " " " " "
RC	Right circular as received from sky by IEEE def.
LC	Left " " " " " " " "

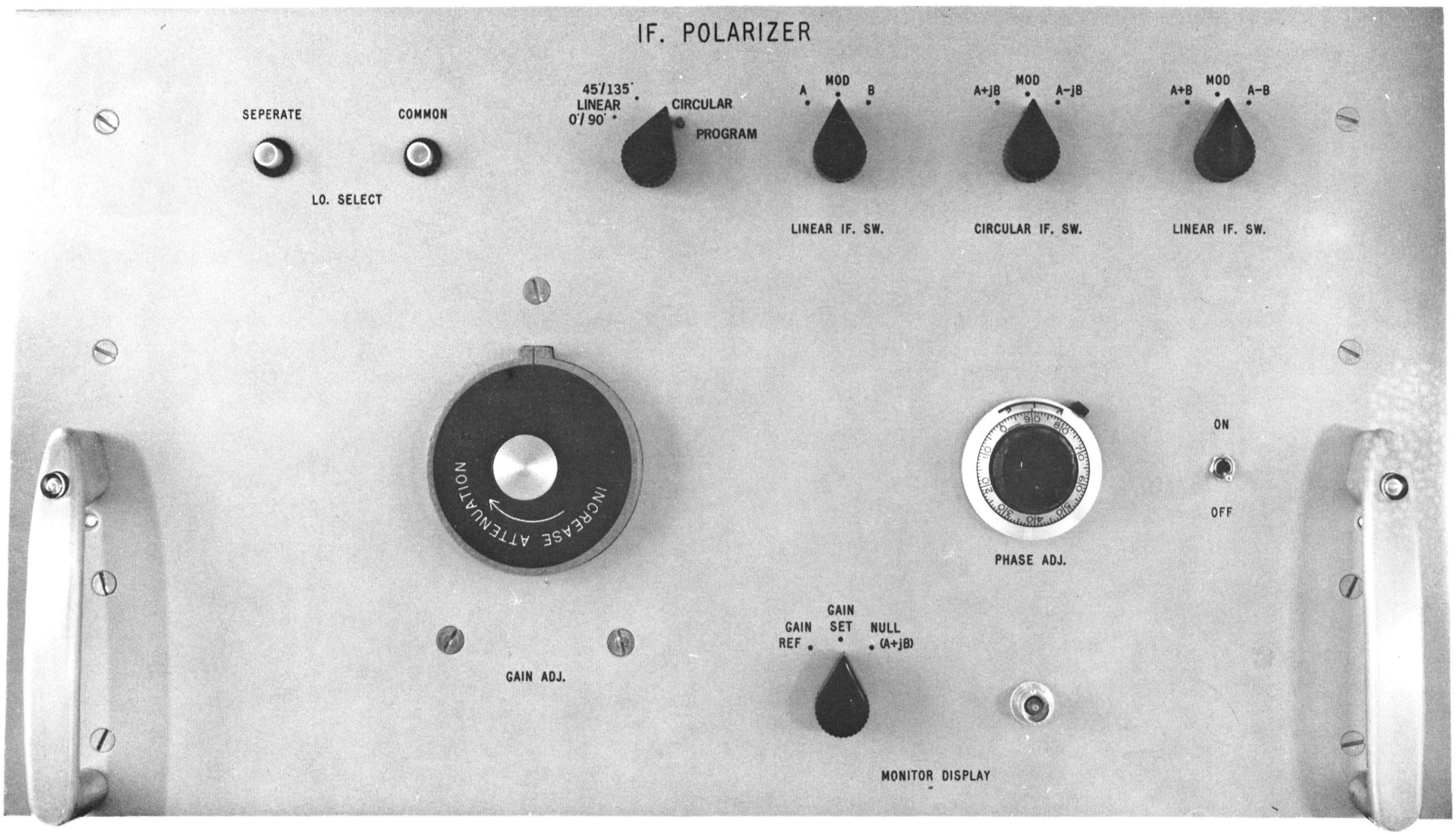
APPENDIX II

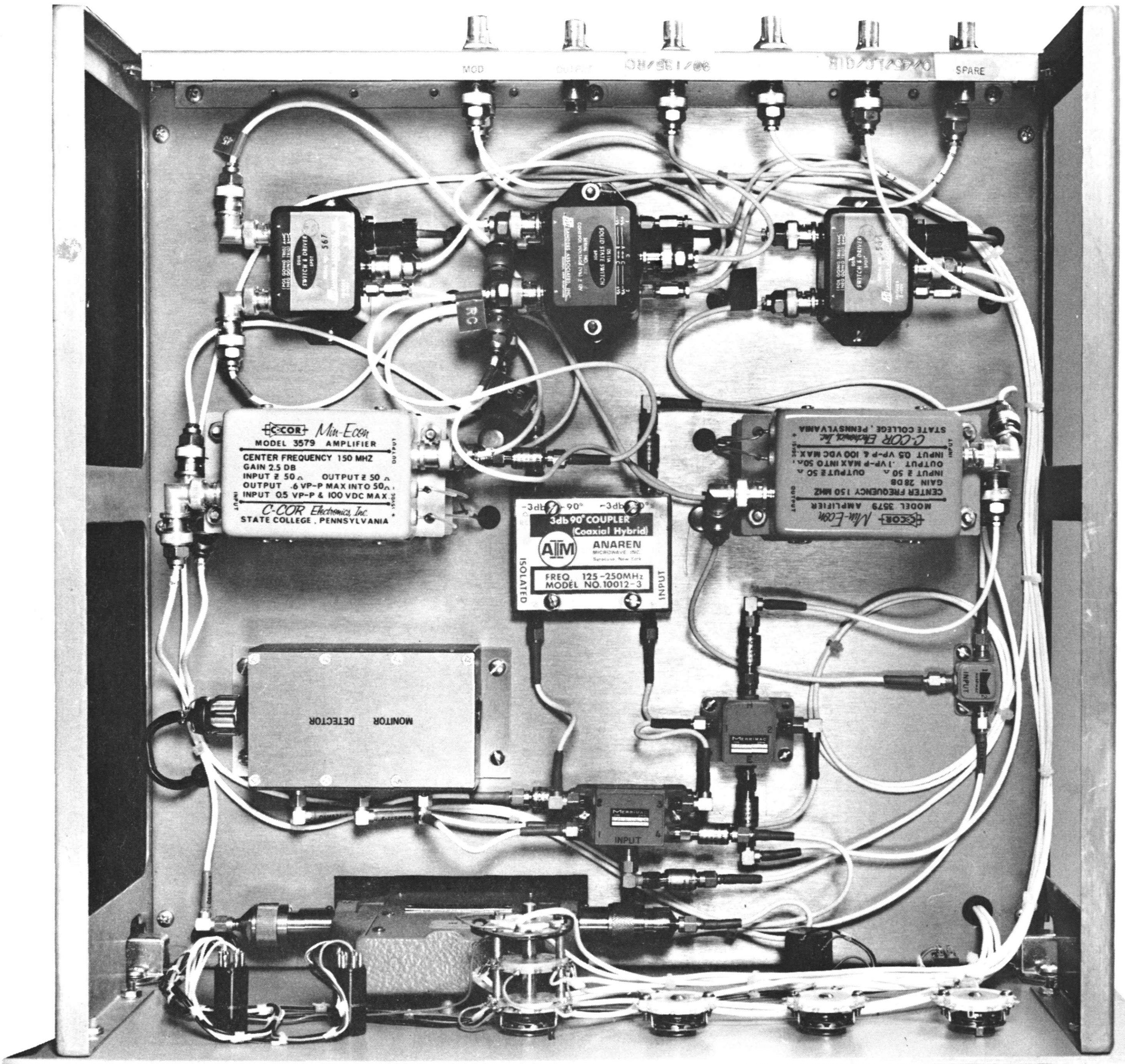
PHOTOGRAPHS

AND

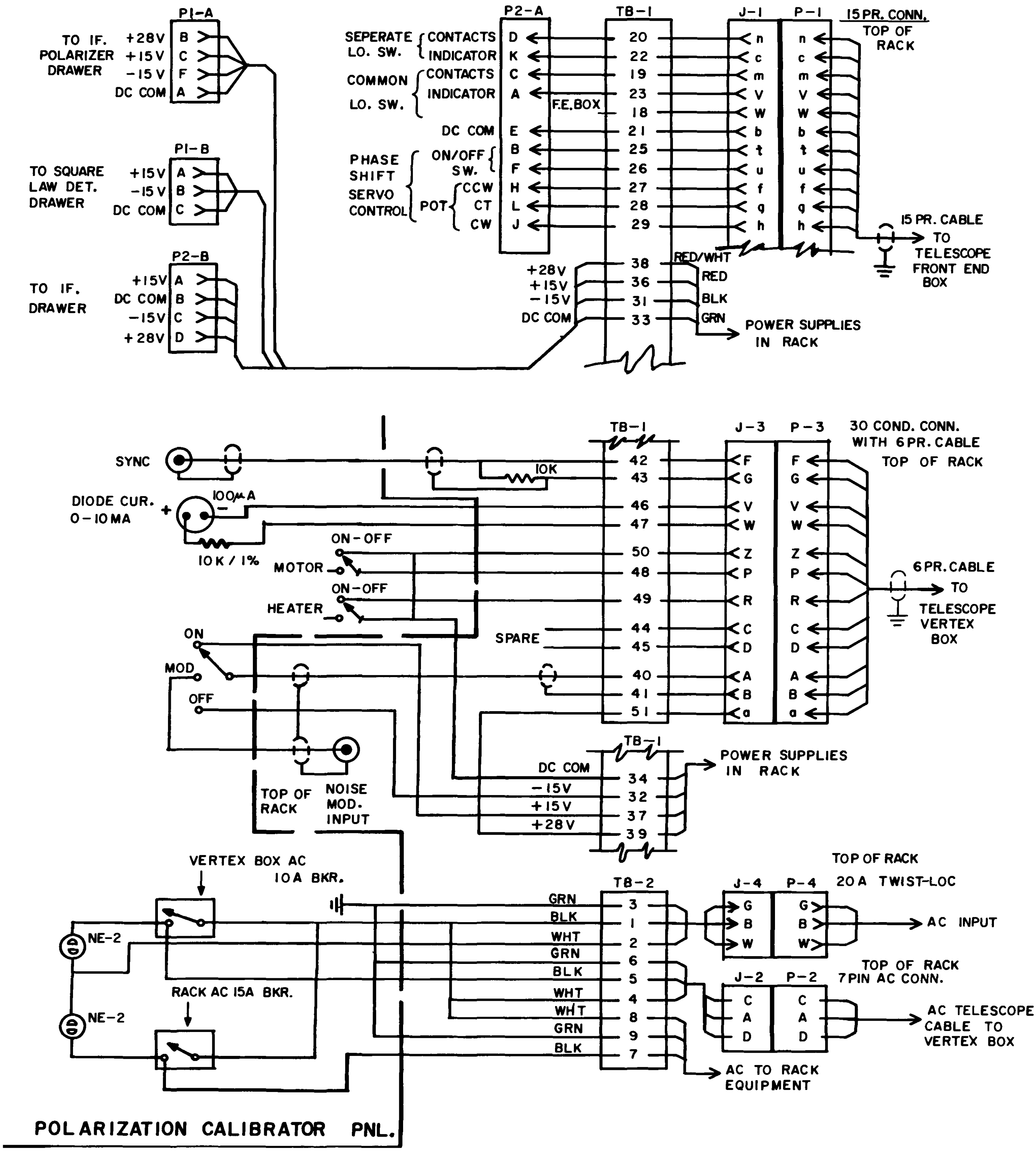
SCHEMATICS


POLARIZATION CALIBRATOR
RACK
BOX
AC POWER
ON
OFF
HEATER
ON
OFF
MOTOR
ON
MOD
OFF
NOISE DIODE
DIODE CURRENT
SYNC
1206B OSCILLOSCOPE
FIND BEAM
TRACE ALIGN
POWER
INTENSITY
FOCUS
NRAO
Cal Date
VERTICAL
HORIZONTAL
SWEEP
EXT HORIZ
RESET
IF. POLARIZER
SEPERATE
COMMON
LO. SELECT
45/135
LINEAR
0/90
CIRCULAR
PROGRAM
A
MOD
B
LINEAR IF. SW.
A+jB
MOD
A-jB
CIRCULAR IF. SW.
A+B
MOD
A-B
LINEAR IF. SW.
ATTENUATION
INCREASE
B
GAIN ADJ.
ON
OFF
PHASE ADJ.
A
GAIN REF
GAIN SET
NULL (A+jB)
MONITOR DISPLAY
SQUARE-LAW DETECTOR
45
135
OUTPUT 1
OUTPUT 2
OUTPUT 3
OUTPUT 4

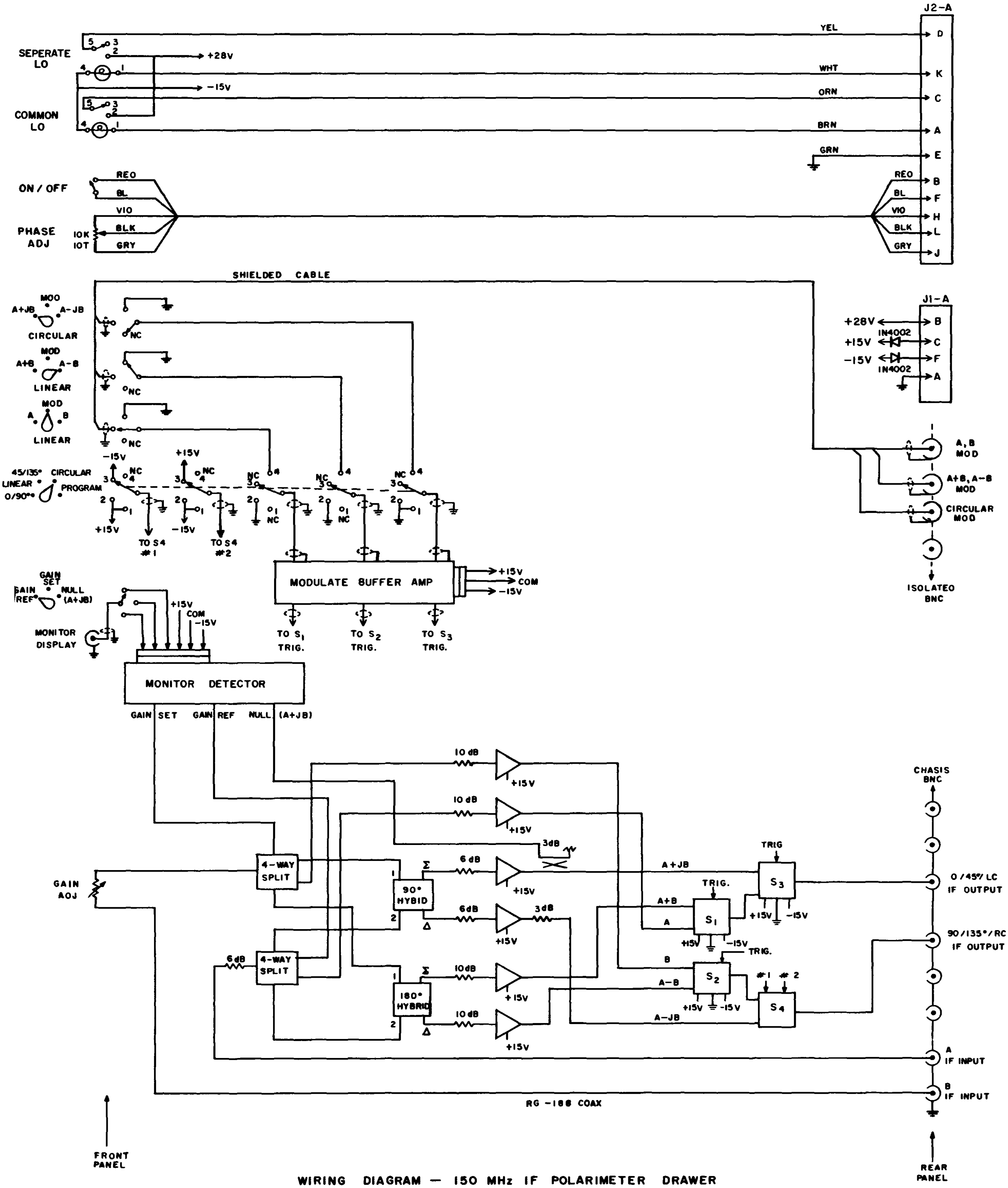

IF. POLARIZER
SEPERATE
COMMON
LO. SELECT
45°/135°
LINEAR
0°/ 90°
CIRCULAR
PROGRAM
A
MOD
B
LINEAR IF. SW.
A+jB
MOD
A-jB
CIRCULAR IF. SW.
A+B
MOD
A-B
LINEAR IF. SW.
INCREASE ATTENUATION
GAIN ADJ.
PHASE ADJ.
ON
OFF
GAIN
SET
GAIN
REF
NULL
(A+jB)
MONITOR DISPLAY



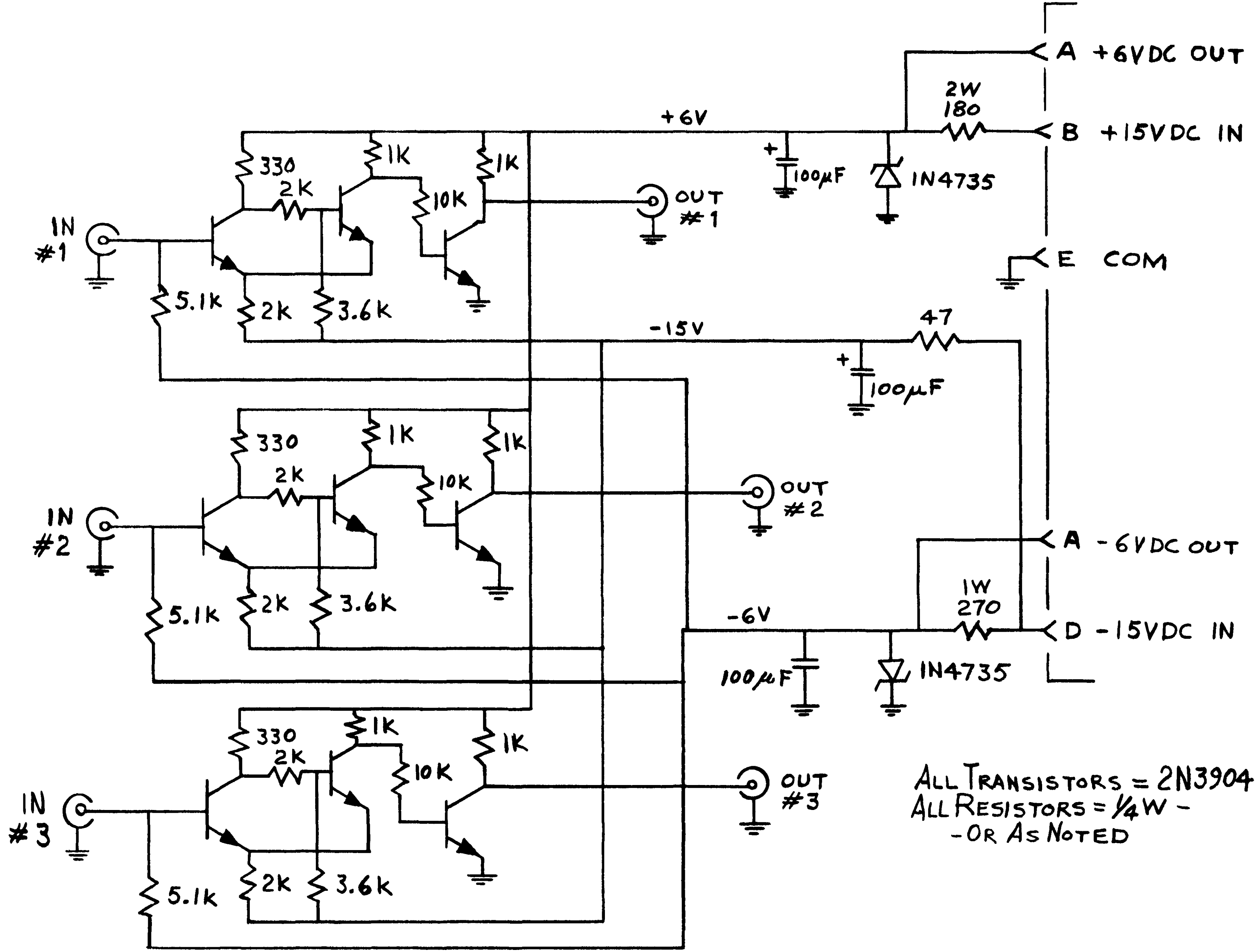
MOD
SPARE
C-COR Min-Econ
MODEL 3579 AMPLIFIER
CENTER FREQUENCY 150 MHZ
GAIN 25 DB
C-COR Electronics, Inc.
STATE COLLEGE, PENNSYLVANIA
3db 90° COUPLER
(Coaxial Hybrid)
ANAREN
FREQ. 125-250MHz
MODEL NO.10012-3
ISOLATED
INPUT
MONITOR DETECTOR



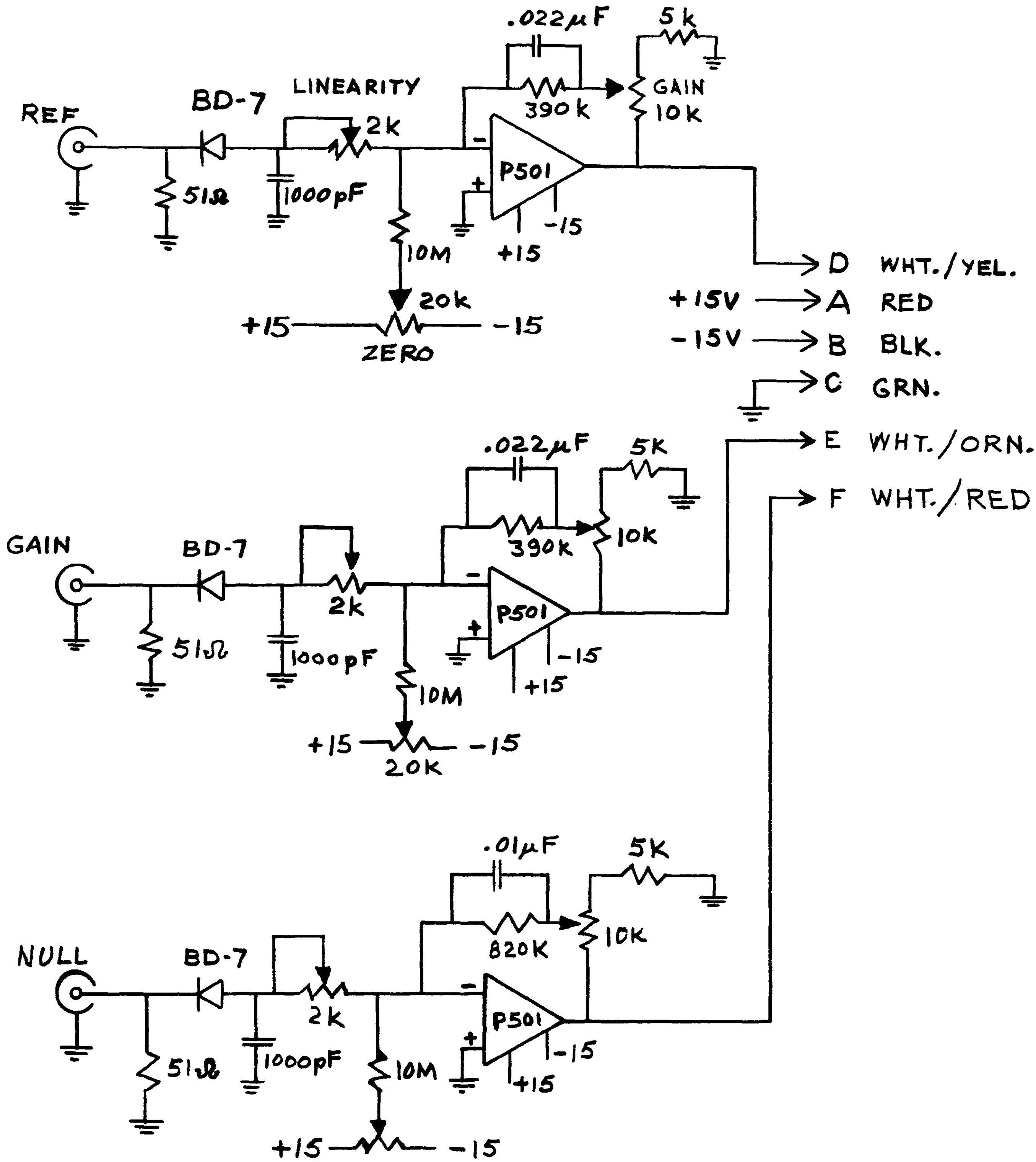
WIRING DIAGRAM — IF POLARIMETER RACK



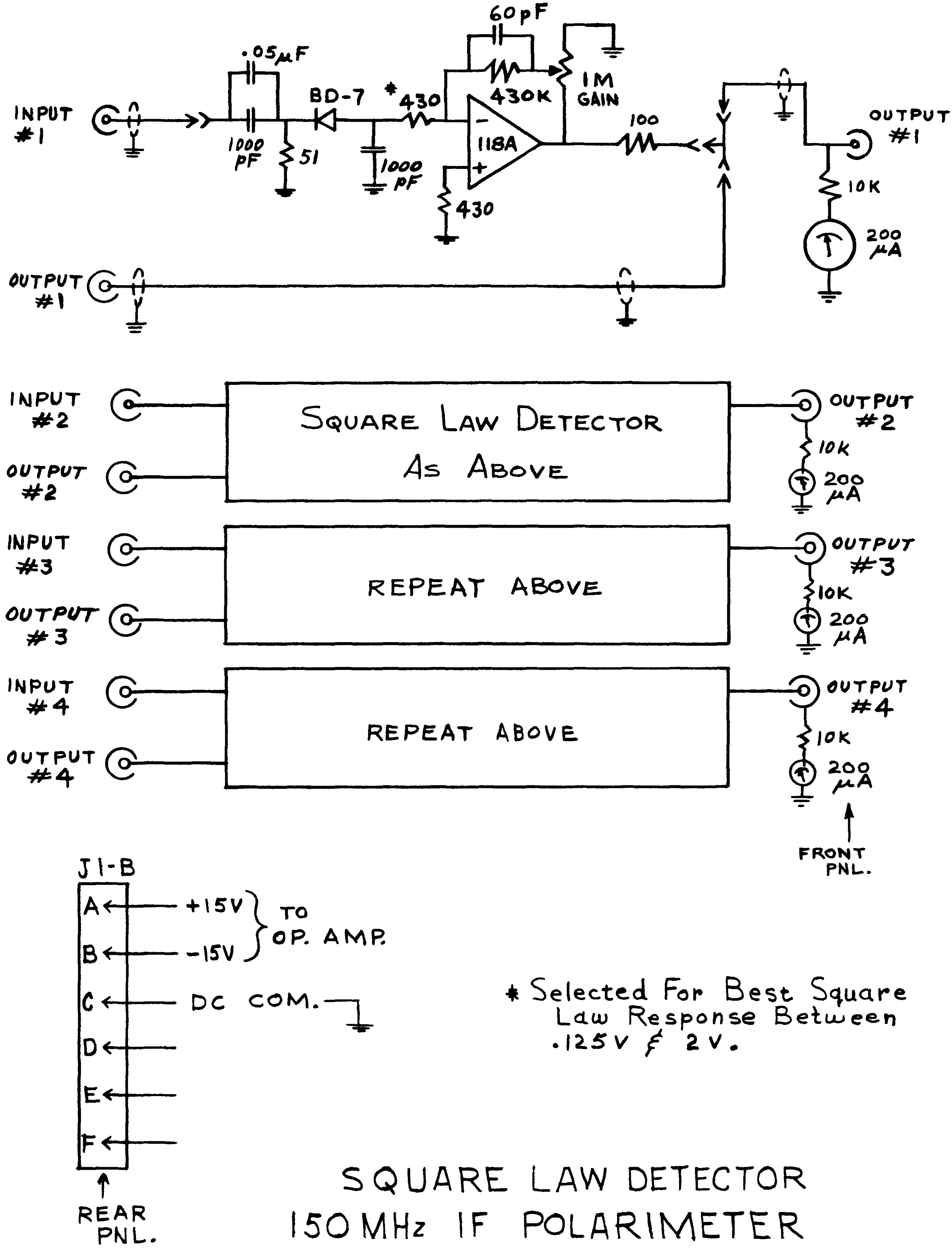
WIRING DIAGRAM — 150 MHz IF POLARIMETER DRAWER



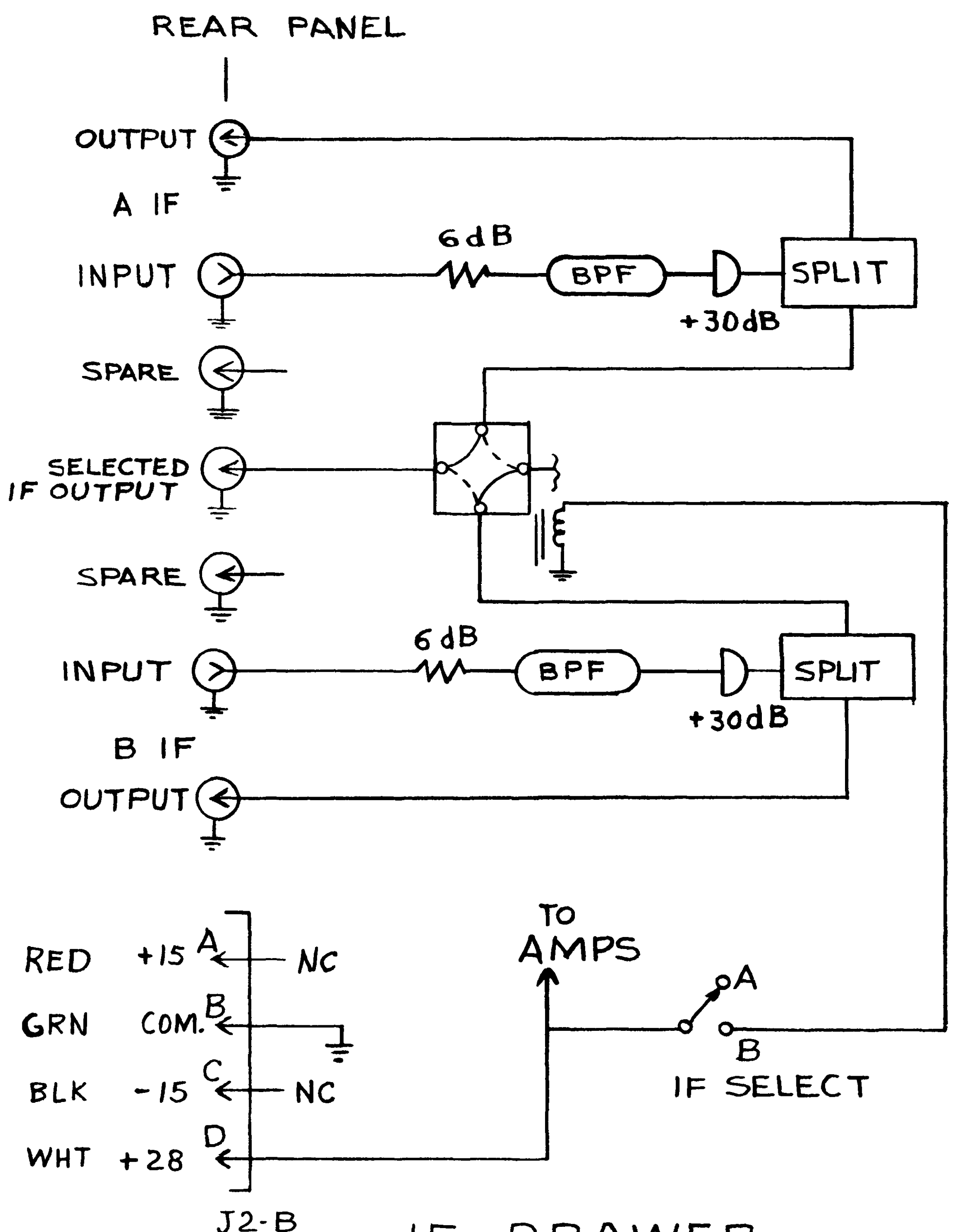
IF MODULATE BUFFER
150 MHz IF POLARIZER



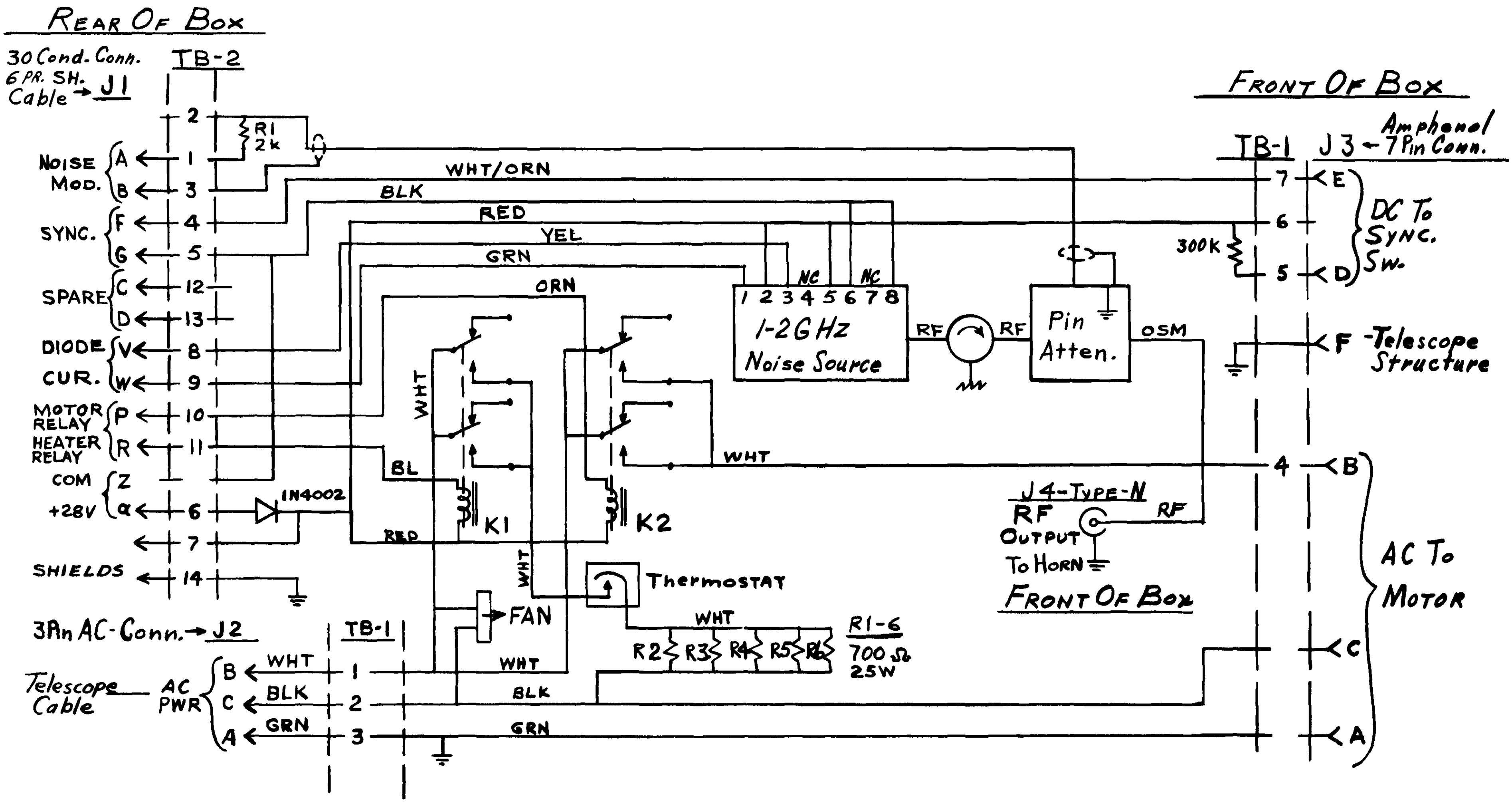
MONITOR DETECTOR
150 MHz IF POLARIZER



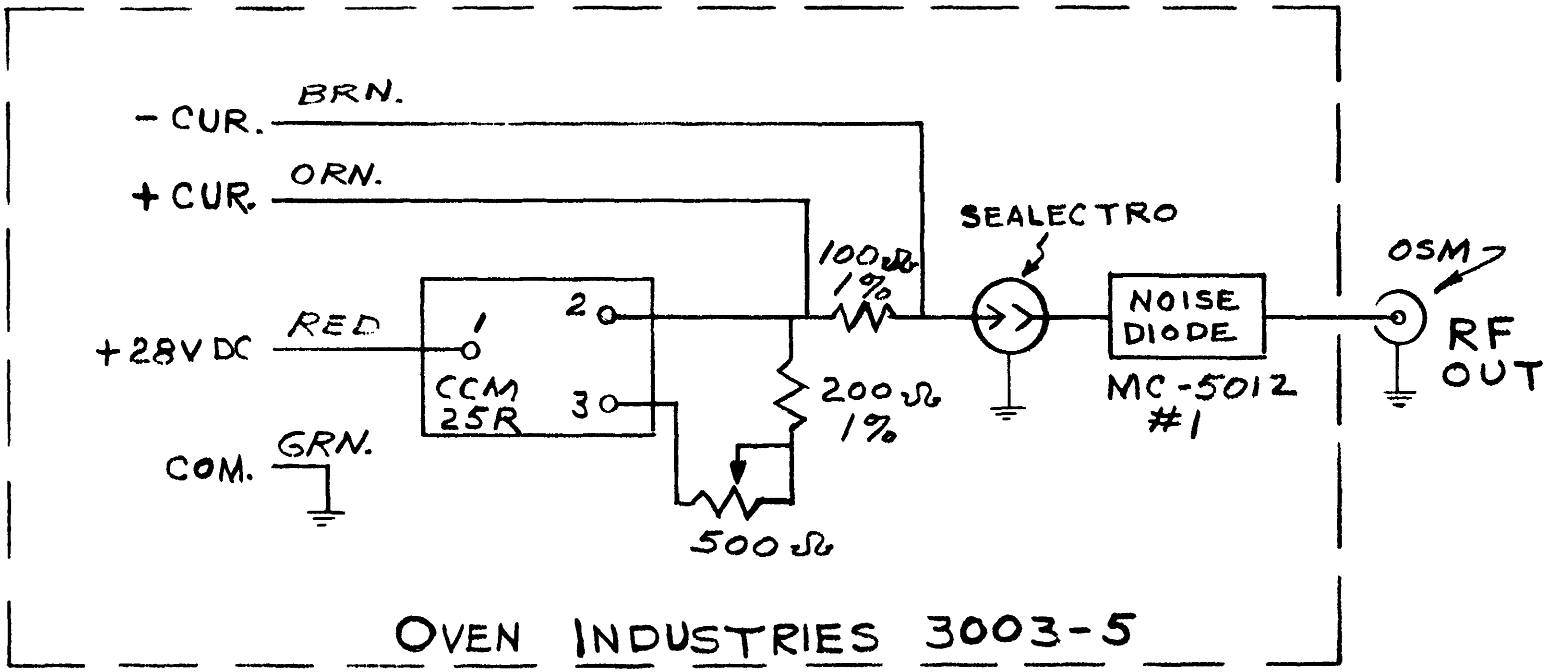
SQUARE LAW DETECTOR
150 MHz IF POLARIMETER

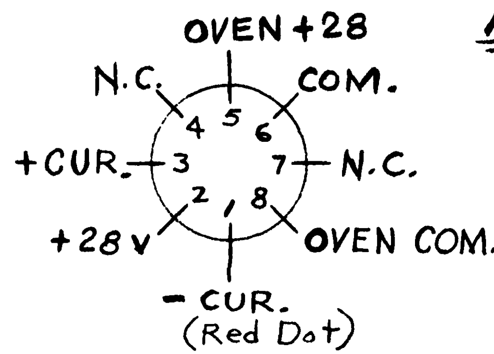


IF DRAWER
150 MHz POLARIMETER



WIRING DIAGRAM - VERTEX CALIBRATION SOURCE

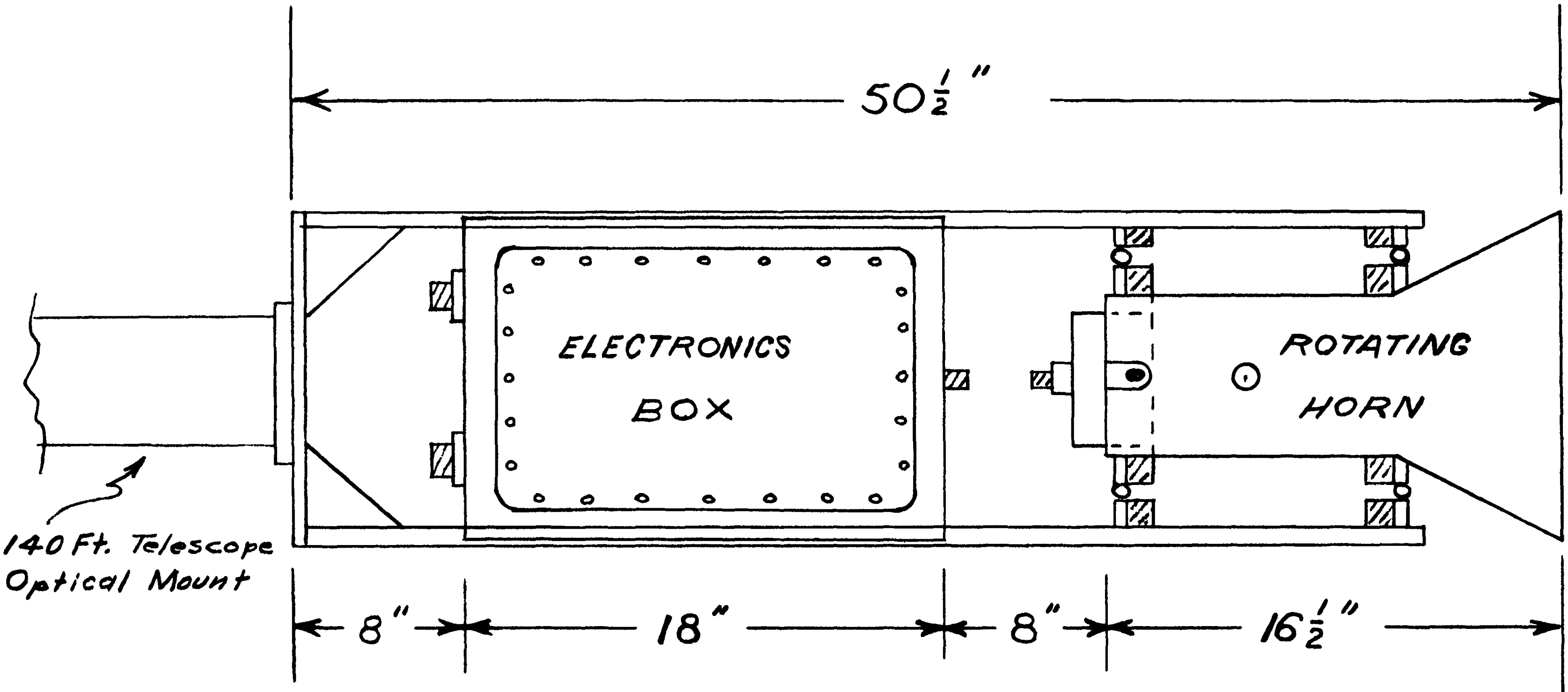




BOT. VIEW

NOTE:
Voltage Between Pins
1 & 6 EQ. +15VDC. NOM.
For 4 mA Diode Cur.

1 - 2 GHz NOISE SOURCE
VERTEX CALIBRATION SOUCE



VERTEX CALIBRATION SOURCE