NATIONAL RADIO ASTRONOMY OBSERVATORY
Green Bank, West Virginia

Electronics Division Internal Report No. 124

COOLED 21 CM RADIOMETER

D. L. Thacker

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I. Introduction

The cooled 21 cm dual-channel radiometer employs four NRAO constructed parametric amplifiers, two of which are cooled to ≈ 20 °K by a closed cycle helium refrigerator, CTI model 350. The paramp design is scaled from the paramps which are presently used in the cooled 18 cm system. The cooled 21 and 18 cm systems are very similar and share many virtues as well as faults.

II. System Specifications

The 21 cm system was designed for use as a low-noise spectral-line receiver and was optimized for low-noise temperature. The system noise temperature is about 50 °K which is almost 15 °K less than the 18 cm system. A substantial portion of the 15 °K temperature reduction is from the direct mechanical interface between the feed and the cooled paramps. With this mechanical arrangement no provision was made for load switches, alternate feed configuration, or polarizers to be placed between the feed and the cooled paramps.

The system is designed to cover a velocity range of -1000 to +10,000 km/sec for the 21 cm hydrogen line. This represents a tuning range of 60 MHz centered at 1400 MHz. Instantaneous 3 dB bandwidth of the system is greater than 20 MHz. The performance of paramps has been optimized over the 1400 to 1425 MHz range. The system is usable to frequencies as high as 1450 MHz and as low as 1370 MHz. Table I shows the specification of the radiometer. Table II lists the recombination lines covered by the receiver.

TABLE I

21 cm System Specifications

Noise Temperature	50 °K	Maximum
Instantaneous Bandwidth	20 MHz	Minimum 3 dB
Tuning Range	1375-1445	Center Freq.
Calibration Value [1] System A	3.0 °K	± .2 °K
System B	4.9 °K	± .3 °K
Cooled Paramps		
Gain	15 dB	Nominal
Pump Frequency A	20.425 GHz	
B	20.202 GHz	
Bias Voltage	0 to +3 volt	Depends on tuning
Bias Current	0	
Ambient Paramps		
Gain	15 dB	Nominal
Pump Frequency	20.175 GHz	Same for both
Bias Voltage	0 to +3 V	Depends on tuning
Bias Current	0-1 μA	Depends on tuning
3rd Stage Avantek AM-1000		
Gain	27 dB	Nominal
Bandwidth	1-2 GHz	Instantaneous
1 dB Gain Compression Point	-7 dBm	Manf. spec. min.
LO Power [2]	20 mW	Nominal
	100 mW	Maximum
Noise Balance	50 °K [3]	Maximum — either channel.

[1] Measured June 1972.

[2] Referred to input connector on back of box with common LO.

[3] Subject to change.

TABLE II

Recombination Lines Covered by 21 cm Receiver

From:
"Table of Radio Frequency Recombination Lines",
A. E. Lilley and Patrick Palmer

f in MHz	Line
1429.772	H 262 D
1428.101	H 282 E
1425.314	He 166 A
*1424.734	H 166 A
1420.814	He 209 B
*1420.236	H 209 B
1418.334	H 239 C
1413.645	H 263 D
1413.145	H 283 E
1400.787	H 240 C
1400.708	He 210 B
*1400.138	H 210 B
1399.938	He 167 A
*1399.368	H 167 A
1398.398	H 284 E
1397.761	H 264 D
1383.855	H 285 E
1383.528	H 241 C
1382.113	H 265 D
1380.980	He 211 B
*1380.417	H 211 B
1375.161	He 168 A
*1374.601	H 168 A
1369.514	H 286 E

III. Operations

A. Procedures

INSTALLATION

1. Disconnect previous system.
2. Evacuate dewar (Vacion pump valve normally closed).
3. Connect front-end box cables and refrigerator lines.
4. Turn refrigerator on first and then compressor.
5. Verify that power controls and temperature controls are off (see "Turn Off Procedure) and then connect front-end rack cables, IF, LO, thermistors, and cal control cables.
6. Turn on using following procedure.

TURN ON

1. Verify that system is off (see "Turn Off Procedure").
2. Plug into 117 V, 60 Hz power.
3. Turn main power switch ON.
4. Turn front-end box AC ON (Light ON indicates ON).
5. Turn on Vacion supply ON.
6. Turn on Temperature Controller — verify that controller is of proper polarity.
7. Cycle tune switches thru one position to prime circulator.

TURN OFF

1. Vacion supply off.
2. Temperature control 0 - current then off.
3. Front-end box AC OFF (light out).
4. Main power off.

POWER FAILURE

In case of AC power failure, turn front-end off by following "Turn Off Procedure" before restoring power — then after restoring power, follow "Turn On Procedure".

SPECIAL PRECAUTIONS

1. Vacion pump and supply have lethal voltages (4000 volts maximum). USE EXTREME CAUTION.

2. Front-end box AC switch supplies power to fans on outside of box as well as power to the Gunn oscillators. Do not run the heat pumps on the box without this switch on.

3. The back (cable end) of the front-end box has some exposed terminals with 117 V AC on them. Do not work on this end of the box with either the Vacion pump or the front-end box AC ON unless absolutely necessary.

SPECIAL PRECAUTIONS (continued):

4. As with most NRAO boxes, there is 117 V AC on the fans on the heat pumps. Use caution here also.

B. Comments and General Suggestions

1. For best baselines and baseline stability use total power (AC-9) with the off's at frequent intervals.

2. When frequency switching is necessary, experiment. Several of the following techniques give different baselines depending on the observing frequency. Try several and pick the one you like best.

    1. LO above or below the signal frequency.

    2. Switch ref LO either higher or lower than signal LO on both. Also, change the distance that you switch.

    3. Change the IF frequency.

    4. Move feed focus and average spectra taken. See S. Weinreb's memo of November 14, 1967.

    5. Try noise balance either by itself or with gain modulator.

    6. Retune paramp and/or change other front-end components (last resort).

3. System A is more stable at some polarization angles than others. If instability is noticeable, rotate the box. (Points of instability seem to be elevation sensitive.)

C. Sweeping and Tuning the System

In order to monitor the tuning of the system, a sweep generator and oscilloscope are mounted in the rack. (See Figure 1.)

The sweep signal is fed up the telescope cable and injected in the calibration part of the directional coupler between the feed and the first paramp. (See block diagram, Figure 7.) The signal is sampled and detected after the third stage. The detected signal is amplified, then sent down the telescope cables to be displayed on the oscilloscope. Along with the usual controls on the sweeper and scope, the group of controls on the right side of the aux control panel control the sweep signal. It is important to turn the sweep generator and attenuator off during observations. When the sweep status light on the main control panel (Figure 2) and on the remote control panel (Figure 3) are off (not lit), the sweep generators are off (unless someone has bypassed the interlock).

There are five internally preset tunings which are controlled by the tune switch on the main control panel (Figure 2). When the tune switch is in the F. P. (front panel) position, the pots on the front panel control the tuning parameters of the system and can be adjusted by the observer, if necessary. Do not exceed 2 μA bias current on any of the paramps.[1/] If the paramp breaks into oscillation, as indicated by excessive bias current, turn paramp off immediately and reduce pump power setting before turning on again.

Due to hysteresis in the cooled circulators, always saturate the circulator (maximum circulator current) and then decrease to the current desired. This is done automatically when the tune switch is cycled.

[1/] Bias current meters are ± 10 μA full scale.

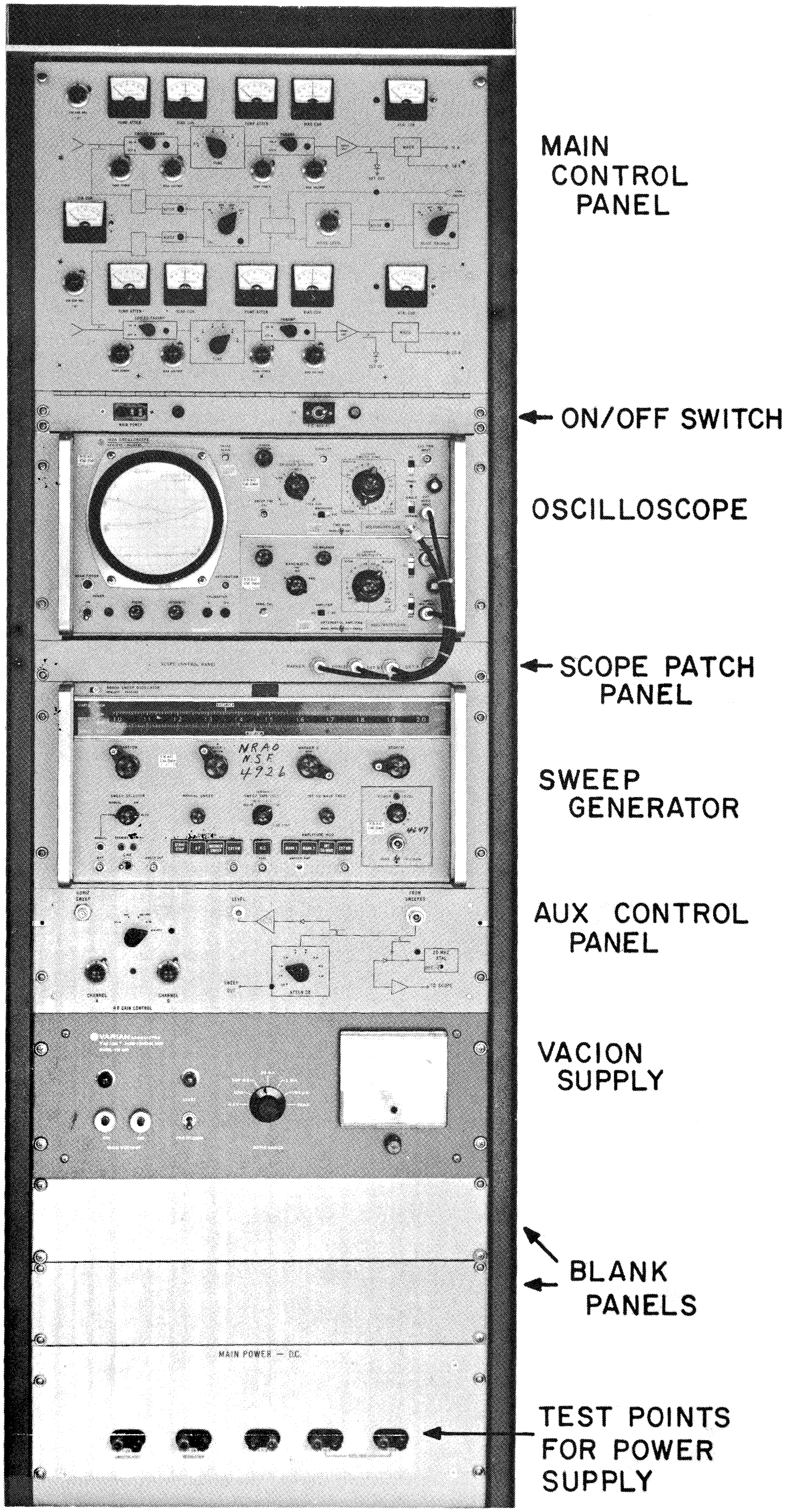


Figure 1 — 21 cm System Control Rack, Front View

D. Noise Balance and RF Gain Modulator

The system is equipped with both a RF gain modulator and noise balance. These features may be used when observing against strong continuum sources to improve baselines. When the continuum temperature approaches the system temperature (~ 50 °K), the IF gain modulator on the IF attenuators give better baselines than either noise balance or RF gain modulation. For continuum background in the range of 10-50 °K the noise balance and RF gain modulation are worth experimenting with if baseline flatness is of great importance. Both the gain and the added noise are controlled independently for channels A and B. (See Figure 3, Remote Control Panel.) The injected noise as well as the gain can be modulated at the switching frequency.

IV. In Case of Difficulty

A. For the Observer/Operator

There are several means by which a malfunction can be detected. The surest of them is to daily observe a known source and compare the on-line spectral output to previous spectra. Another critical point that should be monitored closely is the ratio of the system noise temperature to the calibration temperature that the computer prints at the end of every scan. After multiplying by the appropriate cal value, this number should be approximately 50° + T_{sky}. The total power (x 10) output of the autocorrelation should be continuously monitored on a chart recorder by the telescope operator. Interference, gain instabilities, long-term drift are usually detected first on the chart recorder.

At the first sign of trouble check the bias current meter on the main control panel. If any of these meters read more than 3 μA bias current (the meters are ± 10 μA full scale), turn the associated paramp off immediately and call the engineer in charge of the system.

In case of power failure do not forget to cycle the turn switches.

If the computer prints out "system temperature unreasonable", check the following:

(1) Is the cal firing correctly? (Red light in noise box lit when cal is on.)

(2) Are the paramps on?

(3) Is there sufficient LO power? (20-50 reading on all xtal current meters)

(4) Is the LO frequency correct?

(5) Is IF getting to the autocorrelator? (IF processor attenuation should not be on Z_o.)

The sweep status light should be out during observations and the sweep generator should be off.

The normal operating vacuum is 10^{-6} Torr or better (200 μA vacion current or less).

When in doubt, call the engineer assigned to the system.

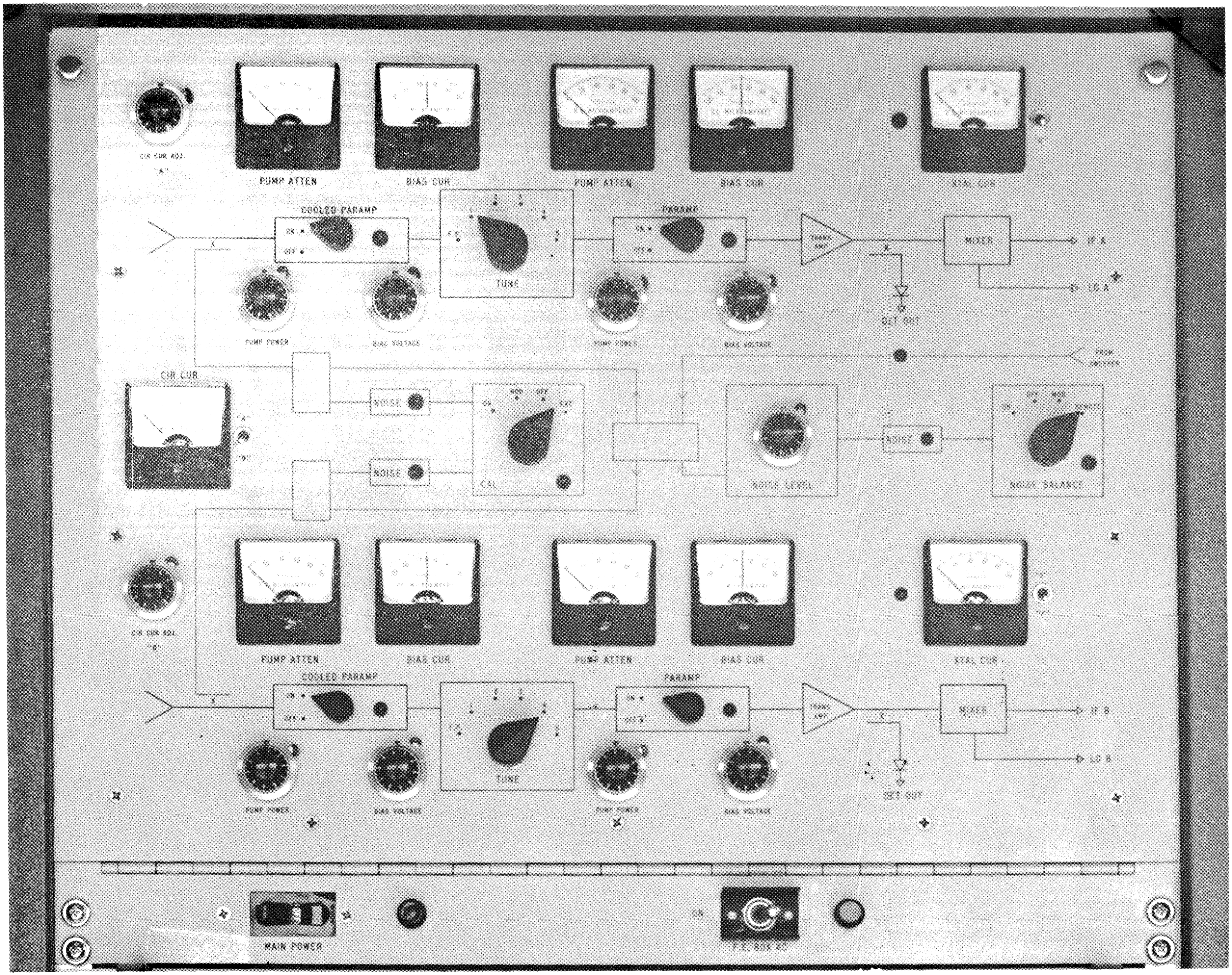


Figure 2 — Cooled 21 cm Main Control Panel

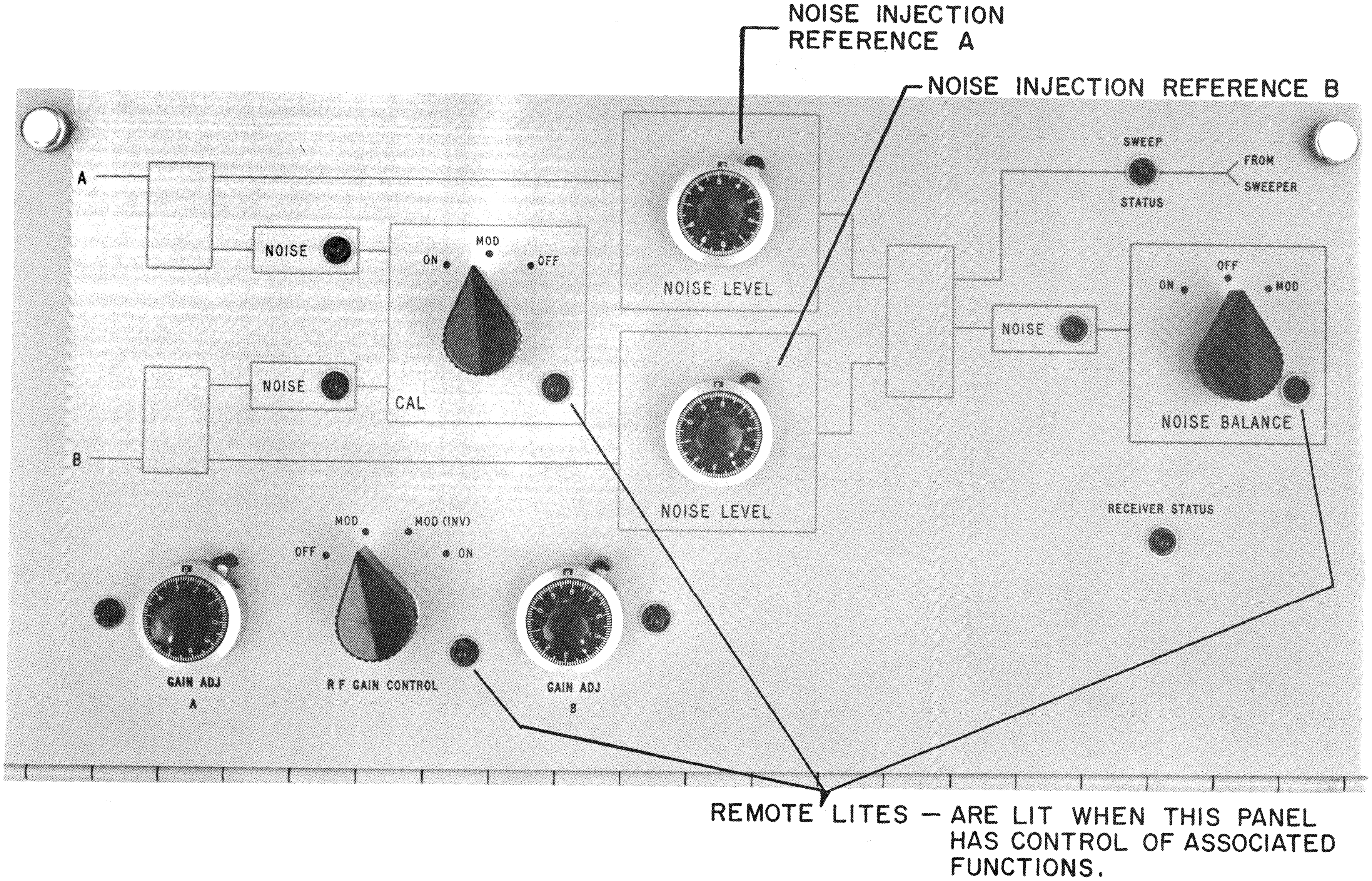


Figure 3 — Remote Control Panel

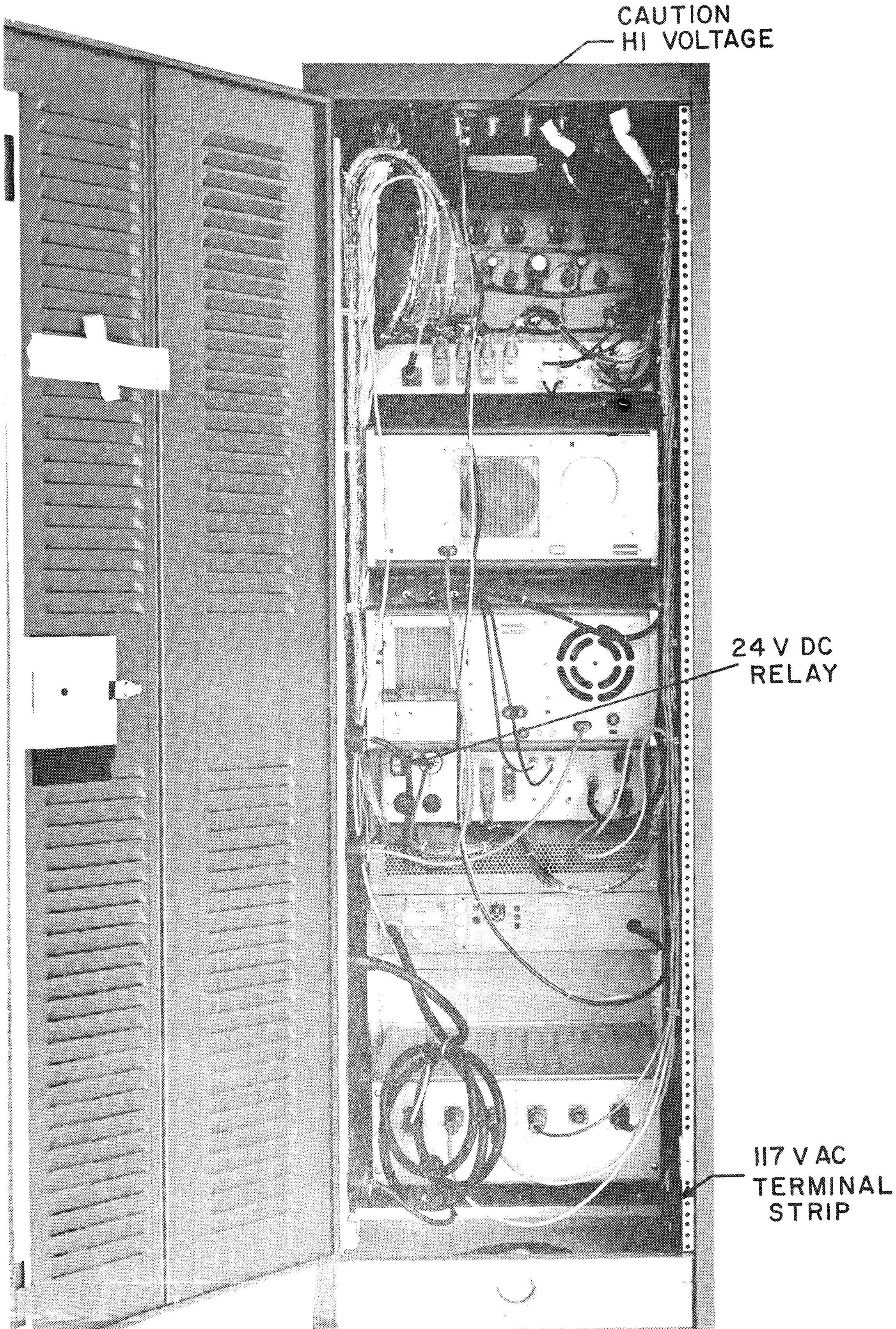


Figure 4 — Front-End Box Control Rack, Back View

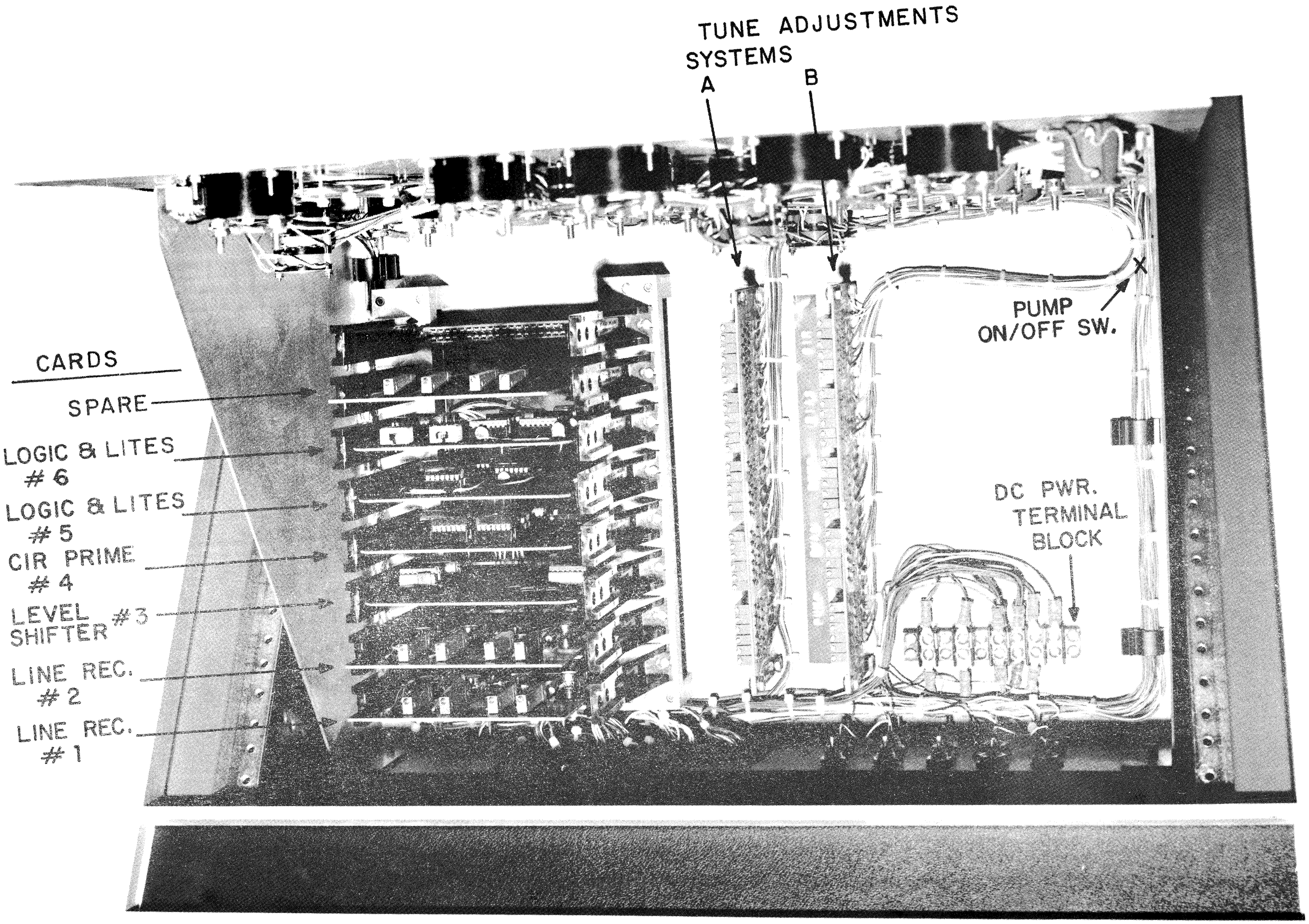
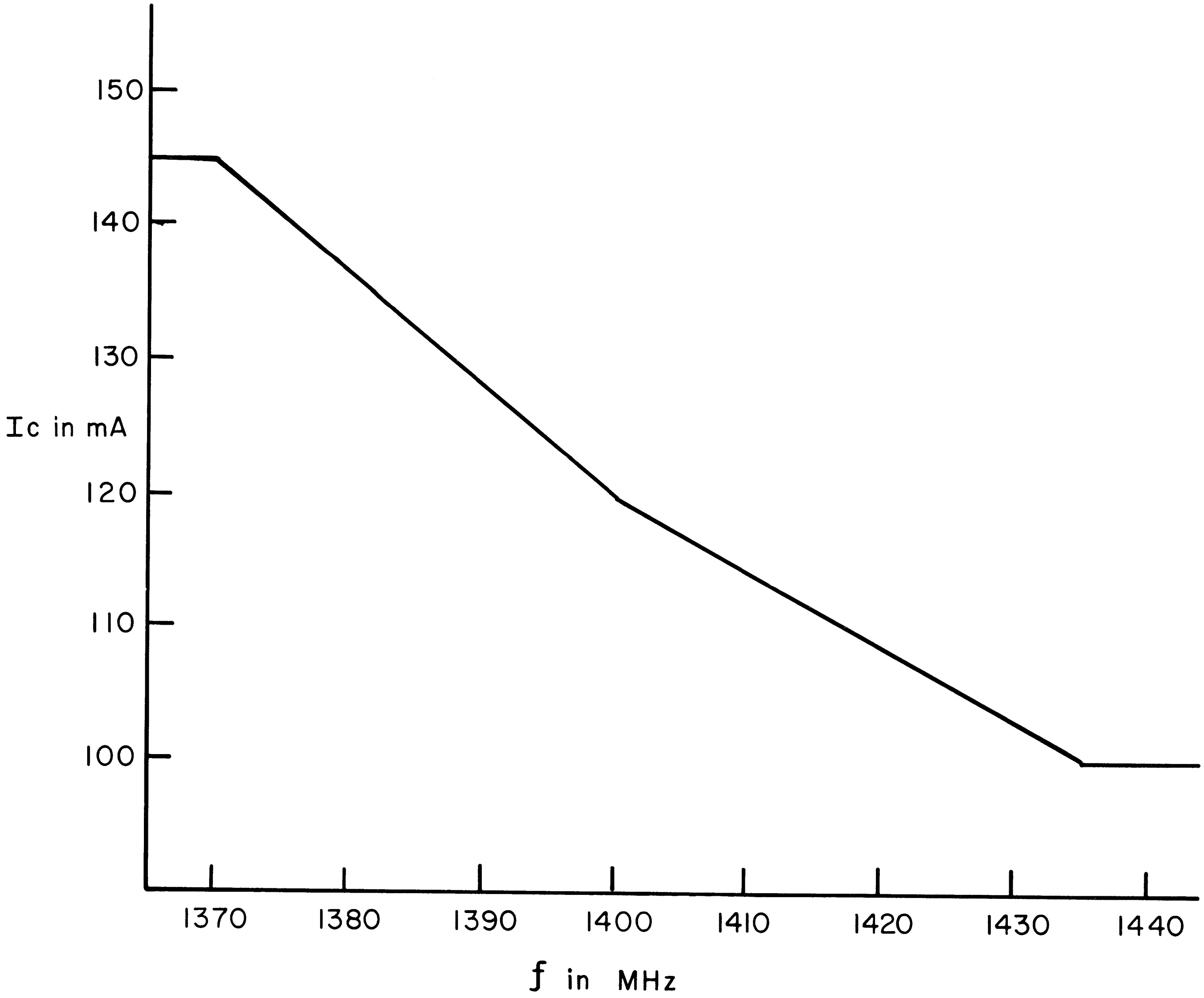


Figure 5 — Main Control Panel, Inside View

B. For the Engineer Responsible for the System (Internal Adjustments)

Adjust the circulator currents for the preset tunings according to Figure 6. The two switches on card 6 in the main control panel are to invert the cal and reference signal if necessary. The pots on cards 1 and 2 main control panel are the common mode adjust on the line driver. Located inside the main control panel on its right wall there are two small toggle switches. One switch controls the DC power to the pumps for the cooled paramp. The other switch controls the pumps for the ambient paramps.

In the front-end box, the two toggle switches on card 6 reverse the circulator current through the cooled circulator. The three pots on card 5 (front-end box) adjust the current in the noise diodes.



CIRCULATOR CURRENT VS FREQUENCY

COOLED CIR. 21 cm

FIG. 6

V. Comments, Suggestions, Acknowledgments

In spite of our best efforts to minimize extraneous noise contributions, about half of the system temperature is from sources other than the cooled paramps. One area greatly in need of improvement is the feed. The present feed suffers from high VSWR, non-concentric phase centers, poor isolation between polarizations, resonances at 1405, 1442 MHz, and high loss. If we knew when we started this system what we know now, we could have achieved system temperatures of 35 to 40 °K without significant sacrifice in cost or delivery. Any further improvements at this frequency would be very difficult.

Several people have contributed to the success of this project. I would like to thank Dr. Jochen Edrich for teaching me all I know about paramps. In developing the cooled 18 cm paramps Dr. Edrich laid the foundation for NRAO's low-noise receiver development. His contribution here is acknowledged and greatly appreciated. Jack Cochran and Dr. Edrich also developed the cooled circulator used in the cooled 21 cm system. Jesse Davis did an excellent job on the input lines. Bernie Pasternak is the man who made it all work; without Bernie this system as well as the 18 cm system would not have been possible.

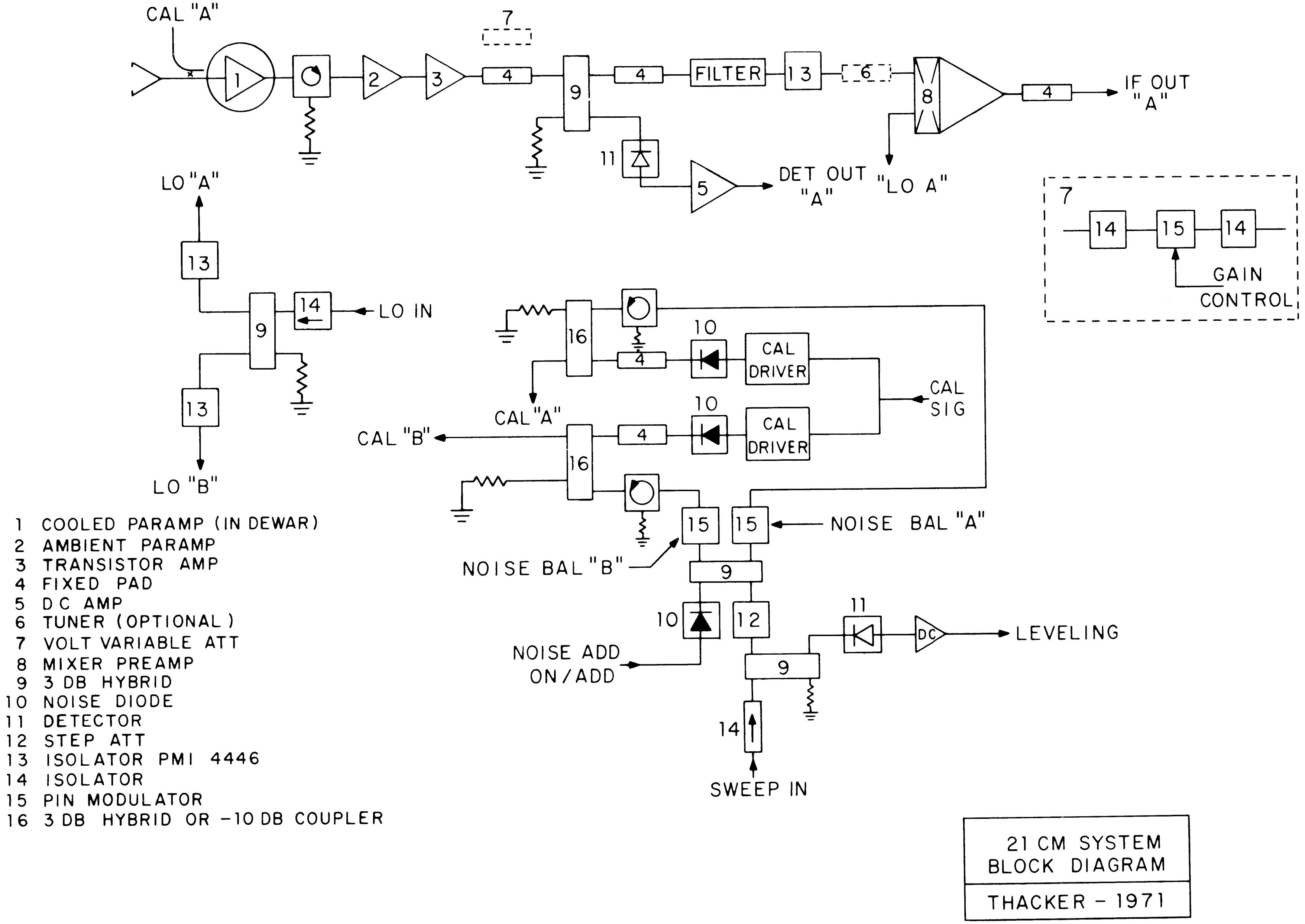


Figure 7 — 21 cm System Block Diagram

APPENDIX A

21 cm Dewar Lines

by

J. E. Davis

The design of the RF lines entering the dewar is based on the following considerations:

1) Heat Flows
2) Resistive Loss
3) Mechanical Configuration
4) Best Match

1. Heat Flows:

Each paramp requires two RF lines to carry the signal to and from the paramp circulator. In addition to these are two pump waveguides. The second stage, including the paramp, is maintained at 20°K. The temperature difference between ambient and the second stage (270°K) gives rise to a large thermal gradient along the RF lines ($\sim$ 13.5°K/cm). A limited refrigeration capacity (1st stage - 5 watts; second stage - 2 watts) dictates careful design to minimize heat flows down the input lines.

2. Resistive Loss and Impedance Match:

The noise temperature of the receiver depends on the RF losses between the feed horn and the paramp. For lowest noise temperature it is desired to keep these losses to a minimum. Of secondary importance is the minimization of losses in the output lines. As paramps are very impedance sensitive, it is desirable to present the best possible match to the input and output ports of the circulator. Consistent with these requirements is the requirement that the bandwidth of the lines be considerably broader than that of the paramp.

3. Mechanical Configuration:

Mechanical considerations were complicated by space limitations and differential expansion of the elements. Past experience with coaxial lines showed differential expansion of the center conductor with respect to the outer conductor to be a problem. Vacuum integrity proved to be a problem. The large number of lines passing through the dewar in addition to the refrigerator and vacuum piping, gives a large cross section for leaks. Considerable effort was expended finding and sealing the leaks.

Design of Input Lines

A design based on the above considerations was made. The loss considerations indicated the use of 7/8" EIA - 50 ohm coaxial line from the feed probes to the paramp circulator. Initial heat flow calculations showed this to be practical if the lines were made of stainless steel tubing with a wall thickness of 0.010 inch. To minimize loss the tubing was plated with a 65 μ inch layer of gold. A tapered section from 7/8" to 7 mm was made to allow a standard type N connector to be used at the circulator end of the line. Both the center and outer conductor were tapered, maintaining constant impedance. The upper end of the input line consists of a feed thru, which also incorporates a vacuum seal, to take the line through the dewar top and a standard EIA flange designed to provide mechanical support for the directional coupler, in addition to its connector function. In an effort to reduce heat flow down the center conductor and to eliminate differential expansion problems it was decided to attach the center conductor to the first (77°K) stage. A broadband T-stub was used to tie the center conductor to the outer conductor at a point approximately midway between the ends. This common point was then tied to the 77°K stage. To provide DC isolation a blocking capacitor was inserted in the center conductor just above the tapered section. This line was built, tested and is now in use.

Input Line Component Descriptions

A. Taper (See Figure 1)

The figure is self-explanatory. For electrical description see:

Meinke/Gundlach, Taschenbuch der Hoch Frequenztechnik, Springer-Verlag, Berlin, 1962, p. 266.

The taper was fabricated of stainless steel. The center conductor was bored to reduce heat flow and weight. The outer conductor of the line slips into the taper and is soldered in place. The tapered center conductor is threaded to attach to a threaded stainless plug pressed into the center conductor of the line. The opposite end of the taper is a nipple which presses into the Weinschel Model 1510 type N connector.

B. Blocking Capacitor

The blocking capacitor is formed of a sheet of 1/2 mil. teflon tape inserted in a slip joint in the center conductor.

C. Thermal Short (See Figures 2 - 6)

The thermal short consists of a broadband T-stub as described in the following articles:

Ragan, Microwave Transmission Circuits, Radiation Laboratory Series, Vol. 9, McGraw-Hill Book Co., Inc., 1948, p. 173-176.

Muehe, C. E., Quarter-Wave Compensation of Resonant Discontinuities, IRE Transactions on Microwave Theory and Techniques, Vol MTT-7, April 1959, p. 296-297.

The center conductor is formed of stainless steel bored to reduce weight and heat flow. The center conductor of the stub is of brass with a brass shorting plug to proved thermal contact with the outer conductor. An aluminum block surrounding the outer conductor of the line provides support for the outer conductor of the stub. All joints are press fit. All components are gold plated. A copper strap fitted with indium contact pads provides the thermal connection to the second stage.

D. Feed-Thru (See Figures 7 - 11)

The feed-thru is designed around a standard EIA flange. The center conductor is of beryllium copper and is made in two sections with a Rexolite bead in the center. The outer conductor of the line is soldered in a stainless steel nut which screws into the vacuum seal flange. This nut clamps the center conductor bullet against the vacuum flange providing a center conductor vacuum seal. This flange is constructed of stainless steel with an O-ring providing the vacuum seal. The vacuum flange is held in a recess in the dewar top by the RF flange/coupler support shell. The center of this flange provides the outer conductor for the RF line and is gold plated. The lower flange bolts to the dewar top, pressing down on the vacuum flanges, compressing the O-ring. A gold plated contacting surface is provided for RF conduction. The upper flange is a standard EIA flange which bolts to the coupler. The center conductor bullet extends from the input line inside the dewar through the two flanges to form the center pin for connecting to the directional coupler. All RF surfaces are gold plated. All vacuum seals depend on surface contact/pressure. No sealers are used except for vacuum grease on the O-ring. Steel alignment pins are provided as necessary.

Output Line Design

The same design considerations were followed in the design of the output lines as used in the design of the input line. Since loss is not as important here the output lines were standard 7 mm lines fabricated of stainless steel tubing. The circulator connector is a Weinschel model 1510. The outside world end is an APC-7 modified to provide a vacuum seal. The same broadband T-stub provides thermal conduction to the refrigerator second stage. The output lines provide a DC path for the paramp varactor bias. In accordance with this the DC blocking capacitor is moved to the stub to prevent a DC short in the line. The block is fabricated as part of the RF short instead of being placed in the center conductor as before.

Output Line Component Description

Since much of the output line is a duplicate (except for dimensions) of the input line only those portions which differ are described.

Upper Connector

A standard Amphenol APC-7 connector is assembled using epoxy to seal the joints. This provides the vacuum seal for the inner conductor. The outer conductor is soldered into a copper sleeve which is then indium soldered into the dewar top to provide a vacuum seal for the outer conductor.

A drawing of the dewar top is included for reference. (See Figure 12)

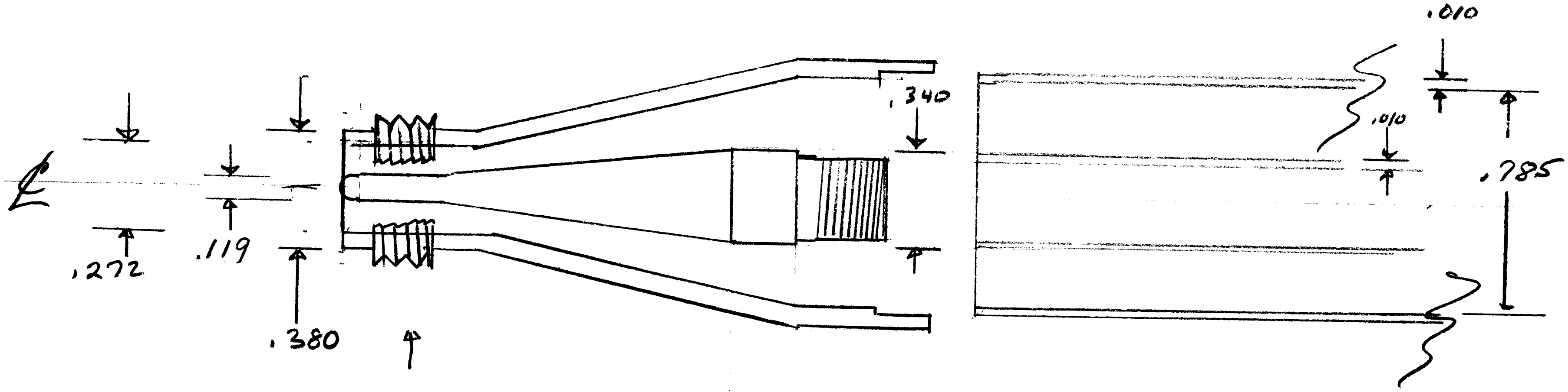
I wish to thank Dr. Jochen Edrich for the initial idea and Mr. W. C. Luckado for his help with the mechanical design, fabrication and his infinite patience.

Material Availability

Stainless Steel tubing:

Input Lines	Maury Microwave Corp. 8610 Helms Avenue Cucamonga, California 91730
Output Lines	Center conductor - standard 1/8" OD X .028 WA centerless ground to .119 OD. Outer conductor - standard 5/16" OD X .020 WA stainless steel (304) Both are available from Williams and Company, Inc.
Gold plating was done by:	American Chemical and Refining Co., Inc. Sheffield Street Waterbury, Connecticut 06714

The vacuum system welding was done by the Department of Physics, University of Virginia, Charlottesville, Virginia.



STANDARD
Weinschel Model 1510
Connector Adapter.

TAPER
FIGURE 1

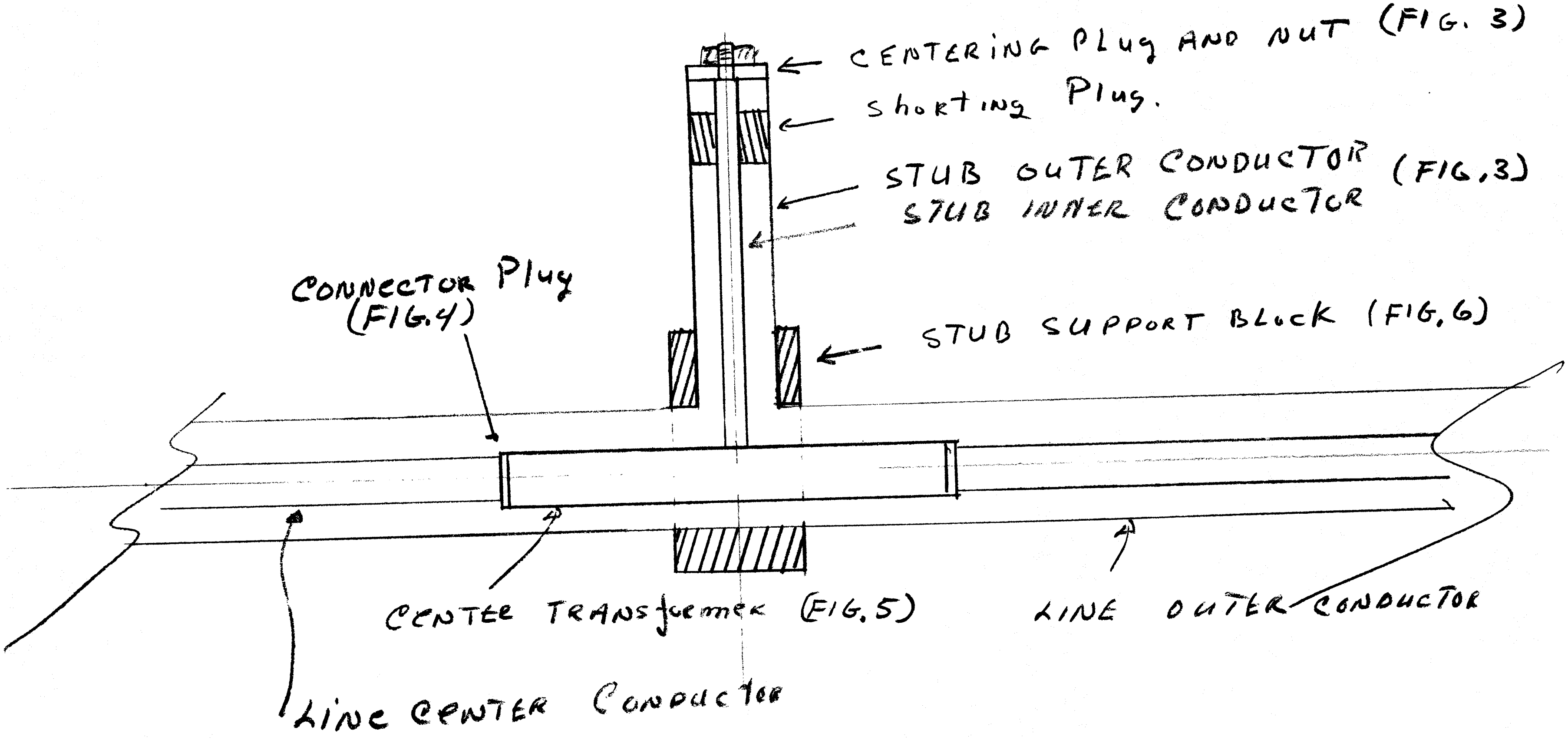
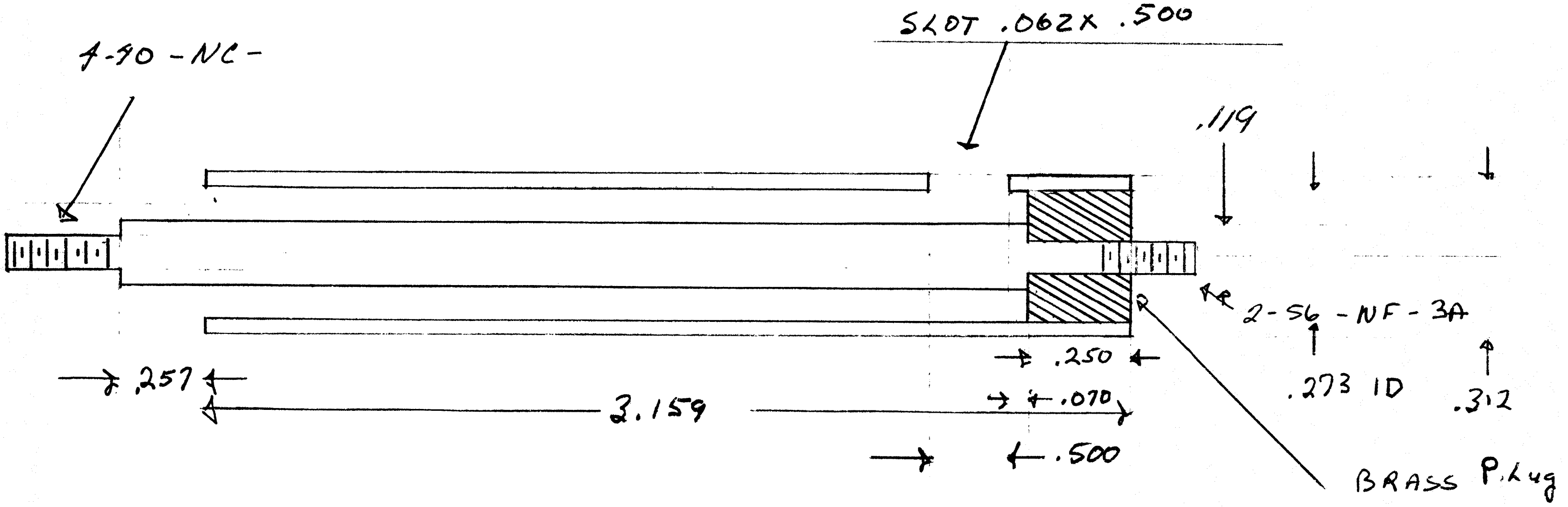


FIGURE 2
ASSEMBLY DIAGRAM
NOT TO SCALE.



BROAD BAND STub.

Thermal Shorts

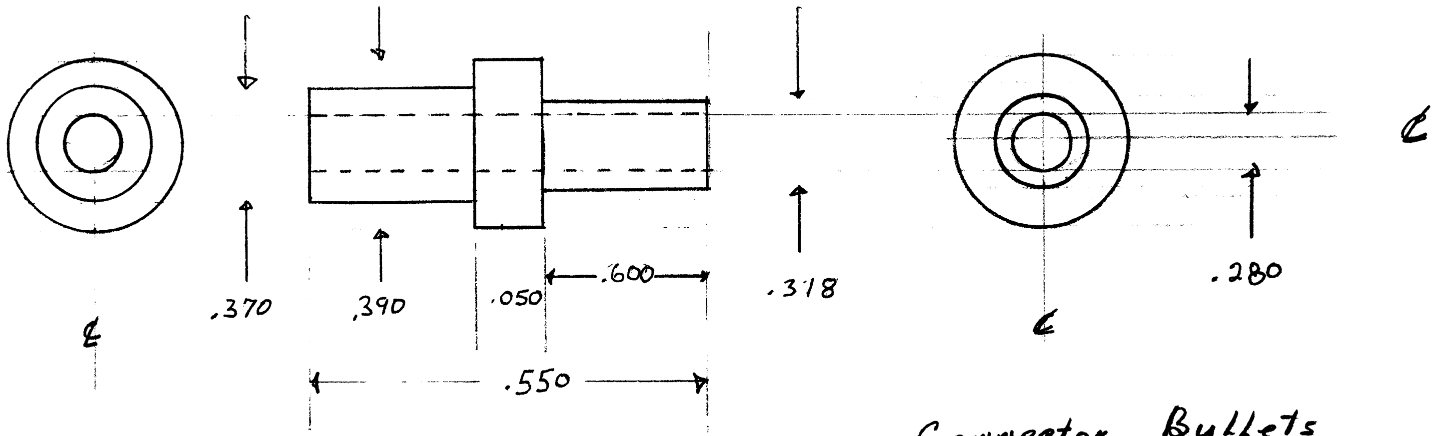
7/8" Liner

MAT. ST. ST. & BRASS

TOL ± .001

Qty 2 ea.

FiG 3



Connector Bullets

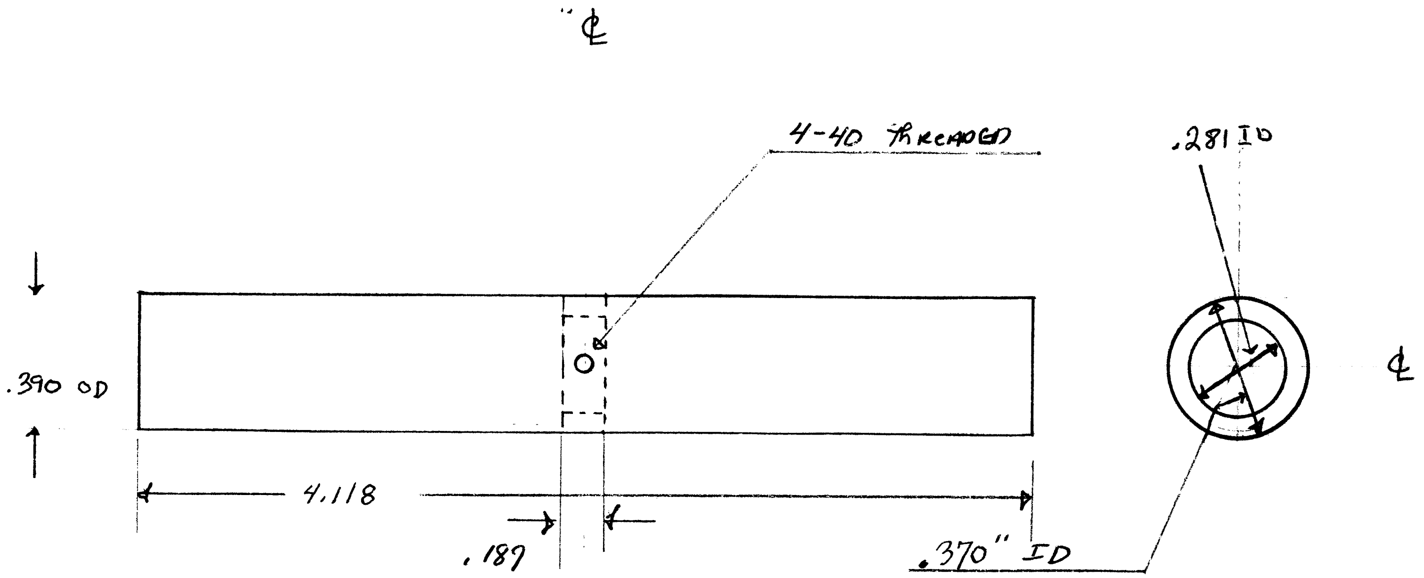
7/8" Th Short

Material St. St.

Quantity 4

Tol ± .005"

F1G 4



Center Cond. Transformer.

7/8" Thermal Shod.

Quantity	2
Material	ST. ST.
Tol	± .001

FIG 5

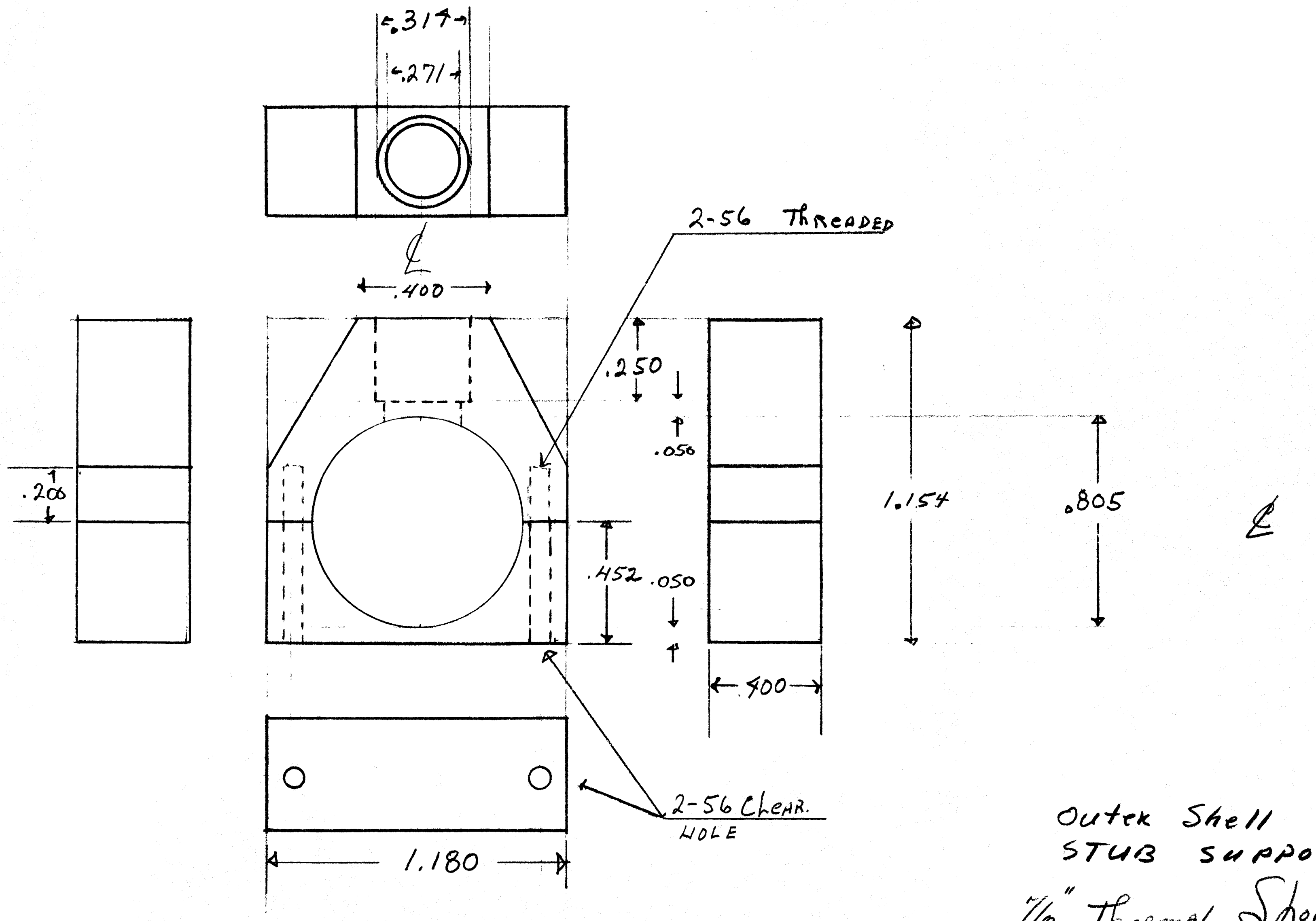
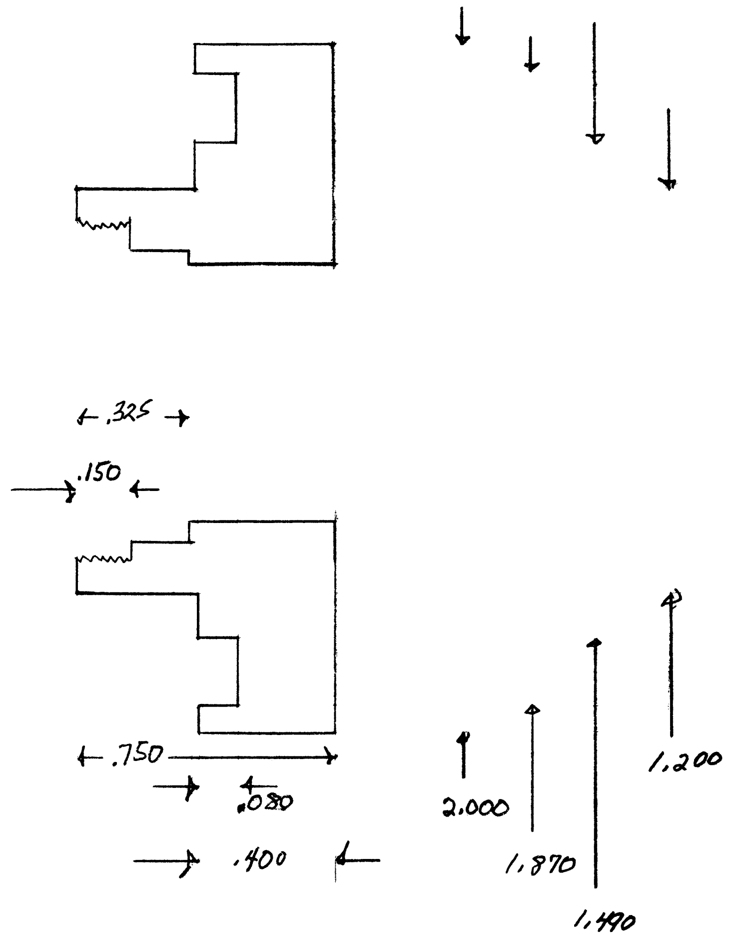
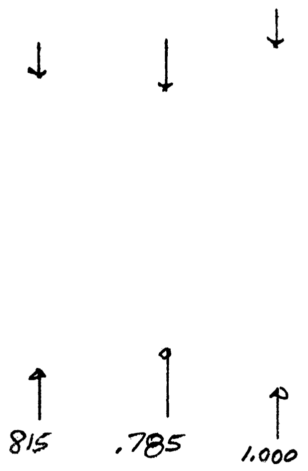


FIG 6

Outer Shell
STUB SUPPORT.
7/8" Thermal Short
MAT: AL
Qnty 2
Tol ±.001

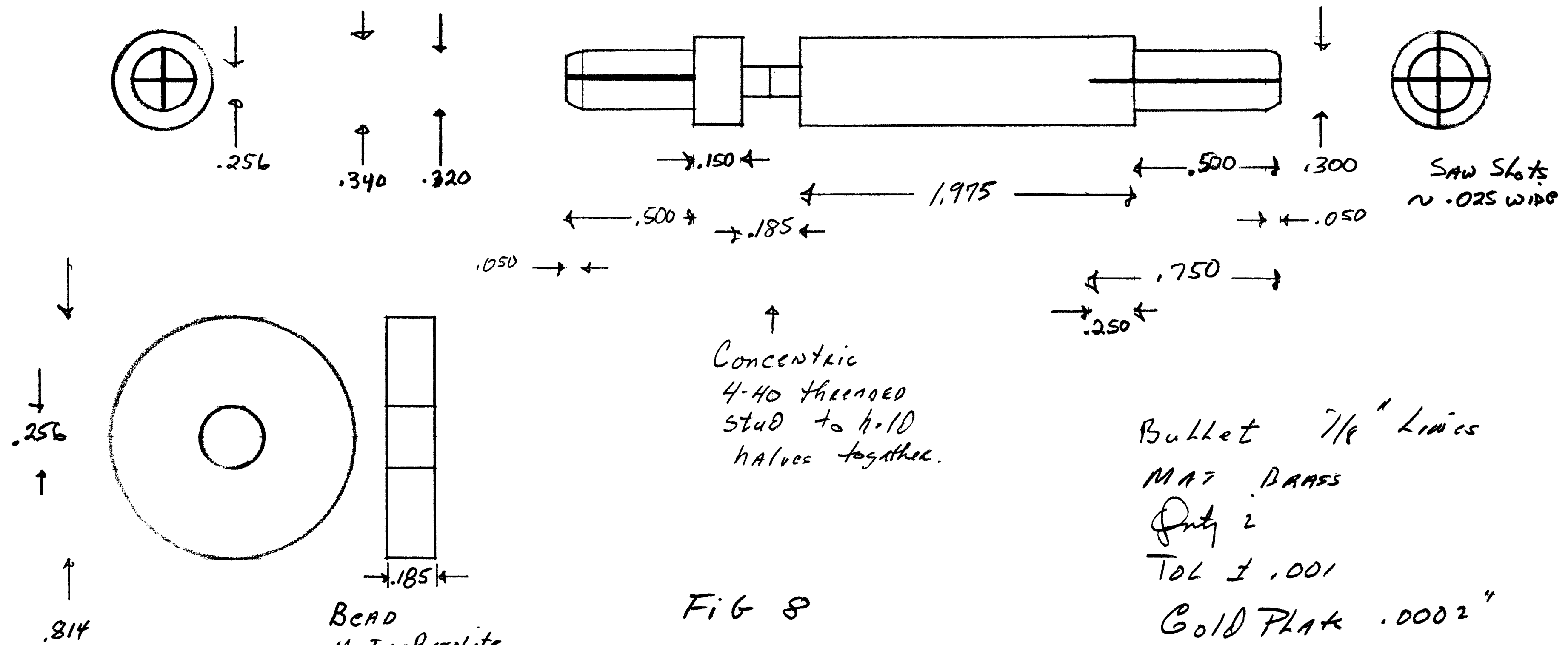




Parker O-Ring # 2-222
Compound Parker # B 318-7

Fig 7

Vacuum Seal 7/8"
MAT. ST. ST.
Qty 2 Tol ± .001

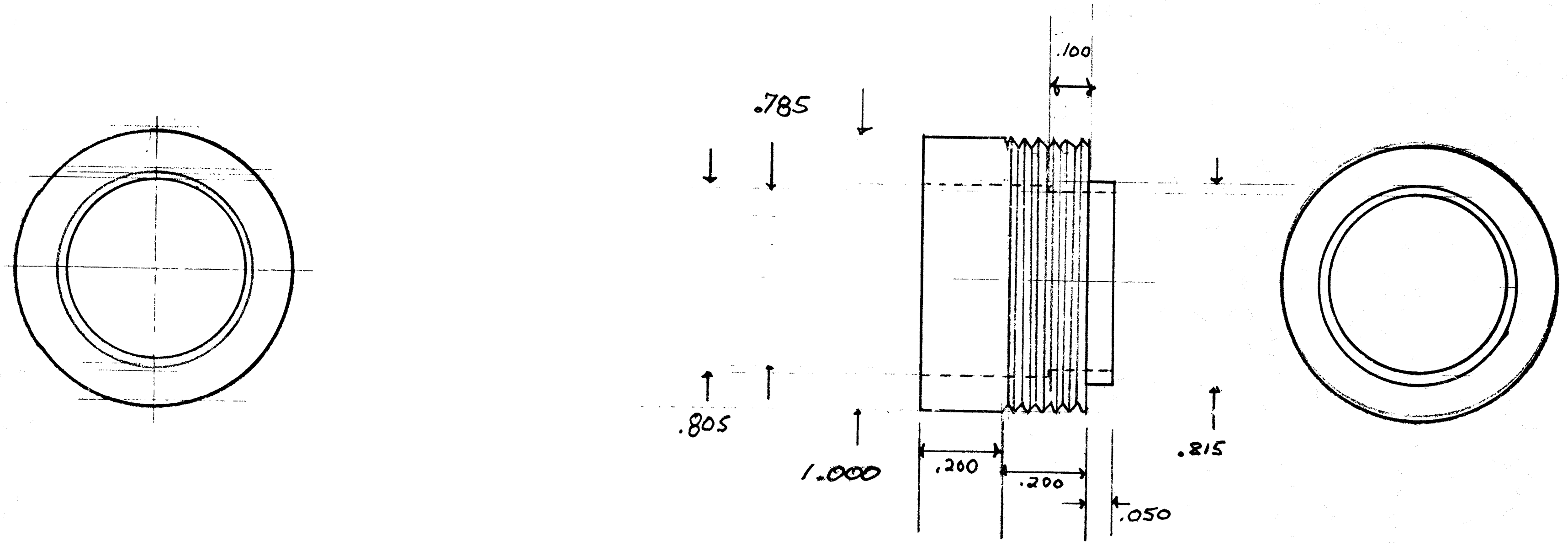


Concentric
4-40 threaded
stud to hold
halves together.

Bead
MAT: Rexolite
T.L ± .001
Qnty 2

FiG 8

Bullet 7/8" Lines
MAT BRASS
Qnty 2
Tol ± .001
Gold Plat .0002"



Bead Retaining Ring

Qnty : 2

Material : ST. ST

Tol ± .001"

FIG 9

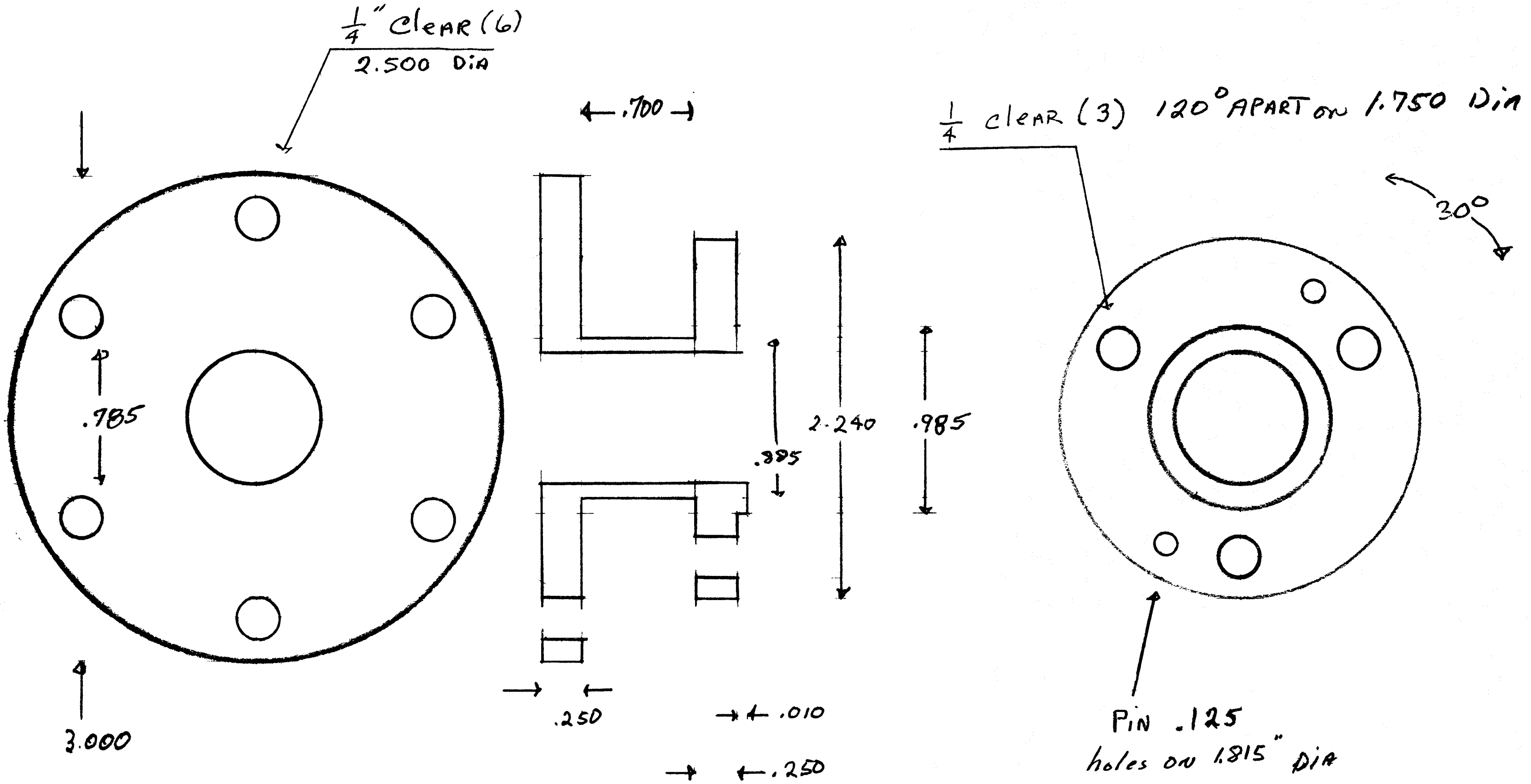
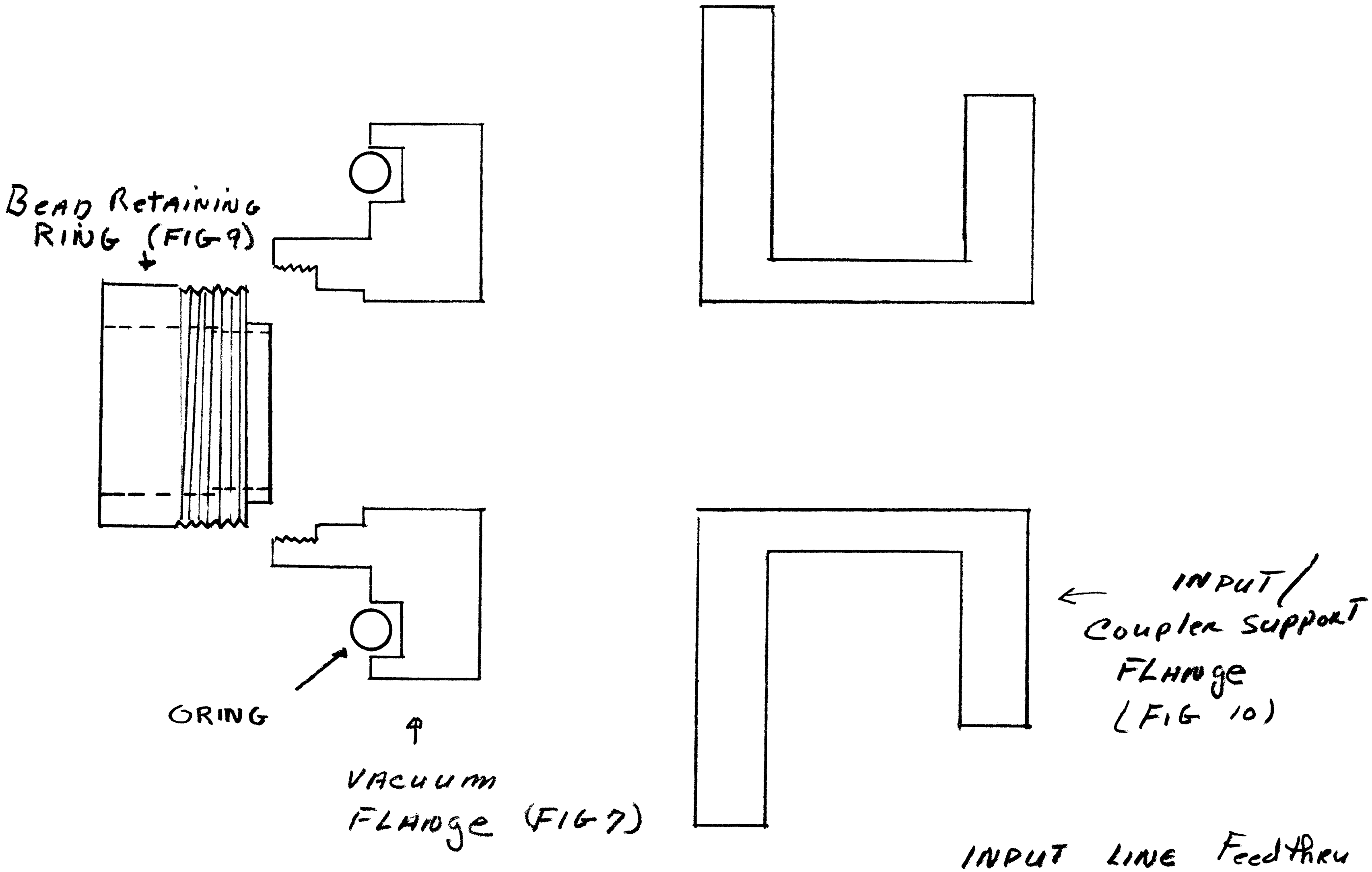


FIG 10

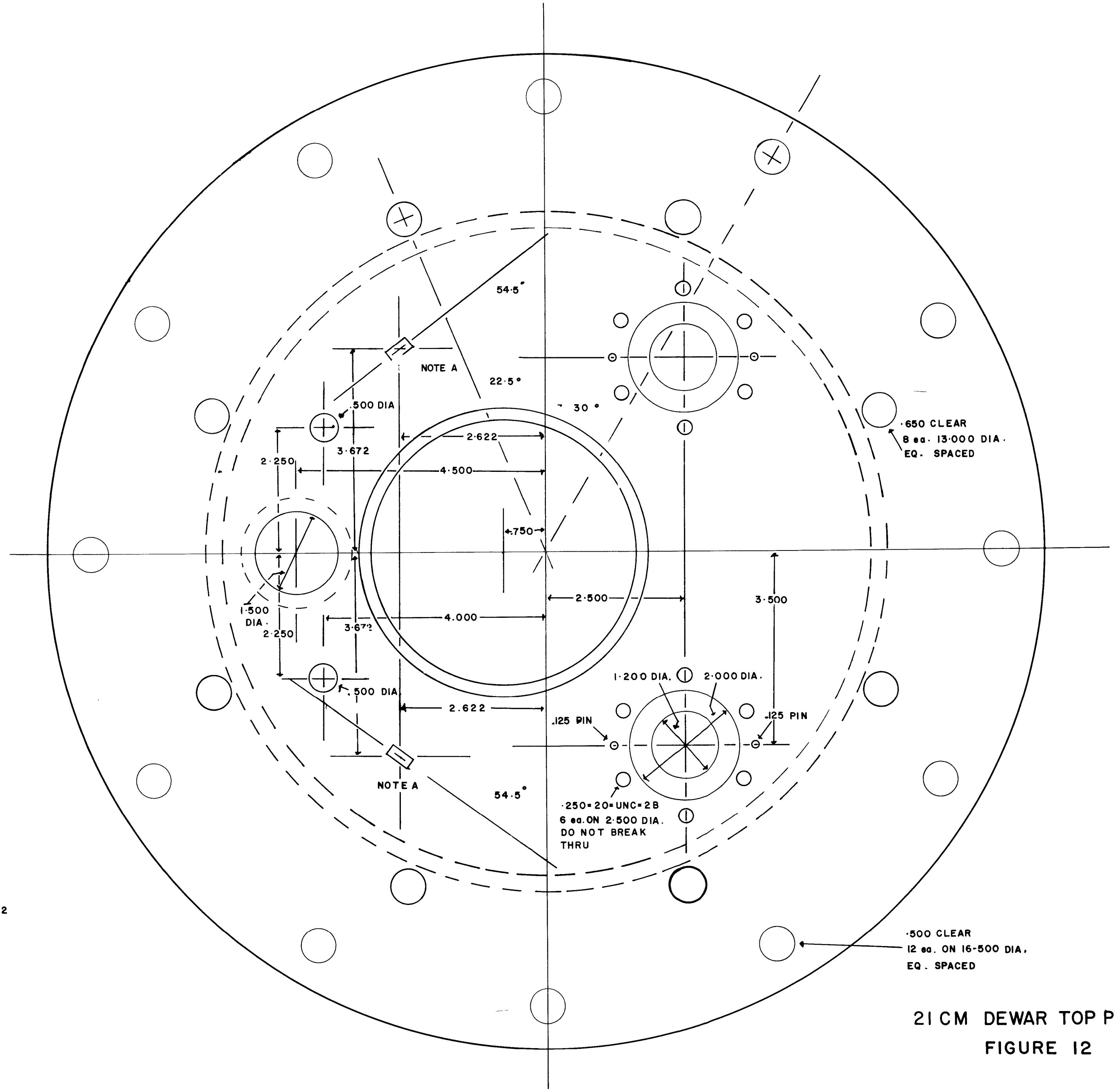
Gold Plate .0002"
Inside Surface +
both end faces

Vacuum Seal 7/8"
Compression flange +
7/8" EIA Connector.
Mat: Stainless Steel.
Qty 2
Tol ±.001



INPUT LINE Feedthru
Assembly Drwg

Figure 11



NOTE A STANDARD WR 42 WAVEGUIDE

21 CM DEWAR TOP PLATE

FIGURE 12

APPENDIX B

Cooled 21 cm Circulator

by

Jack Cochran

Cooled 21 cm Circulator

Following is the design characteristics of a cooled L-band circulator. Operating at a center frequency of 1400 MHz with a 25 dB bandwidth of 50 MHz this circulator exhibits 0.5 dB insertion loss at 18 °K (Figure 1). Figure 2 shows the change in circulator isolation versus temperature.

A type 'N' connector (μG 58/AU) was modified (drawing 1) to adapt to the 7 mm stripline housing. A 15° taper on the stripline inner conductor (drawing 2) produced a VSWR of 1.03:1 for the connector and stripline.

The polycrystalline YALIG ferrimagnets (Trans-Tech, Inc. — MS4400-QC12212R) were prepared with a saturation magnetization ($4\pi M_s$) value of 278 Gauss (Figure 3). Other important characteristics of the ferrities are as follows:

Size = 1.102" dia. x 0.118"

$4\pi M_s$ = 278 Gauss

ϵ = 13.75

$\tan \delta_\epsilon$ = 10^{-3}

ΔH = 41 oe

The optimum magnetic field of 105 oe was supplied by electro-magnets. The magnetic circuit consists of two coils (400 turns each of No. 28 gauge aluminum wire), two magnetically soft steel cores, a pair of magnetically soft steel laces, and 120 mA of current from a suitable power supply. Effects of the magnetic field on circulator isolation is shown in Figure 3.

The ferrite impedance was optimized for maximum bandwidth by adjusting the diameters of the ferrites and the center of the inner conductor. Transformation of the ferrite impedance to the 50 Ω stripline using rexolite (0.510" x 0.500" x 0.118") spaced 0.393" from the ferrites was accomplished with an IBM 360 program.

(Appendix B)

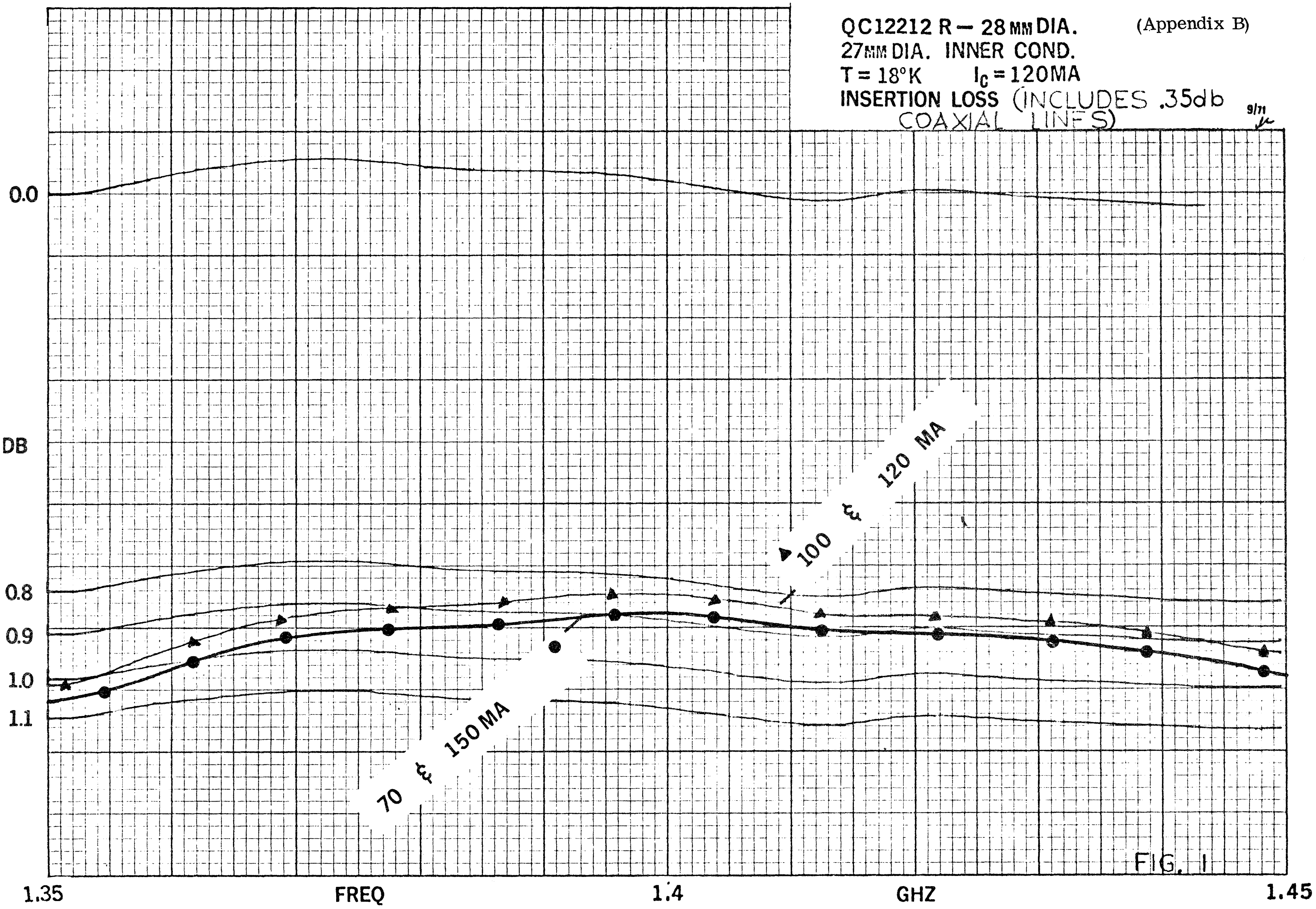


FIGURE 1 — CIRCULATOR LOSS VS. FREQUENCY

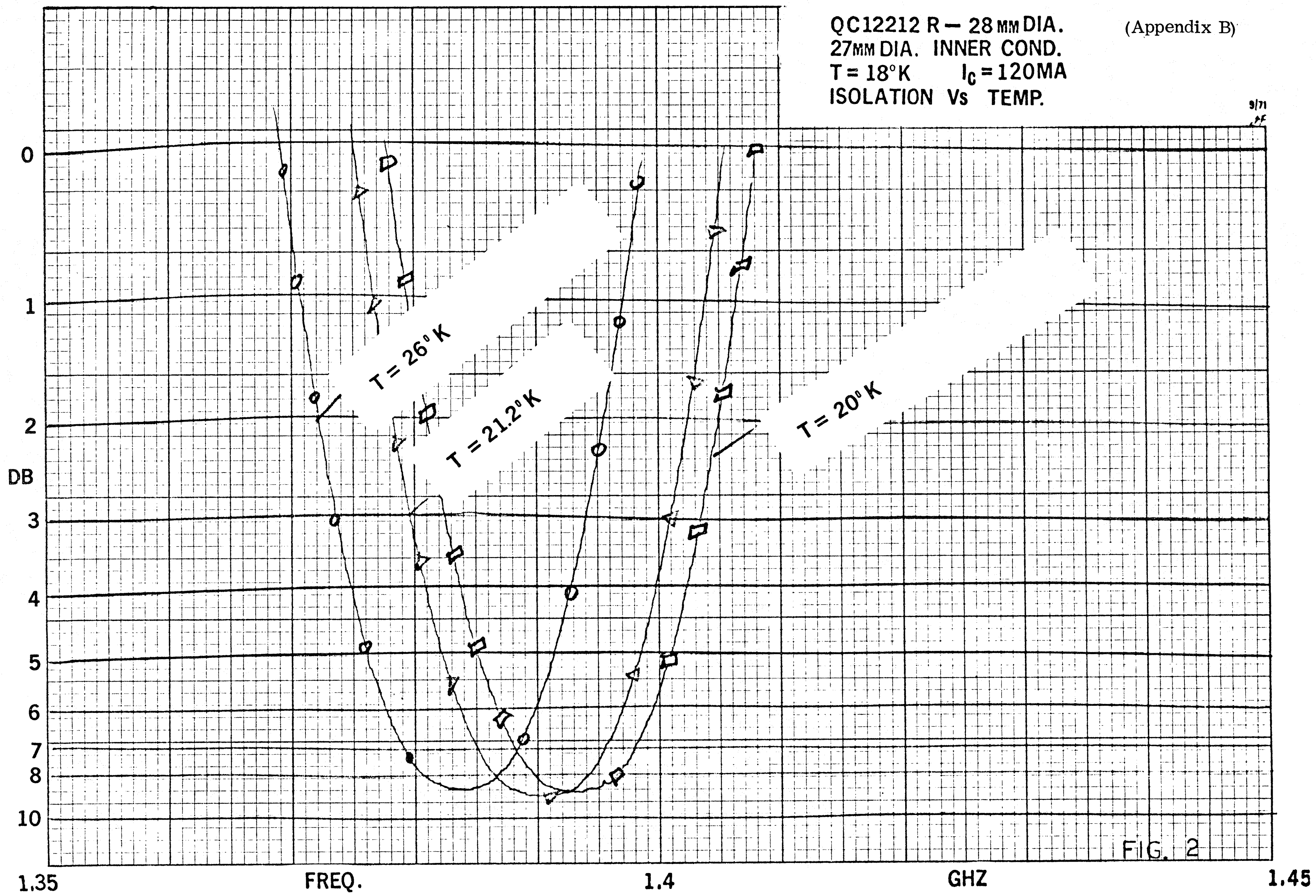


FIG. 2

FIGURE 2 — CIRCULATOR ISOLATION VS. FREQUENCY FOR 3 TEMPERATURES

(Appendix B)

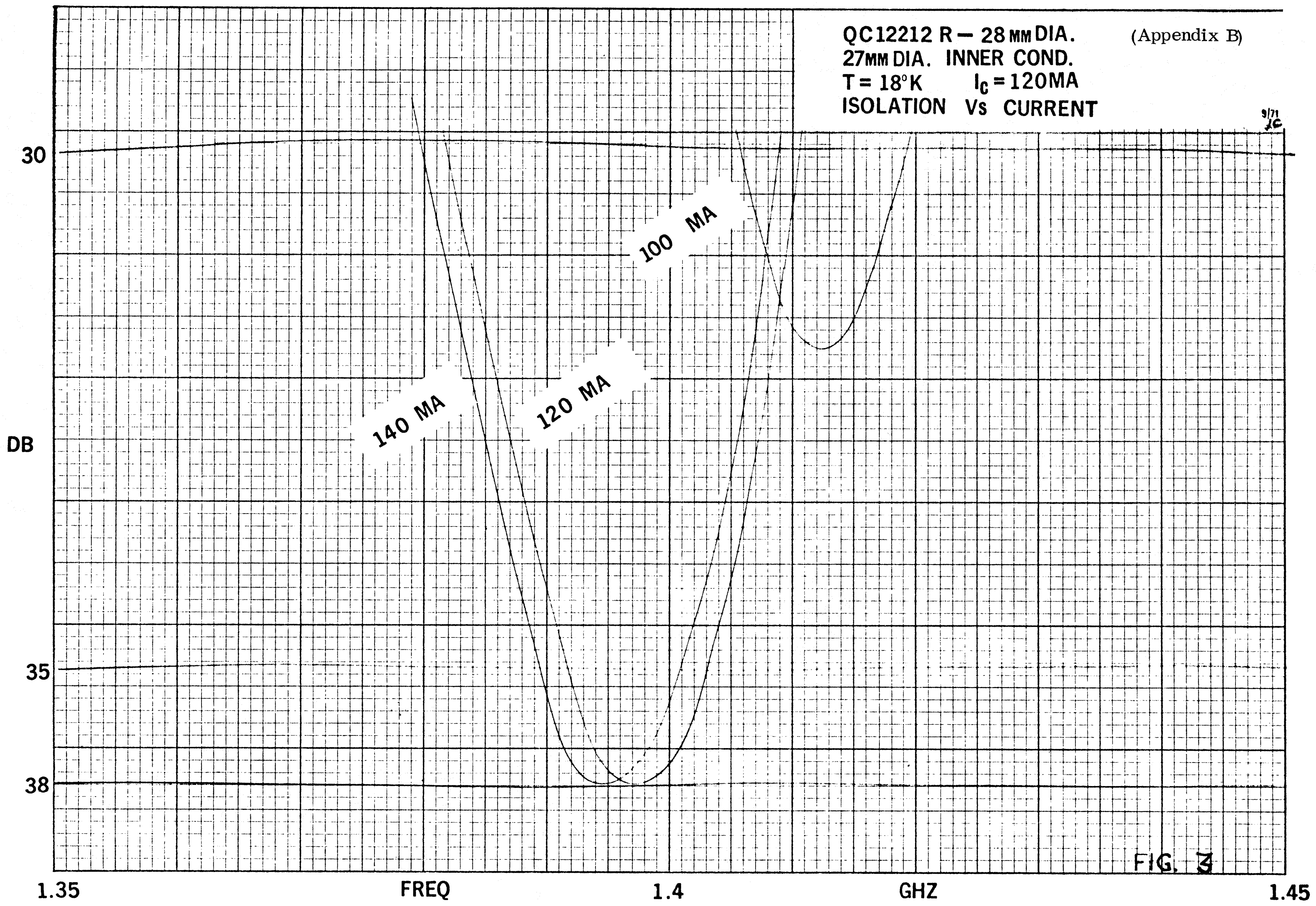
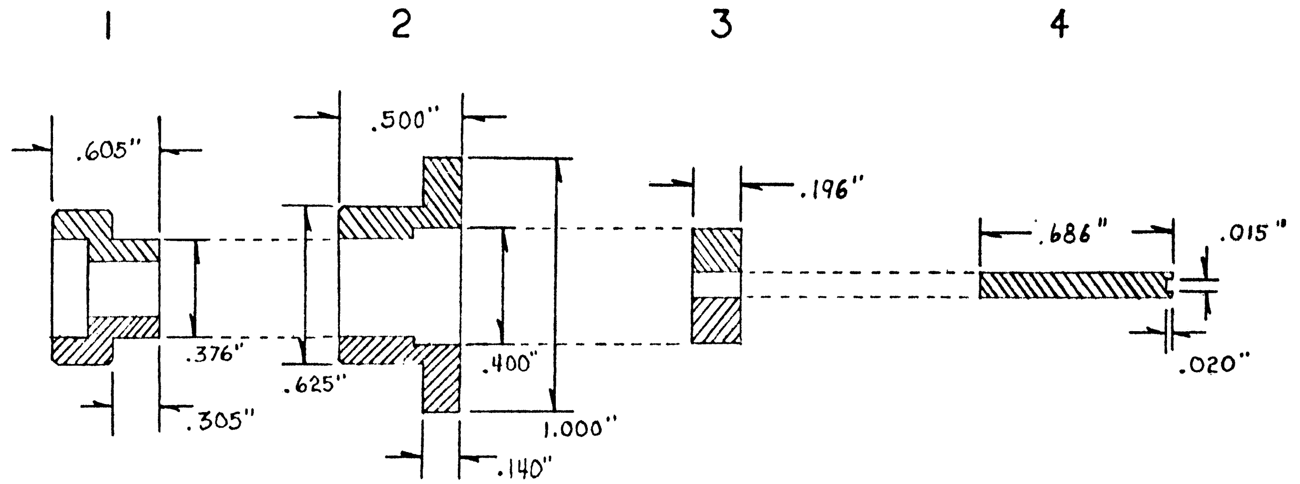


FIGURE 3 — CIRCULATOR ISOLATION VS. FREQUENCY FOR 3 CIRCULATOR CURRENTS



NOTES:

a) PART 1 : UG 58A/U MODIFIED

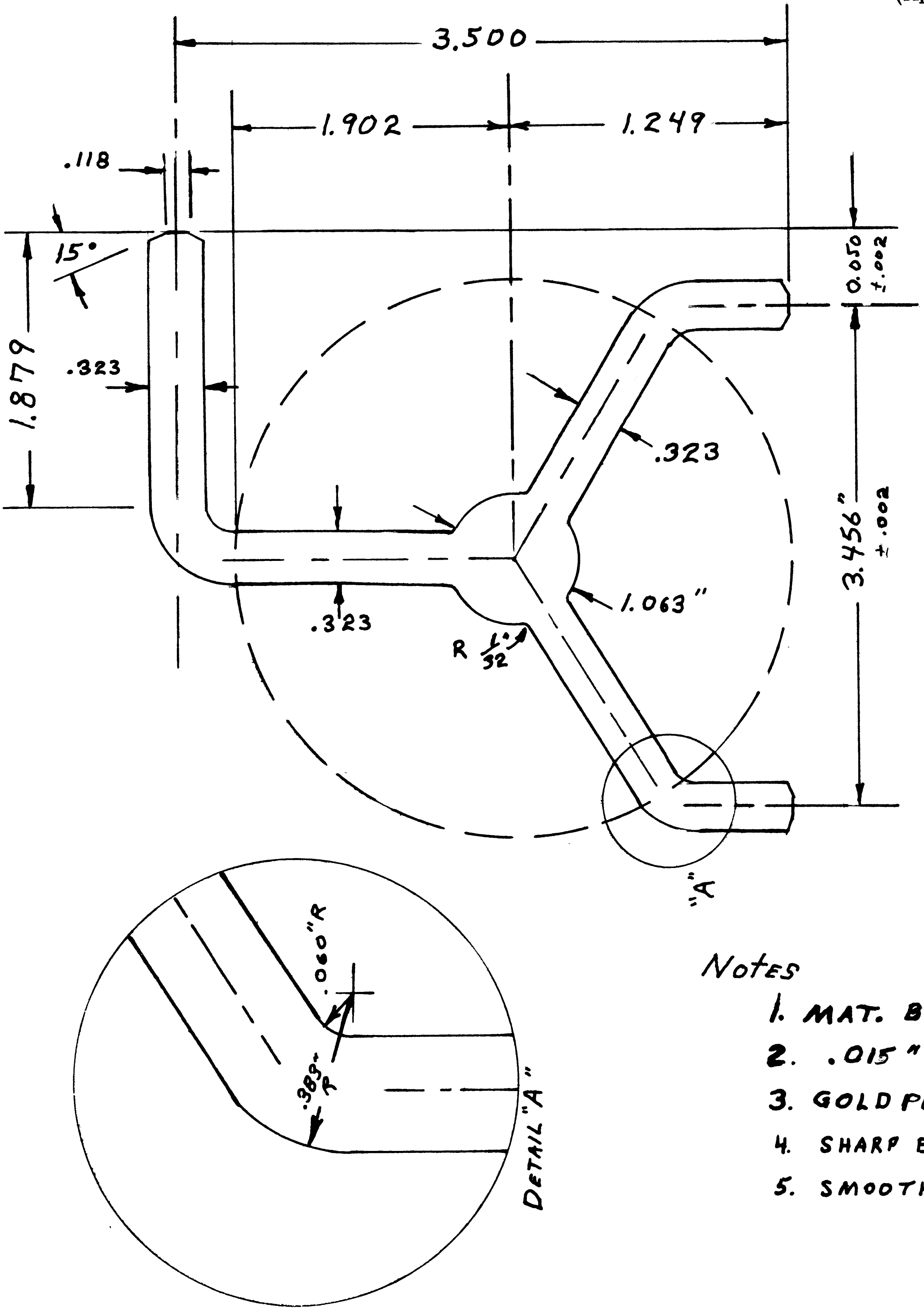
b) PART 2 : ALUMINUM SHRINK FITTED TO PART 1

c) PART 3: TEFLON SHRINK FITTED TO PART 2

d) PART 4: UG 58A/U CENTER CONDUCTOR MODIFIED

e) TOTAL WEIGHT = .67 OZ.

DRAWING 1 — 7 mm STRIPLINE LAUNCHER



Notes

1. MAT. BRASS
2. .015" THICK
3. GOLD PLATE
4. SHARP EDGES
5. SMOOTH SURFACES

DRAWING 2 — STRIPLINE INNER CONDUCTOR

APPENDIX C

Beam Position and Polarization

by

C. Heiles and G. Wrixon

Beam Position and Polarization

In an attempt to measure linear polarization in the hydrogen line by turning the front-end box to various position angles, we found large effects which could not possibly have been due to polarization. The cause of these effects was subsequently traced to the exact position of the center of the beam being dependent on polarization angle, and furthermore being different for channels A and B. We therefore attempted to measure the variation of the beam position with box rotation for each channel.

This was done by going off the peak of a strong source (Virgo A) to the half-power point and turning the box to various position angles. The antenna temperature varied with position angle. We then held the position angle constant and moved the telescope a small amount to produce a comparable variation in antenna temperature, which provided a calibration of deflection in antenna temperature versus position change. We then derived the manner in which the beam position for each channel depends on position angle.

A deficiency in this procedure is that we failed to calibrate the gain of each channel as the position angle was changed. Although the changes in antenna temperature for channel A were much larger than could be expected from gain changes, this was not necessarily true for channel B. As a result our results for channel B must be accepted with caution, and probably best not accepted; better to make the measurement again on a source nearly overhead to remove the effects of position angle rotation on gain change.

Our results were:

CHANNEL A: The beam moves around in a circle of radius 0.75 minutes of arc:

$$\Delta\alpha = 0.75 \text{ min arc} \times \sin(\text{P.A.} - 240°)$$

$$\Delta\delta = 0.75 \text{ min arc} \times \cos(\text{P.A.} - 240°)$$

CHANNEL B: The beam moves along a line of half-length 0.175 min of arc:

$$\Delta\alpha = 0.175 \text{ min arc} \times \cos(\text{P.A.} - 55°)$$

$$\Delta\delta = 0.175 \text{ min arc} \times \cos(\text{P.A.} - 55°)$$

In both cases, P.A. is the position angle indicated by the panel display.[1]

---

[1] P.A. = 221 for E-plane Channel A North-South. (D.L.T.)

APPENDIX D

Wiring, Cable Lists, Schematics, Data Sheets and Specifications of Parts

CABLE NUMBER 18-19-20-21 TYPE 15 Twisted Pair No. 18 A

Color Code Per Pair	Color Code	Pin No.	Remarks
Blue Tracer	Red	A-1	Bias Current Cooled A
	Yellow	B-2	
	Sheild	E	(Meter)
Purple Tracer	Red	C-3	Bias Current Ambient A
	Yellow	D-4	
	Shield	J	(Meter)
Grey Tracer	Red	O-5	Pump Atten. Curr. Cooled A
	Yellow	P-6	
	Shield	H	(Meter)
Green Tracer	Red	F-7	Pump. Atten. Curr. Amb. A
	Yellow	G-8	
	Shield	M	(Meter)
Yellow Tracer	Red	T-9	Bias Voltage Cooled A
	Yellow	U-10	
	Shield	N	(Pot)
Center Pair No Tracer	Grey	K-11	Bias Voltage Ambient A
	Yellow	L-12	
	Shield	R	(Pot)
Center Pair No Tracer	Blue	X-13	Pump Atten. Adj. Cooled A
	Yellow	Y-14	
	Shield	Q	(Pot)
Center Pair No Tracer	Grey	Z-15	Pump Atten. Adj. Ambient A
	Red	a-16	
	Shield	S	(Pot)
Center Pair No Tracer	Red	V-17	Detector Output A
	Yellow	W-18	
	Shield	d	
Black Tracer	Red	m-19	Xtal A1
	Yellow	n-20	
	Shield	e	
Orange Tracer	Red	b-21	Xtal A2
	Yellow	c-22	
	Shield	k	
Red Tracer	Red	r-23	Circulator Adj. A
	Yellow	s-24	
	Shield	x	(Pot)
Brown Tracer	Red	t-25	Circulator Current
	Yellow	u-26	
	Shield	y	(Meter)
Center No Tracer	Blue	f-27	Noise Balance A
	Grey	g-28	
	Shield	p	(Pot)
Center Pair No Tracer	Red	h-29	RF Gain A
	Blue	j-30	
	Shield	q	(Pot)
Spare Pins (3)		v	
		w	
		z	

CABLE NUMBER 18-19-20-21 TYPE 15 Twisted Pair No. 18 B

Color Code Per Pair	Color Code	Pin No.	Remarks
	Red	A-1	Bias Voltage Cooled B
Blue Tracer	Yellow	B-2	
	Shield	E	(Meter)
	Red	C-3	Bias Voltage Ambient B
Purple Tracer	Yellow	D-4	
	Shield	J	(Meter)
	Red	O-5	Pump Atten. Curr. Cooled B
Grey Tracer	Yellow	P-6	
	Shield	H	(Meter)
	Red	F-7	Pump Atten. Curr. Ambient B
Green Tracer	Yellow	G-8	
	Shield	M	(Meter)
	Red	T-9	Bias Voltage Cooled B
Yellow Tracer	Yellow	U-10	
	Shield	N	(Pot)
	Grey	K-11	Bias Voltage Ambient B
Center Pair No Tracer	Yellow	L-12	
	Shield	R	(Pot)
	Blue	X-13	Pump Atten. Adj. Cooled B
Center Pair No Tracer	Yellow	Y-14	
	Shield	Q	(Pot)
	Grey	Z-15	Pump Atten. Adj. Ambient B
Center Pair No Tracer	Red	a-16	
	Shield	S	(Pot)
	Red	V-17	Detector Output B
Center Pair No Tracer	Yellow	W-18	
	Shield	d	
	Red	m-19	Xtal B1
Black Tracer	Yellow	n-20	
	Shield	o	
	Red	b-21	Xtal B2
Orange Tracer	Yellow	c-22	
	Shield	k	
	Red	r-23	Circulator Adj. B
Red Tracer	Yellow	s-24	
	Shield	x	(Pot)
	Red	t-25	Sweeper Leveler
Brown Tracer	Yellow	u-26	
	Shield	y	
	Blue	f-27	Noise Balance B
Center No Tracer	Grey	g-28	
	Shield	p	(Pot)
	Red	h-29	RF Gain B
Center Pair No Tracer	Blue	j-30	
	Shield	q	(Pot)
		v	
Spare Pins (3)		w	
		z	

CABLE NO. 43-44 TYPE 30/C No. 16 CONNECTOR 81-194228-15P (Bendix OWL)

Color Code	Pin Number	Remark
Orange Purple	A	Thermistor Monitor
Orange Blue	B	
Yellow White	C	Thermistor Control
Yellow	D	
Red Purple	E	Cal Control Signal
Red Blue	F	RF Gain Control Sig
Orange Green	G	Noise Bal Cont Sig
Yellow Black	H	Return for above
Yellow Brown	J	Step Attenuator
Black	K	
White Yellow	L	
Red Green	M	
Orange Yellow	N	+15
Orange	P	-15
Brown	R	Common (± 15)
Red	S	+5
Red Black	T	Common (+5)
Red Yellow	U	+28 V regulated
Red Brown	V	Common (28 regulated)
Orange Brown	W	Common (28 V unreg)
Green	X	Pump on/off relay
Orange White	Y	Pump relay return
Orange Black	Z	Pump on/off relay
Blue	a	
Purple	b	
Purple White	c	
Green White	d	
Green Black	e	
Green Brown	f	+15 V
Red White	g	Ret Circulator Curr Meter Relay
Shield	1	

NOTE: 1% RESISTORS ONLY
50K TRIM RESISTOR
BOURNS 3059Y-1-101 POT.

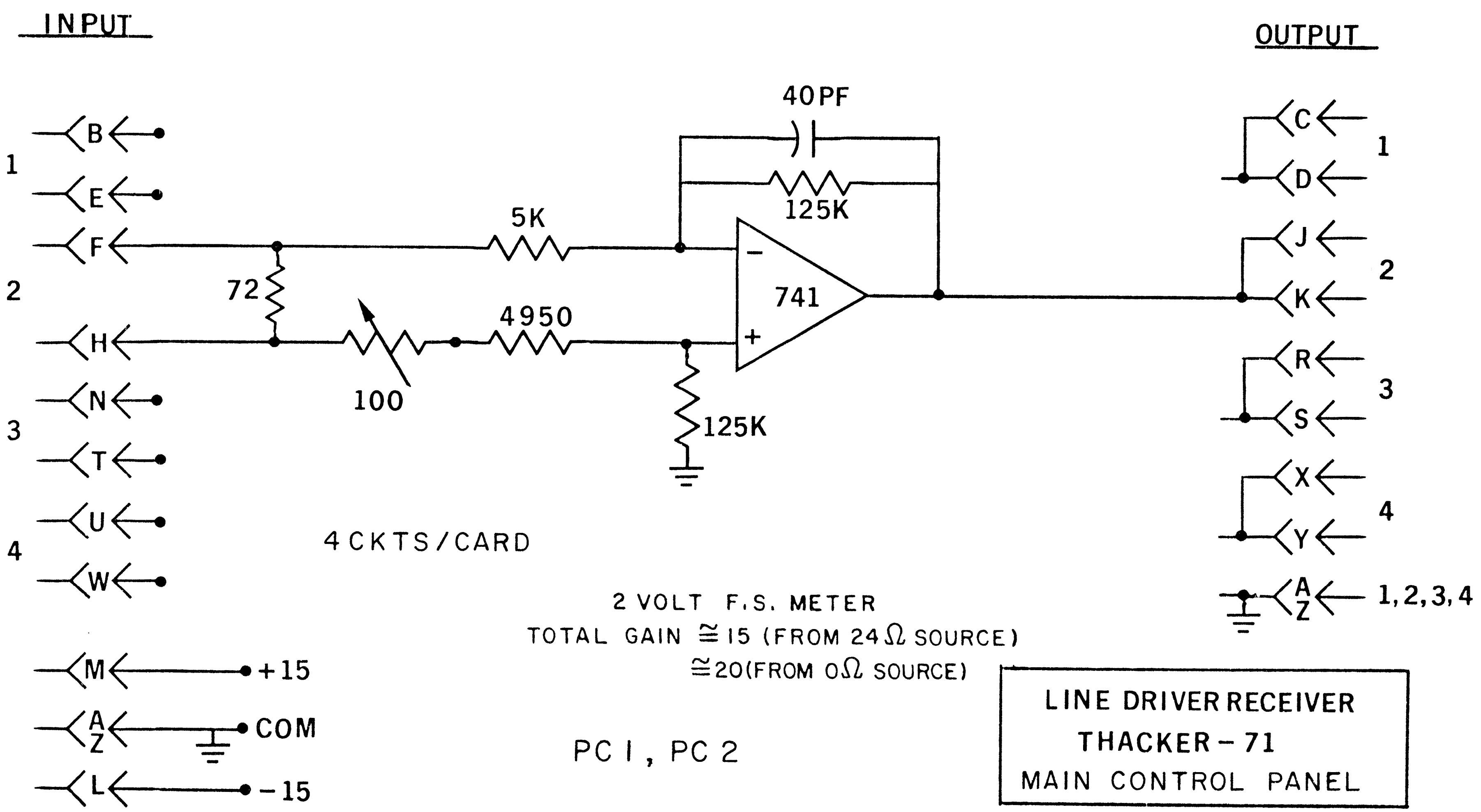
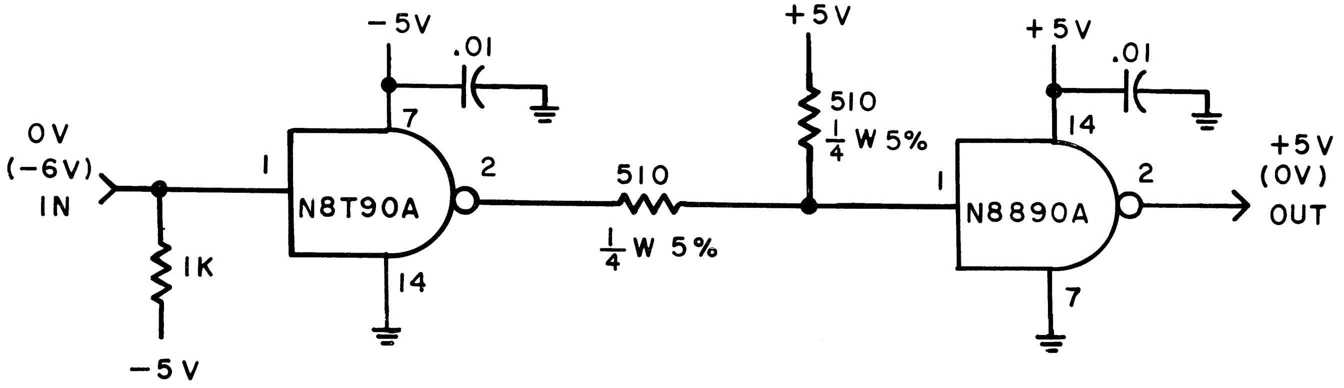
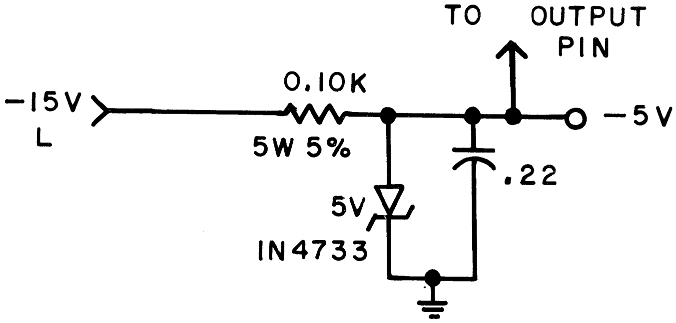
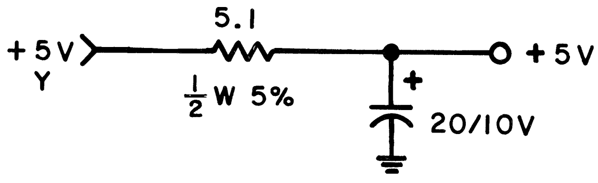


Figure 8 — Line Driver Receiver, Main Control Panel







PIN NUMBERS

	N8T90A		N8890A		
	IN	OUT	IN	OUT	
1	1	2	1	2	1
2	3	4	3	4	2
3	6	5	5	6	3
4	8	9	9	8	4
5	11	10	11	10	5
6	13	12	13	12	6

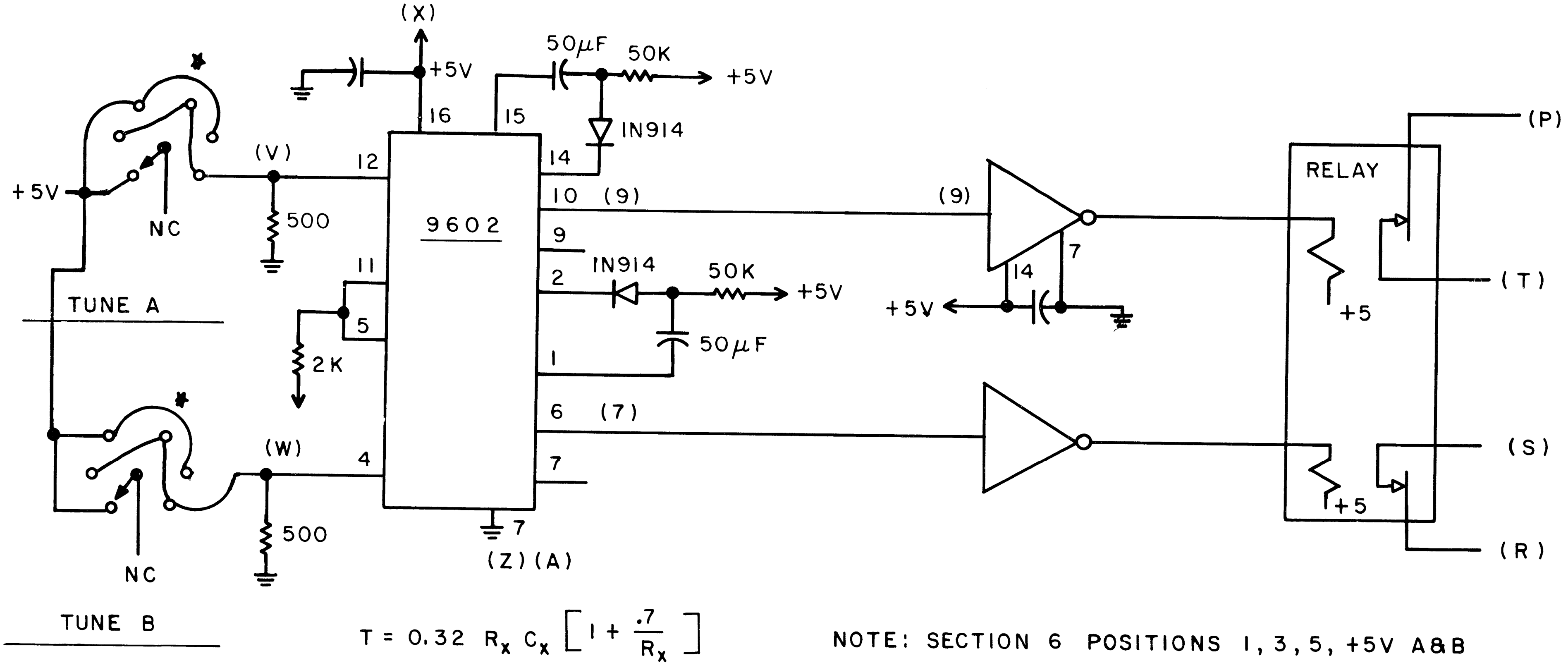
PIN 7 = −5V
PIN 14 = GND

PIN 14 = +5V
PIN 7 = GND

BUILD ON UNIVERSAL CARD USING STD. PWR, PINS
MAIN CONTROL PANEL CARD # 3 (PC 3)

LEVEL SHIFTERS FOR 21cm 0, −6V TO 0, +5V
TYPICAL CHANNEL (6 CH. TOTAL)
D.L.THACKER (per A.M.SHALLOWAY) 11-9-71

Figure 9 — Level Shifters for 21 cm



$T = 0.32\ R_x\ C_x \left[1 + \frac{.7}{R_x} \right]$

R_x – IN KΩ

C_x – IN pF

T – IN ns

NOTE: SECTION 6 POSITIONS 1, 3, 5, +5V A&B

*6 th POLE OF TIME SWITCH CIRCULATOR PRIME CKT. PC 4

Figure 10 — 6th Pole of Time Switch, Circulator Prime Circuit PC 4

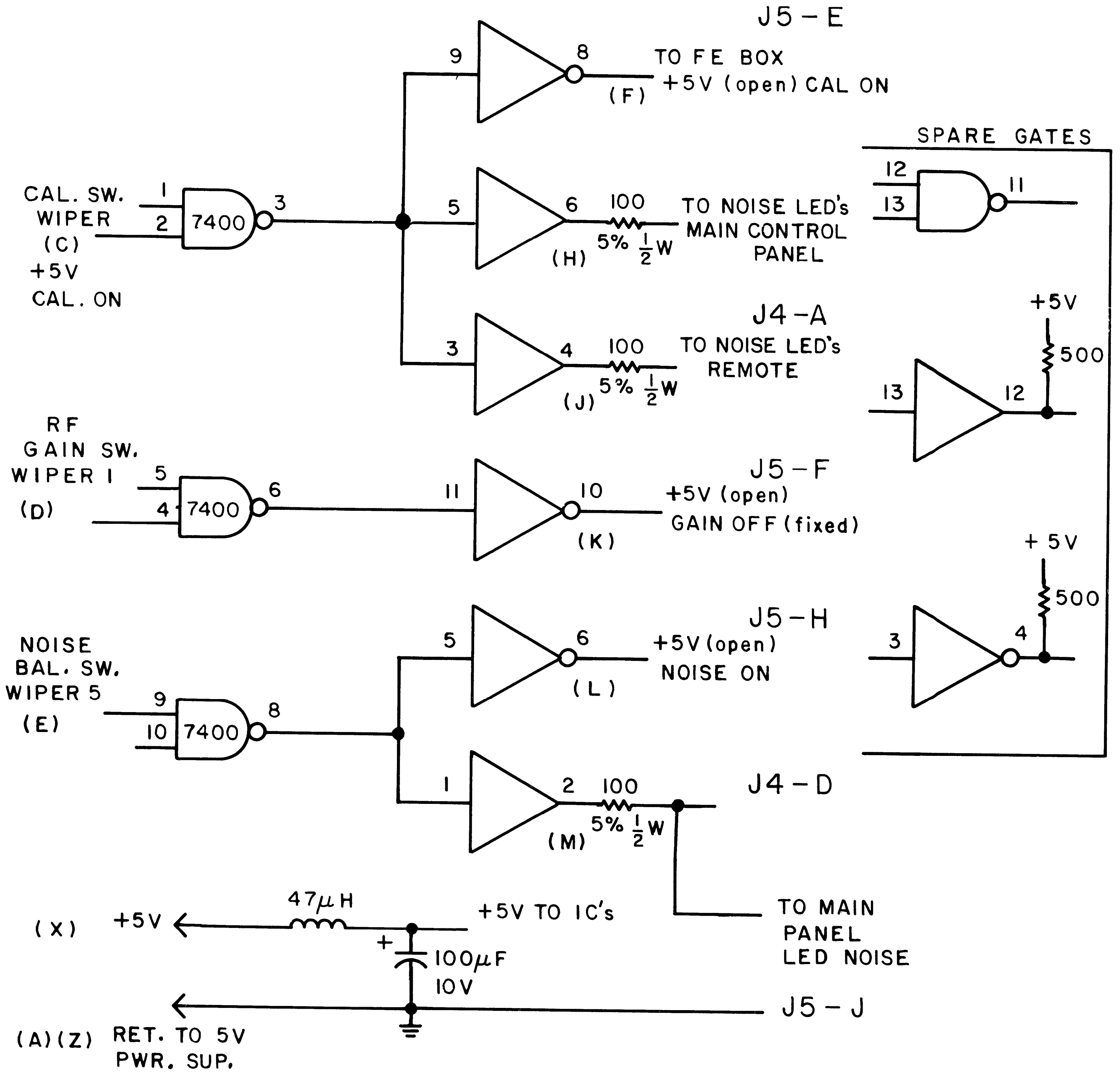


Figure 11 CAL., N.B., RF GAIN CONTROL & LITES PC5 MAIN CONTROL PANEL

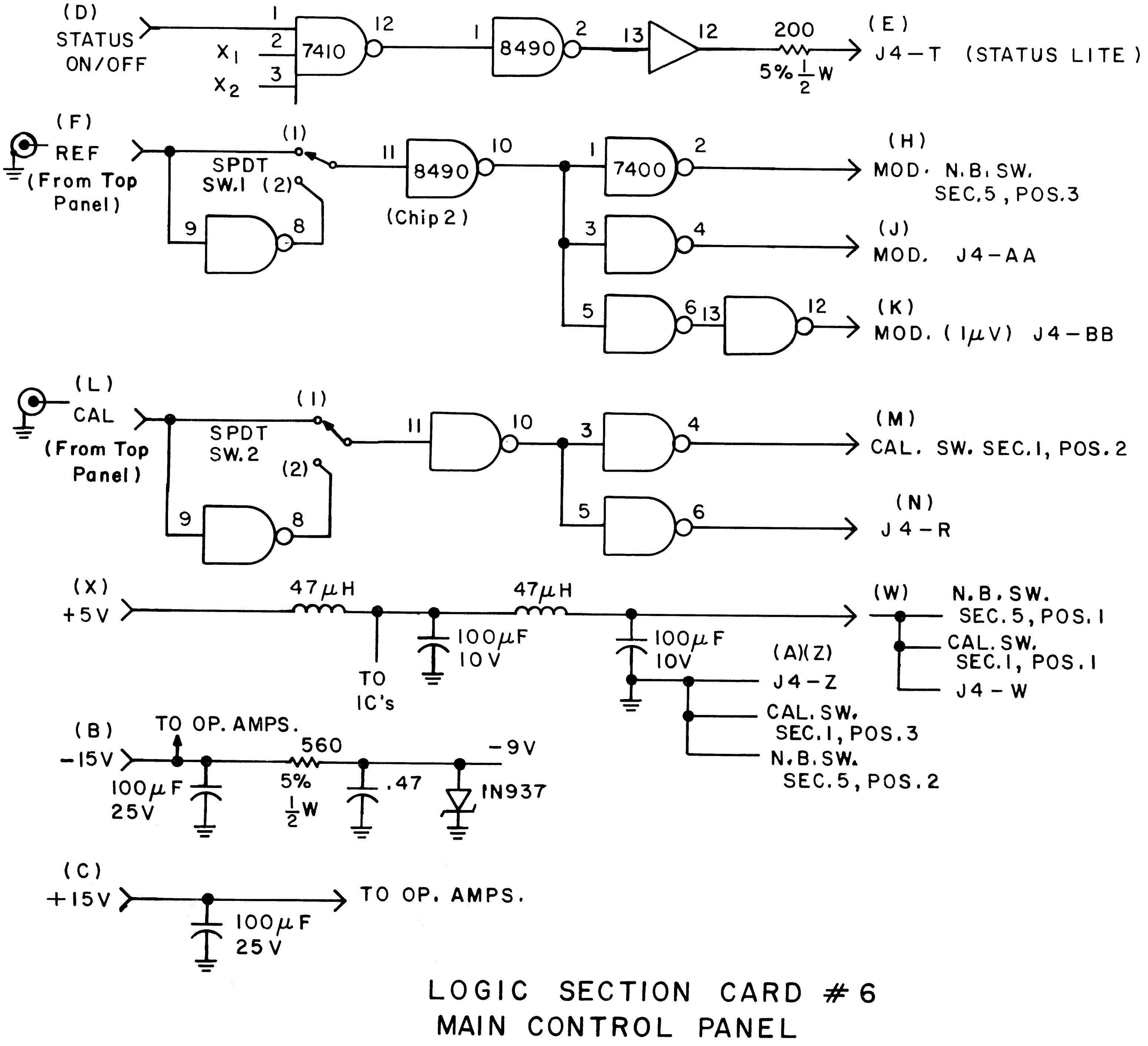


Figure 12 — Logic Section Card 6, Main Control Panel

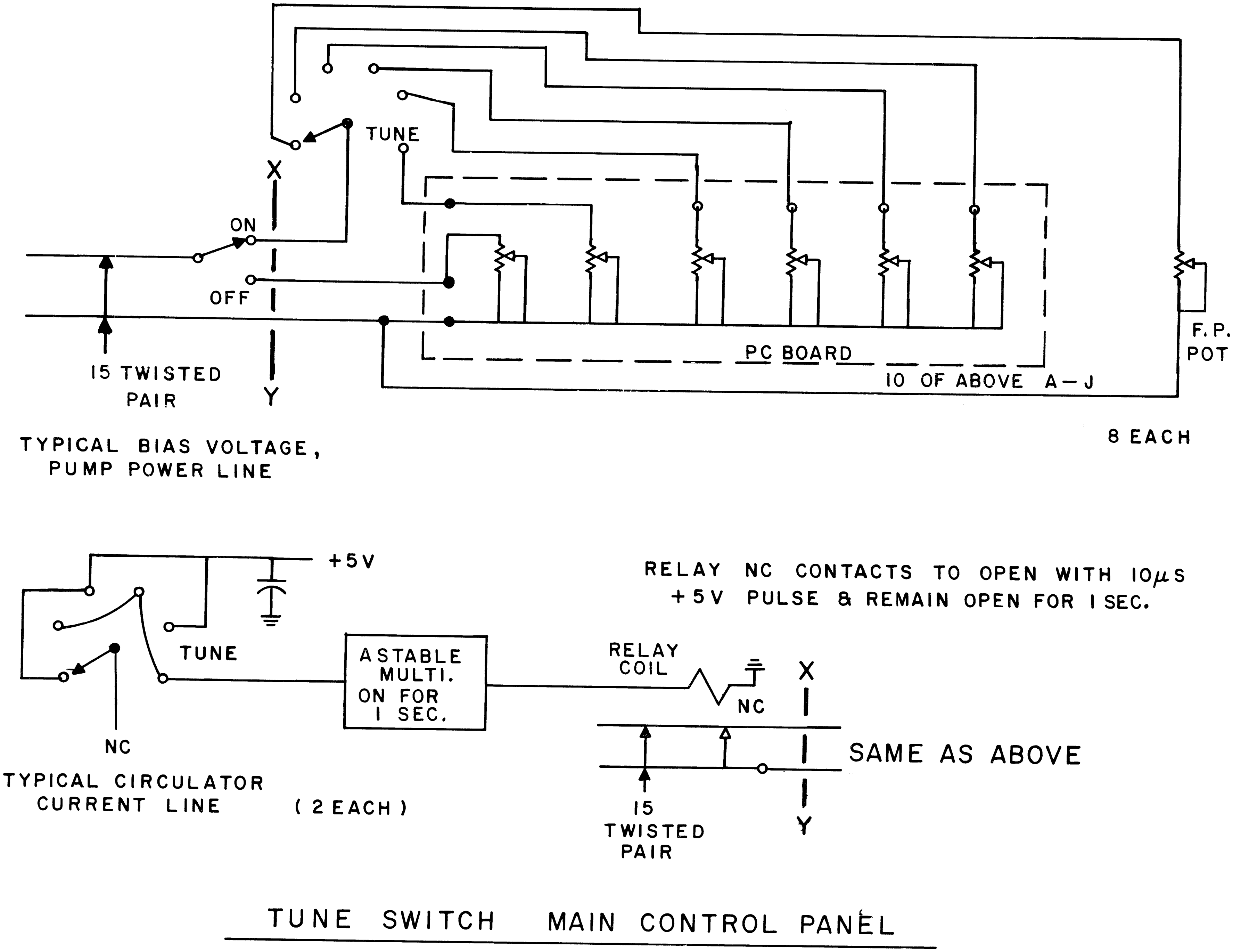


Figure 13 — Tune Switch, Main Control Panel

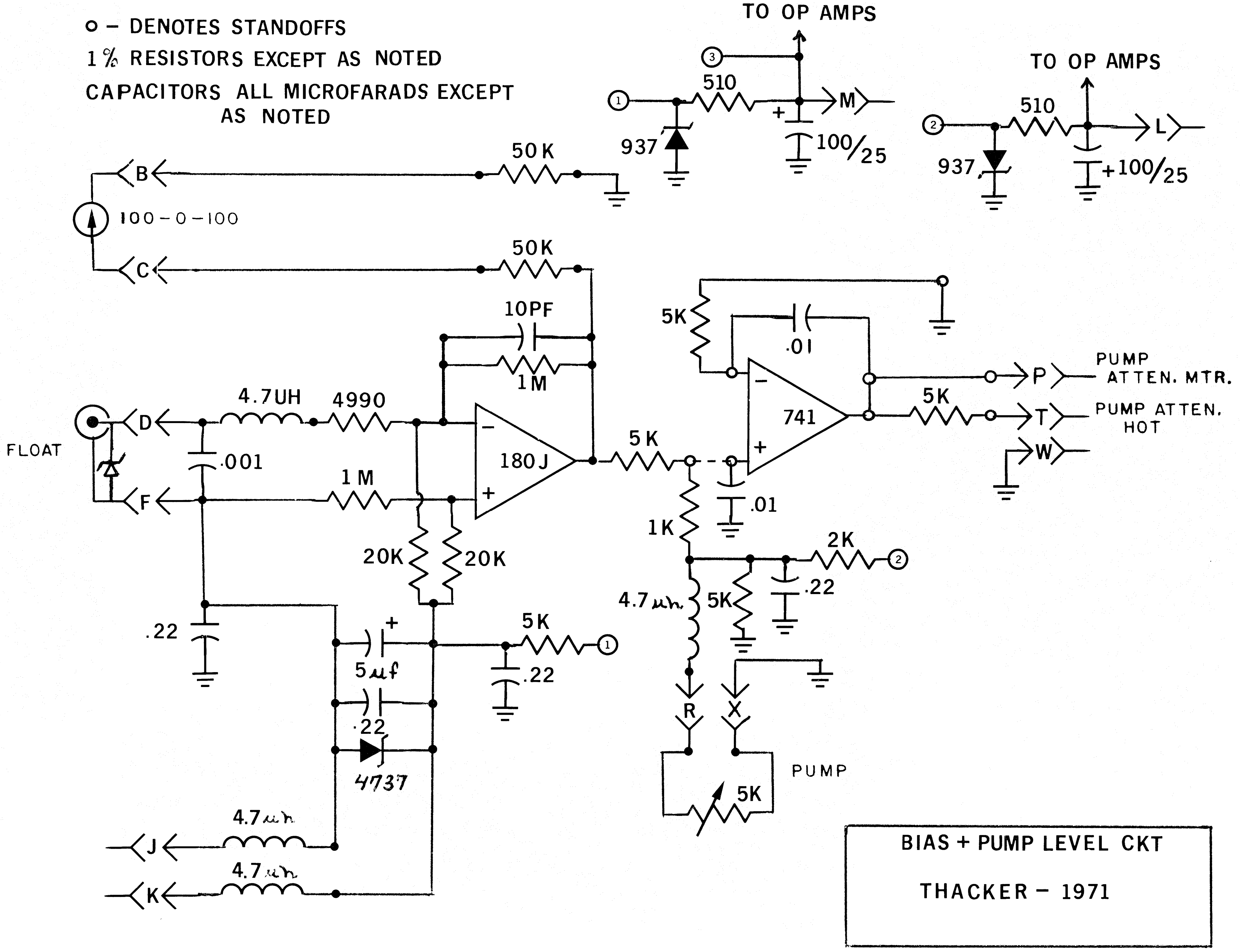


Figure 14 — Bias + Pump Level Circuit

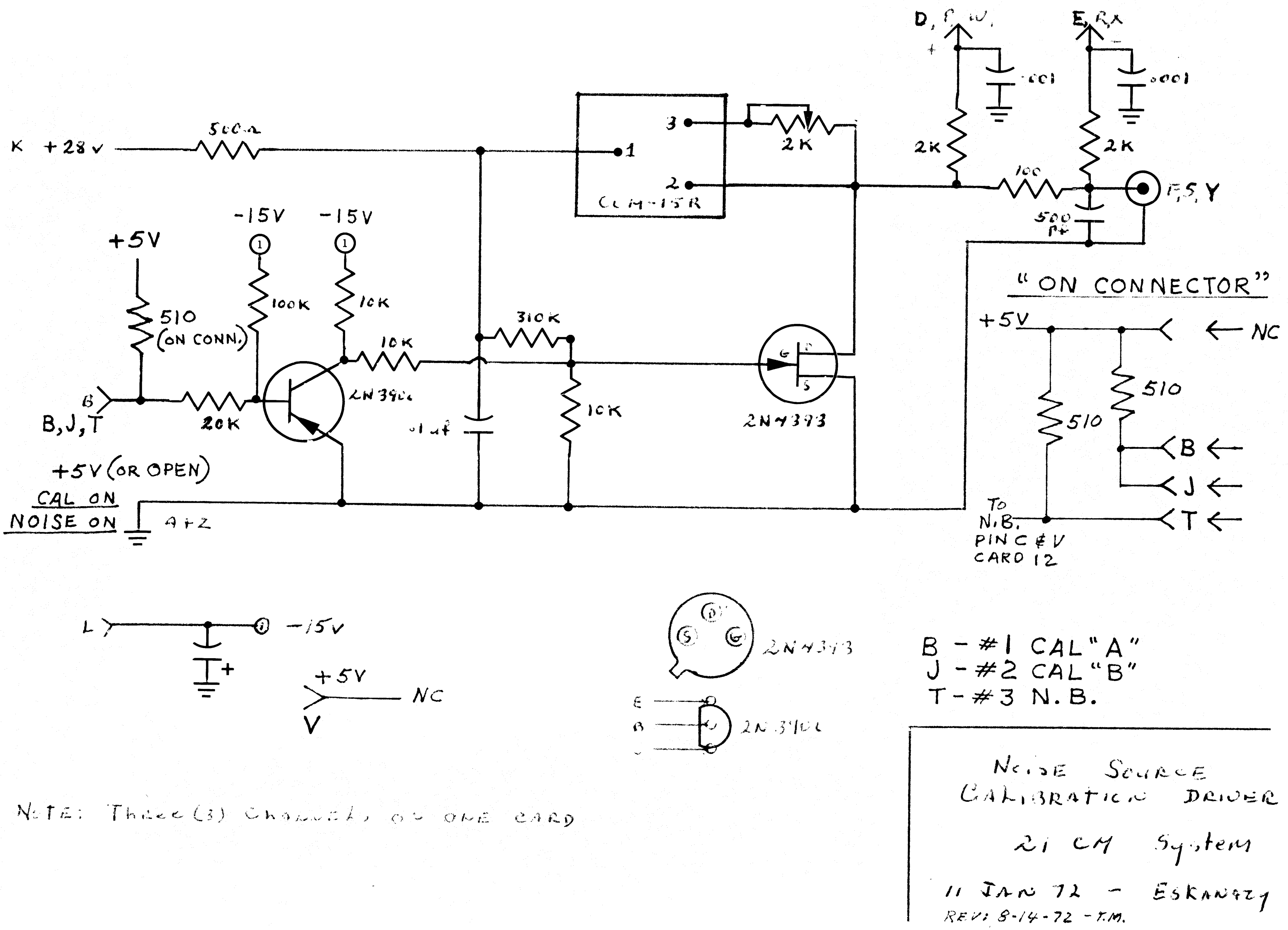


Figure 15 — Noise Source Calibration Driver

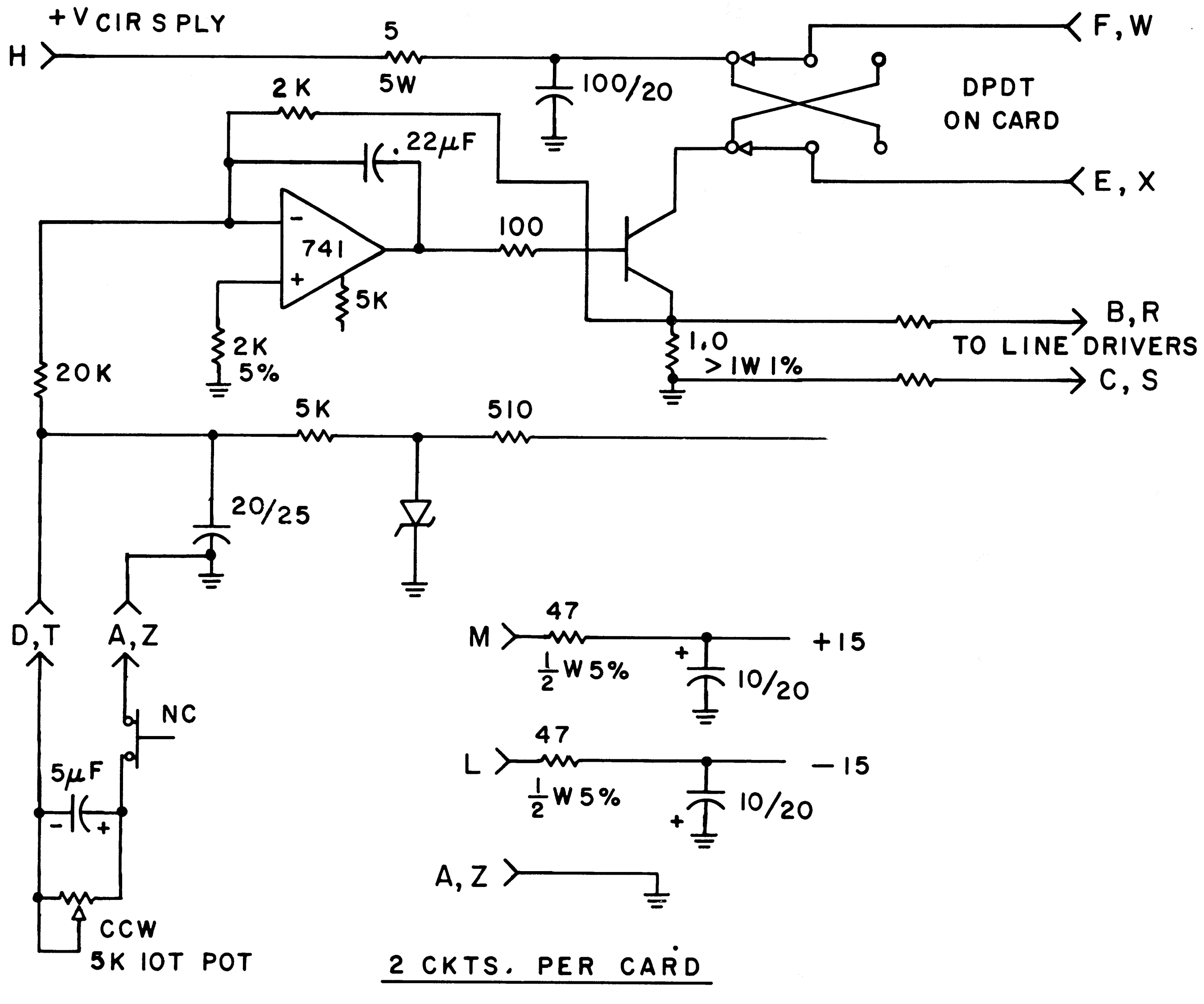
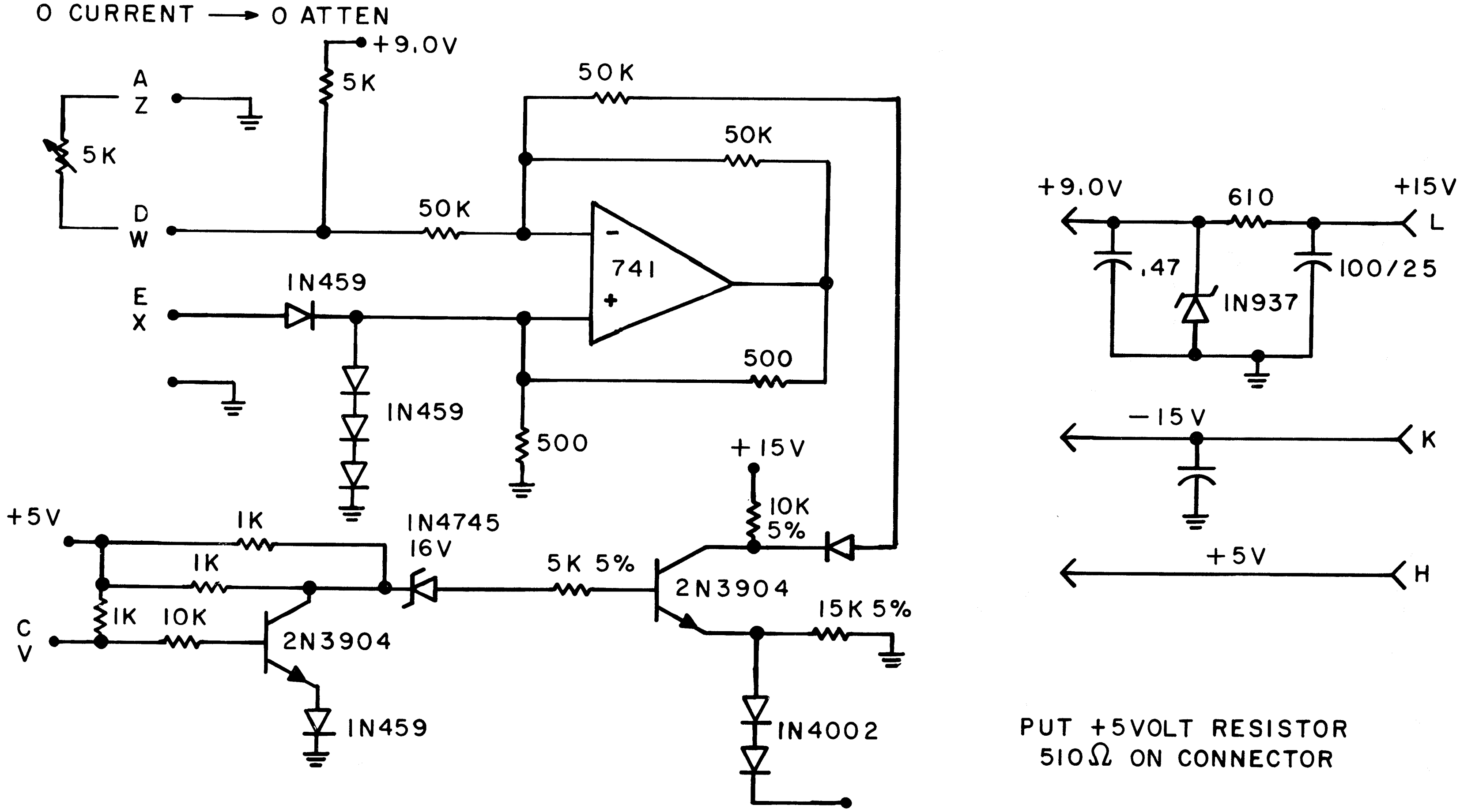


Figure 16 — Circulator Current Regulator



PUT +5VOLT RESISTOR
510Ω ON CONNECTOR

H/P 33000C PIN MOD DRIVER CARD

Figure 17

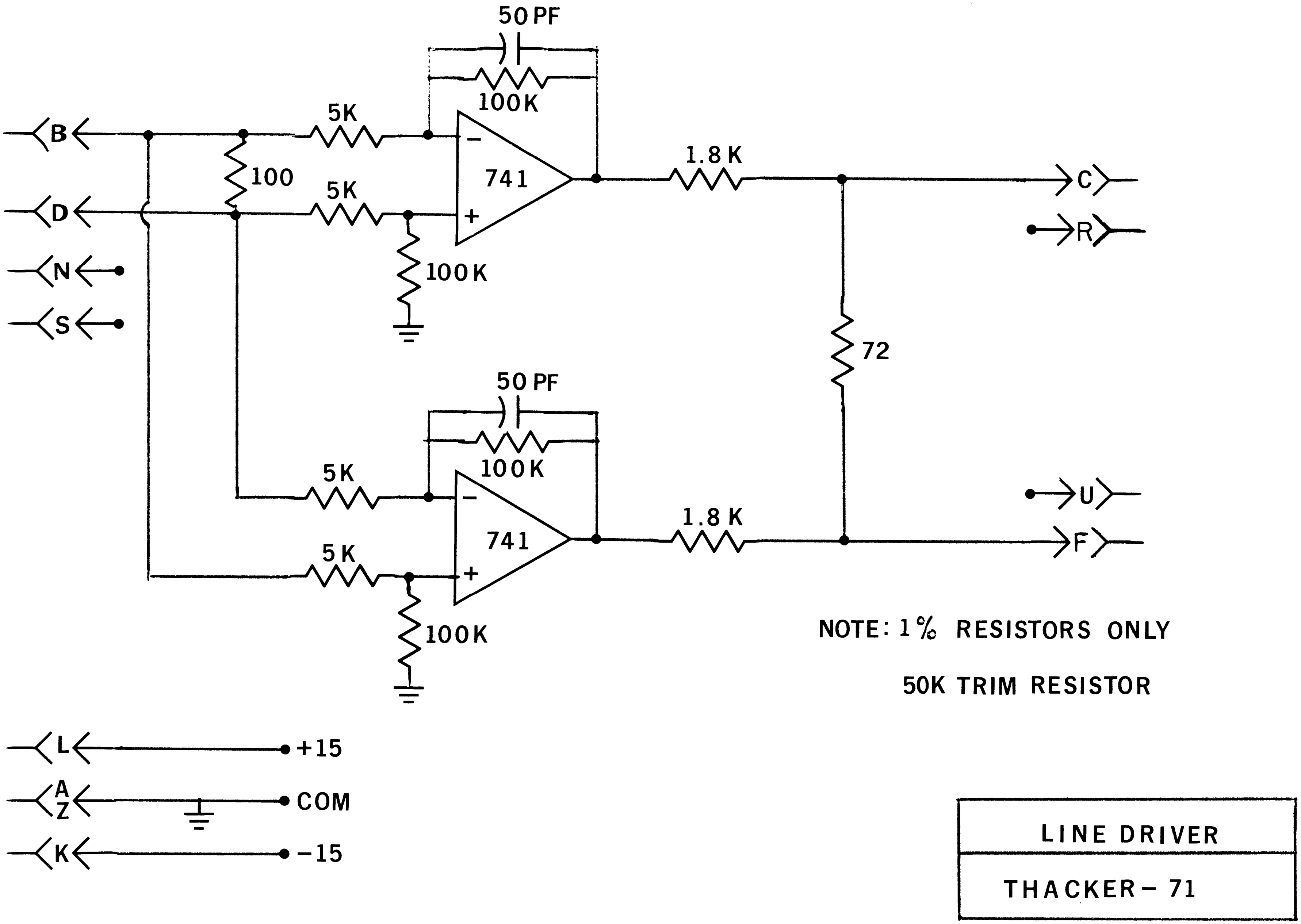


Figure 18 — Line Driver

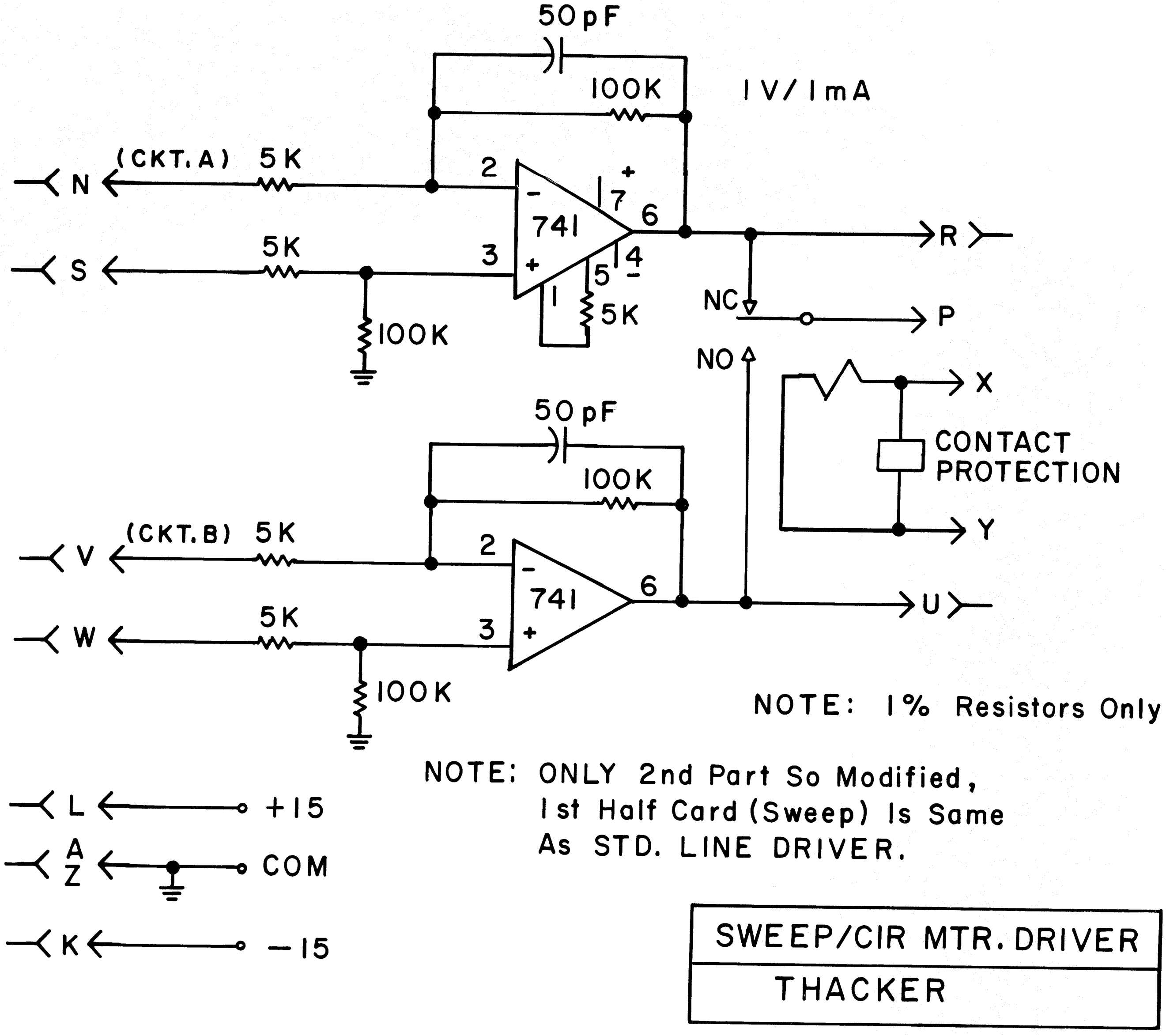
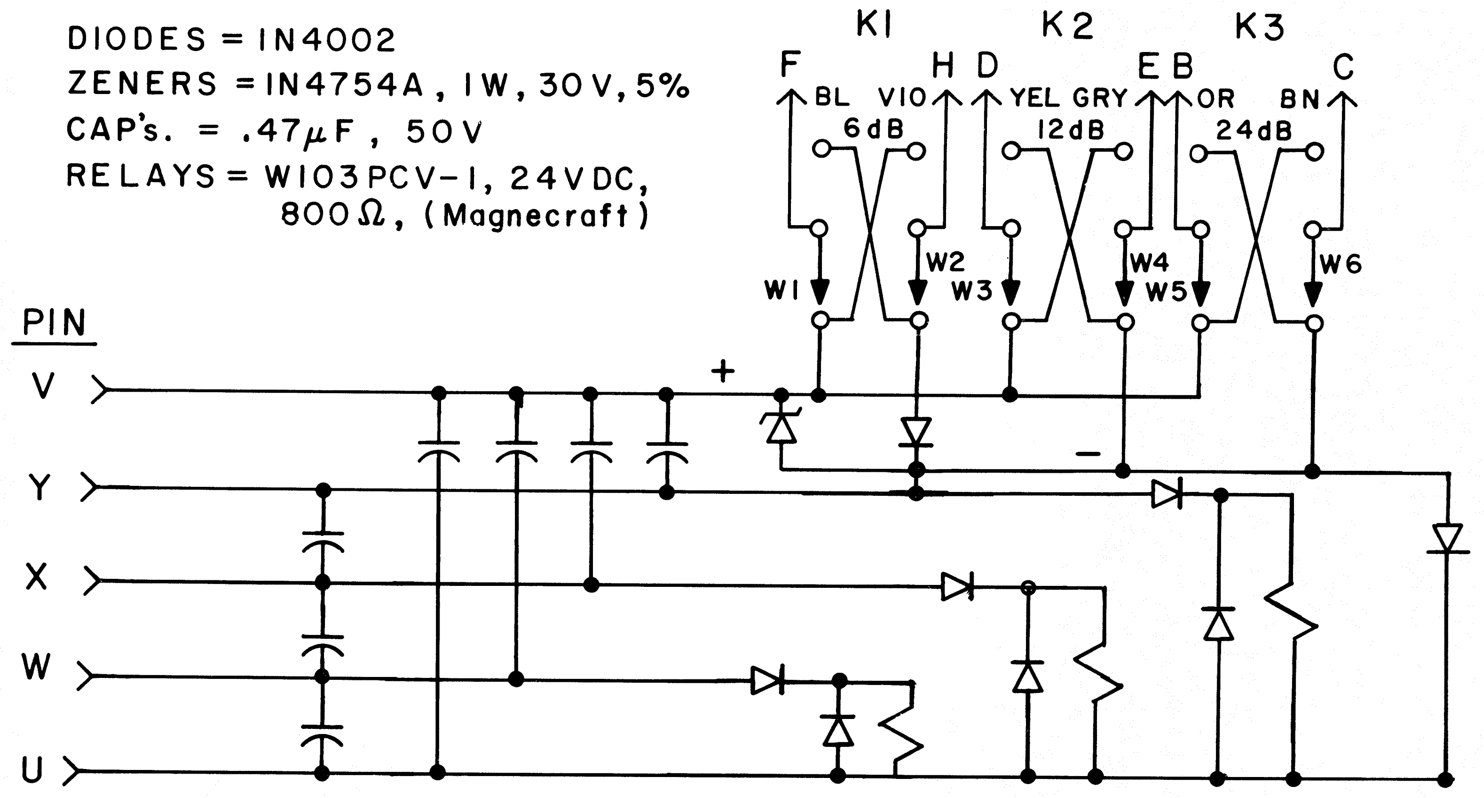


Figure 19 — Sweep/Cir Mtr. Driver

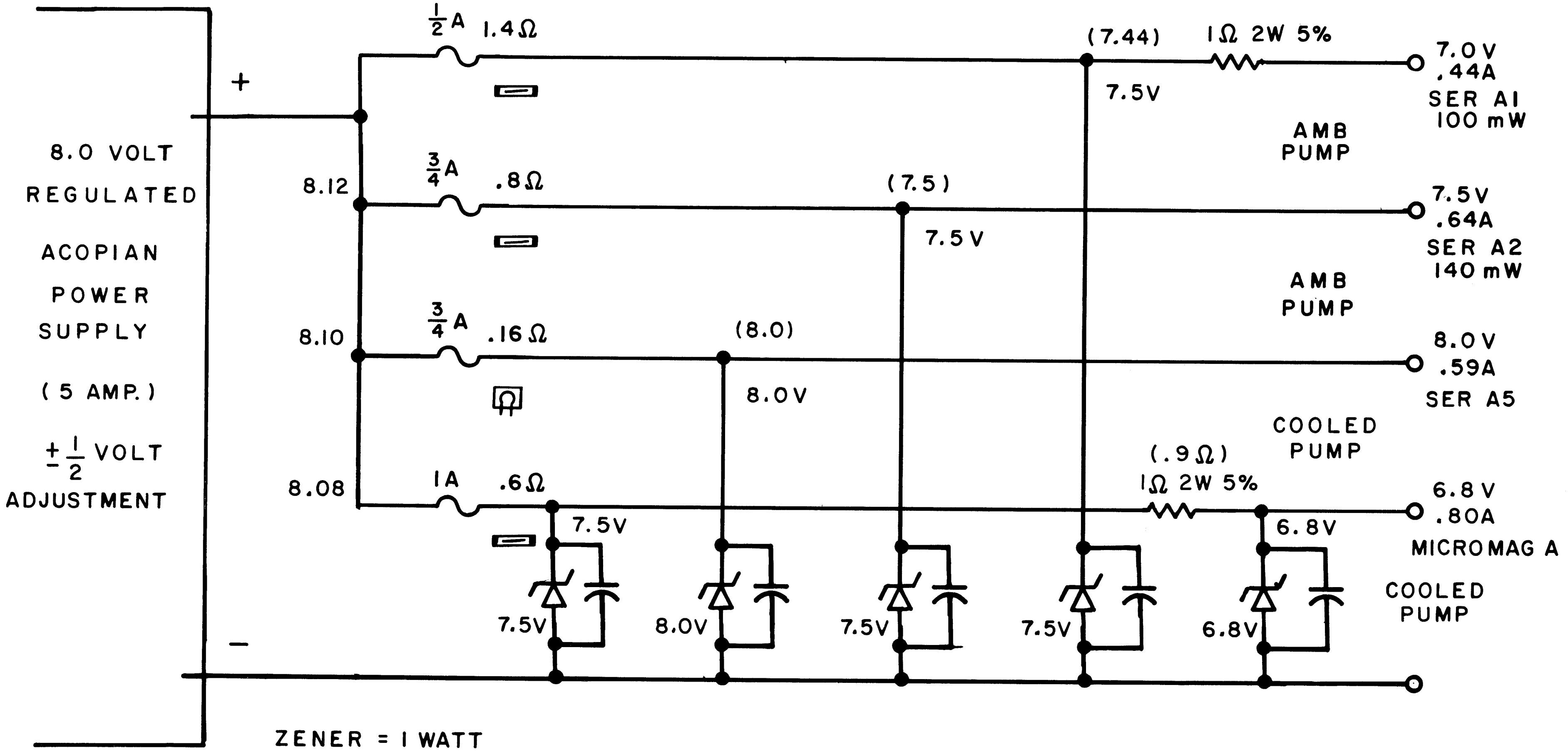
DIODES = IN4002
ZENERS = IN4754A, IW, 30V, 5%
CAP's. = .47μF, 50V
RELAYS = WI03PCV-I, 24VDC,
800Ω, (Magnecraft)



NOTE: This Card Subject To Changes
This Circuit Not Recomended For New Design

STEP ATTENUATOR DRIVER COOLED 21 cm REC'R.

Figure 20 — Step Attenuator Driver, Cooled 21 cm Receiver



ZENER = 1 WATT
CAP. = .47μF (or .22μF), 25 or 50 V
FUSE = AGC LITTLEFUSE

NOTE WELL: THE FUSES (AND ZENERS) WERE HAND PICKED – DO NOT MAKE SUBSTITUTIONS.

GUNN EFFECT OSCILLATOR POWER SUPPLY FRONT END BOX

Figure 21 — Gunn Effect Oscillator Power Supply Front-End Box

VacIon Pump 8 l /s
Model 911-5000

1. Make sure that the ground and high-voltage leads to the pump and Control Unit are securely connected.

2. Start the roughing process and open the roughing valve.

3. On the Control Unit, turn the START-PROTECTION switch to START and turn the METER RANGE switch to the voltage scale.

4. When the roughing pressure has fallen to 10 microns or less, turn the Control Unit ON. Pump voltage should be approximately 300 V. A temporary rise in roughing pressure may occur. As the pressure falls, the voltage will slowly rise.

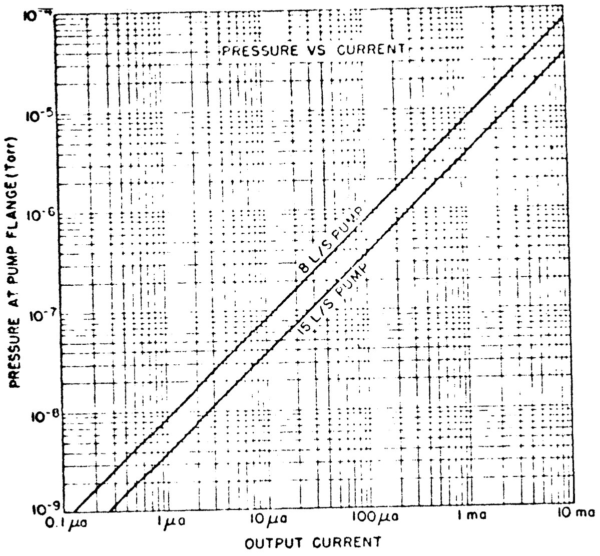
5. Close the roughing valve when the base pressure of the roughing system is reached. If the pump voltage fails while the roughing valve is closed, re-open it for further rough pumping.

6. After the roughing valve is closed and the pump voltage has reached 2 kV, place the START-PROTECTION switch in the PROTECTION position.

CAUTION

Failure to use the PROTECTION provision during unattended operation can cause damage to both the pump and the Control Unit.

7. Turn the METER RANGE switch to LOG to read pump pressure. The normal pumping discharge is confined in the pump cells at 1 to 2 kV. However, the pump current is not linear with pressure until the voltage exceeds 2.5 kV.



Pump current read on the Control Unit meter can be converted to pressure by means of this graph.

SHUTDOWN

To avoid contamination, vent the system to dry argon or nitrogen gas, rather than to room air.

If the system has a high-vacuum valve between the VacIon Pump and the vacuum chamber, close this valve before admitting air to the system, leaving the VacIon Pump operating at low pressure.

On subsequent pumpdowns, rough the rest of the system to 10 microns. Then open the high-vacuum valve gradually, so as to throttle the gas load to the VacIon Pump. It is important to limit the gas load when evolving a gas or introducing a gas sample into a vacuum system. Otherwise, the pressure may rise above the maximum throughput point for the VacIon Pump, making it necessary to rough pump and start the VacIon Pump again.

CAUTION

Before disconnecting the high-voltage feedthrough from the pump, wait at least 30 seconds after turning off the high voltage to allow the capacitors to discharge completely.

Figure 22 — VacIon Pump Data Sheet

BAKEOUT

After extended use, the VacIon Pump may become hard to start and will operate slowly. This condition is usually caused by the presence of water vapor or other contamination in the pump or connecting tubing. To improve performance, bake the pump according to the following table. During bakeout, maintain a vacuum in it that is below 5 x 10^{-4} Torr by using another VacIon Pump, a staged series of VacSorb Pumps, a trapped diffusion pump, or a trapped mechanical pump. Remove the pump magnet when baking above 400°C. Do not bake the cable above 250°C.

TYPICAL BAKEOUT CONDITIONS

Interval	Temperature	Heat Source
2 hours	550°C	Special oven, usually with inert gas or reducing atmosphere
4 hours	400°C	Special oven
12 hours	300°C	Bakeout mantle*

*Bakeout mantle for 8 l/s VacIon Pump, 115 V, 200 W Model No. 915-0026
Bakeout mantle for 8 l/s VacIon Pump, 230 V, 200 W Model No. 915-0046
Bakeout mantle for 15 l/s VacIon Pump, 115 V, 250 W Model No. 915-0027
Bakeout mantle for 15 l/s VacIon Pump, 230 V, 250 W Model No. 915-0047

CAUTION

Never use a torch for bakeout. Localized heating may cause the stainless steel pump body to buckle or warp.

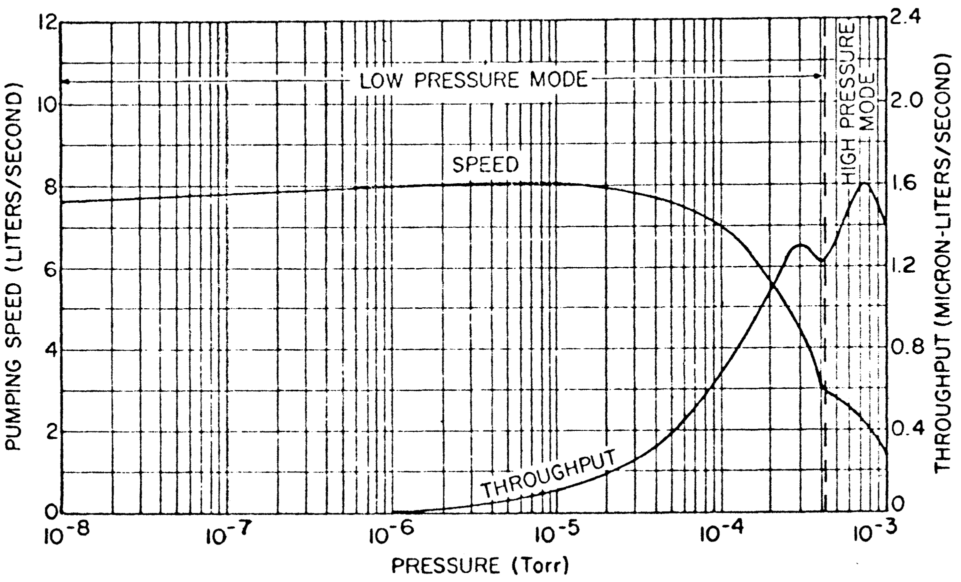
CAUTION

Before disconnecting the high-voltage feedthrough from the pump, wait at least 30 seconds after turning off the high voltage to allow the capacitors to discharge completely.

Pumping speed of VacIon Pumps is nearly constant over a wide pressure-range. These graphs show the speed for air as a function of pressure.

Speeds for other pure gases as a percent of the speed for air are:

Hydrogen	270%
Deuterium	190%
Light Hydrocarbons	90–160%
Nitrogen Carbon Dioxide Water Vapor	100%
Oxygen	57%
Helium	10%
Argon: Super VacIon Pump	6%
Flat Cathode Pump	1%



8 l/s VacIon Pump: Pumping Speed and Throughput for Air vs Pump Pressure

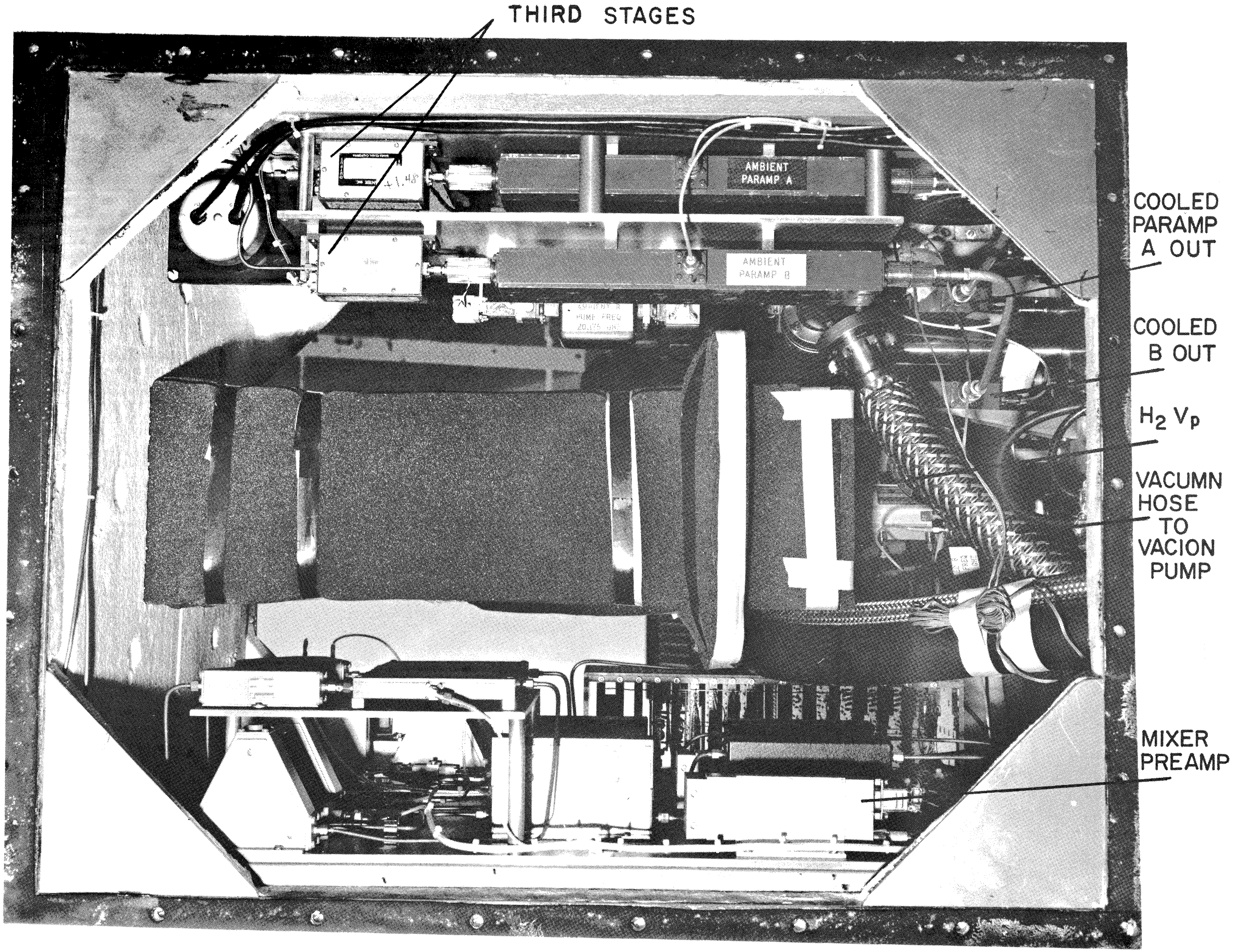


Figure 23 — Cooled 21 cm System - View A

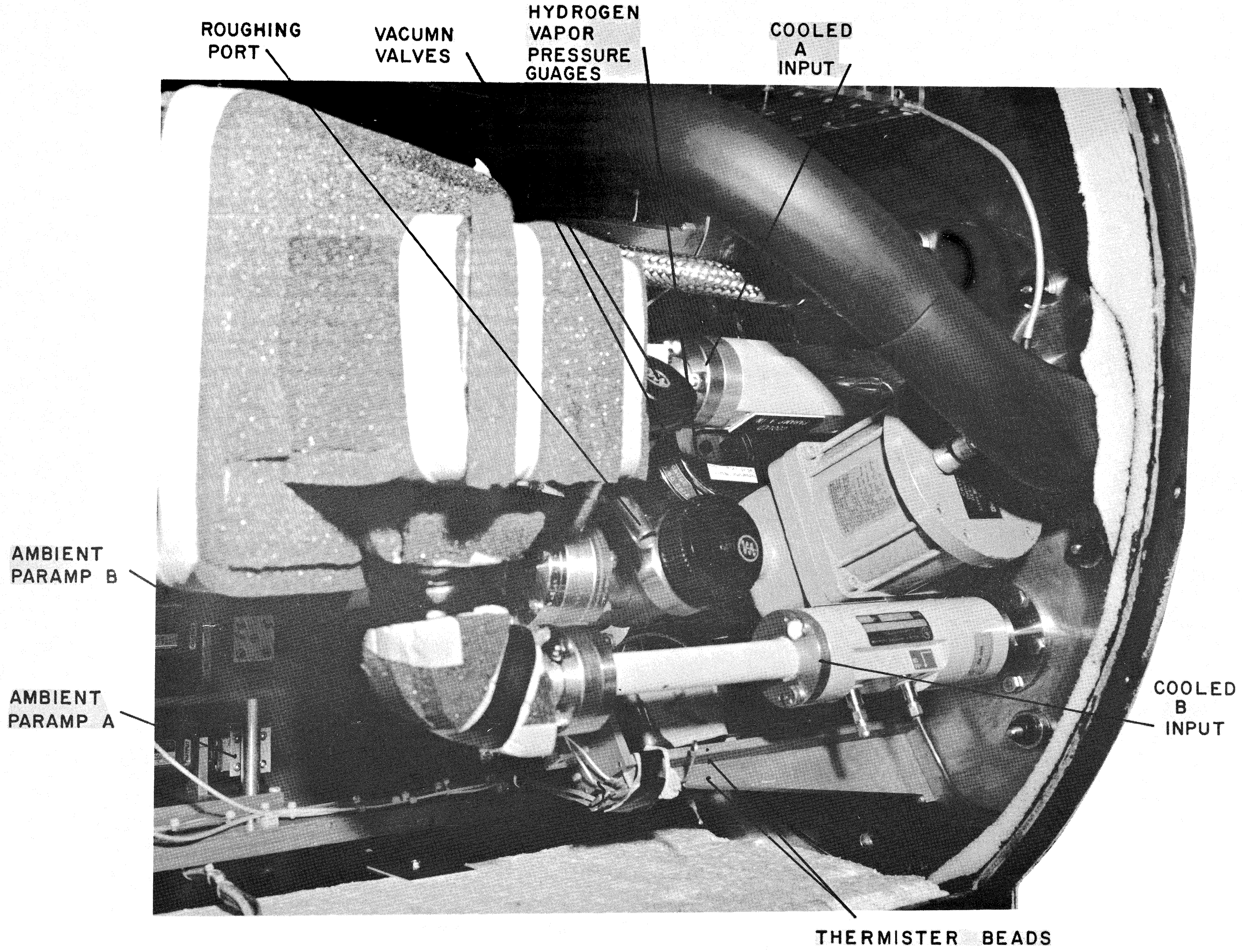


Figure 24 — Cooled 21 cm System - View B

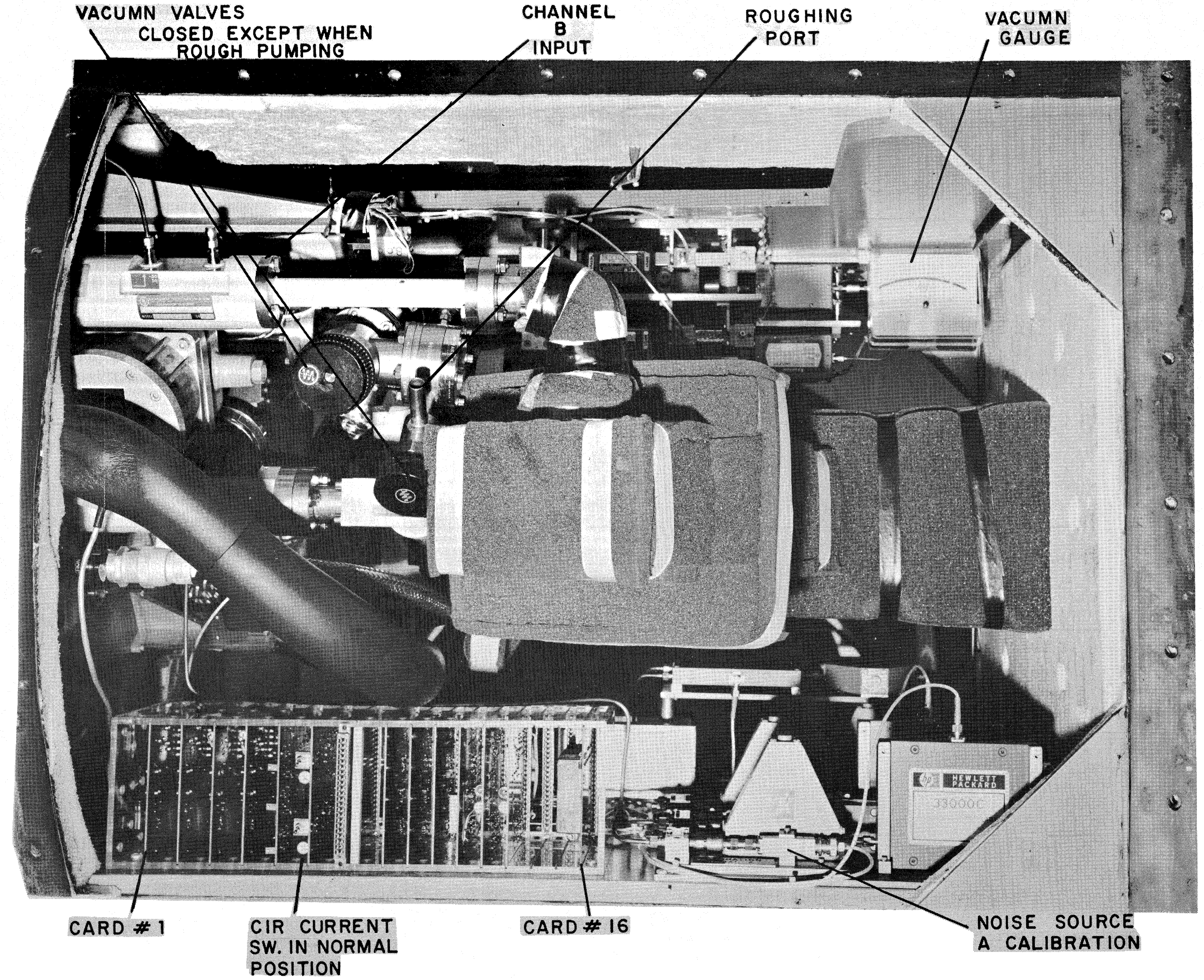


Figure 25 — Cooled 21 cm System - View C

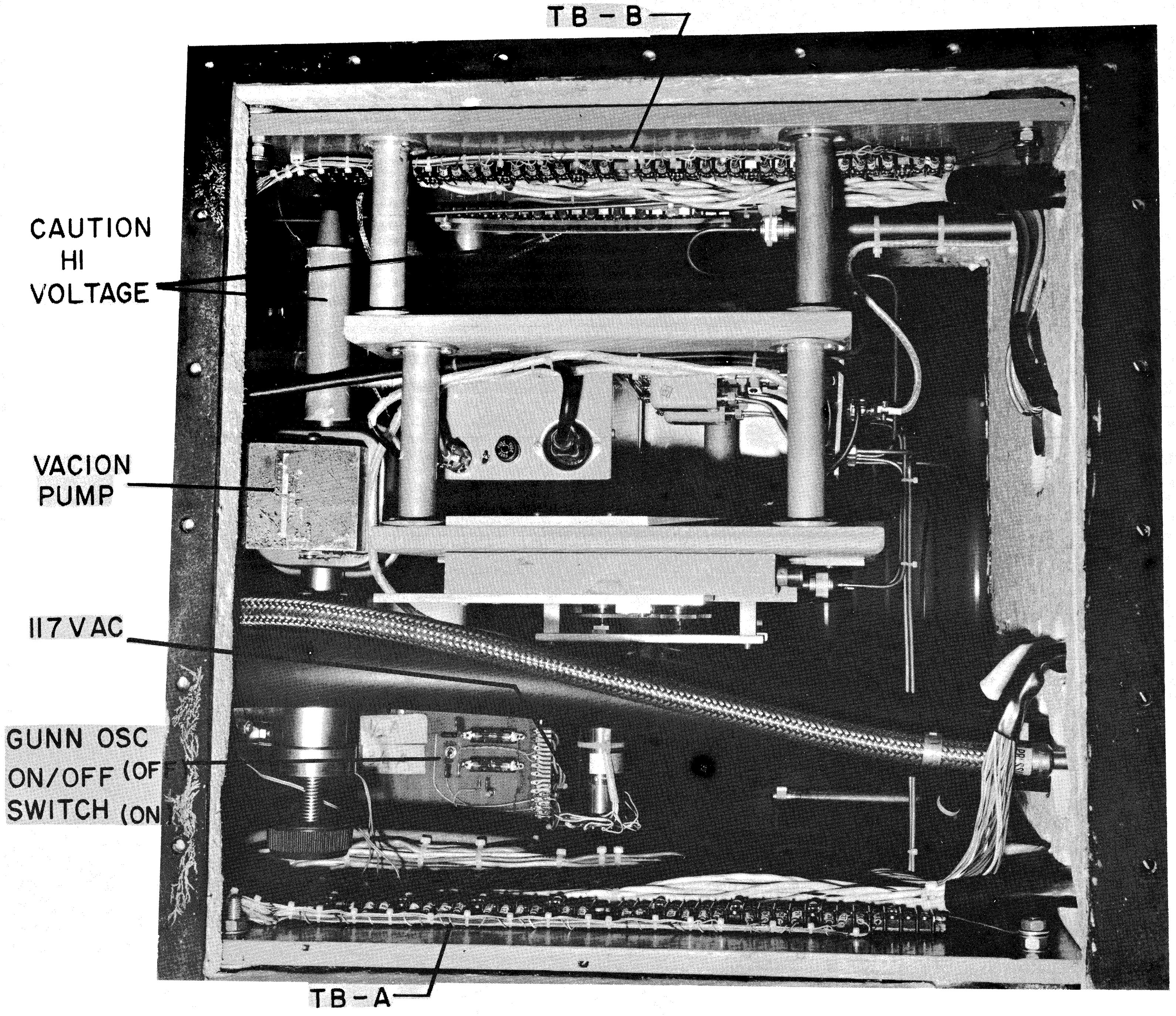


Figure 26 — Cooled 21 cm System - View D