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GREEN BANK, WEST VIRGINIA

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L AND C-BAND CRYOGENIC FRONT-END FOR HARVARD RADIO ASTRONOMY STATION, FORT DAVIS, TEXAS

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HARVARD OBSERVATORY, FORT DAVIS, TEXAS

George H. Behrens, Jr.

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L AND C-BAND CRYOGENIC FRONT-END FOR HARVARD OBSERVATORY, FORT DAVIS, TEXAS

George H. Behrens, Jr.

INTRODUCTION

The purpose of this report is to describe the characteristics of a new dual band (L and C band) front-end built at NRAO for Harvard's Observatory (HRAS) at Fort Davis, Texas. Information in this report will include a brief description of the front-end, wiring diagrams, schematics, and measured test data.

Installed at Fort Davis during January 1981, this front-end should significantly improve the sensitivity of the VLB observations from that station. The previous system noise temperature at Fort Davis was 120-160°K at 18 cm and about 180°K at 6 cm. Telescope measurements with the new receiver indicate an approximate system temperature of 70°K at 18 cm and 60°K at 6 cm. The design frequencies are 1.4-1.7 GHz for the L-band and 4.9-5.1 for the C-band channel. In this report the L-band and C-band channels are sometimes referred to as the 18 cm and 6 cm, respectively.

GENERAL SYSTEM DESCRIPTION

The front-end system is shown in the block diagram of Figure 1A. The system is made up of three chassis: the vacuum dewar assembly, the front-end instrumentation chassis, and the control room monitor and control chassis. Cabling between the three chassis is also shown in Figure 1B.

Vacuum Dewar Assembly

The vacuum dewar assembly houses the low noise GaAs FET amplifiers, associated wiring, waveguide transitions, RF input and output lines and cryogenic refrigerator. Photographs of the dewar assembly are shown in Figures 2 through 4. Internal dewar wiring is shown in Figure 5.

1. Dewar

The aluminum dewar is surplus equipment obtained from the National Oceanic and Atmospheric Administration (NOAA) and previously used to house low noise amplifiers for one of that agency's projects. Some modification of the dewar was required to accommodate the new front-end components and stop previous vacuum leaks. A new stainless-steel RF input/output plate replaced the previous aluminum plate which had several unrepairable leaks. Vacuum integrity now appears excellent, as revealed by room temperature leak testing with a mass spectrometer.

It has been found that at room temperature the dewar can be evacuated to about 5 microns, then valved off, and over a period of about one hour the vacuum increases to only 6 microns. This characteristic can be used as a check if future leaks are suspected.

2. Low Noise Amplifiers

GaAs FET amplifiers cooled to approximately 15°K are used as the low noise amplifiers at both L and C band. In both cases, two stage amplifiers are used. These amplifiers were designed and built by S. Weinreb and C. Pace at NRAO, Charlottesville, VA, and are similar to those described in Electronics Division Internal Report No. 202 and S. Weinreb's paper entitled "L-Band, Cryogenically-Cooled GaAs FET Amplifiers," Microwave Journal, October 1980.

The L-band amplifier (NRAO S/N 33) is designed to operate from 1.4-1.7 GHz with a gain greater than 20 dB and a measured noise temperature less than 20°K. See Figure 6 and Table 1. It should be noted the amplifier operates well above and below the design frequencies with considerable gain.

The C-band amplifier (NRAO S/N 18) operates from 4.9-5.1 GHz with a measured noise temperature less than 27°K and a gain greater than 27 dB. (See

Table 2.) It should also be noted that the C-band amplifier, unlike the L-band device, requires an input circulator. On the gain response curve it should be noted a small "suck out" occurs at about 5.15 GHz and is thought to be caused by the circulator rather than the amplifier. Since the suck out is out of band, no attempt was made to eliminate it.

3. Future X-Band Channel

Components were laid out with the possibility of adding an X-band channel at some time in the future, if so desired. A hole in the dewar RF input/output plate provides access for X-band waveguide if such a channel is to be added.

4. Refrigerator Temperature Monitor

The physical temperature of the low noise amplifiers is monitored by a temperature monitor system designed by M. Balister and described in EDIR No. 204. The temperature sensing device, a Lake Shore silicon diode, is mounted on the cold finger of the refrigerator. The monitor system permits the user to continuously monitor refrigerator temperature from either the control room or the front end as a check on cryogenic performance.

5. Vacuum Monitor

The dewar vacuum is continuously monitored through the use of a Hastings compact vacuum gauge (Model VT5) described in the manual covering this device. In this system a gauge tube is mounted through the dewar and is connected to either a vacuum meter at the front-end instrumentation chassis or a vacuum meter at the control room monitor and control chassis. A switch on the front-end instrumentation chassis selects which vacuum meter the gauge tube is connected to.

6. C-Band Waveguide Coax Transition

The C-band input waveguide changes to coaxial line as it enters the dewar. The coaxial line is designed in such a way to minimize thermal loading and at the same time provide the necessary vacuum seal. This transition was obtained from the VLA site in Socorro, NM and further information regarding its characteristics can be obtained from P. Lilie of that facility.

Front-End Instrumentation Chassis

The front-end instrumentation chassis (Figure 7) houses the power supplies for the low noise GaAs FET amps, the refrigerator temperature monitor, a vacuum monitor, and a solid-state relay which can be used to turn the system on and off from the control room. Wiring for this chassis is shown in Figure 8.

1. Constant Current Power Supplies for GaAs FET's

The power supplies for the GaAs FET amplifiers are housed in two small packages located within the front-end instrumentation chassis. Each package contains two supplies: one for the first stage and one for the second stage of each amplifier. The schematic for each power supply package is shown in Figure 9. Each supply has monitor points to check the various gate and drain voltages of each amplifier along with the drain currents. The measured values of these voltages are given in Table 3.

2. Solid State Relay

A solid state relay is housed in this unit which permits the front-end system to be turned on and off from the control room monitor and control chassis. To use this feature, the power switch on the front-end instrumentation chassis must be in the control room position. If the switch is left in the F.E. position, the S/S relay is bypassed and the system can function without the control room monitor and control chassis.

TABLE 3

Operating Voltages for GaAs FET Amplifiers

	C-Band	L-Band
First Stage (volts)		
V_{D1}	+4.679	+2.999
V_{g1}	-1.364	-1.406
I_{D1}*	+0.696	+0.987
Second Stage (volts)		
V_{D2}	+3.000	+2.993
V_{g2}	-1.531	-1.861
I_{D2}*	+0.996	+0.486

* $I_{D\ mA}$ = measured voltage x 10.

Control Room Monitor and Control Chassis

This unit (Figure 10) allows the user to monitor dewar vacuum and refrigerator temperature from the control room. It also permits one to turn the system on and off remotely, if necessary. The wiring for this unit is shown in Figure 11.

1. Vacuum Meter

Since long lengths of cable affect the accuracy of the vacuum meters, the monitor in this chassis was modified to compensate for 350 feet of #20 telescope cable. This was done by changing zener diode D1 to a 10 V zener. (See vacuum meter instruction manual.) This allows the gauge to compensate for the voltage drop in the long cable between the gauge tube and the meter. The meter should be calibrated at the telescope during installation to get accurate vacuum readings. This can be done by reading the vacuum at the front-end instrumentation chassis and then adjusting the meter in the control room to read the same value.

2. Refrigerator Temperature Monitor

This monitor should read the same value as displayed at the front-end instrumentation chassis. If it does not, adjust P1 located inside the chassis and adjacent to the DPM.

Refrigeration System

The cryogenic refrigeration system is part of the dewar dystem received from NOAA and was manufactured by Cryogenic Technology, Inc., Waltham, MA. The Model 350 cryodyne helium refrigerator has a thermal capacity of 3 watts at 20°K. For full details regarding specifications, operation, and maintenance, refer to the refrigerator operator's manual.

With the present thermal load the operating temperature is approximately 15.5°K as read by the refrigerator temperature monitor. Any significant increase in temperature (2 degrees or more) warrants investigation of either refrigeration or vacuum problems.

Measurements in the lab indicate the system takes 3 hours and 5 minutes to cool down to 15.5°K. Any significant increase in time to achieve cool down means either a poor vacuum or a refrigeration problem exists.

Before initiating cool down, the dewar should be evacuated to 10 microns or less. The vacuum pump should be allowed to pump until the hydrogen vapor pressure gauge drops to 70 psi (refrigerator temperature approximately 30°K). At that point the roughing valve may be shut and the vacuum pump removed from the front end.

LAB TEST DATA

Gain Measurements

Gain measurements were performed with the equipment set up as shown in Figure 12. Gain curves traced from the oscilloscope are shown for both bands in Figure 6.

Noise Temperature Measurements

Noise temperature measurements were made using the Y factor and power meter technique shown in Figure 13. In both cases coaxial liquid nitrogen and room temperature loads were used for the measurements. In the case of the C-band unit, the noise temperature values include a waveguide to coaxial adapter which was required to connect the loads to the front end. The resulting measurements are given in Tables 1 and 2.

Input Impedance Measurements

Input impedance measurements were made on both channels with an H-P network analyzer. The results are shown in Figures 14A and 14B. The reference plane for the L-band channel was the L-band coaxial input transition. The reference plane for the C-band measurements was at the waveguide flange of the waveguide-to-coaxial transition.

The measurements indicate a VSWR less than 2.5:1 for the L-band channel and less than 1.3:1 for the C-band channel.

TELESCOPE TEST DATA

The front-end was installed on the HRAS 85-foot telescope during the week of 12 January 1981. During this period the cryogenic compressor and helium lines were also installed. The dewar was evacuated and the vacuum integrity appeared normal. Cooled down was achieved in a normal amount of time (approximately 3 hours), but the refrigerator temperature never went below 16.5°K. In the lab at Green Bank, the normal operating temperature was 15.5 K. It was also observed at HRAS that the return pressure on the compressor was running on about 80 psi with the supply pressure at 250 psi. At Green Bank, the normal return pressure was 62 psi. It was also noted that the refrigerator temperature fluctuated up and down over the range from 16.5°K - 18.0°K over a period of a few yours. This seems to indicate some problem with the cryogenic system which should be looked into.

Aside from the above-mentioned cryogenic difficulties, the front-end appears to be operating normally as confirmed by the tests described below.

Gain Measurements

Measurements of gain on both channels were repeated on the telescope using the same equipment previously used in the lab measurements. It was found that the gain response on the telescope for all practical purposes repeated those measured in the lab.

Noise Temperature Measurements

System noise temperature measurements of the HRAS 6 cm and 18 cm radiometers were planned but, unfortunately, the mixers and/or the LO systems were inoperative at the time the measurements were to be made. Therefore, noise temperature measurements of the front-end after installed on the telescope were made exactly like those made in the lab. (See Figure 13.) The same second stage amplifiers and bandpass filters were also used.

Two sets of noise temperature measurements were made on the telescope for each channel. The first set of measurements were made to determine the front-end noise temperature without the feed assembly but included the transmission line and directional couplers between the dewar and the feed assembly. The second set of noise temperature measurements were made with the telescope pointed to zenith and the feed assembly connected. The second set of noise temperature measurements gives the expected system noise temperature during observations. The difference between the first and second set of noise temperatures is the noise contribution due to the feed and telescope.

In making the above measurements, the same liquid nitrogen and room temperature loads used in the lab measurements were used to determine the system noise temperature without the feed assembly. During this measurement the noise sources were also calibrated. The calibrated noise sources were then used to measure the system noise temperature with the feed assemblies connected and the telescope at the zenith position.

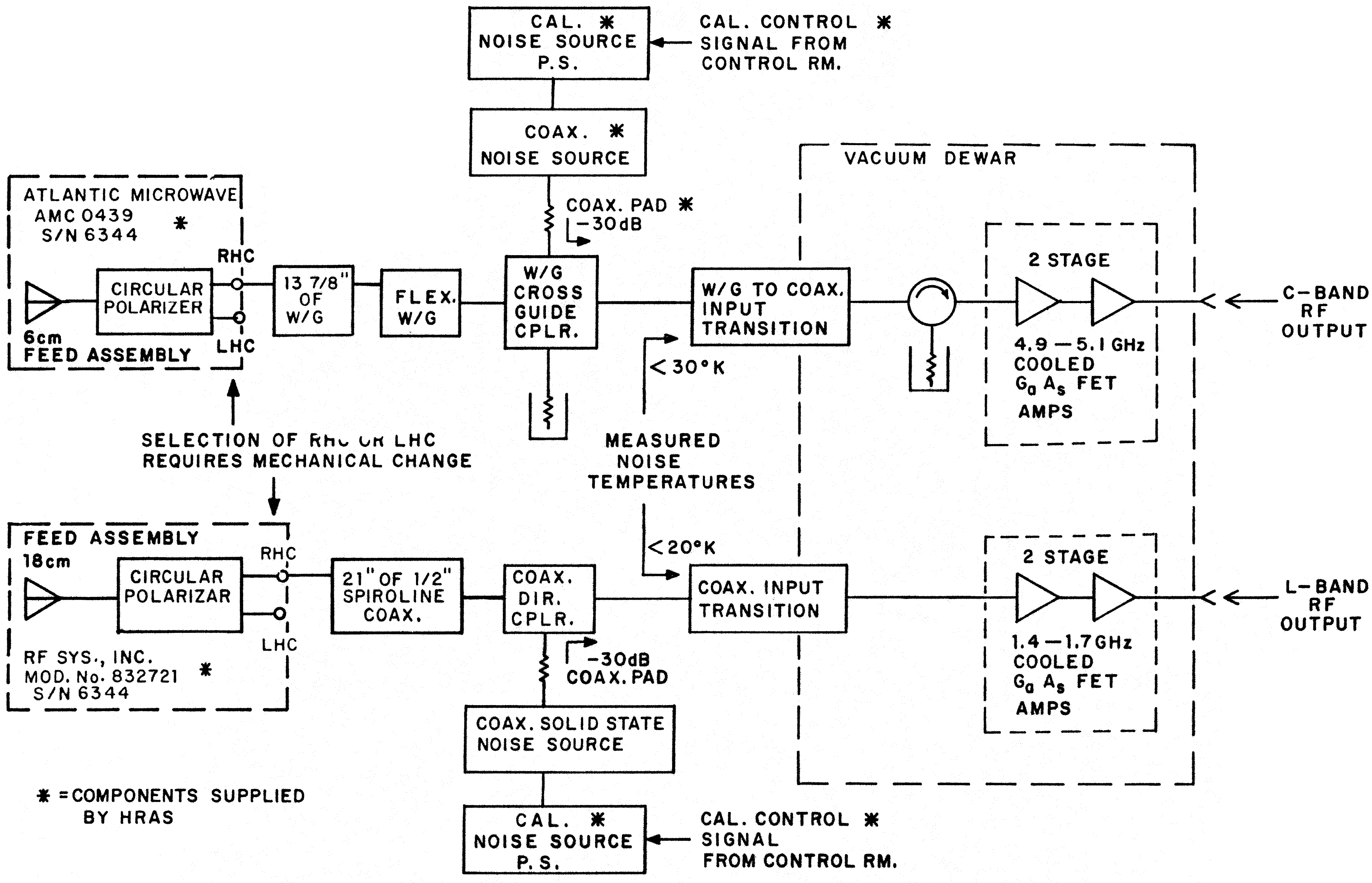
The results of these measurements along with the in-lab measurements are shown in Table 4. The table also shows the measured noise contribution due to transmission lines and couplers and the noise contribution due to the antenna. The measured noise calibration is also shown. It should be pointed out that when measuring the total system noise for both channels, a snow storm was in progress. In the case of the L-band measurement, which was performed one day after the C-band measurement, snow accumulation in the dish was rather heavy and may have accounted to some extent for the unexpectedly high antenna noise contribution.

CONCLUSION

Results of the above tests indicate the new front-end should significantly improve the sensitivity of measurements at 6 cm and 18 cm. The 6 cm measurements indicate reasonable values of noise contribution due to losses in the waveguide components between the feed assembly and the dewar input (average value = 7.4°K). This value corresponds to a loss of 0.1 dB. The average noise contribution due to the feed assembly was 26.4°K, although reasonable, it seems possibly 5° or 10° higher than might be expected (based on the writer's past experience with similar measurements of 6 cm feeds at the NRAO 140-ft telescope). This 5° or 10° excessive noise might be attributed to the weather and reflector conditions mentioned above. Another reason for the higher than expected noise contribution could very well be the long piece of waveguide (approximately 3 feet) which is an integral part of the feed assembly. Theoretical loss of 3 feet of brass guide is 0.07 dB at 5 GHz which corresponds to approximately 5°K. However, the loss of the waveguide could easily be twice its theoretical value due to dirt, corrosion, flange contacts, etc.

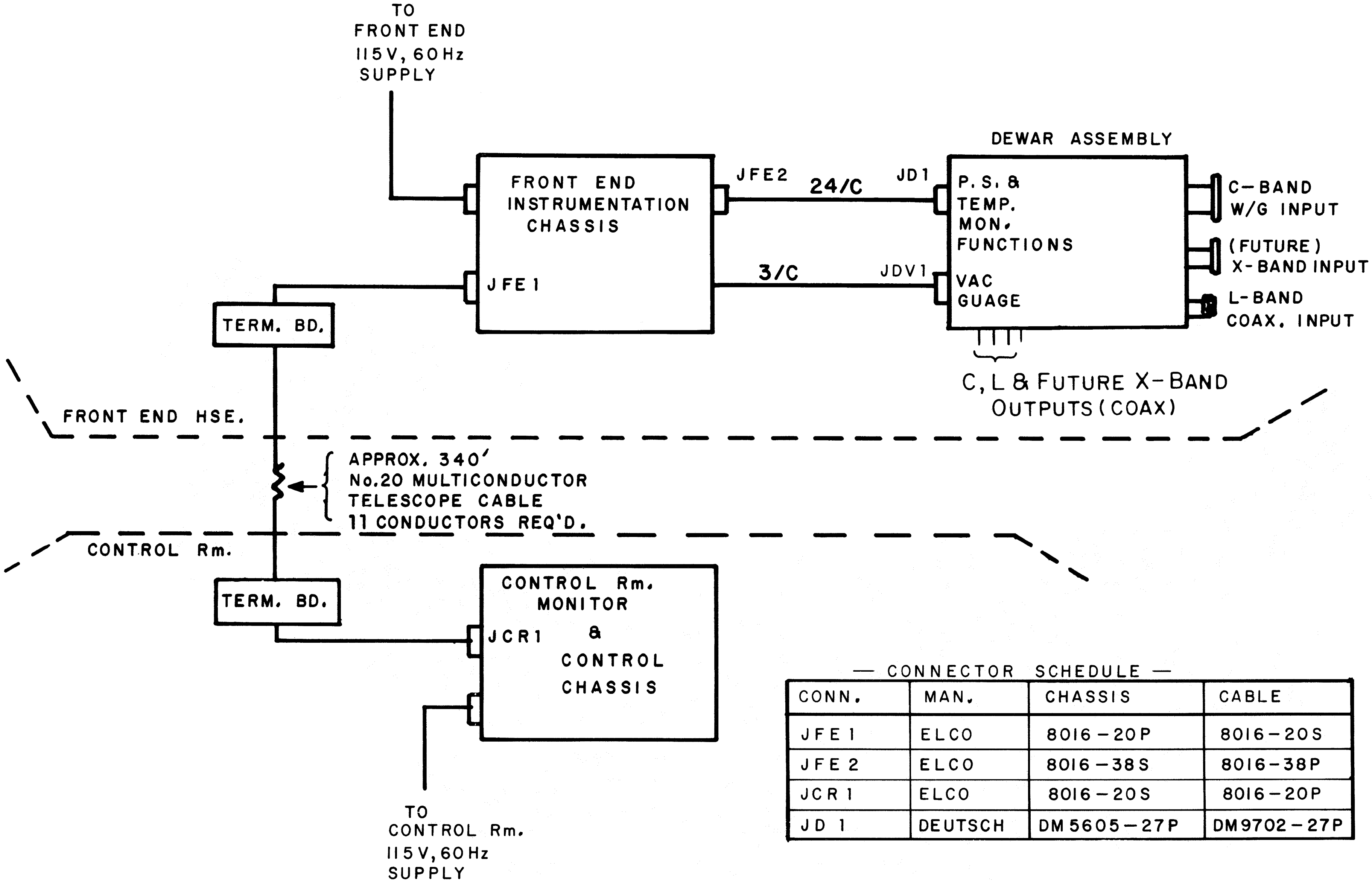
Similarly, at 18 cm the results of the measurements indicate reasonable noise temperature contribution due to transmission line components between the feed assembly and the dewar input (average value = 10°K). This corresponds to 0.14 dB of loss due to the directional coupler and a 21" piece of 1/2" Spiroline cable between the feed assembly and the directional coupler which is very close to the theoretical value. However, noise contribution due to the feed assembly (average = 47.3°K) is about 20°K higher than what one would expect. As mentioned above, this could be due to weather conditions and snow in the dish. It could also be due to a feed with a high spillover temperature (over-illumination).

In view of the above, measurements of feed assembly noise contribution should be repeated in good weather to determine the causes of the higher than normal antenna temperatures and corrective action taken, if practical.



RF BLOCK DIAGRAM OF HRAS, FT. DAVIS L/C BAND CRYOGENIC FRONT END

FIG. 1A

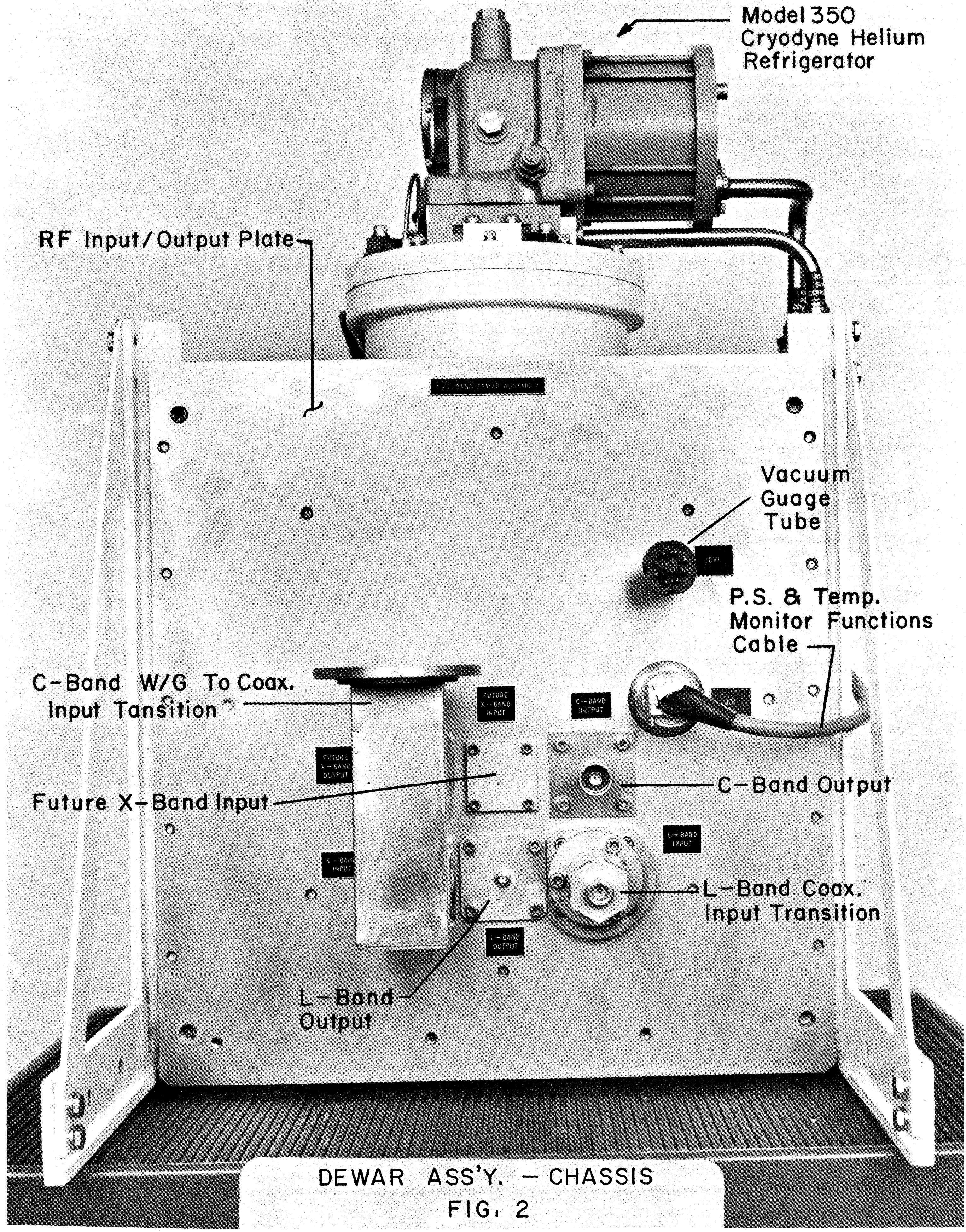


— CONNECTOR SCHEDULE —

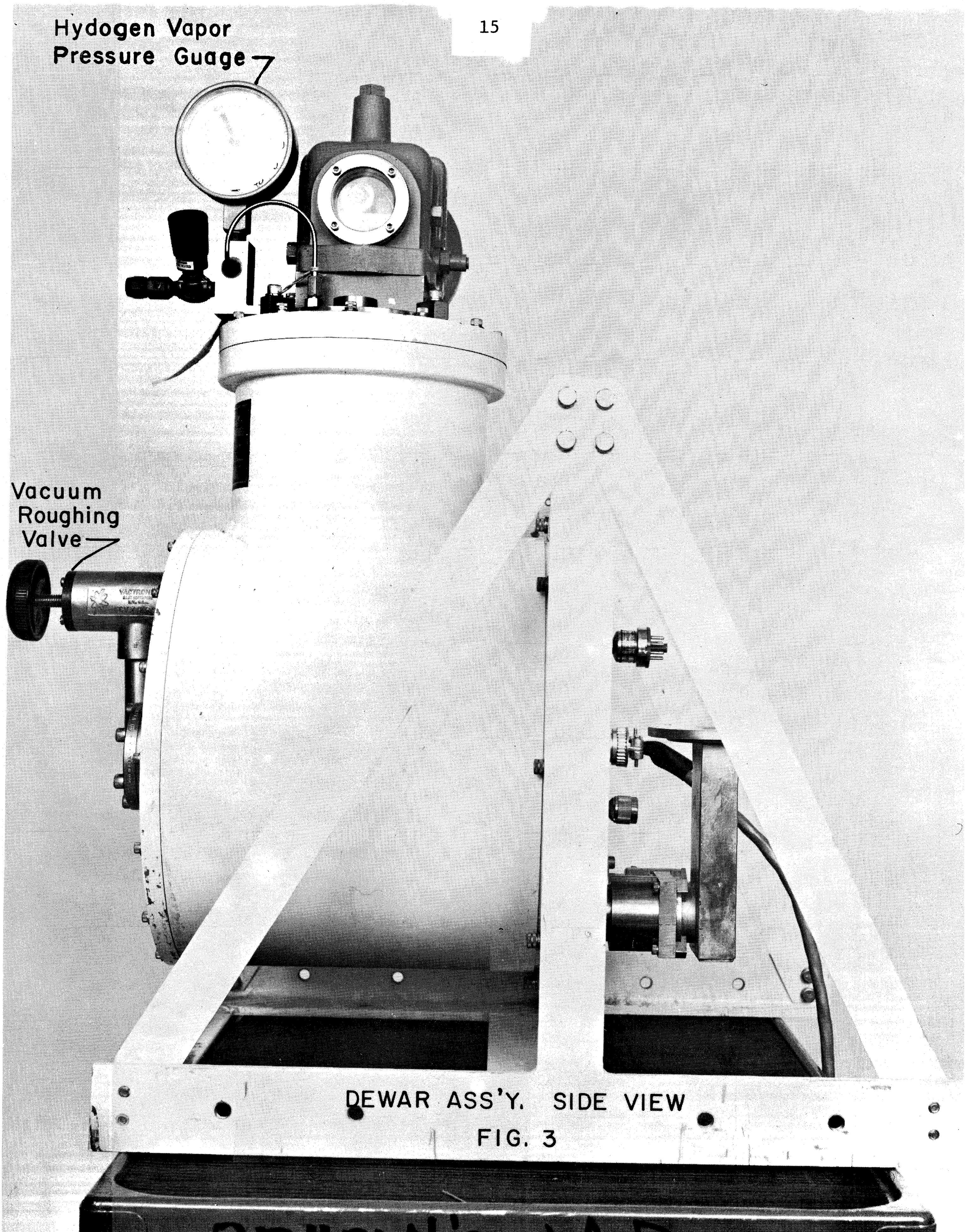
CONN.	MAN.	CHASSIS	CABLE
JFE 1	ELCO	8016-20P	8016-20S
JFE 2	ELCO	8016-38S	8016-38P
JCR 1	ELCO	8016-20S	8016-20P
JD 1	DEUTSCH	DM5605-27P	DM9702-27P

NRAO 6/18cm RX POWER & CONTROL ONE LINE DIAGRAM

FIG. 1B

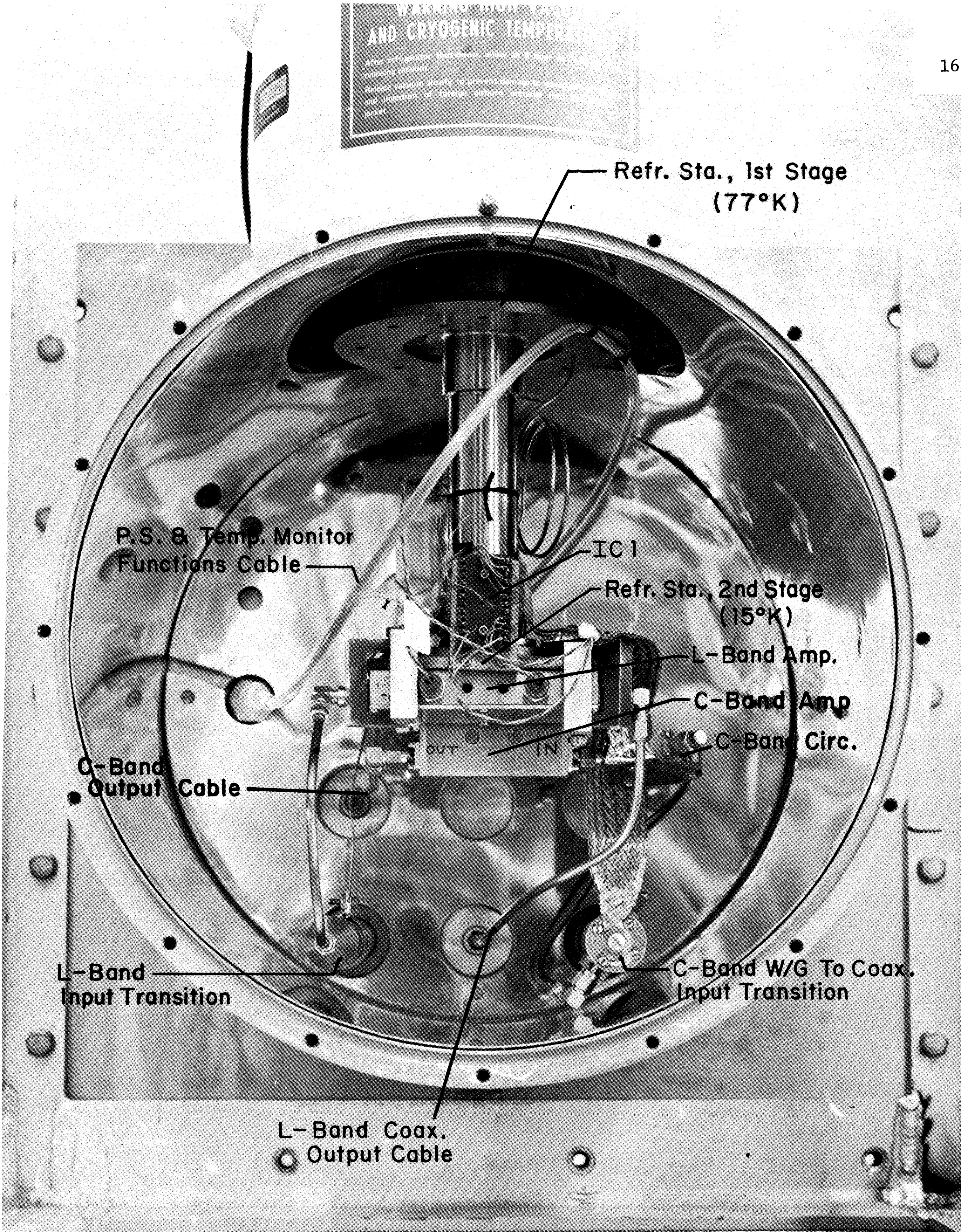


DEWAR ASS'Y. — CHASSIS
FIG. 2

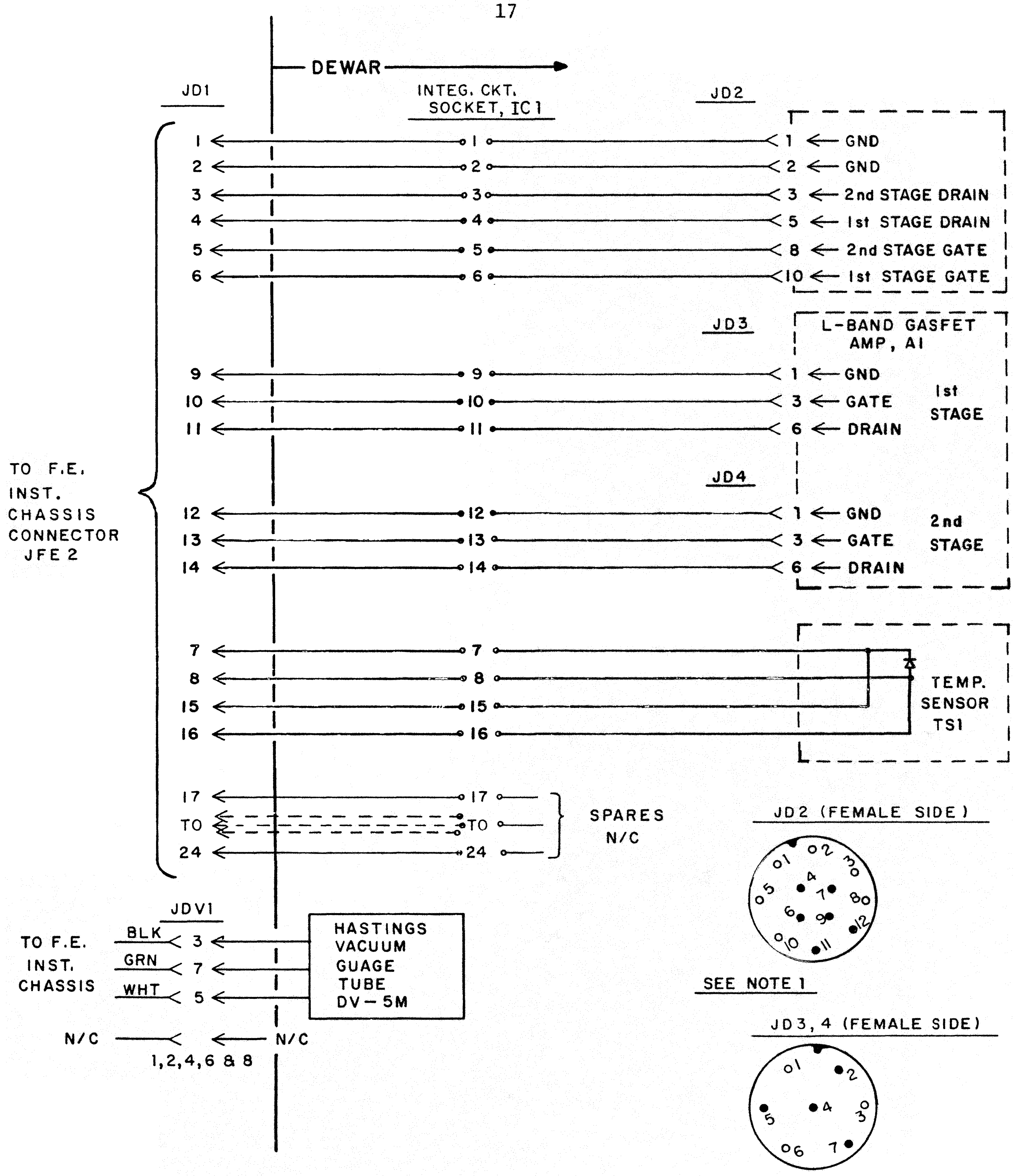


DEWAR ASS'Y. SIDE VIEW

FIG. 3



DEWAR— INSIDE VIEW
FIG. 4



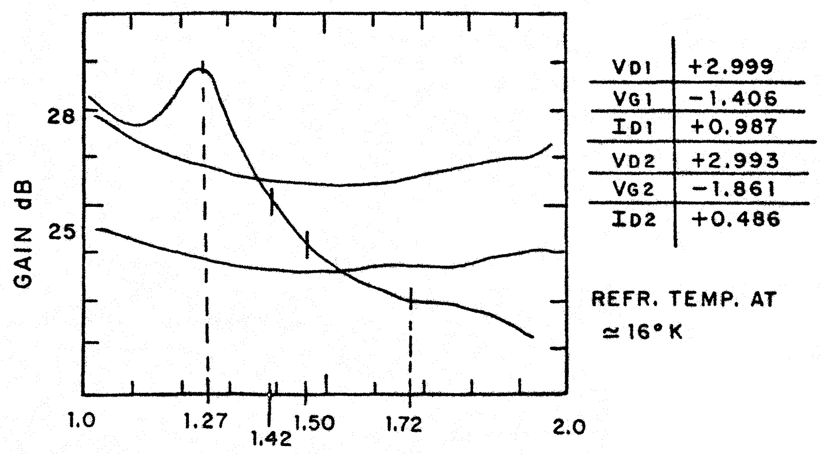
NOTES:
1) PIN NUMBERING SCHEME PER NRAO, SINCE NO NUMBERS APPEAR ON CONNECTORS.

N.R.A.O. L/C BAND RX. DEWAR WIRING

FIG. 5

TABLE 1 L-Band Noise Temperature Measurements

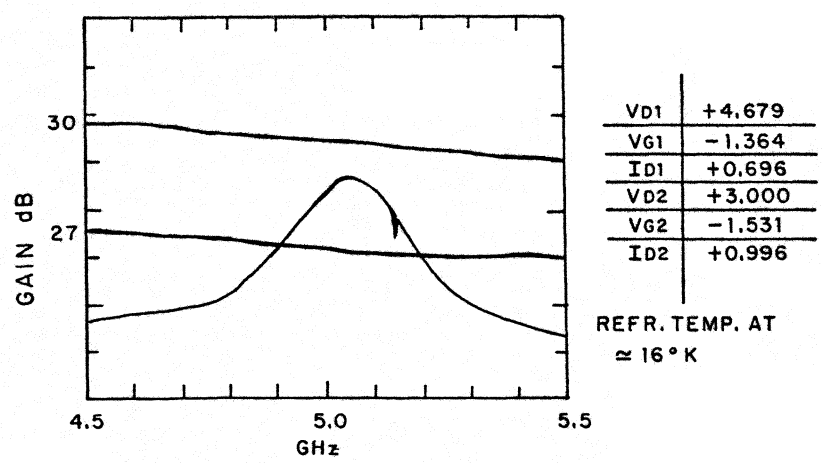
Frequency (GHz)	Noise Temperature (°K)
1.40	16
1.45	15
1.50	14
1.55	13
1.60	10
1.65	12
1.70	15
1.75	13



L-BAND
RX. BANDPASS

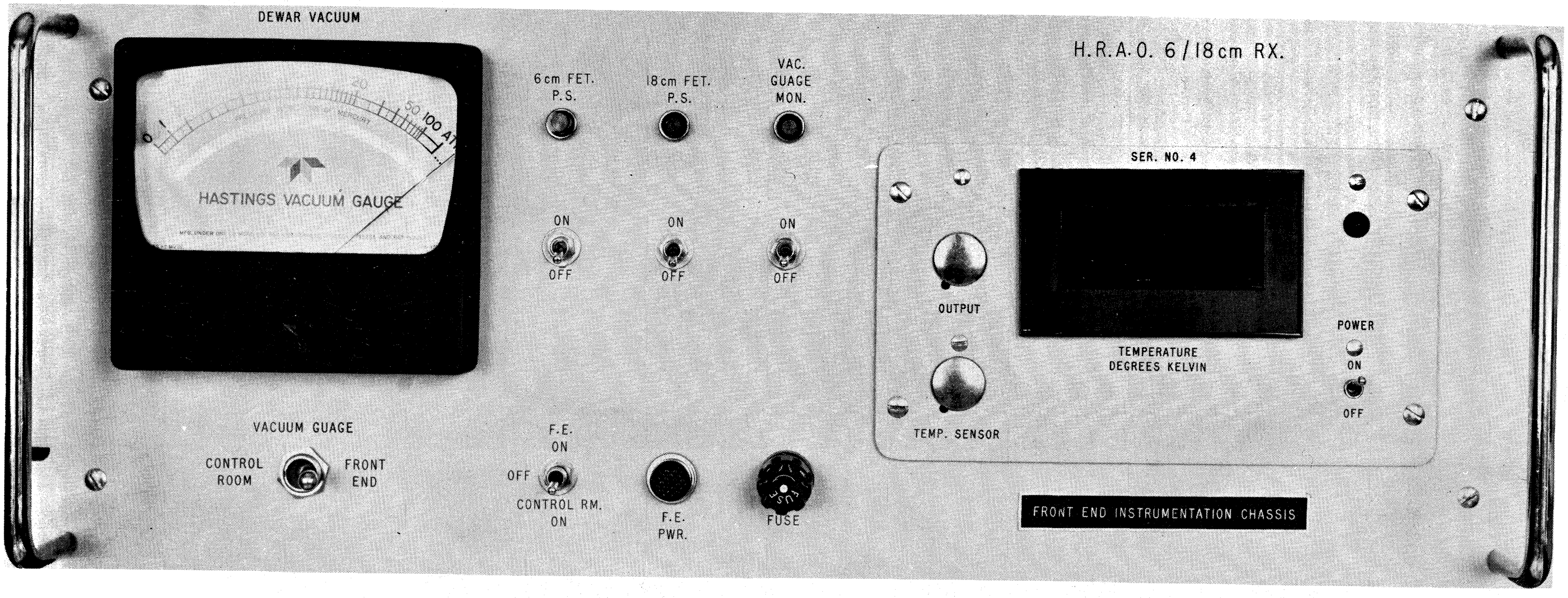
TABLE 2 C-Band Noise Temperature Measurements

Frequency (GHz)	Noise Temperature (°K)
4.90	25
4.95	25
5.00	26
5.05	23
5.10	25

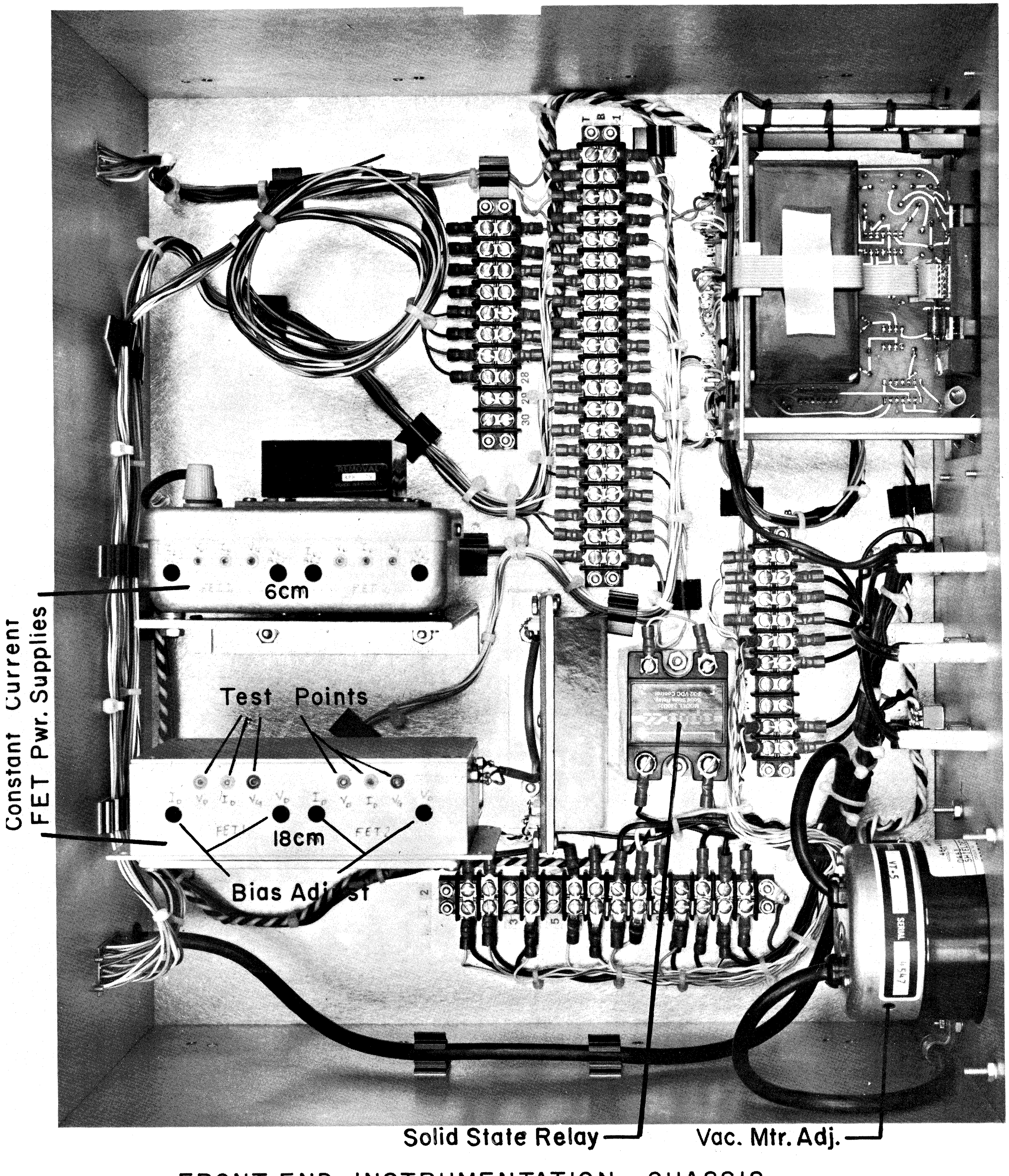


C − BAND
RX. BANDPASS

FIG. 6

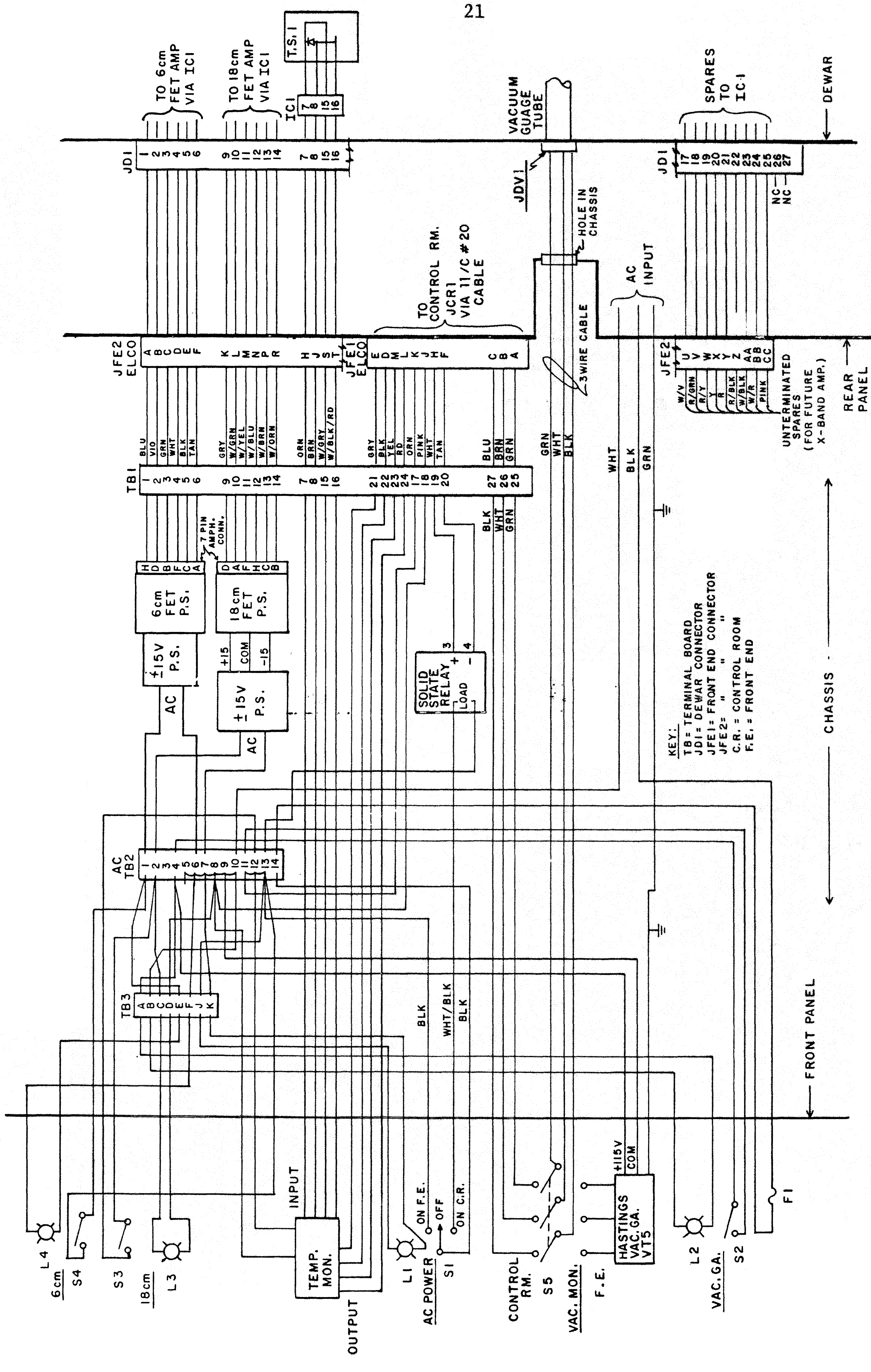


FRONT END INSTRUMENTATION CHASSIS
FRONT PANEL
FIG. 7A



FRONT END INSTRUMENTATION CHASSIS

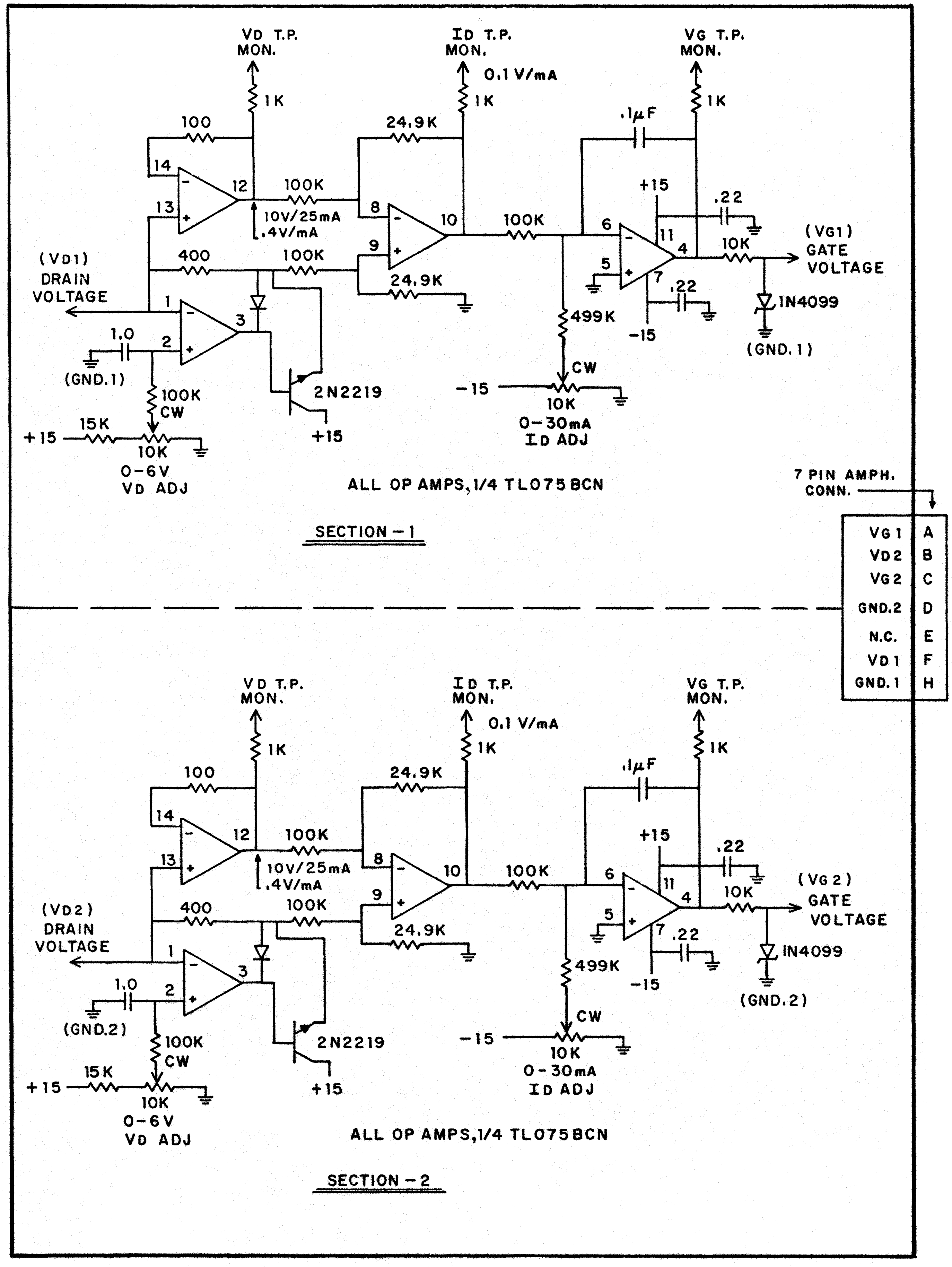
FIG. 7B



FRONT END INSTUMENTATION

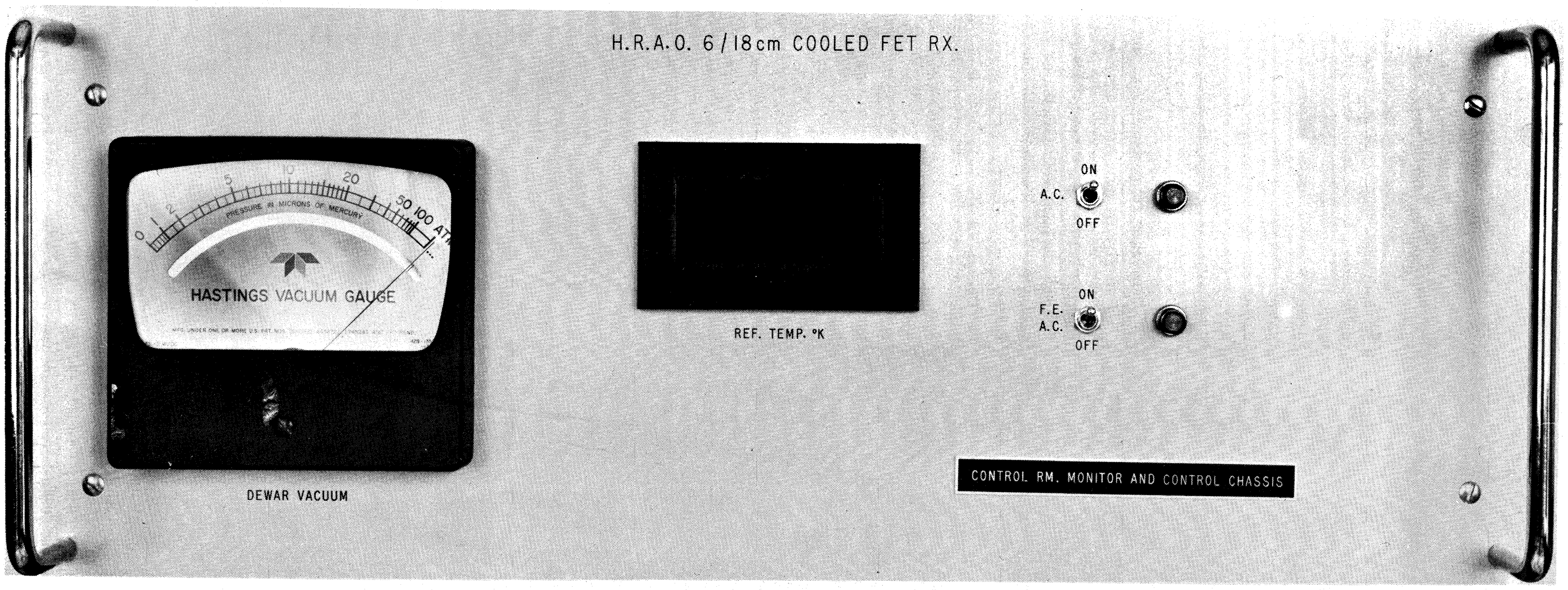
CHASSIS WIRING

FIG. 8



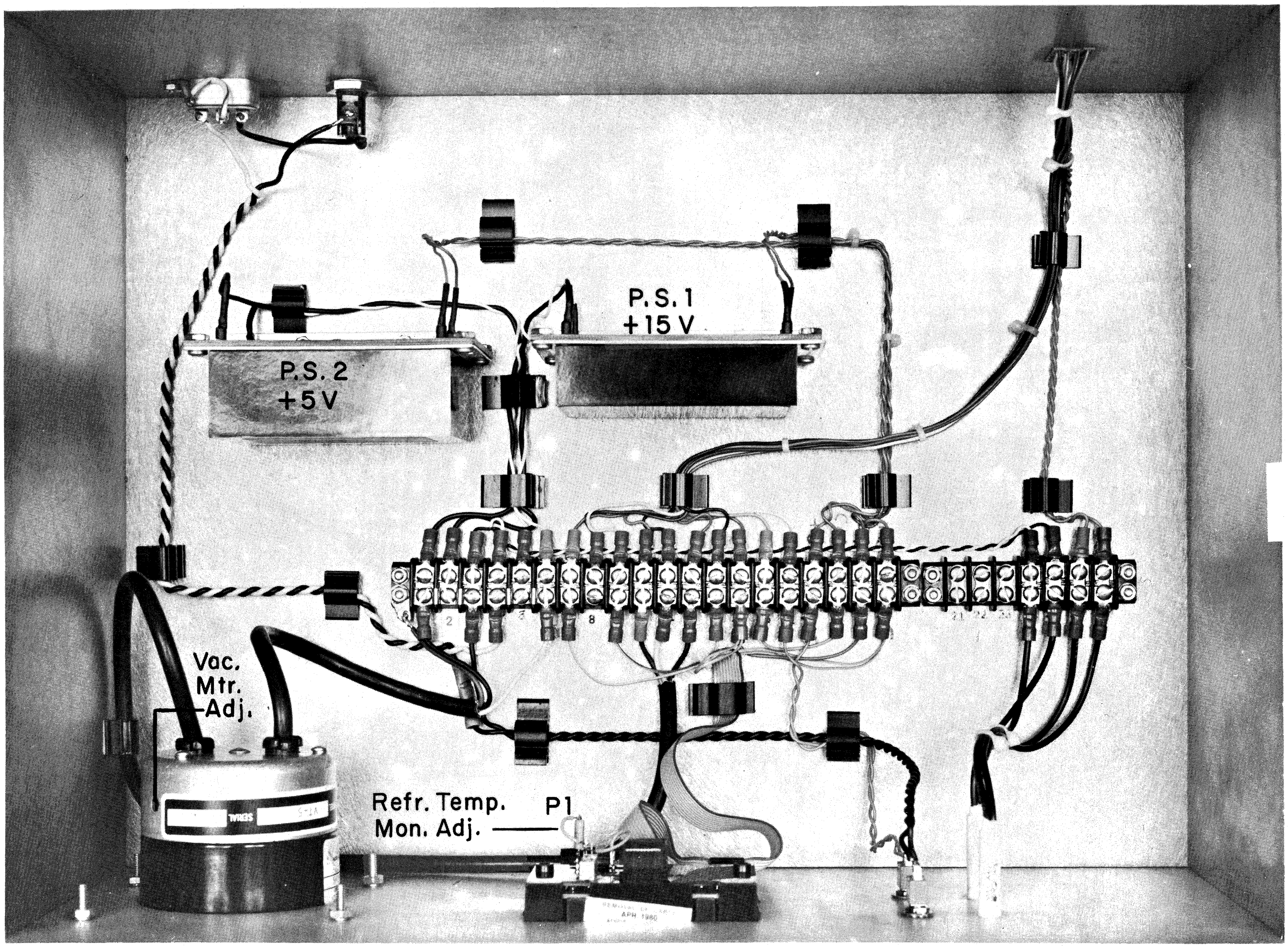
CONSTANT CURRENT FET SUPPLY FOR
6cm & 18cm FET's (One, 2 section, as shown for each)

FIG. 9

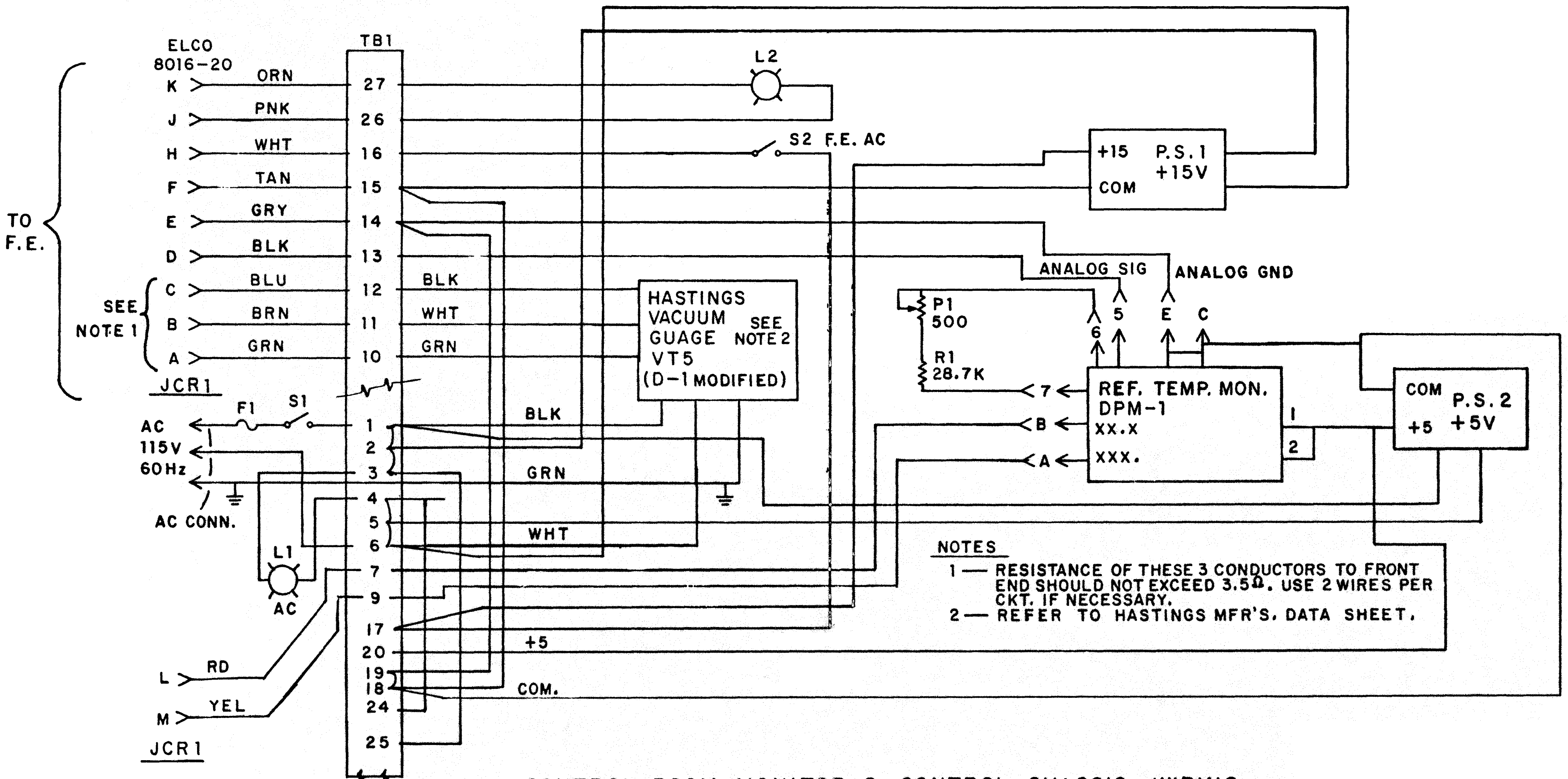


CONTROL ROOM MONITOR & CONTROL CHASSIS
FRONT PANEL

FIG. 10A

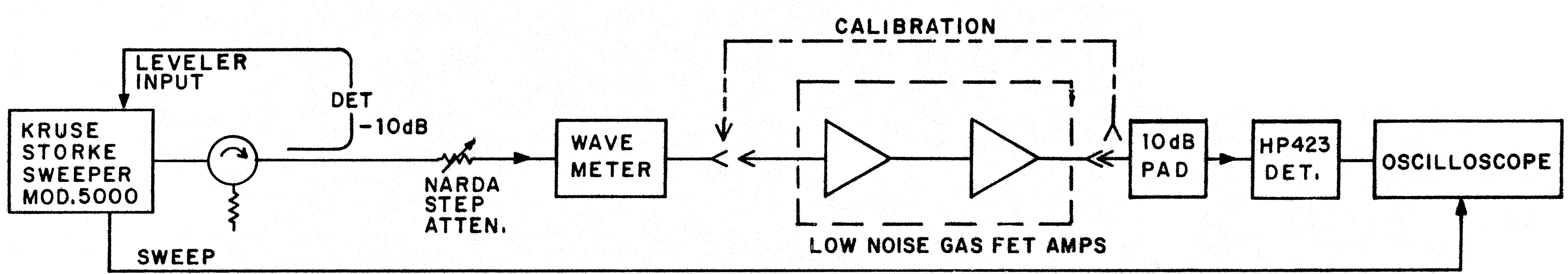


CONTROL RM. MON. & CONTROL CHASSIS — INSIDE VIEW
FIG. 10B



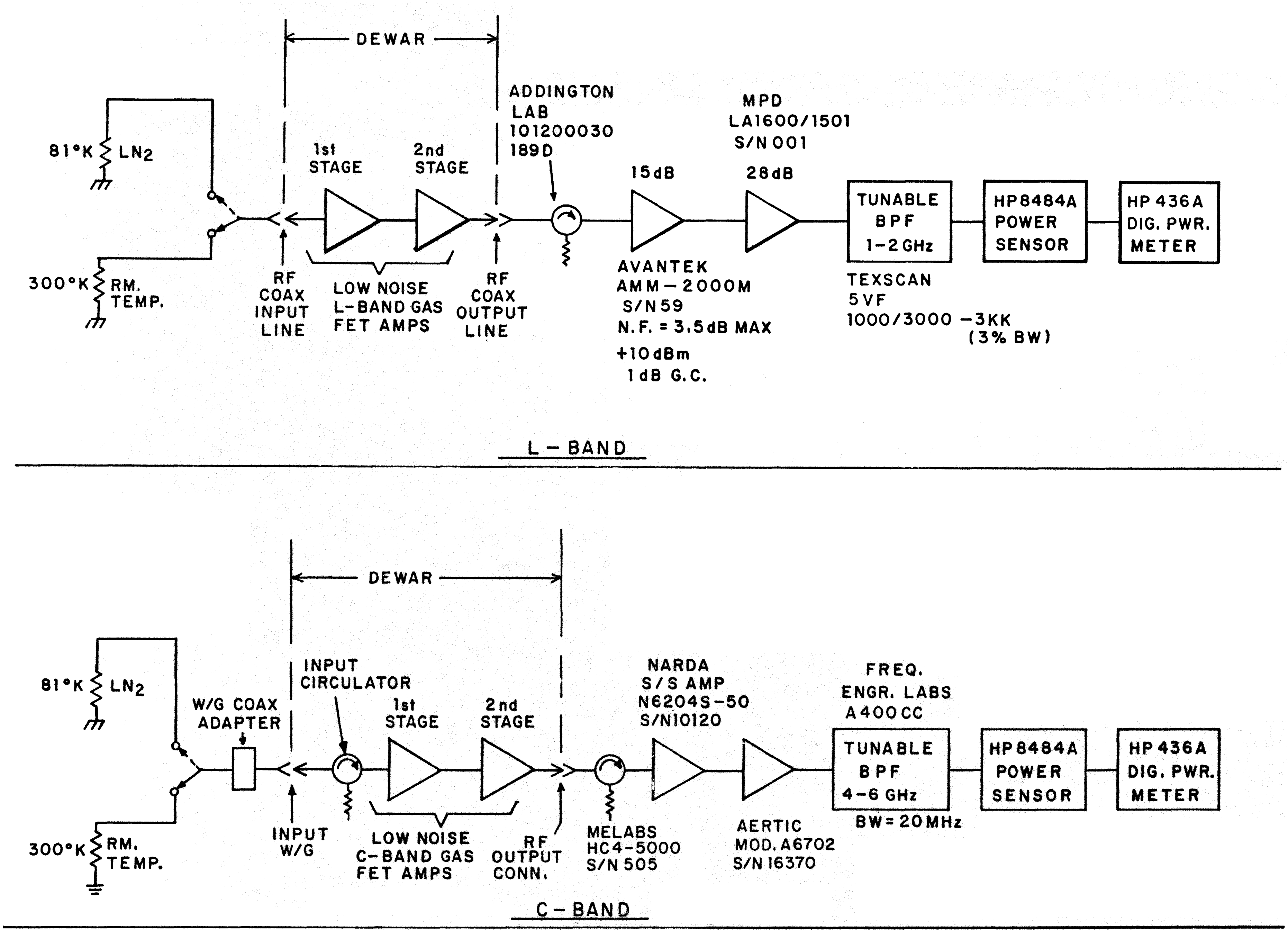
CONTROL ROOM MONITOR & CONTROL CHASSIS WIRING

FIG. 11



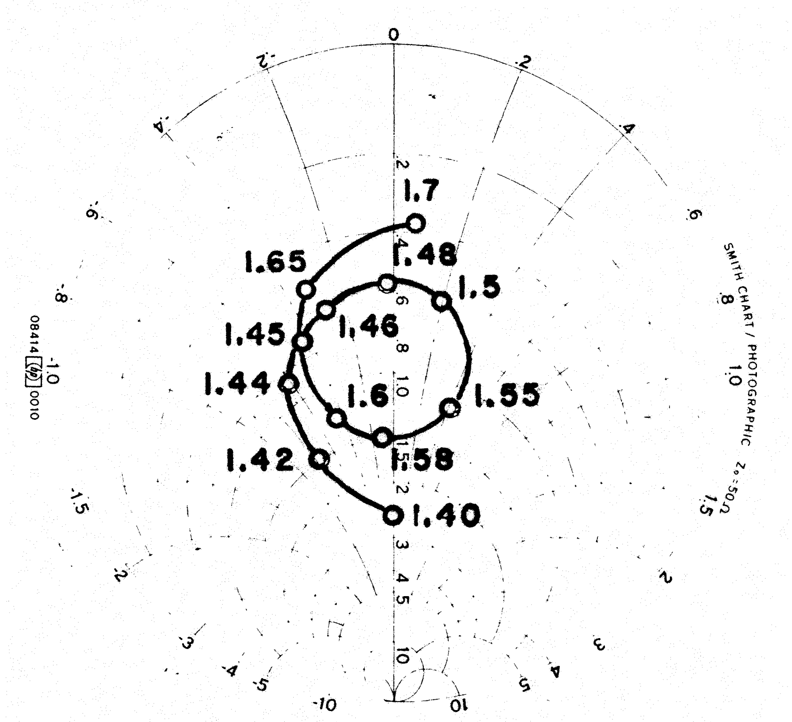
GAIN MEASUREMENT SET-UP

FIG. 12



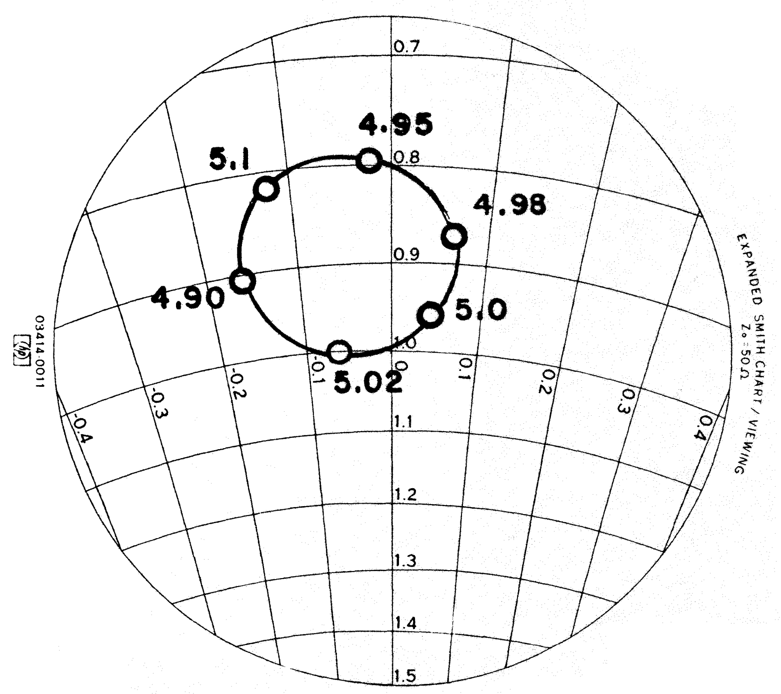
NOISE TEMPERATURE MEASUREMENT SET-UP

FIG. 13



Measured Input Impedance
Reference Plane at Dewar Input Connector

FIG.14A



C-BAND
12/24/80

Measured Input Impedance
Reference Plane at Waveguide/Coax
Dewar Input Transition

FIG. 14B

TABLE 4

Measured Noise Temperatures and Noise Source Calibration (°K)

(Measurements were made the week of January 12, 1981.)

Channel	Frequency (GHz)	Noise Temperature at Dewar Input	Noise Temperature with Input Transmission Line and Coupler	Noise Contribution due to Input Transmission Line and Coupler	Noise Temperature with Feed Assembly (Telescope at Zenith)	Antenna Temperature	Noise Source Calibration
L-Band	1.40	16	24	8	64	40	10.6
	1.45	15	24	9	75	51	10.7
	1.50	14	25	11	72	47	10.6
	1.55	13	21	8	79	58	10.7
	1.60	10	23	13	79	56	10.7
	1.65	12	23	11	66	43	10.9
	1.70	15	24	9	68	44	10.6
	1.75	13	24	11	63	39	10.0
	Ave.	13.5	23.5	10.0	70.8	47.3	
C-Band	4.90	25	33	8	60	27	14.8
	4.95	25	33	8	58	25	14.4
	5.00	26	33	7	56	23	14.2
	5.05	23	31	8	58	27	14.6
	5.10	25	31	6	61	30	14.4
	Ave.	24.8	32.2	7.4	58.6	26.4	