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22 - 24 GHz TUNABLE
SPECTRAL LINE RECEIVER

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CABLE RECORD

1. INTRODUCTION

Predictions and actual detections of a number of molecules by means of their often fairly weak spectral line emissions in K-band (18 to 26 GHz) have created a need for a receiver that exhibits a lower noise figure than existing mixer receivers can yield ($T_{SSB} \sim 2500$ °K). The development of the uncooled paramp receiver described in this report lowered the noise substantially ($T_{SSB} < 640$ °K). Masers [1] or cooled paramp receivers [2, 3], which can give even better noise performance, could not be considered because of the limitations of the present NRAO 36-foot front-end boxes in regard to size and weight.

In addition to the demand for a low noise temperature, a wide tuning range is highly desirable in order to observe as many spectral lines as possible using a single receiver. Furthermore, a wide instantaneous bandwidth $B_{3\ dB} \geq 40$ MHz) is needed which yields a small baseline slope; a flat baseline is very important for wide-band line searches and investigations of side-bands and fine structures of relatively wide lines.

The user of such a system requires in addition that the receiver can be tuned and phase locked remotely by adjusting a minimum number of controls in a stable, simple and reproducible way.

Some of the above-mentioned requirements are contradictory: for example, a wide electronic tuning range means automatically a deterioration of the instantaneous bandwidth and an increase of the noise temperature.

The optimization process of the paramp receiver described below resulted in the following performance characteristics:

1. Tuning range from 22 to 24 GHz.
2. Instantaneous bandwidth of more than 65 MHz (3 dB points).
3. Single-side-band noise temperature of less than 640 °K.

2. GENERAL DESIGN CRITERIA AND FUNCTIONAL DESCRIPTION OF THE SYSTEM

The widest instantaneous bandwidth and the lowest noise figure can be acheived in a system with an optimally pumped amplifier. However, such a receiver would have to be fixed tuned and could cover only a fraction of the frequency range, which a tunable version can be tuned through. For example, an instantaneous bandwidth of 500 to 600 MHz for 20 dB detector-measured gain can be achieved with a single tuned degenerate paramp in K band. On the other side, tuning over an octave of frequency is possible if mechanical and electronic adjustments on the amplifier are feasible [3]. If only bias voltage, pump-power and frequency are the variable parameters, the tuning range will shrink to 10 to 15% - as we shall see later on - and the noise will increase by about 80%. Yet one can cover 3 to 4 times more frequency range than is possible with a fixed tuned version.

Another question of importance is whether a nondegenerate amplifier would offer advantages over a degenerate one. Theoretically, a fixed tuned nondegenerate version would be advantageous in regard to bandwidth and noise temperature, provided the ratio of idling to signal frequency is higher than 4, i.e., if the pump frequency is higher than 100 GHz. Even then, the improvement in noise performance is only in the order of percents and is not worthwhile in the view of greatly increased cost and reduced reliability.

The synchronous operation of pump and LO source is known to half the noise temperature of a receiver if used for detecting broad band (continuum) signals, which cover both the signal and the idling bands [4]. In our case, where narrow band lines have to be detected, the signal can be only in one side-band, that is, either in the idling or in the signal band; this operation resembles somewhat the single side-band mode of a simple unenhanced mixer. The advantage of this mode in our receiver lies in the fact that the second stage mixer contribution to the system noise is reduced by an additional factor 4 as compared to the free running case.

On the other hand, going from the free running to the synchronous mode means that the gain of the paramp can be reduced and the bandwidth accordingly increased, when keeping the second stage contribution constant. The additional reduction of second stage noise contribution is important for the receiver reported here, for the following reason: It uses only one single low-noise preamplifier, and the second stage consists of a mixer with a comparatively much higher noise figure. ($T \overset{-}{>} 1800$ °K DSB for the mixer including switch, isolator and low pass). The gain of the preamplifier is limited because of stability requirements and the need for a wide bandwidth in order to obtain a good baseline for wide-band filter receivers. The voltage-gain bandwidth product is therefore rather important and it becomes obvious that the concept of this receiver constitutes a compromise between wide tuning range, low noise temperature and wide instantaneous bandwidth.

Figure 1 shows the block diagram of the front-end of the receiver. The signal path consists of the reference and the main horn where the cal signal is injected. The front-end switch can be used for beam or load switching. The parametric amplifier is connected to it and is followed by a balanced mixer and IF amplifier. This IF amplifier is wide-band, however, only a small portion of its bandwidth (12 to 40 MHz) around 50 MHz is used because of the limitations of the bandwidth of the paramp and available filter receivers. A wide-band tunable Klystron serves as pump and LO source. It drives a solid state doubler which in turn supplies the pump power for the degenerate parametric amplifier. A current controlled phase shifter in the LO line allows to align the phase of the LO with the phase of the pump, which is required for the "synchronous pumping" operation. Locking of the Klystron to a 2 GHz source is done by means of a harmonic mixer and a phase lock system with an IF frequency around 400 MHz. This frequency is compared in phase with a standard 400 MHz source; the phase detected voltage is used to lock the Klystron via its reflector. Details of this phase lock system can be found in reference [4]. A leveling loop helps to stabilize the paramp gain. For this purpose the detected pump current in the varactor is amplified and fed back to control the pump attenuator (#13 in Fig. 1). The wavemeter (#20 in Fig. 1) and the tuner of the klystron (#28 in Fig. 1) can remotely be tuned with the help of servo motors.

The front end is packaged in a standard 36 ft. box (14" x 14" x 60") as shown in the photographs (Fig. 2) and weighs approximately 110 pounds. Adapter boxes have made it possible to use the receiver on the NRAO 140 ft. telescope and the NRL 85 ft. telescope.

The photograph in Fig. 3 shows the control rack with its remote controls and power supplies. These controls enable the observer to tune the receiver in a few minutes from one frequency to another. A more detailed tuning procedure is given in section 6.1.

Another Klystron, which stays with the system, allows use of the receiver between 18 and 22 GHz with reduced sensitivity. In this range one has to bypass the parametric amplifier as indicated by the dashed line in Fig. 1. That means that the full IF bandwidth of the mixer preamplifier (approx. 260 MHz) can be used, which is of advantage for continuum observations. However, the noise temperature of the system for line observations increases approximately four fold.

3. DESCRIPTION OF INDIVIDUAL RF COMPONENTS (F. E. BOX) (Numbers Refer To Block Diagram In Fig. 1 and Table 1 on page 35)

3.1 Feed Horns:

Two fairly identical pyramidical horns (for linear polarization measurements) are used on the 36 foot telescope; they were built by NRL and exhibit an edge taper of 9.5db ± 0.5db in the E and H planes at 22.2 GHz. The first side lobes in the E planes occur at an angle of approximately 66° away from the main beam. The side lobe level is down from the main beam by 16 db. A bent waveguide section for the offset horn provides a minimum beam separation of 40.5 mm (≃ 3 half-power beam widths (HPBW) at 23 GHz). A second assembly of two waveguide sections allows a spacing of 66 mm (≃ 5 HPBW's at 23 GHz). The latter assembly can be used to either produce a larger offset (up to 10 HPBW's) by means of several spacers or to make cross polarization measurements using a twisted waveguide section.

3.2 CAL Injection Coupler

A low-loss cross coupler (waveline, mod WL 870-20) is used to inject the calibration signal; it exhibits less than 0.06 db insertion loss. The measured coupling values are

20.0 db	at	22 GHz
20.2 db	at	24 GHz
21.3 db	at	26 GHz

The directivity is greater that 30 db across the 22 to 26 GHz frequency range.

3.3 Test-signal Injection Coupler

A 10 db directional coupler (HP, K 752 C), located close to the noise tube, is terminated at its decoupled port, when the receiver is operated. Its decoupled port can be used to inject a swept frequency signal in order to test the paramp response by monitoring at the detector output behind the paramp (#17 in Fig. 1) or to look at the overall response of the system at the output of the mixer pre-amp (#18 in Fig. 1). The loss between the decoupled port of this coupler and the port "S" of the front-end switch is 30.9 db across the 22-24 GHz range.

3.4 CAL Modulator

A voltage controlled attenuator (VCA), model E&M K120VAM, is driven by a circuit which is located behind the control panel (Fig. 18). The insertion loss for 0V drive voltage (corresponding to a coil current of 0 mA) is approx. 1.1 db; the drive voltage of 0.5 V (excluding the telescope cable contribution corresponds to a coil current of 50 mA and provides more than 20 db isolation across the frequency range 22 to 26 GHz. A switch on the control panel allows a choice of one of the three modulator modes: "Off", "Modulated", "On".

3.5 Noise Tube

Presently, an AIL noise tube (model 07053T) is used which has an excess noise ratio of 16.1 db (ΔT = 12 100 °K). The noise power output of the tube is attenuated down by approximately 23 db (cross coupler loss, insertion loss of VCA, loss of 10 db coupler, and connecting waveguide sections). The resulting "Cal" signal for spectral line observations, while modulating, is 60 °K ± 5 °K across the 18-24 GHz frequency range (Fig. 4). The drive current of 150 mA required to fire the tube is supplied by the noise tube power supply, which is mounted in the control rack. The tube can be fired by a switch on this supply or another switch on the control panel. Because of the limited life time of the tube it is recommended to turn it off, if the intervals between the "Cals" are more than half an hour. A resistor (R = 200 ohms) in series with the tube (located in a small blue box with

BNC-connectors close to the noise tube) is provided in order to reduce switching transients.

3.6 Front-End Switch

Either beam switching or load switching can be accomplished with the help of a switchable circulator (E&M, Mod. K102LTS S/N 101). A drive current of ± 1.1A is required to switch the amplifier between the main and the reference feed horn. The isolation of this switch is more than 20 db, the insertion loss less than 0.3 db in the "through" direction (main feed) and less than 0.4 db in the "reference" position. This difference in the two arms together with the loss of the waveguide sections connecting the reference feed with the switch result in an overall imbalance of approximately 0.15 db. The switch ratio can be as high as 100 Hz (with a relative rise time of less than 5%).

3.7 Four-port Circulator for Paramp

The four-port circulator (E&M, Mod. K102 LTDI, S/N1) is constructed in such a way that an isolator is formed, which lies in front of the section used for the paramp. The isolation from port 2 (amplifier) to port 1 (input) is more than 26 db, the insertion loss 1 to 2 less than 0.4 db and the insertion loss 2 to 3 is approximately 0.25 db over the frequency range 22 to 24 GHz. The VSWR at the input of the operating amplifier (for 18 db gain) is less than 1.25:1 over the entire frequency range.

3.8 Parametric Amplifier Mount

3.8.1 General Design Considerations

The mount of the degenerate parametric amplifier contains the varactor wafer, a modified Sharpless wafer with a Schottky Barrier junction; the latter one produces the negative impedance, which is needed for the amplification of the incoming signal. This gold-gallium arsenide Schottky Barrier junction was fabricated and mounted in the wafer diode by R. Mattauch, University of Virginia. The wafer diode was designed and fabricated at NRAO. This wafer is contacted on the one side by a block which contains a tapered transformer for the signal; the other side is contacted by another block which contains a tapered transformer for the signal. A rejection filter inserted between the diode and the signal block reduces the pump leakage by more than 20 db. Additional design considerations can be found in references [3] and [4].

3.8.2 Paramp Performance and Comparison With Theory. (Saturation, pump power, bandwidth, noise temperature)

The Schottky Barrier junctions used in the amplifier are naturally very sensitive to power. The 1 db gain-compression occurs for an output power level of approximately -18 dBm to -29 dBm depending on the signal frequency as shown in Fig. 6.

The pump power P_P required to drive the described degenerate parametric amplifier can be approximated by

$$P_P = \frac{8\, V^2\, f_s^{\,2}}{R_S\, f_c^{\,2}} \; . \tag{3.1}$$

It is proportinate to the squared ratio $\frac{f_s}{f_c}$ of signal to cutoff frequency. The amplitude V of the pump drive voltage for the voltage-pumping case and the resistance R_S of the varactor are also determining factors. The expected minimum pump power at the lowest signal frequency (22 GHz) for relatively light pumping should accordingly be around

$$P \simeq 1.3 \text{ m W}$$

The varactor exhibits a higher cutoff frequency at the high end of the tuning range (24 GHz) since the applied bias voltage is here higher than at 22 GHz. This tends to decrease the pump power towards increasing signal frequency. The midband-frequency of the fixed tuned pump circuit has been set below 23 GHz. This has been done in order to achieve a wide electronic tuning range, without deteriorating the noise figure and the instantaneous bandwidth too much, and in order to stay within the output power limits of the doubler, which is supplying the pump power. This fact together with the need for an increase in pump voltage at the upper end of the signal tuning range increases the required pump power at 24 GHz significantly as can be seen in Fig. 6.

The bandwidth for a degenerate amplifier can be derived by considering a negative impedance which appears in both the idling and the signal bands. The bandwidth B can be expressed in terms of the power gain G_c, the RF midband frequency f_o and the elastance modulation factor

$$\gamma = \frac{S_1}{2\,S_m} \qquad (3.2)$$

where S_m and S_1 are the Fourier coefficients of the pumped elastance $S = \frac{1}{C}$. The voltage-gain bandwidth product is given by

$$\sqrt{G_C}\,B = \gamma\, f_o \qquad (3.3)$$

The gain G_C is here defined as the power gain, measured with a crystal detector. The gain G_C should not be confused with the gain G_1 used to calculate the second stage noise contribution in a synchronously pumped amplifier. The bandwidth B includes both the signal and the idling bands. Equation (3.3) suggests an upper limit for the bandwidth.

$$B = 253 \text{ MHz}$$

at 23 GHz with $\gamma = 0.11$ and a gain $G_C = 20$ db. Fig. 5 shows that the actually measured bandwidth is slightly less than 240 MHz at 23 GHz. The roll-off towards lower and higher frequencies is due to the signal circuit bandwidth limitations.

The noise figure of a degenerate amplifier can be characterized by the double-sideband noise temperature.

$$T = T_o \left(\frac{f_1}{\gamma f_c} + \left(\frac{f_1}{\gamma f_c}\right)^2\right) \qquad (3.4)$$

where T_o is the physical temperature of the mount.

An important parameter in this equation is the cutoff frequency

$$f_c = \frac{1}{2\pi\gamma C_m r} \qquad (3.5)$$

It is dependent on:

a) the resistance r, which represents loss in the semiconductor, the ohmic contact and the whisker

b) the average value C_m of the pumped junction capacitance. The cutoff frequency of our varactor, which has been measured by means of various RF methods, lies around 600 GHz at a reverse bias voltage of 1V. The varactor is not fully pumped (elastance modulation factor $\gamma \simeq 0.11$) in order to achieve the wide electronic tuning range. Equation (3.4) would predict a double-sideband noise temperature.

$$T_{DSB} = 141\ ^\circ K$$

for the mount only at a signal frequency $f_1 = 23$ GHz. The experimental value ($T_{SDB} = 152\ ^\circ K$) which has been extrapolated out of system noise measurements (Fig. 4) agrees reasonably well with it. The noise budget at 23 GHz is shown for the complete receiver in Table 2;

TABLE 2

Noise Budget of the Receiver at 23 GHz

Contribution of the Second Stage for a gain G_1 = 26 db (mixerpreamp, manual switch, isolator, low pass)	= 12 °K
Varactor Mount	= 304 °K
Circulator (2 paths)	= 88 °K
Front End Switch	= 71 °K
Calibration-Signal Coupler (including 2 inch long waveguide)	= 19 °K
SINGLE-SIDE-BAND NOISE TEMPERATURE (excluding feed and sky contributions)	= 494 °K

Recent tests of the receiver on the 85 ft telescope of NRL have shown that the gain stability is sufficient to operate the receiver for certain observing programs in the total power mode. This means that the front-end switch could be removed and the receiver noise temperature would then be lowered by approximately 17%.

The use of a fully pumped varactor in a fixed tuned amplifier will reduce the noise temperature of the varactor mount by more than an additional factor 2. The reduction of the overall system noise temperature should accordingly be around 80%.

3.8.3 Testing of the Varactor Used in the Parametric Amplifier

The wafer diode used in the amplifier mount was briefly described in Section 3.8.1. It should not be taken out of the mount unless the tests outlined below have clearly proven that the diode itself is responsible for the failure or abnormal behavior of the amplifier. Otherwise a permanent damage of the unencapsilated diode or the various amplifier circuits might result. Also, it is unlikely that a failure will happen, since the diode and the mount have been tested extensively by means of mechanical and electrical shocks. The most vulnerable regions are:

a) The waveguide input ports for pump and signal frequencies. Do not blow air into them or try to remove dirt from these ports by reaching into them with tools!

b) The bias port (OSM connector). The extremely small junction capacitance and the associated burnout danger make special precautions necessary.

Testing of the diode should therefore be done in the following order:

α) Switch the ferrite front end switch into "Signal" position and turn the manual switch in such a way that the amplifier is connected with the HP crystal detector.

β) Connect a leveled K-band sweeper with the decoupled arm of the 10 db coupler (HP) in the noise injection line. The power level at this point should be approx. -25 dB_m, when setting the gain to $G_o = 20$ db. This corresponds to a midband dc - voltage of 400 μV at the Hp detector (#17 in Fig. 2).

γ) Set the pump attenuator counter clockwise to "0" and increase the signal level from -25 to -5 dB_m. Now, the response of the unpumped amplifier should be visible on the oscilloscope which is connected with the detector. One should see an expressed absorption (6 to 8 db). The center frequency of this absorption should lie between 22 and 24 GHz, depending on the varactor bias voltage. If this absorption is visible but cannot be influenced by the varactor bias dial on the control panel, check the bias supply and/or connections to the control panel and the varactor bias port, because the mount is most likely not the reason for this failure. If there is no absorption visible, however, and the detected voltage on the HP crystal detector is approximately 200 μV, go to Step δ.

δ) Connect a short cable with a BNC connector on the one end and an OSM connector on the other end to the "Varactor Bias Box", which will stay with receiver. Set the Dial to 0 Volt, the current range switch to 0.1 μA and the power switch to "On". Discharge the cable by briefly shorting it at its open end and connect it with the bias port of the paramp mount. Do not use a DVM for any tests of the diode!

ε) Check the I-V curve in the 1 μA and 10 μA current range while setting the polarity switch into the "FORWARD" (negative) position. A fairly good agreement with the I-V curve in Fig. (3.4) should be found, if the diode is in tact. Do not drive the diode beyond a reverse current $I_D = 0.01\ \mu A$, which corresponds to a reverse voltage $V_D \sim 4V$; otherwise a permanent damage of the diode will result.

ζ) A damage to the diode has occurred if this test reveals an open circuit; it is likely that the diode has been burned out. A thermal or pulse overloading condition might have existed if the I-V curve has changed considerably, that is, if the forward resistance is higher and/or the reverse leakage has increased. In the burnout case it may be necessary to replace the whiskers. In the case of a higher forward resistance and/or a higher reverse leakage, a resetting of the whisker may cure the problem. (In either case a retuning of the whole amplifier may be necessary in order to obtain the original performance characteristics.)

3.9 Pump Isolator

A faraday rotation isolator (TRG Mod. U112/18) is used for matching the pump port. It exhibits more than 16 db isolation and less than 0.5 db insertion loss across the pump frequency range 44 to 48 GHz.

3.10 Pump Monitor Coupler

A 22 db cross coupler (TRG Mod. U565/10) allows monitoring of pump power. Its directivity is more than 15 db and the VSWR less than 1.08:1 across the 44 to 48 GHz range. Its decoupled port must be terminated in the usual operation of the receiver.

3.11 Pump-Line Filter

A waffle iron low pass filter, which was designed and built at NRAO, rejects third and higher order harmonics coming out of the doubler output. It exhibits less than 1 db insertion loss within the 44 to 48 GHz frequency range; the stop band rejection is more than 35 db from 61 to at least 96 GHz.

3.12 Doubler

A varactor doubler (Sylvania SYG 2045) is used to obtain the pump power by doubling the LO frequency. Its output power varies between 15 and 40 mW for an input power of 400 mW assuming that the bias voltage dial on the control panel (V_{MU}) is set to 0 divisions corresponding to an actual bias voltage of 1.26 V. The bias circuit shown in Fig. 4.4 is located in a blue box close to the harmonic mixer in the front-end box. Its output voltage can be varied between 1.26 V and 5.16 V by means of a ten-turn potentiometer on the control panel, which is labelled "V_{MU}". It should generally be set to "0" divisions; however, it may be detuned in order to eliminate slight parametric oscillations of the doubler, which have been observed occasionally. Protection against overloading, transients and false bias polarity is provided by a series resistor (1.5 KΩ) and a Zener diode (12V) at the bias terminals.

3.13 Pump Attenuator

A voltage controlled attenuator (E&M, K 120 VAM S/N 105) is used to control the drive power of the doubler, which in turn controls the pump power.

The insertion loss of the VCA for 0 current is approximately 1 db. More than 20 db insertion loss are inserted when the drive current, supplied by the level circuit (Fig. 8) located in a box underneath the terminal strip in the front end box, is at its maximum value of 150 mA. This attenuator is controlled by a ten-turn potentiometer labelled "pump attenuator". The relative pump power, as measured by the current through this attenuator is displayed by the meter labelled "pump power" at the control panel.

3.14 Pump Rejection Filter

A low pass filter (HP, K362A S/N 603) between the pump rejection filter and the mixer helps to improve the match and reject LO leakage. It exhibits more than 25 db isolation and less than 0.7 db insertion loss across the 22 to 24 GHz frequency range.

3.16-17 Signal Monitor Switch and Detector

A 4-port (double pole double throw) switch (Waveline 878 H) allows to:

a. Monitor the response of the parametric amplifier at a detector (HP, K422A) while injecting a swept frequency signal into the injection coupler. (#3 in Fig. 1).

b. To bypass the parametric amplifier by connecting a composite waveguide section with the switch port, which is normally terminated, and the output port of the front end switch (Port "A" of #6 in Fig. 1). This bend together with a servo mounted Klystron for the 18 to 22 GHz range (OKI 20 V10) allows the use of the receiver over the entire waveguide band 18 to 26 GHz as will be explained later on.

3.18 Mixer Preamplifier

The mixer preamp used in the system (Aerojet General, Mod 02 S/N 4), exhibits a double sideband noise temperature of less than 1500°K across the 18 to 26 GHz when driven with approximately 2 mW LO power. The IF amplifier has been modified to cover the if frequency range from 10 to 277 MHz (3 db points). Its schematic is shown in Fig. 10. The LO power should be adjusted by means o the LO attenuator so that the "mixer current" meter shows a deflection of approx. 20 divisions.

3.19 LO Phaseshifter

A ferrite phase shifter (Baytron, 2K-40 S/N 23 GHz) produces the phaseshift in the LO line, which is required in order to obtain the synchronous operation of the degenerate parametric amplifier. Since the phase-shift in the pump-and LO lines are varying differently across the 22 to 24 GHz range, the amount of phase shift produced by the variable phase shifter has to be adjusted, too. More than 180° phaseshift can be obtained by changing the coil drive current (through the center conductors of the two OSM connectors) from "0" to 250 mA. This current can be varied by a ten turn potentiometer located on the front panel, which controls the drive circuit (Fig. 11) located in a blue box close to the harmonic mixer. The insertion loss of the phase shifter is less than 0.8 db.

3.20 Frequency Meter

A wavemeter (HP, K532A S/N 765) allows to measure the LO frequency by observing the absorption dip on the "mixer current" monitors of the control panel (I_1 and I_2). The accuracy of this meter has been tested by means of a phase lock system and turned out to be within 10 MHz of its reading. An attached servomotor and 10 turn potentiometer facilitate the remote control of this meter from the control panel. The servo amplifiers for this wavemeter and the klystron tuner are located in a box underneath the terminal strip in the front-end box. Figures 12 to 15 show details of these circuits.

3.21 LO Attenuator

A ferrite attenuator (E&M, K126, VAM S/N 101) controls the LO drive power. A drive circuit (Fig. 11, located in a blue box close to the harmonic mixer) in conjunction with a ten turn potentiometer labeled "LO Attenuator" on the control panel, controls the mixer drive power. The setting of this dial to "0" corresponds to 0 mA current through the attenuator coil or 1 db insertion loss. The maximum setting (10 divisions) corresponds to a coil current of 78 mA or more than 20 db insertion loss.

3.22 LO Coupler

A cross coupler (Waveline 870 - 20 DB) is used to decouple the required LO power. This 20 db coupler has been modified in order to obtain a coupling value of 17 db. The directivity is still more than 30 db across the full waveguide band and the insertion loss is less than 0.2 db.

3.23 Harmonic Mixer Coupler

The power needed to drive the harmonic mixer (phase lock loop) is decoupled from the main line by means of a 20 db cross coupler (Waveline 870 - 20 DB).

3.24-25-26 Harmonic Mixer Line

A pad (NRAO, 30 db insertion loss, #24 in Fig. 1) and an isolator (Sperry, D 41K5) are used for setting the level for the power entering the harmonic mixer (Tektronix, 119-0098-00).

3.27 Klystron Isolator

A low loss isolator (E&M, K102 LTI S/N 102) is used to provide a good match for the Klystron. It exhibits 0.3 db loss and more than 27 db isolation across the 22-24 GHz frequency range. Across the wider frequency range 18 to 26 GHz its isolation is more than 10 db and its insertion loss less than 0.7 db.

3.28 Klystrons

The Klystron used for the paramp system (OKI 24V11, S/N653) is equipped with a servo motor and a ten turn potentiometer; it can be tuned remotely by a ten turn potentiometer, which is located on the control panel and labeled "Klystron Tune". Its servo amplifier circuits (Fig. 12, 13), are located in the same box as the wavemeter circuits underneath the terminal strip of the front-end box. This Klystron is cooled by a fan and gets its beam voltage and current (1800V, 35 mA) from a supply (Power Design, Mod HV1547) in the control rack. The grid voltage (∿60V) is derived from the reflector voltage in a circuit box, called "OKI adapter", which is attached to the back of the beam supply. The potentiometer should be adjusted so that the beam current is 30 mA. The filament voltage (6.3V) is supplied by the phase lock box. For details on the phaselock loop, consult the Electronics Division Internal Report No. 97 by S. Weinreb [5].

For the operation of the receiver between 18 and 22 GHz (use of the mixer portion only, without the paramp) one can install a motorized Klystron which covers this range (OKI, 20V10). It requires a beam voltage of 2000V and a beam current of 12 mA; its reflector voltage lies between 190 and 440 volts. A separate protection card is provided for it behind the control panel; it should be replaced by the one provided for klystron 24V11, when exchanging the klystrons.

4. CIRCUITRY

4.1 Paramp Bias, Pump Level and Mixer Circuits

The circuits for

a. monitoring and biasing the parametric amplifier diode,

b. leveling and monitoring the pump power, and

c. monitoring the crystal currents of the mixer

are located in a flat box underneath the terminal strip of the front end box. The schematics of these circuits are shown in Figures 8 and 9. Never disconnect the cable leading to the varactor mount or the pump attenuator while the Klystron is operating, since too much pump power could be applied to the diode and burn it out. The schematic of the modified IF amplifier in the Aerojet mixer preamp is shown in Fig. 10.

4.2 Doubler Bias, LO Attenuator Drive, Phase Shifter Drive-Circuit

Fig. 11 is a schematic of the circuits, which drive and bias the doubler, LO Attenuator and phase shifter; they are located in a blue box in the front-end box, close to the harmonic mixer. These circuits are remotely adjustable from the control panel by means of ten turn potentiometers.

4.3 Servo Circuits (for Wavemeter and Klystron)

A flat box underneath the terminal strip of the front-end box contains the servo amplifiers (Fig. 12) for the wavemeter and Klystron drive motors. Fig. 13 shows the connections between the motors, and the amplifiers; indicated also are the connections with the terminal strip in the front end box and the remote adjust potentiometers and protection circuits behind the control panel (Figures 14 and 15).

4.4 OKI Adapter

The grid voltage for the Klystrons is derived from the reflector voltage; these divider circuits are located in a box attached to the back of the beam supply. A potentiometer with an HV-insulated shaft allows to adjust it from -35 to -120V in order to accommodate the various Klystrons (Fig. 16). Attention: Do Not Open This Box While Operating the Beam Supply Since Lethal Voltages Exist In It.

4.5 Control Rack and Its Wiring

All the wiring of the control panel which connects to the 15-twisted-pair telescope cable is shown in Fig. 17. Details of the control and drive circuit for the cal modulator (#4 in Fig. 1), which is located in a blue box behind the control panel, are shown in Fig. 18. In the "Modulated" position of the cal control switch an external signal coming from the computer may modulate the switch with a frequency up to 50 Hz. The interconnections of the servo controls (wavemeter and Klystron) with the 30-conductor cable are given in Fig. 14. The schematic of the noise tube power supply and its connections with the remote firing control and current monitor on the control panel are given in Fig. 19. Figures 20 and 21 show details of the dc power supplies on the bottom of the control rack and the wiring of the main ac power for the control rack. The records of the three telescope cables (pages 32 to 34) are provided for ease of trouble shooting.

4.6 Phase Lock Loop

The same phase lock loop system as built into the NRAO 3 mm line receiver is used in this receiver; it was designed by S. Weinreb and is described in the Electronics Division Internal Report No. 97 [5].

It consists of two units: One unit is located in the front end box underneath the terminal ship. It contains the reflector amplifier, the klystron filament supply and most of the IF components. The second unit is located in the control rack and contains the remote controls and the separate low voltage supplies for the phase lock system.

5. SUMMARY OF IMPORTANT ELECTRICAL SPECIFICATIONS AND MEASUREMENTS OF THE SYSTEM

5.1 Important Electrical Specifications

TUNING RANGE:		22 to 24 GHz
NOISE TEMPERATURE (SSB)		$T_{SSB} < 640°K$
22 GHz: 595°K		
23 GHz: 550°K		
24 GHz: 640°K		
(G_c = 20 db)		
INSTANTANEOUS BANDWIDTH		$B \gtrsim 110$ MHz
(For both sidebands and a crystal detector gain of G_c = 20 db between circulator input and mixer input)		
INTERMEDIATE FREQUENCY		30 to 70 MHz
SWITCHING MODES:		
a) Beam Switching:		
Speed		$f \lesssim 50$ Hz
Beam Separation:		
Linear-Linear	36 ft, 140 ft telescope	$\Delta \gtrsim 3$ HPBW
Ortho-Linear		$\Delta \gtrsim 5$ HPBW
b) Load Switching		
Speed		$f \lesssim 50$ Hz
Temperature of Load		T = 300°K (AMB.)
TEMPERATURE STABILITY (Total Power Change/Temp. Change)		$K \leqq 0.1$ db/°C

5.2 LABORATORY MEASUREMENTS ON MAY 23, 1971

LO FREQUENCY			PARAMP AND DOUBLER							PHASE LOCK LOOP (16)						KLYSTRON (14)		MIXER		NOISE (15)
$f_{1.LO}$																				
TRUE GHZ (1)	MEAS. DIV. (2)	MEAS. GHZ (3)	G_0 dB (4)	B MHZ (5)	V_{VAR} DIV. (6)	I_{VAR} μA (7)	I_P DIV. (8)	L_P DIV. (9)	V_{MU} DIV. (10)	$f_{2LEV.}$ DIV. (11)	f_1 MHZ (12)	HARM. MIXER CURR. DIV.	IF LEVEL DIV.	CORR. VOLT DIV.	SYNTH MHZ (13)	V_{REFL} V	KLY. TUNE DIV.	I_1 DIV.	I_2 DIV.	T_{DSB} °K (17)
22.000	2.71	21.992	18	150	0.18	0.16	74	1.98	3.46	44	1963.636	28	87	28	98.1818	336	1.42	18	19	283
"	"	"	15	188	"	0.048	72	1.54	"	44	"	"	"	"	"	"	"	"	"	301
22.200	3.23	22.198	18	152	0.40	0.18	70	2.10	"	50	1981.818	30	89	"	99.0909	354	1.66	22	21	279
"	"	"	15	210	"	0.048	"	1.60	"	50	"	"	"	"	"	"	"	"	"	297
22.400	3.69	22.393	18	160	0.85	0.076	63	1.49	0	50	1999.999	"	88	"	99.9999	366	1.90	"	"	275
"	"	"	15	218	"	0.024	"	1.36	0	50	"	"	"	"	"	"	"	"	"	283
22.600	4.13	22.592	18	168	1.29	0.2	64	2.15	0	45	1916.666	24	96	"	96.8333	367	2.10	22	22	264
"	"	"	15	240	"	0.042	63	1.51	0	45	"	"	"	"	"	"	"	"	"	279
22.800	4.55	22.792	18	210	1.89	0.45	"	3.20	0	46	1933.33	33	97	29	96.6666	390	2.28	18	15	261
"	"	"	15	290	"	0.072	"	1.68	0	46	"	"	"	"	"	"	"	"	"	269
23.000	4.97	22.993	18	240	2.82	0.54	60	3.54	0	44	1949.989	31	96	28	97.48999	405	2.55	26	23	249
"	"	"	15	320	"	0.064	59	1.64	0	44	"	"	"	"	"	"	"	"	"	261
23.200	5.39	23.195	18	240	3.64	0.58	60	3.81	0	44	1966.666	32	95	"	98.3333	422	2.71	"	"	249
"	"	"	15	330	"	0.066	"	1.64	0	44	"	"	"	"	"	"	"	"	"	261
23.400	5.80	23.397	18	215	4.34	0.58	"	3.84	0	52	1916.667	39	87	"	95.8333	433	3.02	28	27	255
"	"	"	15	285	"	0.054	"	1.55	0	52	"	"	"	"	"	"	"	"	"	275
23.600	6.20	23.594	18	158	5.08	0.58	61	3.86	0	51	1933.333	31	75	"	96.6666	447	3.27	26	28	263
"	"	"	15	210	"	0.04	"	1.51	0	51	"	"	"	"	"	"	"	"	"	275
23.800	6.58	23.791	18	130	6.8	0.14	64	1.87	0	51	1949.999	44	90	29	97.4999	466	3.52	25	26	275
"	"	"	15	185	"	0.01	"	1.33	0	51	"	"	"	"	"	"	"	"	"	297
24.000	6.97	23.991	18	123	9.45	0.02	65	1.38	0	50	1966.666	41	88	28	98.3333	474	3.80	21	27	298
"	"	"	15	180	8.75	0.02	64	1.38	0	50	"	"	"	"	"	"	"	"	"	316

NOTES:

(1) Using Phase Lock System
(2) Servo Dial on Control Panel
(3) Reading of HP Meter HPK532A1745
(4) Power Gain from Input of Circ. to Input of Mixer
(5) Double Sideband (3 dB Points)
(6) V_{VAR} = Bias Volt. of Paramp (0 Div = 0.22V; 5 Div = 1.65V; 10 Div = 2.65V)
(7) I_{VAR} = Bias Curr. of Paramp
(8) Reading of "Pump Power" - Meter on Control Panel
(9) Pump Attenuator
(10) Doubler Bias Voltage
(11) 400-MHz Level (PLL)
(12) 2 GHz Frequency (PLL)
(13) $f_{1LO} = f_{SYNTH} \times 20 \times n \pm 400$ MHz; n = 11 or 12
(14) Klystron; OKI 24 V11/453, I_{BEAM} = 33.5 mA; V_{BEAM} = 1800V
(15) $T_{DSB} = \frac{\Delta T}{Y_s - 1} - T_1$; $\Delta T = 300^\circ K - T_1$; $T_1 = 92^\circ K$;
$T_1 = T_{C.L.} \cdot L + (L-1) \cdot T_0$; $T_0 = 300^\circ K$; $T_{C.L.} = 85^\circ K$ (NRAO #1)
(15) cont.
L = .13 dB (3" WG + M. Switch);
IF = 50 ± 10 MHz
(16) R = 3, C = 4 (PLL - Box)
(17) Front End Switch Curr = 1.3A

5.3 System Measurements on the 36-ft. Telescope

Fig. 22 shows the output of the spectral line processor (PROGRAM used at the 36-ft. telescope in connection with two filter receivers. Plotted is the averaged noise temperature per channel in millikelvin vs. the channel number. Channels 0-49 belong to the NRAO 50 Channel receiver with 250 KHz bandwidth per channel and an overall bandwidth of 12.5 MHz. Channels 50-89 represent the averaged outputs of the NRAO 40 Channel receiver, which has a bandwidth of 2 MHz per channel with an overall bandwidth of 40 MHz; it is in parallel to the 50 channel receiver, that is, the channels 24 and 69 represent approx. the same signal midband frequency (23.815 GHz) and/or image frequency (23.715 GHz). The peak to peak noise fluctuation is given by

$$\Delta T_{PP} = \frac{T_S \times 5 \times 2}{\sqrt{B \cdot \tau_{TOT}}} \tag{5.1}$$

where T_S is the single sideband noise temperature of the system. τ_{TOT} is the total integration time (including the "off" time) assuming the beam is switched and the source is in the main beam during the "on" time and in the reference beam during the "off" time. The factor 5 relates the "rout-mean square" - Δt to the "peak-to-peak" - Δt. The factor 2 takes care of the fact that only half of the total integration time is spent on the source (factor $\sqrt{2}$) and that the averaging in the program increases the ΔT_{pp} by another factor $\sqrt{2}$. The fluctuation ΔT_{pp} = 0.225°K displayed in the first 50 channels (B = 250 K Hz, τ_{TOT} = 50 MIN) indicates a single sideband noise temperature of 616°K. The fluctuation ΔT_{pp} = 0.070°K displayed in the channels 50 to 89 (B = 2 MHz, τ_{TOT} = 50 MIN) indicates a slightly lower noise of 542°K. This compares reasonably well with the temperature of 580°K measured in the laboratory (Fig. 4).

Fig. 23 gives a typical example for the actual use of the system. The channels 24 and 69 (f_s = 21.9817 GHz) show the line profiles of the transition $1_{01} - 0_{00}$ of Isocyanic acid (HNCO) detected in Sgr B2 with this receiver in June 1971 [6]. The noise calibration on the ordinate is again given in millikelvin. The continuum temperature of the source turns out to be 1°K, the antenna temperature of the line lies around 0.2°K. The noise fluctuation $\Delta T_{PP} \sim 0.12$°K of channels 0 to 49 seems to indicate a system noise temperature of only 420°K (B = 250 K Hz, τ_{TOT} = 80 MIN). The value ΔT_{PP} = 0.066°K of the channels 50 to 89 suggests a noise temperature of more than 650°K (3=2 MHz; τ_{TOT} = 80 MIN).

The laboratory measured value is 570°K (Fig. 4). The too high value of 670°K can be caused by gain shifts in the 40 channel receiver since the output is referred to a "cal" run at the beginning of the 80 minute long integration. That means some of the "lumps and bumps" in the channels 50 to 89 represent the base line of the 40 channel receiver. The too low value of ΔT_{PP} in channels 0 to 49 might be due to the uncertainty how and where to read the ΔT_{PP} on the plot. Again, the question, what is a base line effect and what is noise fluctuation, is difficult to answer. It is therefore concluded that a noise temperature measurement through the filter receivers is accurate to ±20% only if the integration time τ_{TOT} is less than 20 minutes. The planned use of the new NRAO program which refers the difference between signal and reference to the reference should alleviate these problems greatly and enable the observer to use the receiver for the detection of much weaker line temperatures by integrating over longer periods of time.

6. OPERATIONAL DESCRIPTION

6.1 Turn-On Procedure

A. Set: 1) Pump attenuator dial to "0"

2) Phase lock loop switch to "Open Loop"

3) Beam voltage supply to "0 Volts"

4) "High Voltage" switch of reflector supply to "Off" position

B. Turn on AC power on the bottom of the control rack.

C. Turn on "Main Power" (Below control panel)

D. Turn on "AC Power" of reflector supply

E. Turn on "High Voltage" of reflector supply as soon as "Stand-By" light is on

F. Switch on HV of beam supply

G. Increase beam voltage slowly to 1800V,
when operating between 22 and 24 GHz (OKI 24 V11) or 2000V when operating between 18 and 22 GHz (OKI 20 V10)

H. Set: 1) the reflector supply voltage
2) the (servo-controlled) klystron tuner
3) the (servo-controlled) wavemeter

to the values given in graph in Fig. 24 when operating between 22 and 24 GHz (OKI 24 V11) or graph in Fig. 26 when operating between 18 and 22 GHz (OKI 20 V10), for the desired 1.LO frequency (=Klystron Frequency)

$$f_{LINE} = f_{1.LO} \pm 50 \text{ MHz}$$

$$(f_{LINE} \text{ and } f_{1.LO} \text{ in MHz})$$

J. Check the beam current by pushing the current switch (should be 34 mA when operating between 22 and 24 GHz (OKI 24 V11) and 12 mA when operating between 18 and 22 GHz (OKI 20 V10), after the mixer current has been peaked by means of the reflector voltage). If the beam current is not within these limits, adjust it by means of the grid voltage (box in the back of the rack behind the beam supply).

6.2 LO Frequency Equation, Phase Lock Loop

(a) The equation for the line frequency f_{LINE} is given by

$$f_{LINE}/\mathrm{MHz} = f_{SYNT}/\mathrm{MHz} \times 20 \times n \overset{\swarrow +\mathrm{Lock}}{\underset{\nwarrow -\mathrm{Lock}}{\pm}} 400\ \mathrm{MHz} \overset{\swarrow \mathrm{USB}}{\underset{\nwarrow \mathrm{LSB}}{\pm}} 50\ \mathrm{MHz}$$

$$\left.\begin{array}{l} +\ \mathrm{LOCK}\ \&\ n = 11\ \mathrm{for}\ f_{LINE} < 22{,}560.0\ \mathrm{MHz} \\ \\ -\ \mathrm{LOCK}\ \&\ n = 12\ \mathrm{for}\ f_{LINE} > 22{,}560.0\ \mathrm{MHz} \end{array}\right\}\ \text{Preferred Locks}$$

when using the lockable 2 GHz sources (FAIRCHILD or MICROMEGA)

It is recommended to use the lower sideband (LSB) when approaching 22 GHz and to use the upper sideband (USB) when approaching 24 GHz.

(b) Lock 2 GHz - source to synthesizer, and check at its monitor jack for the correct lock point.

(c) Set frequency switch on PLL unit to "Signal", connect its monitor jack with the counter and adjust the frequency to 400.000 MHz. As next step connect this 400 MHz jack with the spectrum analyzer and observe it (with 10 MHz scanwidth and 1 MHz bandwidth).

(d) Observe the PLL IF at its monitor jack with the spectrum analyzer and adjust the frequency of the Klystron by means of the "Klystron Tuner" until it is 400 MHz. Peaking of the mixer current and a repeated readjustment of the Klystron tuner and the reflector voltage may be necessary. Double-check the frequency with the help of the wavemeter, the mixer current-dip and graph in Fig. 24.

(e) Check the meters:

- α) 400 MHz - level
- β) Harmonic mixer current
- γ) IF - level
- δ) Correction voltage

for the marked operating ranges and put the loop-switch into "Normal" position. The corresponding lock light should come on. If it does not come on, switch the reflector voltage back and forth by approx. ± 40V. This will usually cause locking. Now, adjust the reflector voltage so that the correction-voltage meter reads 28 divisions.

6.3 Paramp Adjustments

a) Set: 1) "Bias Voltage" dial (V_{VAR})

2) Doubler voltage dial (V_{MU})

to the values given in graph (Fig. 25).

b) Adjust the LO attenuator dial so that the current is within the marked range

c) Switch the varactor bias current meter to the correct range (according to the bias current curve I_{VAR} in graph in Fig. 25

d) Increase the pump power by turning the pump attenuator dial clockwise until the leveling loop locks, which can be seen as an abrupt change of pump monitor reading from "0" to approximately 60 divisions.

e) Adjust the pump attenuator so that the bias current meter reads the value of I_{VAR} given in graph in Fig. 25

f) Peak the total power by means of the phase shifter.

6.4 Turn Off Procedure

a) Reset pump attenuator dial to "0"

b) Open phase lock loop by putting loop switch on PLL - unit to "Open" loop position.

c) Reduce Klystron beam voltage slowly

d) Turn the high voltage switch of reflector supply to "Off" position

e) Turn the AC "Power" switch of reflector supply to "Off" position

f) Turn the "Main Power" switch (below control panel) to "Off" position

g) Turn the AC switch on the bottom of the control rack to "Off" position (downward).

6.5 Use of the Receiver Between 18 and 22 GHz

a) Replace the Klystron OKI 24 V11 by the Klystron OKI 20 V10. Remove straigth waveguide section between front-end switch and circulator and termination on the manual waveguide switch. Insert the complex waveguide section which by-passes the parametric amplifier.

b) Exchange the printed circuit cards provided for the limits of the servos of the Klystrons 20 V10 and 24 V11. (Marked cards located behind the control panel)

c) Set the potentiometer of the OKI adapter (on the back of the beam supply) clockwise to full scale.

d) Follow instructions 6.1 for turn-on procedures, 6.2 for Phase Lock Loop adjustments and 6.4 for the turn-off procedures.

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15 PAIR CABLE RECORD

General Location: Telescope Cable - 15 Pair
From : Front End
Connector : QWL 81-194236-10S
To : Control Room Rack

From Pin	Cond. Color	Tracer	To Pin*	Purpose	No. On Terminal Strip Of F. E. Box
A	Red	Blue		Varactor Bias Pot. Ct.	4
B	Yellow	"	B	" " " Ret.	2
C	Red	Purple	C	Pump Pot. Ct.	3
D	Yellow	"	D	" " Ret.	15
O	Red	Grey	O	Varactor Curr. Mon.	1
P	Yellow	"	P	Pump. Mon.	6
F	Red	Green	F	Doubler Bias Pot. Ct.	29
G	Yellow	"	G	Ret. for O, P. F	15
T	Red	Yellow	T	LO Attenuator Pot. Ct.	11
U	Yellow	"	U	" " " Ret.	12
K	Grey	No	K	Mixer Mon. 1	9
L	Yellow	"	L	Mixer Mon. 2	10
X	Blue	"	X	Phase Shifter Ct.	30
Y	Yellow	"	Y	" " Ret.	15
Z	Grey	"	Z	PLL Search	33
a	Red	"	a	PLL Harmonic Mixer Curr.	34
V	Red	"	V	PLL Quad. Phase	35
W	Yellow	"	W	PLL Correction Volt.	36
m	Red	Black	m	PLL 400 MHz Level	37
n	Yellow	"	n	PLL IF Ref.	38
b	Red	Orange	b	PLL 2 GHz Amp. Bias	39
c	Yellow	"	c	PLL 15V for Above	40
r	Red	Red	r	PLL Open Loop Relay	47
s	Yellow	"	s	PLL GND	46
t	Red	Brown	t	Front End Switch Ct.	
u	Yellow	"	u	" " " Ret.	
f	Blue	No	f	CAL Modulator Ct.	
g	Grey	"	g	" " Ret.	
h	Red	"	h	Spare	
j	Blue	"	j	Spare	
E,J,H,K,N	Shields		E,J,H,K,N		
R,Q,s,d,c,k	"		R,Q,s,d,c,k	Tied to F. E. Box GND	
x,y,p,g	"		x,y,p,g		

Notes: *Refer also to upper labels of terminal strip J_2 in back of control rack.

30 CONDUCTOR-CABLE RECORD

General Location: Telescope Cable - 30 Conductor
From : Front End
Connector : QWL 81-194228-15P
To : Control Room Rack

From Pin	Conductor Color	Purpose	No. On Terminal Strip of F. E. Box
A	Orange Purple	PLL +28V	41
B	Orange Blue	PLL +15V	43
C	Yellow White	PLL -14V	44
D	Yellow	Base Grid Return for Above	42,45,16
E	Red Purple	+28V (Other than PLL)	22
F	Red Blue	+15V (" " ")	13,14
G	Orange Green	-15V (" " ")	18,19,20
H	Yellow Black	Box GND, Return for E, F, G	15,16,17
J	Yellow Brown		
K	Black		
L	White Yellow		
M	Red Green	Thermistor (36 ft.)	48
N	Orange Yellow	" (" ")	49
P	Orange		
R	Brown		
S	Red	115V AC (Fan)	
T	Red Black	115V AC (Fan)	
U	Red Yellow	Servo Motor #1 (Klystron)	23
V	Red Brown	Servo Motor #1&2 (Common)	24
W	Orange Brown	Servo Motor #2 (Wavemeter)	25
X	Green	Servo F.B. Pot. CCW	26
Y	Orange White	Servo #2 INP	27
Z	Orange Black	Servo #1 INP	28
a	Blue	GND (Return for Above)	16,42,45
b	Purple		
c	Purple White		
d	Green White		
e	Green Black		
f	Green Brown		
g	Red White		
1	Shield	Shield	42,45,16

HIGH VOLTAGE CABLE RECORD

General Location: Telescope Cable - 8 Conductor
From : Front End
Connector : Bendix QWL 72-435449-70S

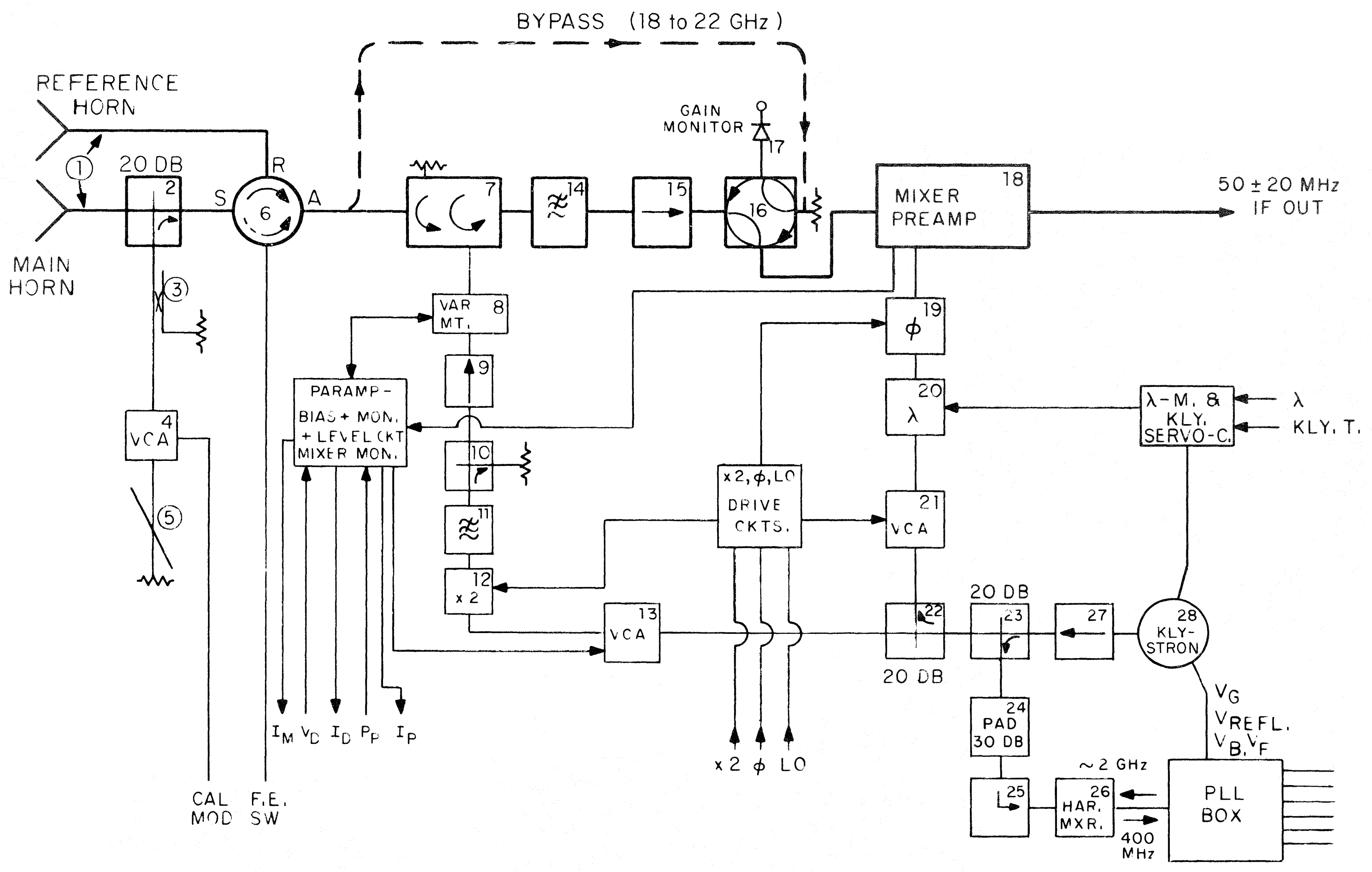
FROM PIN	CONDUCTOR COLOR	PURPOSE
1	Black	Klystron GND
2	Brown	Heater
3	Red	Cathode
4	Orange	Heater
5	Green	Reflector
6	Yellow	Grid
7	Blue	Noise Tube (Hot)
8	Violet	Noise Tube (Common)

NOTE: Cathode and Heater (Pins 1 and 2) not jumpered in this cable.

TABLE 1

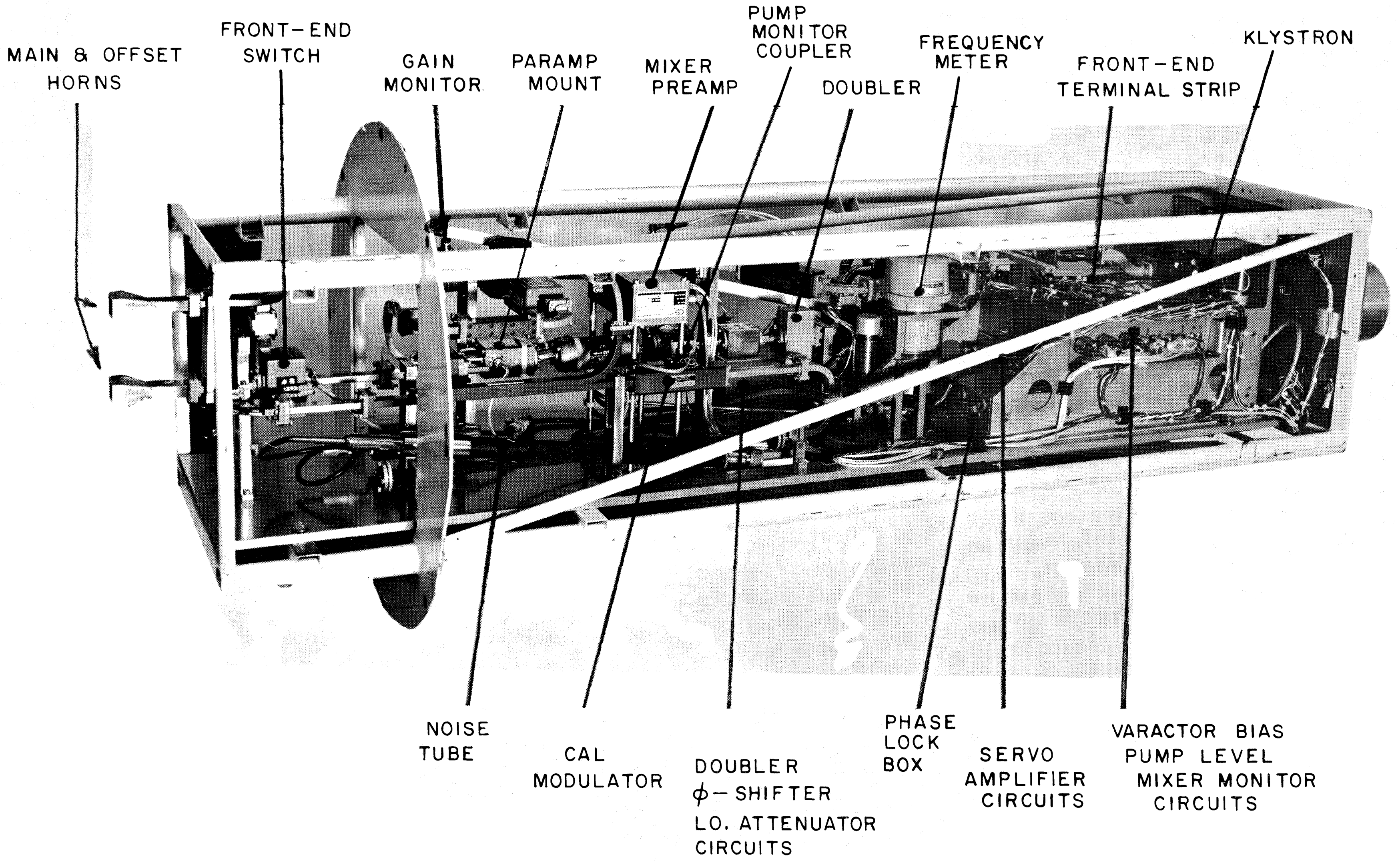
RF COMPONENTS IN 24 GHz RECEIVER: (Numbers refer to Fig. 1)

1 : 2 Horns (NRL) + Variable Spacers + Twist for Offset Beam
2 : Cross-Coupler, Waveline, 870-20 dB
3 : Directional Coupler 10 dB, Hp, K752 C
4 : Voltage Controlled Attenuator, E&M, K120 VAM
5 : Noise Tube, AIL, 07053T S/N 700
6 : Switchable Circulator, E&M, K102 LTS S/N 101
7 : 4 Port Circulator, E&M, K102, LTD I S/N 101
8 : Paramp Mount, NRAO, Diode C6
9 : Isolator, TRG, U112/18
10 : Cross-Coupler, TRG, U565/11
11 : Low Pass (Waffle Iron), NRAO, 33-50 GHz
12 : Doubler, Sylvania, SYG 2045
14 : Low Pass, HP, K 362A S/N 603
15, 25 : Isolator, Sperry, D41K5 S/N 148
13 : Voltage Controlled Pump Attenuator, E&M, K120 VAM S/N 105
16 : Manual WG-Switch, WL, 878 H
17 : Crystal Detector, HP, K422A
18 : Mixer Preamp, Aerojet General, M002 S/N 4
19 : Phase Shifter, Baytron, 2 K - 40 S/N 23 GHz
20 : Wavemeter, HP, K532A S/N 745
21 : Voltage-Controlled Attenuator (Mixer), E&M, K126 VAM, S/N 101
22 : Cross-Coupler, Wavel. 870-20 dB
23 : Cross-Coupler, " " "
24 : Pad NRAO (3 dB)
27 : Isolator, E&M, K102 LTI S/N 102
26 : Harmonic Mixer, Tektronix, 119-0093-00
28 : Klystron, OKI, 24 V11 S/N 653
or
Klystron, OKI, 20 V10 S/N 337



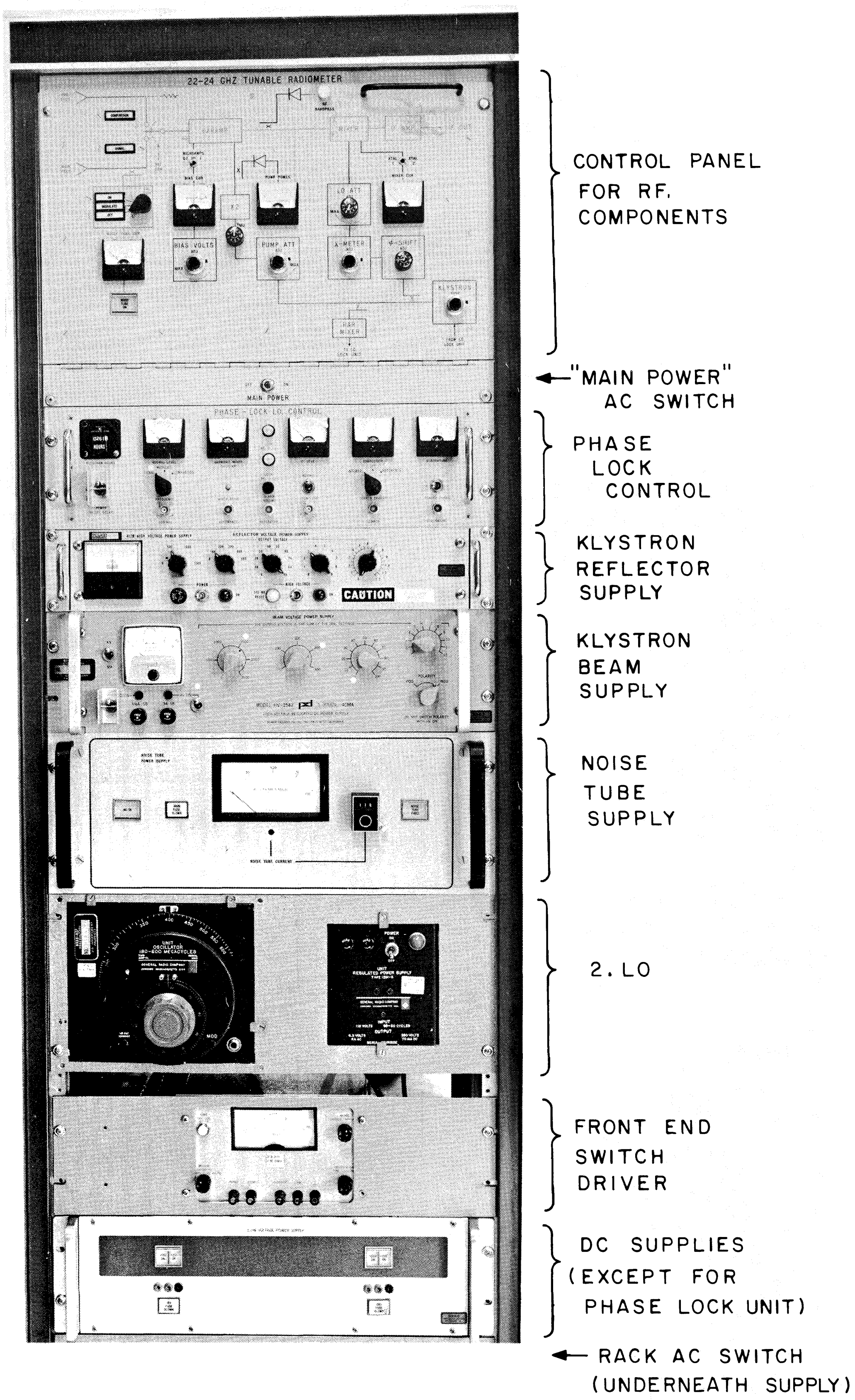
BLOCK DIAGRAM OF THE FRONT-END OF THE 22 TO 24 GHz RECEIVER
(NUMBERS REFER TO TABLE 1)

FIG. 1



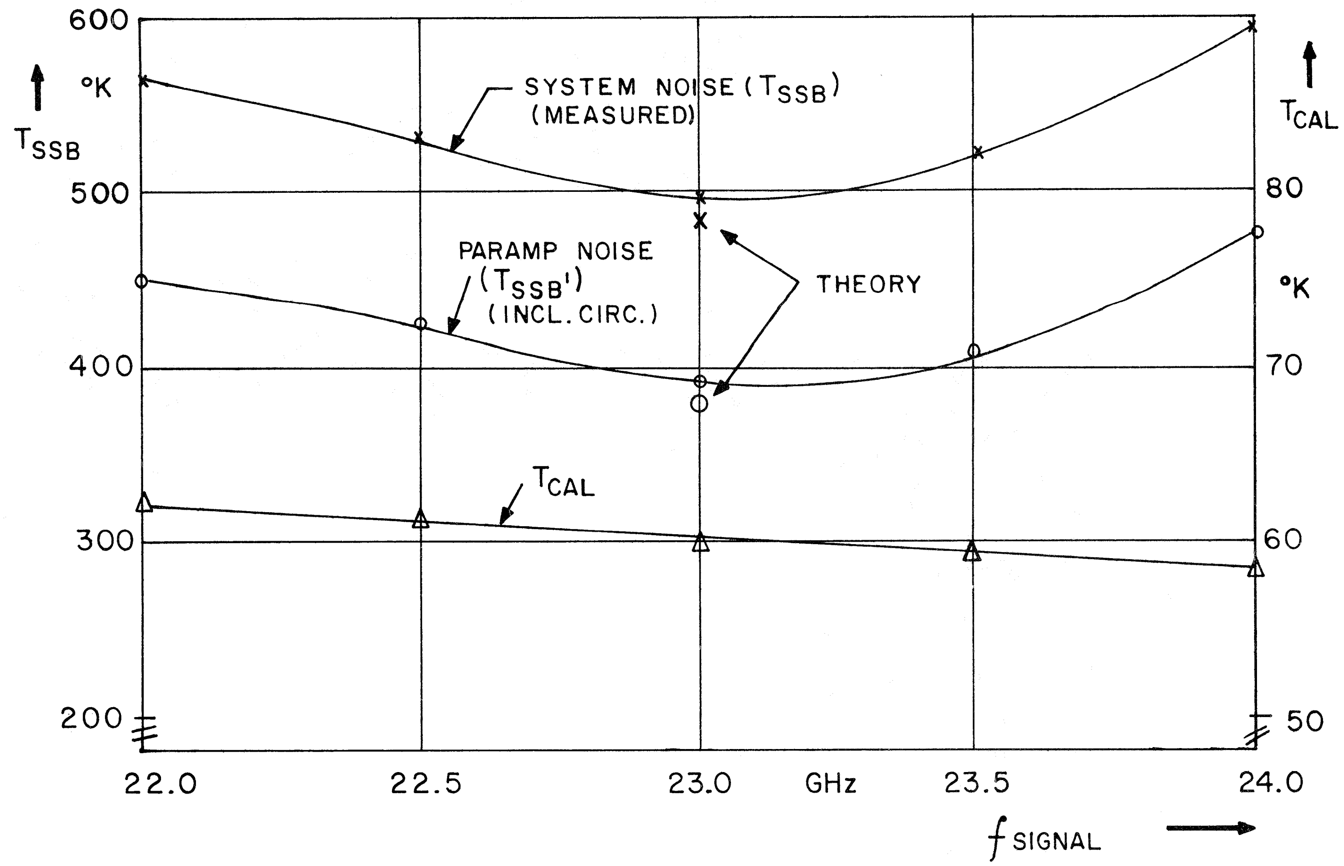
FRONT END OF THE 22 TO 24 GHz RECEIVER

FIG. 2



PHOTOGRAPH OF THE CONTROL RACK

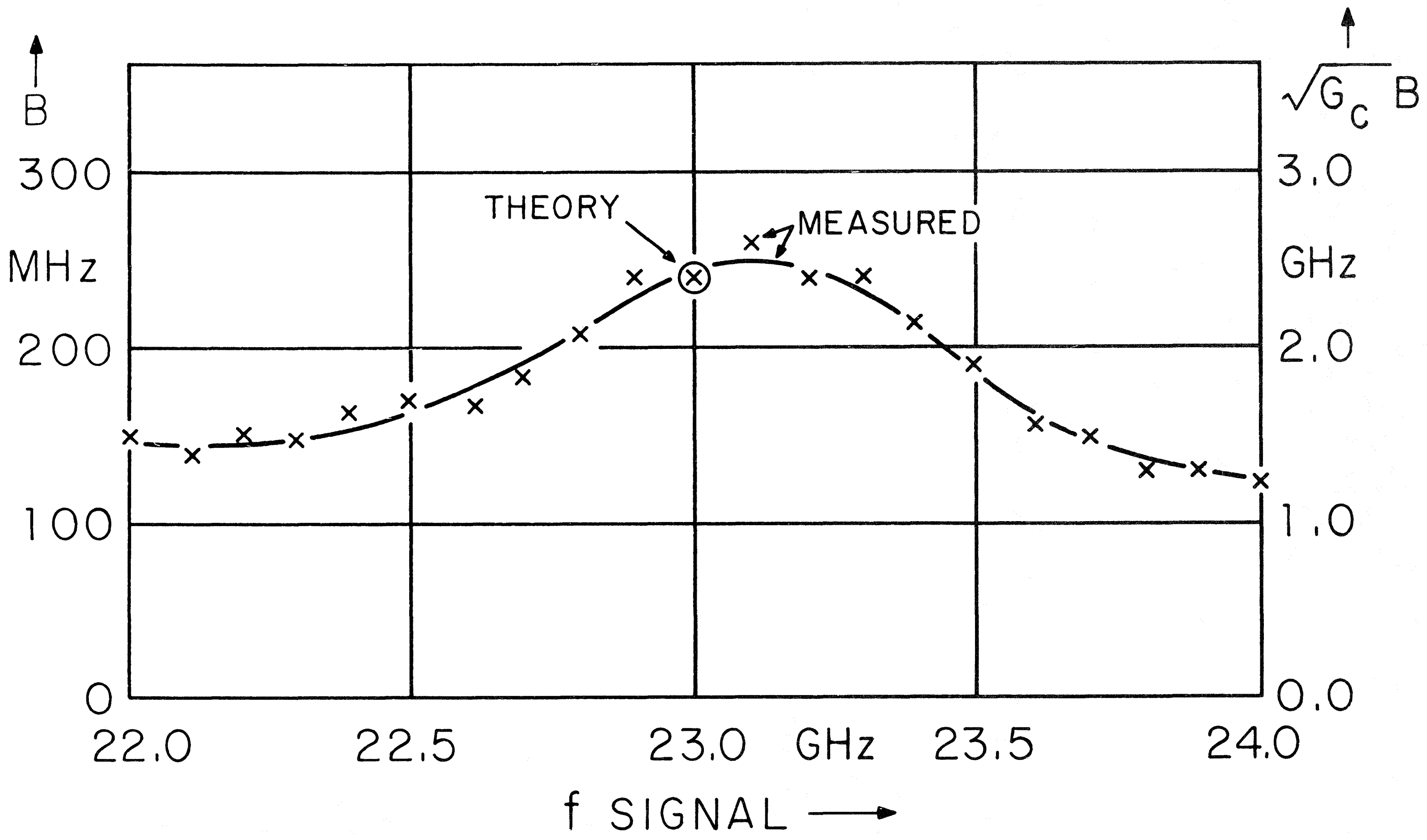
FIG. 3



a) Calibration signal T_{cal} for spectral line observations (while operating the front end switch) vs. signal frequency f_{signal}.

b) System noise temperature T_{SSB} and paramp noise temperature T_{SSB} vs. signal frequency f_{signal}. T_{SSB} = single side band noise temperature using the synchronous mode and an electronic gain of G_c = 20 dB as measured with a crystal detector in the laboratory, May 1971. Intermediate frequency: 50 ± 10 MHz. Date Measured: May 23, 1971.

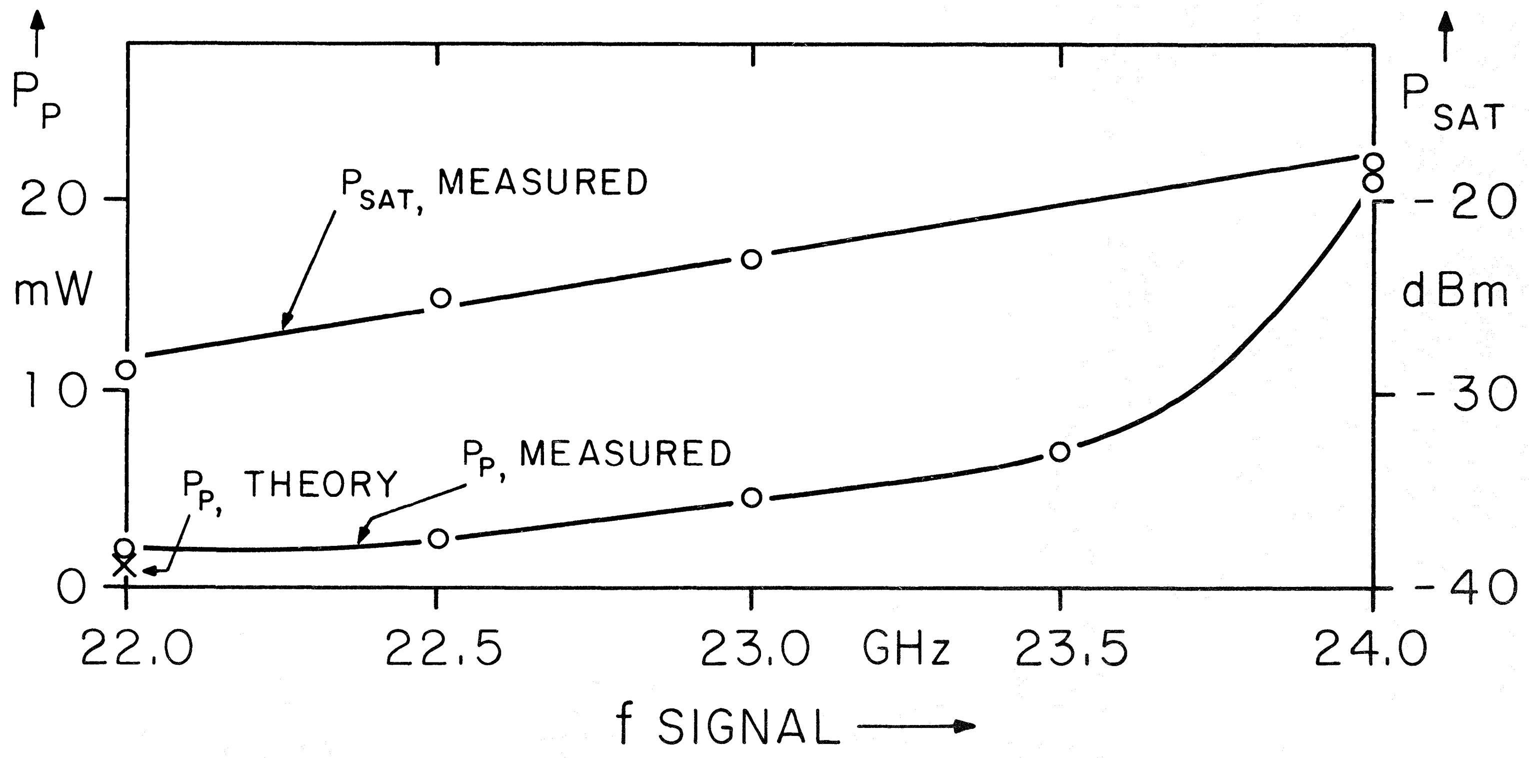
FIG. 4



Bandwidth B and voltage-gain-bandwidth product $\sqrt{G_c}B$ of the 22 to 24 GHz tunable parametric amplifier vs. signal frequency.

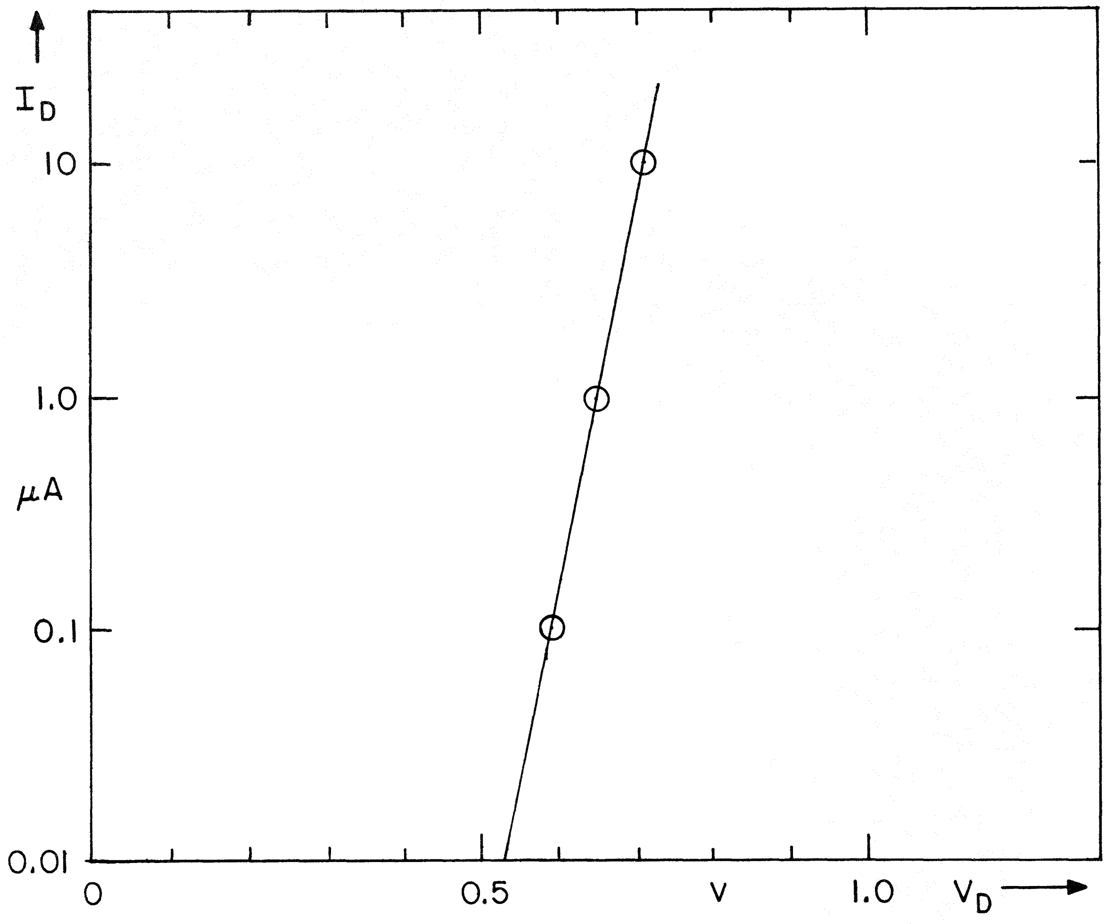
B = double-sideband bandwidth at 3 dB points.
G_c = 20 dB = power gain referred to varactor mount as measured with a crystal detector.
Corresponding gain G_0 = 18 dB from circulator input to mixer input.

FIG. 5



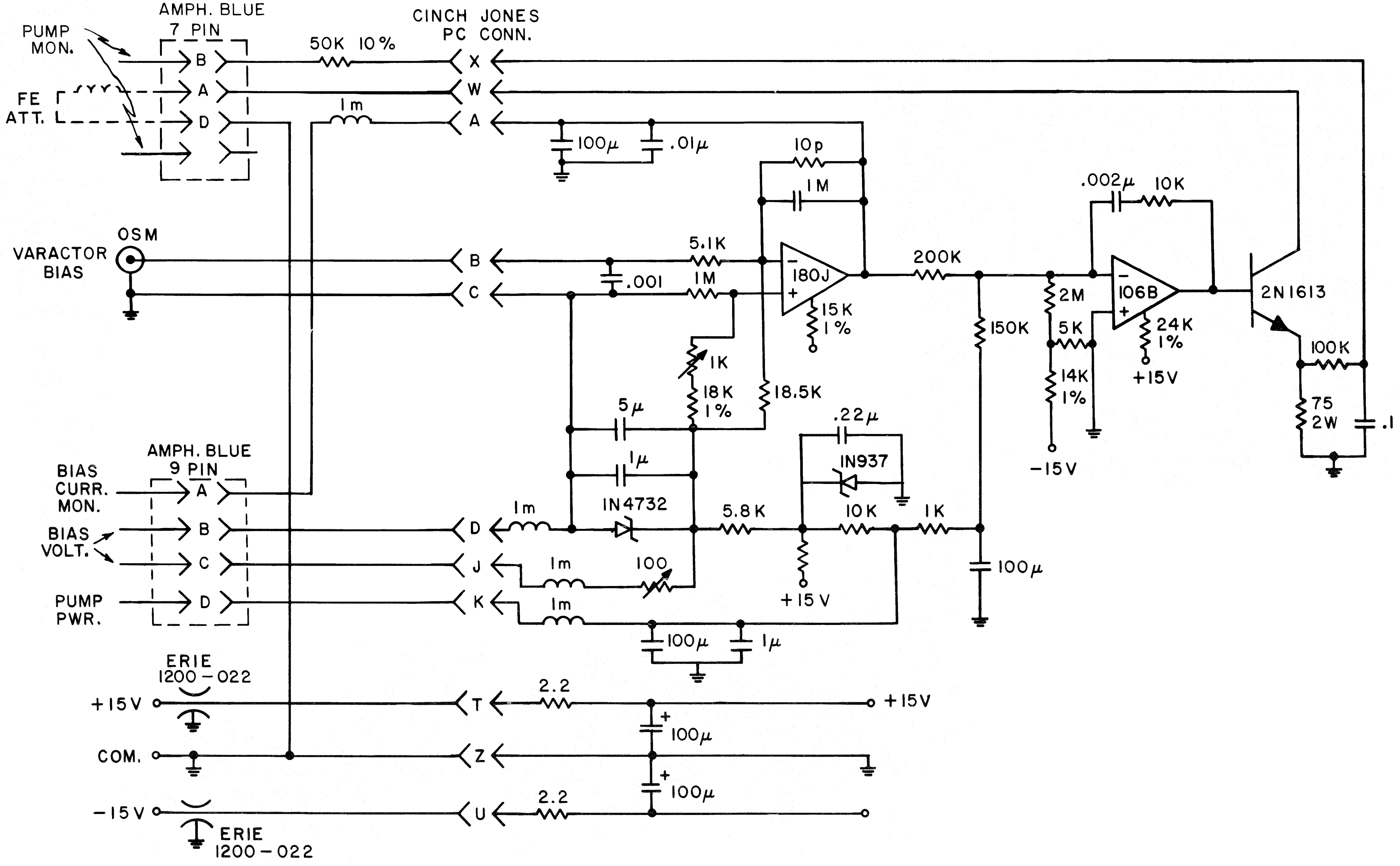
Pump power P_p and 1 dB compression level P_{sat} at the output vs. signal frequency. Gain $G_0 \approx 20$ dB.

FIG. 6



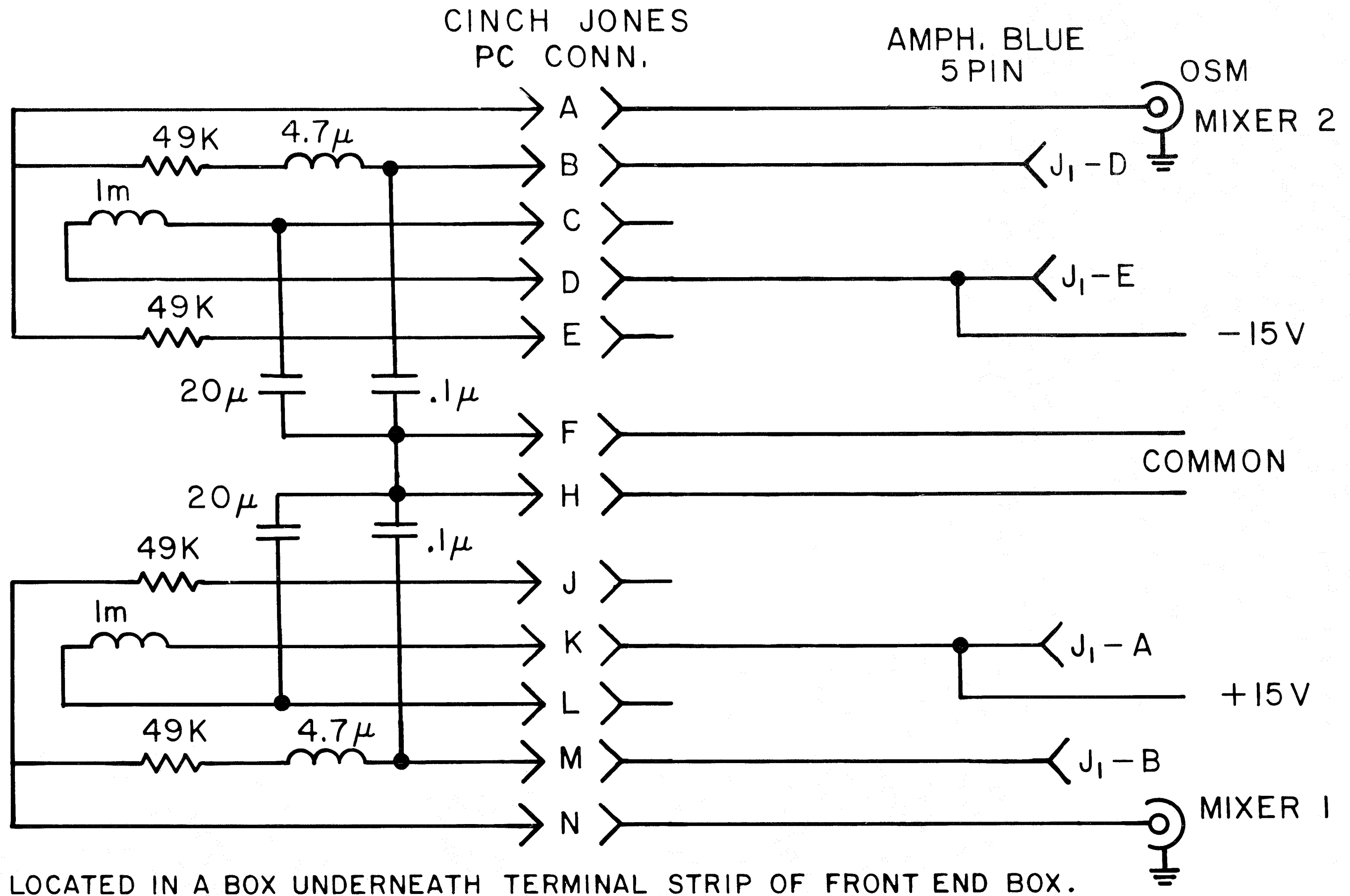
Forward 1-V characteristic of the varactor used in the parametric amplifier. Reverse breakdown voltage $V_B = 3.7$ V (I_D = -.002 μA).

FIG. 7



PARAMP BIAS & MONITOR, PUMP LEVEL & MONITOR CIRCUIT. LOCATION: BOX UNDERNEATH TERMINAL OF F.E. BOX.

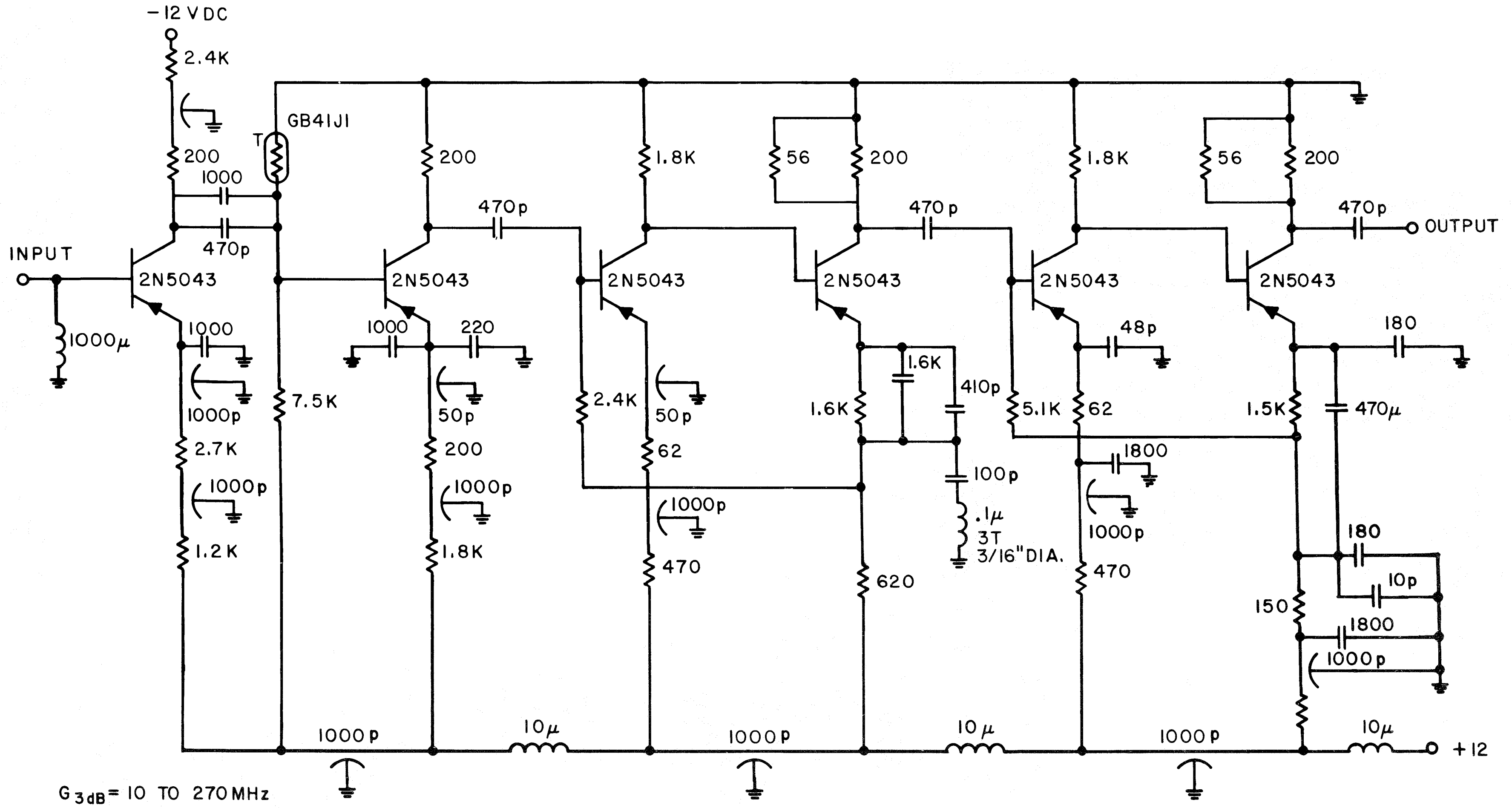
FIG. 8



LOCATED IN A BOX UNDERNEATH TERMINAL STRIP OF FRONT END BOX.

MIXER MONITOR CIRCUIT

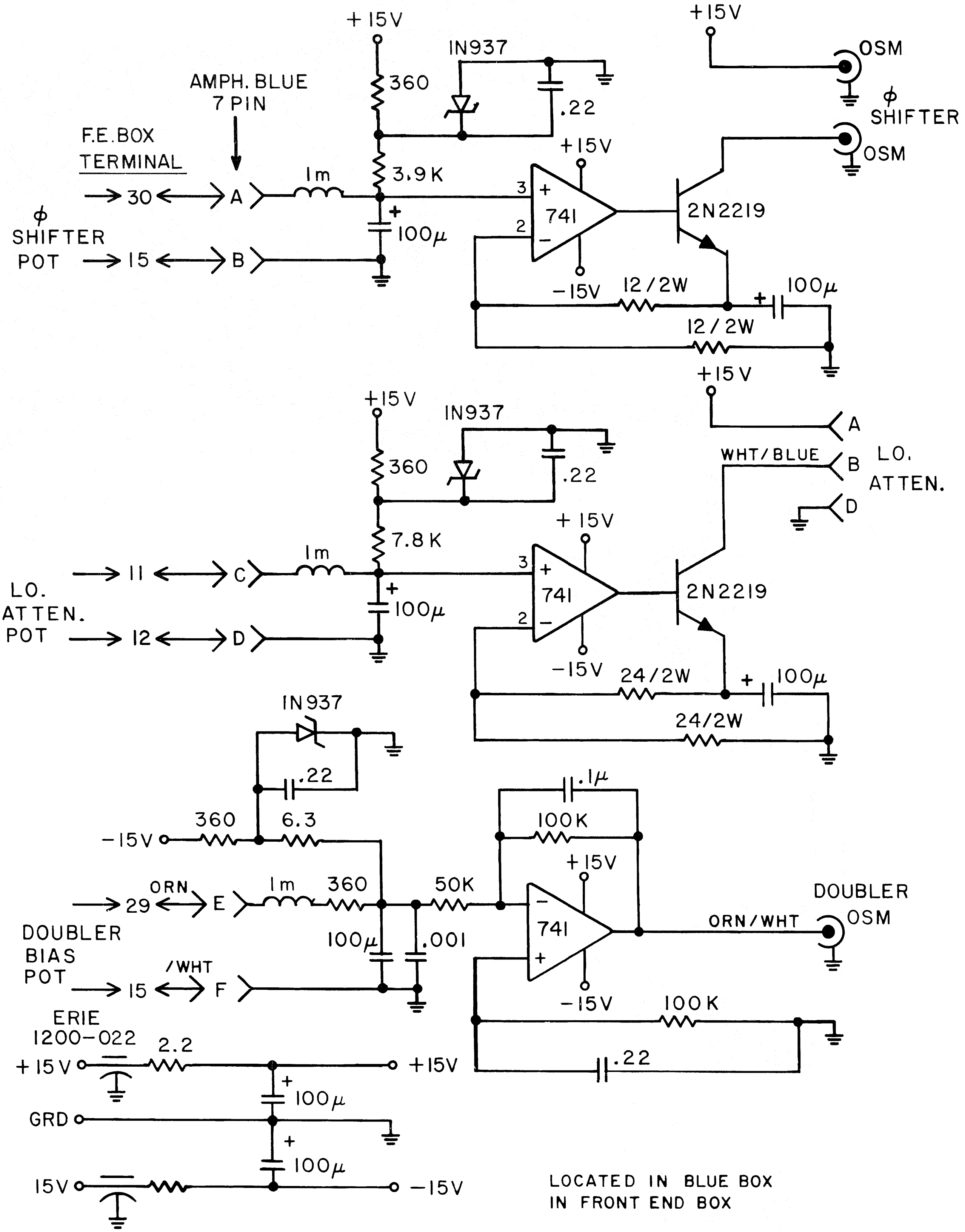
FIG. 9



G_{3dB} = 10 TO 270 MHz
G_p = 50 dB AT 100 MHz

MODIFIED AEROJET GENERAL IF AMPLIFIER 002/4

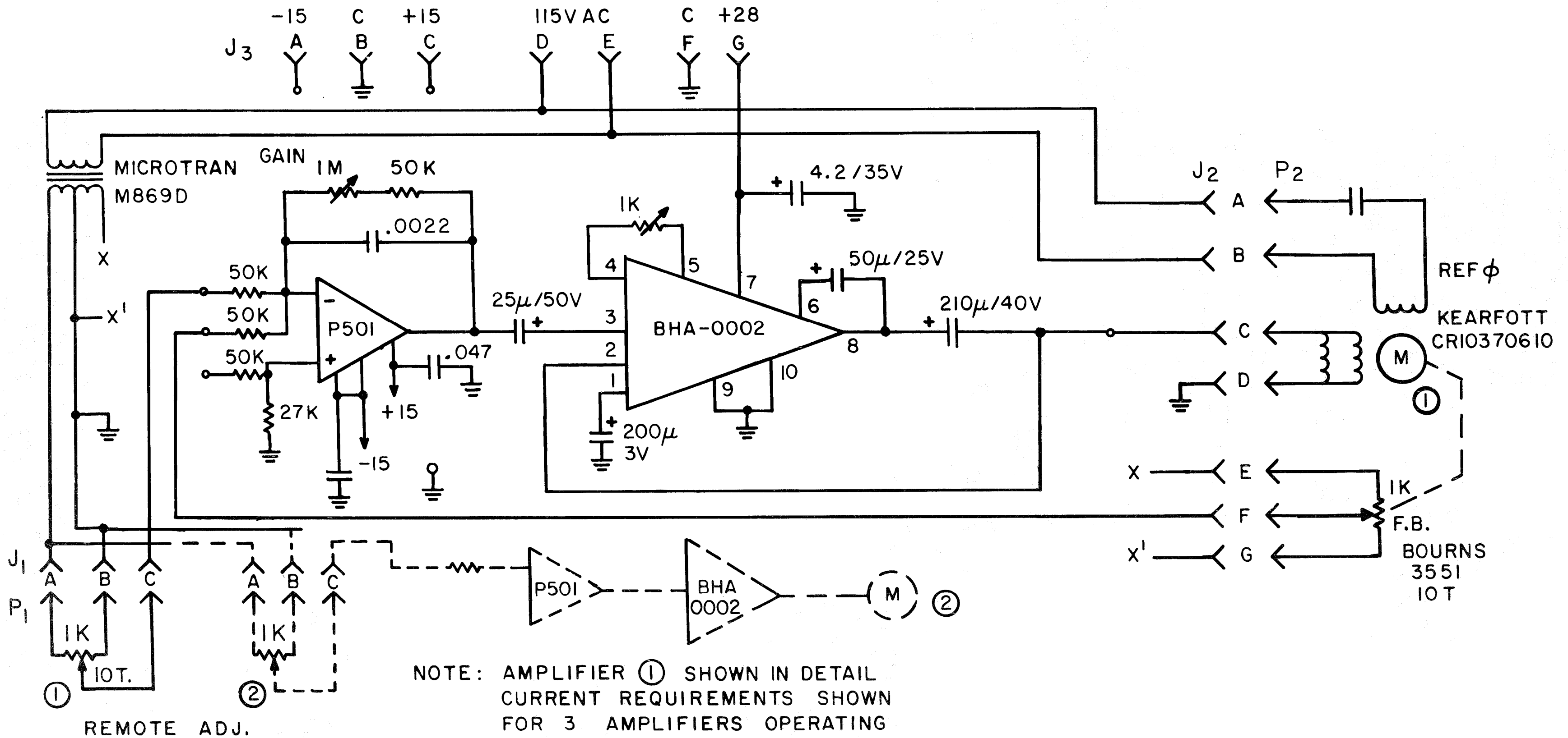
FIG. 10



LOCATED IN BLUE BOX
IN FRONT END BOX

φ SHIFTER — DOUBLER — LO. ATTENUATOR CIRCUITS

FIG. 11

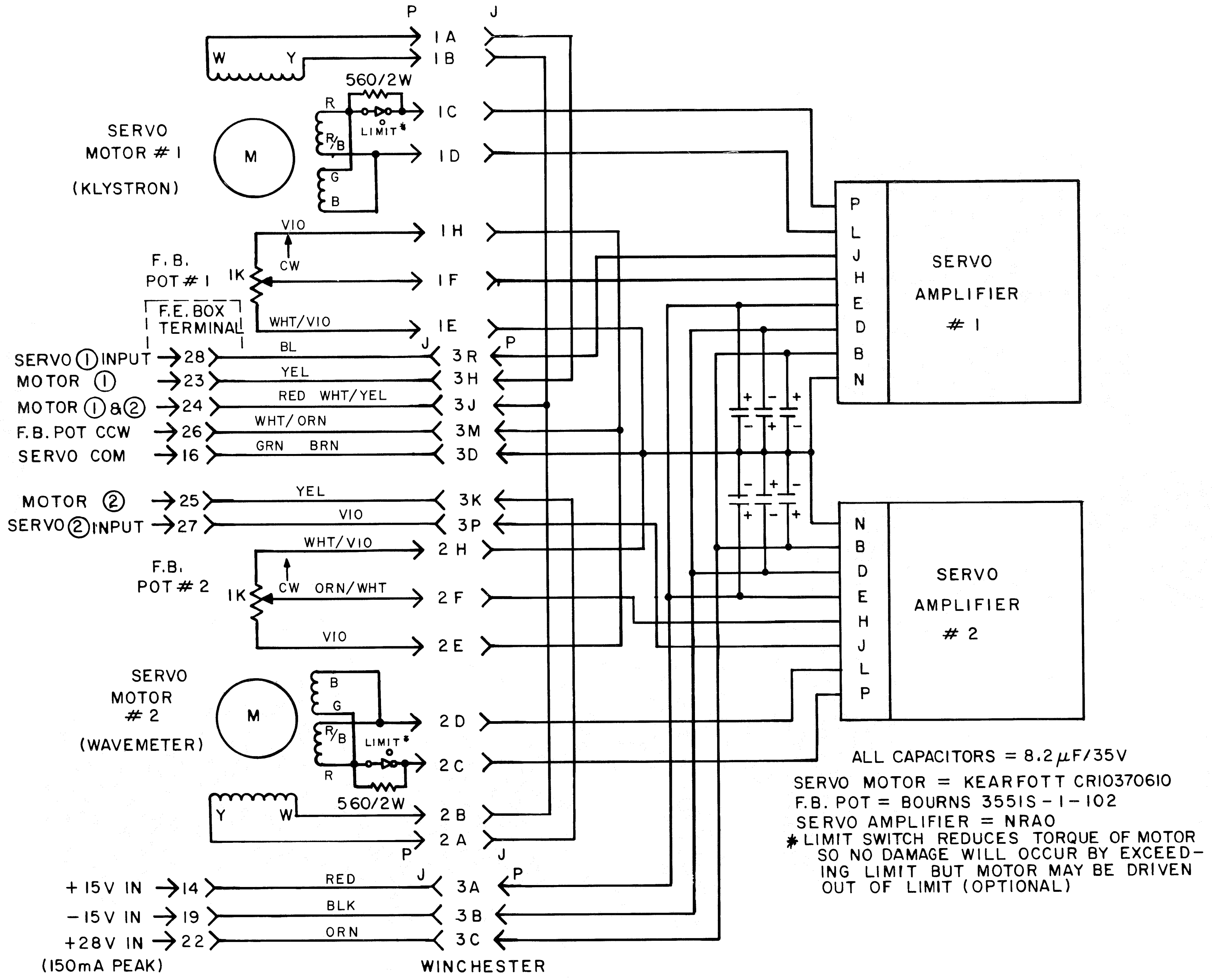


NOTE: AMPLIFIER ① SHOWN IN DETAIL
CURRENT REQUIREMENTS SHOWN
FOR 3 AMPLIFIERS OPERATING
SIMULTANEOUSLY

J_4 J_5 J_6 J_7 NOT SHOWN

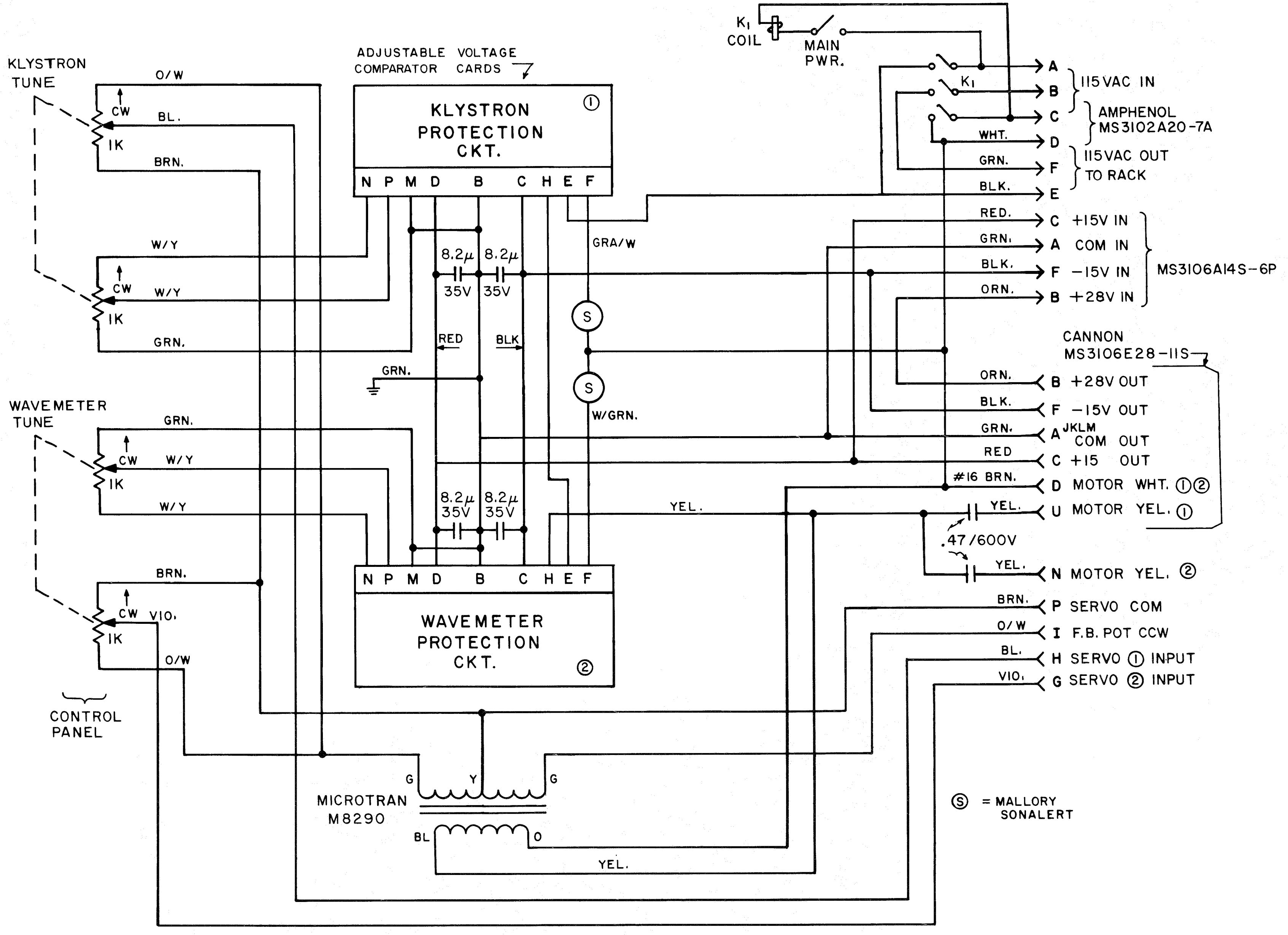
SERVO AMPLIFIER & CONNECTIONS TO SERVO MOTOR
(USED FOR WAVEMETER & KLYSTRON) & REMOTE ADJUST POTENTIOMETER

FIG. 12



ALL CAPACITORS = 8.2 μF/35V
SERVO MOTOR = KEARFOTT CR10370610
F.B. POT = BOURNS 3551S-1-102
SERVO AMPLIFIER = NRAO
* LIMIT SWITCH REDUCES TORQUE OF MOTOR SO NO DAMAGE WILL OCCUR BY EXCEEDING LIMIT BUT MOTOR MAY BE DRIVEN OUT OF LIMIT (OPTIONAL)

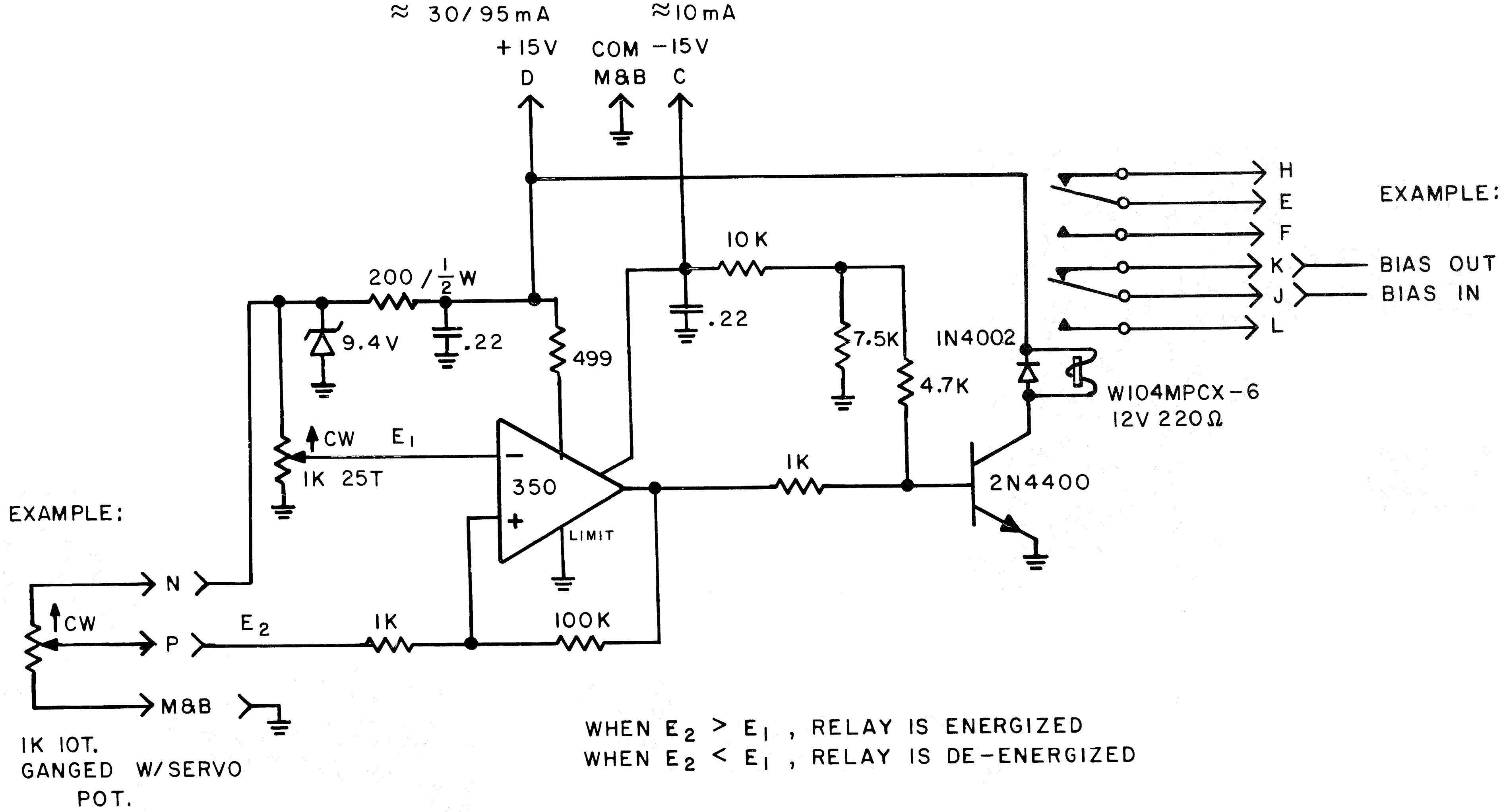
CONNECTION BETWEEN SERVO AMPLIFIERS & MOTORS IN FRONT END BOX
FIG. 13



(LOCATED IN CONTROL BOX)

INTERFACE OF REMOTE ADJUST PROTECTION METERS & PROTECTION CIRCUITS – FOR THE SERVOMOTORS.

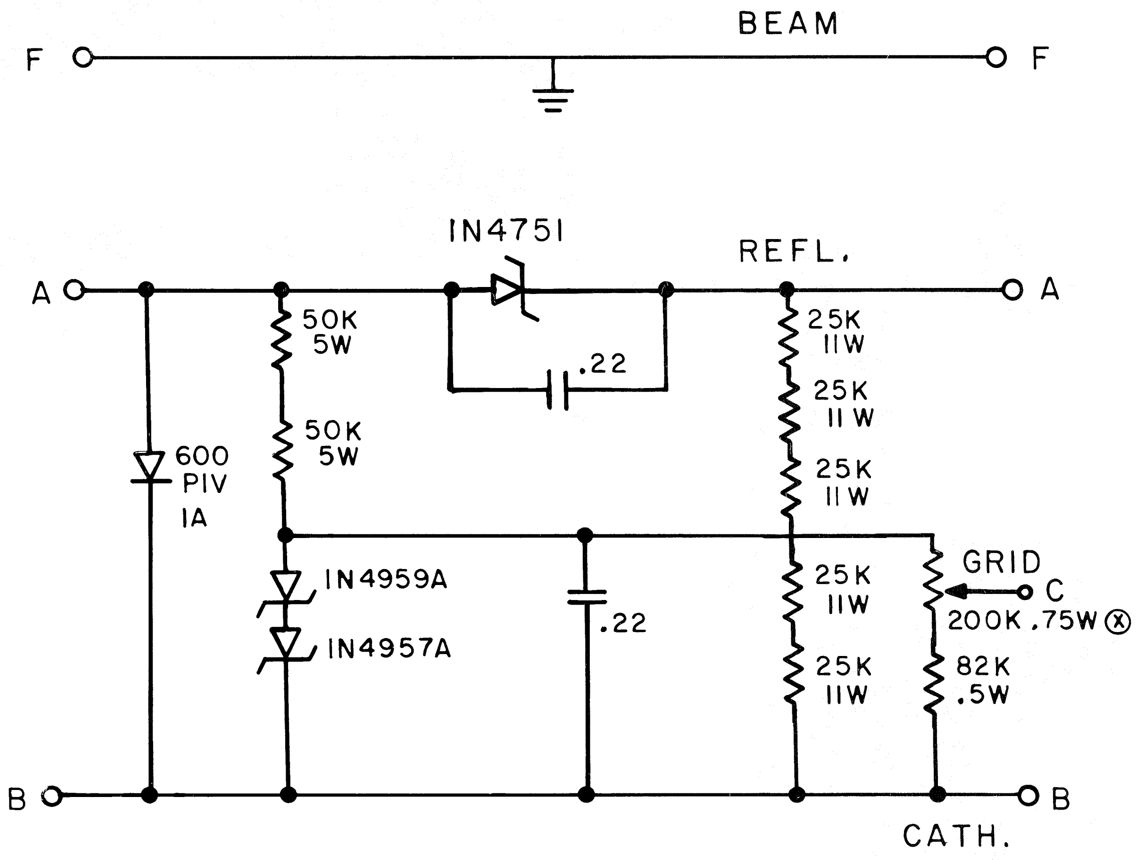
FIG. 14



WHEN $E_2 > E_1$, RELAY IS ENERGIZED
WHEN $E_2 < E_1$, RELAY IS DE-ENERGIZED

ADJUSTABLE VOLTAGE COMPARATOR
(PROTECTION CIRCUITS FOR SERVOS OF KLYSTRONS & WAVEMETERS —
LOCATED BEHIND CONTROL PANEL)

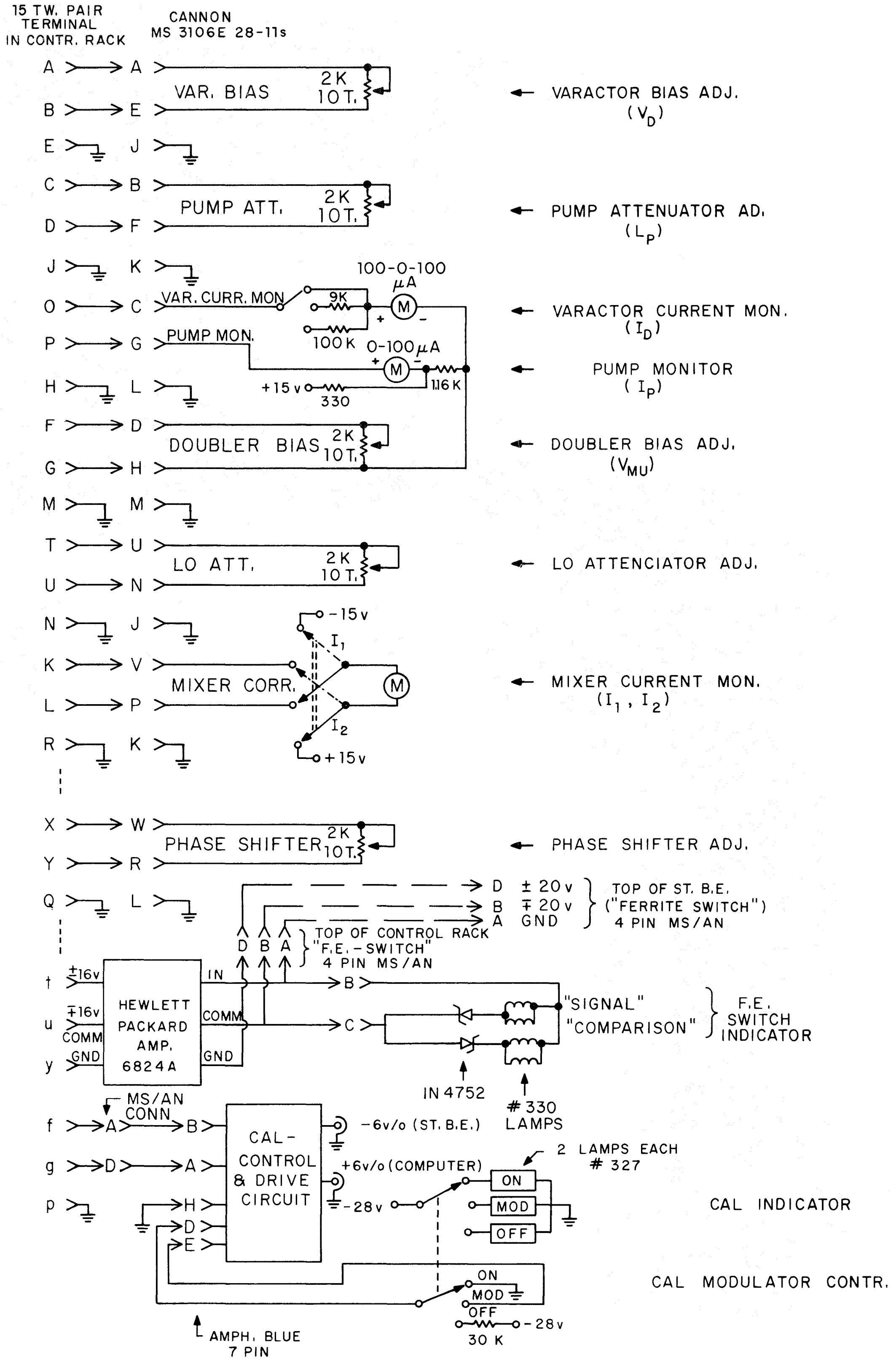
FIG. 15



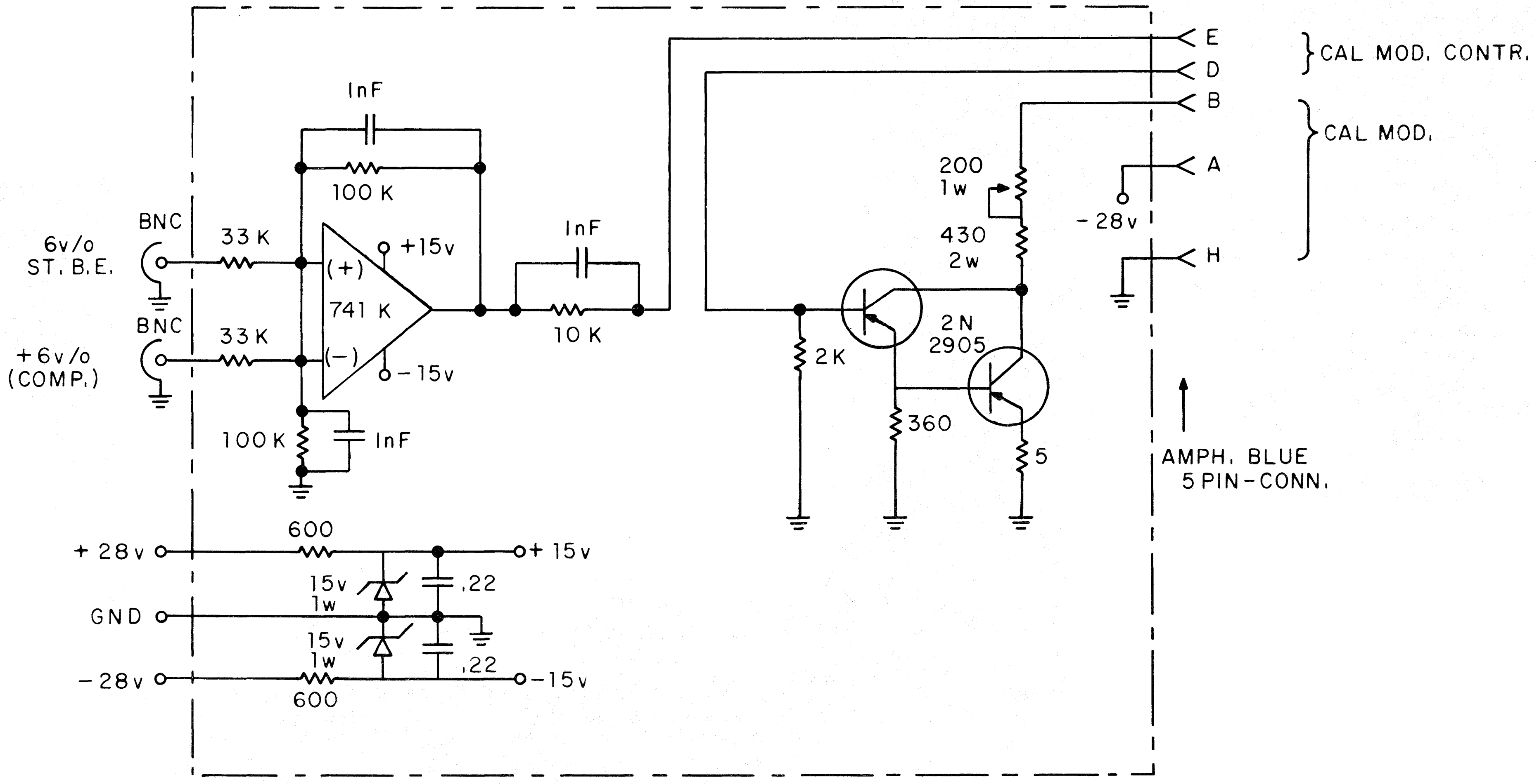
ⓧ ACCESSIBLE FROM THE OUTSIDE OF THE BOX BY MEANS OF A TEFLON INSULATED SHAFT.

CK1- ADAPTER (Located in a box behind the reflector supply)

FIG. 16

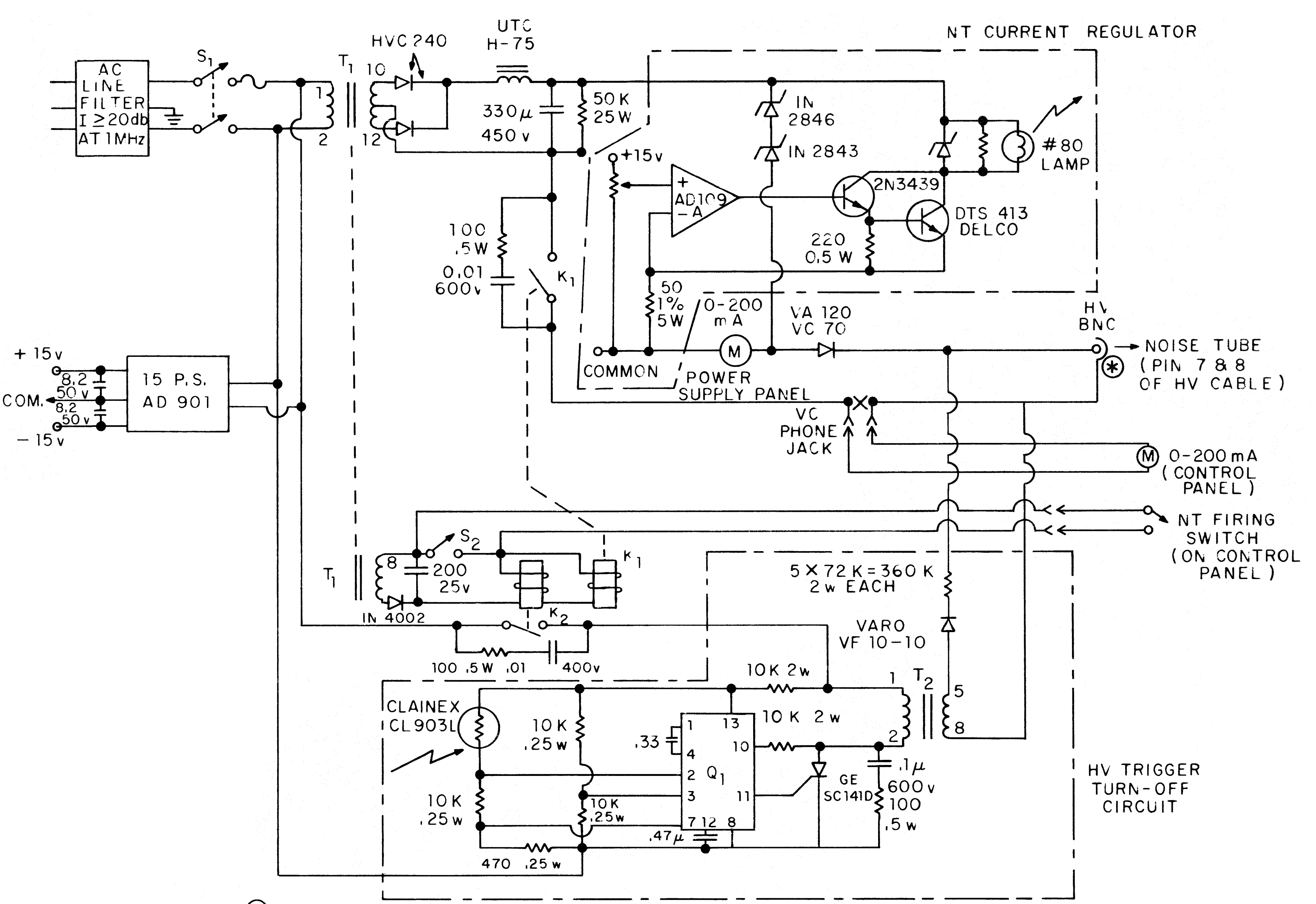


CONTROL PANEL
(CONNECTIONS WITH 15 TWISTED PAIR TELESCOPE CABLE)
FIG. 17



CAL MODULATOR CONTROL & DRIVE CIRCUIT (LOCATED IN BLUE BOX BEHIND CONTROL PANEL)

FIG. 18



NOTE: ✱ GROUNDED IN F.E. BOX

T1 : UTC H-91

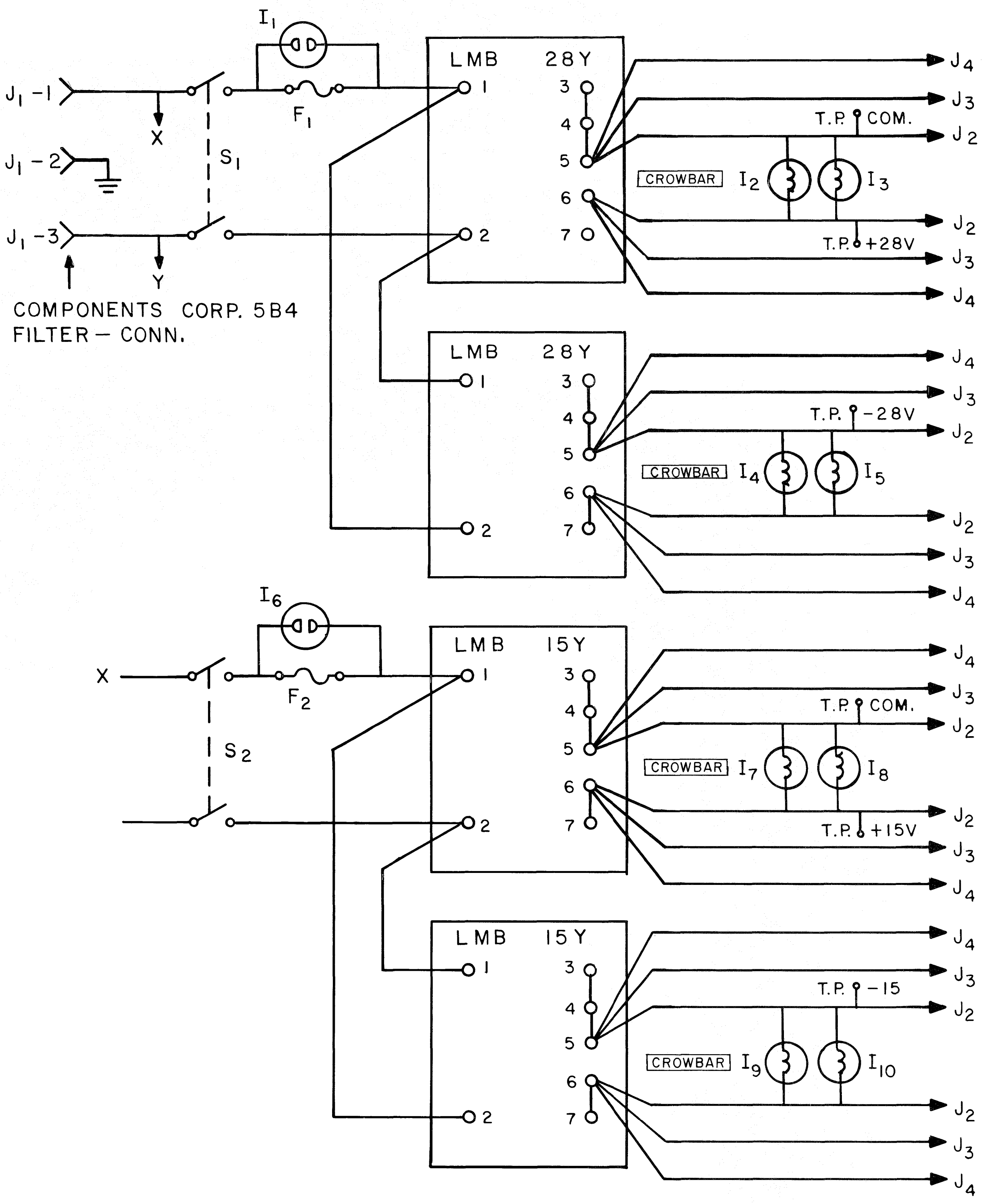
T2 : UTC H-198

K1 , K2 : MAGNECRAFT 102 Vx-11

Q1 : FAIRCHILD VA 747

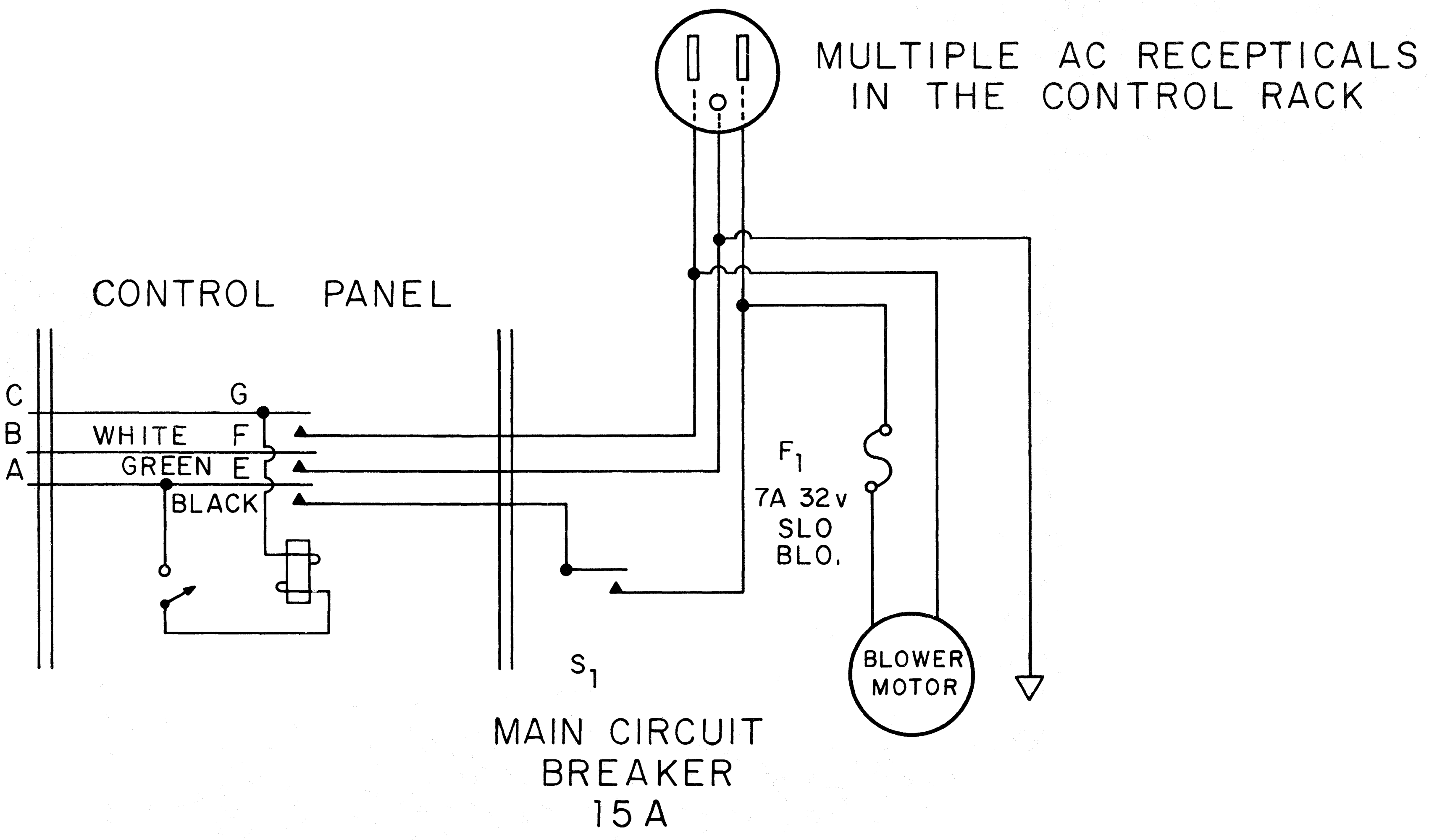
NOISE TUBE POWER SUPPLY

FIG. 19



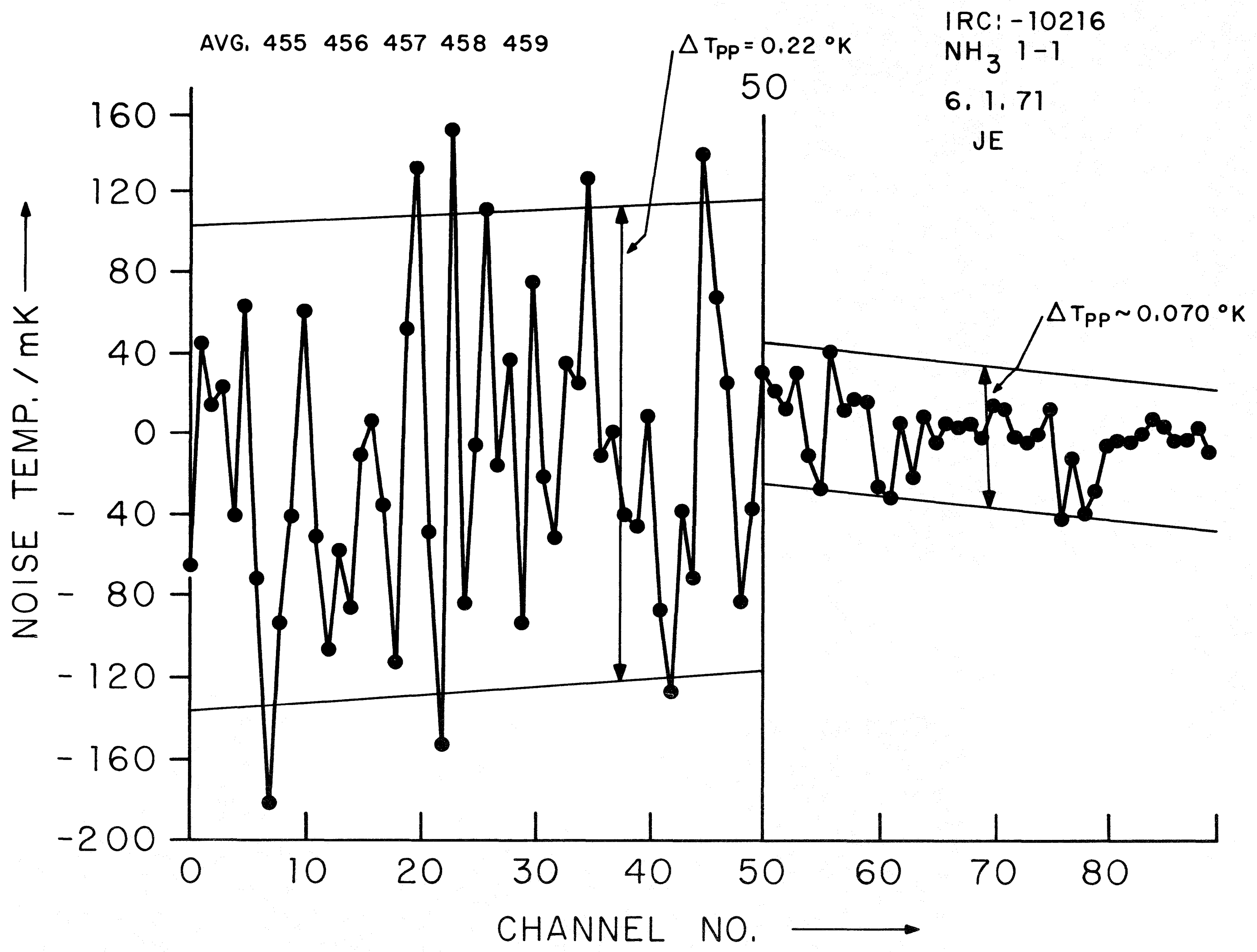
LOW VOLTAGE POWER SUPPLIES
(BOTTOM OF THE CONTROL RACK)

FIG. 20



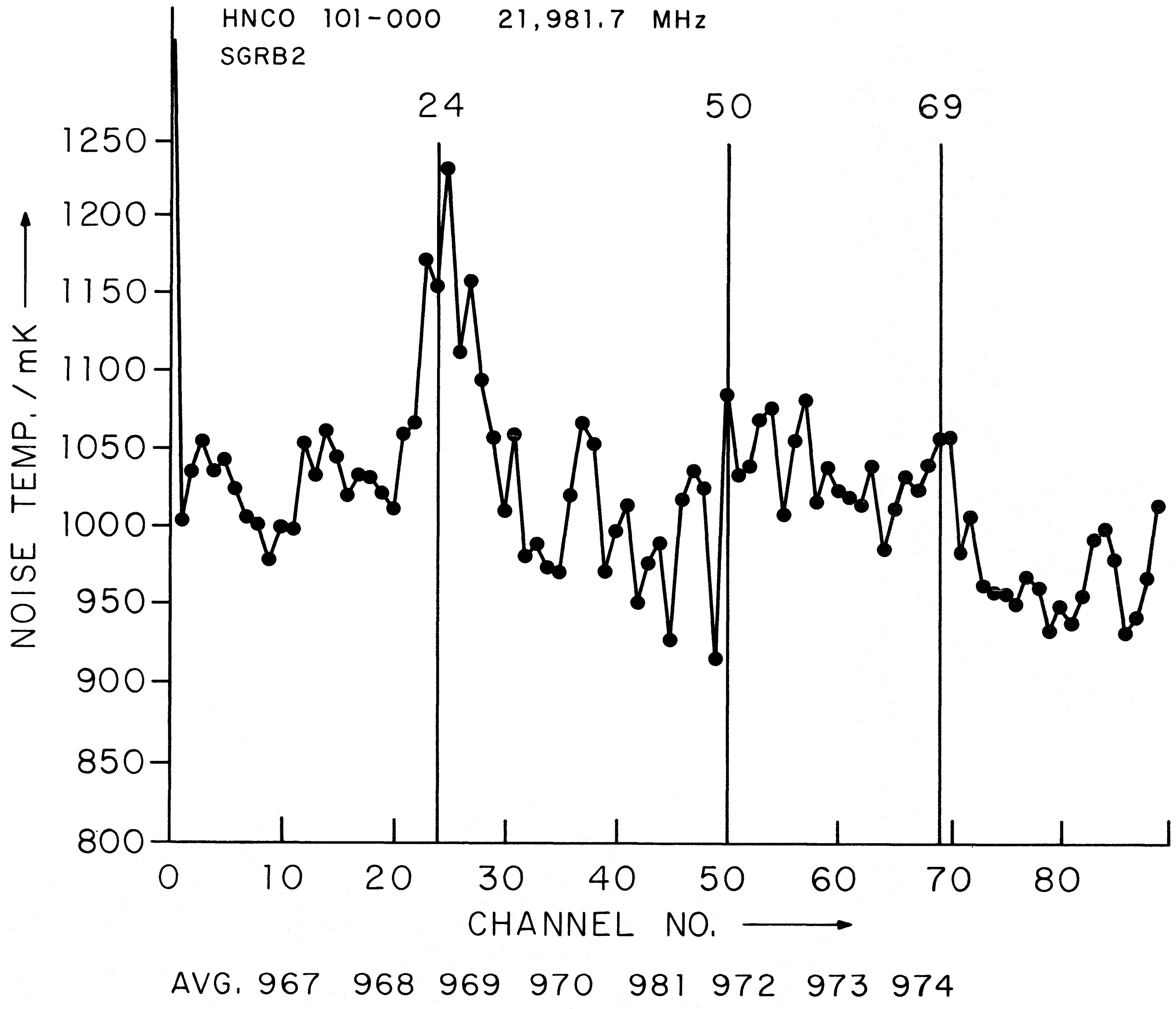
AC WIRING OF THE CONTROL RACK

FIG. 21



Noise temperature vs. channel number of the 22 to 24 GHz spectral line receiver as shown by the output of the NRAO spectral line processor. The output of the 50-channel filter receiver is displayed in channels 0 through 49 (bandwidth = 250 kHz/channel). The output of the 40-channel filter receiver is displayed in channels 50 through 89 (bandwidth = 2 MHz/channel).

FIG. 22



Noise temperature vs. channel number of the 22 to 24 GHz receiver centered at 21.9817 GHz (LSB) showing the $1_{01} - 0_{00}$ transition of isocyanic acid (HNCO) in the channel 24 of the 50-channel filter receiver (BW = 250 kHz; τ_{TDT} = 80 min).

FIG. 23

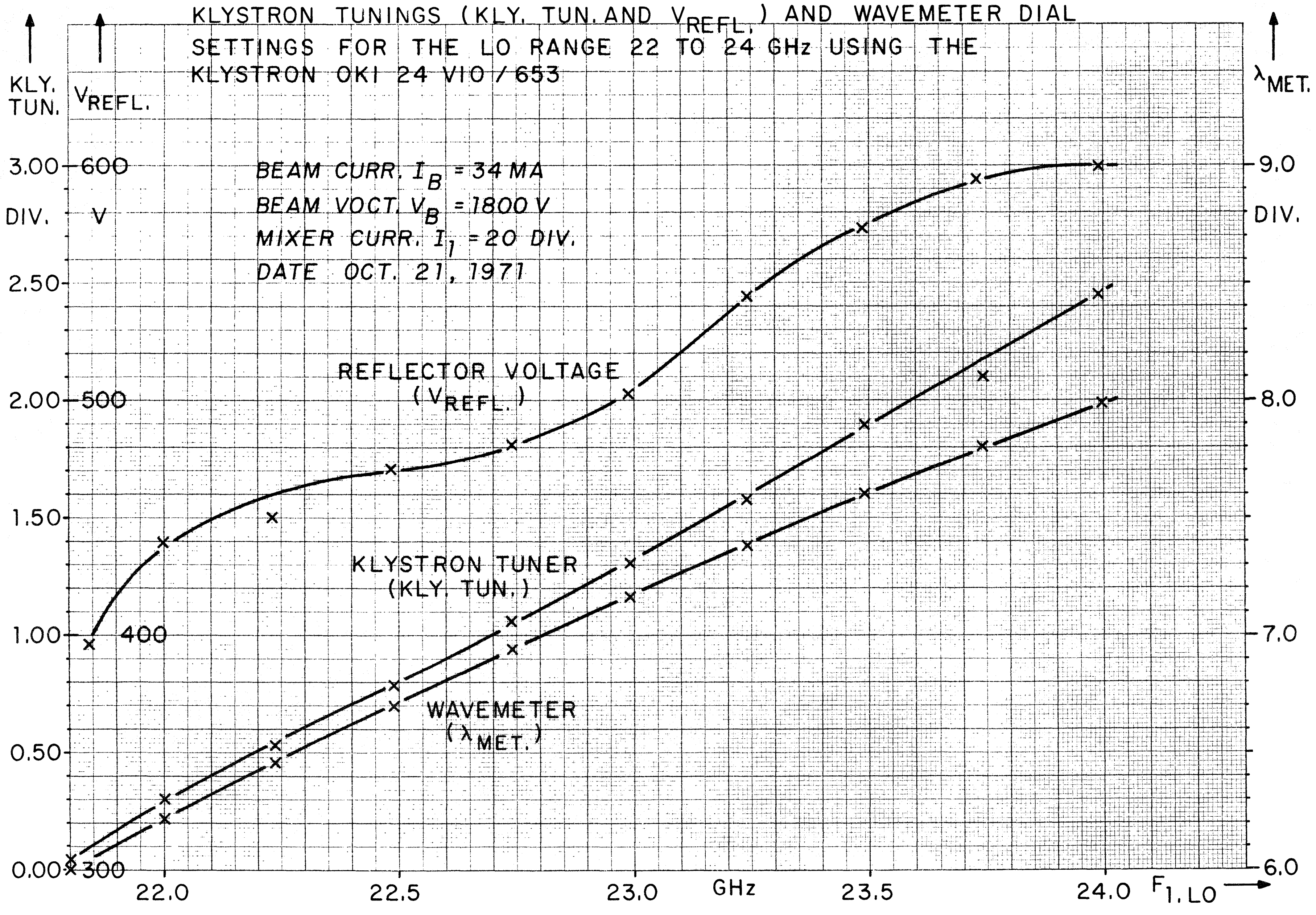
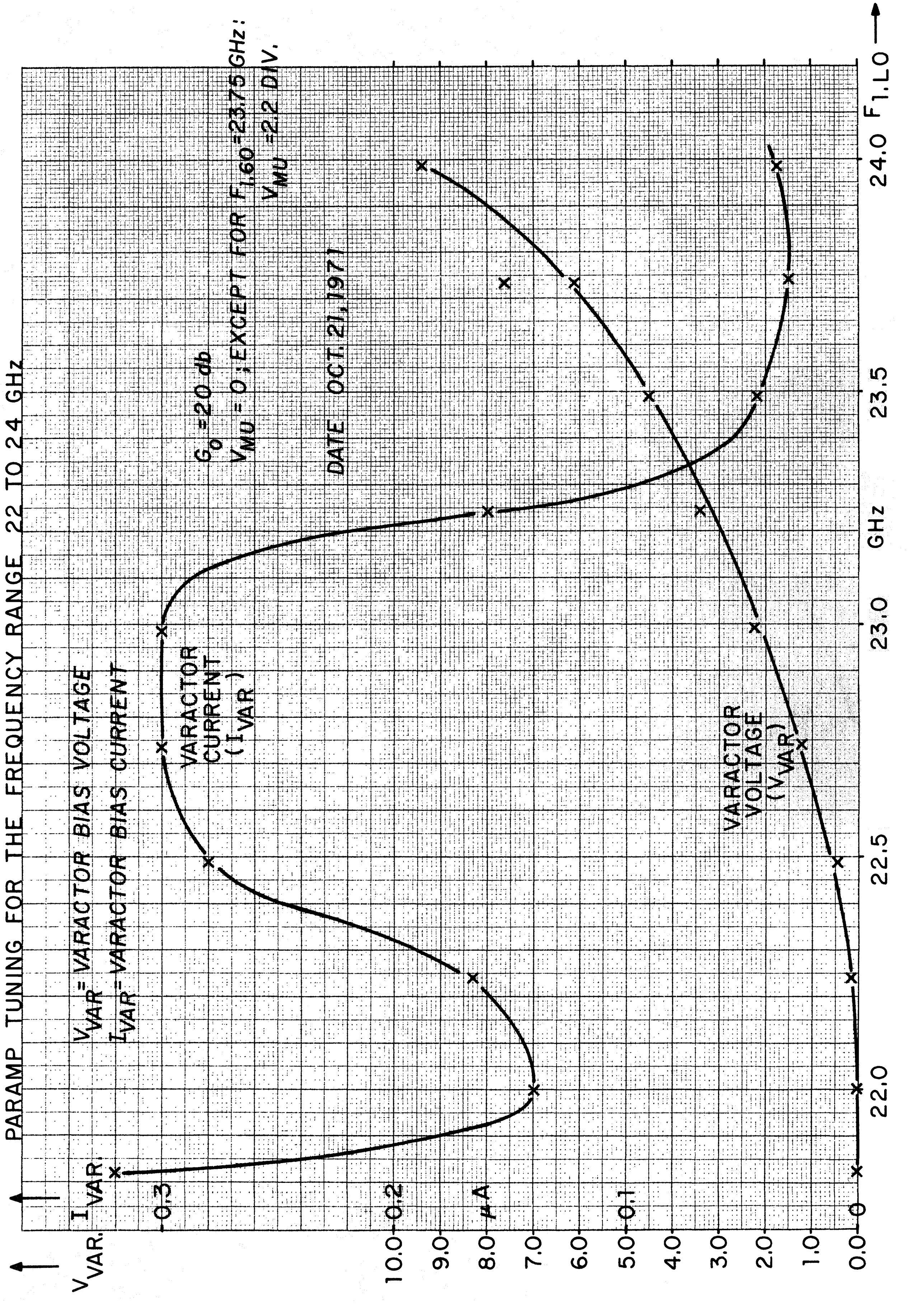

KLYSTRON TUNINGS (KLY. TUN. AND $V_{REFL.}$) AND WAVEMETER DIAL
SETTINGS FOR THE LO RANGE 22 TO 24 GHz USING THE
KLYSTRON OKI 24 VIO / 653
BEAM CURR. I_B = 34 MA
BEAM VOCT. V_B = 1800 V
MIXER CURR. I_1 = 20 DIV.
DATE OCT. 21, 1971
KLY. TUN.
DIV.
$V_{REFL.}$
V
$\lambda_{MET.}$
DIV.
3.00
2.50
2.00
1.50
1.00
0.50
0.00
600
500
400
300
9.0
8.0
7.0
6.0
22.0
22.5
23.0
GHz
23.5
24.0
$F_{1,LO}$
REFLECTOR VOLTAGE
($V_{REFL.}$)
KLYSTRON TUNER
(KLY. TUN.)
WAVEMETER
($\lambda_{MET.}$)

FIG. 24



PARAMP TUNING FOR THE FREQUENCY RANGE 22 TO 24 GHz

V_{VAR} = VARACTOR BIAS VOLTAGE

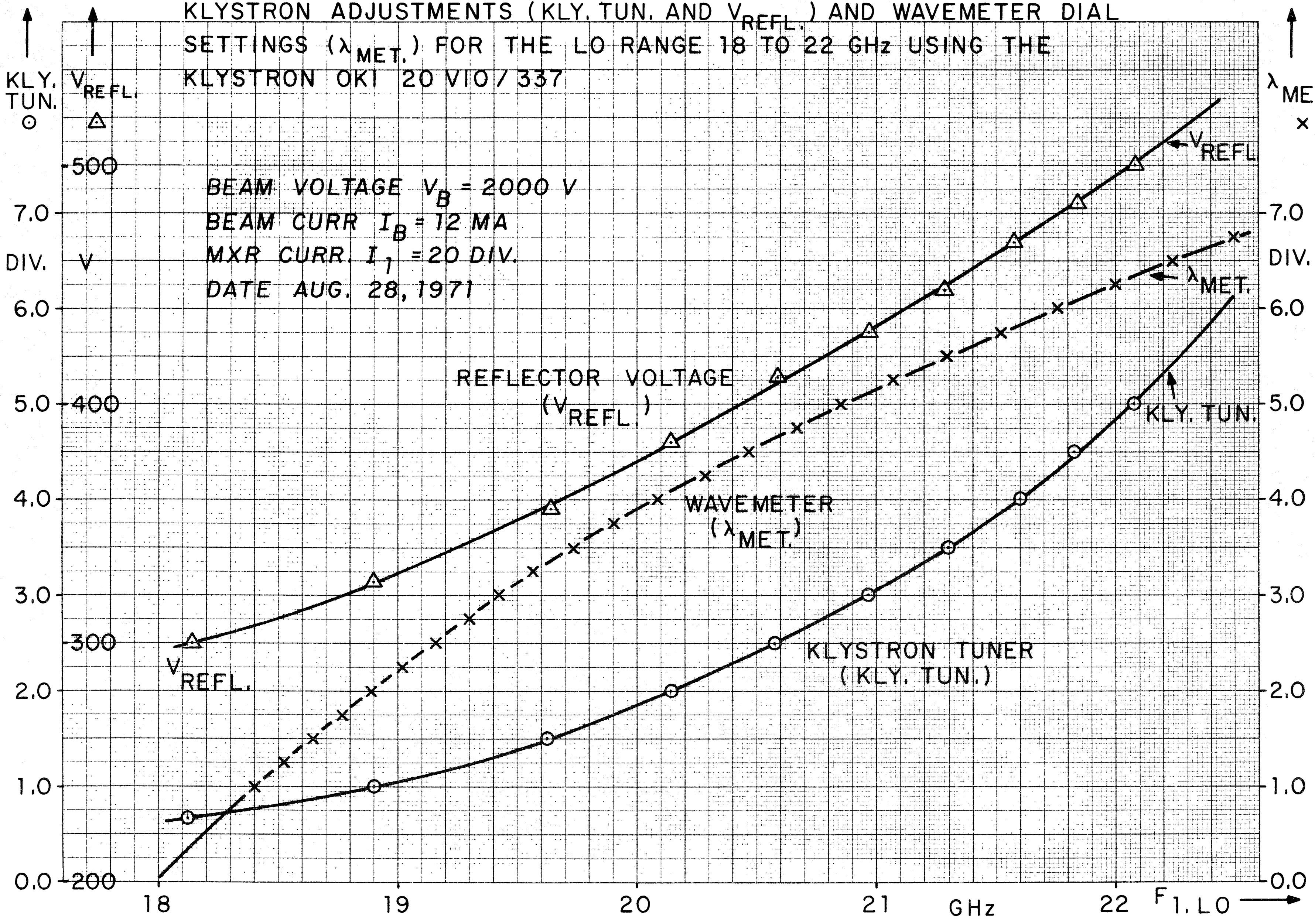
I_{VAR} = VARACTOR BIAS CURRENT

G_o = 20 db

V_{MU} = 0; EXCEPT FOR $F_{1.60}$ = 23.75 GHz: V_{MU} = 2.2 DIV.

DATE OCT. 21, 1971

FIG. 25



KLYSTRON ADJUSTMENTS (KLY. TUN. AND $V_{REFL.}$) AND WAVEMETER DIAL SETTINGS ($\lambda_{MET.}$) FOR THE LO RANGE 18 TO 22 GHz USING THE KLYSTRON OKI 20 V10/337

BEAM VOLTAGE $V_B = 2000$ *V*
BEAM CURR $I_B = 12$ *MA*
MXR CURR. $I_1 = 20$ *DIV.*
DATE AUG. 28, 1971

FIG. 26