NATIONAL RADIO ASTRONOMY OBSERVATORY
Green Bank, West Virginia

Electronics Division Internal Report No. 8

CERAMIC TUBE - LOW NOISE FRONT ENDS

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January 1963

NUMBER OF COPIES: 30
Rerun November 1963: 100

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I. INTRODUCTION

Contained in this report is a description of both the 1400 mc and the 750 mc low noise front ends. These units follow the same basic design used by NRAO for mixer-preamplifier front ends except that the mixer and preamplifier are of a special low noise design.

Certain sections of this report pertain to only one of the two units and are noted accordingly.

II. DESCRIPTION

A block diagram of the front end is shown in figure 1. Signals from the antenna enter the unit through the normally closed side of coaxial relay No. 1. Closing this relay disconnects the receiver from the antenna and connects it to the noise tube through a 10 db attenuator, thus allowing the noise temperature of the receiver to be measured. Also, if the relay is closed and the noise tube turned off, stability runs on the receiver can be made.

A calibration signal can be fed into the signal path through the directional coupler. The size of the calibration is determined by the positions of coaxial relays 2 and 3; a choice of two calibrations is available.

The diode switch compares the signal from the directional coupler output with the signal from a comparison load. For best receiver stability, the comparison load should have a constant temperature which is as nearly equal to the antenna temperature as possible.

1400 mc unit

The switched signal from the diode switch enters the mixer. The tuning stub, followed by a quarter wave transformer, transforms the 50 ohm input impedance of the mixer to the impedance required by the mixer crystal.

750 mc unit

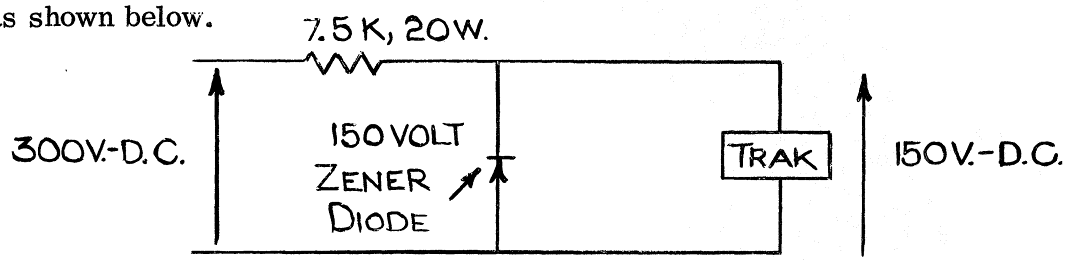
The switched signals from the diode switch enter the mixer. The input section of the mixer is the input section of an Empire Devices mixer, while the output section was built by NRAO.

Both units

Only 1N21F crystals should be used in this mixer. Local oscillator power is supplied by a TRAK oscillator, which uses a General Electric 7486 ceramic tube. The oscillator frequency can be adjusted over about a 100 mc range. Crystal current can be remotely adjusted by the motor connected to the local oscillator injection probe on the mixer.

The entire mixer is mounted on the 30 mc preamplifier box. The preamplifier uses three General Electric 7768 ceramic tubes (see figure 2) and has sufficient output to drive a NRAO standard receiver back end.

The power and control circuits are shown in figure 3. There are two power supplies -- a 300 VDC supply for the B+ circuits and a 6.3 VDC supply for the tube filaments. The local oscillator requires a plate voltage of only 150 VDC. This voltage is obtained as shown below.



An ammeter is provided to measure the current drawn from the 300 volt supply. The voltmeter can be switched to measure the voltage of either the 300 volt or 150 volt supplies. Other control features include switches in both the 115 VAC and 300 VDC lines as well as fuse protection of the power supplies. A thermistor is mounted near the preamplifier to measure the temperature of the mounting plate.

III. ADJUSTMENTS

Power Supply Voltages

The B+ supply can be adjusted to 300 volts by turning the voltage adjustment located on the power supply chassis. Filament voltage should be set at ~ 6.3 VDC. The voltage adjustment is located on the mounting plate of the DC filament supply and is accessible from the back of the front end mounting plate. Filament voltage can be measured between the two test points located on the control box.

Local Oscillator Frequency

The local oscillator frequency can be measured by connecting a frequency meter (NARDA Model 805 will do) to the comparison side of the diode switch and locking the switch in the comparison position. With normal crystal current (0.5 to 1.0 ma) enough local oscillator power will be available to accurately measure the frequency. The frequency is adjusted by a screw located on the top of the local oscillator.

Noise Temperature (Note: Doubled underlined words pertain only to the 1400 mc front end.)

Correct adjustments of the tuning stub and the mixer crystal current is necessary in order to realize the best possible noise temperature of the front end. The adjustments can be made in the following manner:

1. Connect the comparison side of the diode switch to a 50 ohm load at room temperature.
2. Energize coaxial relay No. 1 and fire the noise tube.
3. Connect the front end to a standard receiver back end and set-up the entire system for switched receiver operation.
4. With the receiver balanced, adjust the tuning stub and the crystal current for a maximum phase detector output. (An increase in phase detector output is the direction in which the output would go if an increase in signal were received from the antenna.) Rebalance the gain modulator if necessary. When the maximum output is obtained, the noise temperature should be at its lowest value.
5. Check the noise temperature. 300 °K to 350 °K is acceptable.

The reason this method works is as follows: When the diode switch is in the signal position, the receiver sees the signal temperature, T_S, plus the receiver temperature, T_R; i.e., it sees $T_S + T_R$. With the diode switch in the comparison position, the receiver sees the comparison temperature, T_C, plus the receiver temperature; or, $T_C + T_R$. The ratio

$$\frac{T_S + T_R}{T_C + T_R} = k$$

is defined. The factor k is the factor by which the gain modulator must be unbalanced in order that the phase detector output be zero. Changing k, without rebalancing the gain modulator, will change the phase detector output. If $T_S = T_C$, a change in the receiver noise temperature will not show up on the phase detector output since k would always equal one. However, if $T_S \neq T_C$, any change in T_R will be seen at the output since k would then change with a change in T_R. (As a side light, it should be noticed that having the comparison load temperature equal to the antenna temperature makes the receiver insensitive to changes in noise temperature and thus increases its stability.)*

IV. LOW NOISE MIXER-PREAMPLIFIER

Description

1400 mc unit -- The mixer consists of a stub tuner, a quarter wave transformer with a local oscillator injection probe, a 1N21F crystal, and an output filter.

The tuning stub serves three purposes:

1. It provides a DC path to ground for the crystal current.
2. It prevents 30 mc signals from entering the mixer and passing on to the preamplifier.
3. The combination of the stub tuner and the quarter wave transformer serves to match the mixer crystal to the 50 ohm mixer input.

The tuner is considered as part of the mixer.

750 mc unit. -- The mixer consists of an Empire Devices input section (which includes an input transformer, a quarter-wave length stub, and a local oscillator injection probe), a 1N21F crystal, and an output filter.

The input section performs the following functions:

1. The quarter-wave length stub provides a path to ground for the crystal current and any 30 mc signals which might enter the mixer.
2. The transformer section matches the mixer crystal to the 50 ohm mixer input.

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* E. Filloy, "Noise Temperature Measurements With the Standard Receiver," NRAO Electronics Division Internal Report No. 7.

Both units. -- Local oscillator power is loosely coupled to the output of the input section by means of a probe which can be moved in and out to increase or decrease the amount of coupling. It is generally a good idea to have as loose of a coupling as permissible. The local oscillator injection probe assembly is constructed so that a 50 ohm match will be presented to the local oscillator. However, the insertion of at least a 3 db attenuator at the mixer's local oscillator input is advisable, especially if the cable connecting the local oscillator to the mixer is long.

The crystal is, of course, the non-linear device which performs the mixing. Type 1N21F works best of all crystals tried, but better crystals should be tried upon their availability.

RF power passing through the crystal is bypassed to ground by the mixer's output filter. The filter and the remainder of the mixer can be separated to allow accessibility to the mixer crystal by unscrewing the fastening ring located at the input end of the filter.

The output end of the filter is fastened to the box located on top of the preamplifier. Housed in this box are the crystal current monitoring circuit and the preamplifier input circuit (see figure 2).

Crystal current is allowed to flow through a filter composed of L7, L8, L9, and the .001μfd and .05 μfd capacitors. This filter prevents the loss of any of the 30 mc signal from the mixer. Crystal current is measured with a meter connected across the BNC connector, located just below the base of the mixer. The total resistance of the metering circuit should not exceed 100 ohms in order to prevent a back bias voltage (which will increase the mixer's noise temperature) from developing across the crystal.

The 30 mc component of the mixer output passes on to the input coil, L12. This is a high Q coil which serves to match the mixer output to the preamplifier input. The optimum source resistance for the 7768 tube is around 700 ohms* and may vary from tube to tube. A 1N21F crystal would present a source resistance of around 300 ohms, so the transformation performed by L12 is relatively small.

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* According to General Electric.

The first two tubes are connected in a cascode configuration. Cathode current for V2 is given a choice of two paths to ground -- through L4 and through L12. L4 is merely a safety device. If L4 were omitted, and if during the adjustment of L12 the DC path between the grid of V_1 and ground were broken, a large positive grid to cathode voltage will be developed at V_1 -- an unhealthy condition to say the least.

L11 is the neutralizing coil. Its purpose is to resonate out the grid to plate capacitance of V_1, thus improving the noise temperature of that stage.

The output of the cascode is coupled to the last stage, V_3, by means of transformer T_1, and transformer T_2 couples the output of V_3 to the preamplifier output. T_2 is built to provide close to a 50 ohm output impedance.

There is enough output power from the preamplifier to drive a NRAO standard receiver back end.

For more information on this low noise mixer-preamplifier see Development and Test Data on Low Noise Mixer-Preamplifiers.

Construction Hints

Details given here for the construction of another mixer-preamplifier will be based on the assumption that a previously built unit is available for comparison.

Mechanical drawings can be found in Development and Test Data on Low Noise Mixer-Preamplifiers (see "7768 Ceramic Tube Amplifier").

The mixer used will, of course, depend on the frequency at which the unit is to operate. Past experience indicates that the output section should be similar to the one shown in the drawings referred to above. The type of RF section used will depend on the frequency.

The wiring of the preamplifier is fairly straight forward. Many of the radio frequency chokes used are wound on small toroide coil forms. The exact values of all the RFC's L1 through L10 are, of course, not critical; the method of constructing these coils may be changed to suit the builder.

However, the remaining coils are critical. The neutralizing coil, L11, should not be wound on an iron core and should be mounted so that the capacitive coupling to ground is a minimum.

The input coil L12 is mounted inside the large square box. The grounded end is soldered to the center of a 1/4 inch square brass bar located in top of the box. The other end of the coil is supported by a teflon rod fastened to the bottom of the box.

Connections to the ceramic tube filaments are made via pins removed from a seven pin tube socket. The remaining connections can be made by soldering directly to the tubes. The tube filaments should be turned on several minutes before soldering and should remain on during the soldering in order to prevent damage to the seals of the tubes. A high melting point solder should be used -- regular solder could melt from the heat of the tubes. See General Electric's suggestion on tube socketry for the 7768 tube.

Adjustments

Voltage checks

Before any adjustments are made, the plate current through each tube should be computed from the measured voltage drops across the 4000 ohm plate resistors. A value of 20 to 25 ma is acceptable. The grid bias voltages, as measured across the cathode resistors, should be around 0.5 volts. See figure 4 in General Electric's specifications for the 7768 tube for information concerning the effects of tube voltages and current on the tube's noise figure.

Coupling transformers T_1 and T_2

T_1 and T_2 should be adjusted for maximum gain and bandwidth. Connect the output of a sweep generator to the input of V_1 (between the grid and ground) and load the input with a 47 ohm resistor. Adjust the tuning slugs of T_1 and T_2, and the secondary turn spacing of T_2 for best gain and bandwidth. A bandwidth of at least 10 mc at the 1 db points, centered at 30 mc, should be possible. The turn spacing of the secondary of T_2 should be adjusted so that the output impedance of the amplifier is close to 50 ohms. The Boonton RX Meter, type 250-A, can be used to measure the output impedance. Changing the turn spacing of the secondary of T_2 will change the bandpass of the amplifier. Therefore, the bandpass and output impedance measurements should be repeated until the desired conditions are reached.

Neutralizing Coil, L11

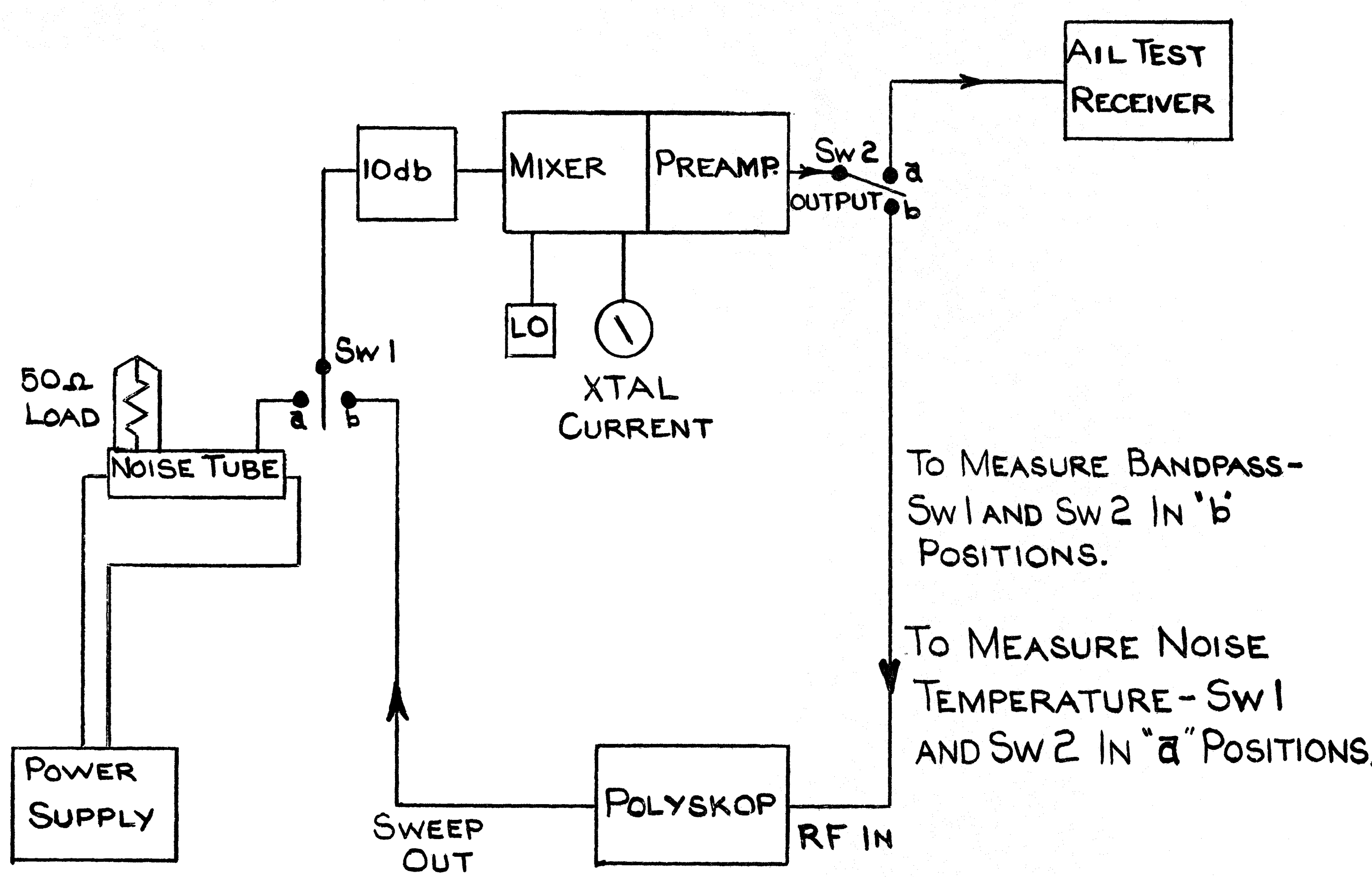
To adjust L11:

1. Disconnect the heater of V_1
2. Connect a 30 mc signal generator to the input of V_1 (grid to ground).

3. Monitor the preamplifier output with an AIL test receiver or equivalent.
4. Adjust L11 for <u>minimum</u> 30 mc output as indicated by the test receiver.
5. Reconnect the heater.

<u>Input Coil, L12</u>

The adjustment of the input coil, L12, is extremely important, for the adjustment of this coil largely determines both the noise temperature and the bandpass of the preamplifier. Below is shown a test set-up which will make this rather difficult adjustment a little easier to make.



This system will allow the alternate measurement of both noise temperature and bandpass. An improvement of this system would be to replace the Rhode and Schwarz Polyskop, type SWOB, with an RF sweep generator and suitable detector so that the system RF bandpass, not just the IF preamplifier bandpass, can be measured.

Both the input and output taps on L12 should be adjusted to give the lowest possible noise temperature and the widest possible bandpass. A noise temperature at least as low as 300 °K to 400 °K and a bandpass of at least 6 mc at the 3 db points and centered at 30 mc should be obtainable. Note that T_1 and T_2 were previously adjusted to give a bandpass wide enough so that the overall bandpass will be determined mainly by L12.

V. LOCAL OSCILLATOR STABILITY TESTS

A Simple Check of Frequency Stability

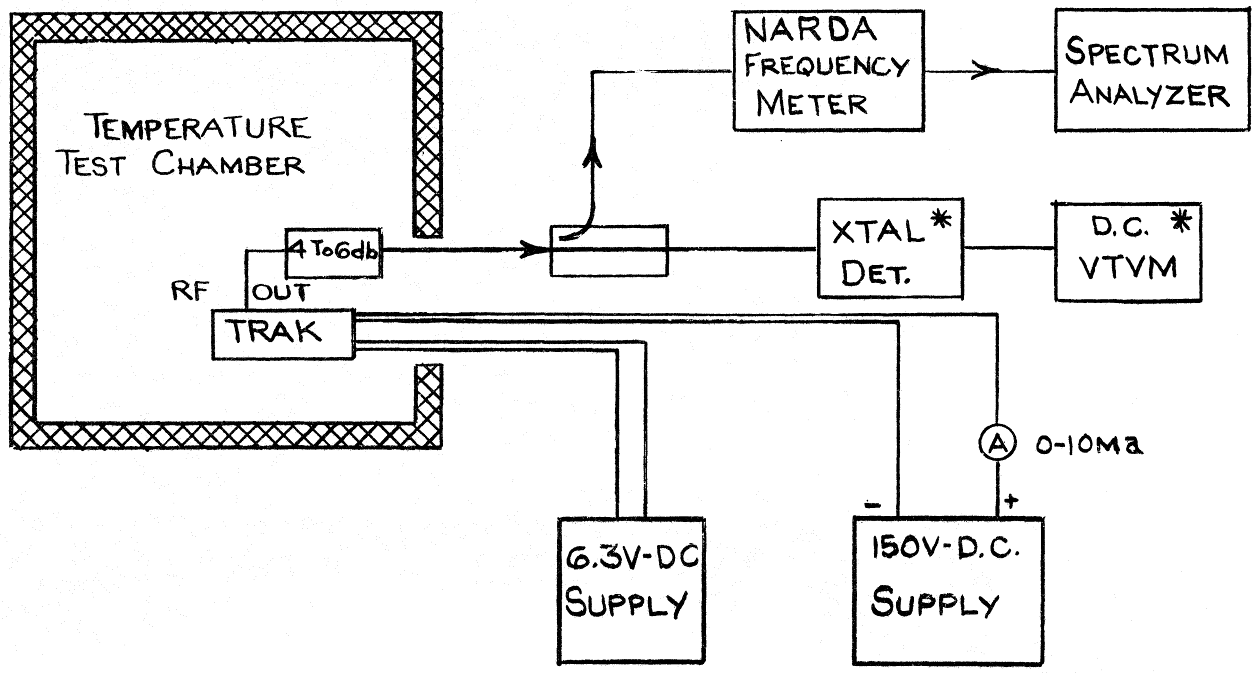
When our first TRAK oscillator was received, a simple check of its frequency stability was made. The oscillator was connected to regulated power supplies. Its RF output was connected directly to the HP Frequency Counter and Transfer Oscillator. The frequency of the oscillator was checked every hour or so; the results are shown below:

Time	Frequency (mc)
1004	1381.7
1104	1381.6
1224	1381.6
1302	1381.6
1400	1381.7
1600	1381.6
1700	1381.7

Tests made sometime later give a better picture of the frequency and amplitude stability of the oscillator. The test set-ups and results are shown below.

Effects of Temperature Changes

The arrangement shown below was used to measure the local oscillator frequency and output as a function of frequency. The spectrum analyzer was used to check for squegging, an occurrence in some of the TRAK oscillators. (This is described later.)



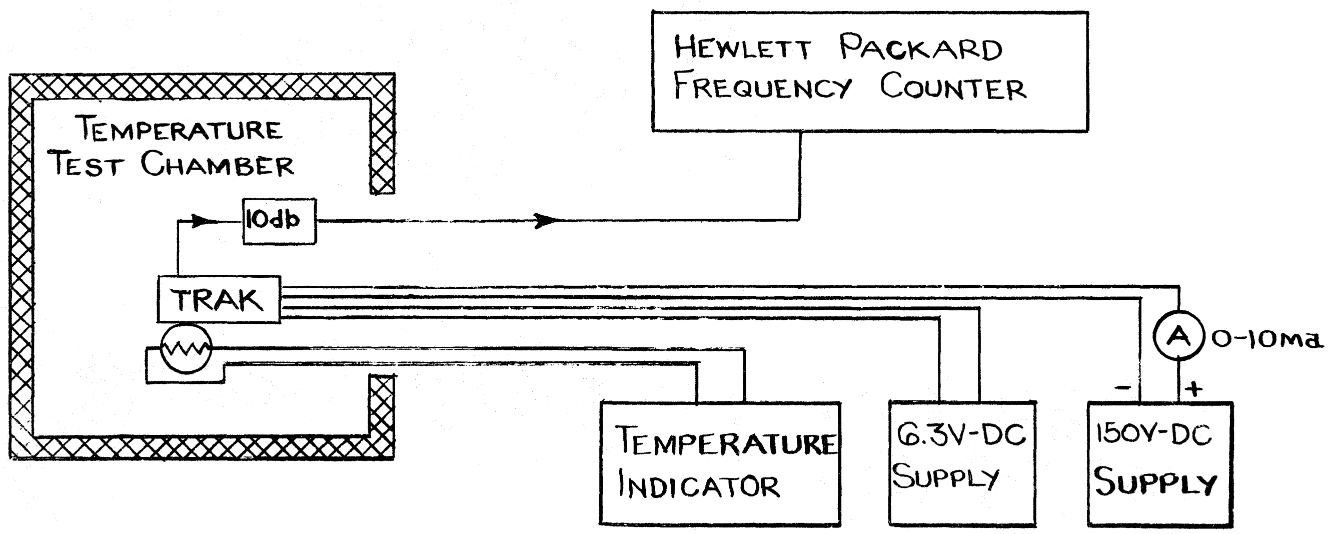
* A power meter was not available.

Results:

	Temperature (°F)	Frequency (mc)	Detector Output (volts)
750 mc. oscillator	34	767	1.72
	62	767	1.69
	80	767	1.71
	110	767	1.70
1400 mc. oscillator	30	1402	0.780
	56	1401	0.810
	85	1401	0.825
	94	1401	0.820

Effects of Voltage Changes

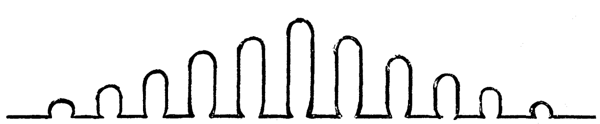
Set-up:



The results are shown in figures 4 and 5. As can be seen, the frequency of the TRAK oscillator is fairly insensitive to voltage change.

"Squegging"

Several of our TRAK oscillators have, under certain conditions, appeared to oscillate at several different frequencies. The pattern displayed on the spectrum analyzer is sketched below. The pipes are about one to two megacycles apart. If the oscillator was being used as a receiver's local oscillator when this odd oscillation occurred, the cyrstal current would decrease slightly, the detector current would pin the meter (at least 10 db decrease in IF gain was necessary to bring the detector current meter back on scale), and the phase detector output would go off scale.



When informed of this problem, TRAK Microwave Corporation suggested that it might be squegging. They recommended that the grid resistor, R_G, be reduced from 2.2 K, the value listed on the oscillator specification sheet, to 1.8 K, provided that the plate current does not exceed 12 ma. If this does not work, they suggested that varying the feed back adjustment might help. Changing the grid resistor to 1.8 K has stopped the squegging of the oscillators which have given this trouble. The chances of squegging being a problem are small if, when oscillator is tuned to the high end of the tuning range, squegging does not occur over a temperature range of 0 °C to 40 °C when the grid terminal is touched or when the oscillator output is connected to a large mismatch through a 4 db attenuator.

VI. TOTAL FRONT END STABILITY AND PERFORMANCE

Stability Runs as Part of a Complete Receiver

Many hours of stability runs have been made using the front ends in conjunction with standard receiver back ends. Runs have been made with the receiver switching between unequal temperature as well as equal temperatures. Several typical records are shown in figures 6 through 9. The statements "N_2-300," "300-300," and "Hot-300" indicate signal temperature (left of dash) and the comparison temperature (right of dash). "Hot" refers to the hot source in the AIL Hot-Cold Body Standard Noise Generator, "N_2" refers to a nitrogen load, and "300" refers to a 50 ohm load at room temperature. Much more information was obtained when one front end was connected to two back ends and the two back end outputs compared. Figures 6 and 7 are records made in this manner. If instability occurred in the front end it would show up on both outputs, but if instability occurred in either of the back ends it would, of course, show up only on that back end's output. Many of the instabilities observed were back end instabilities.

Use of an Isolator

An attempt was made to determine whether or not an isolator inserted between the diode switch and the mixer would improve receiver stability. Perhaps some instability would occur through changes in noise temperature caused by changes in antenna VSWR. A way to check the receiver sensitivity to changes in antenna VSWR is to simply connect a tunable load to the "signal" input of front end, change the VSWR of the load, and observe the phase detector output of the receiver. This was done for two different comparison load temperatures using an isolator, and for the same different comparison load temperatures without using an isolator. A summary of the receiver records is shown in figure 10. Two things should be noted:

1. The addition of an isolator between the diode switch output and the mixer did reduce the effect of changes of input VSWR.

2. Lowering the comparison temperature so that

$$k = \frac{T_S + T_R}{T_C + T_R} \neq 1$$

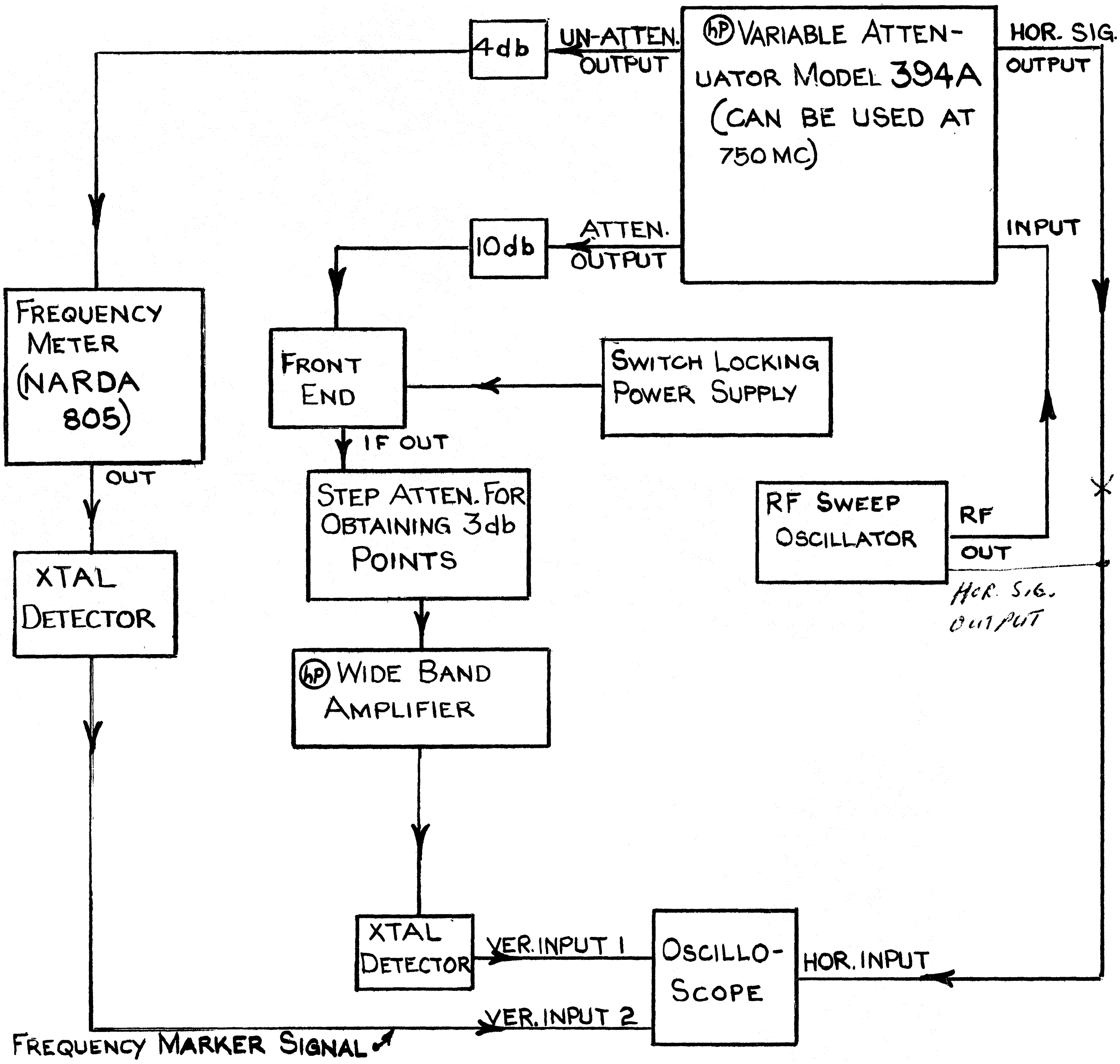
where T_S = signal temperature, T_C = comparison temperature, and T_R = receiver noise temperature ($\sim$ 500 °K), did not change the effect of changing input VSWR.

If it had been a change in noise temperature, resulting from a change in input VSWR, that caused the phase detector output to change, the change in phase detector output for a given change in input VSWR would be smaller, or non-observable, when the comparison temperature was equal to the signal temperature -- k, as defined above, would then equal one. This was not the case as can be seen on the graphs. There is even some question as to whether or not the isolator actually did help. Changes in the line length between the mixer and the diode switch also change the effect on the phase detector output due to input VSWR changes, and the line length did change by several inches when the isolator was inserted into the circuit. So, perhaps the only thing this experiment has to tell us is that changes in receiver noise temperature, resulting from changes in input VSWR, are not harmful.

The receiver was run for several hours with an isolator inserted as described above. The record produced was compared with records produced without an isolator. No difference in recevier stability was noticed.

Bandpass

To measure the front end bandpass, the system shown below was used.



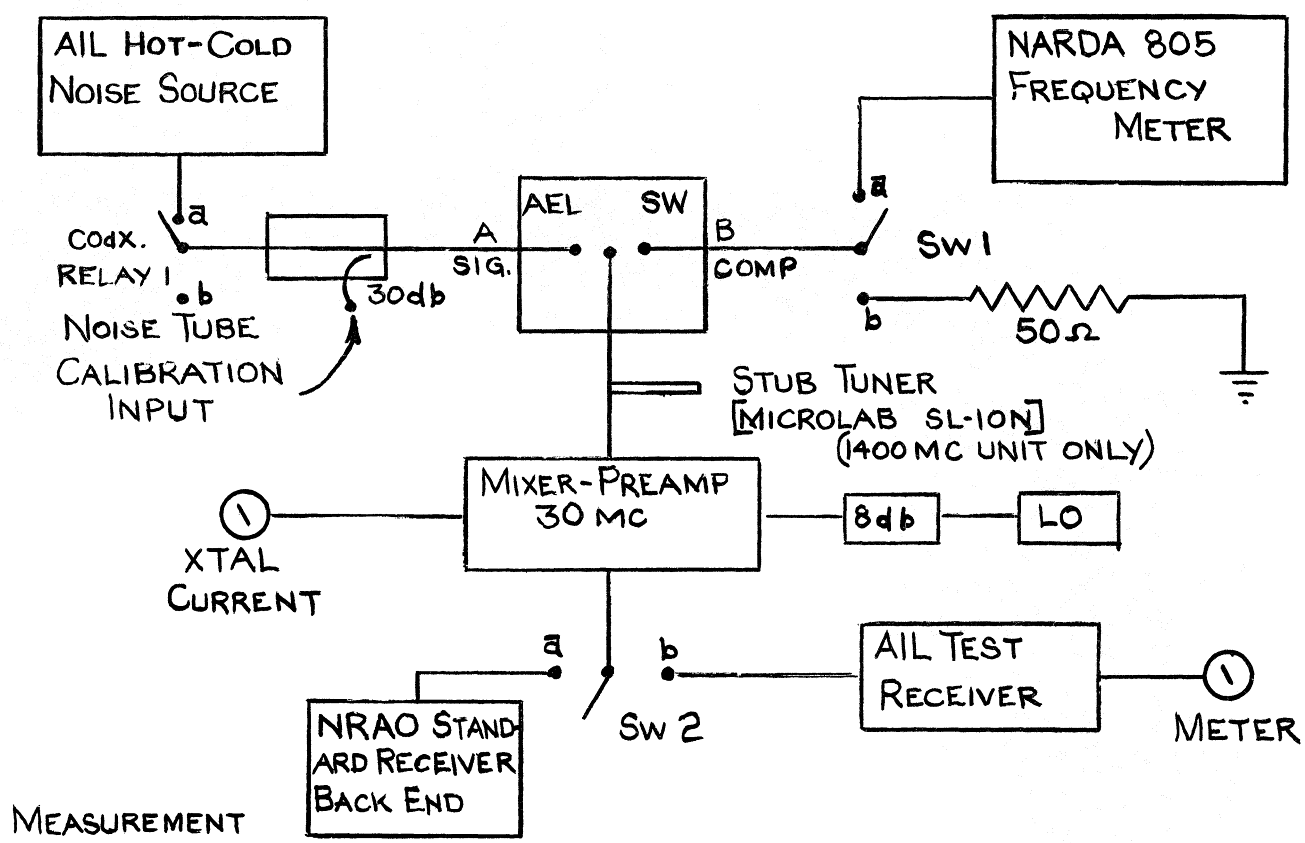
The bandwidth for the 1400 mc unit measured about 4 mc per channel (signal or image) at the 3 db points. A larger (at least 6 mc) bandwidth was expected. The 750 mc unit has a bandwidth of around 8 mc at the 3 db points. A flat bandpass cannot be expected as long as a single-tuned circuit is used for the preamplifier input network.

The system for bandpass measurements described above, while believed to be accurate, did not give the same bandpass indication obtained with a 30 mc sweep generator (see Adjustments - Input Coil, L12), especially on the 1400 mc unit where the bandpass as measured with the 30 mc sweep generator exceeded 6 mc.

Noise Temperature

The noise temperature of the 750 mc and 1400 mc front ends was measured at several local oscillator frequencies throughout the tuning range of the local oscillator. On the next few pages are shown the test set-up and procedure used in making this measurement and the results of the measurement.

Set-up:



MEASUREMENT PROCEDURE — SWITCH POSITIONS

STEP	AIL NOISE SOURCE	COAX. RELAY	SW 1	SW 2	AEL SW	NOTES
1	—	a	a	—	B	ADJUST FOR LO FREQUENCY WANTED
2	COLD	a	b	a	SWITCHING	ADJ. STUB (1400 MC UNIT) AND XTAL CURRENT FOR BEST NOISE TEMP. (MIN. φ DET. READING)
3	{COLD / HOT	a	b	b	B	MEASURE TR.

Results:

	Local oscillator frequency (mc)	Y factor (db)	T_R (°K)
1400 mc unit	1330	1.85	490
	1340	1.85	490
	1350	1.85	490
	1360	1.75	530
	1380	1.75	530
	1390	1.75	530
	1400	1.75	520
	1410	1.78	520
	1420	1.78	520
	1430	1.75	530
	1440	1.75	530
	1450	1.75	530
750 mc unit	750	1.85	460
	740	1.80	470
	730	1.80	470
	720	1.76	480
	710	1.71	490
	700	1.72	490
	760	1.80	470
	770	{1.82 1.83	465
	780	1.80	470
	790	1.83	460
	800	1.84	460

Sensitivity to Line Voltage Changes

One of the more remarkable characteristics of these two front ends is their remarkable insensitivity to line voltage changes. A very simple measurement illustrated this. One of the front ends was connected to a standard back end. The entire system was set for switched operation with a nitrogen load (750 mc unit), or an antenna (~60 °K - 1400 mc unit) as the signal source and a load at room temperature as the comparison load. Line voltage was supplied to the front end through a Variac. With the receiver's recorder running, the line voltage supplied to the front end was varied between 125 volts to the lowest value at which the unit would function. The results for both front ends are shown in figures 11 and 12. As can be seen, no change in receiver output is observed over a range of 125 volts to 80 or 90 volts. The 300 volt supply is the first component to complain about the low line voltage, and it does so by dropping its output to around 250 VDC. This insensitivity to line voltage changes is accredited to the good regulation of both the 300 volt supply and the regulated DC filament supply.

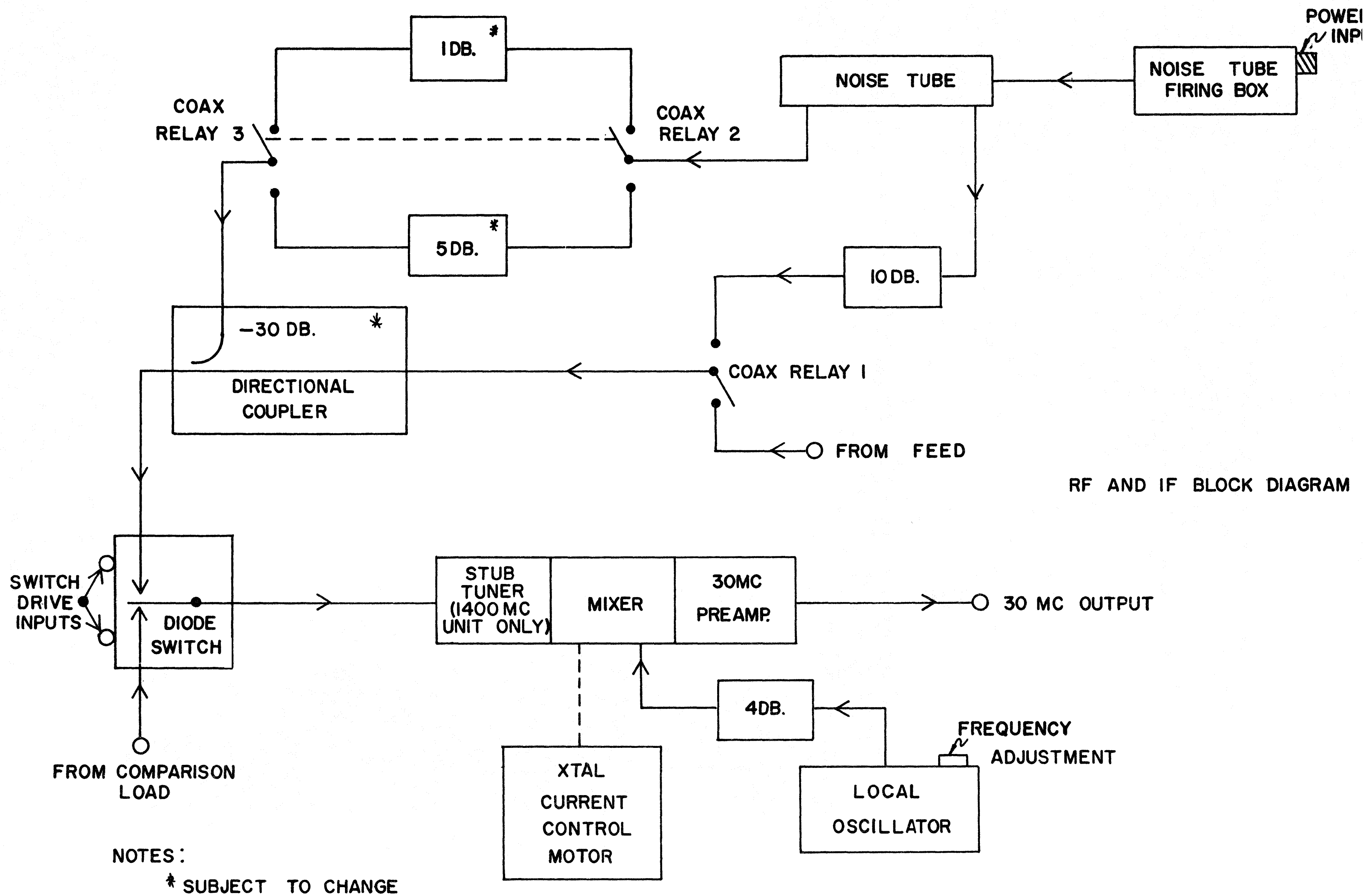
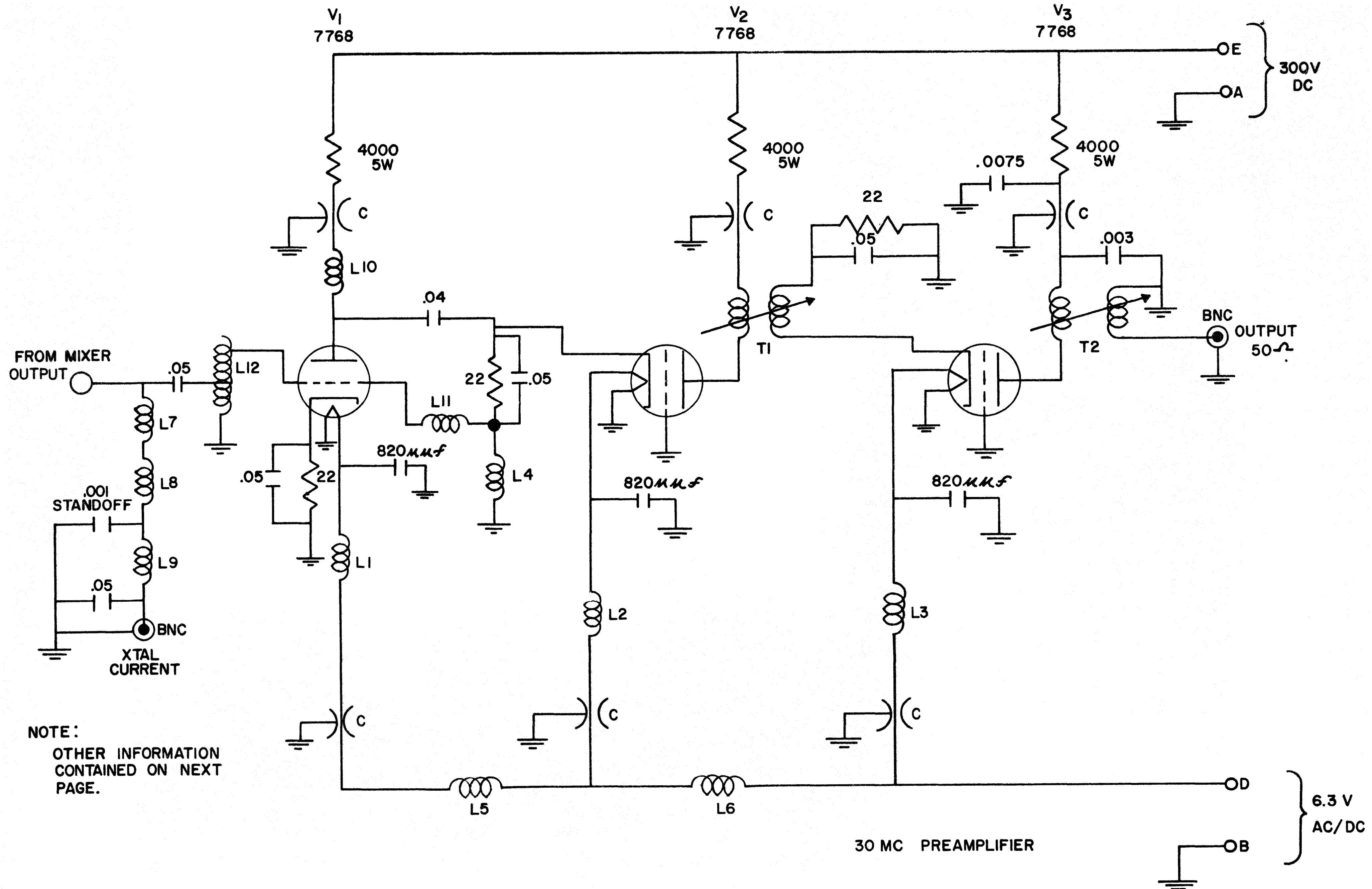

RF AND IF BLOCK DIAGRAM
POWER INPUT
NOISE TUBE FIRING BOX
NOISE TUBE
1 DB. *
5 DB. *
COAX RELAY 3
COAX RELAY 2
10 DB.
COAX RELAY 1
FROM FEED
-30 DB. *
DIRECTIONAL COUPLER
SWITCH DRIVE INPUTS
DIODE SWITCH
FROM COMPARISON LOAD
STUB TUNER (1400 MC UNIT ONLY)
MIXER
30MC PREAMP.
30 MC OUTPUT
4DB.
FREQUENCY ADJUSTMENT
LOCAL OSCILLATOR
XTAL CURRENT CONTROL MOTOR
NOTES:
* SUBJECT TO CHANGE

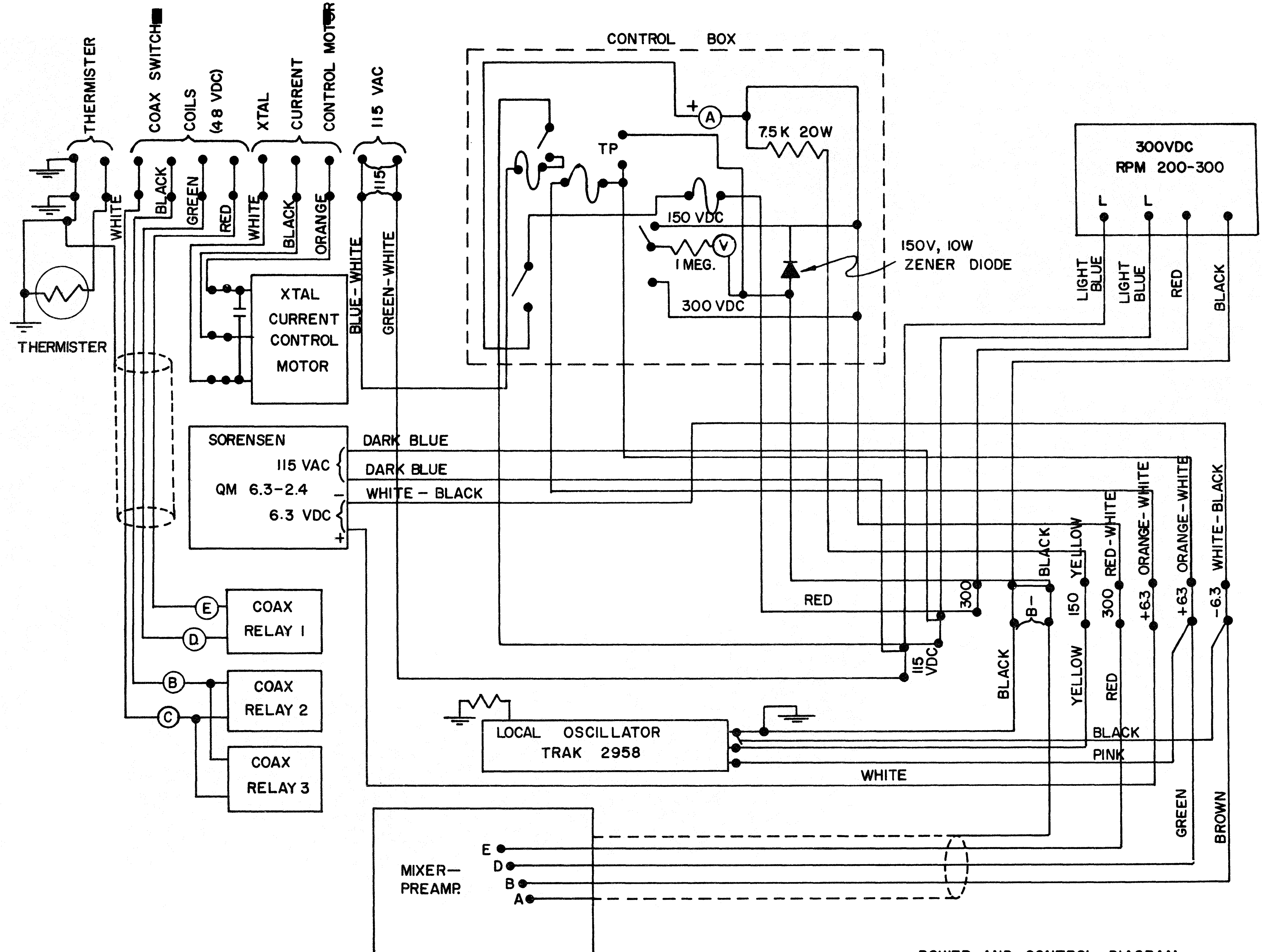
FIGURE I



NOTE:
OTHER INFORMATION CONTAINED ON NEXT PAGE.

30 MC PREAMPLIFIER

FIGURE 2



POWER AND CONTROL DIAGRAM

FIGURE 3

[redacted]FILA[redacted]ENT [redacted]ONST[redacted]T A[redacted]
6.3 VDC
L.O. TEMP. 106°F

FREQUENCY CHANGE VS. B^+ VOLTAGE

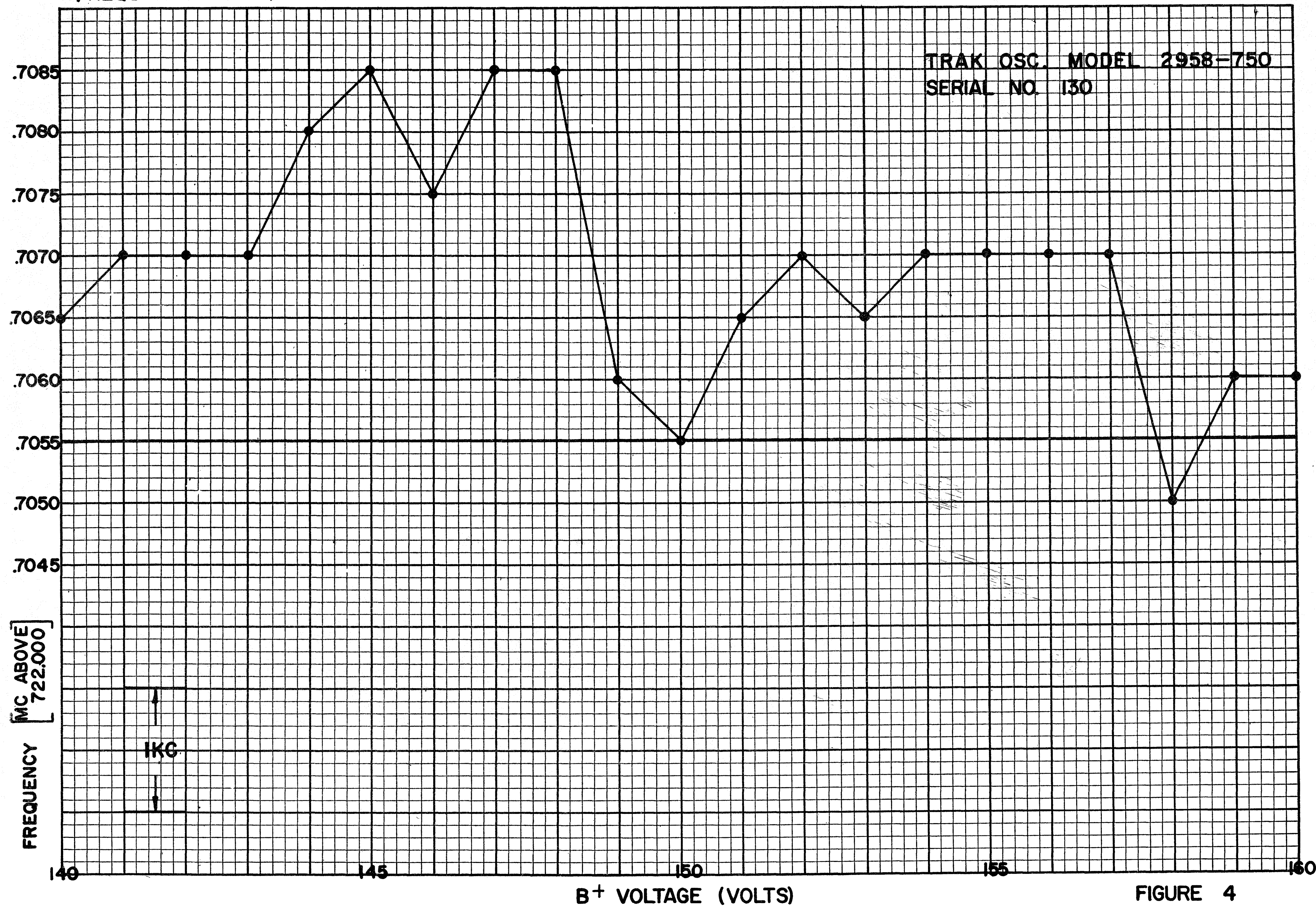


FIGURE 4

[redacted] CON[redacted]ANT[redacted] 1[redacted]DC

L.O. TEMP. 106° F

FREQUENCY CHANGE VS. FILAMENT VOLTAGE

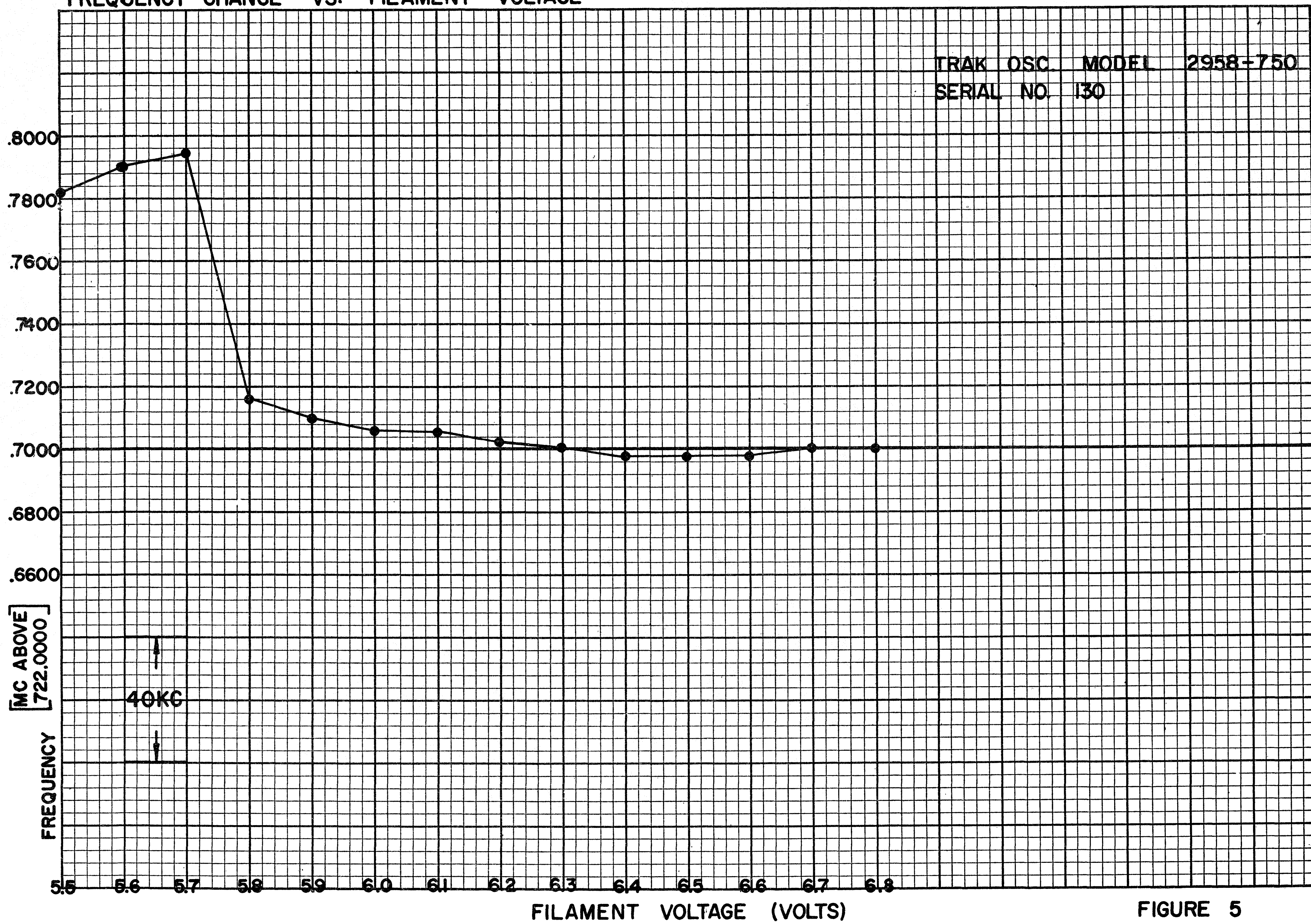


FIGURE 5

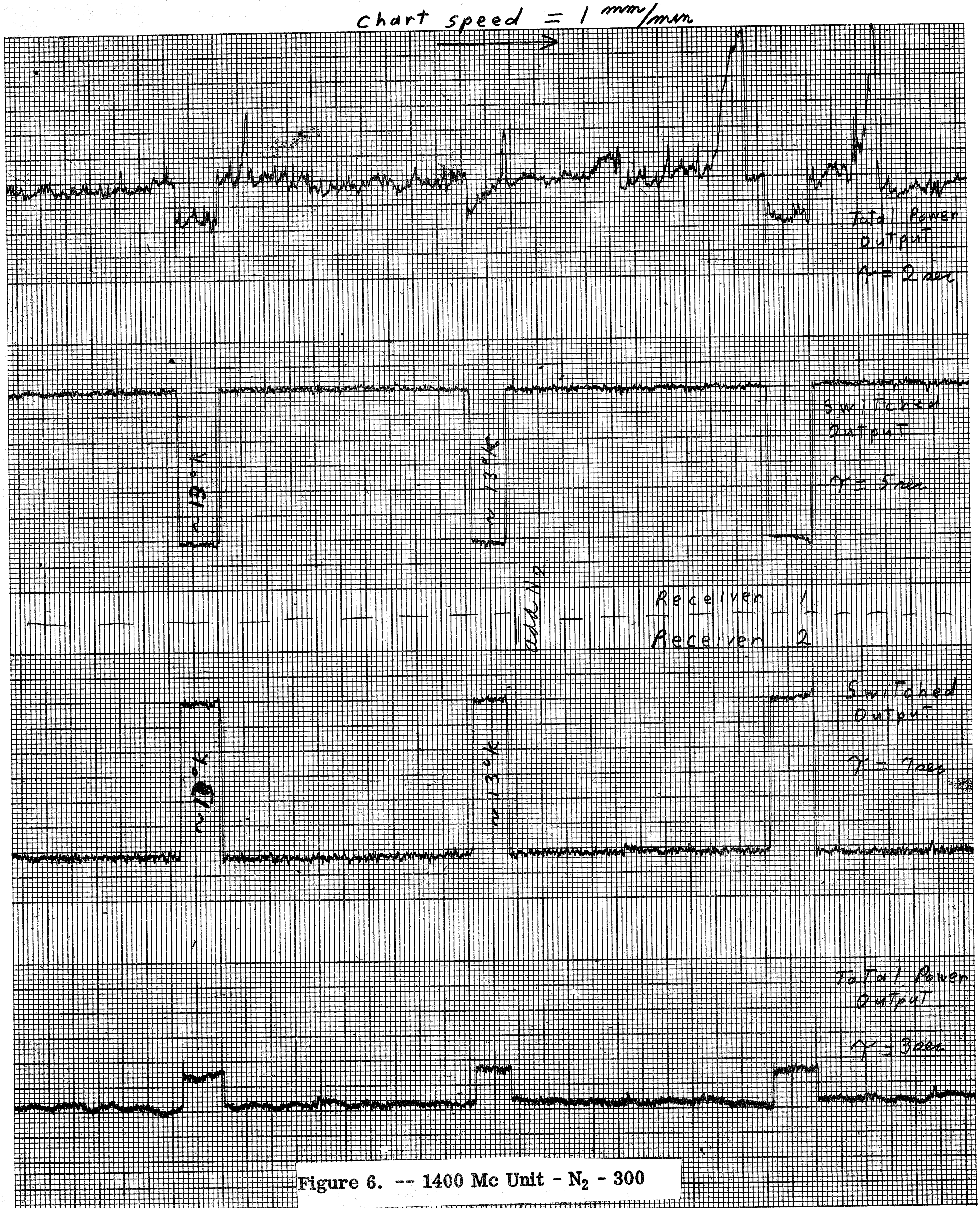


Figure 6. -- 1400 Mc Unit - N_2 - 300

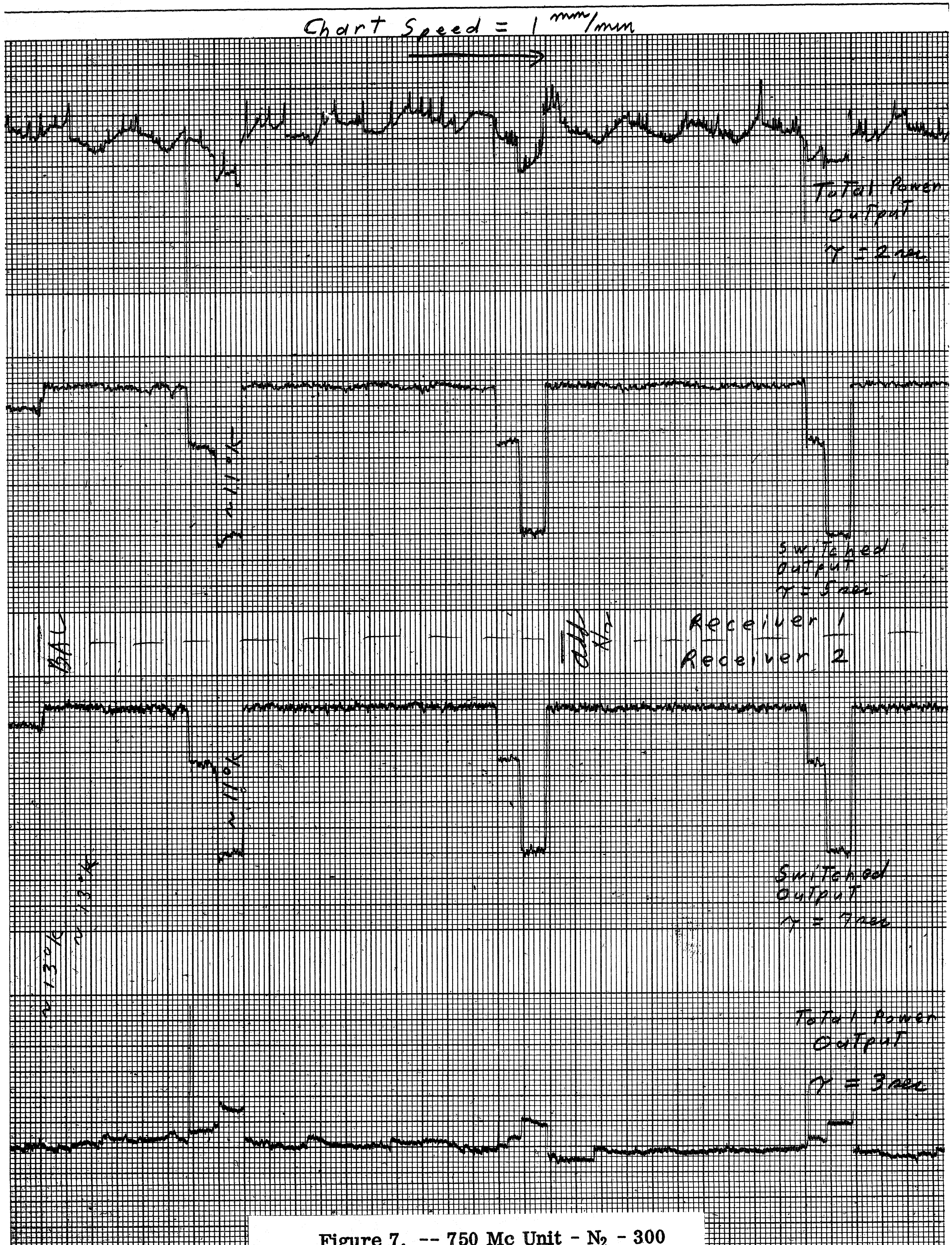


Figure 7. -- 750 Mc Unit - N_2 - 300

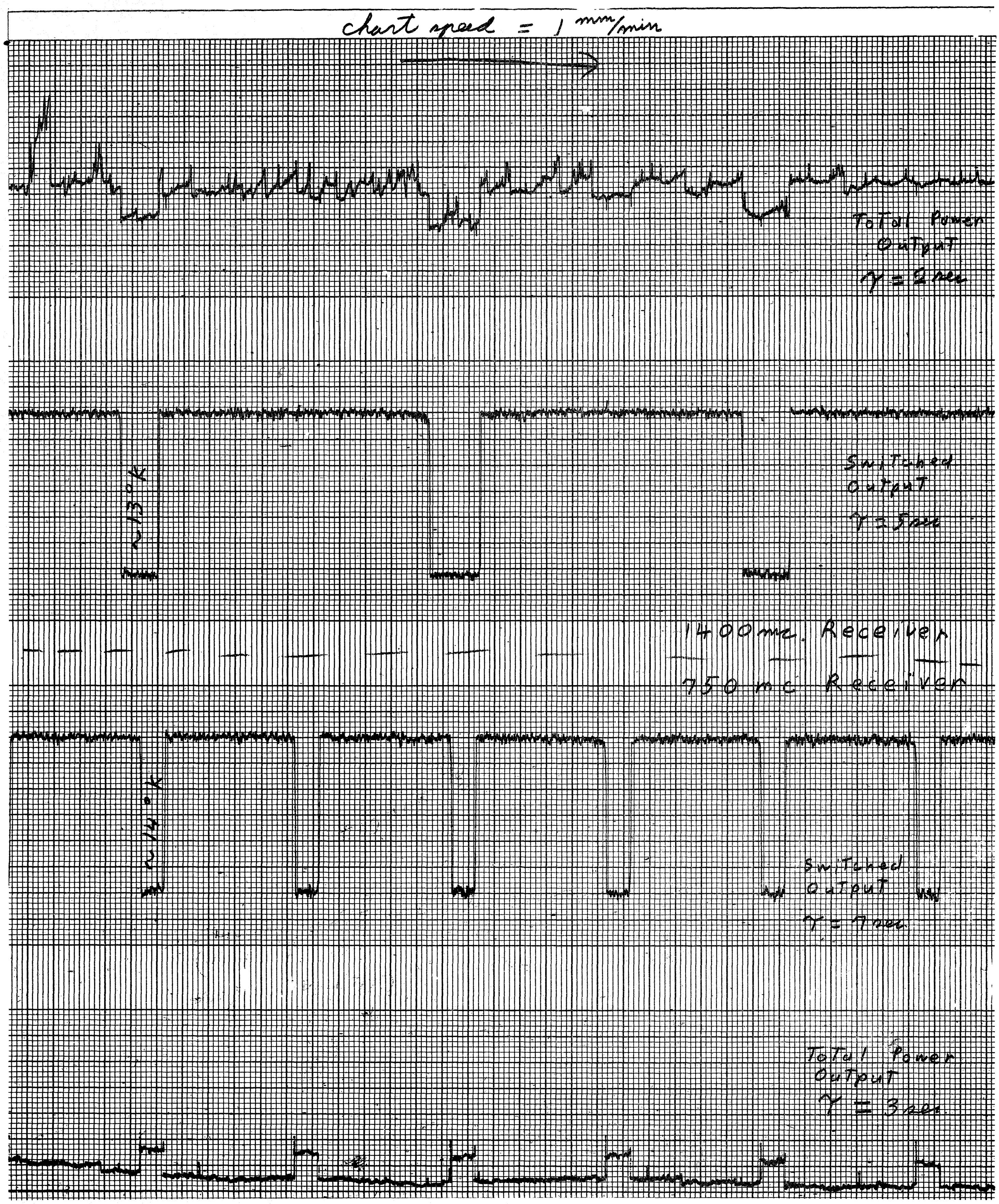


Figure 8. -- 1400 Mc and 750 Mc Units, 300-300 (750 Mc back end known to be noiser - see Figures 6 and 7)

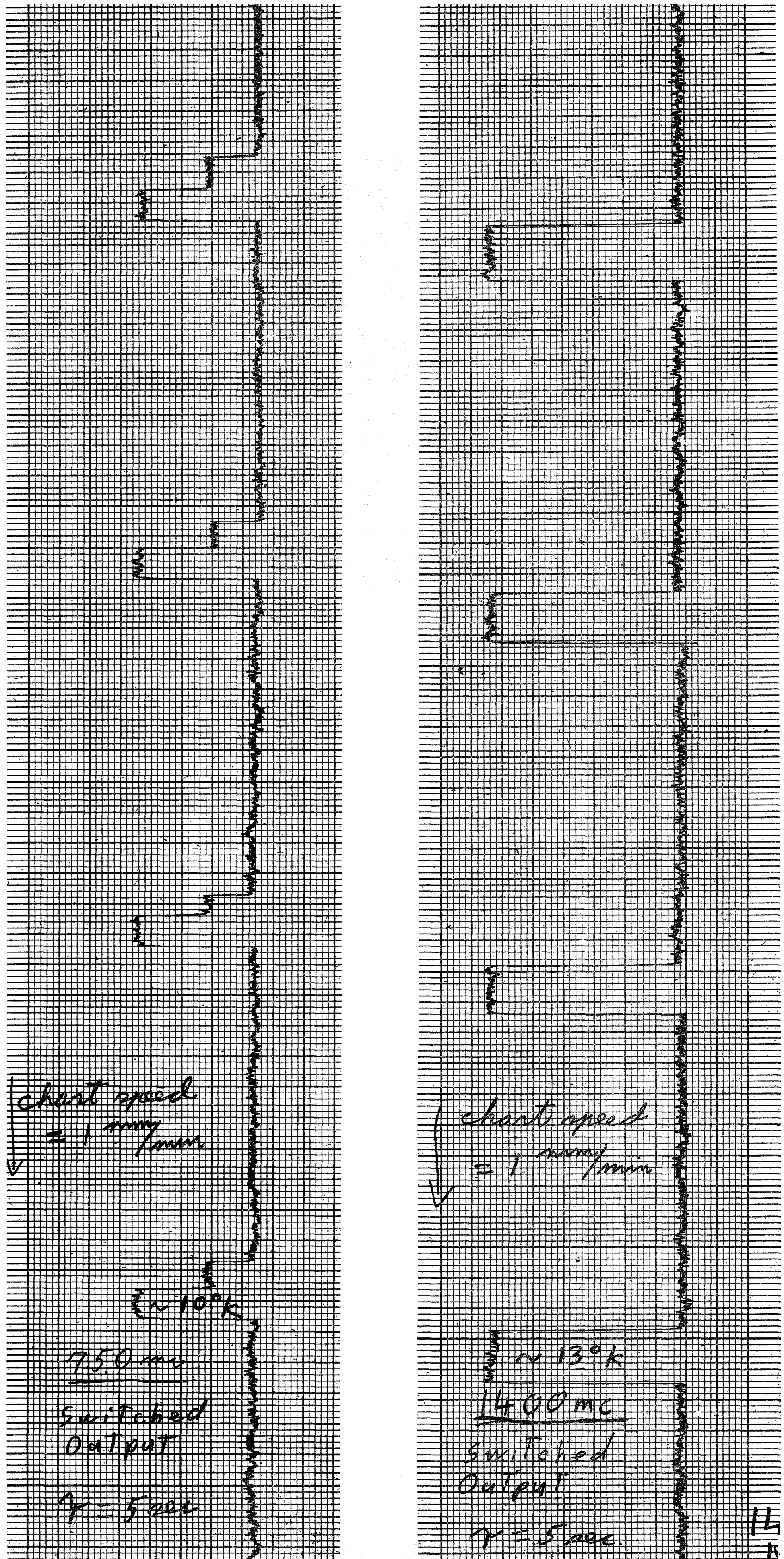
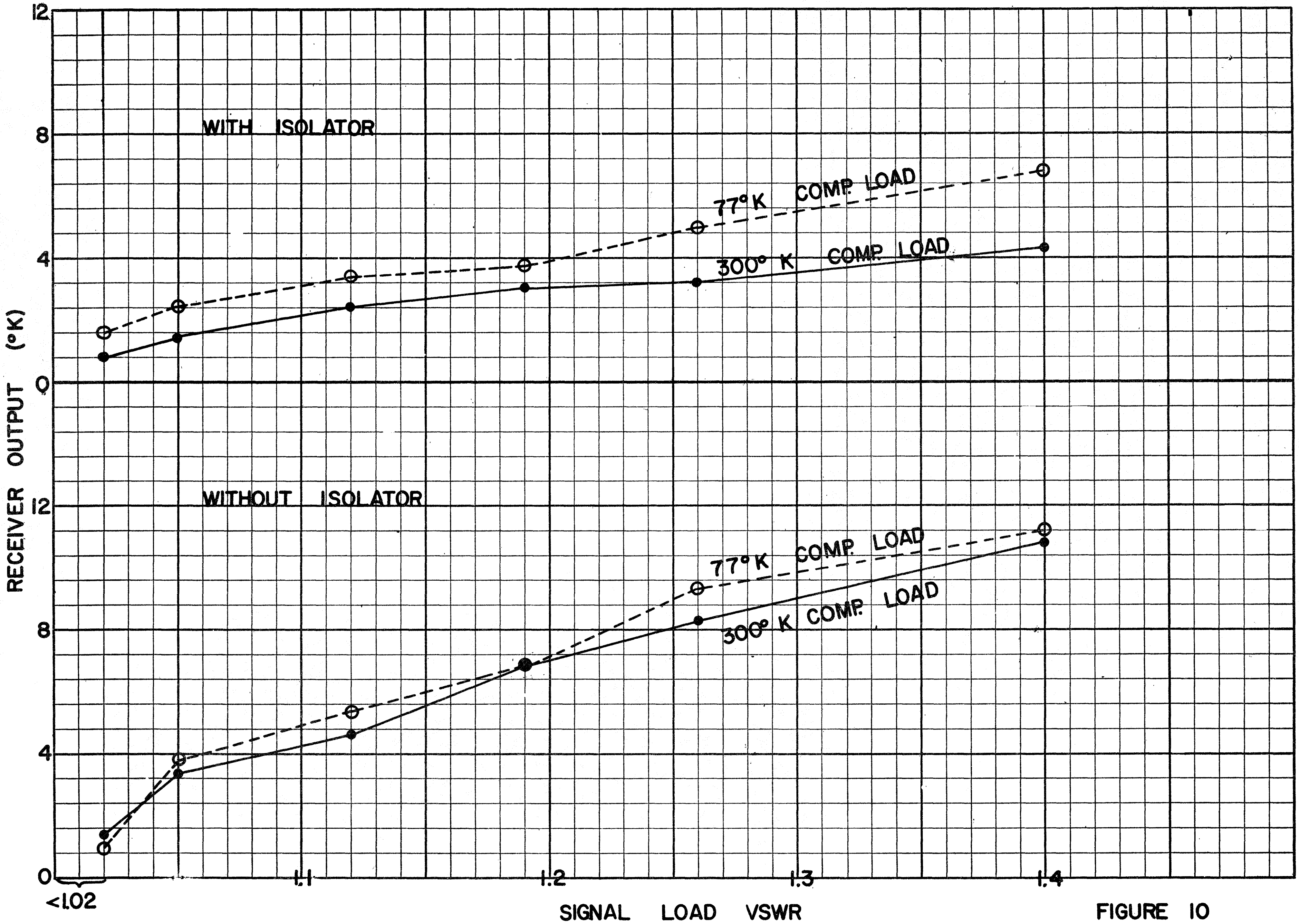


Figure 9. -- 1400 Mc and 750 Mc "Hot" – 300



RECEIVER OUTPUT (°K)
12
8
4
0
12
8
4
0
WITH ISOLATOR
77° K COMP. LOAD
300° K COMP. LOAD
WITHOUT ISOLATOR
77° K COMP. LOAD
300° K COMP. LOAD
<1.02
1.1
1.2
1.3
1.4
SIGNAL LOAD VSWR

FIGURE 10

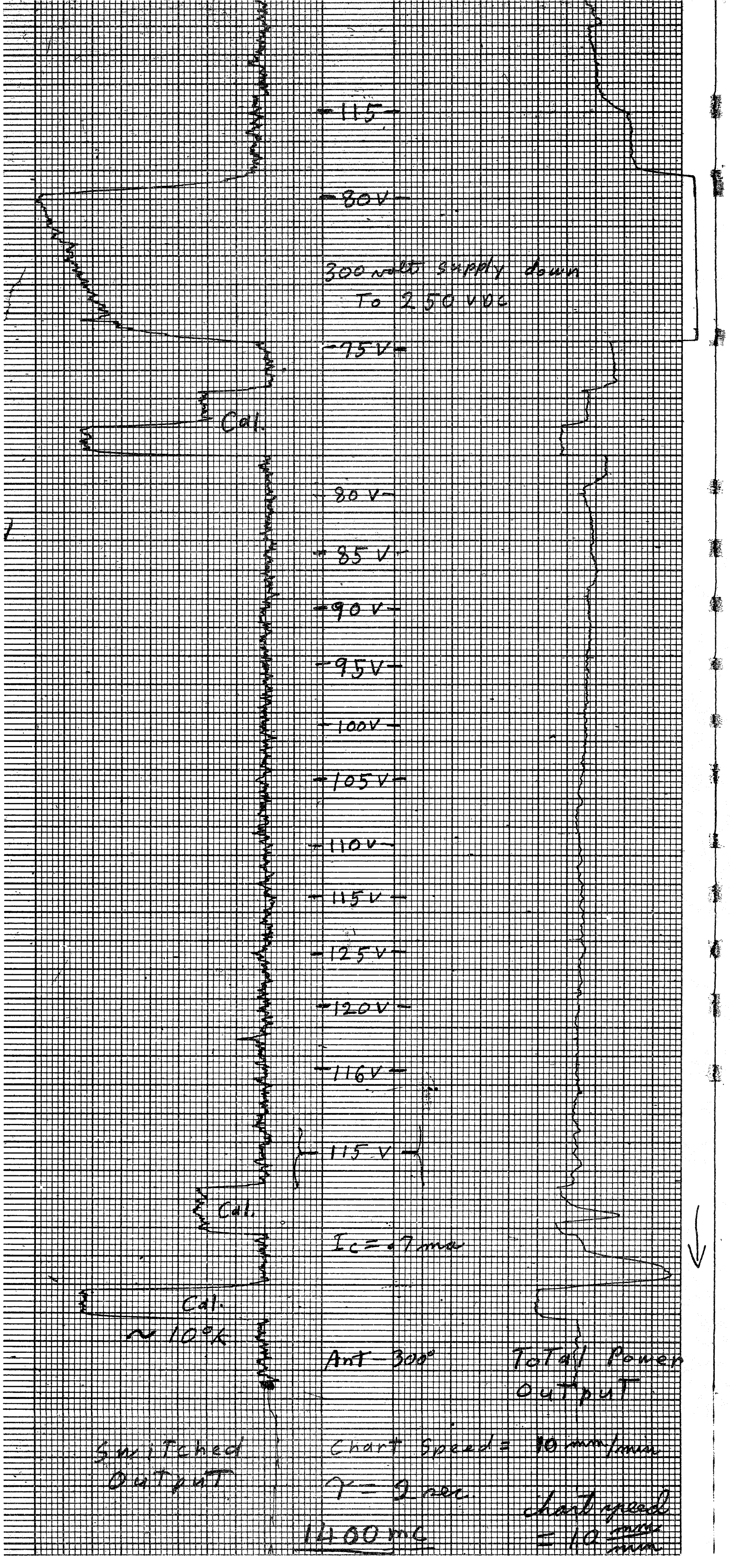


Figure 11. -- Line Voltage Tests on 1400 Mc Front End

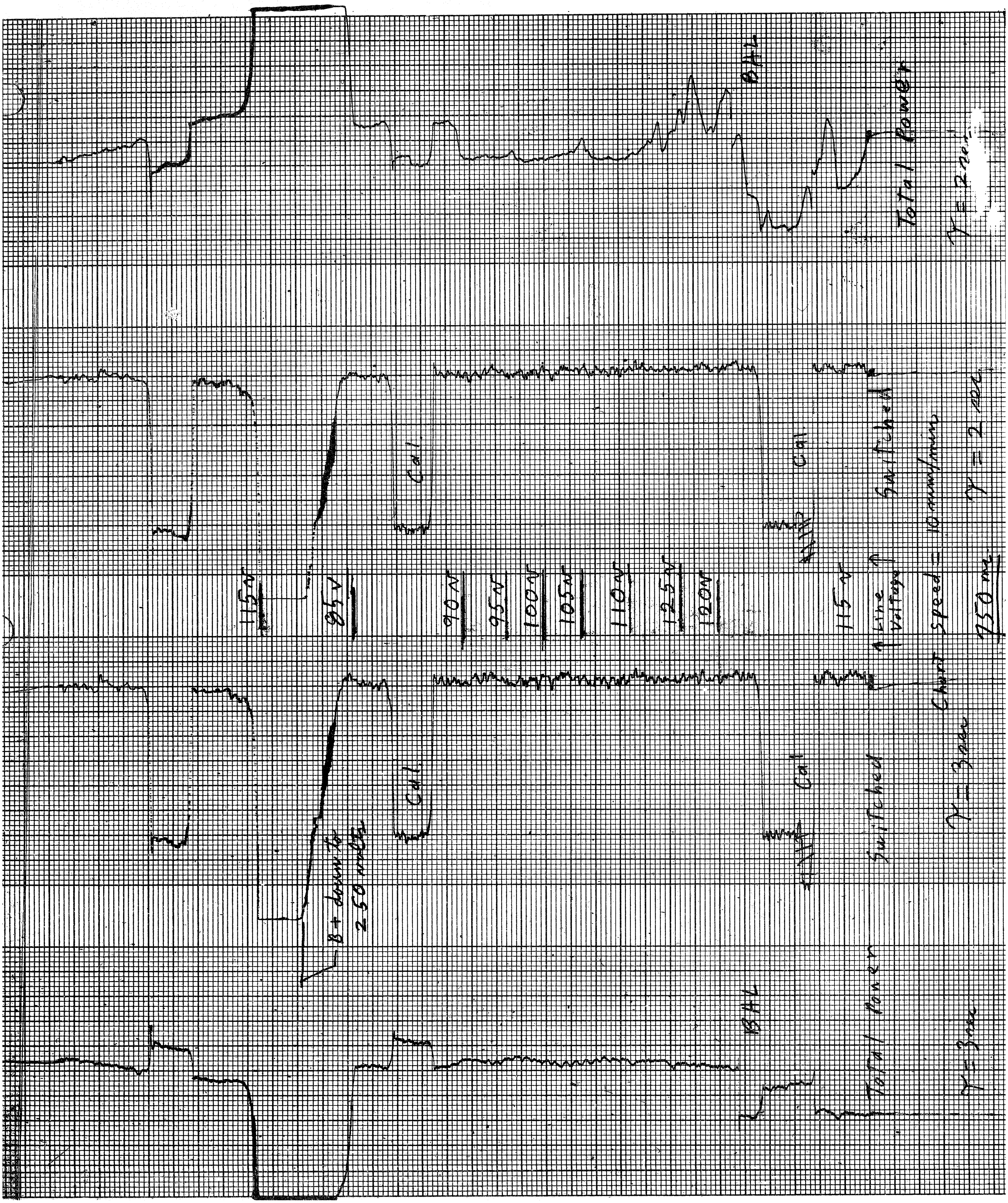


Figure 12. -- Line Voltage Tests on 750 Mc Front End (two back ends used)