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BROADBAND PULSED/CW CALIBRATION SIGNAL STANDARD FOR FIELD INTENSITY METER (FIM) RECEIVERS

Philip A. Simpson

Electromagnetics Division
Institute for Basic Standards
National Bureau of Standards
Boulder, Colorado 80302

June 1974

Final Report

Prepared for:
Calibration Coordination Group
Army/Navy/Air Force
Attn. Mr. M.L. Fruechtenicht
Redstone Arsenal, Alabama 35809
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U.S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary

NATIONAL BUREAU OF STANDARDS Richard W. Roberts, Director

CONTENTS

Page

1. INTRODUCTION....1
2. CHARACTERISTICS OF RECEIVERS....2
   2.1. Detection Modes....2
   2.2. Bandwidth of Receivers....2
   2.3. Narrowband Signals....3
   2.4. Broadband Random Signals....3
   2.5. Broadband Impulsive Signals....3
   2.6. Calibration of Receivers....4
   2.7. VSWR Effects on Receiver Accuracy....4
3. STANDARD SIGNAL SYSTEM....5
   3.1. Theory....5
   3.2. Description of Standard Signal System....6
   3.2.1. Voltage Tuned Oscillator....9
   3.2.2. YIG-Tuned Multiplier....9
   3.2.3. YIG-Locking Loop....9
   3.2.4. RF Burst Generating Section....9
   3.2.5. Monitor and Attenuator Section....11
   3.2.6. Pulse Trigger Circuit....11
   3.2.7. Avalanche Pulser and Bias Circuits....15
   3.2.8. VTO Tuning and Metering Circuits....15
   3.2.9. Filter Switching Circuit for 1 to 2 GHz, 1-Watt Signal....15
   3.2.10. YIG Bias Supply....15
   3.3. Calibration of Standard Signal System....21
   3.3.1. Calibration of Power Monitor....21
   3.3.2. Calibration of Pulse Duration....21
   3.3.3. Calibration of Step Attenuator....21
   3.4. Experimental Checks of Spectral Intensity....22
   3.5. Sample Problem of Calibrating a Receiver....23
   3.6. Maintenance....24
4. ACCURACY OF STANDARD SIGNAL SYSTEM....25
   4.1. Uncertainty of Gain Calibrations....25
   4.2. Accuracy of Bandwidth Measurements....26
5. FUTURE WORK....26
   5.1. Improvements to Prototype Standard Signal System....26
   5.2. Second Generation Standard Signal System....27
6. ACKNOWLEDGMENT....27
7. REFERENCES....28

Page

APPENDIX A. CONSTANT VOLTAGE GENERATOR FOR THE STANDARD SIGNAL SYSTEM....29
APPENDIX B. CALIBRATION CHARTS AND TABLES....31
APPENDIX C. MAINTENANCE....41

LIST OF FIGURES

Fig. 1. Time and frequency domain characteristics of a pulsed rf signal....5
Fig. 2. Photograph of Standard Signal System for calibrating Field Intensity Meter receivers....7
Fig. 3. Block diagram of Standard Signal System....8
Fig. 4. Amplifier for locking YIG tuned multiplier to VTO....10
Fig. 5. Photographs of incoherent rf bursts made on a sampling oscilloscope. Horizontal scale = 5 ns/div. (a) 1 mW, 1.5 GHz; (b) 1 mW, 3 GHz; (c) 1 mW, 6 GHz; (d) 0.1 mW, 11 GHz....12
Fig. 6. Block diagram of circuit for generating coherent rf bursts....13
Fig. 7. Pulse trigger circuit....14
Fig. 8. Avalanche pulser circuit....16
Fig. 9. Circuit for mixing bias and switching signals to diode switches....17
Fig. 10. VTO tuning circuit....18
Fig. 11. Low pass filter switching circuit....19
Fig. 12. YIG bias supply circuit....20
Fig. 13. Circuit used for calculating components of the π pad....29
Fig. 14. Monitor reading in milliwatts for 1 milliwatt reference level....30
Fig. 15. Wiring diagram for power supply chassis....44
Fig. 16. Power supply interlock circuit for protecting VTO and 1-watt amplifier....45
Fig. 17. Wiring diagram for frequency tuning chassis....46
Fig. 18. Wiring diagram of remote head....47

ABSTRACT

This report describes the constructional details and the operation of a system for calibrating microwave field intensity meter (FIM) receivers in the frequency range 1 to 12.4 GHz. The system uses known levels of CW power to calibrate the receiver, and short duration (~20 ns) rf bursts to measure the bandwidth. An error analysis of the system is given. Schematic drawings of various circuits in the system are provided along with charts and tables for facilitating computations encountered when performing calibrations.

Key words: Broadband signal generator; impulse bandwidth; receiver bandwidth calibration; rf burst generator; spectral intensity.

BROADBAND PULSED/CW CALIBRATION SIGNAL STANDARD FOR FIELD INTENSITY METER (FIM) RECEIVERS

1. INTRODUCTION

A long standing need has existed in DoD and elsewhere for an accurate and convenient means of calibrating receivers in the broadband mode. For frequencies in the VHF and even into the UHF regions methods involving the use of CW, baseband impulsive type signals, radiometric techniques have been employed [1,2,3]. However, at frequencies above 1 GHz these techniques tend to become ineffective or inaccurate.

For example, the spectrum of baseband signals usually begins to exhibit an excessive roll-off in amplitude which is associated with the finite duration of the impulse. In addition the spectrum is often complicated by stray parasitic reactances inherent in the impulse generating elements and their associate circuitry.

CW techniques suffer also since they do not truly represent the conditions receivers will be subjected to when measuring broadband signals. Furthermore, obtaining measurement data to determine the pass band characteristics requires elaborate automatic test equipment or else can be quite laborious. Also, the conversion from some measured bandwidth, e.g., 3 dB, 6 dB or 20 dB, to impulse bandwidth is usually cumbersome and complicated and quite often yields a poor approximation [4].

The technique described in this report employs a known rf signal consisting of a train of evenly spaced, short-duration, rf bursts to determine the bandwidth of the receiver. It has the advantage of concentrating most of the energy in the signal uniformly in the frequency region where the receiver is tuned and subjecting the receiver to a broadband signal similar to signals encountered in actual use. An additional advantage of this technique is that the measurement is quick, accurate and, therefore, quite convenient to make.

As originally planned, this endeavor was to develop detailed calibration procedures for all microwave receivers in the frequency range 1 to 12.4 GHz in the DoD inventory. By mutual agreement this objective was discarded and an investigation into the general techniques of calibrating receivers in the aforementioned frequency range was substituted.

2. CHARACTERISTICS OF RECEIVERS

2.1. Detection Modes

As used in this paper, the term "receiver" means a frequency selective voltmeter used to measure the strength (or amplitude) of an unknown signal. Two modes of detection are available in most receivers*, average and peak. The average mode is used to measure the average value of the envelope of the signal and is usually employed with CW signals. The peak mode measures the maximum value of the envelope of the signal. It is usually employed when measuring pulsed signals, because the average value is so small it is difficult to measure accurately while the peak value is often several orders of magnitude greater than the average value.

2.2. Bandwidth of Receivers

Several different types of bandwidths are referred to when discussing receivers. Most common in usage are the random noise bandwidth and impulse bandwidth. The random noise bandwidth is usually approximately equal to the 3 dB points on the actual voltage response curve of the receiver. It is often found experimentally by determining the "equivalent area" rectangle** of the voltage squared response curve.

The impulse bandwidth of a receiver is that equivalent rectangular bandwidth which produces a measured voltage in the receiver when it is subjected to an impulsive type signal. An equation for it is

$$BW_{imp} = \frac{V_M}{G_O (S)_{imp}} , \tag{1}$$

where

V_M = the maximum value of receiver transient response in volts as a function of time,

G_O = gain of receiver expressed as a voltage ratio, and

$(S)_{imp}$ = impulse strength of the signal in volts per Hz.

As pointed out by Larsen [5], there are many definitions of impulse strength. The definition chosen for this report is based on RMS voltages, since this value of voltage is generally used in practice.

*Sometimes a third mode, "quasi-peak" is also available. Its response is between that of the other two.

**An "equivalent area" rectangle is one which has the same area and peak amplitude as the particular response curve under consideration.

Typical bandwidths in microwave receivers range from less than 1 kHz to 5 MHz or more. The bandwidth of the final i.f. section for all practical purposes determines the bandwidth of the receiver. For certain types of signals narrow bandwidths can be employed effectively, and for other types of signals wide bandwidths have better application.

2.3. Narrowband Signals

This type of signal is defined as one which has all its energy contained within the passband of the receiver. Some examples are CW, AM and SSB modulated carriers, and FM. When measuring these type of signals, especially "weak" or low amplitude ones, it is advantageous to use narrow bandwidths so as to enhance the signal-to-noise ratio. The amplitude of narrowband signals is expressed in volts or some submultiple, e.g., microvolts.

2.4. Broadband Random Signals

A broadband signal is one which has its energy distributed over a bandwidth greater than the passband of the receiver. A random signal has the additional property of being composed of a large number of signals having components of random amplitude, frequency and phase. In this type of signal there are no clearly distinguishable pulses but rather they tend to overlap. The most common example of a random signal is thermal noise. The measured strength of random broadband signals is proportional to $\sqrt{BW}$ and is usually expressed in terms of an amplitude density function*. Units of measurement are V/Hz, or some submultiple such as μV/MHz.

2.5. Broadband Impulsive Signals

Like the previous signal, this type has its energy distributed over a bandwidth greater than the passband of the receiver. However, in this type the signal is periodic and the amplitude, frequency, and phase of the component signals have definite fixed relationships with each other. In the time domain, this signal is represented by one which does have clearly distinguishable pulses. Common examples are pulse modulated rf, ignition noise, and motor brush noise. The measured strength of this type of signal is proportional to BW; thus to enhance signal to noise ratio of this type of signal one would increase bandwidth (random noise is proportional to $\sqrt{BW}$). Units of measurement are also V/Hz, or μV/MHz.

*"Spectral Intensity" is often used but is a misnomer. In all other disciplines intensity denotes power while spectral intensity refers to volts, the square root of power.

2.6. Calibration of Receivers

In order for a receiver to measure a narrowband signal correctly, only the gain must be known. This is most easily done by applying a signal of known amplitude to the input and noting the receiver indication.

For measuring the impulse strength, $(S)_{imp}$, of broadband signals, equation (1) indicates two factors must be known, the gain and the bandwidth. However, one cannot simply know the gain-bandwidth product for if the receiver is calibrated with a known broadband signal and the bandwidth changes, the gain will be unknowingly misadjusted to compensate for the change. This in turn will cause an error when measuring narrowband signals. The same reasoning applies if the impulse supplied by the internal calibrator changes with time. The spectral distribution of the impulse will change causing one again to misadjust the gain.

The technique employed at NBS [6] to calibrate FIM receivers is to first set the gain of the receiver using an input signal of known amplitude. The internal calibrator (usually an impulse generator) is then connected to the receiver input and the meter reading is noted so that the gain may be accurately set in the field. With the gain thus set the bandwidth of the receiver is measured and a correction factor developed which is applied to the nominal bandwidth associated with the receiver. This, too, is the approach used with the Standard Signal System.

2.7. VSWR Effects on Receiver Accuracy

Receivers very often have appreciable input VSWR, 1.5 or 2. The condition is often aggravated on the more sensitive ranges where the input attenuators are removed from the signal path. Larsen [7] has shown that the input impedance varies widely within the passband of the receiver, and the point of zero phase angle and minimum VSWR do not coincide; nor does either one necessarily occur at the frequency to which the receiver is tuned. This mismatch problem can cause an error in setting the gain of the receiver if it is done on a constant incident power basis since some of the power may be reflected. A low-impedance constant voltage generator, which is unaffected by the receiver input VSWR, would reduce errors from this source and is desirable. Unfortunately, well characterized, low-impedance voltage sources in this frequency range are not readily available so a constant incident power method is used in this system. A possible means of converting this system to a constant voltage generator using a π pad is given in Appendix A.

3. STANDARD SIGNAL SYSTEM

3.1. Theory

The technique described here uses a pulsed rf signal to establish a broadband signal suitable for determining the impulse bandwidth of receivers. A consideration of the characteristics of the spectrum of this type of signal will be helpful. Figure 1 is a sketch of a pulsed rf signal in the time and frequency domains.

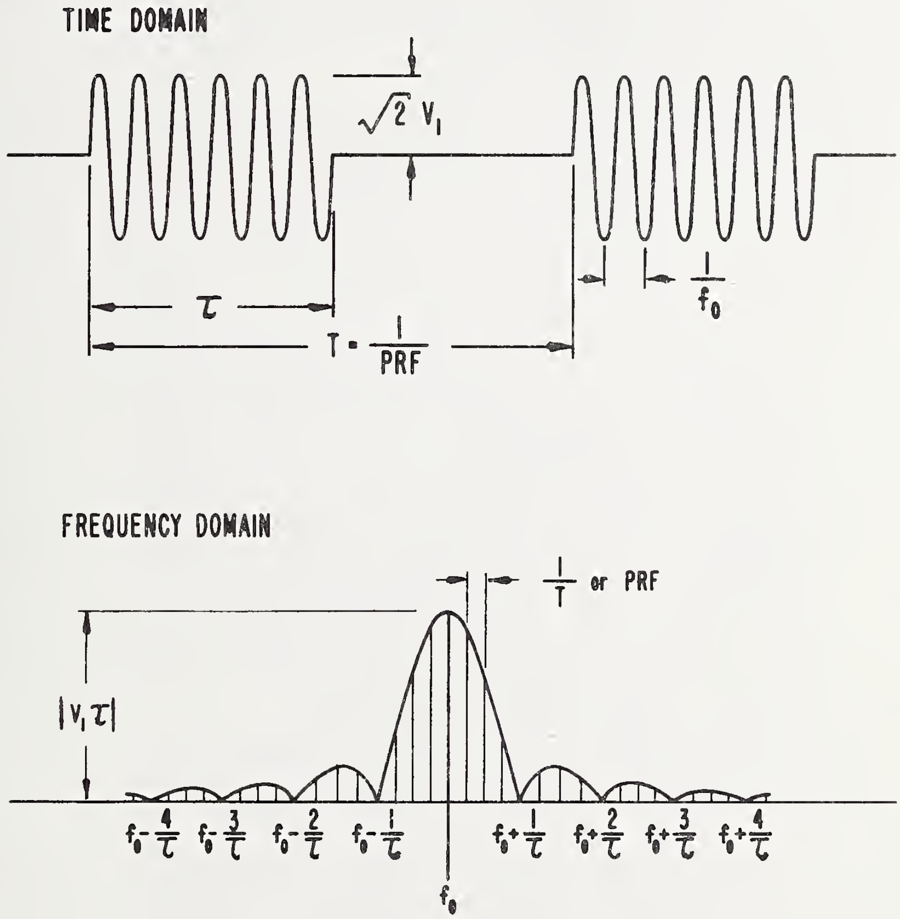


Figure 1. Time and frequency domain characteristics of a pulsed rf signal.

The spectrum of an rf signal of frequency f_o, modulated by a rectangular baseband pulse of duration, τ, and repeated at every time interval, T, is a series of lines spaced 1/T apart. To a first order approximation, the amplitude of the lines for frequencies above and below f_o decreases according to a $\frac{\sin x}{x}$ relationship where $x = \pi\,(f_o \pm f)\,\tau$. Second order effects, as discussed by Reeve [8], can be neglected when a sufficient number of cycles exist within the rf pulse. The amplitude of the lines is zero when the quantity $(f_o \pm f)$ equals some integer multiple of $1/\tau$.

The amplitude of the line at f_o can be shown to be equal to $V_1\tau$, and over a frequency range near f_o where $\frac{\sin x}{x} \simeq 1$ the impulse bandwidth of a receiver can be determined by the following equation

$$BW_{imp} = \frac{V_M}{G_o V_1 \tau} \tag{2}$$

where

V_M = maximum response of the receiver transient as a function of time in volts,

G_o = gain of the receiver expressed as a voltage ratio,

V_1 = RMS voltage of the rf carrier applied to the input of the receiver in volts, and

τ = time duration of the rf burst in seconds. If the burst is not rectangular, τ is the effective rectangular time duration.

Since the impulse strength of the signal is $V_1\tau$, the observed voltage, E_P (which equals V_M/G_O), will be $V_1\tau$ integrated over the bandwidth and can be calculated by the following equation:

$$E_P = \int_{f_o - \frac{BW}{2}}^{f_o + \frac{BW}{2}} V_1 \tau df$$

$$= V_1 \tau f \Big|_{f_o - \frac{BW}{2}}^{f_o + \frac{BW}{2}}$$

$$= V_1 \tau (BW) \tag{3}$$

A table of bandwidth vs. observed voltage has been derived from (3) and is given in Appendix B. This table assumes 1 mW input power for the bands 1-2, 2-4, 4-8 GHz and 0.1 mW for the 8-12.4 GHz band.

3.2. Description of Standard Signal System

The Standard Signal System is composed of three parts. These are (1) the power supply chassis, (2) the frequency tuning chassis, and (3) the remote head. Also included in the system is a commercial power bridge for monitoring the output power. The two chassis are housed in a rack, and the remote head is connected to the frequency tuning chassis by two shielded cables and a power cable. Figure 2 is a photograph of the system. A block diagram of the system is shown in figure 3. The following sections describe the more important parts of the system and their function.

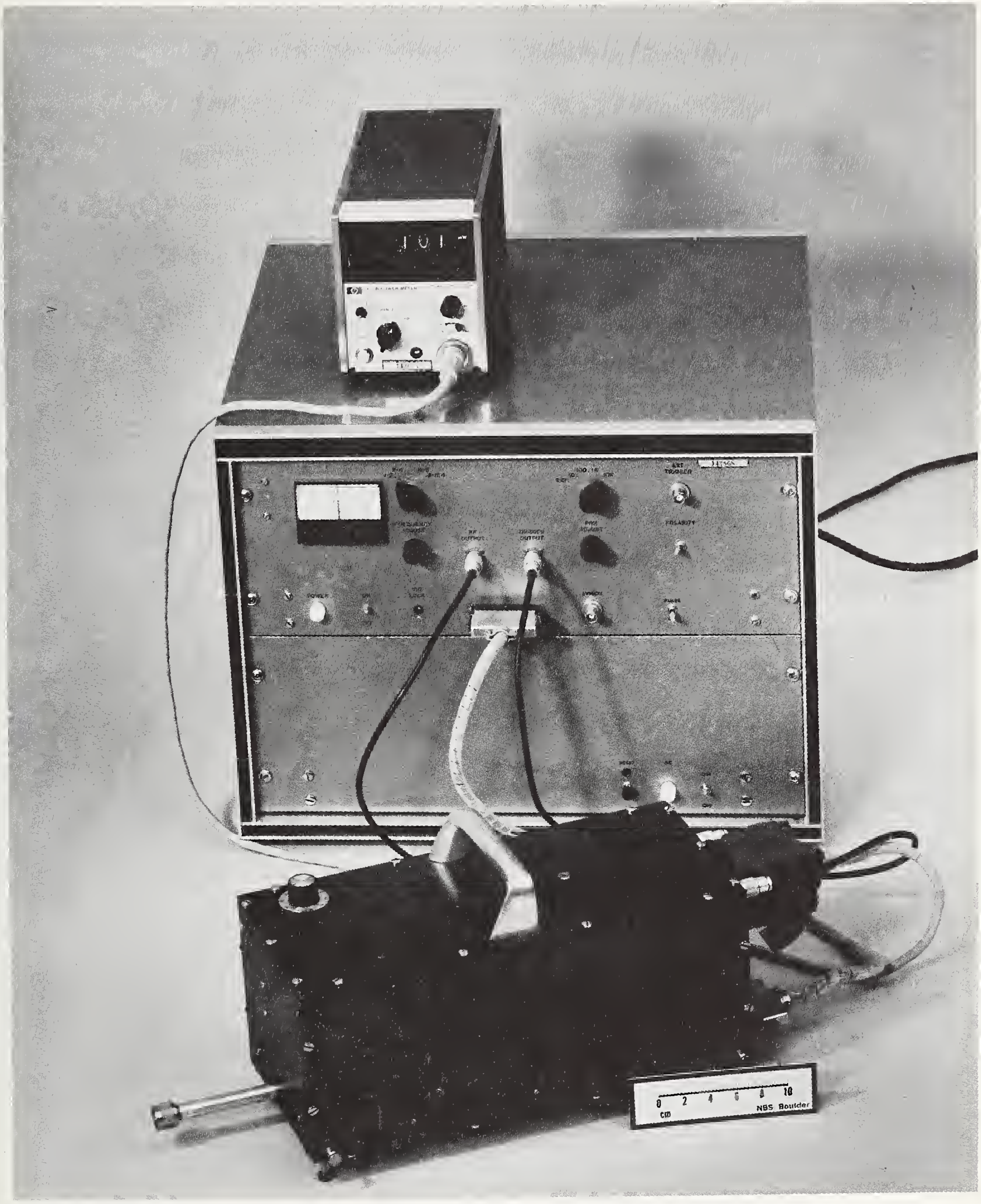


Figure 2. Photograph of Standard Signal System for calibrating Field Intensity Meter receivers.

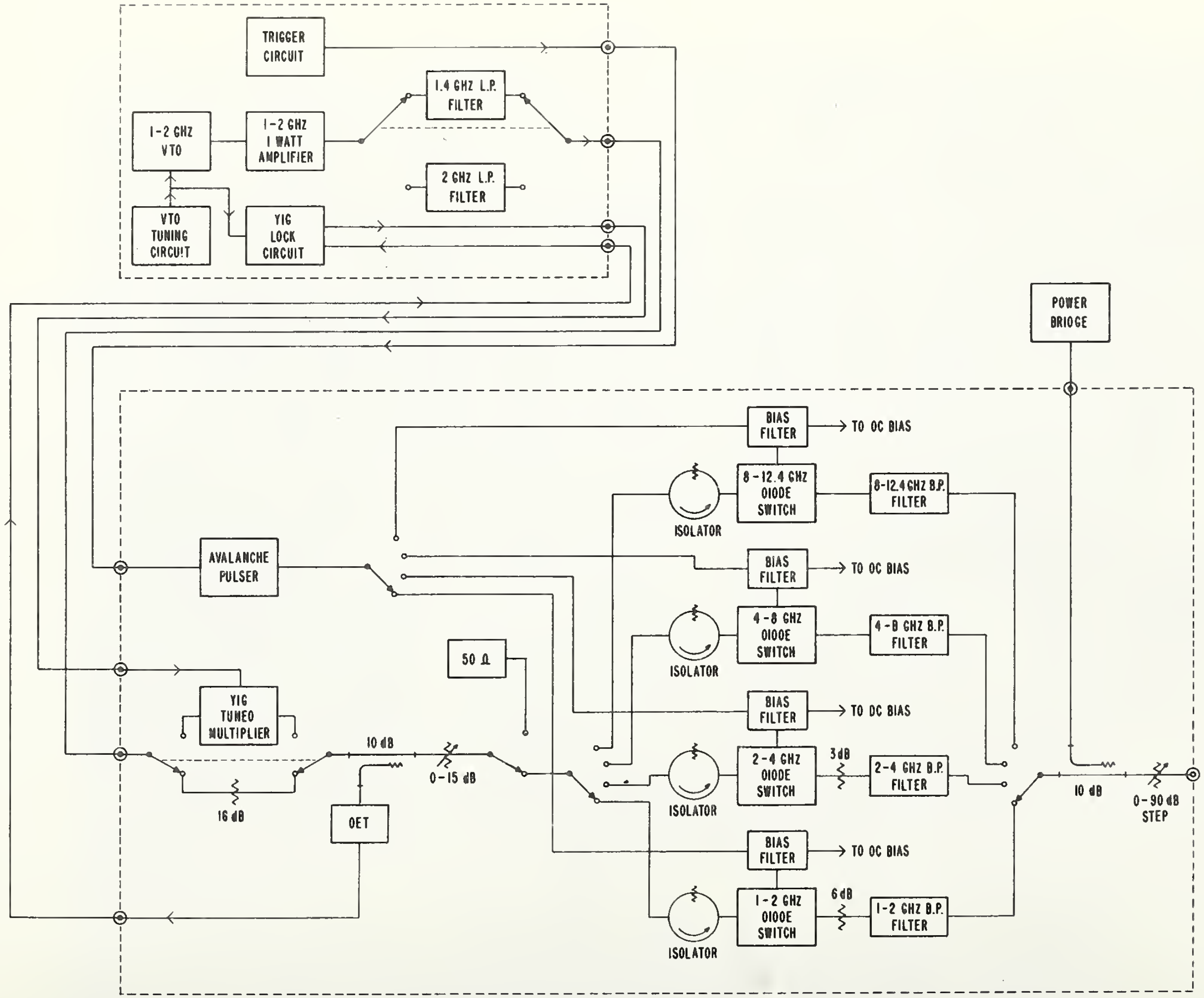


Figure 3. Block diagram of Standard Signal System.

3.2.1. Voltage Tuned Oscillator

The voltage tuned oscillator (VTO) is located on the frequency tuning chassis. The VTO operates over a frequency range 1 to 2 GHz with an output greater than 50 mW. Its output is amplified to 1 watt, filtered, and connected to the remote head by means of an RG223 cable where it is routed through either the 1 to 2 GHz channel or to the YIG-tuned multiplier (YIG).

3.2.2. YIG-Tuned Multiplier

The YIG-tuned multiplier, located in the remote head, is used to generate higher frequencies from the 1 to 2 GHz signal. The multiplication factor of the YIG in the different frequency bands is listed below.

BAND	MULT. FACTOR
1-2 GHz	out of circuit
2-4 GHz	x 2
4-8 GHz	x 4
8-12.4 GHz	x 7

After the YIG, the signal passes through a switch which is used to turn off the signal so that the zero of the monitor may be checked.

3.2.3. YIG-Locking Loop

Following the switch is a 10-dB directional coupler with a diode detector on the coupled port. The detector furnishes a dc signal to the YIG lock circuit. This circuit (on the frequency tuning chassis) provides a correction signal to the YIG so that it will stay tuned to the precise multiple of the VTO frequency. This allows one knob tuning of the system making it easier to operate.

If the lock is broken, e.g., when switching ranges or first turning on, the circuit provides a temporary ramping voltage to sweep the YIG frequency through the region of the harmonic of the 1 to 2 GHz signal until lock is re-established. A LED indicator on the front of the frequency tuning chassis glows when the loop is locked. A schematic diagram of the YIG locking circuit is shown in figure 4.

3.2.4. RF Burst Generating Section

After passing through a continuously adjustable attenuator which is used to set the reference level of the signal on the monitor, the signal is routed through one of the four bands listed in 3.2.2. Here it encounters an isolator, a diode switch, and a bandpass filter. The isolators are used to reduce the effect of the diode switches on the frequency generating elements of the system.

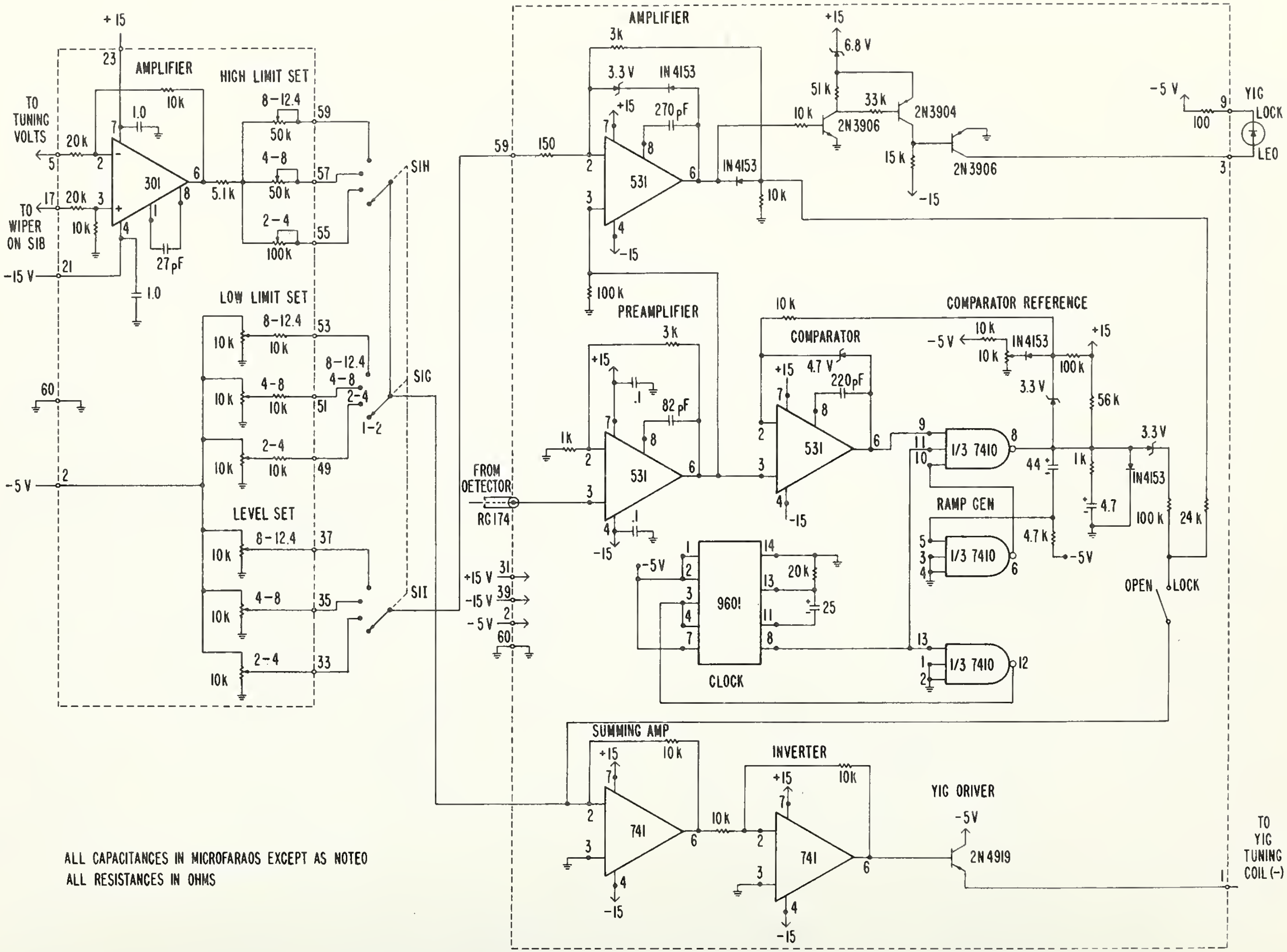


Figure 4. Amplifier for locking YIG tuned multiplier to VTO.

The commercial diode switches (all four channels) have high isolation (>90 dB) and fast transition times ($\leq$5 nsec). They are in the conducting state with a negative voltage applied and are in the high insertion loss state with a positive current of 100 mA applied.

The bandpass filters are used to remove harmonics of the rf frequency and the low frequency transients caused by the switching pulse. Because the VSWR of the filter affects the turn-off characteristic of the rf pulse, some isolation in the form of pads is provided between the switch and the filter in the 1 to 2 GHz and 2 to 4 GHz bands, where sufficient excess power makes this possible. Figure 5 shows photographs of the rf pulse waveforms for each of the four ranges. It can be seen that the two lower frequency ranges have "cleaner" waveforms.

3.2.5. Monitor and Attenuator Section

After passing through one of the rf burst generating sections, the signal is connected to a single common channel where it passes through another 10-dB directional coupler which has the power bridge monitor connected to the coupled port. The signal then passes through a calibrated step attenuator to the output connector of the remote head.

The attenuator is calibrated in steps of 1 dB up to 99 dB. This allows setting of accurate rf levels below the reference level established by the monitor.

3.2.6. Pulse Trigger Circuit

A pulse trigger circuit located on the frequency tuning chassis is used to initiate the signal which produces the rf burst. The trigger has the following characteristics:.

Amplitude = 1 V triangular into 50 ohms,
Duration = 20 nsec, and
PRF = 10 to 10,000 pps.

This circuit can also be operated from an external trigger source. In the external mode the PRR is adjustable over a range of single shot to several megahertz, which exceeds the 100 kHz maximum repetition rate of the pulser it drives. Both modes of operation are disabled when the system supplies a CW signal.

One common use for the external mode is generating coherent pulses. A coherent pulse is one that is triggered at the same type of zero crossing (positive or negative going) every time. In this way the rf carrier maintains the same phase relationship with the envelope in each pulse. The trigger for initiating the modulating pulse is usually derived from some sort of countdown circuit on the carrier. A block diagram of a simple arrangement with a sampling oscilloscope is shown in figure 6. A schematic of the trigger circuit is shown in figure 7.

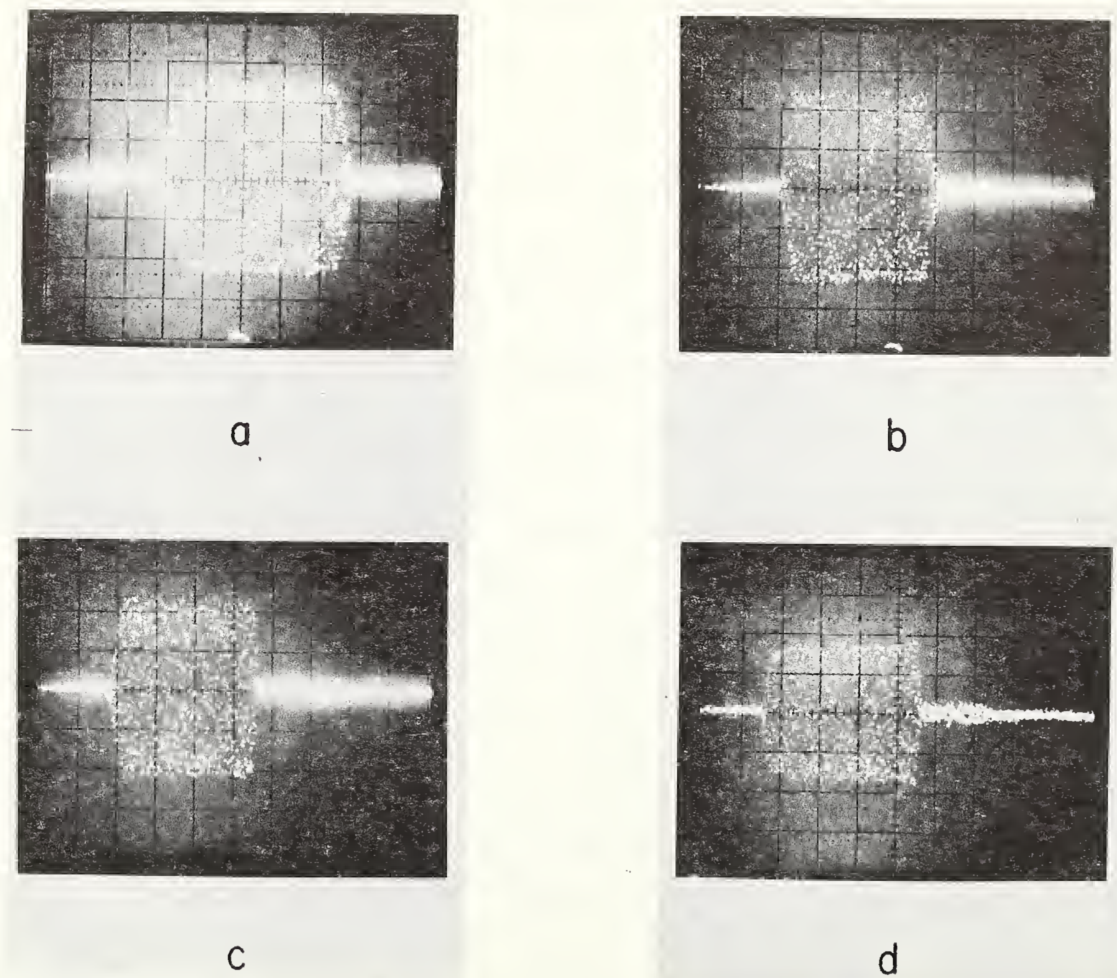


Figure 5. Photographs of incoherent rf bursts made on a sampling oscilloscope. Horizontal scale = 5 ns/div. (a) 1 mW, 1.5 GHz (b) 1 mW, 3 GHz (c) 1 mW, 6 GHz (d) 0.1 mW, 11 GHz.

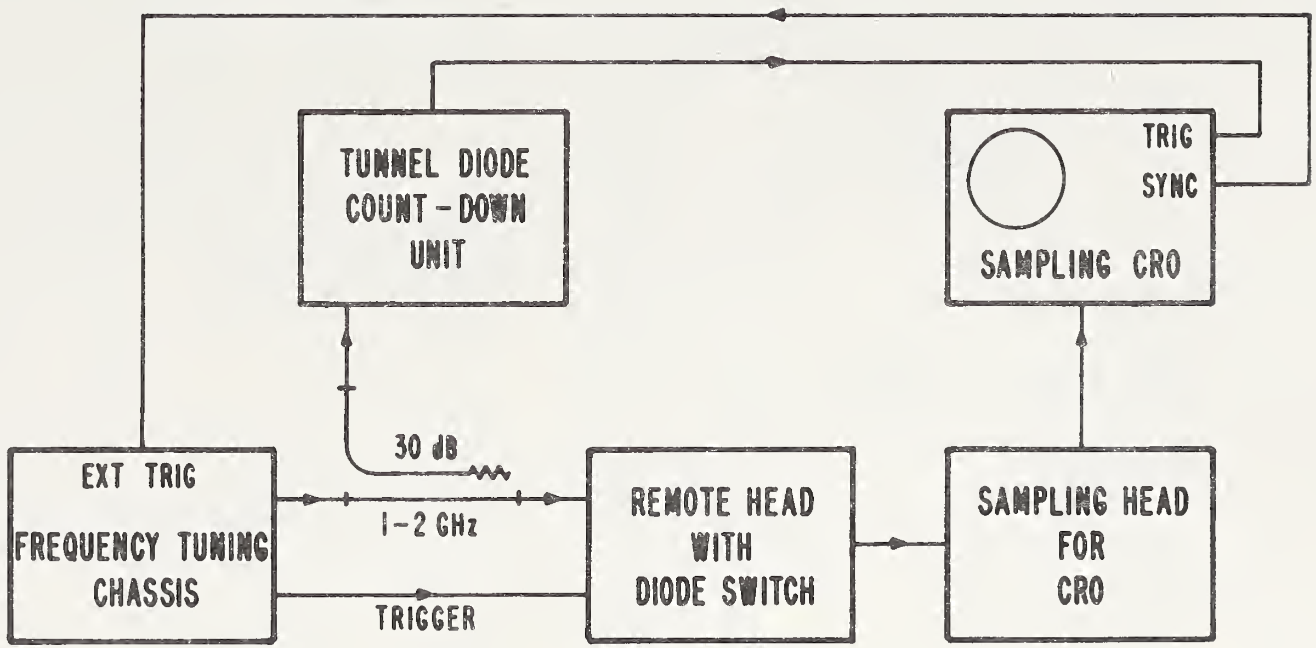


Figure 6. Block diagram of circuit for generating coherent rf bursts.

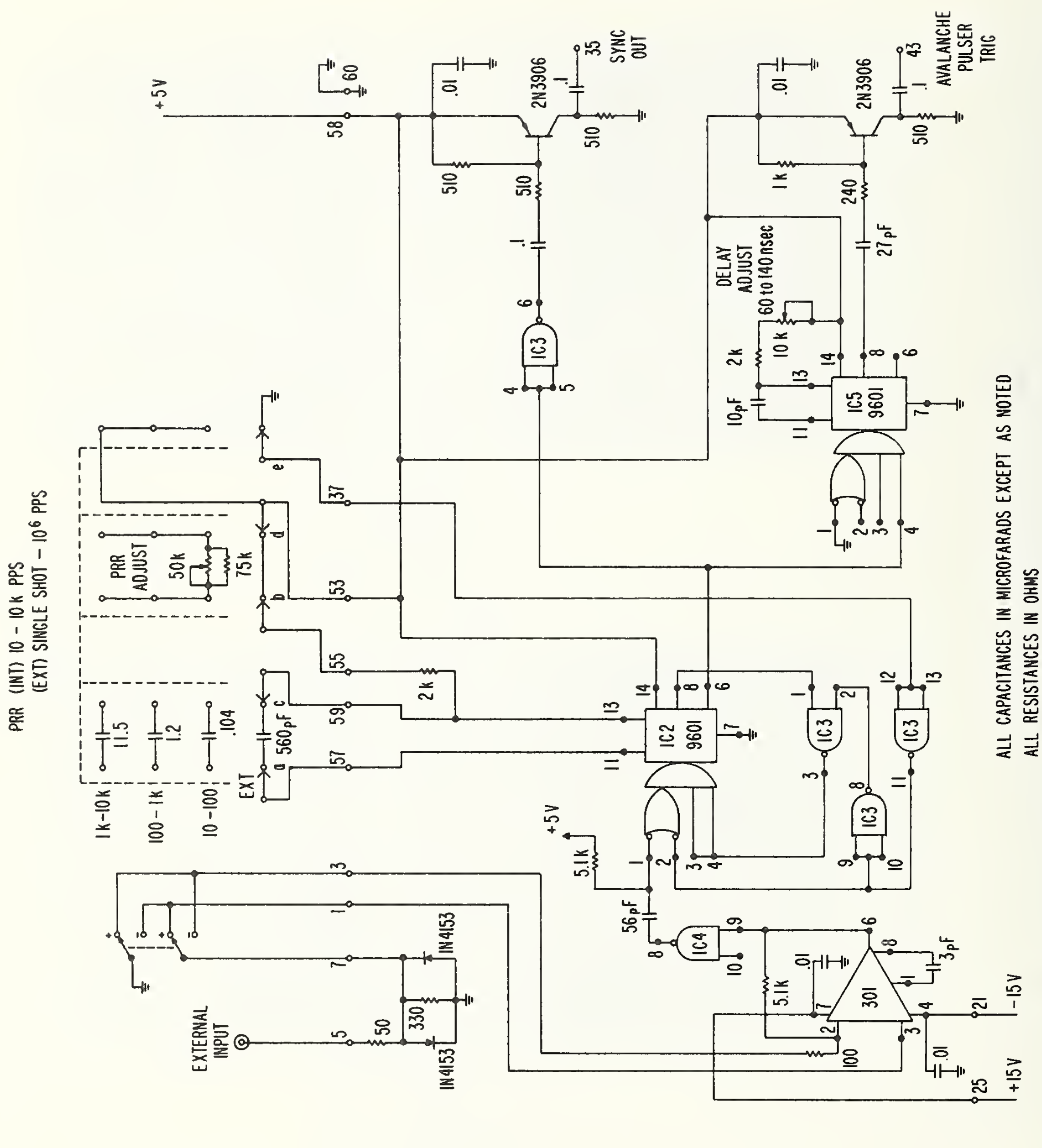


Figure 7. Pulse trigger circuit.

3.2.7. Avalanche Pulser and Bias Circuits

The avalanche pulser, located in the remote head, is connected to the trigger circuit in the frequency tuning chassis by means of RG223 cable. Design of the avalanche pulser is based on a circuit developed by Andrews [9]. A schematic is shown in figure 8. The circuit switches in approximately 1 nsec and supplies a -30 V pulse of 20 nsec duration. Its maximum repetition rate is approximately 100 kHz.

The circuit diagram for mixing the negative pulse with the positive bias current is shown in figure 9. The 39-ohm resistor when combined with the 10-ohm resistance of the diode switch bias arm forms a suitable 50-ohm termination for the switching pulse. A blocking capacitor in the avalanche pulser prevents the dc from flowing in that circuit just as a ferrite bead in the mixing circuit keeps the pulse out of the bias supply.

When the system is operated in the CW mode -10 volts is applied to the bias arm which effectively turns the diode switch on.

3.2.8. VTO Tuning and Metering Circuits

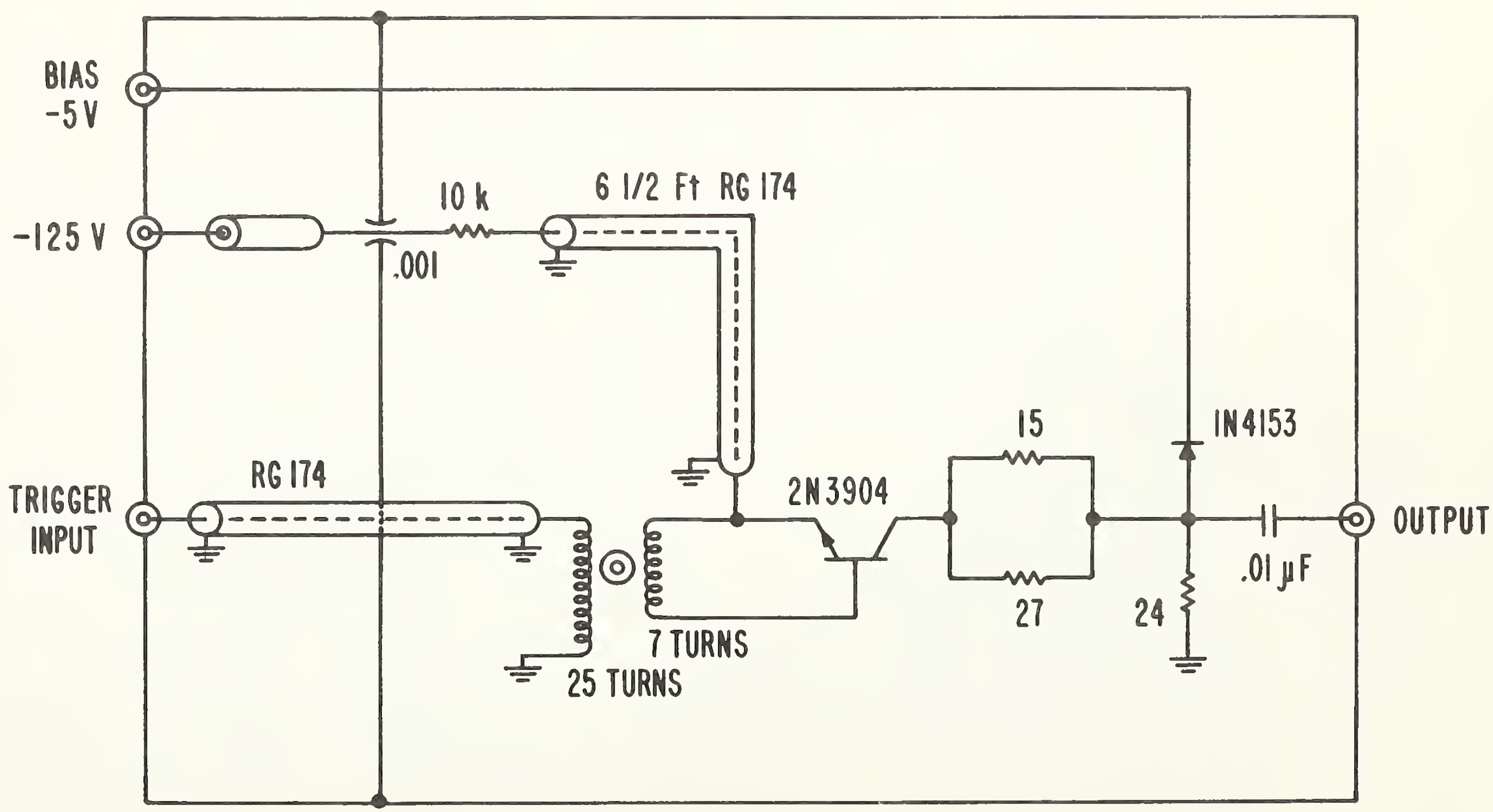
The circuit diagram for supplying the tuning voltage to the VTO is shown in figure 10. The tuning voltage varies from 0 V to 10 V. Much bypassing of the tuning voltage is required to reduce FM to insignificant levels. This voltage is supplied also to the YIG locking loop and to a switching circuit for filters in the output of the 1 to 2 GHz, 1-watt amplifier.

3.2.9. Filter Switching Circuit for 1 to 2 GHz, 1-Watt Signal

The switching circuit for the two filters in the output of the 1-watt, 1 to 2 GHz amplifier is shown in figure 11. Hysteresis has been designed into this circuit so that switching is done at 1300 MHz, when increasing the frequency, and 1100 MHz when decreasing the frequency. The 1400 MHz low pass filter is required to reduce the level of the second harmonic when operating at the bottom end of the 1 to 2 GHz band. In the three other frequency bands the second harmonic is effectively reduced by the action of the YIG.

3.2.10. YIG Bias Supply

Bias voltage is supplied to the YIG in order that it may multiply the fundamental frequency efficiently. Different voltages, depending on the harmonic number, are supplied from a low impedance source shown in figure 12.



V_{OUT} = -30 VOLTS

P.D. = 20 nsec

Figure 8. Avalanche pulser circuit.

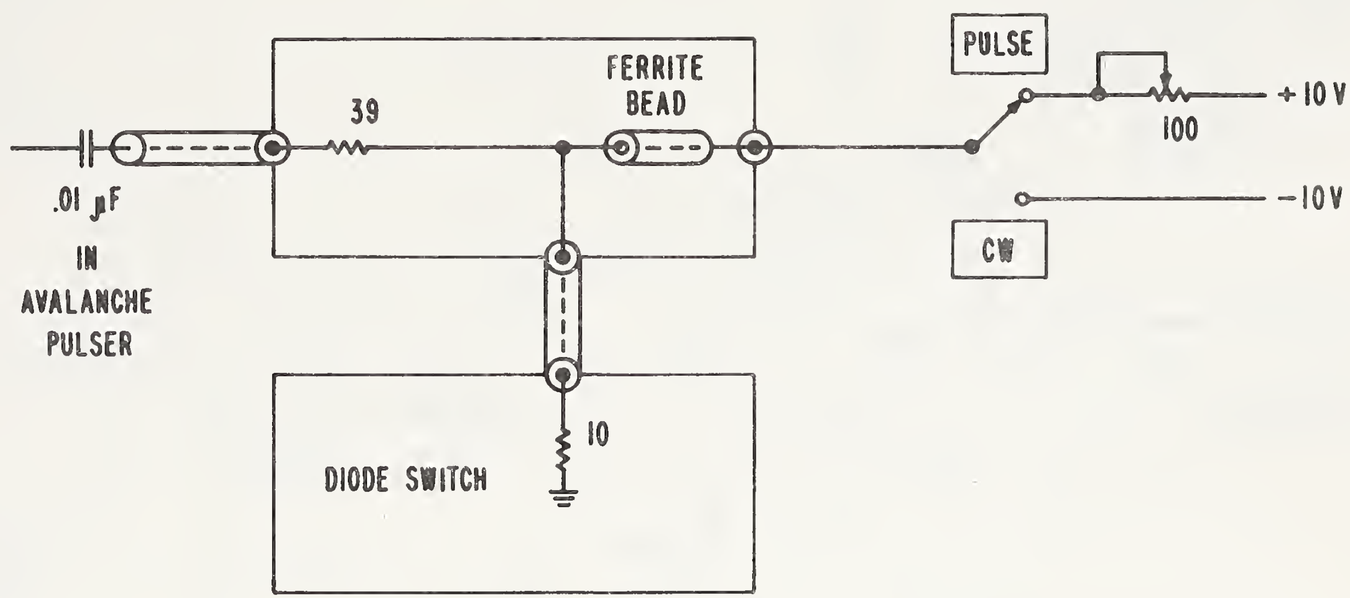


Figure 9. Circuit for mixing bias and switching signals to diode switches.

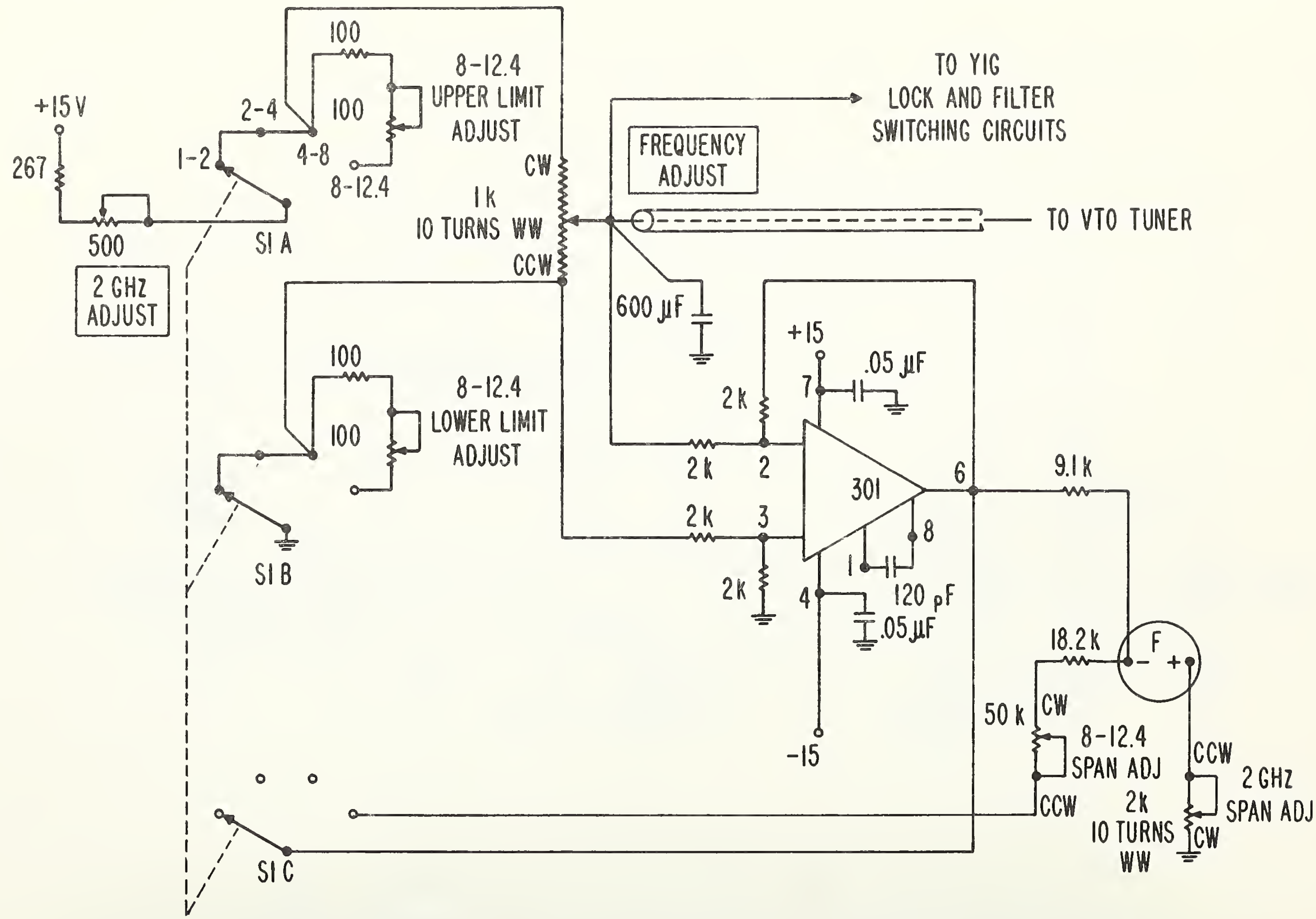


Figure 10. VTO tuning circuit.

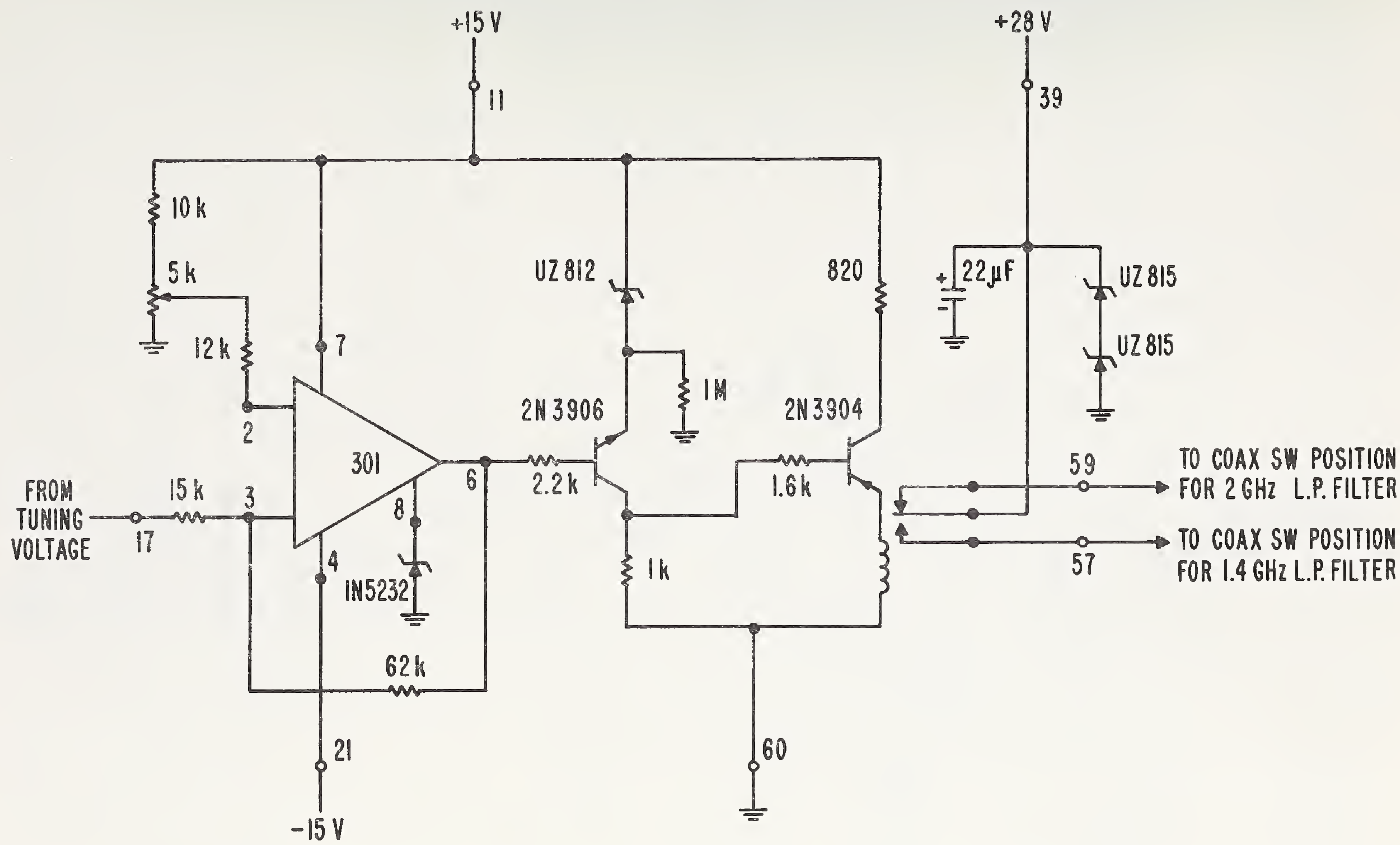


Figure 11. Low pass filter switching circuit.

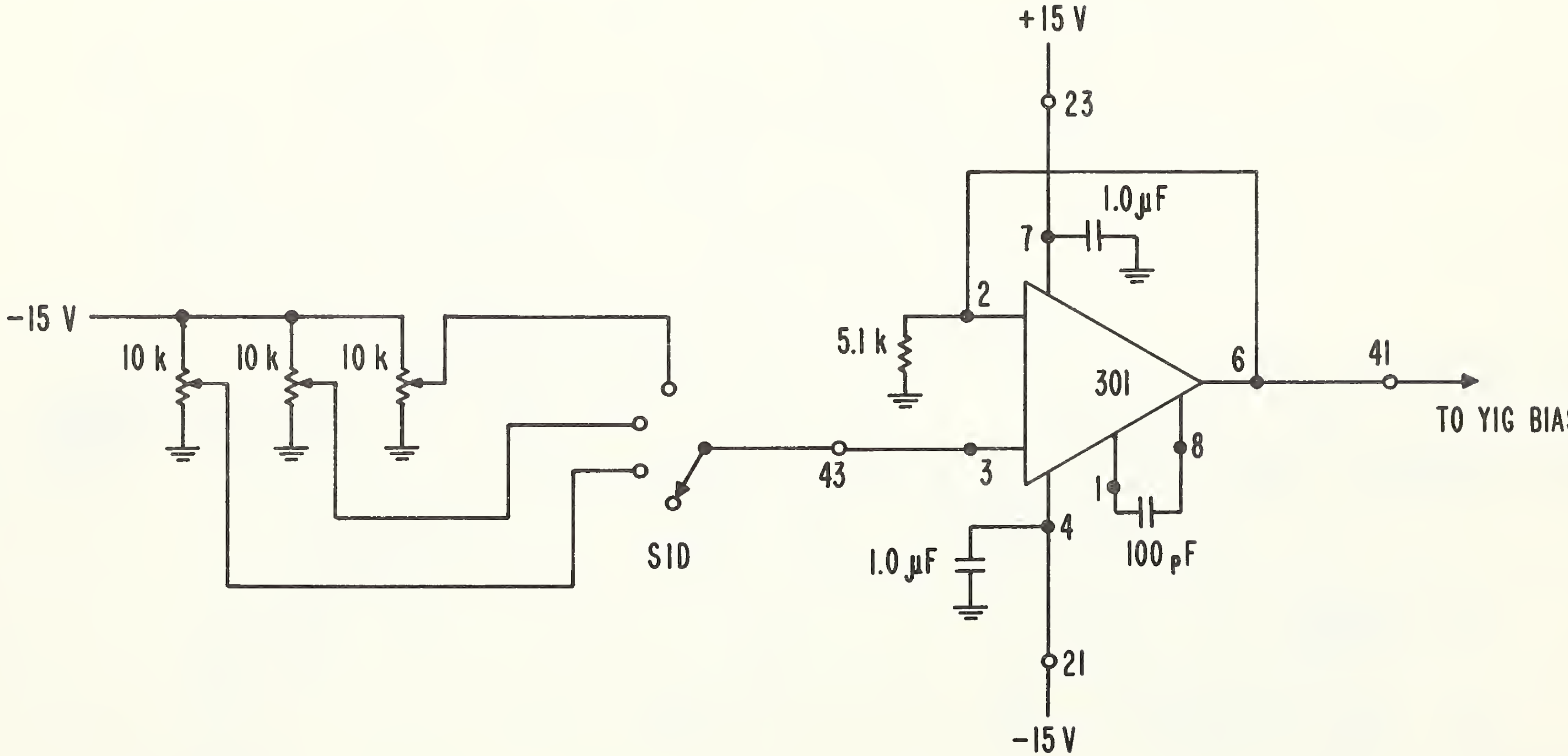


Figure 12. YIG bias supply circuit.

3.3. Calibration of Standard Signal System

Three quantities in the Standard Signal System require calibration for proper operation. These are (1) the monitor reading, (2) the pulse duration, and (3) the step attenuator.

3.3.1. Calibration of Power Monitor

The monitor is calibrated by operating the system in the CW mode and measuring a reference power level at the output connector. The monitor is calibrated at 10 frequency points in each of the four bands. Reference level for the three lower bands is 1 mW and for the 8 to 12.4 GHz band it is 0.1 mW. A calibration chart is shown in Appendix B.

3.3.2. Calibration of Pulse Duration

The pulse duration, needed for the calculation of impulse strength in equation (3), is measured using a sampling oscilloscope. The scope time base is first calibrated with a 1-GHz sine wave. The pulse duration is determined from photographs of incoherent pulses.

It was found that the duration of the pulse within each frequency band varied not more than ±0.1 nsec (±0.6%). The durations measured are;

1 to 2 GHz	--	22.6 nsec,
2 to 4 GHz	--	18.1 nsec,
4 to 8 GHz	--	18.0 nsec, and
8 to 12.4 GHz	--	19.5 nsec.

For the monitor reference levels in 3.3.1 and using the relation $(S)_{imp} = V_1 \tau$

$(S)_{imp}$ = 5053.5 μV/MHz ±3% (1-2 GHz),
$(S)_{imp}$ = 4047.3 μV/MHz ±5% (2-4 GHz),
$(S)_{imp}$ = 4024.9 μV/MHz ±8% (4-8 GHz),
$(S)_{imp}$ = 1378.9 μV/MHz ±8% (8-12.4 GHz).

3.3.3. Calibration of Step Attenuator

The step attenuator is calibrated at four frequencies, 1, 4, 8, and 12 GHz. Attenuation changes relative to the 0-dB position were measured. The attenuator was then inserted in the Standard Signal System and changes in the power output recorded in 1 dB increments up to 30 dB for the three frequencies 1, 4 and 8 GHz and up to 22 dB for 12 GHz. There were relatively small differences (~.1 dB) in the power ratio of corresponding 1-dB steps after about 3 dB attenuation was inserted in the system. Based on this fact curves were derived using a least squares fit on the data. In most cases a linear approximation was sufficient, but for some steps a slight curvature of the attenuation vs. frequency curves required a second degree equation. A table of attenuation vs. frequency for the different steps is given in Appendix B.

3.4. Experimental Checks of Spectral Intensity

As an experimental verification on the calculation of spectral intensity from the time domain data, measurements of the bandwidth of a commercial receiver were made at frequencies where the four bands of the Standard Signal System overlap, viz., 2 GHz, 4 GHz, and 8 GHz. While making measurements at any one of the frequencies, all factors were kept constant, and only the frequency band of the Standard Signal System was changed. Any differences in measured bandwidth, therefore, were attributed to relative errors in the determination of spectral intensity. The results are given in the following table.

Bandwidth Measurements on a
Commercial Microwave Receiver

Standard Signal System		Receiver		Percent Difference
Band GHz	Frequency GHz	Frequency Band, GHz	Bandwidth MHz	
1-2	2	1-2	4.97	±0.5
2-4	2	1-2	4.92	
2-4	4	2-4.4	5.34	±1.0
4-8	4	2-4.4	5.23	
4-8	8	4.4-10	4.83	±2.5
8-12.4	8	4.4-10	4.60	

Manufacturer's specifications for the bandwidth and accuracy of the receiver are

Bandwidth = 5 MHz ± 10%

Accuracy = ± 3 dB

3.5. Sample Problem of Calibrating a Receiver

In this section an example of calibrating a receiver at one frequency is given. This measurement was performed immediately following line 2 in the table in section 3.4 when the receiver was switched from the 1-2 to 2-4.4 GHz band. This serves as an indication of the constancy of the bandwidth when changing bands on the receiver.

The receiver has a 127 mm (5 in.) meter on the front with two scales, linear 0 to 60 dBμV and logarithmic 1 to 1000 μV. In addition, steps of 20, 40, and 60 dB of attenuation may be inserted in the signal path to measure higher voltages, i.e., voltages up to 1 V. In this example, measurements were performed on the +20 dB step which has no attenuation in the rf input section but 20 dB in the i-f section. As a means of increasing the precision, a digital voltmeter was connected to a jack on the rear, labeled Y output. This jack is in parallel with the meter and has an output of 2.25 volts for full scale meter deflection.

One other point affecting the measurement procedure is the internal noise in the receiver. On the three higher ranges (20, 40 and 60 dB) it amounts to approximately 19 dB above the meter zero on the 60 dB scale for a 5 MHz nominal bandwidth but varies with time and frequency. In order to reduce errors from this source, measurements were performed as near full scale as possible.

The procedure for calibrating a receiver is as follows:

1. Select the voltage range, frequency band, and frequency at which the receiver is to be calibrated. These parameters are mentioned earlier in this section and are re-stated below.
    a. voltage range 20 to 80 dBμV
    b. frequency band 2 - 4.4 GHz
    c. frequency 2 GHz
2. Set the Standard Signal System to the desired frequency (CW mode) and output level, and connect to receiver.
    a. set frequency range to 2 to 4 GHz
    b. set frequency to 2 GHz
    c. set monitor to .115 mW (see fig. 14, Appendix B)
    d. set output attenuator to 30 dB
    e. determine from Table 2, Appendix B, the precise attenuation, 30 dB = 29.29 dB
    f. calculate calibrating voltage, 107 dBμV-29.29 dB = 77.71 dBμV
3. Set the receiver to the desired range and frequency
    a. set attenuator to +20 dB (20 to 80 dBμV)
    b. set frequency band to 2.0 to 4.4 GHz
    c. tune frequency to 2 GHz

4. Set the gain of the receiver

   a. set the gain so receiver reads 77.71 dBμV or the digital voltmeter reads

      $$(77.71-20)\text{ dB X }\frac{2.25\text{ V}}{60\text{ dB}} = 2.164\text{ V}$$

   b. switch to "CALIBRATE" position on receiver and record digital voltmeter reading

      $$\text{DVM} = 1.626\text{ V X }\frac{60\text{ dB}}{2.25\text{ V}} = 43.36\text{ dB}\mu\text{V}$$

   NOTE: This reading allows one in the field to set the gain of the instrument. It is independent of input voltage range, hence, no addition for the +20 dB. The manufacturer quotes this value as 43 dB ± 0.5 dB.

5. Measure bandwidth

   a. switch receiver from "CALIBRATE" to +20 dB

   b. switch Standard Signal System to "PULSE"

      DVM = 1.385 V

      = (36.93 + 20 dBμV)

      = 56.93 dBμV or 702.26 μV

   c. To normalize the receiver response to the reference input level (1 mW in the 2-4 GHz band), multiply by attenuation factor in Standard Signal System

      attenuation = 29.29 dB or a voltage ratio of 29.14

      signal = 702.26 μV X 29.14

      = 20464.0 μV

   d. find bandwidth in Table 1, Appendix B in column 2, BW = 5.06 MHz

3.6. Maintenance

Detailed alignment steps for the various circuits are given at the end of this publication in Appendix C. By following the instructions therein, and referring to the appropriate schematic drawings, factors causing improper operation of the system can be isolated and corrected.

The power supply chassis and the frequency tuning chassis are accessible by removing the front panel rack screws and pulling the chassis forward out of the cabinet on the built-in chassis slides.

The interior of the remote head is best exposed by removing the side plates. The control wiring is reached by removing the bottom plate. Due to the compactness of the unit it may be necessary to remove some components in order to reach others.

4. ACCURACY OF STANDARD SIGNAL SYSTEM

4.1. Uncertainty of Gain Calibrations

When setting the gain of an instrument, the accuracy is dependent primarily upon

a. the uncertainty in the CW power calibration and

b. the uncertainty in the step attenuator calibration.

The power calibration has an uncertainty at 1 GHz of 1 percent which increases to 2 percent at 12 GHz. In the table below this fact is shown in the 0-dB row which gives the uncertainty in dB.

The uncertainty in the attenuator calibration at a given attenuation value does not change with frequency in the range 1 to 12.4 GHz, but does increase with higher attenuation values. This is reflected by the values in the boxes in the next three rows which are the sum of the power calibration and attenuator uncertainties. One should remember that rarely will the attenuator be set to 60 dB or greater, since most gain calibrations are best made at full scale for reasons mentioned in 3.5.

It should also be kept in mind that this is an incident power system and mismatch errors will be introduced if the impedance of the receiver is appreciably different from 50 ohms.

Error in Gain Setting in dB (±)

dB Step \ Freq GHz	1 - 4	4 - 8	8 - 12.4
0	.10	.12	.15
1-60	.15	.17	.20
61-80	.33	.35	.39
81-90	.43	.45	not used

4.2. Accuracy of Bandwidth Measurements

Since the measurement of bandwidth basically involves comparing the voltage of a standard 1 mW CW signal with that produced by a 1 mW peak broadband signal, many errors cancel out. For instance, the gain setting affects both readings by the same amount and, therefore, does not contribute to the uncertainty. The same is true for mismatch errors.

The primary source of uncertainty is errors in the measurement of τ, the effective pulse duration, which determines the amplitude spectral density. Contributing factors to this uncertainty are listed below.

a. Duration Measurement - this measurement is made on a sampling oscilloscope. The uncertainty here is 3 percent. There is no detectable difference between results from coherent and non-coherent pulses as discussed by Reeve [10] since at these frequencies and pulse durations the minimum number of rf cycles in a burst is approximately 20.

b. Roll Off in Amplitude Spectral Density - due to the $\frac{\sin x}{x}$ function the amplitude spectral density is not constant but drops off for wide bandwidths. Table 2 in Appendix B lists bandwidths up to 10 MHz assuming a straight linear relationship for voltage vs. bandwidth. The error due to this assumption is 0.5 percent.

c. Aberrations in Pulse Shape - as can be seen in figure 5 the turn-off of the pulse in the three higher frequency bands is not clean but is characterized by a continuation of the signal at low amplitude for a readily discernable time. The shape, amplitude, and duration of this unwanted oscillation varies as the frequency is tuned over the band and contributes to the impulse strength, $(S)_{imp}$, in the region of the carrier. The maximum uncertainty associated with this effect is 5 percent.

These three factors create a total uncertainty in the measurement of bandwidth of 8.5 percent.

5. FUTURE WORK

5.1. Improvements to Prototype Standard Signal System

It is planned in the near future to correct the conditions which cause the aberrations in pulse shape discussed in 4.2. This will be done by adding an isolator or attenuator between the diode switch modulator and the band-pass filter. This may require reducing the output of these stages somewhat, but measurement experience gained with the system so far indicates power levels above -10 dBm which are needed for calibrating receivers above 100 dBμV have only a minor importance. For these ranges there is so much attenuation inserted in the input stages of the receiver that there is little, if any, difference in the gain and bandwidth measurements for this range and the next more sensitive one. The benefit of removing 5 percent uncertainty in the bandwidth measurement should outweigh any disadvantages associated with the possible loss of signal amplitude.

Something of a bigger endeavor is the designing and fabrication of a π pad such as described in Appendix A. This addition to the system would provide a constant voltage source for calibrating receivers. The problem of a constant incident power system and mismatch effects because of high VSWR's would be eliminated. This endeavor would entail an effort lasting approximately six months and requiring moderate funding.

5.2. Second Generation Standard Signal System

Since this effort was started three years ago advancing technology has brought forth many new devices on the market. Some of these devices would now greatly simplify the construction of a standard signal system. For instance, in 1971 there was no suitable solid state oscillator in the 4 to 8 GHz range. Now there are VTO's in this range that will deliver as much as 25 mW.

This means the frequency multiplication system with the YIG is no longer required nor is the locking circuit, the 1-watt amplifier, several power supplies, and the frequency range switching circuits.

Instead four separate remote heads could be built each with its own oscillator and rf burst generating components. Each head would be one fourth the volume and less than one fourth the weight of the existing remote head.

Whichever head was to be used would be connected to a control chassis which would provide the tuning voltage, power and trigger signal to the head. The control chassis, because of less components being required, would be approximately half the size of the present power supply chassis and frequency tuning chassis. This new Standard Signal System would be truly compact and convenient to use.

6. ACKNOWLEDGMENT

I wish to thank Mr. Paul A. Hudson for the many helpful suggestions he has given during the three years of this effort. A very special thanks is due Arthur R. Ondrejka for the fine help he has given both of a theoretical and practical nature. Thanks are also due Ezra Larsen and William Gans for the help they have rendered. The major portion of the construction was done by John R. Benes and for his fine work I am very grateful. Last but not least thanks go to Mrs. Edna Trump who did the typing of this report. To these and all the others who aided me I express my heartfelt thanks.

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[8] Op. cit. [3] pp. 35-37.

[9] J. R. Andrews, "A frequency calibrator for UHF using an avalanche transistor," QST, Vol. LVI, No. 5, pp. 16-18, May 1972.

[10] Op. cit. [3] pp. 35-37.

[11] Op. cit. [4] pp. 20-23.

APPENDIX A. CONSTANT VOLTAGE GENERATOR FOR THE STANDARD SIGNAL SYSTEM

A constant voltage generator (with its low source impedance) is superior to a constant incident power source for calibrating receivers in that the excitation applied to and actually affecting the receiver can be determined with greater accuracy, even in the presence of sizable VSWR's. Larsen [11] has given experimental verification of this fact at lower frequencies.

A design which employs a π pad with 50-ohm input impedance, and 1-ohm output impedance is given in this section. The pad closely approximates a constant voltage source. (A T pad is a constant current source.) In order to be most effective over the frequency range of the Standard Signal System thin film techniques should be used to fabricate the device and precision type N connectors incorporated into the design for the input and output interfaces. A schematic drawing of the pad is shown below.

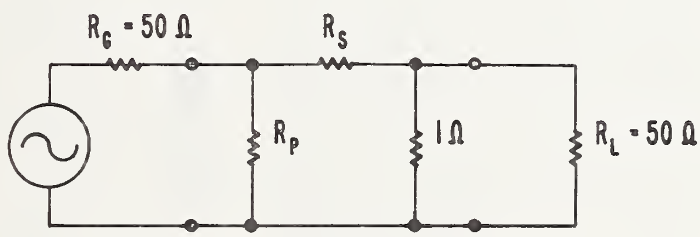

Figure 13. Circuit used for calculating components of the π pad.

Using the above model and the above criteria, namely, Z_{in} = 50 ohms and Z_{out} = 1 ohm, values for R_P and R_S can be calculated for a 40 dB attenuator. These are

$$R_P = 102.1 \text{ ohms}$$
$$R_S = 97.0 \text{ ohms}$$

For a load VSWR of 2:1 the input impedance is constant to 0.01 percent or less, and the attenuation varies over the range of only +1 percent to -1.8 percent. An incident power system with a 50-ohm output impedance, operating into the same VSWR, can be in error by 3.5 dB. Compared to this value the variations using the π pad are quite minor.

APPENDIX B

CALIBRATION CHARTS AND TABLES

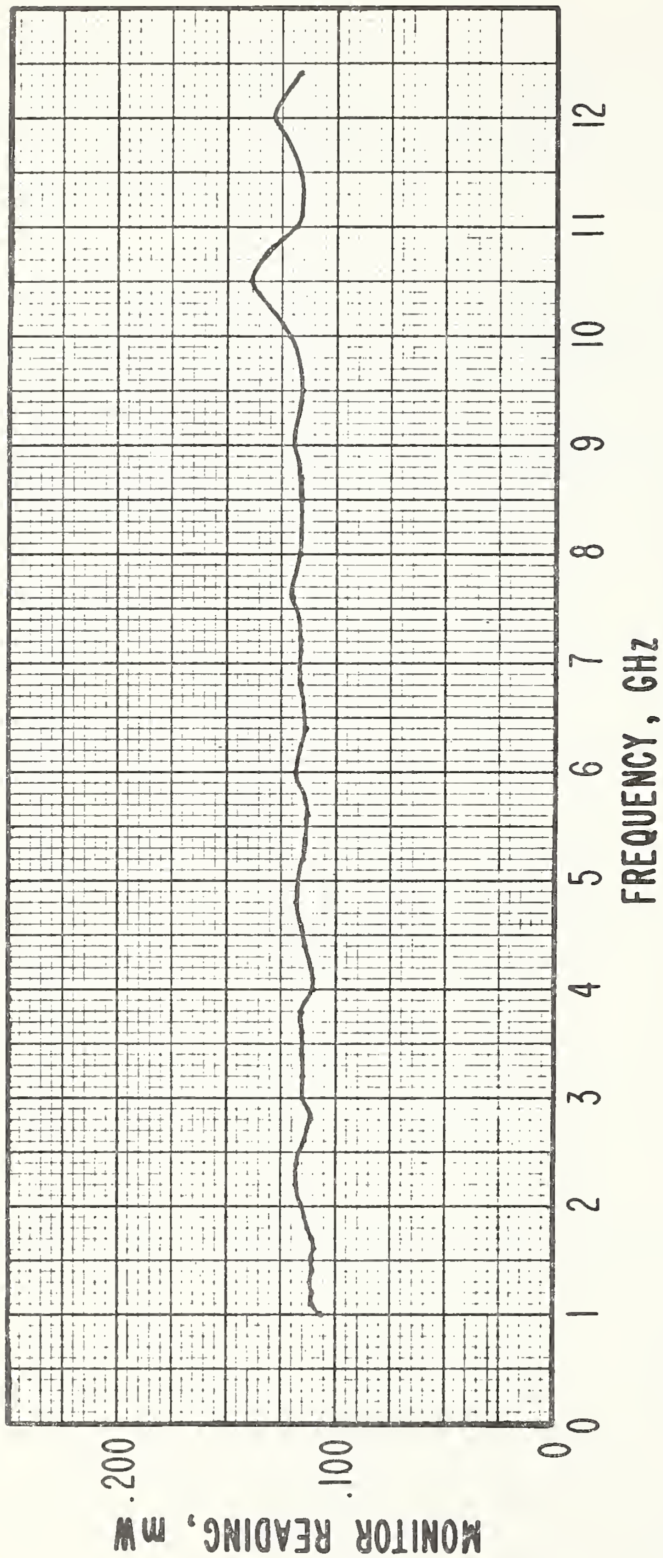

Figure 14. Monitor reading in milliwatts for 1 milliwatt reference level.

Table 1

BANDWIDTH VS OBSERVED OUTPUT VOLTAGE

BANDWIDTH	1 - 2 GHZ	2 - 4 GHZ	4 - 8 GHZ	8 - 12.4 GHZ
MHZ	MICROVOLTS (Ref. to 1 mW input)	MICROVOLTS (Ref. to 1 mW input)	MICROVOLTS (Ref. to 1 mW input)	MICROVOLTS (Ref. to 0.1 mW inpu
0.0	0.0	0.0	0.0	0.0
0.1	505.4	404.7	402.5	137.9
0.2	1010.7	809.5	805.0	275.8
0.3	1516.1	1214.2	1207.5	413.7
0.4	2021.4	1618.9	1610.0	551.5
0.5	2526.8	2023.6	2012.5	689.4
0.6	3032.1	2428.4	2415.0	827.3
0.7	3537.5	2833.1	2817.4	965.2
0.8	4042.8	3237.8	3219.9	1103.1
0.9	4548.2	3642.6	3622.4	1241.0
1.0	5053.5	4047.3	4024.9	1378.9
1.1	5558.9	4452.0	4427.4	1516.8
1.2	6064.2	4856.7	4829.9	1654.6
1.3	6569.6	5261.5	5232.4	1792.5
1.4	7074.9	5666.2	5634.9	1930.4
1.5	7580.3	6070.9	6037.4	2068.3
1.6	8085.6	6475.7	6439.9	2206.2
1.7	8591.0	6880.4	6842.4	2344.1
1.8	9096.3	7285.1	7244.9	2482.0
1.9	9601.7	7689.8	7647.4	2619.8
2.0	10107.0	8094.6	8049.9	2757.7
2.1	10612.4	8499.3	8452.3	2895.6
2.2	11117.7	8904.0	8854.8	3033.5
2.3	11623.1	9308.8	9257.3	3171.4
2.4	12128.4	9713.5	9659.8	3309.3
2.5	12633.8	10118.2	10062.3	3447.2
2.6	13139.1	10522.9	10464.8	3585.0
2.7	13644.5	10927.7	10867.3	3722.9
2.8	14149.8	11332.4	11269.8	3860.8
2.9	14655.2	11737.1	11672.3	3998.7
3.0	15160.5	12141.9	12074.8	4136.6
3.1	15665.9	12546.6	12477.3	4274.5
3.2	16171.3	12951.3	12879.8	4412.4
3.3	16676.6	13356.0	13282.3	4550.3
3.4	17182.0	13760.8	13684.7	4688.1
3.5	17687.3	14165.5	14087.2	4826.0
3.6	18192.7	14570.2	14489.7	4963.9
3.7	18698.0	14975.0	14892.2	5101.8
3.8	19203.4	15379.7	15294.7	5239.7
3.9	19708.7	15784.4	15697.2	5377.6

Table 1 (Continued)

BANDWIDTH VS OBSERVED OUTPUT VOLTAGE

BANDWIDTH	1 - 2 GHZ	2 - 4 GHZ	4 - 8 GHZ	8 - 12.4 GHZ
MHZ	MICROVOLTS (Ref. to 1 mW input)	MICROVOLTS (Ref. to 1 mW input)	MICROVOLTS (Ref. to 1 mW input)	MICROVOLTS (Ref. to 0.1 mW input)
4.0	20214.1	16189.1	16099.7	5515.5
4.1	20719.4	16593.9	16502.2	5653.3
4.2	21224.8	16998.6	16904.7	5791.2
4.3	21730.1	17403.3	17307.2	5929.1
4.4	22235.5	17808.1	17709.7	6067.0
4.5	22740.8	18212.8	18112.2	6204.9
4.6	23246.2	18617.5	18514.7	6342.8
4.7	23751.5	19022.2	18917.2	6480.7
4.8	24256.9	19427.0	19319.6	6618.5
4.9	24762.2	19831.7	19722.1	6756.4
5.0	25267.6	20236.4	20124.6	6894.3
5.1	25772.9	20641.2	20527.1	7032.2
5.2	26278.3	21045.9	20929.6	7170.1
5.3	26783.6	21450.6	21332.1	7308.0
5.4	27289.0	21855.3	21734.6	7445.9
5.5	27794.3	22260.1	22137.1	7583.8
5.6	28299.7	22664.8	22539.6	7721.6
5.7	28805.1	23069.5	22942.1	7859.5
5.8	29310.4	23474.3	23344.6	7997.4
5.9	29815.8	23879.0	23747.1	8135.3
6.0	30321.1	24283.7	24149.6	8273.2
6.1	30826.5	24688.5	24552.0	8411.1
6.2	31331.8	25093.2	24954.5	8549.0
6.3	31837.2	25497.9	25357.0	8686.8
6.4	32342.5	25902.6	25759.5	8824.7
6.5	32847.9	26307.4	26162.0	8962.6
6.6	33353.2	26712.1	26564.5	9100.5
6.7	33858.6	27116.8	26967.0	9238.4
6.8	34363.9	27521.6	27369.5	9376.3
6.9	34869.3	27926.3	27772.0	9514.2
7.0	35374.6	28331.0	28174.5	9652.0
7.1	35880.0	28735.7	28577.0	9789.9
7.2	36385.3	29140.5	28979.5	9927.8
7.3	36890.7	29545.2	29382.0	10065.7
7.4	37396.0	29949.9	29784.5	10203.6
7.5	37901.4	30354.7	30186.9	10341.5
7.6	38406.7	30759.4	30589.4	10479.4
7.7	38912.1	31164.1	30991.9	10617.3
7.8	39417.4	31568.8	31394.4	10755.1
7.9	39922.8	31973.6	31796.9	10893.0

BANDWIDTH VS OBSERVED OUTPUT VOLTAGE

BANDWIDTH	1 - 2 GHZ	2 - 4 GHZ	4 - 8 GHZ	8 - 12.4 GHZ
MHZ	MICROVOLTS (Ref. to 1 mW input)	MICROVOLTS (Ref. to 1 mW input)	MICROVOLTS (Ref. to 1 mW input)	MICROVOLTS (Ref. to 0.1 mW input)
8.0	40428.1	32378.3	32199.4	11030.9
8.1	40933.5	32783.0	32601.9	11168.8
8.2	41438.8	33187.3	33004.4	11306.7
8.3	41944.2	33592.5	33406.9	11444.6
8.4	42449.6	33997.2	33809.4	11582.5
8.5	42954.9	34401.9	34211.9	11720.3
8.6	43460.3	34806.7	34614.4	11858.2
8.7	43965.6	35211.4	35016.9	11996.1
8.8	44471.0	35616.1	35419.3	12134.0
8.9	44976.3	36020.9	35821.8	12271.9
9.0	45481.7	36425.6	36224.3	12409.8
9.1	45987.0	36830.3	36626.8	12547.7
9.2	46492.4	37235.0	37029.3	12685.5
9.3	46997.7	37639.8	37431.8	12823.4
9.4	47503.1	38044.5	37834.3	12961.3
9.5	48008.4	38449.2	38236.8	13099.2
9.6	48513.8	38854.0	38639.3	13237.1
9.7	49019.1	39258.7	39041.8	13375.0
9.8	49524.5	39663.4	39444.3	13512.9
9.9	50029.8	40068.1	39846.8	13650.8
10.0	50535.2	40472.9	40249.3	13788.6

APPENDIX B

Table 2

CALCULATION OF OUTPUT ATTENUATOR STEPS

GHz	1 dB	2 dB	3 dB	4 dB	5 dB	6 dB	7 dB	8 dB	9 dB	10 dB
1.0	0.81	1.84	2.85	3.93	4.84	5.88	6.88	8.07	8.85	9.47
2.0	0.81	1.84	2.85	3.93	4.86	5.88	6.88	8.07	8.90	9.49
3.0	0.81	1.84	2.85	3.93	4.88	5.88	6.88	8.07	8.93	9.50
4.0	0.81	1.84	2.85	3.93	4.90	5.88	6.88	8.07	8.96	9.52
5.0	0.81	1.84	2.85	3.93	4.92	5.88	6.88	8.07	8.99	9.54
6.0	0.81	1.84	2.85	3.93	4.94	5.88	6.88	8.07	9.01	9.56
7.0	0.81	1.84	2.85	3.93	4.96	5.88	6.88	8.07	9.02	9.58
8.0	0.81	1.84	2.85	3.93	4.98	5.88	6.88	8.07	9.03	9.59
9.0	0.81	1.84	2.85	3.93	5.00	5.88	6.88	8.07	9.02	9.61
10.0	0.81	1.84	2.85	3.93	5.02	5.88	6.88	8.07	9.02	9.63
11.0	0.81	1.84	2.85	3.93	5.04	5.88	6.88	8.07	9.00	9.65
12.0	0.81	1.84	2.85	3.93	5.06	5.88	6.88	8.07	8.98	9.67
12.4	0.81	1.84	2.85	3.93	5.07	5.88	6.88	8.07	8.97	9.67

CALCULATION OF OUTPUT ATTENUATOR STEPS

GHz	10 dB	11 dB	12 dB	13 dB	14 dB	15 dB	16 dB	17 dB	18 dB	19 dB	20 dB
1.0	9.47	10.28	11.31	12.32	13.39	14.31	15.35	16.35	17.54	18.32	19.54
2.0	9.49	10.30	11.33	12.34	13.41	14.35	15.37	16.37	17.56	18.38	19.54
3.0	9.50	10.32	11.35	12.35	13.43	14.39	15.38	16.39	17.58	18.44	19.54
4.0	9.52	10.34	11.37	12.37	13.45	14.43	15.40	16.41	17.59	18.49	19.54
5.0	9.54	10.35	11.38	12.39	13.47	14.46	15.42	16.42	17.61	18.53	19.54
6.0	9.56	10.37	11.40	12.41	13.48	14.50	15.44	16.44	17.63	18.57	19.54
7.0	9.58	10.39	11.42	12.43	13.50	14.54	15.46	16.46	17.65	18.60	19.54
8.0	9.59	10.41	11.44	12.44	13.52	14.58	15.47	16.48	17.67	18.62	19.54
9.0	9.61	10.43	11.46	12.46	13.54	14.61	15.49	16.50	17.68	18.64	19.54
10.0	9.63	10.44	11.47	12.48	13.56	14.65	15.51	16.52	17.70	18.65	19.54
11.0	9.65	10.46	11.49	12.50	13.57	14.69	15.53	16.53	17.72	18.65	19.54
12.0	9.67	10.48	11.51	12.52	13.59	14.73	15.55	16.55	17.74	18.65	19.54
12.4	9.67	10.49	11.52	12.52	13.60	14.74	15.55	16.56	17.75	18.65	19.54

Table 2 (Continued)

CALCULATION OF OUTPUT ATTENUATOR STEPS

GHz	20 dB	21 dB	22 dB	23 dB	24 dB	25 dB	26 dB	27 dB	28 dB	29 dB	30 dB
1.0	19.54	20.35	21.38	22.39	23.47	24.38	25.42	26.42	27.61	28.39	29.29
2.0	19.54	20.35	21.38	22.39	23.47	24.40	25.42	26.42	27.61	28.44	29.29
3.0	19.54	20.35	21.38	22.39	23.47	24.42	25.42	26.42	27.61	28.47	29.29
4.0	19.54	20.35	21.38	22.39	23.47	24.44	25.42	26.42	27.61	28.50	29.29
5.0	19.54	20.35	21.38	22.39	23.47	24.46	25.42	26.42	27.61	28.53	29.29
6.0	19.54	20.35	21.38	22.39	23.47	24.48	25.42	26.42	27.61	28.55	29.29
7.0	19.54	20.35	21.38	22.39	23.47	24.50	25.42	26.42	27.61	28.56	29.29
8.0	19.54	20.35	21.38	22.39	23.47	24.52	25.42	26.42	27.61	28.57	29.29
9.0	19.54	20.35	21.38	22.39	23.47	24.54	25.42	26.42	27.61	28.56	29.29
10.0	19.54	20.35	21.38	22.39	23.47	24.56	25.42	26.42	27.61	28.56	29.29
11.0	19.54	20.35	21.38	22.39	23.47	24.58	25.42	26.42	27.61	28.54	29.29
12.0	19.54	20.35	21.38	22.39	23.47	24.60	25.42	26.42	27.61	28.52	29.29
12.4	19.54	20.35	21.38	22.39	23.47	24.61	25.42	26.42	27.61	28.51	29.29

CALCULATION OF OUTPUT ATTENUATOR STEPS

GHz	30 dB	31 dB	32 dB	33 dB	34 dB	35 dB	36 dB	37 dB	38 dB	39 dB	40 dB
1.0	29.29	30.10	31.14	32.14	33.22	34.14	35.17	36.18	37.36	38.14	39.34
2.0	29.29	30.10	31.14	32.14	33.22	34.16	35.17	36.18	37.36	38.19	39.34
3.0	29.29	30.10	31.14	32.14	33.22	34.18	35.17	36.18	37.36	38.23	39.34
4.0	29.29	30.10	31.14	32.14	33.22	34.20	35.17	36.18	37.36	38.26	39.34
5.0	29.29	30.10	31.14	32.14	33.22	34.21	35.17	36.18	37.36	38.28	39.34
6.0	29.29	30.10	31.14	32.14	33.22	34.23	35.17	36.18	37.36	38.30	39.34
7.0	29.29	30.10	31.14	32.14	33.22	34.25	35.17	36.18	37.36	38.31	39.34
8.0	29.29	30.10	31.14	32.14	33.22	34.27	35.17	36.18	37.36	38.32	39.34
9.0	29.29	30.10	31.14	32.14	33.22	34.29	35.17	36.18	37.36	38.32	39.34
10.0	29.29	30.10	31.14	32.14	33.22	34.31	35.17	36.18	37.36	38.31	39.34
11.0	29.29	30.10	31.14	32.14	33.22	34.33	35.17	36.18	37.36	38.30	39.34
12.0	29.29	30.10	31.14	32.14	33.22	34.35	35.17	36.18	37.36	38.28	39.34
12.4	29.29	30.10	31.14	32.14	33.22	34.36	35.17	36.18	37.36	38.27	39.34

Table 2 (Continued)
CALCULATION OF OUTPUT ATTENUATOR STEPS

GHz	40 dB	41 dB	42 dB	43 dB	44 dB	45 dB	46 dB	47 dB	48 dB	49 dB	50 dB
1.0	39.34	40.16	41.19	42.19	43.27	44.19	45.22	46.23	47.42	48.20	49.22
2.0	39.34	40.16	41.19	42.19	43.27	44.21	45.22	46.23	47.42	48.24	49.24
3.0	39.34	40.16	41.19	42.19	43.27	44.23	45.22	46.23	47.42	48.28	49.25
4.0	39.34	40.16	41.19	42.19	43.27	44.25	45.22	46.23	47.42	48.31	49.27
5.0	39.34	40.16	41.19	42.19	43.27	44.27	45.22	46.23	47.42	48.33	49.28
6.0	39.34	40.16	41.19	42.19	43.27	44.29	45.22	46.23	47.42	48.35	49.30
7.0	39.34	40.16	41.19	42.19	43.27	44.31	45.22	46.23	47.42	48.36	49.31
8.0	39.34	40.16	41.19	42.19	43.27	44.33	45.22	46.23	47.42	48.37	49.33
9.0	39.34	40.16	41.19	42.19	43.27	44.35	45.22	46.23	47.42	48.37	49.35
10.0	39.34	40.16	41.19	42.19	43.27	44.36	45.22	46.23	47.42	48.36	49.36
11.0	39.34	40.16	41.19	42.19	43.27	44.38	45.22	46.23	47.42	48.35	49.38
12.0	39.34	40.16	41.19	42.19	43.27	44.40	45.22	46.23	47.42	48.33	49.39
12.4	39.34	40.16	41.19	42.19	43.27	44.41	45.22	46.23	47.42	48.32	49.40

CALCULATION OF OUTPUT ATTENUATOR STEPS

GHz	50 dB	51 dB	52 dB	53 dB	54 dB	55 dB	56 dB	57 dB	58 dB	59 dB	60 dB
1.0	49.22	50.04	51.07	52.07	53.15	54.07	55.10	56.11	57.29	58.07	59.53
2.0	49.24	50.05	51.08	52.09	53.16	54.10	55.12	56.12	57.31	58.13	59.53
3.0	49.25	50.07	51.10	52.10	53.18	54.14	55.13	56.14	57.32	58.19	59.53
4.0	49.27	50.08	51.11	52.12	53.19	54.17	55.15	56.15	57.34	58.23	59.53
5.0	49.28	50.10	51.13	52.13	53.21	54.21	55.16	56.17	57.35	58.27	59.53
6.0	49.30	50.11	51.14	52.15	53.22	54.24	55.18	56.18	57.37	58.31	59.53
7.0	49.31	50.13	51.16	52.16	53.24	54.28	55.19	56.20	57.39	58.33	59.53
8.0	49.33	50.14	51.17	52.18	53.26	54.31	55.21	56.21	57.40	58.36	59.53
9.0	49.35	50.16	51.19	52.20	53.27	54.35	55.23	56.23	57.42	58.37	59.53
10.0	49.36	50.17	51.20	52.21	53.29	54.38	55.24	56.24	57.43	58.38	59.53
11.0	49.38	50.19	51.22	52.23	53.30	54.42	55.26	56.26	57.45	58.38	59.53
12.0	49.39	50.20	51.23	52.24	53.32	54.45	55.27	56.28	57.46	58.38	59.53
12.4	49.40	50.21	51.24	52.25	53.32	54.47	55.28	56.28	57.47	58.37	59.53

Table 2 (Continued)

CALCULATION OF OUTPUT ATTENUATOR STEPS

GHz	60 dB	61 dB	62 dB	63 dB	64 dB	65 dB	66 dB	67 dB	68 dB	69 dB	70 dB
1.0	59.53	60.35	61.38	62.38	63.46	64.38	65.41	66.42	67.61	68.38	68.99
2.0	59.53	60.35	61.38	62.38	63.46	64.40	65.41	66.42	67.61	68.43	69.00
3.0	59.53	60.35	61.38	62.38	63.46	64.42	65.41	66.42	67.61	68.47	69.01
4.0	59.53	60.35	61.38	62.38	63.46	64.44	65.41	66.42	67.61	68.50	69.02
5.0	59.53	60.35	61.38	62.38	63.46	64.46	65.41	66.42	67.61	68.52	69.03
6.0	59.53	60.35	61.38	62.38	63.46	64.48	65.41	66.42	67.61	68.54	69.04
7.0	59.53	60.35	61.38	62.38	63.46	64.50	65.41	66.42	67.61	68.55	69.05
8.0	59.53	60.35	61.38	62.38	63.46	64.52	65.41	66.42	67.61	68.56	69.06
9.0	59.53	60.35	61.38	62.38	63.46	64.54	65.41	66.42	67.61	68.56	69.07
10.0	59.53	60.35	61.38	62.38	63.46	64.55	65.41	66.42	67.61	68.55	69.08
11.0	59.53	60.35	61.38	62.38	63.46	64.57	65.41	66.42	67.61	68.54	69.09
12.0	59.53	60.35	61.38	62.38	63.46	64.59	65.41	66.42	67.61	68.52	69.11
12.4	59.53	60.35	61.38	62.38	63.46	64.60	65.41	66.42	67.61	68.51	69.11

CALCULATION OF OUTPUT ATTENUATOR STEPS

GHz	70 dB	71 dB	72 dB	73 dB	74 dB	75 dB	76 dB	77 dB	78 dB	79 dB	80 dB
1.0	68.99	69.80	70.83	71.84	72.92	73.83	74.87	75.87	77.06	77.84	78.92
2.0	69.00	69.81	70.84	71.85	72.93	73.86	74.88	75.88	77.07	77.90	78.88
3.0	69.01	69.82	70.85	71.86	72.94	73.89	74.89	75.90	77.08	77.94	78.85
4.0	69.02	69.83	70.86	71.87	72.95	73.92	74.90	75.91	77.09	77.99	78.81
5.0	69.03	69.85	70.88	71.88	72.96	73.95	74.91	75.92	77.10	78.02	78.77
6.0	69.04	69.86	70.89	71.89	72.97	73.98	74.92	75.93	77.11	78.05	78.74
7.0	69.05	69.87	70.90	71.90	72.98	74.02	74.93	75.94	77.12	78.07	78.70
8.0	69.06	69.88	70.91	71.91	72.99	74.04	74.94	75.95	77.13	78.09	78.66
9.0	69.07	69.89	70.92	71.92	73.00	74.07	74.95	75.96	77.14	78.10	78.63
10.0	69.08	69.90	70.93	71.93	73.01	74.10	74.96	75.97	77.16	78.10	78.59
11.0	69.09	69.91	70.94	71.94	73.02	74.13	74.97	75.98	77.17	78.10	78.55
12.0	69.11	69.92	70.95	71.96	73.03	74.17	74.99	75.99	77.18	78.09	78.52
12.4	69.11	69.92	70.95	71.96	73.03	74.18	74.99	75.99	77.18	78.08	78.50

Table 2 (Continued)

CALCULATION OF OUTPUT ATTENUATOR STEPS

GHz	80 dB	81 dB	82 dB	83 dB	84 dB	85 dB	86 dB	87 dB	88 dB	89 dB	90 dB
1.0	78.92	79.73	80.76	81.77	82.84	83.76	84.80	85.80	86.99	87.77	88.73
2.0	78.88	79.70	80.73	81.73	82.81	83.75	84.76	85.77	86.95	87.78	88.67
3.0	78.85	79.66	80.69	81.70	82.77	83.73	84.73	85.73	86.92	87.78	88.62
4.0	78.81	79.62	80.65	81.66	82.73	83.71	84.69	85.69	86.88	87.77	88.57
5.0	78.77	79.59	80.62	81.62	82.70	83.69	84.65	85.66	86.84	87.76	88.51
6.0	78.74	79.55	80.58	81.59	82.66	83.68	84.62	85.62	86.81	87.74	88.46
7.0	78.70	79.51	80.54	81.55	82.62	83.66	84.58	85.58	86.77	87.72	88.40
8.0	78.66	79.48	80.51	81.51	82.59	83.64	84.54	85.55	86.73	87.69	88.35
9.0	78.63	79.44	80.47	81.48	82.55	83.63	84.51	85.51	86.70	87.65	88.30
10.0	78.59	79.40	80.43	81.44	82.51	83.61	84.47	85.47	86.66	87.61	88.24
11.0	78.55	79.36	80.39	81.40	82.48	83.59	84.43	85.44	86.62	87.56	88.19
12.0	78.52	79.33	80.36	81.37	82.44	83.58	84.40	85.40	86.59	87.50	88.14
12.4	78.50	79.31	80.34	81.35	82.43	83.57	84.38	85.38	86.57	87.47	88.11

CALCULATION OF OUTPUT ATTENUATOR STEPS

GHz	90 dB	91 dB	92 dB	93 dB	94 dB	95 dB	96 dB	97 dB	98 dB	99 dB
1.0	88.73	89.54	90.57	91.58	92.65	93.57	94.61	95.61	96.80	97.58
2.0	88.67	89.49	90.52	91.52	92.60	93.54	94.55	95.56	96.74	97.57
3.0	88.62	89.43	90.46	91.47	92.54	93.50	94.50	95.50	96.69	97.55
4.0	88.57	89.38	90.41	91.42	92.49	93.47	94.45	95.45	96.64	97.53
5.0	88.51	89.32	90.35	91.36	92.44	93.43	94.39	95.40	96.58	97.50
6.0	88.46	89.27	90.30	91.31	92.38	93.40	94.34	95.34	96.53	97.47
7.0	88.40	89.22	90.25	91.25	92.33	93.37	94.28	95.29	96.47	97.42
8.0	88.35	89.16	90.19	91.20	92.28	93.33	94.23	95.23	96.42	97.38
9.0	88.30	89.11	90.14	91.15	92.22	93.30	94.18	95.18	96.37	97.32
10.0	88.24	89.06	90.09	91.09	92.17	93.26	94.12	95.13	96.31	97.26
11.0	88.19	89.00	90.03	91.04	92.11	93.23	94.07	95.07	96.26	97.19
12.0	88.14	88.95	89.98	90.99	92.06	93.20	94.02	95.02	96.21	97.12
12.4	88.11	88.93	89.96	90.96	92.04	93.18	93.99	95.00	96.18	97.09

APPENDIX B

Table 3

DBM (NEGATIVE) TO MICROVOLTS
(Referenced to 50 ohms)

DBM	MILLIWATTS	DB/MICROVOLT	MICROVOLTS
0.	1.0000000	106.98970	* 2.2360680+05
-1.0000000	.79432823	105.98970	* 1.9926977+05
-2.0000000	.63095734	104.98970	* 1.7761719+05
-3.0000000	.50118723	103.98970	* 1.5830149+05
-4.0000000	.39810717	102.98970	* 1.4108635+05
-5.0000000	.31622777	101.98970	* 1.2574334+05
-6.0000000	.25118864	100.98970	* 1.1206887+05
-7.0000000	.19952623	99.989700	* 9.9881488+04
-8.0000000	.15848932	98.989700	* 8.9019470+04
-9.0000000	.12589254	97.989700	* 7.9338686+04
-10.000000	.10000000	96.989700	* 7.0710678+04
-11.000000	.079432823	95.989700	* 6.3020958+04
-12.000000	.063095734	94.989700	* 5.6167488+04
-13.000000	.050118723	93.989700	* 5.0059326+04
-14.000000	.039810717	92.989700	* 4.4615422+04
-15.000000	.031622777	91.989700	* 3.9763536+04
-16.000000	.025118864	90.989700	* 3.5439289+04
-17.000000	.019952623	89.989700	* 3.1585300+04
-18.000000	.015848932	88.989700	* 2.8150428+04
-19.000000	.012589254	87.989700	* 2.5089095+04
-20.000000	.010000000	86.989700	* 2.2360680+04
-21.000000	.0079432823	85.989700	* 1.9928977+04
-22.000000	.0063095734	84.989700	* 1.7761719+04
-23.000000	.0050118723	83.989700	* 1.5830149+04
-24.000000	.0039810717	82.989700	* 1.4108635+04
-25.000000	.0031622777	81.989700	* 1.2574334+04
-26.000000	.0025118864	80.989700	* 1.1206887+04
-27.000000	.0019952623	79.989700	* 9.9881488+03
-28.000000	.0015848932	78.989700	* 8.9019470+03
-29.000000	.0012589254	77.989700	* 7.9338686+03
-30.000000	.0010000000	76.989700	* 7.0710678+03
-31.000000	* 7.9432823-04	75.989700	* 6.3020958+03
-32.000000	* 6.3095734-04	74.989700	* 5.6167488+03
-33.000000	* 5.0118723-04	73.989700	* 5.0059326+03
-34.000000	* 3.9810717-04	72.989700	* 4.4615422+03
-35.000000	* 3.1622777-04	71.989700	* 3.9763536+03
-36.000000	* 2.5118864-04	70.989700	* 3.5439289+03
-37.000000	* 1.9952623-04	69.989700	* 3.1585300+03
-38.000000	* 1.5848932-04	68.989700	* 2.8150428+03
-39.000000	* 1.2589254-04	67.989700	* 2.5089095+03
-40.000000	* 1.0000000-04	66.989700	* 2.2360680+03
-41.000000	* 7.9432823-05	65.989700	* 1.9928977+03
-42.000000	* 6.3095734-05	64.989700	* 1.7761719+03
-43.000000	* 5.0118723-05	63.989700	* 1.5830149+03
-44.000000	* 3.9810717-05	62.989700	* 1.4108635+03
-45.000000	* 3.1622777-05	61.989700	* 1.2574334+03
-46.000000	* 2.5118864-05	60.989700	* 1.1206887+03
-47.000000	* 1.9952623-05	59.989700	* 9.9881488+02
-48.000000	* 1.5848932-05	58.989700	* 8.9019470+02
-49.000000	* 1.2589254-05	57.989700	* 7.9338685+02

Table 3 (Continued)

DBM (NEGATIVE) TO MICROVOLTS
(Referenced to 50 ohms)

DBM	MILLIWATTS	DB/MICROVOLT	MICROVOLTS
-50.000000	* 1.0000000-05	56.989700	* 7.0710678+02
-51.000000	* 7.9432823-06	55.989700	* 6.3020958+02
-52.000000	* 6.3095734-06	54.989700	* 5.6167488+02
-53.000000	* 5.0118723-06	53.989700	* 5.0059326+02
-54.000000	* 3.9810717-06	52.989700	* 4.4615422+02
-55.000000	* 3.1622777-06	51.989700	* 3.9763536+02
-56.000000	* 2.5118864-06	50.989700	* 3.5439289+02
-57.000000	* 1.9952623-06	49.989700	* 3.1585300+02
-58.000000	* 1.5848932-06	48.989700	* 2.8150428+02
-59.000000	* 1.2589254-06	47.989700	* 2.5089095+02
-60.000000	* 1.0000000-06	46.989700	* 2.2360680+02
-61.000000	* 7.9432823-07	45.989700	* 1.9928977+02
-62.000000	* 6.3095734-07	44.989700	* 1.7761719+02
-63.000000	* 5.0118723-07	43.989700	* 1.5830149+02
-64.000000	* 3.9810717-07	42.989700	* 1.4108635+02
-65.000000	* 3.1622777-07	41.989700	* 1.2574334+02
-66.000000	* 2.5118864-07	40.989700	* 1.1206887+02
-67.000000	* 1.9952623-07	39.989700	99.881488
-68.000000	* 1.5848932-07	38.989700	89.019470
-69.000000	* 1.2589254-07	37.989700	79.338686
-70.000000	* 1.0000000-07	36.989700	70.710678
-71.000000	* 7.9432823-08	35.989700	63.020958
-72.000000	* 6.3095734-08	34.989700	56.167488
-73.000000	* 5.0118723-08	33.989700	50.059326
-74.000000	* 3.9810717-08	32.989700	44.615422
-75.000000	* 3.1622777-08	31.989700	39.763536
-76.000000	* 2.5118864-08	30.989700	35.439289
-77.000000	* 1.9952623-08	29.989700	31.585300
-78.000000	* 1.5848932-08	28.989700	28.150428
-79.000000	* 1.2589254-08	27.989700	25.089095
-80.000000	* 1.0000000-08	26.989700	22.360680
-81.000000	* 7.9432823-09	25.989700	19.928977
-82.000000	* 6.3095734-09	24.989700	17.761719
-83.000000	* 5.0118723-09	23.989700	15.830149
-84.000000	* 3.9810717-09	22.989700	14.108635
-85.000000	* 3.1622777-09	21.989700	12.574334
-86.000000	* 2.5118864-09	20.989700	11.206887
-87.000000	* 1.9952623-09	19.989700	9.9881488
-88.000000	* 1.5848932-09	18.989700	8.9019470
-89.000000	* 1.2589254-09	17.989700	7.9338686
-90.000000	* 1.0000000-09	16.989700	7.0710678
-91.000000	* 7.9432823-10	15.989700	6.3020958
-92.000000	* 6.3095734-10	14.989700	5.6167488
-93.000000	* 5.0118723-10	13.989700	5.0059326
-94.000000	* 3.9810717-10	12.989700	4.4615422
-95.000000	* 3.1622777-10	11.989700	3.9763536
-96.000000	* 2.5118864-10	10.989700	3.5439289
-97.000000	* 1.9952623-10	9.9897000	3.1585300
-98.000000	* 1.5848932-10	8.9897000	2.8150428
-99.000000	* 1.2589254-10	7.9897000	2.5089095

APPENDIX C. MAINTENANCE

C.1. Power Supply Section

All power supplies except that for the 1-watt, 1 to 2 GHz amplifier are commercial models. Their voltages should be set to the values shown in figure 15 using the screwdriver adjustments on the individual units.

The amplifier supply derives +24 volts and +15 volts from the +28 volt commercial unit by using zener diodes. The nominal +24 volts is produced from two 12-volt zener diodes in series. The +15 volts is produced by a 12-volt zener diode which drops the +28 volts to approximately 16 volts and the adjustable 50-ohm tapped resistor.

A schematic diagram of a safety interlock is shown in figure 16. This circuit protects the VTO and the 1-watt amplifier should certain critical voltages fail. The manufacturer states the VTO should not be powered if the tuning voltage is removed, nor should the -5 volts be applied to the 1-watt amplifier if the +24 and +15 volts are not present.

C.2. VTO Alignment

Figure 10 should be referred to when performing this operation. An electronic counter capable of measuring 1 to 2 GHz should be connected to the output of the remote head, and the Standard Signal System switched to 1-2 GHz range. The PULSE-CW switch (fig. 17) should be in CW.

<u>CAUTION:</u> Up to 1 watt can be delivered in this range so make sure enough attenuation is inserted to protect the counter.

1. Turn the FREQUENCY ADJUST knob full CCW. This applies 0 volts to the tuning terminal on the VTO. The counter should read approximately 997 MHz and the frequency meter on the Standard Signal System should indicate 1000 MHz.
2. Set 500-ohm, 2 GHz ADJUST resistor for maximum resistance. Turn FREQUENCY ADJUST knob full CW. Set 2 GHz ADJUST resistor so counter reads approximately 2002 MHz. Allow several minutes for frequency to stabilize.
3. Set 2 GHz SPAN ADJ. so meter reads 2 GHz.
4. Switch to 8-12.4 GHz range and set FREQUENCY ADJUST knob full CCW.
5. Set 8-12.4 GHz LOWER LIMIT ADJUST so counter reads 1141.4 MHz.
6. Rotate FREQUENCY ADJUST knob full CW and set 8-12.4 GHz UPPER LIMIT ADJUST so counter reads 1785.7 MHz.
7. Set 8-12.4 GHz SPAN ADJUST so meter reads 12.5 GHz.

C.3. YIG Lock Circuit Alignment

The equipment required for this operation is as follows:

a. A clip-on milliammeter connected to the negative tuning lead (black) of the YIG.

b. An oscilloscope connected to the output of the ramp generator (see fig. 4).

c. A spectrum analyzer (range 2-12.4 GHz) connected to the output of the remote head. This is used to measure the frequency and output power. A frequency counter may be substituted. If so, during the following steps sufficient power can be realized by obtaining as large as possible readings on the monitor. After alignment power output should be measured to verify the output level is greater than the reference level.

Alignment of 2-4 GHz range

1. Switch Standard Signal System to 2-4 GHz band.
2. Set YIG bias (fig. 12) to 0.75 volt.
3. Turn FREQUENCY ADJUST knob full CCW and adjust LOW LIMIT SET pot on YIG lock card so milliammeter reads 70 mA.
4. Turn FREQUENCY ADJUST knob full CW and adjust HIGH LIMIT SET pot so milliammeter reads 145 mA.
5. Increase LEVEL SET pot to obtain lock as indicated by LED display labeled YIG LOCK. Increase level to obtain higher output over entire 2-4 GHz range.
6. Slightly decrease LOW LIMIT pot to increase output power.
7. Break lock by turning off switch on frequency tuning chassis. Then re-start VTO with RESET button.
8. The ramping generator should start, effect a lock and shut off. Adjust COMPARATOR REFERENCE pot to obtain proper operation as observed on the oscilloscope.
9. Repeat steps 6 through 8 until sufficient power is obtained.

Alignment of 4-8 GHz range

1. Switch Standard Signal System to 4-8 GHz band.
2. Repeat steps of 2-4 GHz alignment except set YIG bias to -1.0 volts, set LOW LIMIT current to 145 mA and HIGH LIMIT current to 295 mA.

Alignment of 8-12.4 GHz range

1. Switch Standard Signal System to 8-12.4 GHz band and decrease monitor range by 10 dB.

2. Repeat steps of 2-4 GHz alignment except set YIG bias to -1.4 volts, set LOW LIMIT current to 295 mA and HIGH LIMIT current to 460 mA.

3. Output power on this range should be 0.1 mW or greater.

<u>Adjustment of diode switch bias</u>

1. Switch PULSE-CW switch to CW.

2. Set CW ON pot (see fig. 17) so -10 volts is applied to wiper of S1G.

3. Switch PULSE-CW switch to PULSE. Set Standard Signal System to 1 to 2 GHz band.

4. Adjust 1-2 GHz BIAS pot for 100 mA current. This can be measured with a clip-on milliammeter connected on the lead to the pot.

5. Repeat steps 3 and 4 for the other three bands.

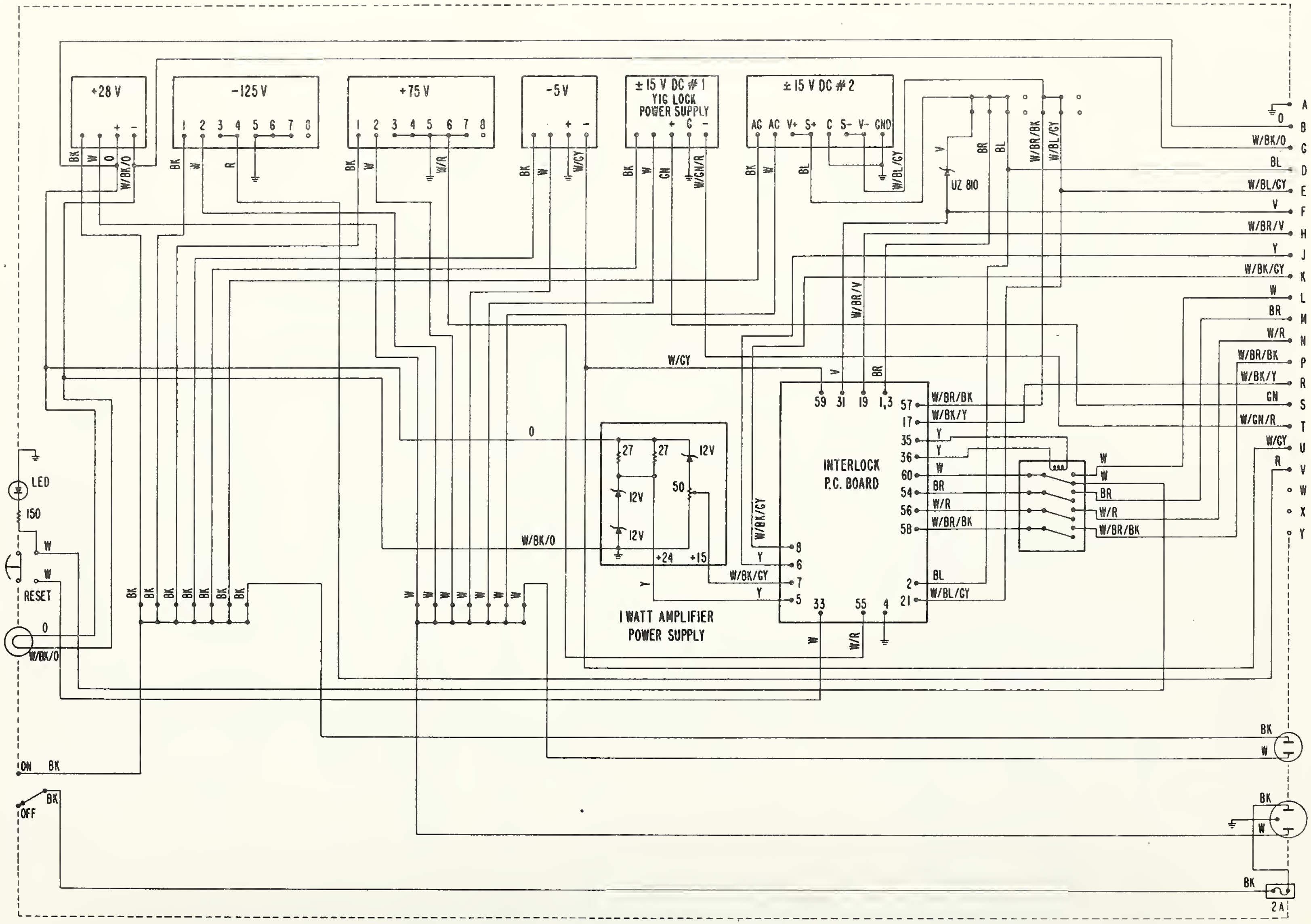

Figure 15. Wiring diagram for power supply chassis.

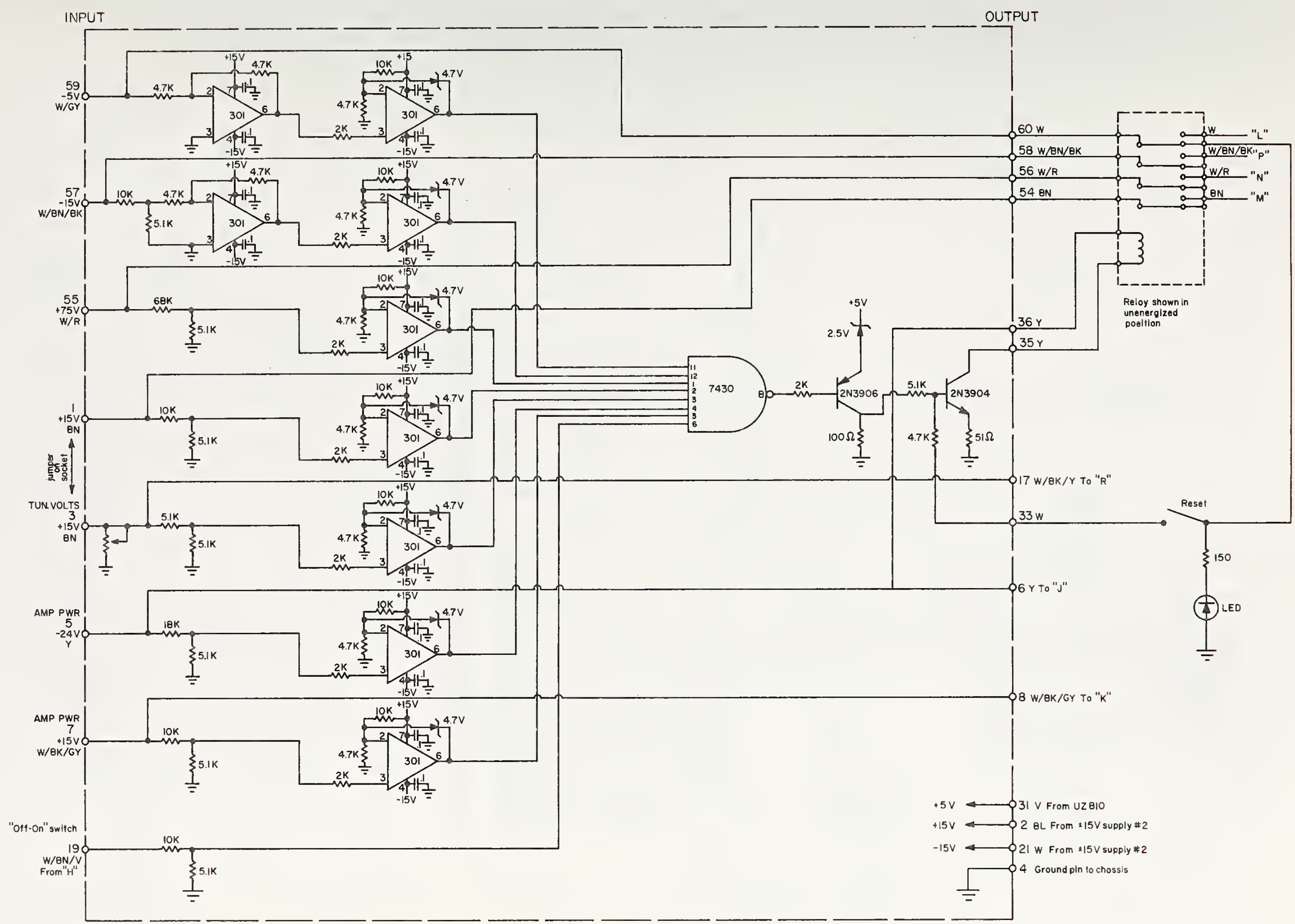

Figure 16. Power supply interlock circuit for protecting VTO and 1 watt amplifier.

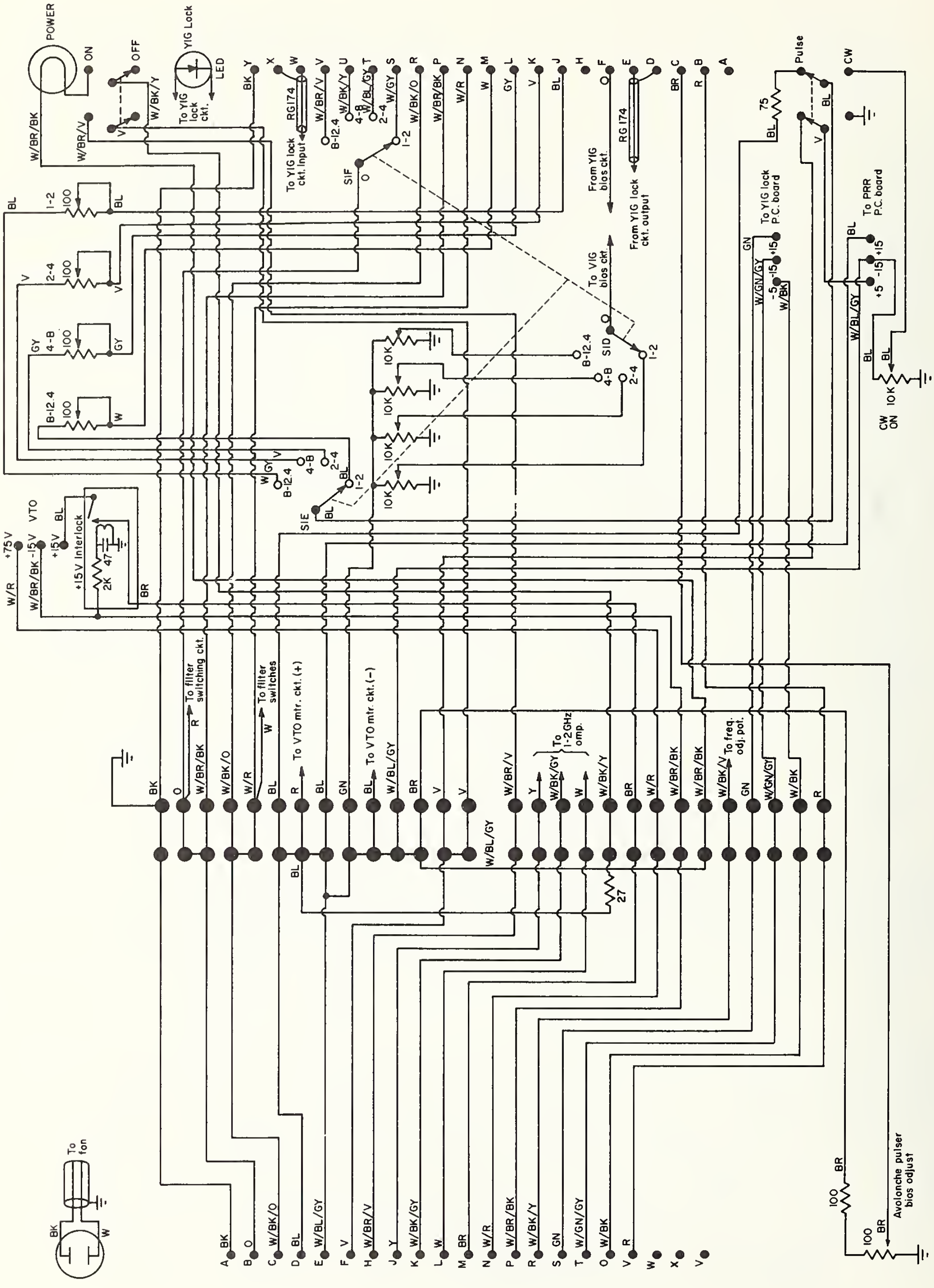

Figure 17. Wiring diagram for frequency tuning chassis.

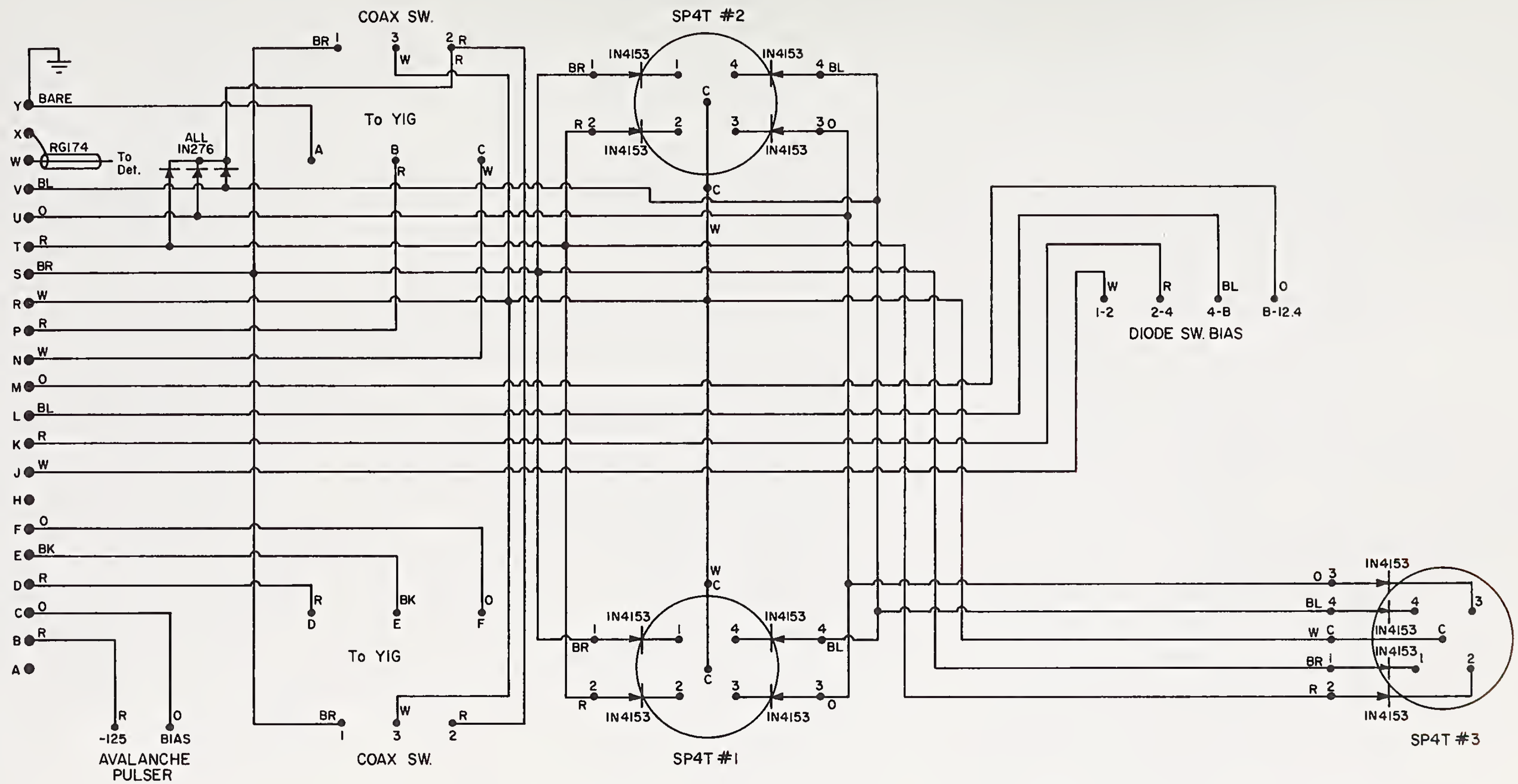

Figure 18. Wiring diagram of remote head.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report describes the constructional details and the operation of a system for calibrating microwave field intensity meter (FIM) receivers in the frequency range 1 to 12.4 GHz. The system uses known levels of CW power to calibrate the receiver, and short duration (~20 ns) rf bursts to measure the bandwidth. An error analysis of the system is given. Schematic drawings of various circuits in the system are provided along with charts and tables for facilitating computations encountered when performing calibrations.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Broadband signal generator; impulse bandwidth; receiver bandwidth calibration; rf burst generator; spectral intensity.

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