Test Equipment

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This paper describes the transmitter-receiver test set and the FM termina test panel, designed for maintaining the TD-3 radio equipment, and discusses the instrumentation and measuring techniques used to achieve accuracy consistent with the high performance of the TD-3 system. Circuits of special interest are covered in some detail.

I. INTRODUCTION

The TD-3 test equipment for routine maintenance and trouble-shooting procedures is designed to match the high performance of the TD-3 system and is simple and convenient to operate. The units have good long term stability and may be readily interconnected for testing or self-calibration. This is desirable because much of the TD-3 equipment is located in remote, unmanned sites where testing time must be kept to a minimum.

The equipment consists of a transmitter-receiver test set mounted in a rolling console and an FM terminal test panel mounted in (and used with) the existing TD-2 FM terminal test set.

The major functions of the test set are to measure amplitude and return loss in the 3700 to 4200 MHz (RF) and the 50 to 100 MHz (IF) frequency ranges, AM noise figure, frequency, and RF and IF power. These are similar to the functions of other test consoles,[1,2] but significant advances have been made in implementation. Solid state devices and RF coaxial instrumentation made such advances possible. Accurate IF frequency markers, low level power measurements, and direct reading frequency measurements are used extensively.

The FM terminal test panel is designed to enable the TD-2 FM terminal test set to test TD-3's 3A FM terminals. A major influence to this approach was that the 3A terminals[3] are now standard equipment in TD-2 production and are replacing TD-2 terminals in the TD-2 improvement program. Because many 3A terminals are being installed in TD-2 stations, it was decided to use existing terminal test equipment wherever feasible. The test panel has the greater accuracy required for 3A terminals.

The new test panel, which replaces a blank panel in the TD-2 FM terminal test console,[2] measures FM transmitter deviation sensitivity, deviator oscillator frequencies, baseband transmission, and sensitivity of the frequency alarm and level alarm circuits.

II. TRANSMITTER-RECEIVER TEST SET

The transmitter-receiver test set is used to measure IF and RF amplitude characteristics, IF and RF return loss, IF and RF power, frequency, and AM noise figure. Its major instruments are the IF and RF sweep oscillators, RF and IF detectors, oscilloscope, power meter, counter, IF amplifier, and noise lamp. They are integrated into a single console with a common control circuit, their power supplies, and peripheral equipment. The common control circuit is a centralized point for interconnecting many of the instruments.

Figure 1 shows the console, which also houses cables, coaxial to waveguide transducers, attenuators, and similar items.

2.1 *Design Considerations*

In recent years high quality test instruments have become increasingly available from many sources. Such instruments have been incorporated in the test set, usually with minor modifications. New circuits were developed to perform specific functions for which instruments were not available.

One of the most stringent functions that the test set must perform is to measure amplitude deviations of approximately one hundredth of a dB on IF to IF, IF to RF, RF to IF, and RF to RF measurements. This usually is achieved in laboratory and factory test apparatus by the comparison technique; that is, comparing the amplitude characteristic of the unit being tested with the characteristic of a known standard. But this is not practical for field tests.

The TD-3 transmitter-receiver test set uses the simpler and more economical direct method of amplitude measurement, which consists of inserting the unit to be tested between a signal source which has constant amplitude vs frequency and a detector which gives constant dc output vs frequency. This method trades the complexity of the comparison method for more stringent requirements on the swept signal source and the detector.

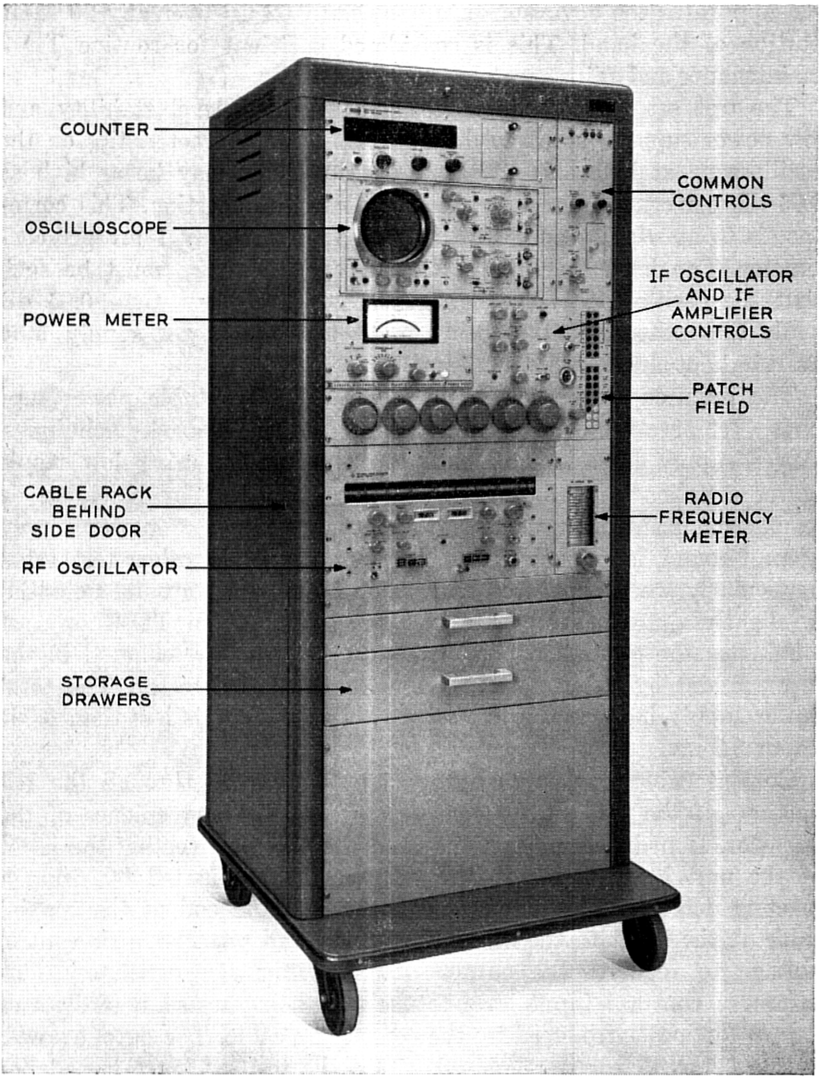

Fig. 1 — The transmitter-receiver test set.

Measuring amplitude deviations of approximately one hundredth of a dB by direct techniques ideally would require test apparatus with deviations much less than 0.01 dB. This is beyond present technology. The over-all deviations in the test set IF amplitude measuring apparatus are less than 0.15 dB from 60 to 80 MHz and in the

RF apparatus the deviations are less than 0.02 dB over any 20 MHz portion of the band. This is considered sufficient for routine TD-3 maintenance and adjustment.

The test set components must have excellent level stability and low power supply "hum" to display amplitude characteristics on the oscilloscope at high sensitivities. The sensitivity may be as high as 0.05 dB per centimeter of vertical oscilloscope deflection. This corresponds to an oscilloscope sensitivity of approximately 1 mv per centimeter. The level stability of the IF and RF units must be such that the oscilloscope trace changes considerably less than 0.05 dB while the measurement is being made and the power supply hum must be kept much lower than 1 mv.

The required stability was achieved by using stable power supplies,[4] temperature-compensated circuitry, and feedback techniques. Power supply hum is kept satisfactorily low by using low ripple power supplies,[4] by eliminating ground loops, and by shielding dc leads from transformers, motors, and other sources of power supply hum. Ground loop problems have been severe in other test sets,[1] particularly when connected with radio bays whose ground potential is slightly different from the test set ground. The TD-3 test set eliminates the ground loop by using an IF detector mounted in the test set and by using a dc block with the RF detector. The total power supply hum on the test set oscilloscope trace is less than 0.001 db, or 0.2 mv.

Coaxial cables rather than waveguides are used through the RF portions of the test set for compactness and the convenience of the operator. Impedance interactions from the cable connecting the input of the unit being tested to the test set are eliminated by using a leveling detector. This detector is located at the end of the coaxial cable at the input to the unit being tested and provides a dc control voltage to regulate the output power of the RF oscillator. This insures a constant input level to the unit being tested regardless of any distortions introduced by the connecting cable. The output power of the IF oscillator is regulated within the test set since impedance interactions in the IF connecting cables are small.

2.2 *Transmission Measurements*

Figure 2 illustrates the method of making transmission measurements. Either the RF oscillator or the IF oscillator may be the signal source. Similarly, either the RF or IF detector may be used.

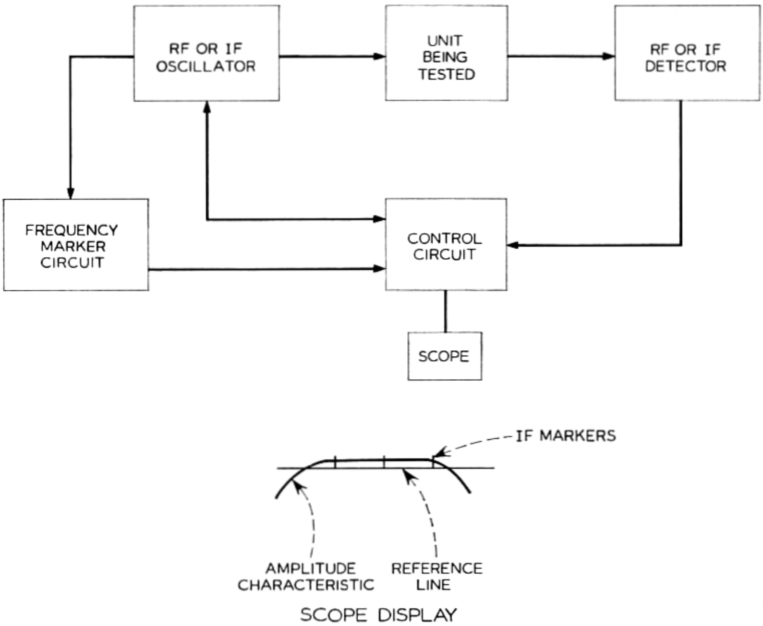

Fig. 2 — Transmission measurement.

This permits measurement of any IF or RF unit, modulator, or combination of units. The oscillators give constant output power and the detectors have flat frequency responses over their respective bands. This permits a direct display on the oscilloscope of the amplitude characteristic without the necessity of any corrections for test set characteristics.

The amount of patching required is kept to a minimum consistent with test set flexibility. The desired mode of operation is selected by a control switch which connects the output of the appropriate detector and frequency marker through the control circuit to the oscilloscope. The control circuit alternately connects the test signal and a dc reference voltage to the oscilloscope at a 31 Hz rate.

The oscilloscope display consists of a plot of the amplitude characteristic vs frequency of the unit being tested with appropriate frequency markers and a dc reference line. The vertical sensitivity is variable to 0.05 dB per cm maximum sensitivity. The sweep width is variable from 0 to 50 MHz and from 0 to 500 MHz for the IF and RF oscillators, respectively.

2.3 *IF Return Loss*

The IF return loss bridge shown in Fig. 3 measures IF return loss. The bridge separates the wave reflected from the unit being tested from the incident wave, and returns it to the test set to be amplified, detected, and presented on the oscilloscope. The oscilloscope displays return loss vs frequency. The dc reference line provides a calibrated reference which is set with the test set IF attenuator. IF frequency markers indicate frequency. The accuracy of the measurement is ±1.5 dB when measuring 40 dB return losses. Lower return losses are measured with correspondingly better accuracy.

The bridge technique overcomes the disadvantages of directional coupler and reflectometer methods sometimes used. A directional coupler has a 6 dB per octave frequency characteristic which must be compensated for when displaying the return loss characteristic. This is generally difficult to achieve with sufficient accuracy. The

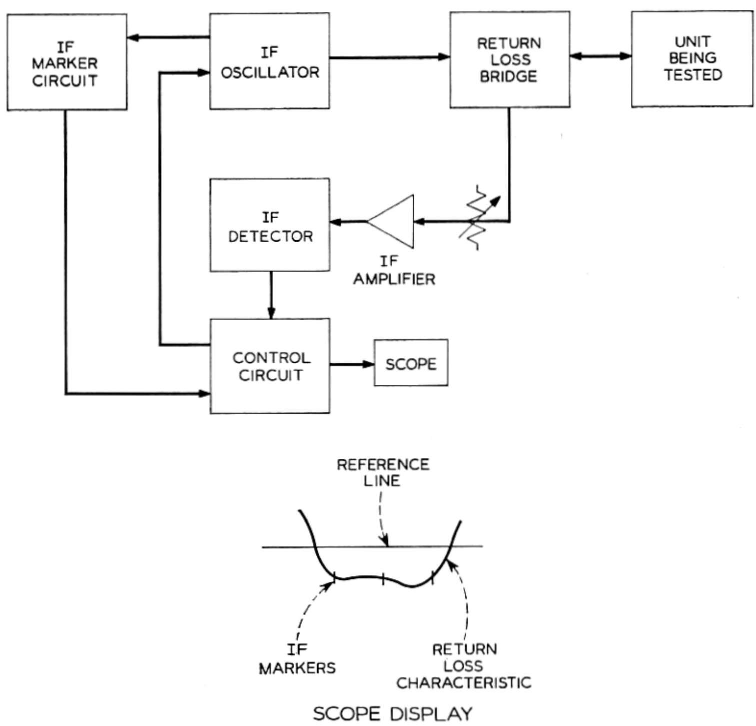

Fig. 3 — IF return loss measurement.

return loss bridge has a flat frequency response and requires no compensation. Reflectometer measurements using amplitude modulation of the test signal are affected by nonlinear elements in the test circuit, thus resulting in poor accuracy. No modulation is required with the bridge method.

2.4 *RF Return Loss*

With this test set, RF return loss measurements can be made only on circuits having the reflecting discontinuity located at a considerable electrical distance from the test equipment. This restriction was imposed because it satisfies the TD-3 system requirements and allows a simple measurement technique to be used. The technique consists of combining the incident and reflected waves in a detector by means of a power divider as Fig. 4 shows. As the frequency of the oscillator is varied, the phase difference between the incident and the reflected wave changes. For the normal 20 MHz sweep width and waveguide lengths of greater than 10 feet, several in phase and out of phase conditions exist over the swept frequency range. The output of the detector changes as the phase changes, thus producing a ripple on the oscilloscope. The amplitude of the ripple is a function of the return loss, and the frequency spacing of the ripples is a function

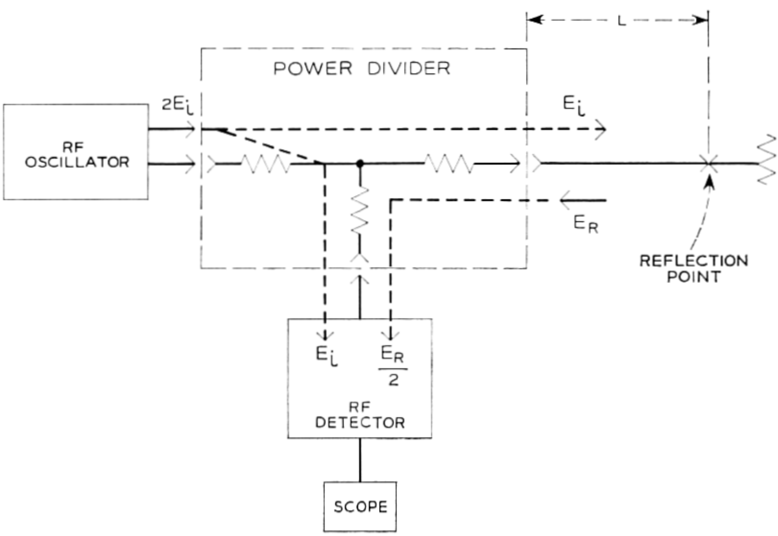

Fig. 4 — RF return loss measurement.

of the electrical distance between the power divider and the point of reflection. Thus, information on the magnitude and location of the reflection is obtained from this measurement.

The magnitude of the peak to peak ripple in dB may be determined from the calibrated oscilloscope display. The ripple amplitude may easily be converted to return loss. As shown in Fig. 4, the magnitude of the incident wave at the detector input is E_i and the magnitude of the reflected wave is $E_r/2$. The factor of ½ takes the 6 dB loss of the power divider into account. When the two signals are in phase the input is $E_i + E_r/2$ and when the signals are out of phase the input is $E_i - E_r/2$. The magnitude of the ripple (R) in dB is:

$$R = 20 \log \left[\frac{E_i + E_r/2}{E_i - E_r/2}\right] = 20 \log \left[\frac{1 + |\Gamma|/2}{1 - |\Gamma|/2}\right]. \tag{1}$$

$$\Gamma = \text{reflection coefficient} = E_r/E_i$$

Solving (1) for Γ

$$|\Gamma| = 2\left[\frac{10^{R/20} - 1}{10^{R/20} + 1}\right].$$

But, return loss (RL) $= -20 \log 1/|\Gamma|$

$$RL = 20 \log \left[\frac{10^{R/20} + 1}{2(10^{R/20} - 1)}\right]. \tag{2}$$

Figure 5 is a plot of equation (2).

2.5 *Frequency Markers*

Both IF and RF markers are provided to indicate frequency on swept measurements. Three IF markers are provided; two use crystal-controlled tuned circuits and one uses a variable oscillator. The mark-

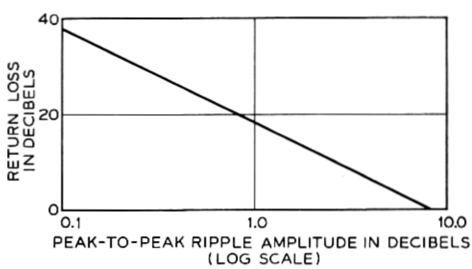

Fig. 5 — Conversion of ripple amplitude to return loss.

ers are driven by a sample of the IF swept signal and appear as "birdies" on the oscilloscope presentation. The variable marker can be shifted from 55 to 95 MHz; the frequency is read directly on the counter, which minimizes marker frequency error. The "birdie" width is such that the frequency of any point on an IF characteristic can be determined within 0.1 MHz.

Figure 6 is a schematic diagram of the IF marker circuit. The circuit consists of a 55 to 95 MHz oscillator associated with transistor Q1 and two tuned circuits consisting of a 64 MHz and a 76 MHz crystal. When the IF swept signal coincides with the frequency of the crystals or the oscillator, a "birdie" is produced at the collector

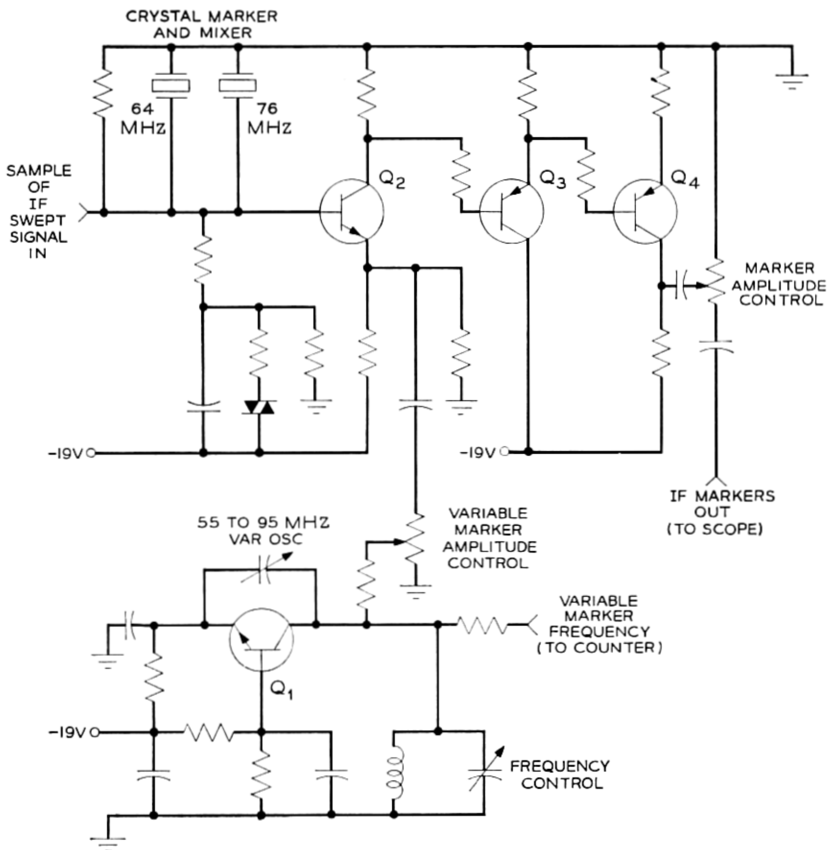

Fig. 6 — IF marker circuit.

of Q2. The "birdie" is amplified by transistors Q3 and Q4 and applied directly to the oscilloscope display. Amplitude controls are provided to adjust the amplitude of the markers.

The IF markers are used for IF to IF, IF to RF, and RF to IF measurements. When the IF oscillator is used in the measurement, the sample of the IF swept signal is obtained from the IF oscillator. When the IF oscillator is not used, the sample of the IF swept signal is obtained from the IF detector. In each case, the output of the marker circuit is added directly to the oscilloscope display and does not pass through the unit being tested.

The RF marker is provided by a resonant-cavity frequency meter which is lightly coupled to the output of the RF oscillator. The frequency meter has a diode rectifier which provides a dc pulse when the frequency of the RF oscillator is at the resonant frequency of the cavity. The pulse is added directly to the scope presentation in the same manner as the IF markers. The RF frequency can be measured to about ±0.6 MHz accuracy.

The RF marker is used for RF to RF measurements and is available for RF to IF measurements. Its use for RF to IF measurements is usually limited to calibration because of the more accurate and more convenient IF markers available.

2.6 *Power Measurements*

The thermocouple type power meter measures IF and RF power from +10 to −30 dBm, to an accuracy of 0.3 dB or better at room temperature. It consists of an indicating unit and three separate power heads, each of which houses a thermocouple. The head used for IF measurements has an impedance of 75 ohms. The heads used for RF measurements each have an impedance of 50 ohms. The IF head and one of the RF heads are used for measuring power outside the test set and are accessible by front panel connectors. The other RF power head is connected to a monitor point on the RF oscillator and provides a continuous measurement of the RF output level. This allows the output of the oscillator to be changed a known amount without the use of a precision variable attenuator.

2.7 *Frequency Measurement*

The frequency counter is used to measure the frequencies of the crystal oscillators in the microwave generator, carrier resupply, and shift oscillator of the TD-3 radio equipment as well as the frequency of the IF marker. The counter is a direct reading unit and measures frequencies as high as 135 MHz. Its stability is such that an accuracy of 5 parts in 10^7 ± 1 digit is maintained for a year. Using a gating time of 0.1 seconds, a 125 MHz oscillator may be conveniently adjusted to a frequency within ± 2 parts in 10^7.

A special technique is used to measure the frequency of the carrier resupply.[5] The resupply provides a 70 MHz carrier and a low level signal of either 61 or 63 MHz at its output. To measure the frequency of the 61 or 63 MHz signal, it is first separated from the 70 MHz carrier by a low pass filter. The amplitude of the signal is then increased by the test set IF amplifier to a power sufficient to drive the counter. However, the amplifier adds noise to the signal and this noise impairs the accuracy of the measurement. A band pass filter between the amplifier output and the counter reduces the effect of the noise.

2.8 *Noise Figure*

The AM noise figure of the TD-3 radio receiver is measured by comparing its noise with the noise of a gaseous discharge tube using the "Y factor" technique. The AM noise is measured rather than the more meaningful FM noise because of the simplicity and economy of the test apparatus. Despite its shortcomings, AM noise measurement is a useful maintenance tool.

The gaseous discharge tube is an argon lamp mounted in a coaxial structure. The noise output of the lamp is available on a type N connector located on the front panel of the test set. A noise measurement using the Y factor technique is made in the following manner. The output of the noise lamp is connected to the input of the receiver being tested. The output of the receiver is connected through the test set IF amplifier and the band pass filter to the power meter. Power meter readings are noted with the noise lamp ON and with it OFF. The Y factor (in dB) is the difference in the two power meter readings.

The noise figure is determined from the Y factor by the following relationship:[6]

$$F = 10 \log \left[\frac{\text{Tex}}{Y - 1} \right] \text{dB} \qquad (3)$$

where

F = noise figure in dB

Tex = excess noise temperature of noise generator and connecting cables

Y = measured Y factor ratio.

The excess noise temperature ratio of the test set generator and cables is 13.9 ± 0.5 dB. Figure 7 is a plot of equation (3) with F, Y, and Tex given in dB. The dotted curves show the accuracy limitations caused by the variation of the excess noise temperature.

2.9 *Control and Common Circuits*

The control circuit merges the several units of the test set into a single functional unit. A single switch in the control circuit makes many of the interconnections required for the different measurements. The control circuit also provides the oscilloscope drive circuit, and generates the 31 Hz IF sweep drive signal.

The four-position switch makes the proper connections for IF to IF, IF to RF, RF to IF, and RF to RF measurements. It selects either the IF or RF detector, the IF or RF markers, and connects the appropriate sweep control voltage to the oscilloscope. The remainder of the connections are made manually on the front panel patch field.

The oscilloscope drive circuit alternately connects the detector output and a dc reference voltage to the vertical input of the oscilloscope. The reference line is applied to the oscilloscope during the retrace interval of the sweep signal. The circuit is synchronized to either the 31 Hz sinusoidal IF sweep signal or the 31 Hz triangular RF sweep signal. There are separate synchronizing controls. The reference line is connected to the scope during the negative going portion of the sweep signal and the test signal is connected during the positive going portion of the sweep signal. Coarse and fine controls position the traces on the oscilloscope.

The dc reference line serves two functions. First, it provides a reference line on the oscilloscope whose relationship to the test signal is independent of any oscilloscope adjustments. This permits use of the oscilloscope controls to set up calibration and position without upsetting the reference position. Second, use of the sweep signal retrace interval for applying the reference line allows the RF and IF oscillators to be on continuously rather than being blanked during the retrace. This permits power measurements to be made while the RF and IF oscillators are being swept, which could not be done without error if the oscillators were blanked during the retrace.

The sweep drive signal for the IF oscillator is provided by a modi-

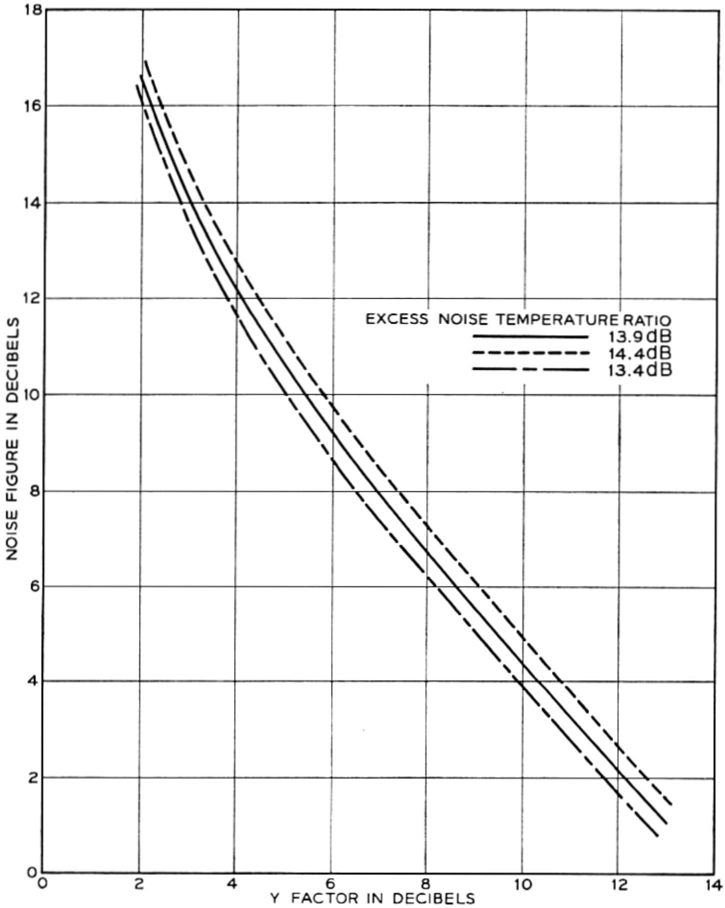

Fig. 7 — Conversion of Y factor to noise figure.

fied Wein Bridge oscillator as shown in Fig. 8. It consists of a 4-stage RC amplifier, operating as an oscillator, followed by two amplifier stages. The amplifier stages provide an output level of 26 volts peak-to-peak which is required to drive the IF oscillator to its maximum sweep width of 50 MHz. In order to achieve this voltage output, the amplifier stages are powered by a −40-volt power supply instead of the −19-volt supply.

2.10 *IF Detector*

The IF detector consists of two IF amplifier stages followed by a diode detector as shown in Fig. 9. The use of the amplifier stages has

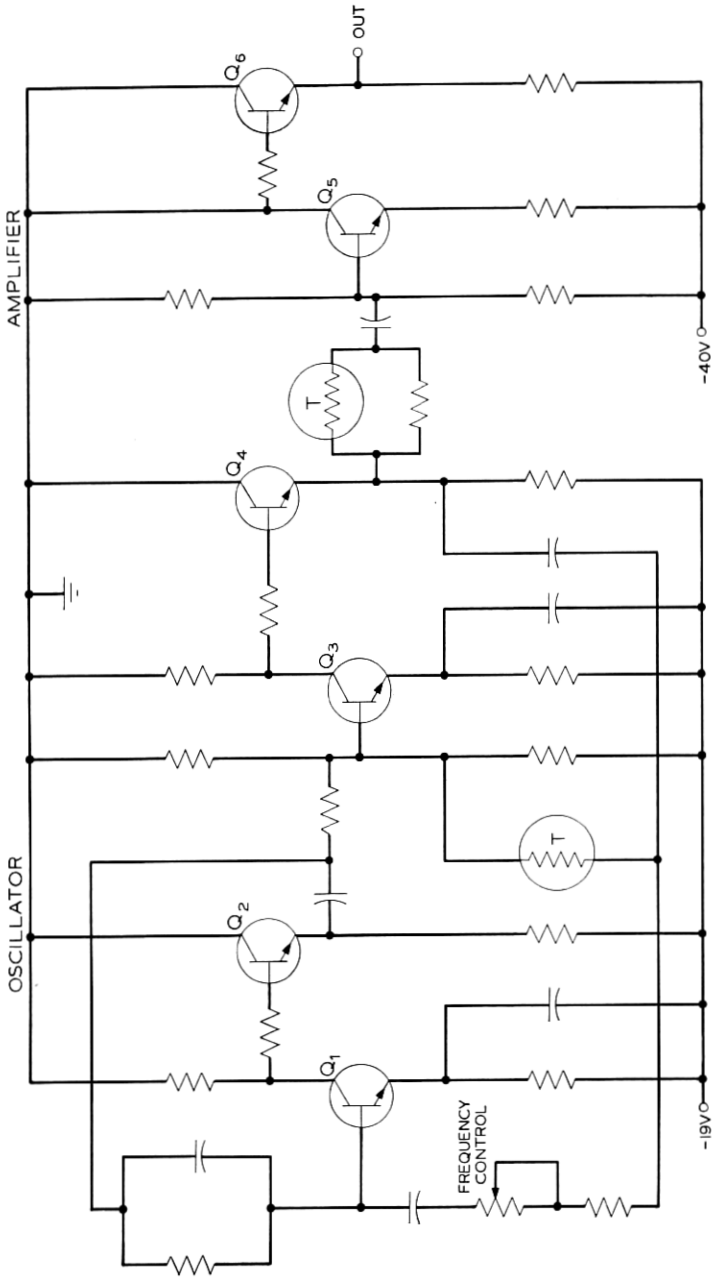

Fig. 8 — 31 Hz oscillator circuit.

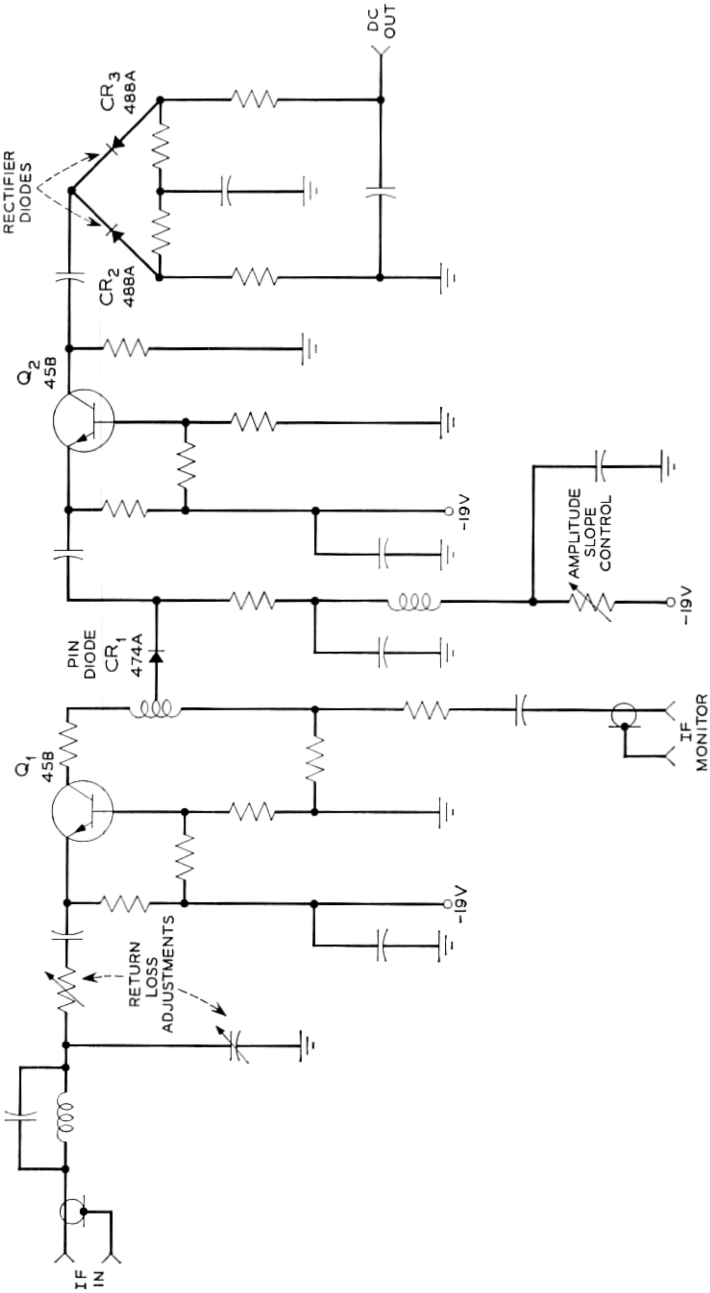

Fig. 9 — IF detector circuit.

great impact on the detector performance. First, the sensitivity is improved by the gain of the amplifier stages. Second, the input return loss is good since the input to the amplifier stages can be well matched to 75 ohms. Third, the amplifier provides an amplitude slope control which may be located outside the detector. Fourth, the nonlinear detector diodes are isolated from the connecting circuit by the amplifier stages. These improved detector characteristics allow the IF detector to achieve high performance and allow the connection to the detector to be made with a long IF cable.

Detectors used in earlier test sets had to be connected directly to the unit being tested. The return loss of the earlier detector sometimes was poor; in addition, the diode generated harmonics of the signal which appeared at the detector input. If a long cable were used to connect the detector to the unit being tested, interferences caused by reflected and phase shifted fundamental and harmonic signals caused a distorted signal envelope (for swept input signals) to appear at the detector output. The good return loss and harmonic isolation provided in the TD-3 test set detector virtually eliminate these problems and permit a cable to be used to connect the detector, mounted on the test set, to the unit being tested. With the detector mounted on the test set, ground loop disurbances, mentioned earlier, are less troublesome.

The IF power available in TD-3 for detection is −7 dBm. This low power, in combination with the high sensitivity required, makes IF amplification in the detector necessary. The amplification consists of two transistor transformer-coupled stages similar to those used in the TD-3 IF main amplifier circuits.[5] A harmonic filter at the input reduces the detector response to harmonics present in the output of the unit undergoing the test. A signal approximately 30 dB lower than the input signal is provided by a monitor circuit to drive the IF marker circuit.

An amplitude slope control in the detector compensates for slope introduced by the connecting IF cabling and test set variations. The control is a screwdriver adjustment on the front panel. As shown in Fig. 9, the slope control circuit consists of a PIN diode between the two amplifier stages. The amplitude slope of the amplifier is controlled by the resistance of the diode which is varied by changing the direct current through the diode.

The detector uses two diodes in a full wave rectification circuit with dc loading to give an output proportional to the average value of the rectified input signal. This configuration was chosen to provide high fundamental sensitivity and low harmonic sensitivity.

In contrast, the RF detector has higher power available for detection (0 dBm) and the RF harmonics are far removed from the TD-3 frequency range. RF power is detected with a high sensitivity diode detector preceded by a low pass filter. Both these units have coaxial structures with type N connectors and are obtained commercially.

2.11 *Test Set IF Amplifier*

The test set IF amplifier provides increased sensitivity or power level for IF return loss, noise figure, and carrier resupply frequency measurements. The amplifier is the IF main amplifier described in Ref. 5 with the AGC function of the main amplifier removed, and with additional gain. The gain of the test set IF amplifier is manually adjustable from 45 to 60 dB.

2.12 *Power Supplies*

Most units in the test set operate directly from commercial 117 volt ac power. Some use a power supply and a 19 volt regulator.[4]

The power supply provides outputs of +300, −150, −40, and −24 V dc, and 6.3 V ac. The −24 V dc output drives the −19 volt regulator. The IF oscillator uses the +300 and −150 V dc, and the 6.3 V ac. The control and common circuits use the +300 and −40 V dc in addition to the −19 V dc output of the regulator.

2.13 *Equipment Considerations*

Figure 1 identifies various parts of the transmitter-receiver test set. Power supply controls are available at the bottom rear of the console. The left side is a door, hinged full length at the rear, to allow access to a cable storage area. The console is slightly wider than similar consoles to concentrate useful functions at a comfortable working height. The base extends forward for greater mechanical stability.

The test bay and equipment undergoing tests are connected by 75-ohm coaxial cables for IF, and by 50-ohm coaxial cable for RF measurements. Special stainless steel type N RF connectors are used in critical locations to maintain proper impedance characteristics. The patch field provides a convenient means of establishing various test connections by use of standard patch plugs and cables.

Most front panel units and the power supplies are supported by their front mounting screws and by horizontal aluminum angle rails running from front to rear. The storage drawer contains molded plastic inserts to hold small loose pieces of test equipment.

III. FM TERMINAL TEST PANEL

The new 3A FM terminal test panel is used to measure and adjust:

FM transmitter deviation sensitivity

Deviator oscillator frequencies (186 and 256 MHz)

Baseband transmission (0.1 to 10 MHz)

Transmitter frequency and level alarms.

Such measurements as FM linearity and the 60 Hz square wave test of low frequency transmission response are made with equipment originally designed for the TD-2 radio system.

Since the 3A FM terminals have unprecedented stability and reliability, the FM test panel was designed only to perform routine adjustments and locate defective terminal plug-in units. When a defective unit has been located, it is simply replaced with a spare unit.

3.1 *General Equipment Features*

The 3A FM terminal test panel, shown in Fig. 10, was designed to simply and easily make the precise measurements needed to insure that the terminals meet their stringent performance requirements. The panel has plug-in circuit packages for flexibility and to aid in trouble shooting. All of the circuits are transistorized and designed for maximum stability and long life. Two microammeters in a sepa-

Fig. 10 — 3A FM terminal test panel.

rate case are connected to the panel by a detachable ten foot flexible cord. This separate case may be held in the hand or hung on the terminal bay for convenience when making adjustments.

Connections to the terminal equipment being tested are made with flexible cables to the test panel patch field, which is laid out to connect the various test panel units by standard coaxial patch plugs. Figure 11 shows the test panel mounted in the TD-2 FM terminal test set, where previously there had been a blank panel.

The test panel plug-in units are powered by a self-contained 20 volt regulated dc power supply which operates from a 117 V ac supply. A pair of connectors on the front of the test panel makes the 20 volt supply available for powering individual terminal plug-in units at a maintenance bench.

3.2 *FM Transmitter Deviation Sensitivity*

FM deviation sensitivity is defined as the ratio of the peak frequency deviation to the amplitude of the input baseband signal. Deviation sensitivity is controlled by adjusting the baseband gain of the FM transmitter. The method used to accurately adjust the transmitter deviation sensitivity is known as the Bessel null, or Crosby, technique.[7] This technique uses the principle that the carrier component of a sinusoidally modulated FM signal vanishes for certain values of modulation index. Consider the FM signal $M(t)$ which arises when the carrier $C(t) = A_c \cos \omega_c t$ is frequency modulated by the sinusoid $V(t) = -A_v \sin \omega_v t$:

$$M(t) = A_c \cos\left[\omega_c t + k \int V(t)\, dt\right] = A_c \cos\left[\omega_c t + \frac{kA_v}{\omega_v} \cos \omega_v t\right] \tag{4}$$

$$= A_c \cos\left[\omega_c t + X \cos \omega_v t\right].$$

Here, the index of modulation X, or peak phase deviation, is expressed as the ratio of the peak frequency deviation kA_v divided by the modulating frequency ω_v:

$$X = \frac{kA_v}{\omega_v} = \frac{\Delta\omega_c}{\omega_v} = \frac{\Delta f_c}{f_v}. \tag{5}$$

The FM signal $M(t)$ may be expanded by use of the Bessel function identity to separate the various frequency components:

$$M(t) = A_c \sum_{n=-\infty}^{\infty} J_n(X) \cos\left(\omega_c t + n\omega_v t + \frac{n\pi}{2}\right). \tag{6}$$

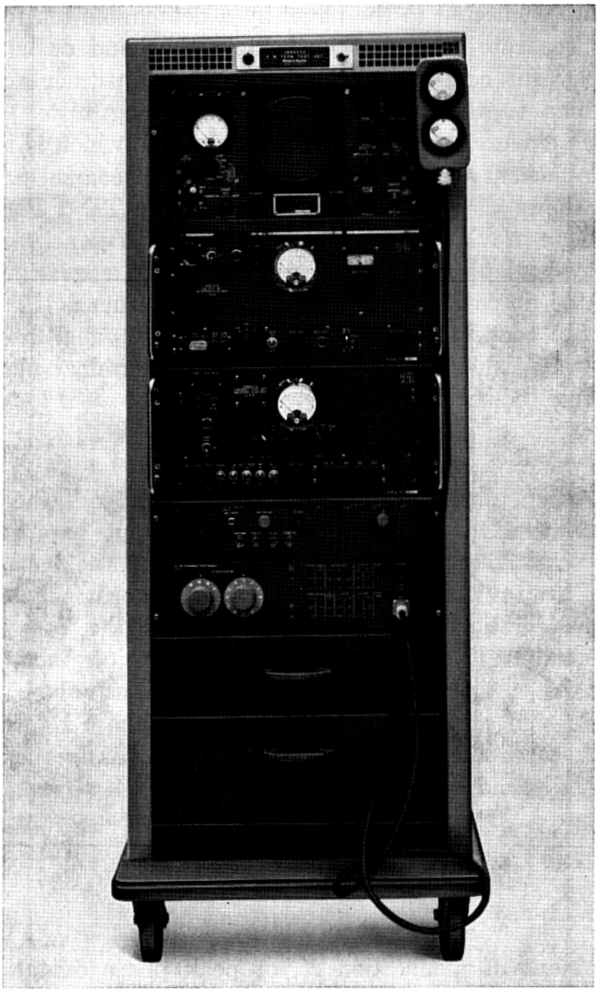

Fig. 11 — TD-2 FM terminal test set with 3A FM terminal test panel in place.

Here $J_n(X)$ is the Bessel function of the first kind of the nth order and of argument X. It is seen from equation (6) that the magnitude of the carrier component of the FM signal is given by $A_c J_o(X)$. For certain values of the argument X, $J_o(X)$ goes to zero, the carrier component of the FM signal vanishes, and all of the signal energy appears in the sidebands. The lowest such value of modulation index for which $J_o(X) = 0$ is $X = 2.405$.

For TD-3 use, it is desired to establish the transmitter deviation sensitivity so that a −12 dBm sinusoidal baseband input signal will produce a peak deviation of 4 MHz. In actually adjusting deviation sensitivity, however, it is not important to use a −12 dBm baseband signal, and in fact, the actual signal level chosen was −16 dBm. The corresponding peak deviation is 4 MHz reduced by 4 dB, or 2.53 MHz. The corresponding baseband frequency which results in a carrier null may be calculated from equation (5):

$$f_v = \frac{\Delta f_c}{X} = \frac{2.53 \text{ MHz}}{2.405} = 1.05 \text{ MHz}. \tag{7}$$

Thus, to obtain the desired deviation sensitivity, a 1.05 MHz signal is applied to the baseband input at −16 dBm, and the gain of the baseband amplifier is adjusted until a carrier null is observed. The technique for measuring the carrier null, shown in Figure 12, pro-

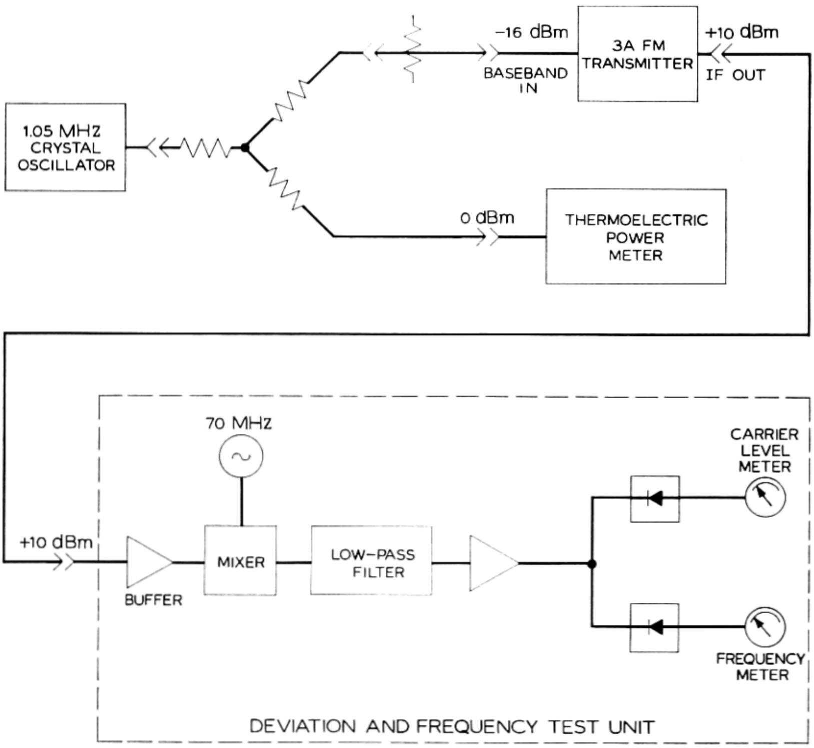

Fig. 12 — Measurement of 3A FM transmitter deviation sensitivity.

vides sufficient sensitivity and frequency separation to detect a carrier null of greater than 60 dB.

The accuracy to which the deviation sensitivity can be adjusted is limited by the accuracy to which the frequency and power of the baseband input signal are known. Therefore, a 1.05 MHz crystal-controlled oscillator is provided in the test panel, and the oscillator output is monitored by means of an external thermocouple power meter. The two stage oscillator provides an output power variable from +2 to +10 dBm into a balanced 124 ohm load, with a frequency accuracy of ±.005 percent.

The test panel deviation and frequency test unit provides a sensitive indication of the carrier null. To accomplish this, it must first separate the carrier from its sidebands, which are spaced at multiples of 1.05 MHz from the 70 MHz carrier. To achieve this separation without using a costly narrow bandpass filter at the carrier frequency, the input FM signal is heterodyned against a 70 MHz crystal-controlled local oscillator. Following this frequency down-conversion, the sideband energy at 1.05 MHz and above is filtered, leaving only the carrier beat component which is amplified and detected. The detected level of the carrier beat component is displayed on the carrier level microammeter.

To establish the proper transmitter deviation sensitivity, the transmitter baseband gain is adjusted until a dip is observed on the carrier level meter, indicating a carrier null. The gain range of the transmitter baseband amplifier is limited to prevent any carrier null except that corresponding to the first zero of the Bessel function $J_0(X)$. Use of the Bessel null technique results in an accuracy of better than ±0.05 dB in the adjustment of the transmitter baseband gain or deviation sensitivity. Figure 13 illustrates the accuracy to which the transmitter deviation sensitivity is adjusted as a function of the null achieved on the test panel carrier level meter when using the Bessel null technique.

3.3 *FM Transmitter Rest Frequencies*

An additional feature of the deviation and frequency test unit is that it may be used to accurately adjust the frequency of an unmodulated input signal to 70 MHz. This is accomplished by a frequency counting detector which provides a dc voltage proportional to the frequency of the carrier beat signal. This voltage is displayed on the hand-held frequency microammeter and is proportional to the frequency difference between the input signal and the local oscillator.

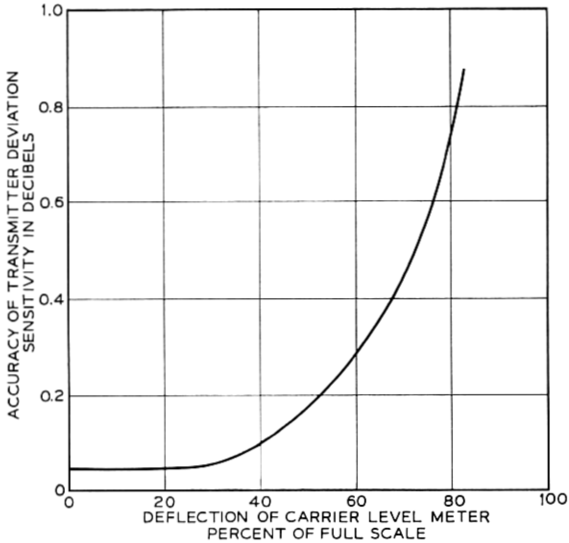

Fig. 13 — Accuracy achieved when using Bessel null technique to adjust FM deviation sensitivity. (The meter is fully deflected when the transmitter being tested is undeviated.)

Thus, if the frequency of the input signal is adjusted until a null shows on the frequency microammeter, the input signal will be identical in frequency to the 70 MHz local oscillator.

In addition to establishing an accurate 70 MHz transmitter carrier frequency, it is necessary that the rest frequencies of the 256 and 186 MHz voltage-controlled oscillators in the transmitter deviator be accurately established. This is important because the rest frequencies have been carefully selected to minimize the interference created by high order modulation products which fall in the baseband spectrum. Therefore, there is a 256 MHz crystal controlled oscillator in the test panel as a stable reference, composed of oscillator, buffer, frequency doubling, and output amplifier stages which will deliver +13 dBm into a 50 ohm load with a frequency accuracy of ±0.006 percent.

Figure 14 shows the procedure for adjusting the rest frequencies of the varactor diode controlled oscillators in the FM deviator. The reference signal is injected into the 256 MHz deviator oscillator and the varactor bias is adjusted until the 256 MHz oscillator becomes phase locked to the reference oscillator, as indicated by the detected output voltage of the deviator oscillator. When the 256 MHz oscillator is

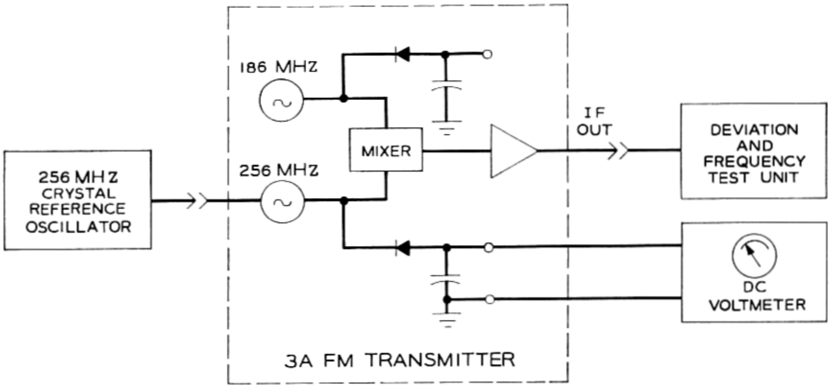

Fig. 14 — Adjustment of varactor oscillator rest frequencies in the 3A FM transmitter.

locked, the 186 MHz deviator oscillator is brought to its proper rest frequency by adjusting for a 70 MHz carrier frequency as measured by a null on the frequency meter of the deviation and frequency test unit. The 256 MHz reference oscillator is then removed, and the 256 MHz deviator oscillator is adjusted for a 70 MHz carrier frequency. With this method, the oscillator rest frequencies can easily be set to within ±5 kHz of their nominal values.

The frequency microammeter has a high sensitivity range with a full scale deflection of 20 kHz and a low sensitivity range with a full scale deflection of 100 kHz. The desired range is selected with a push-button on the hand-held case. Figure 15 illustrates the accuracy of the transmitter 70 MHz IF output frequency as a function of the deflection of the frequency meter.

3.4 *Baseband Transmission*

The baseband frequency response of an FM terminal pair must be maintained flat within ±0.1 dB from 6 Hz to 10 MHz. It is interesting that this allows less transmission shaping than the frequency roll-off of only twelve feet of cable. To achieve such accuracy, a comparison test circuit with an external signal generator and a thermocouple power meter was chosen. This test circuit can be used to measure the baseband transmission of either an FM terminal pair or a transmitter baseband amplifier plug-in unit at a maintenance bench. A typical arrangement of this test circuit, illustrating an FM transmitter baseband amplifier under test, is shown in Fig. 16.

Since the balanced to unbalanced transformer and the test set baseband amplifier are employed in the common transmission path, their frequency response is not critical with respect to the over-all transmission accuracy. The test set baseband amplifier is a three stage, direct-coupled feedback amplifier which provides approximately 12 dB of gain between 100 kHz and 10 MHz. Cables for patching between the terminals and the test panel are provided with the test panel, primarily to increase the accuracy of transmission measurements by controlling the cable length. A length of cable is placed in the reference arm of the comparison test circuit inside the test set in order to maintain equal lengths in the reference and test paths.

3.5 *Frequency and Level Alarms*

The 3A FM transmitter activates station alarms whenever the carrier frequency drifts by more than 200 kHz from its nominal center frequency of 70 MHz, or whenever the transmitter IF output power changes by more than 3 dB from its nominal value of +10 dBm. A 70.2 MHz crystal-controlled oscillator in the test panel is a standard for adjusting the sensitivity of the transmitter control circuits. This three stage circuit provides a variable output power of +7 to +13 dBm into a 75 ohm load, with a frequency accuracy of ±0.006 percent.

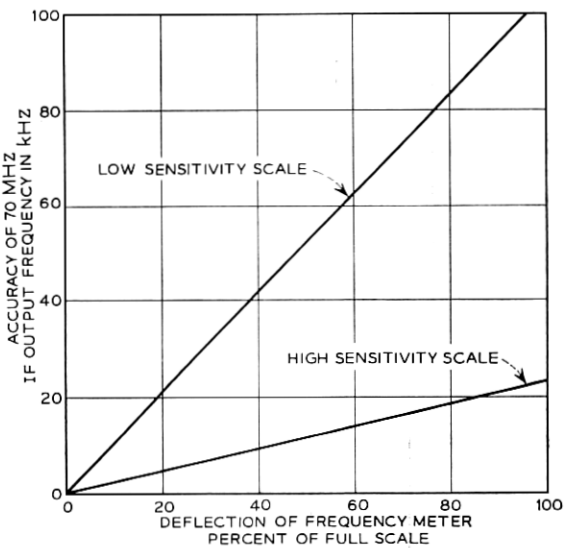

Fig. 15 — Accuracy achieved in adjusting FM transmitter output frequency.

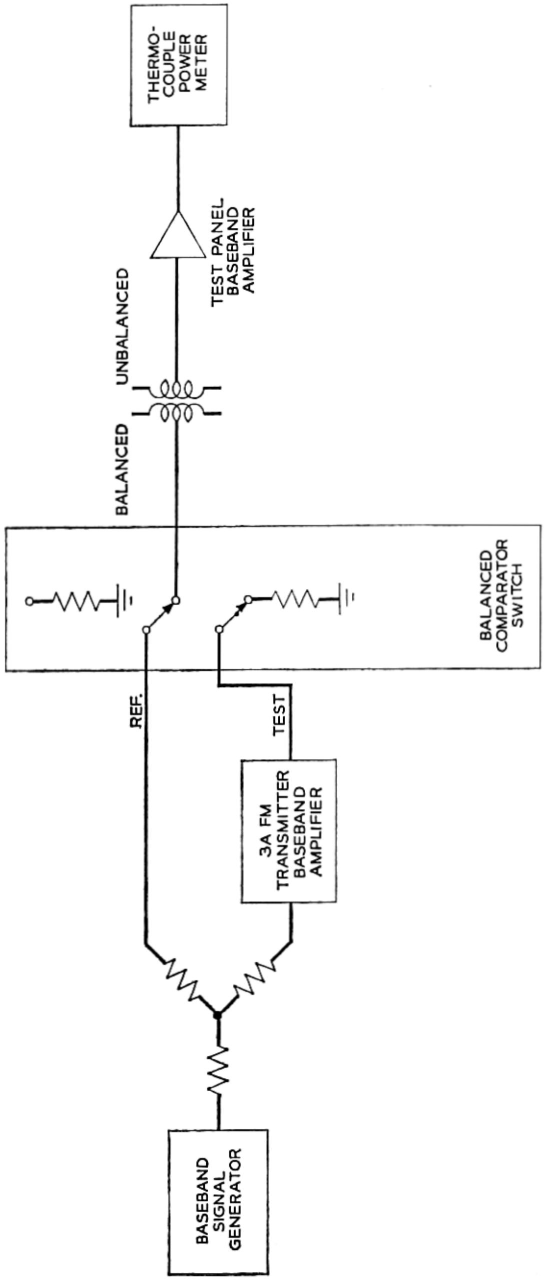

Fig. 16 — Measurement of 3A FM transmitter baseband amplifier transmission.

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