Test Equipment for the TH Radio System

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To maintain the high performance objectives of the TH radio system under operating conditions requires the regular use of accurate field test equipment. The necessary test instruments are incorporated into mobile test consoles, one for each major subdivision of the TH system. Three of these are described in some detail in this article: 1) the broadband radio transmitter-receiver test set; 2) the FM terminal test set; and 3) the protection switching test set.

I. INTRODUCTION

It became apparent early in the development program for the TH radio system that to operate the system in the field and to attain its high performance objectives would require the regular use of accurate field test equipment. Therefore, the planning and development of field maintenance facilities was done concurrently and cooperatively with, and continued throughout, the development of the rest of the TH system.

At the outset it was decided to include in a mobile console all of the test instruments required to make all routine and some trouble location tests on each major subdivision of the system. From this philosophy, there results a number of mobile test consoles, each named for that portion of the system which it is primarily designed to maintain. Transmitter-receiver test sets, available in all repeater stations and maintenance centers, are designed to assure optimum performance of the broadband radio transmitter and receiver and the RF and IF portions of the auxiliary channel.[1] FM terminal test sets, available wherever there are FM terminals and in maintenance centers, are designed to adjust and maintain FM terminal transmitters and receivers.[2] Protection switching test sets, appearing at all switching stations, maintain the protection switching system.[3] Currently under development is an auxiliary channel test set for testing baseband portions of the auxiliary channel.

Most of this paper is devoted to a description of the first three sets. Brief descriptions are given of maintenance center testing facilities, designed to permit trouble-shooting, repair and adjustment of units that have been removed from the system; and test techniques for straight-away video transmission and IF delay distortion measurements on interconnected links of the system.

II. REQUIREMENTS AND OBJECTIVES

Requirements on the performance of the TH system dictate what quantities are to be measured, the frequency bands, and the measurement accuracies. Ideally, test set errors should be very small on an absolute basis. Practically, they must only be small compared to expected instabilities in the quantities being measured. This usually significant gap between possible and practical accuracies in many cases results in large dividends in measuring convenience, compactness and reliability of the test equipment.

2.1 *Test Signals*

Just as the system employs analog transmission signals in three distinct frequency bands to accomplish its purposes, so are maintenance instruments required for each of these bands. Signals appear in a 60-cps to 10-mc baseband, a 58-mc to 90-mc intermediate-frequency band and a 5925-mc to 6425-mc radio-frequency band. All of the signals measured with the first two sets are analog in character. Digital control signals (dc and pulses) are measured in the protection switching test set.

2.2 *Measured Quantities*

A wide variety of quantities must be measured with the transmitter-receiver and FM terminal test sets: impedance, amplitude transmission, frequency, frequency deviation, power, etc. Altogether, there are eleven different quantities, some of them in each of the three bands. To simplify operating instructions, similar quantities are measured by similar methods in the several different bands. This approach, together with a maximum use of common control, amplification and detection circuits, results in a considerable reduction in the equipment required to accomplish the totality of measurements.

While the variety of quantities to be measured by the protection switching test set is not so great, nearly 1000 dc and time interval test observations can be made on the 50 different units of the system.

A summary of the quantities measured in the three signal bands is

TABLE I — QUANTITIES MEASURED BY TH RADIO TEST EQUIPMENT

Quantity	Test Set*	Frequency Band†			
		DC	Video	IF	RF
Frequency	1, 2, 3		x	x	x
Noise figure	1				x
Power	1, 2, 3		x	x	x
Gain or loss (vs. Freq)	1, 2		x	x	x
Reflection coefficient (return loss) (vs. Freq)	1, 2			x	x
FM deviation	2		x	x	
FM deviation sensitivity	2		x	x	
FM receiver linearity	2			x	
FM transmitter optimum linearity	2		x	x	
Square wave response	2		x		
Time interval	3		x		
Voltage	3, 4	x	x		
Current	3, 4	x			

* 1. Transmitter-receiver test set; 2. FM terminal test set; 3. Protection switching test set; 4. DC metering test set associated with system equipment.
† Video, 60 cps to 10 mc; IF, 50–100 mc; RF, 5925–6425 mc.

given in Table I. Throughout this paper we use video (60 cps to 10 mc), IF (50-100 mc) or RF (5925–6425 mc) to designate the general frequency region in which a test set operates.

2.3 *Accuracy*

In keeping with the more exacting objectives of the TH system over its predecessor, the TD-2 system,[4] measurement accuracies are required to be higher. For example, accuracies in the 0.02 to 0.05-db class are generally required in measurements of transmission characteristics, gain, FM deviation and FM sensitivity, etc.* These are laboratory-grade accuracies, and they must be achieved on a routine basis in the field where time is not available for the patience and watchful attention ordinarily devoted to measurements in the laboratory.

2.4 *Convenience, Speed, Reliability*

Operating convenience and speed have been increased by packaging in a single console all of the instruments required for routine tests on major subdivisions of the system, by minimizing calibration adjustments, and wherever possible by using switch controls instead of patching operations to change test functions. Convenience and speed have also

* No distinction is made here between resolution and accuracy. In some cases resolution, the ability to detect changes in a quantity, is more significant than accuracy, the ability to measure absolute value of the quantity.

been increased by using frequency-sweeping techniques for transmission, impedance and linearity measurements; this also increases the accuracy and comprehensiveness of the measured result. In fact, certain system adjustments require this simultaneous presentation of performance at all frequencies in the applicable band. Finally, lost time due to test equipment error or failure has been minimized by design approaches leading to maximum calibration stability and component reliability, and by providing easy access for "maintaining the maintenance equipment."

III. TRANSMITTER-RECEIVER TEST SET

The transmitter-receiver test set is used to measure RF and IF noise figure, power, transmission, and reflection coefficient in the broadband radio transmitters and receivers and in the auxiliary channel. Sweep-frequency techniques are employed for transmission and reflection coefficient measurements in the IF band and in individual channels of the 5925–6425-mc RF band.

3.1 *Transmission and Reflection Coefficient*

The block diagram in Fig. 1 illustrates how RF sweep-frequency transmission characteristics are measured. The frequency of the RF (klystron) oscillator is automatically and continuously swept up to ± 30 mc about a central value which can be set anywhere in the 5925–6425-mc band. The output power is held constant by automatic level control. The signal level at the input of the equipment under test is controlled by the calibrated variable RF attenuator, and by connecting the circuit under test (the "unknown") to the appropriate directional coupler output. After transmission through the unknown, the signal is rectified in the microwave detector (RF detector 3) connected to the unknown output. This rectified output, displayed on the oscilloscope screen, gives a measure of transmission deviations through the unknown. A frequency-marking circuit gives a variable frequency-identification mark on the displayed characteristic. The comparing circuit (relay) puts a reference line on the oscilloscope screen during return sweep (idle) intervals. RF to IF measurements (through networks containing frequency shifters) are made by replacing the RF detector with an IF detector.

The block diagram of Fig. 2 illustrates how reflection coefficient vs. frequency characteristics are measured at RF. The microwave hybrid junction is excited by the sweeping signal generator, described above,

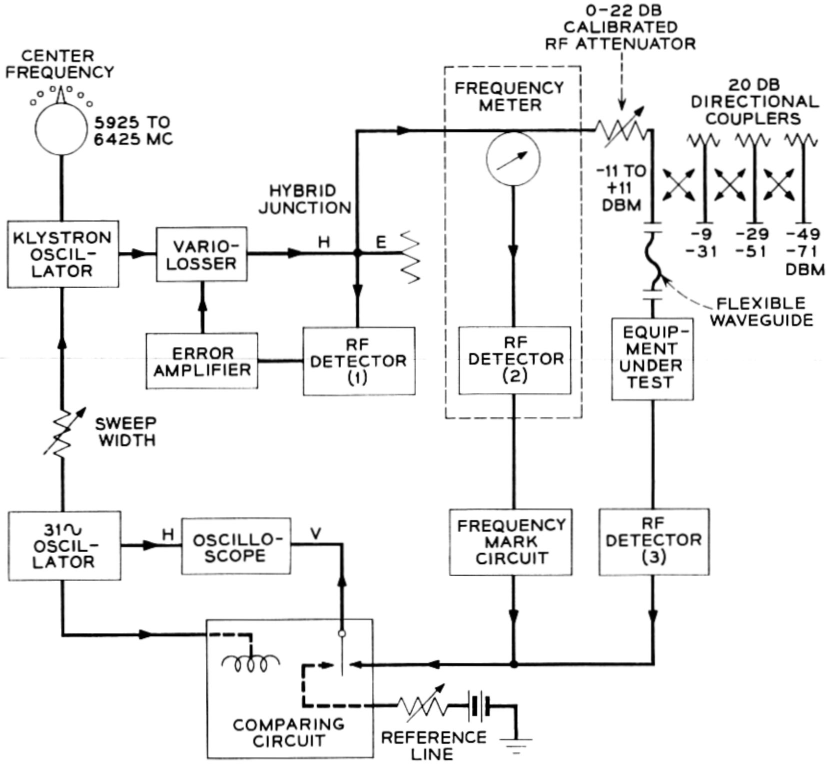

Fig. 1 — Block diagram for RF transmission measurements.

whose output level is now amplitude modulated at a 97-kc rate. Impedance mismatch of the circuit under test, connected to the hybrid junction, unbalances it. The resultant unbalance signal appears in the E-arm of the hybrid junction, where it is demodulated by the RF detector. The detector output is a 97-kc signal having an amplitude proportional to the reflection coefficient of the impedance mismatch. This 97-kc signal is amplified, rectified and displayed on the oscilloscope screen as a reflection coefficient vs. frequency characteristic. Calibration is effected by adjusting the gain of the 97-kc amplifier to give a reference line on the oscilloscope when a known impedance mismatch (reference load) is placed on the measuring arm of the hybrid junction. Subsequent adjustment of the observed characteristics to this reference line with the calibrated 97-kc attenuator gives the reflection coefficient in terms of decibels. Reflection coefficient expressed in db is called return loss; i.e., return loss $= -20 \log_{10}$ (reflection coefficient).

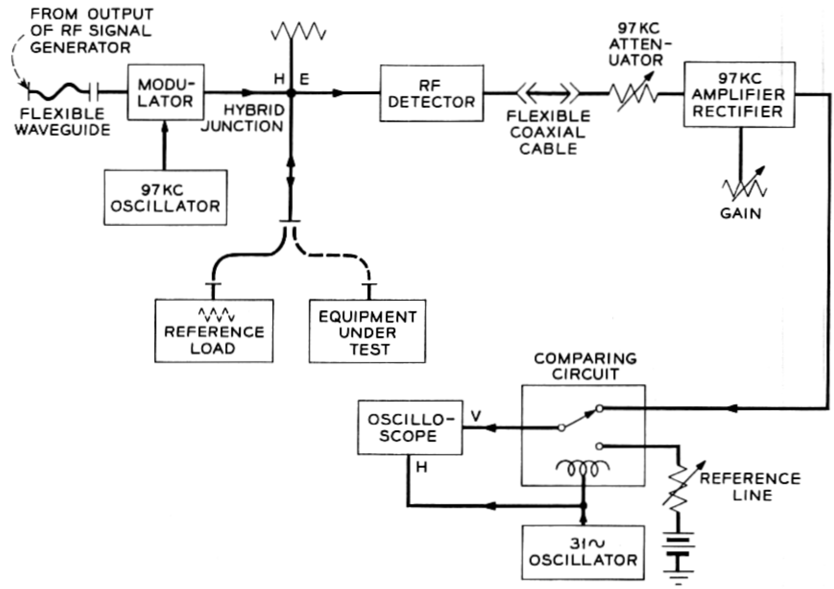

Fig. 2 — Block diagram for RF reflection coefficient measurements.

The same sweep-frequency methods are employed in making transmission and reflection coefficient measurements in the IF band. Functional block diagrams for IF sweep transmission and reflection coefficient measurements would look very similar to Figs. 1 and 2, respectively. Of course, instrumentation of these functional blocks requires different techniques and results in IF components that look quite different from their RF counterparts. However, the 31-cps time base oscillator, the oscilloscope, the 97-kc amplifier-rectifier and other low-frequency control and indicating components are used in common for IF and RF measurements.

3.2 *Noise Figure and Power*

Included in the mobile console are a noise figure test set and a power meter. These are independent of the rest of the set.

The noise figure test set measures the over-all noise figure of a radio receiver by comparing its internally generated noise with "white" noise of known magnitude. A gaseous discharge tube,[5] matched to a waveguide, furnishes the standard "white" noise. Noise figure is read on a calibrated attenuator when it is adjusted to make the sum of receiver noise and discharge tube noise 3 db higher than that of the receiver alone.

The power meter measures RF and IF power in the range of −10 dbm to +6 dbm, using a thermistor in a self-balancing ac bridge circuit. Originally designed for use with the TD-2 System,[4] the power meter is adapted for TH by using a new RF power-measuring head which is matched over the 5925–6425-mc band to the WR 159 rectangular waveguide (inside dimensions of 0.795 × 1.59 inches) used in the TH radio system.

3.3 *Physical Arrangement*

A front panel view of the transmitter-receiver test set is shown in Fig. 3. Identified on this photograph are the sweep generators, power

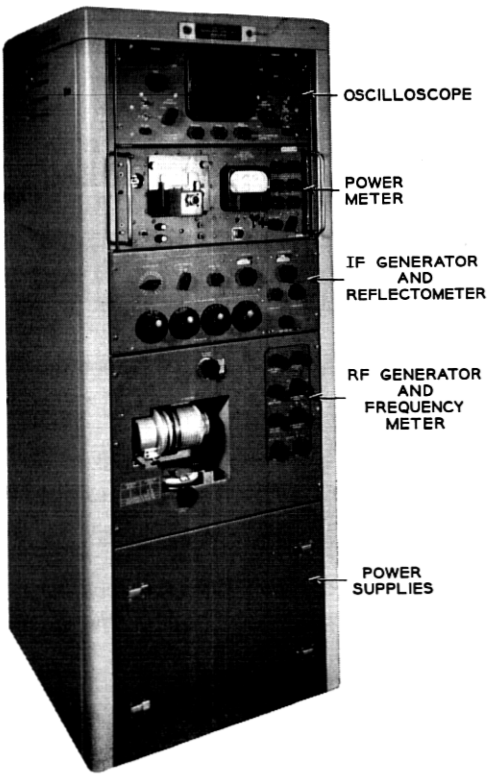

Fig. 3 — Front view of the transmitter-receiver test set.

meter and oscilloscope. The noise figure test set is located on the rear. Power supplies are located in bottom areas of the test set where exterior panel space for controls is not useful.

Connections between the test bay and equipment under test are established by 75-ohm coaxial cables for IF, and by flexible waveguide for RF measurements. Because of the relative rigidity of flexible waveguide, all waveguide connections are made at the rear of the set, leaving the front clear for ease of operation.

A considerable design emphasis was placed on ease of access and maintenance. Unitized construction, cable connectors, removable panels and a drawer-type mounting for the heavy RF generator unit allow quick access for maintenance tests, adjustments and replacement of defective units.

3.4 *Some General Design Principles*

Full realization of the speed and accuracy advantages inherent in sweep-frequency measurement methods demands that the graphic display represent only the transmission or reflection coefficient of the circuit under test and require no correction for frequency characteristics of signal source or detection components. Accordingly, major emphasis was placed on the realization of key components, such as RF and IF detectors, attenuators, hybrid junctions, resistance bridge, and reflection coefficient calibration standards, with a response constant over any 32-mc segment of the RF band and over the whole IF band. Constant response also requires that these components present, to interconnecting transmission lines, well-matched impedances over the entire IF or RF band.

Frequency characteristics due to impedance interactions over what may often be electrically long waveguide or coaxial lines connecting to the equipment under test are minimized by maintaining well-matched output impedances in the RF and IF sweep generators. Additional transmission line errors are precluded by attaching directly to the output of the equipment under test the input connector of the IF and RF detector and the measuring connector of the IF resistance bridge and the RF hybrid junction. Similarly, the RF thermistor power head is arranged for direct attachment to a waveguide output. Information is brought back to the test console through noncritical transmission lines in the form of dc or low-frequency ac.

The decision to use a sweep repetition frequency of 31 cps was made to eliminate a traditional source of error in sweep frequency measurements. This frequency provides a slight offset from multiples of the

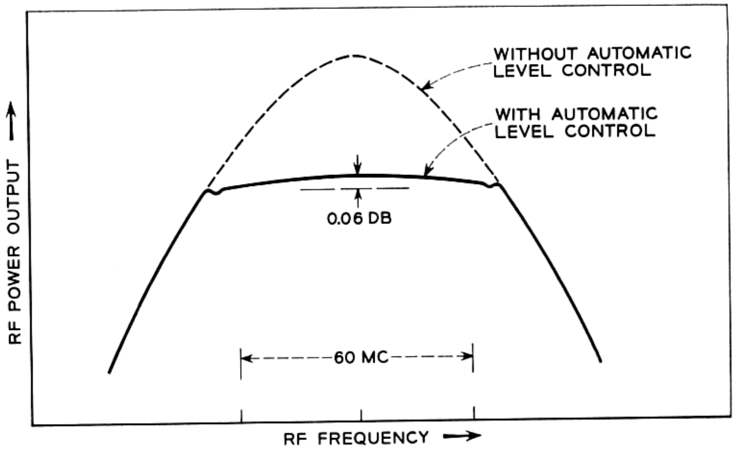

Fig. 4 — Action of the automatic level control.

power supply frequency so that any "hum" which might intrude can be immediately recognized as such and not mistakenly interpreted as a part of a transmission characteristic.* Other factors governing this selection for the sweep frequency were: avoidance of flicker on the one hand, and bandwidth requirements for the fast-acting automatic level control circuits on the other.

3.5 *RF Generator*

The RF generator has already been described briefly in Section 3.1 above and is shown functionally in Fig. 1. The RF source is a Western Electric type 449A klystron; frequency modulation is accomplished by application of a 31-cps voltage to the repeller electrode. As illustrated in Fig. 4, the amplitude modulation incidental to this process is removed by the automatic level control circuit. The loop gain of this circuit is sufficient to maintain the output constant within ±0.03 db of the nominal +11 dbm throughout a ±30-mc sweep range. The vario-losser in Fig. 1 is designed to have a smooth loss vs. exciting current characteristic. It is interesting to observe that this circuit, by regulating only the forward-traveling energy, as sampled by the hybrid junction, provides an excellent source impedance, in a manner analogous to that of a hybrid feedback amplifier.[6] The chain of directional couplers,

* Internally generated "hum" is kept to an unobjectionable level by adequate shielding, minimization of spurious ground currents, well-filtered dc power supplies and finally, by using dc heater supplies on critical electron tubes.

together with the continuously variable precision attenuator, provides output level selection over the range +11 dbm to −71 dbm.

When the RF detector is directly connected to the generator output, the (residual) frequency characteristic for any directional coupler and attenuator setting is less than ±0.1 db over any 30-mc segment of the RF band; RF transmission-frequency characteristics are therefore measured with this accuracy.

Single-control setting of the center frequency is provided by mechanical coupling of the klystron cavity tuning and repeller-voltage controls. Frequency is identified by the resonant-cavity frequency meter, a diode rectifier within the meter producing a rectified pulse as the output frequency of the klystron traverses the resonant frequency. This pulse, after amplification and clipping, is added directly to the oscilloscope signal trace. The frequency-identifying pulse is not transmitted through the circuit under test. Therefore, "stripping" of the pulse when measuring through limiters is avoided. Also, instant assurance that the RF generator is operating properly is provided when, due to a trouble condition in a circuit under test, no test signal is received from it. The frequency meter, a TE_{011} mode resonator having a loaded Q in excess of 8000, is directly calibrated in 1-mc increments. Without correction (for initial calibration error, scale error, temperature and humidity) any frequency from 5850 mc to 6500 mc can be measured with an accuracy of ±2 mc. Of more significance in determining band-edge responses of RF-RF and RF-IF circuits in the system, frequency differences up to 125 mc are measured with an accuracy of ±0.5 mc.

3.6 *IF Generator*

The IF generator is functionally analogous to the RF generator, but, due to the lower operating frequency, employs lumped-element and coaxial-line circuitry. The IF test signal is generated by a balanced inductive-feedback oscillator. The frequency is swept over the IF range by varying the current through a saturable inductor in the "tank" circuit. A high-gain, fast-acting automatic level control, which acts on the anode supply voltage of the oscillator tubes, maintains the output at +20 ± 0.05 dbm as the oscillator sweeps over its frequency range. A well-matched source impedance (a Thevenin generator) results from a series resistance of 75 ohms which is in the center conductor of the coaxial output beyond the sampling point for automatic level control. Filtering and balance maintain the harmonic output 40 db or more below the fundamental. The four-dial decade attenuator shown in Fig. 3 adjusts the output power in 0.1-db steps between +20 dbm and −71 dbm. The residual frequency characteristic, with the IF detector directly connected to the attenuator output, is less than ±0.05 db over the IF band.

The center frequency can be set at any point in the IF band. Frequency is marked in the same way as in the RF generator, but a lumped-element LC resonator is used. The resonator has a Q of about 200, is directly calibrated at 1-mc intervals, and permits identification of frequency with an accuracy of ±0.2 mc.

3.7 *RF Detector*

RF detectors, having the internal configuration shown in Fig. 5, are used as the receiving elements in RF-RF and IF-RF transmission measurements, and as the sensing element in the automatic level control of the RF generator. Since flat response for every silicon diode is essential and high sensitivity is not a requirement, variations in diode

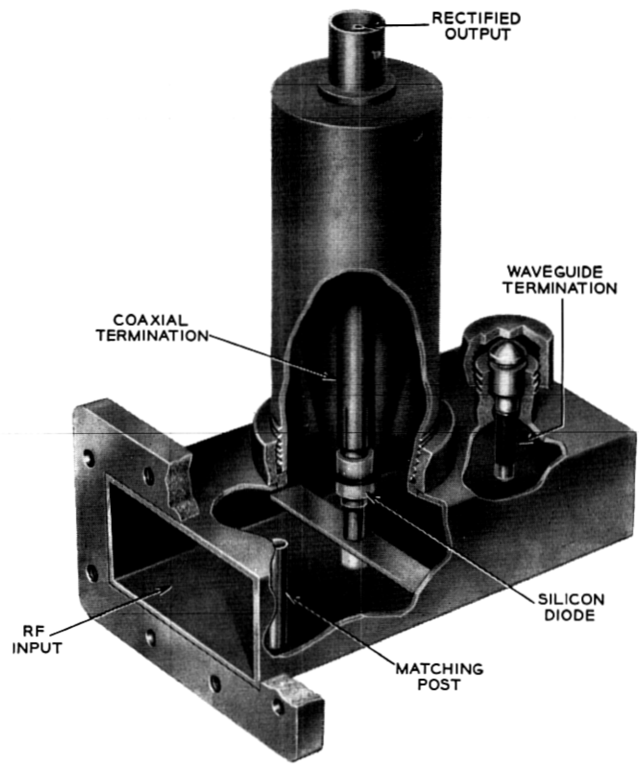

Fig. 5 — Internal configuration of the RF detector.

parameters are masked by a coaxial resistor connected effectively in series with the diode. Further stabilization of the input impedance is obtained by ending the waveguide in a well-matched resistive termination instead of the usual short circuit. A metal post (inductive reactance) completes the impedance-matching structure. Experimental determination of the optimum mechanical dimensions for these elements resulted in an input reflection coefficient of less than 0.14 (>17-db return loss). The response is constant to ±0.05 db over any 32-mc segment of the band.

3.8 *IF Detector*

The receiving element for IF-IF and RF-IF transmission measurements is the IF detector pictured in Fig. 6. The same circuit is used as the sensing detector in the automatic level control of the IF sweep generator. As in the RF detector, rectification is effected by a silicon diode. A rectifier load of low, predominantly resistive impedance causes the detector to respond to the half-wave average, rather than the peak value, of the input signal. This reduces errors due to noise and to even-order harmonics of the test signal. The rectification efficiency of the IF detector is constant within ±0.05 db, and the reflection coefficient is less than 0.032 (>30 db return loss) over the IF band.

3.9 *RF Reflectometer*

The waveguide components of the RF reflectometer are identified on the photograph of Fig. 7. The hybrid junction is a conventional

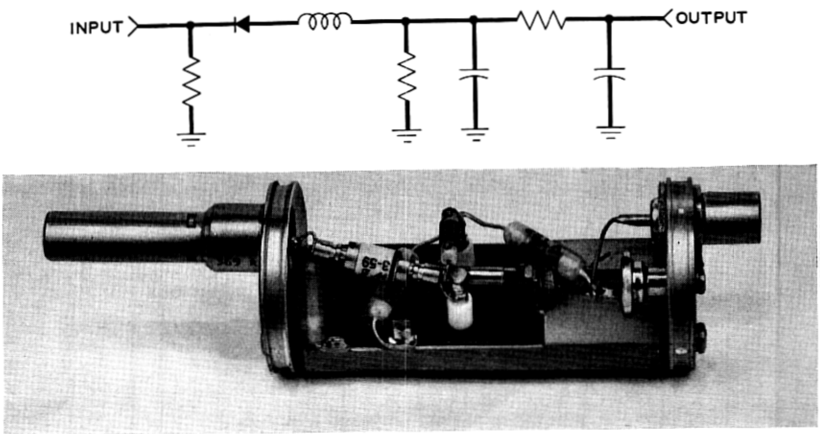

Fig. 6 — The IF detector.

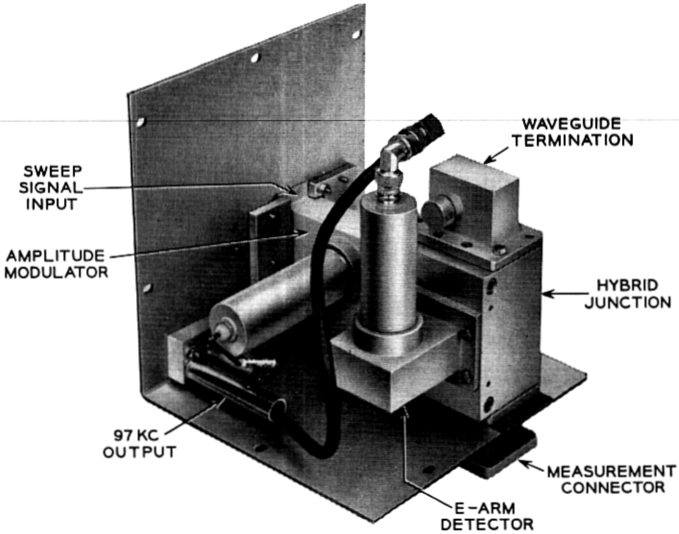

Fig. 7 — Waveguide components of the RF reflectometer.

E-H Tee waveguide junction, containing matching structures to give a well-matched impedance at all of its four waveguide inputs. Mechanical symmetry can be counted on in hybrid junctions of this type for achieving a very high (45-db) balance between the E and H arms. The detector connected to the E-arm of the hybrid has an internal configuration very similar to the one shown in Fig. 5 except that, to increase the sensitivity and hence signal-to-noise ratio, the termination has been replaced by a short circuit located approximately one-quarter wavelength from the silicon varistor. Essentially the same structure is also used in the amplitude modulator, which is connected between the H-arm of the hybrid and the sweep signal input; in this case the waveguide, instead of being terminated, ends in a waveguide flange which attaches to the H-arm.

The hybrid junction compares impedances connected to the measurement connector with the waveguide termination connected on the opposite arm. This termination, a carbon deposited resistor matched to the waveguide in a structure identical to that shown in Fig. 5, has a reflection coefficient below 0.01 over the RF band. This characteristic essentially sets the residual error in reflection coefficient measurements at ± 0.01; residual unbalance in the hybrid junction and inaccuracies in the attenuator, the (square) law of the silicon diode, and the standard waveguide load introduce errors that are small in comparison with

0.01.* The standard waveguide load, which is connected to the measurement connector for the initial setting of sensitivity, is just like the waveguide termination; however, the resistor has a resistance approximately 14 per cent higher to give a calibrating reflection coefficient of 0.178 (15-db return loss).

Use of 97-kc amplitude modulation on the swept signal input and subsequent demodulation, amplification and rectification of a 97-kc signal avoids the need for a high-gain dc amplifier. Internally generated noise in the E-arm silicon diode places a limitation on the lowest reflected signal levels that can be accurately measured. A bandwidth of 3 kc in the 97-kc amplifier is sufficient to display, with little error, the most rapid variations in reflection coefficient that are measured in the system. This selectivity, a low-noise 97-kc amplifier design, and maximum sensitivity in the E-arm detector (consistent with an adequate frequency response) results in a signal-plus-noise display which differs from that due to the signal alone by only 0.3 db. This performance applies when the impedance under test is excited with an incident wave of −1 dbm and has a reflection coefficient of 0.0178 (35-db return loss). The same noise performance would apply at −11 dbm and 25-db return loss, etc. Under these conditions (and at higher levels or higher reflection coefficients) uncertainty in the measured result due to noise is small.

3.10 *IF Reflectometer*

The IF reflectometer employs the same basic principles as its RF counterpart, but differs in instrumentation techniques because of the lower operating frequency. Fig. 8 shows the IF reflectometer, which is a simple equal-arm resistance bridge with a self-contained silicon diode detector. The IF generator, amplitude modulated at a 97-kc rate and simultaneously frequency-swept, supplies the test signal. A 97-kc regulating loop, acting on the oscillator of the IF generator, maintains the modulation constant as the carrier frequency is swept. The 97-kc amplifier-rectifier and indicating circuits are those used for the corresponding RF measurements; the calibrating and measuring procedures are exactly the same.

Noise generated in the diode detector places a limitation on the lowest reflected signal levels that can be accurately measured; for

* Field experience, in connection with measuring the return loss of long waveguide runs, shows that even better performance can be obtained by using a more precise reference termination, of 60-db or better return loss, and by using isolators to suppress secondary reflections, e.g., between the hybrid junction and the amplitude modulator.

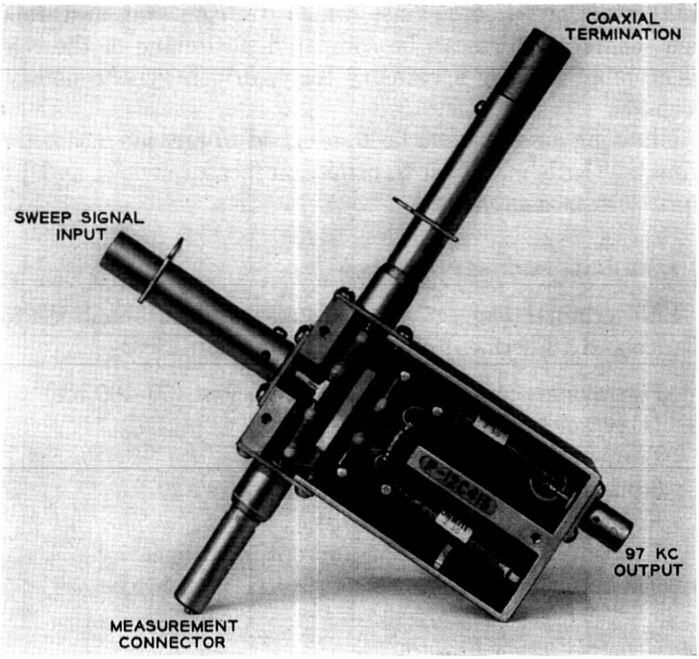

Fig. 8 — The IF reflectometer.

equivalent performance, the power in the impedance under test must be kept 3 db higher than in the RF case because of the added loss in the resistance bridge. The residual error in reflection coefficient is essentially set at ± 0.01 by the return loss characteristic of the coaxial termination, as the resistance bridge contains precision resistors and capacitance trimmers that permit realization of a 50–60-db balance over the IF band.

3.11 *Indicating Circuits*

Transmission and reflection coefficient measurements are presented as traces on the screen of a five-inch oscilloscope especially designed for this application. In this instrument conventional direct coupled amplifier circuitry is employed, but internal sweep generating circuits are omitted, the sweep voltages being supplied by the sweep generator of the test set.

As an operating convenience, a dc potential of adjustable magnitude is substituted for the signal during the return trace. This appears as a horizontal reference line against which transmission and reflection coefficient characteristics can be compared. Switching of the reference trace is accomplished by a mercury relay, driven synchronously with the sweep.

The indicating circuits have been designed to provide a sensitivity of approximately 1 db/in. for all transmission measurements, and $\frac{1}{2}$ db/in. for return loss measurements.

IV. FM TERMINAL TEST SET

The FM terminal test set provides measurement facilities for the surveillance and adjustment of the following quantities:

IF transmission and reflection coefficient (50–100 mc)
IF power and frequency (74.13 mc)
Baseband transmission (0.1–10 mc)
Square wave response (62 cycles)
FM receiver deviation sensitivity
FM transmitter deviation and optimum linearity
FM receiver linearity

4.1 *Some General Design Features*

To make all the required measurements with a single mobile console, the measurement methods make multiple use of as few basic circuit units as possible. In this set, shown in Fig. 9, all of the measurements are accomplished by functional rearrangement of 17 basic circuit units. The functional changes are made with switch controls and patching plugs in the jack field. All connections to the circuit under test are made with flexible cables from jacks on the front panel, using 75-ohm coaxial for IF and unbalanced video signals and 124-ohm shielded pair for balanced video signals.

Wherever feasible, the same features which contribute to accuracy, convenience, and speed of measurement and to internal accessibility for repair and adjustment in the transmitter-receiver test set have been incorporated in the FM terminal test set.

4.2 *IF Transmission and Reflection Coefficient*

The measuring methods employed for sweep frequency IF transmission and reflection coefficient measurements are identical to those described for the transmitter-receiver test set; circuits and instrumentation techniques are also substantially identical.

4.3 *IF Power and Frequency*

A silicon diode rectifier in a circuit like that of the IF detector (Fig. 6), but with an input impedance-matching network and an input attenuator, forms the IF power meter. The matching network increases the sensitivity but restricts the bandwidth to ±0.5 mc around 74.13 mc. The range is −15 dbm to +15 dbm with an accuracy of ±0.5 db; indication is on one of the scales on the dc meter shown in Fig. 9.

A crystal-controlled oscillator, generating a frequency of 74.130 ± 0.003 mc, is used to check the carrier frequency of the FM transmitter by a comparison method. This oscillator is also used as a signal source

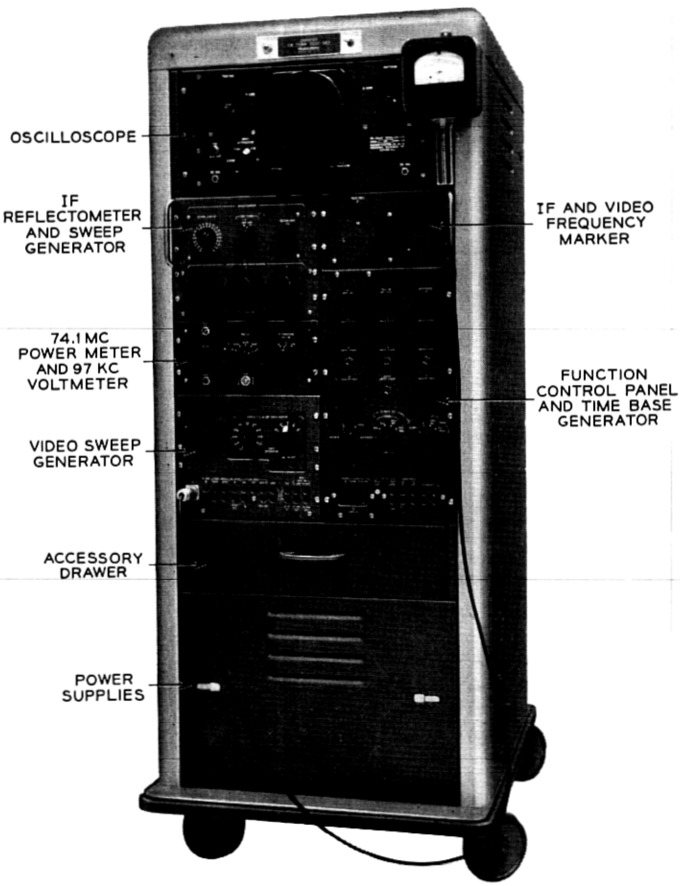

Fig. 9 – Front view of the FM terminal test set.

for the adjustment of FM receiver carrier balance and in the video sweep generator described below.

4.4 *Video Transmission*

For 0.1–10 mc video transmission measurements a sweep-frequency technique is employed. The functional diagram of Fig. 10 shows the method of measurement to be similar to that described for RF and IF transmission. The video test signal is generated as the difference frequency obtained by applying to a modulator the swept frequency from the IF sweep generator, together with the 74.13-mc signal generated by the crystal-controlled oscillator. Sweep range and centering controls permit adjustment of the IF generator to sweep over the range 74.3 mc to 84.3 mc; the resultant baseband sweep covers 100 kc to 10 mc. Fast-acting automatic level control, together with appropriate equalization, maintains the baseband test signal constant at +10 dbm within ±0.01 db as measured through twelve feet of flexible balanced cable.

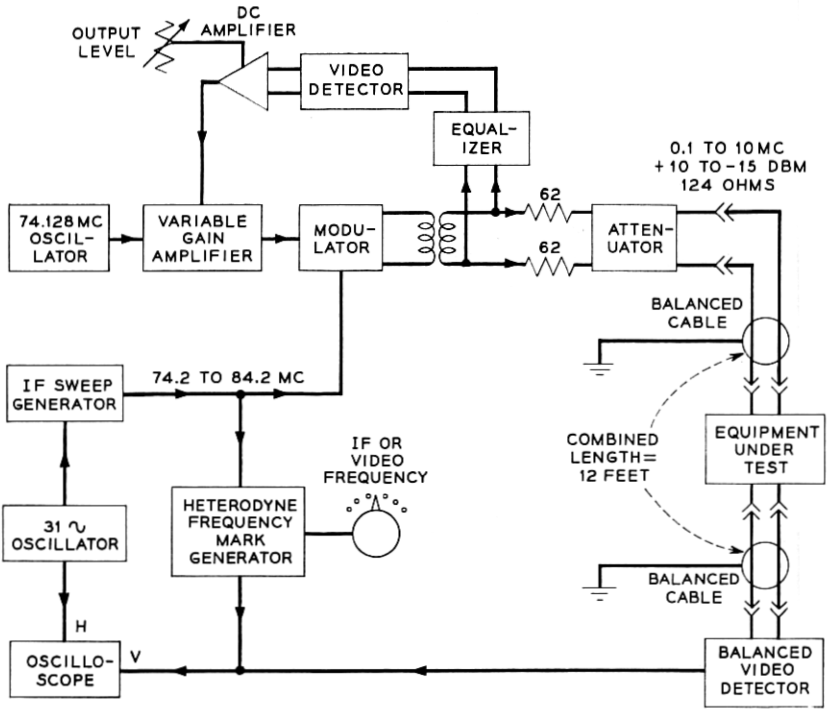

Fig. 10 — Block diagram for video transmission measurements.

Thus no error is incurred so long as two cables of the same total length are used to interconnect between the test set and circuit under test, as shown in Fig. 10. The output impedance is 124 ohms balanced. The balanced attenuator, 0–25 db in 0.5-db steps, permits selection of output levels from +10 to −15 dbm. Balanced and unbalanced video detectors are provided; the former, schematically shown in Fig. 11, employs a full-wave bridge rectifier with low impedance load to ensure immunity to noise, harmonics, and longitudinals. The unbalanced baseband detector circuit is similar to that of the IF detector, but with element values appropriate to the lower frequency range.

The residual frequency characteristics of less than ±0.05 db for the combination of generator, output attenuator, and video detector allow video transmission to be measured with this accuracy over the 10-mc

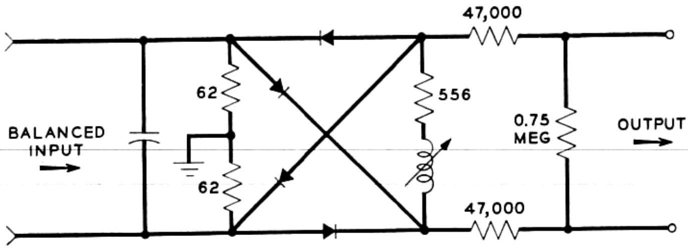

Fig. 11 — Circuit of the balanced video detector.

band. The displayed characteristic on the oscilloscope can be resolved to better than ±0.01 db.

A heterodyne receiver, having a 10-mc intermediate frequency with a 100-kc passband, is used to generate frequency identification marks on the transmission display. A resolution of ±0.1 mc and an accuracy of ±0.25 mc is obtained. This unit, permanently connected in the IF sweep generator circuit, is used for both video and IF identification, the dial having separate scales for the two applications.

4.5 *62-cps Square-Wave Test*

A simple square-wave test, at a frequency of 62 cps, serves to expose irregularities in low-frequency transmission (amplitude and phase) of the FM terminals which might impair television transmission. The test signal is produced by a relay, driven at 62 cps, which alternately makes and breaks a connection to a dc source. By comparing the response with illuminated horizontal scribe lines displayed on the oscilloscope screen, deviations from an ideal flat-top, square-wave response are measured as a percentage of the peak-to-peak amplitude. Measurement accuracy, limited mainly by resolution of the oscilloscope scale, is better than $\frac{1}{2}$ per cent.

4.6 *FM Receiver Deviation Sensitivity*

Fig. 12 shows the method for setting, to a specified value, the sensitivity of the FM terminal receiver to a reference frequency deviation. A synthetic square-wave frequency modulated test signal is created by alternately keying on and off two crystal-controlled oscillators, one having a frequency 1.98 mc higher, the other 1.98 mc lower than 74.13 mc. The keying rate is 97 kc. The receiver output, under these conditions, is a 97-kc square wave. An extremely stable, selective, back-biased, electron tube voltmeter is provided to measure the fundamental component of this square wave. Since the relationship between the amplitude of a square wave and its fundamental is known, the sensitivity of the receiver is thus established. By appropriate selection of the keyed oscillator frequencies (76.112 and 72.147 mc), and of the values of attenuators and resistive coupling networks, need for computation on the part of the operator is eliminated; a "zero" indication of the voltmeter establishes that the receiver sensitivity has been properly adjusted.

Zero indication occurs when the dc output of the electronic voltmeter equals a potential determined by a voltage-reference gas tube. Whenever the gas tube is replaced, the over-all sensitivity of the voltmeter for this zero indication must be readjusted, by comparison with a known 97-kc voltage. Subsequent variations in voltmeter sensitivity are corrected by a self-calibrating feature illustrated in Fig. 12. Prior to each measurement a regenerative loop through the voltmeter and back through stable, fixed attenuators is established by closing the calibrating switch. The gain calibration control is then adjusted so that oscillation at 97 kc is barely sustained. By this method the gain through the active circuit is made equal to the loss through the feedback path attenuation, which is accurate to ± 0.01 db.

As an end result, the long-term accuracy of the voltmeter, mainly dependent upon its initial calibration and the stability of the gas tube reference voltage, is ± 0.05 db. Since the ± 1.98-mc frequency deviation, generated by the keyed crystal oscillators, is accurate to one part in 10^3 (0.01 db), it is expected that receiver sensitivity adjustments can be gauged with an accuracy of better than ± 0.06 db.

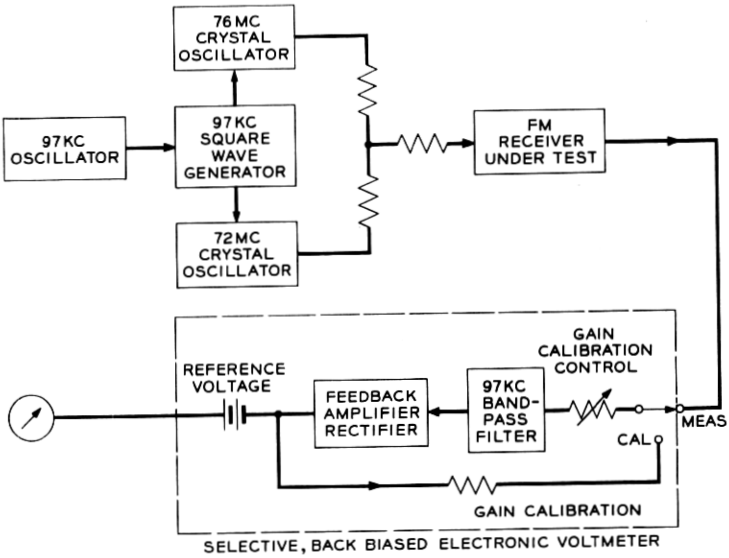

Fig. 12 — Block diagram for FM deviation sensitivity measurement.

4 7 *FM Transmitter Deviation and Optimum Linearity*

Frequency deviation of the FM terminal transmitter is adjusted by applying a 97-kc sinusoidal input signal to the transmitter and setting to a specified value the resulting frequency deviation as observed with an FM receiver This FM receiver is a specialized one, is an integral part of the test set, and is calibrated just prior to use by the technique and instrumentation of the previous section. The amplitudes of the sinusoidal signals at the transmitter input and receiver output are measured sequentially with the selective voltmeter. By the use of suitable values of fixed attenuators and resistive coupling networks, properly adjusted deviation is indicated as a "zero" (actually, mid-scale) reading on the dc meter of the voltmeter. Accuracy of the deviation adjustment will be very nearly the same as for FM receiver sensitivity — better than ±0.06 db.

Optimum linearity of frequency modulation occurs at the repeller voltage for the DO klystron in the FM transmitter, for which small signal deviation is a minimum.[2] Using this principle, optimum linearity is obtained during the adjustment of transmitter deviation, by setting the repeller voltage for a minimum reading on the dc test meter. Differential sensitivity of the electron tube voltmeter ($\pm\frac{1}{16}$ inch deflection for ±0.01 db of level change) is adequate to assure an optimum setting well below linearity requirements set by system considerations.[2]

4.8 *FM Receiver Linearity*

FM receiver linearity (or, more properly, nonlinearity) is defined as the percentage change in the small-signal FM sensitivity (volts/mc) of the receiver over the IF band. Linearity is measured by a method that was first described in connection with TD-2 radio relay system.[4]

A low level, 97-kc signal, producing a deviation of about ±200 kc, is applied to the repeller of the BO klystron of the FM transmitter. Simultaneously, the transmitter's output frequency is deviated over the range 58 mc to 90 mc by application of a 31-cps high-level signal to the DO klystron. The resultant composite FM signal is applied to the input of the FM receiver under test. The same amplifier-rectifier that is used for return loss measurements is now used for selection, amplification, and envelope rectification of the 97-kc component of the receiver output. Variations in this rectified output, displayed on the oscilloscope screen, are measured by comparison with an illuminated horizontal scale having lines which are spaced 0.2 inch apart. Vertical sensitivity, calibrated with the return loss measuring attenuator contained in the amplifier-rectifier unit, is normally set for 0.2 db (approximately 2 per cent) per scale division. Instantaneous frequency is identified by placing, on the display, marks generated by the heterodyne frequency mark generator described above in Section 4.4.

By separately modulating the two klystron oscillators of the transmitter, effects of nonlinear modulation at 97 kc are avoided. The accuracy of measurement is therefore primarily limited by scale resolution and accuracy of the calibrating attenuator; major importance is attached to linearity in the 64–84-mc range, for which nonlinearity is ordinarily less than ±5 per cent. An accuracy of $\pm\frac{1}{4}$ per cent is obtained for such measurements.

V. PROTECTION SWITCHING TEST SET*

This test set is designed for routine tests on the operation of the protection switching system,[3] and for confirmation of adequate performance after repairs have been made. It also provides mounting and testing facilities for individual circuit units that have been removed from the system for repair or adjustment.

In contrast to the analog signal testing techniques employed in the

* H. I. Maunsell made important contributions to this section.

previous two instruments, the protection switching test set features mostly digital testing techniques. While high accuracies of measurement are not required, ability to test the system operation and to make a large number of test observations on as many as 50 different kinds of circuit units is provided. A photograph of the protection switching test set is shown in Fig. 13.

5.1 *System Operation Tests*

The common control panel, identified on the photograph, is connected to the transmitting logic of the protection switching system by connectors on a multi-conductor cable. Digital signals are applied to the logic by manual operation of keys on the control panel. Operation of these "manual exerciser" keys, in a systematic sequence, simulates to the system's logic a failure in the regular broadband radio channels, one at a time. Protection switching action is thereby initiated, and lamps in

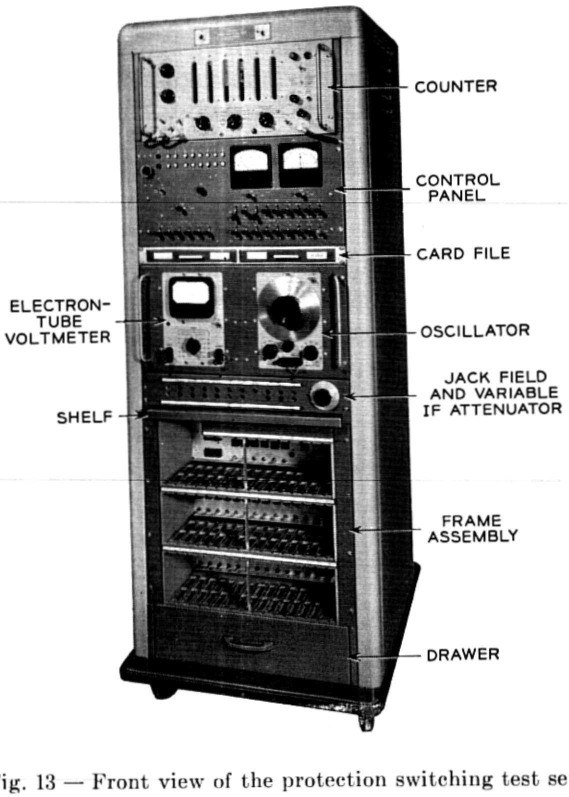

Fig. 13 — Front view of the protection switching test set.

the test set (and in the TH system) indicate the system's response to these simulated failures.* When the response is abnormal, the lamp indications serve to localize where the trouble exists to within three or four circuit units in the system. These units, all or one at a time, are replaced with spares, the logic exerciser being used to confirm that normal operation has been restored.

The time interval between initiation of a simulated failure and completion of protection switching action can be measured with the electronic counter identified on the photograph. Similarly, time intervals between input and output events, important in some of the individual circuit units, can be checked with the counter which is a standard commercial design.

5.2 *Circuit Unit Tests*

Any individual circuit unit can be tested by inserting it in the proper one of the 48 slots in the frame assembly. Insertion of the circuit unit applies power to the unit and connects it to the appropriate testing circuit and resistance termination. Manual operation of the "unit testing" keys on the control panel applies appropriate dc signals (codes) to the unit's input terminals. The response to these signals is indicated on the dc meters. Correlation of the sequential responses provides an aid to localization of trouble in the circuit when these responses are abnormal.

This multi-receptacle method for testing circuit units materially reduces setup time. Testing speed and convenience are also increased by including on the test set a card file giving information (in the form of tables for each type of circuit unit) on key operating sequences and the normal meter responses.

5.3 *Analog Signal Tests*

Included in the test set are a low-frequency electron tube voltmeter and oscillator of standard commercial design. These instruments and the electronic counter are used to check and adjust frequency, voltage output and frequency response of tone transmitter and tone detector circuit units of the system.

To measure powers of around -21 dbm at the output of 74.1-mc IF carrier supply units, a silicon-crystal rectifier is included. The rectifier input appears on the jack field, and its output is applied to one of

* Currently under development is an "automatic exerciser" which will do this regularly once a day and initiate an alarm in case of abnormal response.

the dc meters. A continuously variable (stepless) 5–15-db attenuator is also supplied, to permit transient-free variation of test IF signals at the input of IF level detector circuit units, when checking and adjusting the IF carrier level changes that will initiate protection switching action.

Video transmission, IF transmission and IF reflection coefficient are measured, when required, on certain of the circuit units while inserted in the frame assembly. These analog tests are made with an FM terminal test set; the IF tests can be also made with a transmitter-receiver test set.

VI. MAINTENANCE CENTER TESTING FACILITIES

Illustrated by the line drawing in Fig. 14 are the equipment mounting racks, power supplies and other facilities that are permanently installed in a maintenance center for repair and testing of units that have been removed from the system for repair or adjustment. Not shown, but normally available for use at this center, are the three mobile test

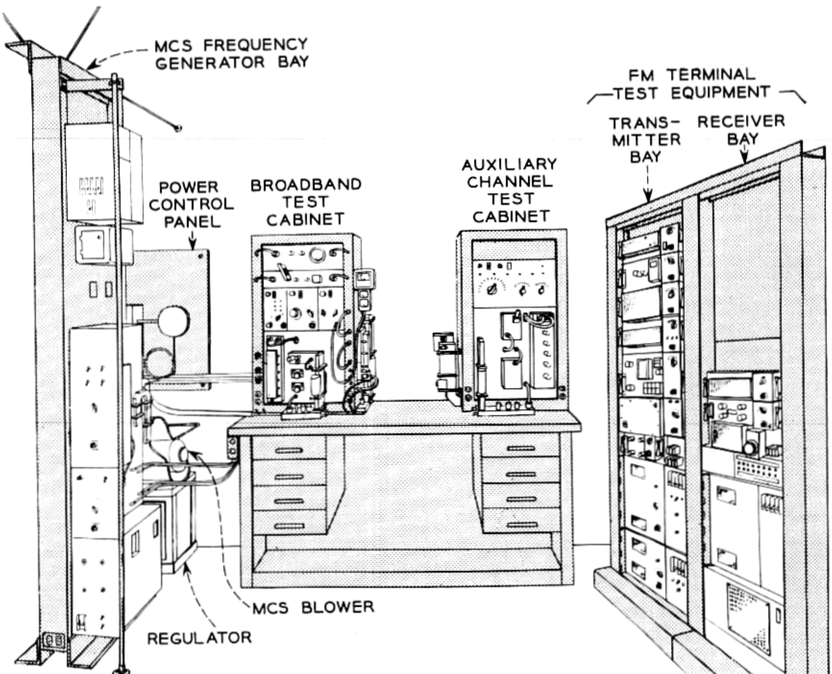

Fig. 14 — Line drawing showing test facilities at a TH maintenance center.

sets described above as well as the regular and special tools and test instruments that are essential at any electronic repair center for maintenance of radio relay equipment. For a 4000-mile system there may be only ten of these repair centers, since each may service system equipment in one or two main switching stations and up to twelve or more radio repeater stations.

As may be inferred from the illustration, the maintenance center is essentially a skeleton radio repeater, including a modified carrier supply and auxiliary channel radio equipment. Units of this maintenance center equipment may be replaced by units removed from the working system to adjust, test and confirm adequacy of repair operations on them. Extender cables permit access to normally covered areas of the unit under test.

Also installed in this center is a repackaged FM terminal transmitter and receiver into which plug-in units from a working system terminal may be connected, either directly or by extender cables.

VII. POWER SUPPLIES

Power supplies for the test equipment are described in some detail in a companion paper.[7] The mobile consoles operate from 117-volt ac convenience outlets, and the maintenance center from a permanently connected 208–230-volt line. On the consoles, the dc power supplies are electronically regulated; some critical heaters are supplied with dc. At the maintenance center the main ac line is regulated and the dc power supplies are the same as those used in the radio equipment.

VIII. STRAIGHTAWAY GAIN AND DELAY DISTORTION MEASUREMENTS

Adjustable gain and delay equalizers will be used in the TH System to compensate for (to mop up) residual distortions that have accumulated over an equalization section that may include up to ten radio repeaters.[8] Test facilities are required to measure and administer adjustment of these equalizers. Since the receiving station is separated from the test-signal sending station by many miles, straightaway measurement techniques are required. As a further requirement, continuous displays of gain-frequency and delay distortion-frequency characteristics are essential for any comprehensive adjustment of equalization intended to produce optimum performance of the system. With these continuous displays, an operator can adjust the equalization to minimize distortion in the end-to-end characteristic.

Included in each FM terminal test set are circuits which permit its use at the sending and receiving stations for sweep-frequency gain measurements. At the sending station, the sweep-frequency video output is combined with a low-level sample of the 31-cps voltage from the time base oscillator (which is sweeping the video frequency). This combined signal is applied to an FM terminal transmitter and sent over the radio link.

At the receiving station, an FM terminal receiver returns the test signal to baseband frequencies. The 31-cps signal is recovered in a separation network, amplified and applied to the time base oscillator circuit in the FM terminal test set at the receiving station. This oscillator's frequency is thereby forced into synchronization with the distant sending time base oscillator. Consequently, the displayed characteristic will remain stationary, since the horizontal deflection for the receiving oscilloscope will be synchronized with the sending video signal sweep.

An adjustable 31-cps phase shifter at the receiving station permits centering the display, and resonance transmission markers at 5 mc and 10 mc provide instantaneous received frequency identification.

There is already available for the TD-2 radio system a straightaway delay distortion test set in which the small-signal phase shift at 278 kc is measured while the center frequency is swept slowly, at 100 cps, over the IF band of interest.[9] The delay distortion-frequency characteristic is displayed on the screen of an oscilloscope. This same equipment can be used in conjunction with TH FM terminals for delay distortion measurements of the TH radio system.

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