TEST AND TROUBLESHOOTING HANDBOOK

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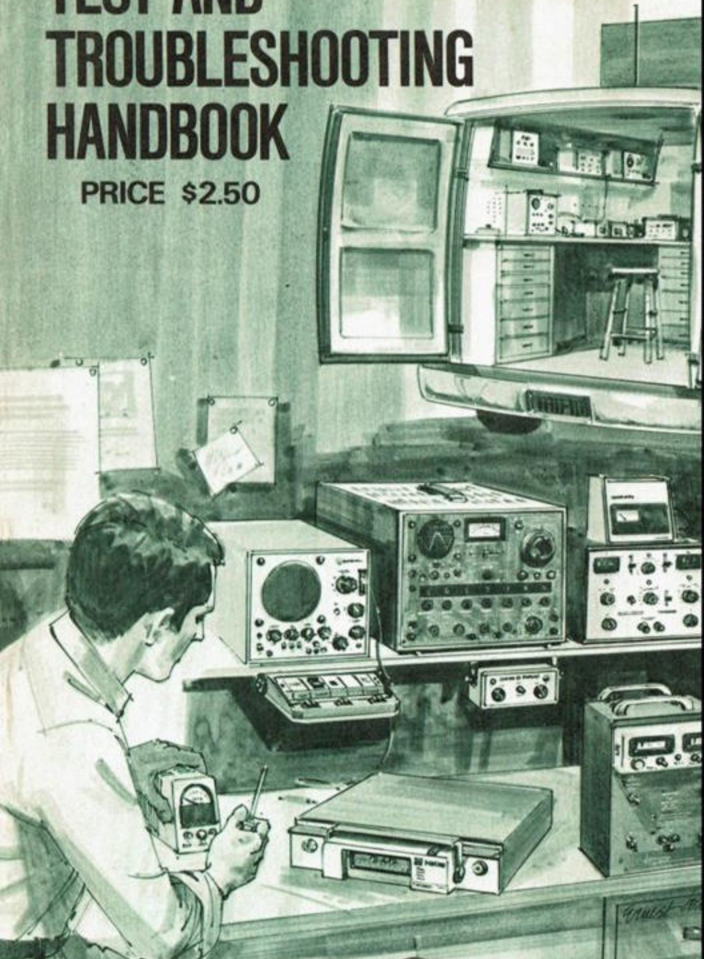

GENERAL ELECTRIC

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TEST AND TROUBLESHOOTING HANDBOOK

Table of Contents

	Page
INTRODUCTION TO STANDARD TESTS	1
Introducing . . . Standard Transmitter Tests	1
Transmitter Power Output	1
Transmitter Frequency	2
Transmitter Audio Tests:	2
Transmitter Maximum Deviation	3
Transmitter Deviation Dissymmetry	3
Transmitter Audio Sensitivity	3
Transmitter Audio Distortion	3
Introducing . . . Standard Receiver Tests	4
Receiver Audio Distortion	4
Receiver 12 dB SINAD Sensitivity	4
Receiver Modulation Acceptance Bandwidth	4
Receiver Critical Squelch Sensitivity	4
Receiver Maximum Squelch Sensitivity	4
Receiver 20 dB Quieting Sensitivity	5
Receiver Frequency	5
TEST EQUIPMENT	6
Audio Generator	6
RF Signal Generator	6
Deviation (modulation) Monitor	7
Frequency Measuring Equipment	7
RF Wattmeter	8
Distortion Analyzer (DA)	8
Measuring Distortion with the DA	10
Indicating 12 dB SINAD with the DA	10
Sinad Meter	11
Audio Voltmeter	11
DC/AC Volt/Amp Meters	11
Audio Load Resistor	12
Couplers (and coupling)	13
Improvised Capacitive Coupler	14
Dummy Microphone Circuit	14
Specialized Metering Testsets	15
Bench Test Accessories	15
Power Supply	15
TEST VOLTAGES	16
TRANSMITTER TEST PROCEDURES	17
Transmitter Power Output	17
Transmitter Frequency	18
Transmitter Maximum Deviation, Deviation Dissymmetry, Audio Sensitivity, Audio Distortion	19
RECEIVER TEST PROCEDURES	21
Receiver Audio Distortion, 12 dB SINAD Sensitivity, Modulation Acceptance Bandwidth, Critical Squelch Sensitivity, Maximum Squelch Sensitivity	21
Receiver 20 dB Quieting Sensitivity	23
PERFORMANCE VERIFICATION	24
TROUBLESHOOTING	25
Transmitter Troubleshooting	25
Receiver Troubleshooting	26
Transmitter Troubleshooting Chart	29
Receiver Troubleshooting Chart	30

INTRODUCTION TO STANDARD TESTS

This Test & Troubleshooting Handbook is built around standard tests for two-way radio equipment. These tests may be performed on any unit, big or little. They apply equally to station, mobile or personal/portable equipment. They yield results in numbers--watts, microvolts, kilohertz or percent. They employ methods which are recognized by the entire two-way radio industry. They allow you to compare your test results with normal characteristics shown in the published specifications for any equipment you service. If a unit meets its specifications, it is OK. It doesn't need fixing! If a unit, having failed to meet its specifications, is repaired or adjusted until it does, the job is finished. When a unit does not meet its specifications, the standard tests provide a series of clues which allow you to focus your troubleshooting efforts in the directions which are most productive.

The "official" backing for the standard tests is in standards published by Electronic Industries Association (EIA). The EIA Standards have been adopted by most major manufacturers of two-way radio equipment in the United States and elsewhere; they are endorsed by most major two-way radio user organizations.

The standards themselves are available for purchase. They are cataloged in: "Index of EIA & JEDC Standards & Engineering Publications." You may obtain a copy of this price list, no charge, by writing to:

Electronic Industries Association
Engineering Department
2001 Eye Street, N. W.
Washington, DC 20006

Literally dozens of standard tests are described in the EIA Standards. Many of them are of interest only to an equipment designer. The ones highlighted in this handbook are chosen with the two-way radio service industry in mind. These tests can be executed with the test equipment and skills found in any up-to-date two-way radio service facility. They evaluate equipment characteristics which are of real importance to the users--the ones which influence the fundamental ability to communicate. And, these tests support the systematic approach to troubleshooting which is included as the final section. These standard tests are performed *outside* the radio. If you can reach the connections, you need not remove the covers. In fact, standard tests may allow you to complete some service jobs with the covers still intact! Since standard tests are the same for every radio, you don't need detailed technical information covering the unit on the bench until tests confirm that you must go inside.

This booklet explains the standard tests. It tells how to run them, and how to interpret the results. It includes helpful information on the test equipment which is used. Put standard tests to work! Practice the procedures until they become second nature. That's when they really help you to get maximum payoff from your most valuable resource--your own time.

Introducing . . . Standard Transmitter Tests

When a transmitter puts out rated RF power, on the assigned RF frequency, with deviation high enough and audio sufficiently free from distortion, the transmitter is doing its job. Inability to communicate may reflect trouble somewhere, but the trouble isn't in the transmitter!

Transmitter Power Output, like all standard tests, is a "how much?" evaluation. The result is in watts. It is obtained by direct measurement of RF voltage across a known 50 ohm impedance. Transmitter Power Output becomes a "go/no go" test when the results are compared with the "right" answer, which is the rated power output shown in the maintenance manual. If a transmitter delivers rated power or more, every stage in the RF chain from oscillator to final power amplifier can be considered "good." Zero power or low power calls for attention, which may range from a simple adjustment to major surgery.

Power output *higher* than specified demands attention, too, because of the impact upon current drain and the possibility of heat-related premature failure. Unlike most standard tests, Transmitter Power Output tells you that you must do something, without telling you what. Usually, there's not even a clue. When the test is failed, get out the maintenance manual, and go inside.

Transmitter Frequency is also obtained by direct measurement. The actual developed frequency is compared against an acceptable internal standard in the frequency measuring equipment. The results are expressed in a number of ways: actual frequency, frequency difference (from assigned frequency) or percentage difference (from assigned frequency). However expressed, it is a real number, related to time. Having determined what the frequency is, and knowing what it should be (the assigned frequency), you must still decide what (if anything) to do about it. This isn't as simple as it looks at first glance, because frequency error can result from two independent causes. These are: long term drift which you can correct by adjustment, and environmental effects (mostly temperature related) for which you must make allowance. Frequency adjustment procedures are not uniform. Obtain instructions for the particular transmitter from the maintenance manual.

If the radio is operating within specified temperature limits and frequency is outside the governmentally-approved tolerance or other system specification, frequency correction is essential. Less acute errors may justify correction or even demand it, but be careful. If done with reckless disregard for the "fine points" (see maintenance manual), correction to assigned frequency at one temperature may guarantee out-of-tolerance operation at another temperature!

For oven-controlled oscillators with the oven warmed to the proper temperature, simply adjust the oscillator to the assigned frequency. If the adjustment range is insufficient, replace the crystal. The same approach holds for non-compensated low-stability oscillators, operated within their specified adjustment temperature range. For compensated oscillators, rely on the maintenance manual to separate long-term drift from environmental effects. Adjust to assigned frequency only when the oscillator is within the specified narrow temperature range. Otherwise, correct to the offset specified for the actual oscillator temperature. If the proper frequency cannot be obtained by adjustment, some component (probably the crystal) is defective and should be replaced. Do not replace crystals in packaged oscillator circuits which contain compensating components which have been matched to a specific crystal. Replace the entire assembly.

A series of four Transmitter Audio tests verifies proper functioning of four inter-related circuit functions: the modulator (accomplishes frequency/phase modulation of the RF carrier), the modulation limiter (holds maximum deviation to a fixed level), the modulation adjustment (sets this fixed level to the desired value) and audio gain (raises microphone input to the level required to drive the modulation limiter). We stretch a point by calling these four separate tests. They are really four different test *results* obtained as we follow a series of programmed manipulations with a single test setup. A transmitter which passes all four "tests" is "good" so far as audio performance is concerned:

- Maximum deviation is not *too high*. Governmentally-imposed limits are not exceeded. Excess energy is not placed into adjacent channels during modulation peaks. Receivers do not receive a signal which is "too wide," creating distortion and squelch closure on modulation peaks.

- Maximum deviation is not *too low*. Audio signal-to-noise performance is not restricted unnecessarily.

- Deviation is symmetrical under peak conditions. Avoidable distortion is minimized during modulation peaks.

- Audio gain is sufficient. A user, properly addressing the microphone, will obtain high average deviation, which is desirable for a good overall audio signal-to-noise ratio.

- Transmitted audio distortion is within design limits. Audio gain stages are properly linear; the modulator stage is working and not grossly mis-adjusted.

All of the transmitter audio tests are run with an Audio Generator (at 1000 Hz) feeding the microphone input at specified voltages. For three of the tests, the test result is deviation in Kilohertz, read directly from the deviation monitor. For the other, the deviation monitor serves as a standard receiver which drives the Distortion Analyzer from which the test result is obtained.

Transmitter Maximum Deviation verifies that legal deviation maximum is not exceeded, and standardizes the setting of the Modulation Adjustment (necessary to validate the remaining tests). The 1000 Hz Audio Generator is set to a specified voltage, typically 0.5-1.0 VRMS (see maintenance manual). This level, which is much higher than normal microphone output, guarantees that a properly working transmitter will be driven into heavy limiting. The resulting deviation, the highest which the transmitter can produce, is the test result.

If necessary, the transmitter Modulation Adjustment is set for specified Maximum System Deviation, usually ±5 kHz. Although this setting is used for the remaining transmitter audio tests, transmitter alignment instructions (see maintenance manual) may call for downward adjustment when the transmitter is placed into service. The recommended setting is typically ±4.5 kHz, and reduced to ±3.75 kHz when the transmitter is equipped with a Channel Guard (tone squelch) encoder.

If the maximum deviation which you can obtain is less than specified Maximum System Deviation, suspect a drastic loss of audio gain.

Transmitter Deviation Dissymmetry is observed in the process of determining Transmitter Maximum Deviation. The higher deviation peak (positive or negative) is the maximum deviation. The difference between peaks, expressed in kHz or as a percentage, is the dissymmetry. Transmitter Deviation Dissymmetry is usually specified as less than 10 percent (corresponds to 0.5 kHz maximum in most systems).

Lack of symmetry can arise in the modulator, the modulation limiters or, occasionally, in the audio stages. Difficulties in the modulator are usually corrected by proper tuning. Difficulties elsewhere require troubleshooting. The contribution of the modulation limiters to this form of distortion is easily confirmed (see Troubleshooting section). Observe symmetry at lower audio input levels (which do not produce limiting). If symmetry improves, the modulation limiting circuits are suspect. If not, the difficulty is elsewhere--most likely in the modulator.

Transmitter Audio Sensitivity verifies the audio gain in a transmitter. The output of an Audio Generator, set to 1000 Hz, is applied to the transmitter's microphone input. Audio Generator output is varied upward from zero until 60 percent of Maximum System Deviation is indicated. For most systems, this is ±3 kHz. The test result, usually in millivolts, is the output voltage of the Audio Generator. Typical values are in the range 60-100 millivolts, RMS (0.06-0.1 volts). If no specification is given for Transmitter Audio Sensitivity you can guess that it should be about 20 dB below the tone voltage prescribed for setting Maximum Transmitter Deviation. Sensitivity which is too low indicates a lack of audio gain, and encourages low average deviation in the system. Sensitivity which is too high brings complaints of "background noise too loud" and "distortion from excessive limiting." Failure to pass Transmitter Audio Sensitivity leads toward troubleshooting in the audio stages.

Transmitter Audio Distortion examines harmonic distortion (harmonics added to the input audio signal) in the transmitter audio stages. The test result, expressed in percentage, is read from a Distortion Analyzer (DA). Values ranging from 3-10 percent are typical. Since the test is run with input of 1000 Hz tone well below the level at which limiting occurs, distortion necessarily produced in the modulation limiter is not a factor. The possible contributors are the modulator (already checked in the Transmitter Modulation Dissymmetry test) and the audio stages. When Transmitter Audio Distortion is too high, troubleshoot the transmitter audio stages first.

Introducing . . . Standard Receiver Tests

Standard receiver tests are less straightforward than are standard transmitter tests. Transmitters, by intent, generate something physical--a signal. Characteristics of the transmitter's signal can be measured directly to provide test results. Receivers, by contrast, generate nothing; their job is to respond. For testing, a quality of receiver response is specified, and the tests determine the characteristics of an input signal necessary to produce it.

For most standard receiver tests, the benchmark for receiver output quality under test conditions is 12 dB SINAD. SINAD is usually indicated with a Distortion Analyzer (DA). You'll find a discussion of SINAD under "Distortion Analyzer" in the test equipment section of this handbook. 20 dB noise quieting is used as the output quality standard for one of the standard receiver tests.

The standard receiver tests of primary importance fall into a compact group: Receiver Audio Distortion, 12 dB SINAD Sensitivity, Modulation Acceptance Bandwidth, Critical Squelch Sensitivity and Maximum Squelch Sensitivity. Although listed as five different standard tests, they can be viewed quite correctly as five different test results, obtained with a single test setup. Nothing changes except the settings of the test equipment. They are combined into a single test procedure in this handbook, listed in the order which allows the entire series to be run with the fewest test equipment manipulations.

Receiver 20 dB Quieting is a diagnostic test, useful when Receiver 12 dB SINAD Sensitivity is failed. Receiver Frequency is not really a standard test, but is mentioned because of its importance to system operation.

Receiver Audio Distortion is taken with a very high (1000 uV) input signal. It doesn't verify gain--an "almost dead" receiver can pass this test with ease. If passed, the test does verify a number of important receiver characteristics: the detector is OK, normal audio gain exists, and audio distortion won't cloud the 12 dB SINAD Sensitivity test results. Receiver Audio Distortion is expressed in percent; typical specifications are in the range 3-10 percent.

Receiver 12 dB SINAD Sensitivity, expressed in microvolts, is a multi-characteristic test. Results which meet the specification verify RF and IF gain, mixer and injection chain performance, and confirm that selectivity is not grossly too wide or too narrow. 12 dB SINAD has no real significance in system operation. It does not represent good signal quality, by any means. Instead, receiver output of this quality is barely usable by an experienced operator. 12 dB SINAD is simply an indicator, valuable for testing because it's about as close to "no response" as one can measure reliably. 12 dB SINAD is produced in a normal receiver with a weak signal (which demands normal gain) and with fairly high deviation (which requires receiver bandwidth which is not too narrow). High audio distortion makes success impossible, thus imposing limits on distortion produced in the detector or audio stages. Typical specifications are in fractional microvolts.

Receiver Modulation Acceptance Bandwidth is expressed in kHz of deviation. It is a follow-on test to 12 dB SINAD Sensitivity, run with slightly increased RF signal level (up 6 dB). It confirms that receiver bandwidth is not too narrow, since it subjects the receiver to deviation much higher than that produced by a properly adjusted transmitter. Normal specifications are in the range 6-9 kHz.

Receiver Critical Squelch Sensitivity and Receiver Maximum Squelch Sensitivity confirm proper operation of the squelch circuits. Critical Squelch Sensitivity finds the signal level which will unsquelch the receiver when the squelch control has been set to the point which barely silences the noise. When not specified, you can expect this level to be about 8 dB *less* than the 20 dB Quieting Sensitivity. Maximum Squelch Sensitivity measures the RF signal level which will unsquelch a receiver when the squelch control is set to full rotation in the squelched direction. Unless otherwise stated, expect this level to be about 6 dB *more* than the 20 dB Quieting Sensitivity.

Receiver 20 dB Quieting Sensitivity confirms that gain is normal--and little else. It's useful to narrow the search for possible causes when a receiver fails to meet its 12 dB SINAD Sensitivity specification.

Although it is just as important as the tests we describe in detail, Receiver Frequency doesn't lend itself to a "canned" test procedure. Different receiver designs demand different approaches. The maintenance manual is your guide. However accomplished, it is essential that the test procedure verify that the receiver oscillator is properly set. An on-frequency input signal *must* be converted to the center of the receiver's IF bandpass.

TEST EQUIPMENT

The following items of test equipment are used in performing one or more of the standard tests:

Signal Sources
- Audio Generator
- RF Signal Generator

Monitors
- Deviation (modulation) Monitor
- Frequency Measuring Equipment

Meters
- RF Wattmeter
- Distortion Analyzer (DA)
- Audio Voltmeter
- DC/AC Volt/Amp Meter(s)

Other
- Audio Load Resistor
- Couplers (or coupling methods)
- Dummy Microphone Circuit (when required)
- Bench Test Accessories (when required)
- Power Supply

The functions of RF Signal Generator, Deviation Monitor and Frequency Measuring Equipment are sometimes combined into a "Communications Service Monitor." The function of Audio Voltmeter is usually provided by a Distortion Analyzer (DA).

Audio Generator

This instrument furnishes audio input for standard transmitter tests (deviation, symmetry, audio sensitivity and audio distortion). Since all of these tests are made at 1000 Hz, a fixed frequency unit will suffice. Output may be single-ended or balanced, but must be adjustable over the range 0.01 VRMS to 1.0 VRMS into 600 ohms. Harmonic distortion must not exceed 1%; lower distortion is preferred.

RF Signal Generator

The RF Signal Generator is used for all standard receiver tests. Functionally, it is a specialized FM radio transmitter in which frequency, modulation and power output are adjustable and accurately calibrated. It should generate any frequency used in two-way radio systems. Output, at 50 ohms, must be variable from 0.1 microvolts to 1000 microvolts or more. Symmetrical modulation at 1000 Hz is essential; distortion must be less than 1 percent. External modulation capability is desirable. Peak deviation must be adjustable from 0 to more than ±10 kHz.

Most RF Signal Generators require an external attenuation pad (usually 6 dB or 20 dB) to stabilize output and improve the output power calibration. These pads also provide a degree of protection against "burnout" (when a transmitter is inadvertently keyed into the generator) and may include a protective fuse.

The RF Signal Generator must be set accurately to the frequency of the receiver under test. A Communication Service Monitor includes a digitally-controlled synthesized generator and meets this requirement easily. Otherwise, you must use external Freqneucy Measuring Equipment for the initial setting, and monitor the frequency often because of the possibility of drift.

TEST EQUIPMENT

Deviation (modulation) Monitor

In function, this instrument is a specialized FM radio receiver which can be set to the frequency of a transmitter which is under test. Like other instruments, it should function on any frequency used for two-way radio systems. Its detector output feeds a peak-reading voltmeter which is calibrated to indicate peak modulation deviation in kilohertz. The output indicator may be an analog meter or digital meter, in which case a polarity-reversing switch is required. Some instruments use a cathode-ray tube display as the readout. These provide peak deviation values (both directions) simultaneously, along with indication of gross distortion.

The Modulation Monitor is the only indicator used for standard transmitter tests which require measurement of deviation. These include: Maximum Deviation, Symmetry and Audio Sensitivity. An external Distortion Analyzer (DA) is driven from an output of the Modulation Monitor to perform the Transmitter Distortion Test. This test requires a 6 dB-per-octave de-emphasis characteristic between the flat detector in the Modulation Monitor and the Distortion Analyzer. If not provided internally, it may be added in the interconnection. A simple RC low-pass filter (series 1.6K ohms, shunt 0.047 F) will do the job.

Full scale indication of the Modulation Monitor should be ±5 kHz peak deviation (or a little higher) for the usual two-way radio systems. Another range (about ±2 kHz peak deviation full scale) is desirable for measurement of modulation from tone squelch (Channel Guard) encoders. Accuracy must be within ±5.0% when indicating peak deviation of a complex waveform.

Frequency Measuring Equipment

Accuracy is the critical requirement in Frequency Measuring Equipment. With transmitters, the equipment is used to verify or set the exact transmitting frequency. With receivers, it is used directly or indirectly to verify or set the exact receiving frequency. Transmitting frequency can be of legal significance; "out of tolerance" operation may be a serious violation of law or regulation.

Off-frequency operation of either transmitter or receiver can cause severe degradation of system performance. When frequency offset between transmitter and receiver exceeds the receiver's capability, increased noise and distortion is inevitable.

Useful measurements require accuracy which is much better (5 times to 10 times better) than the permissible tolerance in the quantity being measured. The frequency tolerance of modern transmitters and receivers ranges from ±.0005 percent to ±.002 percent. This is equivalent to 5 parts-per-million (PPM) to 2 PPM. Measurement uncertainty, from all causes, should be in the following range:

EQUIPMENT FREQUENCY TOLERANCE	MAXIMUM MEASUREMENT UNCERTAINTY
2 PPM	0.2 PPM to 0.4 PPM
5 PPM	0.5 PPM to 1.0 PPM

For a 150 MHz signal and the usual 5 PPM tolerance, you should be able to measure frequency with an error no greater than 75–150 Hz. When 450 MHz signals are subject to a 5 PPM tolerance, error should not exceed 225–450 Hz. When a 2 PPM tolerance applies at 450 MHz, the maximum error should be no more than 90–180 Hz.

The factors which influence measurement accuracy are in two categories: time base accuracy, and resolution. "Time base accuracy" applies to the internal frequency standard within the instrument. It, like the oscillator in a transmitter or receiver, is subject to initial setting errors, long term drift (from component aging) and short term drift from environmental factors (temperature, humidity, supply voltage). "Resolution" refers to the precision to which the indicator or display can be read. Adequate time base accuracy is expensive but essential since it is the ultimate limitation of measurement performance. The inherent accuracy of the time base plus errors from long term drift between calibrations, must not exceed the required maximum measurement uncertainty. Regular calibration is a must! Resolution must be good enough to be insignificant when compared to the limitations of the time base.

Frequency Measuring Equipment should cover all of the frequencies used in two-way radio systems. Sensitivity must be sufficient to allow reliable operation in the transmitter test setups which are used. If it is used to set or verify signal generator frequency (for receiver frequency setting or measurement), sensitivity must be adequate for the signal generator output which is available.

RF Wattmeter

The RF wattmeter serves dual purposes: termination and power measurement. These may be accomplished with a single instrument or with two interconnected devices.

Standard transmitter test conditions require operation into a resistive load of 50 ohms. To insure proper termination and minimize interference to co-channel users, standard tests are run with a non-reactive 50 ohm load resistor. This resistor must dissipate the power output of transmitters under test for long periods, without physical damage or impedance change.

An RF voltmeter across the transmission line feeding the load resistor indicates power in watts when calibrated on the basis: $P = E^2/R$. When the power-calibrated RF voltmeter is combined with the load resistor, you have a *terminating* wattmeter. A power-calibrated RF voltmeter which is inserted in series with the load resistor is an *in-line* wattmeter. Almost all in-line wattmeters have directional characteristics, allowing individual measurement of "forward power" (that delivered to a load) and "reflected power" (that returned from a non-optimum termination). These instruments are called *directional* wattmeters. Although directional wattmeters are essential for measuring antenna system performance, they have no special merit for conducting standard tests which are always made into non-reflecting 50 ohm resistive loads. In fact, the limited frequency response of most directional wattmeters (which necessitates replaceable elements for each frequency band) makes them inconvenient for the service bench. Terminating wattmeters, by contrast, usually operate over a wide frequency range.

Accuracy (seldom better than ±10%) is best near the top end of the scale. Wattmeters should be chosen so that power levels of greatest interest fall within the upper third of a range. Cable loss must be minimized, since it is a source of measurement inaccuracy. A minimum number of connectors should be used between transmitter and load resistor (or terminating wattmeter), and connectors should be assembled with great care. Each is a potential source of impedance discontinuity and power loss.

Distortion Analyzer (DA)

The Distortion Analyzer is used to measure harmonic distortion (both transmitter and receiver) and to indicate SINAD ratio (for most standard receiver tests). The key elements in the DA are an AC (audio) voltmeter, a tunable notch filter, function switching and range switching. The names assigned to controls and switches vary between currently available instruments. Figure 1 shows the block diagram of a typical Distortion Analyzer.

The notch filter is at the heart of the Distortion Analyzer. It suppresses the fundamental frequency of the tone being examined, and leaves only harmonic energy and noise to indicate on the meter. General purpose analyzers cover the range 20-20,000 Hz. For the two-way radio field where standard tests are run at 1000 Hz only, specialized units may be fixed at 1000 Hz or adjustable over a narrow range centered at 1000 Hz. Input impedance of the instrument is high to minimize loading of the source. When any voltage range is selected, the INPUT ADJ control and notch filter are bypassed; the unit serves as a conventional audio voltmeter. When

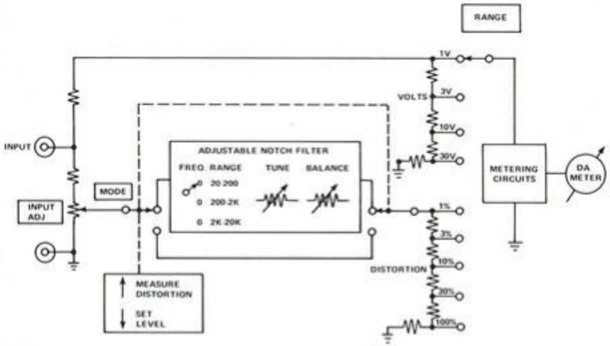


Figure 1. A Distortion Analyzer (DA) includes an AC (audio) voltmeter, a tunable notch filter and some simple switching. With the fundamental of a tone filtered out, only harmonic products and noise are presented to the meter.

a distortion range is selected, the metering circuits are fed through the INPUT ADJ control and the notch filter. The MODE switch allows the filter to be bypassed.

The meter face includes linear scales from 0–3 and 0–10 and a logrithmic scale marked from −10 dB to +2 dB. The 0–10 scale is used for the 1V and 10V voltage ranges, and the 1%, 10% and 100% distortion ranges. The 0–3 scale is used for the 3V and 30V voltage ranges, and the 3% and 30% distortion ranges. The dB scale is used to indicate SINAD. The full length of the scale, from −10 dB to +2 dB, is 12 dB which is convenient for indicating the usual SINAD ratio of 12 dB.

When a tone is applied to the DA, the RMS-reading meter shows the total voltage of the tone (Signal or S), Noise (N) and harmonics of the tone (Distortion or D). Thus, the indication in any unfiltered condition is S + N + D. If Noise (N) and Distortion (D) are negligible, the indication is Signal (S) only. If only Noise (N) is negligible, the indication is S + D. If Signal (S) is removed by filtering, the indication is N + D.

When the RANGE switch is set to any distortion scale and the notch filter is adjusted to remove the fundamental (S) of the applied tone, indications are as follows:

"SET LEVEL" Position:	S + N + D
"MEASURE DISTORTION" Position:	N + D

Since distortion is measured with noise-free input to the DA, the N term is removed and indications are as follows:

"SET LEVEL" Position:	S + D
"MEASURE DISTORTION" Position:	D

Distortion, as specified in the two-way radio field and measured in standard tests, is the voltage ratio between the two measurements, expressed in percent, thus:

$$\text{Distortion (percent)} \quad \frac{D}{S+D} \times 100 = \frac{\text{Voltage (filter "in")}}{\text{Voltage (filter "out")}} \times 100$$

SINAD is the voltage ratio $\frac{S+N+D}{N+D}$, expressed in decibels. In two-way radio, SINAD is seldom measured. Instead, the specific value 12 dB SINAD is used as the output indication for most standard receiver tests. When receiver output is 12 dB SINAD, noise (N) is always of major significance. Distortion (D) is of minor significance (often negligible) when the receiver is in proper working condition. 12 dB SINAD condition is indicated when the readings on the DA are as follows:

Indication, filter "out":	+2 dB
Indication, filter "in":	–10 dB

Measuring Distortion with the DA

The Distortion Analyzer is arranged to read out distortion in percent, avoiding the need to calculate a voltage ratio from voltage readings. Since the exact arrangement and marking vary among commercially available instruments, this procedure uses terminology from Figure 1. Translation to a specific DA is a simple task.

1. Apply proper input to DA. For standard receiver tests, see Test Procedure.
2. Switch the DA MODE switch to SET LEVEL and the RANGE switch to 100% (distortion).
3. Adjust INPUT ADJ to indicate 100 percent (10 on the 0–10 scale).
4. Switch DA to MEASURE DISTORTION. Adjust the notch filter for maximum rejection (minimum meter indication) using the FREQ RANGE switch, and FREQUENCY and BALANCE knobs. Switch to lower distortion ranges as the null is approached, maintaining the meter indication well up-scale.
5. When the deepest null (lowest meter indication) is achieved, the meter reading (read on the scale appropriate for the RANGE switch setting) is Distortion in percent.

If input voltage is too low to achieve a 100 percent indication in Step 2, use the highest RANGE switch distortion position which allows you to adjust to the meter's 100 percent mark. Consider the position actually used as 100 percent full scale, and each lower position to which you switch as the next normal range down. For example, if you use the 30% range as the starting point in Step 2, the next position down (marked 10%) reads 30 percent full scale. The next lower position (marked 3%) is interpreted as 10 percent full scale.

Indicating 12 dB SINAD with the DA

When the difference between indications at SET LEVEL and MEASURE DISTORTION on a DA which has been properly nulled is 12 dB, input to the DA is 12 dB SINAD. This condition exists when the SET LEVEL indication is +2 dB on any distortion range, and the MEASURE DISTORTION indication is –10 dB on the same range. If the spread between the two measurements is less than 12 dB, SINAD is less than 12 dB. If the spread is more than 12 dB, SINAD is more than 12 dB. To increase SINAD, noise must be reduced, requiring increased signal to the receiver under test. If SINAD is too high, reducing signal to the receiver being tested increases noise to the DA and allows you to get to 12 dB SINAD. The procedure for achieving 12 dB SINAD, again using the designations in Figure 1, follows:

1. Apply proper input to DA. For standard receiver tests, see Test Procedure.

2. Switch the DA MODE switch to SET LEVEL and the RANGE to the highest % Range (distortion) which allows compliance with Step 3.

3. Adjust INPUT ADJ for +2 dB on the meter scale.

4. Switch the DA to MEASURE DISTORTION. Adjust the notch filter for maximum rejection (minimum meter indication) using the FREQ RANGE switch and FREQUENCY and BALANCE knobs. Do not change the range selected by the RANGE switch.

5. Switch DA alternately between SET LEVEL and MEASURE DISTORTION. Observe the meter readings while adjusting RF input (from RF Signal Generator) to the receiver under test.

6. 12 dB SINAD is achieved when the difference between readings is 12 dB (+2 dB to −10 dB).

SINAD Meter

Specific needs in the two-way radio industry have encouraged the design of specialized instruments which indicate SINAD directly. They eliminate all of the mechanical operations necessary to indicate SINAD with a Distortion Analyzer.

These instruments use self-leveling circuits to perform the function of INPUT ADJ (see Figure 1). Operation is adjustment-free over a wide input voltage range (typically to 4V maximum). The Notch Filter is fixed at 1000 Hz. Some versions provide a small frequency trim to accommodate signal sources not precisely on 1000 Hz. If no trim is provided, the 1000 Hz tone must be held to ±5 Hz. Operation is automatic. When drive to the SINAD Mete. is 12 dB SINAD, the meter shows 12 dB.

Standard receiver tests require that receiver output power be maintained at a specific level when SINAD indications are taken. This necessitates measurement of audio voltage at the receiver output. If an AC voltmeter is not included within the SINAD Meter, the function must be provided externally.

At least one commercially available instrument includes both AC Voltmeter and Distortion Analyzer functions with a self-adjusting SINAD Meter.

Audio Voltmeter

The Audio Voltmeter is used in standard transmitter tests to set the output of the Audio Generator. In standard receiver tests, it is used to monitor the audio output from the receiver when an AC voltmeter function is not available in the Distortion Analyzer.

A wide range of audio voltages must be measured in the two-way radio field. The Audio Voltmeter should provide full scale indications ranging from 0-0.01 volts to 0-300 volts. A 1-3-10 ratio of scales (approximately 10 dB per step) is ideal. dB scales are desirable and should be based upon the reference: 0 dBM = 1 milliwatt into 600 ohms.

High input impedance is desirable to minimize loading on the circuits measured. 10K ohms is acceptable but 1 Megohm is preferred. Frequency response should extend from 20 Hz to at least 20,000 Hz.

DC/AC Volt/Amp Meter(s)

All standard tests require that equipment under test be supplied with "Standard Test Voltage." Appropriate DC or AC voltmeters are required to set this voltage and to verify that it is maintained during the tests.

DC metering of voltage and/or current may be required to determine power input to the final amplifier and, possibly, other transmitter stages. While only desirable to confirm transmitter efficiency, this metering is essential to validate the standard Transmitter Power Output test.

Some of the required metering capability may be provided by Specialized Metering Testsets recommended for the specific equipment. Other requirements may be met by voltmeters and ammeters which are part of the bench power supply. When essential metering is not provided otherwise, external meters are required.

Audio Load Resistor

Standard receiver tests are not performed into a speaker. Instead, they are performed with the receiver terminated by a resistor with resistance equal to the specified speaker impedance. Receivers which normally feed a telephone line are terminated with a resistor of 600 ohms for standard tests. The power rating of the resistor must allow it to dissipate more than rated receiver audio power for extended periods without damage or impedance change.

With a load resistor substituted for the speaker, it becomes impossible to listen to the receiver output. This may make troubleshooting inconvenient. Monitoring may be obtained by bridging the Audio Load Resistor with a higher impedance speaker (at least ten times the load resistance). Alternately, a series build-out resistor may be used with a low-impedance speaker.

A build-out resistor may also be needed if the audio voltage exceeds the maximum input voltage of the test equipment (4V MAX for some SINAD meters).

Most standard receiver tests require that specified audio power be delivered to the Audio Load Resistor. Voltage is measured across the resistor as the receiver volume control is set for the required power output. Power is converted to equivalent voltage by the formula:

$$E = \sqrt{P R}$$, where:

E = RMS voltage

P = Power in watts, and

R = Load resistance in ohms

Voltages across two common values of Audio Load Resistor which correspond to a range of power outputs are graphed in Figure 2.

Certain standard tests require that receiver output be set to a specified fraction of "full rated power output." The voltage corresponding to the desired fraction may be determined from the voltage corresponding to full rated power output as follows:

Fraction of Full Rated Power Output	Multiplier for voltage corresponding to Full Rated Power Output
One-Quarter (25%)	.5
One-Half (50%)	.707

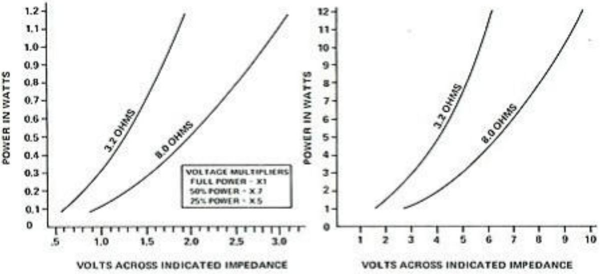


Figure 2. These graphs convert RMS voltage across a load to power dissipated in the load for two common audio load values.

Couplers (and Coupling)

When standard transmitter tests are performed, the transmitter must be directly connected to an RF Wattmeter or some other 50 ohm resistive termination. But, some transmitter energy must be directed to the Frequency Measuring Equipment and the Deviation Monitor. Direct connection between transmitter and test equipment is out of the question. Most transmitters deliver many watts; most test equipment in this class is badly damaged when input power approaches a few milliwatts. Lossy coupling between transmitter and sensitive test equipment is essential.

The simplest approach uses a small antenna at the input of the test equipment. Stray radiation from the transmitter, the RF Wattmeter and the interconnecting cables drives the instruments. The test equipment is protected from burnout, but operation may be unsatisfactory. Digital frequency counters often give erratic indications; test equipment may respond to nearby RF signals or noise sources. While usable, this arrangement is far from optimum.

"Closed" systems are much more satisfactory, since they provide a shielded path with controlled loss. These fall into several classes:

1. In-line power attenuators (usually "T" pads) used in place of the RF Wattmeter. These devices provide a known loss while maintaining 50 ohm resistive terminations in both directions. Sufficient units, in series, attenuate the transmitter power to the level required by the instruments, and dissipate the surplus power.

2. Directional couplers, used in the line between transmitter and RF Wattmeter. Loss from transmitter to RF Wattmeter is normally a fraction of a decibel; proper transmitter termination is maintained. Output at a third "port" is normally attenuated about 20 dB. Instruments are fed from this port through additional fixed or variable attenuators.

3. Capacitive Couplers, used in the line between transmitter and RF Wattmeter. Energy is coupled from the "through" path to a "pickoff" port through a small capacity. This capacity provides attenuation (to protect the instruments) and isolation (to

maintain proper transmitter termination). Unfortunately, loss varies with frequency. Capacitive couplers often include a mechanical arrangement which allows the user to control loss by changing capacity.

All of the devices required for these "closed" coupling arrangements are available commercially.

Improvised Capacitive Coupler

A workable capacitive coupler can be built from commonly available coaxial connectors. For details, see Figure 3.

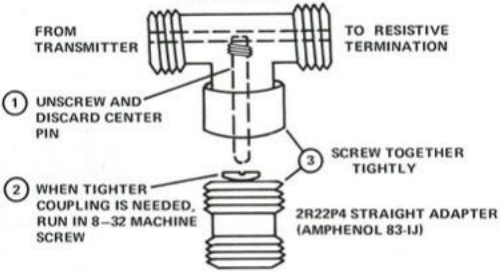


Figure 3. A capacitive coupler, improvised from common coaxial connectors, allows you to set up "closed" coupling to sensitive test equipment. Proper transmitter termination is maintained while instruments are isolated from external RF signals and noise.

The male center pin of the common UHF-series T adapter threads into the tube which serves as the two female contacts. Unscrew the pin and discard it. This leaves the tube loose. Stake it in place with a drop of epoxy so it won't be lost. When a straight adapter is screwed into the modified T adapter, there is no direct contact between the center conductor of the T adapter and the center conductor of the straight adapter. However, there is capacitive coupling between the two masses of metal. The T adapter is installed in-line between transmitter and RF Wattmeter. Test equipment is energized from the straight adapter. If loss is too great, capacity (and coupling) can be increased by threading a machine screw into the unexposed end of the straight adapter. Coarse adjustment is available by running the screw in and out. Of course, direct contact between the screw head and the "through" path must be avoided.

Dummy Microphone Circuit

A Dummy Microphone Circuit (inserted in series between Audio Generator and Transmitter) is needed to perform standard transmitter tests on some transmitters. When it is required, this component or network is specified in the transmitter maintenance manual. This "circuit" usually appears as a single resistor or capacitor, a series-shunt arrangement of two resistors, or a simple R-C filter.

Most frequently, the Dummy Microphone Circuit is a single capacitor which blocks DC at the transmitter microphone input from the Audio Generator. DC is found when microphone input circuits are designed for carbon or transistorized microphones. A Dummy Microphone Circuit may be needed to make the Audio Generator simulate the source impedance and frequency characteristics of the microphone normally used with the transmitter. If the required audio voltage to the transmitter is very low (a few millivolts), a Dummy Microphone Circuit in the form of a loss pad may be specified. This allows the Audio Generator to operate well above the erratic area at the low end of the output voltage control.

Specialized Metering Testsets

Many transmitters and receivers include circuits and connectors for centralized metering. Critically important circuit tuneup points, along with supply voltages, are wired to pins on the connector. When current measurement is important, as with current supplied to transmitter power amplifiers, both sides of a resistor in series with the current path are wired to the connector. A specially designed metering testset plugs into the connector. The testset includes a meter, switches, and other components which coordinate with the metering concept. Different equipment "families" usually require different testsets. In addition to pure metering, most tests include convenient ways to apply and recover the audio signals required for standard transmitter and receiver tests.

When the radio equipment is designed to use specialized metering testsets, it is difficult to perform standard tests without them. In their absence, the metering methods used (especially for current measurements) must duplicate the characteristics of the testset. This requires careful study of the equipment maintenance manual.

Bench Test Accessories

For standard tests to be valid, the cables and controls used must duplicate conditions of normal equipment use. DC drop in supply cables is important; standard test voltages are specified at the input terminals of the cables normally supplied with the equipment. Control cables and controls used for testing must not introduce their own noise or distortion which invalidates the measurement data obtained. Standard cables and controls (or items with duplicate characteristics) should be used to perform standard tests of "trunk mounted" radio units. The test setup for other equipment should conform exactly with that specified in the equipment maintenance manual.

Power Supply

The power supply used to perform standard tests must be adjustable to the Standard Test Voltage specified for the equipment and maintain that voltage while delivering the required current. Regulation, at the very least, must be sufficient to avoid equipment damage when load current is reduced or suddenly removed. The power supply must be free of "ripple" (which appears as noise to invalidate measurements) and transient voltage "spikes" (which may damage equipment).

Internal metering of output voltage and current, adjustable current limiting, and resettable overload protection are desirable features.

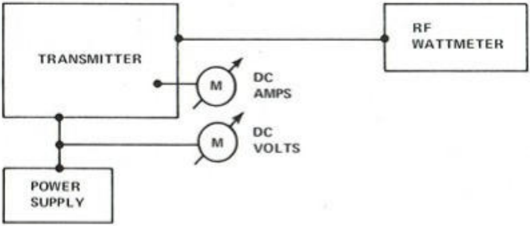
TEST VOLTAGES

Standard tests are run with Standard Test Voltage powering the equipment being tested. For mobile equipment, the test voltage is measured at the battery terminals of the standard cables supplied with the unit. To simulate characteristics of vehicular installations, equipment chassis is connected to the ungrounded battery terminal with 7 feet of No. 6 copper conductor. For AC powered equipment, the test voltage is measured at equipment input terminals, or the input end of a furnished line cord. For personal and portable equipment, both Standard Test Voltage and the measurement point are specified in the maintenance manual.

NOMINAL SUPPLY VOLTAGE	OPERATING CURRENT AMPERES	STANDARD TEST VOLTAGE
6V DC	Less than 10	6.6
	10–22	6.5
	22–36	6.4
	36–54	6.3
	54–70	6.2
	More than 70	6.1
12V DC	Less than 6	13.8
	6–16	13.6
	16–36	13.4
	36–50	13.2
	More than 50	13.0
24V DC	any	26.4
32V DC	any	36.0
48V DC	any	52.5
64V DC	any	72.0
110V DC	any	110.0
120V AC	any	121.0
240V AC	any	242.0

TRANSMITTER TEST PROCEDURES

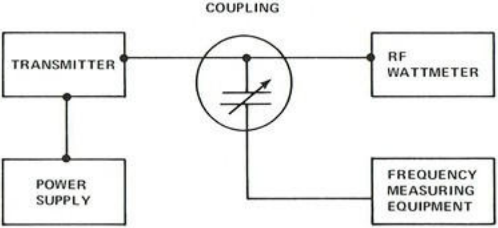
TRANSMITTER POWER OUTPUT



1. Terminate transmitter with RF Wattmeter.
2. Supply transmitter with Standard Test Voltage.
3. Meter* Power Input to transmitter final power amplifier.
4. Adjust (or confirm)* transmitter tuning, loading, coupling and/or POWER ADJUST control setting.
5. Verify* that maximum rated power input to the final power amplifier stage is not exceeded.
6. Read Transmitter Power Output in watts from the scale of the RF Wattmeter.

*See transmitter maintenance manual

TRANSMITTER FREQUENCY



1. Terminate transmitter with RF Wattmeter or other 50 ohm resistive load.

2. Supply transmitter with Standard Test Voltage.

3. Read Transmitter Frequency (or frequency error) from the calibration of the Frequency Measuring Equipment.

4. If necessary, convert data to the form required for comparison with equipment specifications (and/or governmental regulations):

   A. $\frac{\text{Frequency Error (Hz)}}{\text{Assigned Freq (Hz)}} \times 100 = \text{Error (percent)}$

   Examples:

   1. $\frac{+310}{155130000} \times 100 = +0.0002\%$

   2. $\frac{-180}{155130000} \times 100 = -0.00012\%$

   B. $\frac{\text{Freq. (actual)} - \text{Freq (assigned)}}{\text{Freq (assigned)}} \times 100 = \text{Error (percent)}$

   Examples:

   1. $\frac{155.130310 - 155.13}{155.13} \times 100 = \frac{.000310}{155.13} \times 100 = +0.0002\%$

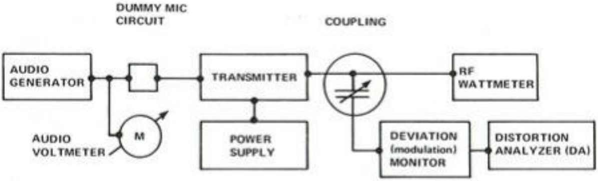
   2. $\frac{155.1298 - 155.13}{155.13} \times 100 = \frac{-0.0002}{155.13} \times 100 = -0.00012\%$

5. If frequency must be reset, verify* that transmitter ambient temperature is within permissible range. Determine* and apply frequency offset which is appropriate for the ambient temperature.

*See transmitter maintenance manual

TRANSMITTER TEST PROCEDURES

TRANSMITTER MAXIMUM DEVIATION
TRANSMITTER DEVIATION DISSYMMETRY
TRANSMITTER AUDIO SENSITIVITY
TRANSMITTER AUDIO DISTORTION



1. PRELIMINARY

   A. Terminate transmitter with RF Wattmeter.

   B. Supply transmitter with Standard Test Voltage.

   C. Remove deviation from Channel Guard (tone squelch) encoder, if present.

   D. Use Dummy Microphone Circuit, if* required.

   E. Apply output from Audio Generator, preset as follows:

      (1) FREQUENCY: 1000 Hz

      (2) AUDIO OUTPUT: Voltage specified* to set Maximum Transmitter Deviation

2. MEASURE: TRANSMITTER MAXIMUM DEVIATION

   A. Observe Deviation in kHz on the Deviation Monitor for both positive and negative peaks. For monitors with 'scope readout, these readings are available simultaneously. For other instruments, the POLARITY REVERSE switch must be operated.

   B. The higher of the two readings (positive peak or negative peak) is Transmitter Maximum Deviation in kHz. This value is normally 5.0 kHz. Recommended* transmitter adjustment procedure may call for final setting to a lower value. This is normally 4.5 kHz except: a value of 3.75 kHz may be specified when the transmitter is equipped with Channel Guard (tone squelch) encoder.

3. CALCULATE: TRANSMITTER DEVIATION DISSYMMETRY

$$\frac{\text{Deviation (higher)} - \text{Deviation (lower)}}{\text{Deviation (higher)}} \times 100 = \text{Deviation Dissymmetry (in percent)}$$

Example: $\frac{5.0\text{ kHz} - 4.75\text{ kHz}}{5.0\text{ kHz}} \times 100 = 5.0\%$

*See transmitter maintenance manual

4. MEASURE: TRANSMITTER AUDIO SENSITIVITY

   A. Observe deviation on the peak (positive or negative) which yielded the higher reading in Step 2A.

   B. Reduce AUDIO OUTPUT of Audio Generator until deviation is reduced to 60 percent of Transmitter Maximum Deviation (Step 2B).

   C. Read Transmitter Audio Sensitivity (usually) in Millivolts from the Audio Voltmeter.

5. MEASURE TRANSMITTER AUDIO DISTORTION

   A. Audio Generator FREQUENCY remains at 1000 Hz.

   B. Audio Generator OUTPUT remains at the voltage which produces 60 percent of Transmitter Maximum Deviation (Step 4B).

   C. Output to the Deviation Monitor must be from a deemphasized source. Refer to: TEST EQUIPMENT, Deviation Monitor (see Table of Contents).

   D. Remove deviation from Channel Guard (tone squelch) encoder, if present.

   E. Operate the Distortion Analyzer (DA) as follows:

      (1) Set DA MODE switch to SET LEVEL and DA RANGE switch to 100%.

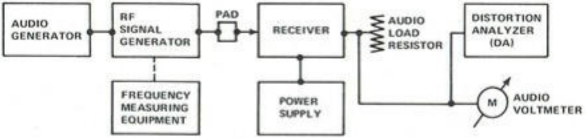
      (2) Adjust DA INPUT ADJ control for DA Meter indication of 100% (full deflection on 0–10 scale).

      (3) Switch DA MODE switch to MEASURE DISTORTION. Adjust DA notch filter for maximum rejection (minimum meter reading). Use DA RANGE, FREQ and BALANCE controls. Switch to lower percentage (%) ranges as the null is approached.

   F. When minimum DA Meter reading is obtained, read Transmitter Audio Distortion in percent on the DA Meter scale appropriate for the DA RANGE switch position.

RECEIVER TEST PROCEDURES

RECEIVER AUDIO DISTORTION
RECEIVER 12 dB SINAD SENSITIVITY
RECEIVER MODULATION ACCEPTANCE BANDWIDTH
RECEIVER CRITICAL SQUELCH SENSITIVITY
RECEIVER MAXIMUM SQUELCH SENSITIVITY



1. PRELIMINARY

   A. Terminate receiver with Audio Load Resistor

   B. Supply receiver with Standard Test Voltage

   C. Disable Channel Guard (tone squelch) decoder, if present

   D. Adjust receiver SQUELCH control for minimum squelch (full rotation in unsquelched direction)

   E. Apply output from RF Signal Generator, preset as follows:

      (1) FREQUENCY: to receiver operating frequency
      (2) MODULATION: 1000 Hz
      (3) DEVIATION: 60% of Maximum System Deviation (normally ±3 kHz
      (4) RF OUTPUT: 1000 uV (–47 dBm; –77 dBW)

   F. Set receiver VOLUME control for rated Receiver Audio Power Output. Use Audio Voltmeter or voltage scale of DA. See Figure 2 for "Watts to Volts" conversion.

2. MEASURE: RECEIVER AUDIO DISTORTION

   A. Set DA MODE switch to SET LEVEL and DA RANGE switch to 100%. See Figure 1 for identification of Distortion Analyzer switches and controls.

   B. Adjust DA INPUT ADJ control for DA Meter indication of 100% (full deflection on 0–10 scale)

   C. Switch DA MODE to MEASURE DISTORTION. Adjust DA notch filter for maximum rejection (minimum meter reading). Use DA RANGE, FREQ and BALANCE controls. Switch to lower percent(%) ranges as the null is approached.

   D. When minimum DA Meter reading is obtained, read Receiver Audio Distortion in Percent on the meter scale appropriate for the DA RANGE switch position.

3. MEASURE: RECEIVER 12 dB SINAD SENSITIVITY

A. Switch DA MODE to SET LEVEL (leave DA RANGE unchanged).

B. Adjust DA INPUT ADJ for reading of +2 dB on DA Meter. Switch DA RANGE to next higher percent (%) range if necessary.

C. Determine SINAD by switching DA MODE between SET LEVEL and MEASURE DISTORTION, observing DA Meter readings in each position. SINAD, in dB, is the difference between these readings. The initial indication is much greater than 12 dB.

D. Reduce RF Signal Generator RF OUTPUT while observing SINAD (compare meter readings while switching DA MODE between the two positions). When the difference between readings is 12 dB, read Receiver 12 dB SINAD Sensitivity in Microvolts from the RF Signal Generator RF OUTPUT calibration. Allow for pad loss.

4. MEASURE: RECEIVER MODULATION ACCEPTANCE BANDWIDTH

A. Increase RF Signal Generator RF OUTPUT by 6 dB (in microvolts to two times the 12 dB SINAD Sensitivity measured in Step 3). Note that SINAD is now more than 12 dB.

B. Increase RF Signal Generator DEVIATION while observing SINAD. When SINAD is reduced to 12 dB, read Receiver Modulation Acceptance Bandwidth in ± kHz from the RF Signal Generator DEVIATION calibration.

5. MEASURE: RECEIVER CRITICAL & MAXIMUM SQUELCH SENSITIVITY

A. RF Signal Generator:

(1) DEVIATION: Restore to 60% of Maximum System Deviation (normally ±3 kHz)
(2) RF OUTPUT: Reduce to zero

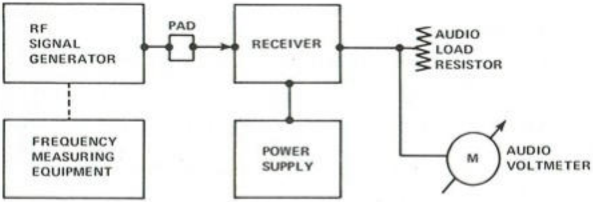
B. Rotate receiver SQUELCH control slowly until receiver is barely squelched (Audio Voltmeter reads zero).

C. Slowly increase RF Signal Generator RF Output until receiver is barely unsquelched (Audio Voltmeter reads more than zero). Read Receiver Critical Squelch Sensitivity in Microvolts from the RF Signal Generator RF OUTPUT calibration. Allow for pad loss.

D. Rotate receiver SQUELCH control to maximum squelch (full rotation in the squelched direction). Audio Voltmeter reads zero.

E. Slowly increase RF Signal Generator RF Output until receiver is barely unsquelched (Audio Voltmeter reads more than zero). Read Receiver Maximum Squelch Sensitivity in Microvolts from the RF Signal Generator RF OUTPUT calibration. Allow for pad loss.

RECEIVER 20 dB QUIETING SENSITIVITY



1. PRELIMINARY

   A. Terminate receiver with Audio Load Resistor.

   B. Supply receiver with Standard Test Voltage.

   C. Disable Channel Guard (tone squelch) decoder, if present.

   D. Adjust receiver SQUELCH control for minimum squelch (full rotation in unsquelched direction).

   E. Apply output from RF Signal Generator, preset as follows:

      (1) FREQUENCY: to receiver operating frequency
      (2) MODULATION: none
      (3) DEVIATION: zero
      (4) RF OUTPUT: initially zero

   F. Set receiver VOLUME control for 25 percent of rated Receiver Audio Power Output (on noise). Use Audio Voltmeter. See Figure 2 for "Watts to Volts" conversion.

2. MEASURE: RECEIVER 20 dB QUIETING SENSITIVITY

   A. Increase RF Signal Generator RF OUTPUT while observing Audio Voltmeter. Reading decreases as RF OUTPUT increases. When voltage is reduced by 20 dB (to one-tenth of the voltage set in Step 1F, read <u>Receiver 20 dB Quieting Sensitivity in Microvolts</u> from the RF Signal Generator RF OUTPUT calibration. Allow for pad loss.

PERFORMANCE VERIFICATION WITH STANDARD TESTS

Not all testing is done in connection with troubleshooting. Sometimes, you test for assurance that equipment is good.

- You may want to test new equipment for acceptance before it goes into a warehouse for later installation or use.
- You may be installing at a location where it is inconvenient to deal with unanticipated problems. You may prefer to handle initial defects in the comfort of your own shop.
- A unit may come in for service with no clear statement of the problem. You must start somewhere!
- You may want to evaluate the performance of your shop to make sure that repaired equipment is leaving in good operating condition.
- You may wish to attack a reported system problem by first verifying that the equipment involved is doing its job.

Although there are many ways to approach equipment checkout, performance of the Standard Tests listed in this handbook gives you the most assurance for the least effort. Any transmitter or receiver which passes all of the tests in this handbook is unlikely to fail to perform when used in a reasonable system.

The order in which Standard Tests are listed in the troubleshooting charts and test procedures is optimum for checkout also. In some cases, the order is dictated by the tests themselves--one must be passed before another is valid. In other cases, order is chosen to minimize test equipment manipulations.

For transmitters, the right order is Power Output, Frequency, Maximum Deviation, Deviation Dissymmetry, Audio Sensitivity and Audio Distortion. If your test equipment is well arranged, and includes a Service Monitor and a dedicated Distortion Analyzer (already nulled to your Audio Generator), the entire sequence requires less than one minute from the time a unit is on the bench and hooked up. That's a small investment for a lot of assurance!

For receivers, start by verifying normal reactions as you rotate the squelch control. This gives you fair confidence that the receiver is in normal condition from the output of the mixer, all the way to the loudspeaker. Then, the Standard Tests should be performed in this order: Audio Distortion, 12 dB SINAD Sensitivity, Modulation Acceptance Bandwidth, and Critical & Maximum Squelch Sensitivity. Again, if your test equipment is well arranged and includes a Service Monitor, a SINAD Meter and a dedicated Distortion Analyzer, the entire sequence takes no more than one minute!

Frequency verification is necessary, of course. When you use a Service Monitor (with known RF output frequency), receiver frequency should be set or verified just as soon as the receiver is found operational end-to-end. When a VFO-controlled RF Signal Generator is used, frequency verification can be postponed provided the generator is maintained on the actual receiver center frequency until the Standard Tests are completed.

TROUBLESHOOTING WITH STANDARD TESTS

The transmitter and receiver troubleshooting charts (last pages in this handbook) give you a systematic troubleshooting process which assures you that a transmitter or receiver is in functional condition. When a test is failed, the chart suggests the most logical next step. The discussion in this section fills in some of the gaps within the charts.

Transmitter Troubleshooting

When Transmitter Power Output is failed, you know something is wrong, but you don't know what. Start with the Final Amplifier stage. Verify that it has proper supply voltage and drive. If it does, verify proper tuning or Power Adjust control setting. If proper tuning is found, suspect the output filter(s) or antenna switch. If final amplifier drive is not correct, go through the RF stages, one by one. Make use of all of the built-in metering points which are provided. Use an RF voltmeter or Spectrum Monitor to check stages which are not monitored by the built-in metering facilities.

If power output and drive to the final amplifier are both zero, start your investigation at the oscillator stage. Use an oscilloscope or RF voltmeter to make sure it is running, and then check the following stages, one by one.

If a transmitter fails Transmitter Frequency, adjustment is called for. Refer to page 2 under "Transmitter Frequency" for some of the considerations which must be kept in mind.

If the transmitter won't "trim" to the correct frequency, a defective crystal is the most likely cause. In compensated oscillators, however, also suspect the compensating components (thermistors, voltage-variable capacitors). When voltage on the compensating line can be measured, do so. Since this line is invariably at high impedance, use a high-impedance voltmeter. "Bad" readings on the compensation line may lead you to a defective component other than the crystal. Don't attempt to replace a crystal or compensating component inside a packaged compensated oscillator. These components have been chosen to work together; you don't have the facilities to select and test to be sure that the repaired assembly will operate properly at all temperatures.

When a transmitter passes Maximum Deviation, you know that the entire audio chain is alive and working. If it fails, the trouble can lie anywhere between microphone input and modulator. If Maximum Deviation is too high, it can be adjusted downward with the MODULATION ADJUST control. If too low, you may be able to adjust it upward. If you can't, it indicates a lack of audio gain or a modulation limiter which limits at a level which is too low. Proper readings, with or without adjustment, don't guarantee that everything in the audio chain is proper, but it does give you a starting point.

If Deviation Dissymmetry is passed, you know that modulator distortion is acceptable at full deviation (and is almost certain to be so at lower levels).

If failed, trouble possibilities include the modulator, modulation limiter, and all audio stages. To narrow the possibilities, check for dissymmetry with audio input reduced to get out of modulation limiting (deviation less than ±3 kHz). If dissymmetry stays the same, suspect the modulator (occasionally an audio amplifier); the modulation limiter should not contribute distortion when operated below the threshold of limiting. Dissymmetry in the modulator is usually corrected by tuning the modulator stage. In multi-frequency transmitters with phase modulators, dissymmetry increases as frequency is switched away from that at which the modulator was tuned. Tune the modulator to a center (or compromise) frequency.

Dissymmetry contributed by the modulation limiter can be confirmed by examining the limiters. Bias problems are the usual cause of dissymmetry. In diode limiters, look for improper bias and open diodes. Distortion in audio stages preceding the modulation limiter can show up as dissymmetry, but only in very aggravated cases. This distortion is most likely "picked up" in the Audio Distortion test.

While Maximum Deviation shows up a gross lack of audio gain, Audio Sensitivity verifies that gain is correct and confirms that the modulation limiter does, indeed, limit. Although Maximum Deviation is taken with an audio input which should produce heavy limiting, the mere fact that one can adjust for ±5 kHz doesn't guarantee that the audio *is* in heavy limiting. (Waveform observation when the deviation meter has 'scope display does give you that assurance). When a transmitter passes Audio Sensitivity, you know there is sufficient audio gain to get ±3 kHz deviation (a level normally below limiting) *after* the MOD ADJUST control has been set for ±5 kHz under maximum (normally heavily limited) conditions. So, passing Audio Sensitivity has two implications: (1) Audio gain *is* adequate, and (2) Audio *was* heavily limited when Maximum Deviation was set.

If Audio Sensitivity is failed so that it takes *too many* millivolts of audio to produce ±3 kHz deviation, look for low audio gain, but also suspect a modulation limiter which may not limit. If it takes *too few* millivolts, suspect that audio gain is abnormally high--a possible indicator of regeneration.

Failure to pass Audio Distortion causes one to focus directly on the audio stages; the modulator and modulation limiter have already been evaluated with the Deviation Dissymmetry test.

Stage-by-stage examination of the audio portion of a transmitter is one of our easier tasks. Gain is easily measured with a high-impedance AC voltmeter or a 'scope. Almost any audio oscillator can be used for signal injection. Gross distortion in any stage shows up with casual examination of waveforms with an oscilloscope. Lower-level distortion can be tracked by applying audio to the Distortion Analyzer (through an isolating probe or resistor when necessary to minimize loading).

Receiver Troubleshooting

The Receiver Troubleshooting chart starts out with a "test" which is deceptively simple. It requires no test equipment, but gives you a wealth of information. If a receiver, with no signal applied, squelches and unsquelches normally as the squelch control is rotated, you can assume that about 75 percent of the receiver circuitry is in "apple pie" order!

The fact that you *hear* noise under unsquelched conditions assures you:

- Noise is being generated in the front end, implying that the mixer (and probably the injection chain) is working.
- There is sufficient IF gain to drive the detector.
- The detector is working, converting this amplified RF noise to audio.
- The audio amplifiers (including stages switched by the squelch circuit) are working.

The fact that the receiver will also squelch, so that you *don't hear* noise, gives additional information:

- The switched audio stages will switch "off" under squelched conditions.
- The squelch circuit functions (noise amplifier, noise rectifier, DC amplifiers) are all working.
- IF gain is high enough and detector performance is good enough to properly excite the noise-responsive part of the squelch circuit. It's highly unlikely that any IF gain or detector problems exist.

TROUBLESHOOTING

What you *don't* know at this point, makes a much shorter list, and includes:

- RF gain (that which precedes the mixer) is unknown.
- Condition of the injection chain is unknown. The oscillator may be dead; injection voltage may be low or zero.

The first Standard Test on the chart, Audio Distortion, is taken with a rock-crushing RF signal (1000 uV) and with ±3 kHz deviation. It serves five useful purposes. First, any response at all verifies that the oscillator and injection chain are working, at least to some extent. Even if the pre-mixer gain is low (even "dead"), something should blast through at this RF level. Second, with the receiver working end-to-end, you are able to verify or set frequency. With a synthesized Service Monitor which generates a known on-channel signal, bring the receiver to the generator frequency. With a VFO-type RF Signal Generator, you may prefer to move the generator to the receiver frequency and defer final frequency setting. Third, the Audio Distortion test verifies that the receiver will develop full rated audio output power. Fourth, you measure Audio Distortion. Finally, the Distortion Analyzer (DA) is set up so that you can move through the remaining tests in the series with minimum effort.

If you get no response at all, look for trouble in the injection chain--most probably a dead oscillator. The metering provisions in most receivers help to confirm this condition. If the injection chain seems dead, start your investigation at the oscillator. Observation with a 'scope will confirm that the oscillator is running, so you can move your troubleshooting attention through the various multipliers and filters between oscillator and mixer.

Unless the receiver output appears completely free of noise (as befits a 1000 uV input signal), there's no point in trying to measure distortion--you're doomed to failure. There's a gross sensitivity problem. Improve sensitivity until receiver output is noise-free, and then proceed with the distortion measurement.

If the receiver fails to develop rated audio power output and the detector output is normal (inferred by proper squelch operation and can be confirmed by measurement), there's a loss of gain somewhere between detector and speaker output. You're faced with a simple signal tracing job. Measurements can be made with a high-impedance AC voltmeter or an oscilloscope.

If distortion exceeds specification, the detector and audio stages are the proper places to look. Measurements can be made stage-by-stage with the Distortion Analyzer. 'Scope observations of the waveforms are easier and will usually pinpoint the trouble areas. Gross irregularities in the IF bandpass may show up as excessive distortion, but this is quite unlikely. Cross-over distortion, which causes complaints from users but seldom degrades measured distortion, shows up best when audio power output is reduced to 10 percent of rated, or less.

With test equipment set up for measuring Audio Distortion, a few changes in test equipment control settings allow measurement of 12 dB SINAD Sensitivity. If receiver performance is up to specification, RF Generator output will be low--a fraction of a microvolt.

Passing 12 dB SINAD Sensitivity confirms that a lot of things are *right* in the receiver:

- Gain and injection are adequate
- Bandwidth is sufficiently wide to pass marginal signals with ±3 kHz deviation
- Distortion (already measured) is within reason. It's impossible to achieve 12 dB SINAD if distortion exceeds 25 percent.

Failure to pass 12 dB SINAD Sensitivity implies "too much noise" since low recovery from the detector and audio distortion are already ruled out by the Audio Distortion test. There are two likely noise sources: Noise from inadequate receiver quieting because of lack of gain (RF, IF or injection), and Noise due to selectivity problems in the IF strip (bandwidth too narrow; passband irregular). Gain is verified by running 20 dB Quieting. If a receiver passes 20 dB Quieting, it has adequate gain; selectivity-related matters must be the problem. Selectivity problems can be confirmed by examining the shape of the selectivity curve, using a sweep alignment setup. Once found, some selectivity problems are cured by alignment. Others require replacement of a filter crystal or a crystal filter assembly.

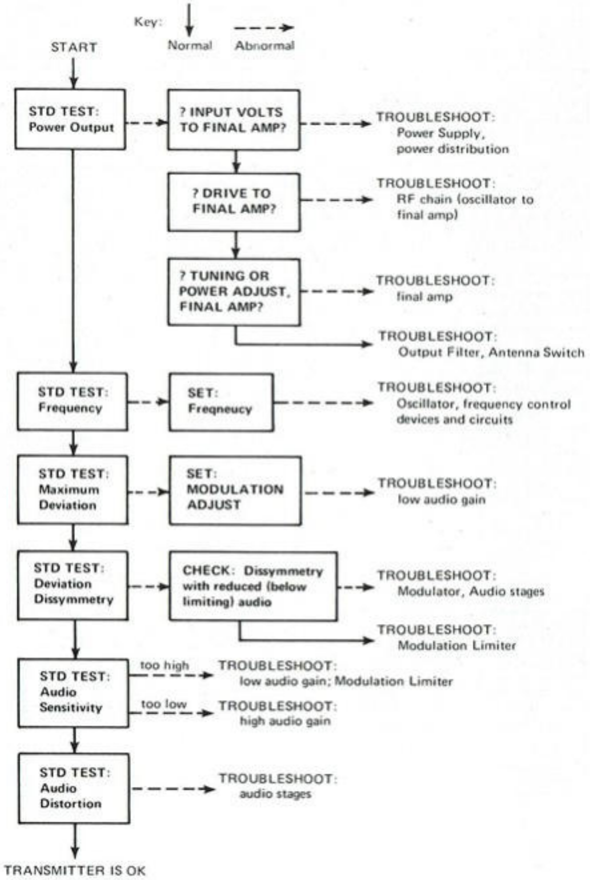
Modulation Acceptance Bandwidth continues the evaluation of the receiver's selectivity characteristic. By passing 12 dB SINAD Sensitivity, the receiver demonstrates it can accept a signal, modulated at 1000 Hz with ±3 kHz deviation, at an RF level slightly above threshold. Selectivity is not too narrow at that level. Modulation Acceptance Bandwidth measures the deviation (from a 1000 Hz tone) which can be accepted with signal 6 dB higher, a level which should permit good communication. The specification tells us what this deviation should be; the measurement tells us what it is. Typical specifications fall within the range ±6 kHz to ±9 kHz. If the receiver passes Modulation Acceptance Bandwidth, we know that selectivity is neither too narrow nor too wide at this signal level. Failure in either direction is bad. If too wide, unnecessary noise is presented to the detector, detracting from receiver quieting. If too narrow, properly modulated signals will exceed the bandwidth, generating noise pulses which detract from communication and may tend to squelch the receiver on each modulation peak. Except for rare component failures, most failures to meet Modulation Acceptance Bandwidth are caused by mistuning in the IF strip. Since it's difficult (almost impossible) to tune the crystal filters in a modern receiver too wide, most problems will show up as "bandwidth too narrow."

Critical Squelch Sensitivity and Maximum Squelch Sensitivity check the performance of the squelch circuits in a receiver known to be in good shape otherwise. If all other Standard Receiver Tests are passed, failure to pass these tests points very clearly to the squelch circuits, themselves.

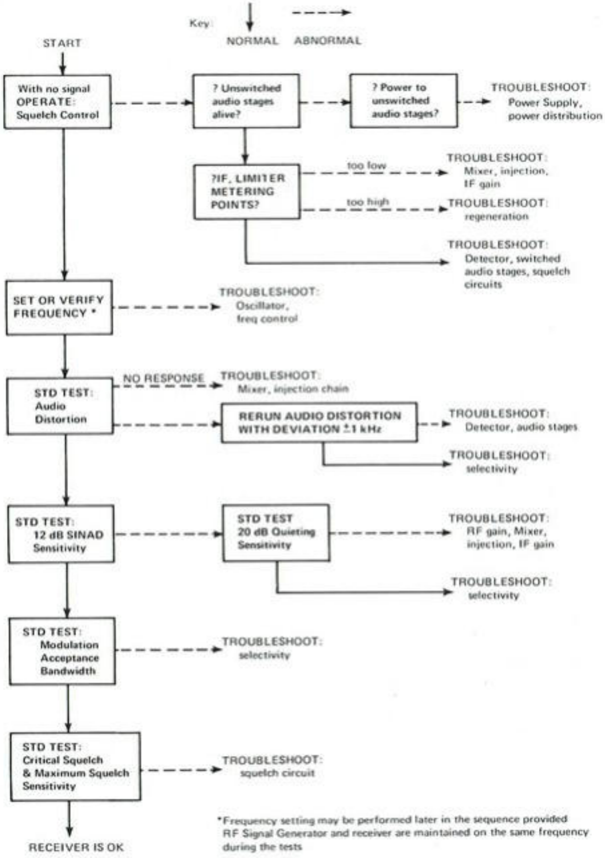
Since the squelch circuits work by processing noise delivered by the detector under no-signal conditions, the frequency (normally 6-9 kHz) and amplitude of this noise must be confirmed. If a receiver passes 12 dB SINAD Sensitivity and Modulation Acceptance Bandwidth, you can expect this noise to be "right" when it leaves the detector. You should then signal trace the noise through the filters (which separate it from the audio) and through the noise amplifiers. Operation of the noise rectifier must be checked to make sure that noise is converted to the proper DC voltage. If OK to this point, you must then examine the DC amplifiers and switches which control the audio path. Typically, these circuits are either on or off--nothing in between. They respond to the techniques used to troubleshoot digital circuits. Gates can be switched on and off, to sectionalize trouble, with a well placed clip lead.

When a receiver *won't unsquelch,* but otherwise appears normal, look for trouble in the squelch circuits. If a receiver *won't squelch,* be sure that the receiver is devoid of gain or selectivity difficulties before attacking the squelch circuits.

TRANSMITTER TROUBLESHOOTING



RECEIVER TROUBLESHOOTING



*Frequency setting may be performed later in the sequence provided RF Signal Generator and receiver are maintained on the same frequency during the tests

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