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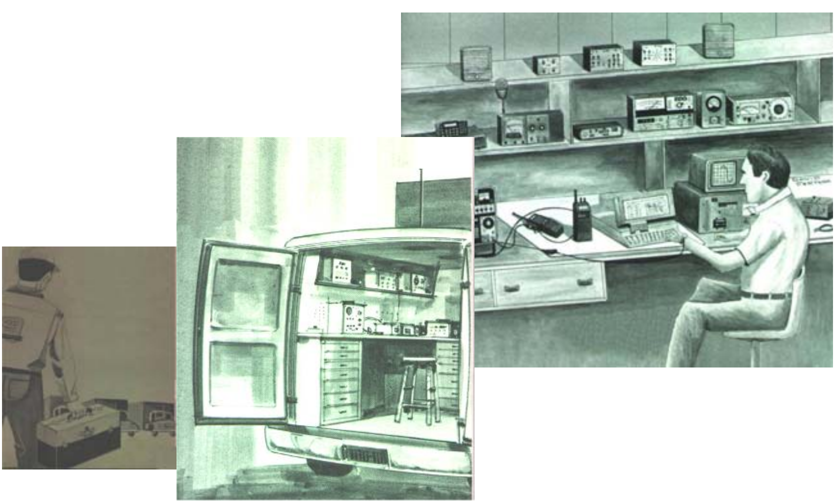
TEST AND TROUBLESHOOTING HANDBOOK



TEST AND TROUBLESHOOTING HANDBOOK

Table of Contents

INTRODUCTION TO STANDARD TESTS

This Test & Troubleshooting Handbook describes standard tests for two-way radio equipment. These tests are performed on any unit. The standard tests are recognized by the two-way radio industry. Compare the results of these tests with normal characteristics shown in the published specifications for any equipment. If a unit does not meet specifications, the standard tests provide a series of clues, which allow you to focus your troubleshooting efforts.

The Electronic Industries Association (EIA) publishes the standards of these tests. EIA Standards are supported by most major manufacturers of two-way radio equipment in the United States and worldwide.

The standards are available for purchase and are listed in the "Catalog of EIA ELECTRONIC INDUSTRIES ALLIANCE STANDARDS and ENGINEERING PUBLICATIONS. Contact:

Global Engineering Documents
15 Inverness Way East
Englewood, CO 80112-5704 or call
U.S.A. and Canada 1-800-854-7179, International (303) 397-7956

Visit the TIA web site at: http://www.tiaonline.org/.

Many of the standard tests described by EIA focus on equipment design. This handbook highlights the minimum standard tests for the two-way radio service industry to ensure that a radio will communicate. These tests can be executed with the test equipment and skills found in any up-to-date two-way radio service facility. This booklet describes equipment characteristic evaluation and the systematic approach to troubleshooting. Most of the standard tests are performed without removing the cover of the radio. If you can reach the connections, you need not remove the cover. Since standard tests are the same for every radio, you don't need detailed technical information describing the type of unit on the bench until tests confirm that internal repair is required.

This booklet describes the methods to conduct and interpret results from the standard tests. Each test specifies the type of test equipment required.

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 operating properly. Inability to communicate reflects trouble; however, this does not indicate trouble in the transmitter.

Transmitter Power Output

The Transmitter Power Output is obtained by direct measurement of RF voltage across a load of 50-ohm impedance. The result of the Transmitter Power Output measurement is compared with 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 means the transmitter is not operating correctly.

Power output *higher* than specified may impact upon current drain and the possibility of heat-related premature failure. If the test failed, refer to the maintenance manual.

Transmitter Frequency

The actual developed frequency is compared against an acceptable internal standard in the frequency measuring equipment. The results can be expressed in a number of ways:

- Actual frequency
- Difference (from assigned frequency)
- Percentage difference (from assigned frequency)
- Parts Per Million (ppm) difference (from assigned frequency)

The result is a real number, related to time. A difference between actual and assigned frequency can result from two independent causes:

- Long-term drift (can be corrected by adjustment).
- Environmental effects (mostly temperature related).

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 regulatory-approved tolerance or other system specification, frequency correction is essential. Less acute errors may justify or demand correction. Remember, correction to assigned frequency at one temperature may cause out-of-tolerance operation at another temperature.

The transmitter specification, RF frequency measuring equipment, and the tolerances established by the technician or organization all establish the overall tolerance of the transmitter frequency error. As a rule, it is appropriate to establish a requirement for field tolerances (5 times better than specifications) when making normal or preventative maintenance measurements. If the measurement is out of tolerance, then a lab grade tolerance (10 times better than specifications) is assumed in the adjustment or alignment of RF frequencies.

The following examples of tolerances for Percent Error and Parts Per Million show some expected values.

- Percent (%) Error allowable tolerance
  - Assuming ±0.0005% tolerance and 5 times better measurement for field accuracy.
  - Assigned frequency MHz • (.0005% / 100% / 5) = ±Tolerance
  - Example: 158.970 MHz • .000001 = ±158 Hz
- Parts Per Million (ppm) allowable tolerance
  - Assuming ±2-ppm tolerance and 5 times better measurement for field accuracy.
  - Assigned frequency MHz • (.000002 / 5) = ±Tolerance
  - Example: 469.550 MHz • .0000004 = ±187 Hz

There are basic requirements that should always be met before attempting to adjust RF oscillators. The transmitter as well as the frequency measurement equipment should be powered up and operational for one half hour before attempting any adjustments or determining if adjustment is needed. Always consult the particular maintenance manuals for additional requirements.

- For oven-controlled oscillators:
  1. Warm the oven to the proper temperature.
  2. Adjust the oscillator to the assigned frequency.
  3. If the adjustment range is insufficient, replace the crystal.
- For non-compensated low-stability oscillators:
  1. Adjust the oscillator to the assigned frequency.
  2. If the adjustment range is insufficient, replace the crystal.

- For compensated oscillators:
  1. Refer to the maintenance manual to separate long-term drift from environmental effects.
  2. Adjust to assigned frequency only when the oscillator is within the specified narrow temperature range.
  3. Correct to the offset specified for the actual oscillator temperature.
  4. If the proper frequency cannot be obtained by adjustment, some component (probably the crystal) is defective.
  5. Do not replace a crystal in packaged oscillator circuit. These modules contain compensating components that have been matched to a specific crystal. Replace the entire assembly.

Transmitter Audio Tests

Four transmitter audio tests verify four interrelated circuits are functioning properly. These circuits are:

- Audio gain - raises microphone input to the level required to drive the modulation limiter.
- Modulation limiter - holds maximum deviation to a fixed level.
- Modulation adjustment - sets this fixed level to the desired value.
- Modulator - accomplishes frequency/phase modulation of the RF carrier.

These four different transmitter audio test results are obtained through a series of sequential manipulations with one test setup. The following transmitter audio characteristics are verified during the tests:

- Maximum deviation is not too high. Regulatory imposed limits are not exceeded. Excess energy is not placed into adjacent channels during modulation peaks. Receivers do not receive a signal that 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 and distortion is minimized during modulation peaks.
- Audio gain is sufficient. A user, properly addressing the microphone, will obtain high average deviation, which is desired for overall audio signal-to-noise ratio.
- Transmitted audio distortion is within designated limits. Audio gain stages are linear.

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 result is deviation in kilohertz, read directly from the deviation monitor. For the other, the deviation monitor serves as a standard receiver that drives the Distortion Analyzer from which the test result is obtained. A transmitter that passes all four audio performance tests is considered "good."

Transmitter Maximum Deviation

While the FCC* no longer requires a legal system deviation, it does regulate bandwidth limits imposed by emission masks. TIA/EIA and the land mobile radio industry still recognize the system deviation requirements to maintain interoperability of radios and as an easy means of measurement to maintain bandwidth limits. For those reasons, it is important to measure and maintain deviation within established limits.

The Transmitter Maximum Deviation test verifies that the system deviation 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 0.1-1.0 VRMS (see maintenance manual). This level, which is much higher than normal microphone input, guarantees that a properly working transmitter will be driven into heavy limiting. The highest resulting deviation is the test result.

If necessary, the transmitter Modulation Adjustment is set for a specified Maximum Deviation that will guarantee total deviation not to exceed the system deviation. System deviation is regulated or established to ensure that adjacent channel power is not exceeded. System deviation is not normally exceeded for any voice or signaling frequency. Adjustments and testing, using the 1000 Hz test tone, necessitates a reduction of Maximum Deviation for the test tone to ensure that system deviation is not exceeded for other frequencies and signaling schemes. The recommended Maximum Deviation setting is typically 90% of system deviation with a modulated test tone of 1000 Hz. On channels where Channel Guard (CG)# is used, the Maximum Deviation is further reduced to allow this sub-audible signal to be transmitted within the deviation limits. The Modulation Table depicts the values used for different channel bandwidths.

If the maximum deviation cannot be set to specified System Deviation, suspect a drastic loss of audio gain.

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* Federal Communications Commission – U.S. Regulatory Authority

CG is an abbreviation for Channel Guard, which is Tyco Electronics' brand name for CTCSS or Continuous Tone Coded Squelch System. Throughout this handbook, CG will be used synonymous with DCG (Digital Channel Guard), CTCSS and CDCSS.

Modulation Table

	Wideband (20/25/30 kHz)		NPSPAC[1]		Narrowband (12.5 kHz)	
System Deviation (Regulated)	<5.00[2]		<4.00		<2.50	
Transmit Limiter (90%)						
Channel with out CG - Tone	4.50		3.60		2.25	
Channel with CG - Tone	3.75		3.00		1.75	
Channel Guard (15%)	0.75		0.60		0.50	
Standard Deviation (60%)						
Channel with out CG - Tone	3.00		2.40		1.50	
Channel with CG - Tone	3.0	2.25	2.40	1.80	1.50	1.00
Channel Guard	0.75	0.75	0.60	0.60	0.50	0.50
Composite – Sum of tone and CG	3.75	3.00	3.00	2.40	2.00	1.50

[1]NPSPAC is in the 800 MHz band. 821 to 824 and 866 to 869 MHz United States National Public Safety

[2]All values are ± peak deviation

Some technicians use the shaded area parameters in their interpretations of the EIA specifications for standard test modulation. One should follow the manufacturer's parameters.

Transmitter Deviation Dissymmetry

Not a separate TIA/EIA standard, but an "Industry Standard," Transmitter Deviation Dissymmetry should be observed in the process of determining Transmitter Maximum Deviation. The high deviation peak (positive or negative) is the maximum deviation. The difference between absolute value of the plus and minus peaks, expressed in kHz or 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 be caused by the modulator, the modulation limiters or, occasionally, the audio stages. Difficulties in phase modulators 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 modulation amplifier.

Transmitter Audio Sensitivity

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 System Deviation is indicated. For 5 kHz 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 (rms) millivolts for mobiles and 4 to 14 millivolts for personal radios. 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 that is too low indicates a lack of audio gain, and encourages low average deviation in the system. Sensitivity that is too high brings complaints of “excessive background noise and distortion” from overdriving limiters. Failure to pass Transmitter Audio Sensitivity leads toward troubleshooting in the audio stages.

Transmitter Audio Distortion

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 2-5 percent are typical. Since the test is run with a 1000 Hz input, well below the level at which limiting occurs, distortion produced in the modulation limiter is not normally 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 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 a noise and distortion measurement that is performed with a Distortion Analyzer (DA) or a dedicated SINAD meter. You will 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 but it is not usually specified for modern receivers.

Receiver Frequency

Receiver Frequency is not universally considered a standard test, but is mentioned because of its importance to system operation. Remember, that a receiver cannot pass the full sequence of tests unless it comes very close to meeting its frequency specification. For this reason, you will find many test procedures do not call specifically for making this test. As a practical matter, it is usually easier to measure the frequency rather than waiting for another test to fail and indirectly show you the problem.

Receiver Audio Distortion

Receiver Audio Distortion is taken with a very high (-47 dBm or 1000 µV) input signal. It doesn't verify gain - an "almost dead' receiver can pass this level 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 will not cloud the 12 dB SINAD Sensitivity test results. Receiver Audio Distortion is expressed in percent; typical specifications are in the range 2-5 percent.

Receiver 12 dB SINAD Sensitivity

Receiver 12 dB SINAD Sensitivity, expressed in microvolts, is a multi-characteristic test. Meeting the specification verifies RF and IF gain, mixer and injection chain performance, and confirms that selectivity is not too narrow. The 12 dB SINAD result 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. The 12 dB SINAD test is simply an indicator, valuable for testing because it is as close to the threshold of 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 an above normal deviation (which requires receiver bandwidth that 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 fractions of a microvolt but may be in dBm. This test is done with standard modulation or 60 percent of the system deviation. (See the Modulation Table in the Transmitter Maximum Deviation section of this handbook.)

Receiver Signal Displacement Bandwidth

The Signal Displacement Bandwidth test verifies that the channel bandwidth of a receiver is greater than a specified amount. The test is done by increasing the RF input to the receiver by 6 dB or double the SINAD reference sensitivity. Then the RF frequency modulated with 60% system deviation is displaced or offset from the center frequency until the SINAD measurement returns to 12 SINAD. This is done in both up in frequency and down in frequency directions. The smallest displacement from the carrier is the Signal Displacement Bandwidth. The minimum signal displacement bandwidth shall not be less than 40% of the rated system deviation.

The Signal Displacement Bandwidth verifies that the IF is wide enough, but does not verify that the IF meets adjacent channel selectivity specifications. One can assume that the IF is sufficiently narrow, if an upper limit is placed on the test. Such as stating that, "The minimum signal displacement bandwidth shall not be less than 40% of the rated system deviation or greater than 60% of rated system deviation."

The Signal Displacement Bandwidth test replaced the Receiver Modulation Acceptance Bandwidth test. The Receiver Modulation Acceptance Bandwidth test is done by varying the amount of deviation rather than offsetting the carrier. Both tests provide similar information. Since Receiver Modulation Acceptance Bandwidth has been removed from the TIA standards, it will not be covered in this handbook.

Receiver Squelch Operation

Receiver squelch operation is often done by applying an on channel signal to a receiver and increasing the RF level until the receiver unsquelches (opens), then decreasing the RF level until the receiver returns to the squelched condition (closes).

The applied signal should be modulated at standard deviation. The measurement of proper squelch should be a unit of SINAD since the detection of noise is an audio function and not a function of RF gain. However, some receivers will specify squelch operation as units of RF level while other receivers are specified in SINAD. One should verify that the receiver opens and closes within specifications and there is a reasonable amount of hysteresis between the two points.

Receivers with user accessible squelch controls should be tested for the minimum and maximum adjustments that can be set by the user.

Receiver 20 dB Quieting Sensitivity

The Receiver 20 dB Quieting Sensitivity test confirms that gain is normal and little else. It is useful to narrow the search for possible causes when a receiver fails to meet its 12 dB SINAD Sensitivity specification. An RF signal without modulation is easier to view on a spectrum analyzer during troubleshooting than a modulated signal.

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

- Modulation (Deviation) Monitor
- Frequency Measuring Equipment

Meters

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

Other

- Audio Load Resister
- Couplers
- Dummy Microphone Circuit (when required)
- Bench Test Accessories (as required)
- Power Supply
- Assorted Cables and Adapters

In many cases, you will need additional test equipment to carry out detailed troubleshooting of radios that has failed one or more of the standard tests.

The functions of the Audio and RF Signal Generators, Deviation Monitor and Frequency Measuring Equipment, and sometimes other functions such as Distortion and SINAD measurement can be combined into a "Communications Service Monitor" or "RF Communications Test Set." The function of the Audio Voltmeter is usually provided by a Distortion Analyzer (DA) in cases where a separate Distortion Analyzer is utilized.

Names of test equipment are not defined as absolutes. What one calls an instrument can vary in conversation according to the test or application one is addressing. Examples: a modulation monitor may be called a deviation meter or monitor, or an audio function generator may be called an audio oscillator. Effort has been made to maintain some sort of uniformity in this handbook, but there are instances where this is not the case.

Audio Generator

This instrument furnishes audio input for standard transmitter tests (deviation, dissymmetry, audio sensitivity and audio distortion). Since all of these tests are made at 1000 Hz, a fixed frequency unit will suffice but you will probably want a variable frequency generator in order to facilitate other tests. Output may be single-ended or balanced, but must be adjustable over the range 0.001 VRMS to 1.0 VRMS into 600 ohms. Harmonic distortion must not exceed 1 %. Lower distortion is preferred.

RF Signal Generator

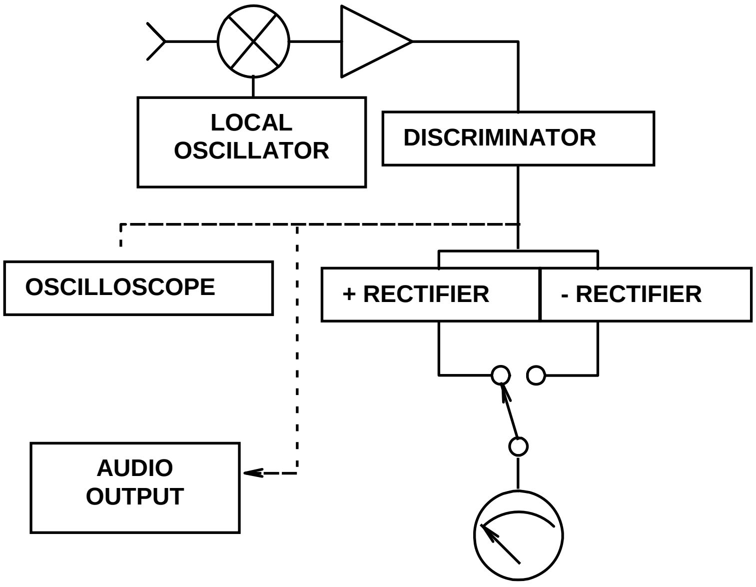
The RF Signal Generator is used for all standard receiver tests. Functionally, it is a specialized FM radio transmitter in which, frequency, modulation and power output are adjustable and accurately calibrated. It should generate any frequency used in two-way radio systems. Output, at 50 ohms, must be variable form 0.1 microvolts to 1000 microvolts and preferably up to .1 volt or more. Symmetrical modulation at 1000 Hz is essential; distortion must be less than 1 percent. External modulation is mandatory, especially when a second internal audio source capable of generating the Channel Guard tones is not provided. Peak deviation must be adjustable from zero to more than ±20 kHz.

Many older RF Signal Generators required an external attenuation pad (usually 6 dB or 20 dB) to stabilize output and improve the output calibration. These pads also provided a degree of protection against “burnout" (when a transmitter is inadvertently keyed into the generator). These older RF Signal Generators often required external RF frequency metering. Modern Digital Phase-Lock Looped synthesized generators are very stable and accurate in regards to their frequency and level. Protection against inadvertent keying a high power transmitter into an unprotect port should be maintained.

Modulation (Deviation) Monitor

In function, this instrument functions as a specialized FM radio receiver, which can be set to the frequency of a transmitter 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 that is calibrated to indicate peak modulation deviation in kilohertz. The output indicator may be an analog or digital meter, in which case a polarity-reversing switch is required. Some instruments have an oscilloscope as a display. The oscilloscope could be the primary or secondary display. In any case, the oscilloscope provides a display of peak deviation values (both directions) simultaneously, along with indication of gross distortion.

FM Deviation Meter



The Modulation Monitor is the only instrument needed for standard transmitter tests that require measurement of deviation. These include Maximum Deviation, Dissymmetry and Audio Sensitivity. An external Distortion Analyzer (DA) can be 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. Some choices of filtering include 75 µsec de-emphasis or 750 µsec de-emphasis. The 750 µsec de-emphasis is the preferred filter. If not provided internally, it may be added in the interconnection. A simple RC low-pass filter (series 1.6K ohms, shunt 0.047 pF) will do the job.

Most of the modern communications tests sets provide many choices of filters and their location in the measurement circuits. Choices include IF and audio filters. You should become very familiar with your equipment and these choices to prevent erroneous test results. Here are some filter response choices:

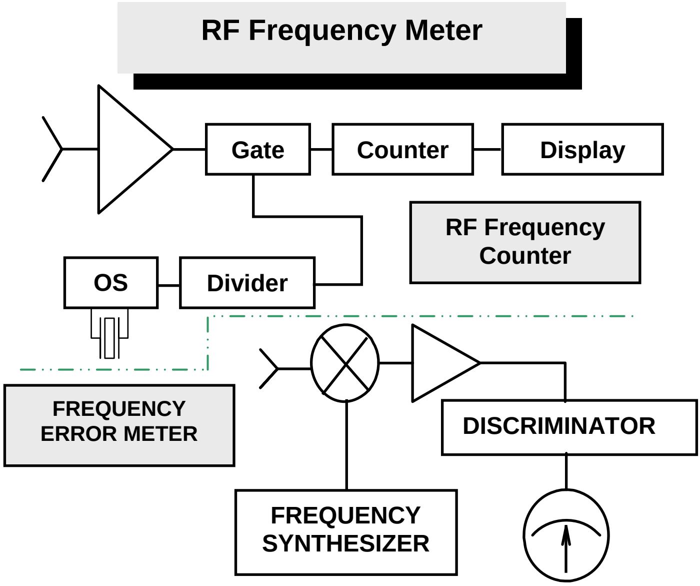
- The use of 15 kHz IF filter should be restricted to testing of tone modulation of 1 kHz or below and not over 5 kHz of deviation. 25 to 50 kHz IF filtering is preferred for most testing including complex waveforms like voice and data. If the mid range IF filters are not available, it is not unreasonable to use 100 or 200 kHz, but the wider the filtering – the more likely that noise will interfere with the deviation measurements. (No true requirement – other than the measurement accuracy of the instrument must be met.)

- Modulation Meter & Scope – Audio filter - 15 kHz Low-Pass Filter (no high pass filter selected)
- Output to Distortion Analyzer – 750 µsec de-emphasis

Full-scale indication of the Modulation Monitor should be ±5 kHz 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% of full scale 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 the transmitter or the receiver can cause severe degradation of system performance. When frequency offset between transmitter and receiver exceeds the receiver's capability, increased noise and distortion are inevitable.

Useful measurements require accuracy that is much better (5 times to 10 times better) than the permissible tolerance in the quantity being measured. Modern transmitters and receivers range from ±0.0005 percent to less than ±0.0001 percent in frequency stability. This is equivalent to 5 parts-per-million (ppm) to less than 1 ppm. Some of the later systems require accuracies of .05 ppm or better. This can mean that specialized frequency control devices that lock the system to external high stability sources may be included in the system.

For a 150 MHz signal and the usual 5-ppm tolerance, you should be able to measure frequency with an error no greater than 150 Hz. When 450 MHz signals are subject to a 5-ppm tolerance, error should not exceed 450 Hz. When a 2-ppm tolerance applies at 450 MHz, the maximum error should be no more than 90-180 Hz. At 800 MHz, 2.5 ppm tolerance and accuracy of frequency meter of 5 time better would have an error of up to 435 Hz at 870 MHz. It would be wise to require lab grade accuracies of 10 times better for the higher frequencies such as 800 and 900 MHz.

The factors, which influence measurement accuracy, are in two categories: time base precision and resolution measurement. Time base precision applies to the internal frequency standard within the instrument. It is subject to initial setting errors like the oscillator in a transmitter or receiver, long-term drift (from component aging), and short-term drift from environmental factors (temperature, humidity, supply voltage). Resolution refers to number of digits which the indicator or display can be read. Adequate time-base precision 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 necessary! Resolution must be good enough to be insignificant when compared to the limitations of the time base.

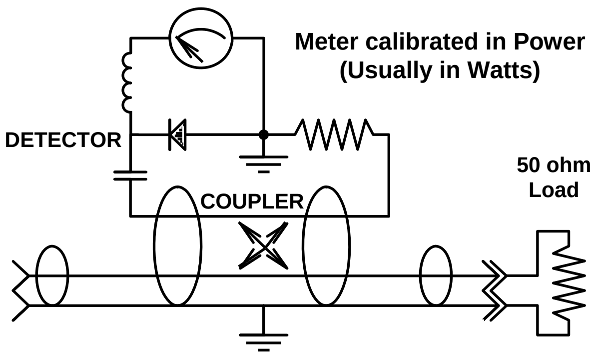
Frequency Measuring Equipment should cover all of the frequencies used in two-way radio systems. Instrument sensitivity must be sufficient to allow reliable operation in the test setups that are used. The RF counter is often used to set or verify RF signal generator frequency (for receiver frequency setting or measurement). The sensitivity must be adequate for the signal generator output that is available.

RF Wattmeter

The RF wattmeter serves a dual purpose: 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.

RF Power Meter



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 form 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 that 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 the 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.

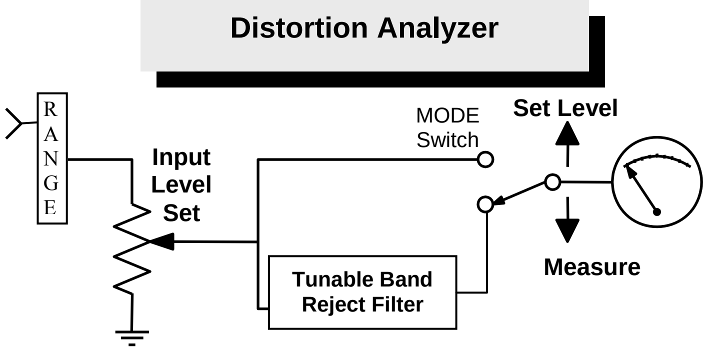
Audio Voltmeter

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 form 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.

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 accompanying figure shows a simplified block diagram of a Distortion Analyzer.



The key elements in the DA are an AC (audio) voltmeter with range switching, a tunable notch filter, and mode selection. While many modern Distortion Analyzers may not have these controls physically present, they exist in some form within the instrument. The elements will be used to explain the operation.

The range selection positions of the AC voltmeter are not shown. Input impedance of the instrument is high to minimize loading of the source. The meter face includes linear scales from 0-3 and 0-10 and a logarithmic 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 displays the dBm value of the applied AC volts or to indicate dB change from a reference. 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. Each position of the range selector represents a 10 dB change.

The notch or band reject filter is 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 of 20-20,000 Hz. For the two-way radio field where standard tests are run at 1000Hz only, specialized units may be fixed at 1000 Hz or adjustable over a narrow range centered at 1000 Hz.

When any voltage range is selected, the "Input Level Set" control and notch filter are bypassed; the unit serves as a conventional voltmeter. When a distortion range is selected, the metering circuits are fed through the "Input Level Set" control and notch filter. The "Mode Switch" placed in the "Set Level" position bypasses the filter. The input level is then set to provide a full-scale reading that represents a 100% distortion measurement. Placing the "Mode Switch" to the "Measure" position returns the notch filter to the circuit and only the residual voltage is measured. The residual voltages contain the harmonics, noise or any other signal other than the one kHz tone that is filtered out.

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, then indication is S + D. If Signal (S) is removed by filtering, the indication is N + D.

When measuring distortion, 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" 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" 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:

$$\text{Distortion \%} = \left(\frac{D}{S+D}\right) X\ 100\% = \left(\frac{\text{Voltage (Filter “in”)}}{\text{Voltage (Filter “out”)}}\right) X\ 100\%$$

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 the figure. Translation to a specific DA is a simple task.

1. Apply audio tone to be measured to the input of the DA.
2. Switch the DA MODE switch to “Set Level” and the RANGE switch to 100% (distortion).
3. Adjust INPUT ADJ to indicate 100 percent.
4. Switch DA to “Measure.” Adjust the notch filter for maximum rejection (minimum meter indication) if it is adjustable. Switch to lower distortion ranges to maintain the indication within the upper scale of the meter as the null is approached.
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 the input voltage is too low to achieve a 100 percent indication in Step 2, use the highest RANGE switch distortion position that 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

Distortion tests are done on both transmitter recovered audio and receiver audio tones. However, SINAD is a receiver test only.

SINAD is an acronym for SIgnal, Noise And Distortion, all of which are measured with a distortion analyzer. Rather than express distortion in the usual percent value, if it is expressed as a ratio in dB, then the unit is dB SINAD. Noise is of importance in the measurement, so N is inserted back into the formula. The expression for SINAD would be:

$$\text{dB SINAD} = 20\ \text{Log}\left(\frac{N+D}{S+N+D}\right) = 20\ \text{Log}\left(\frac{\text{Voltage (Filter “in”)}}{\text{Voltage (Filter “out”)}}\right)$$

Solving for a ratio of 1 to 4, or 25% distortion, results in a value of –12 dB SINAD. The negative sign is ignored or the formula is inverted to make the sign positive.

The analog meter scales used in many Distortion Analyzers lend themselves well for 12 dB SINAD measurements because the scales show a range of –10 to +2 dB or a range of 12 dB. If the reference for the distortion measurement is set to the +2 dB position (very close to 100%), then a reading of 12 dB can be observed without changing the range selector. SINAD condition is indicated when the readings on the DA are as follows:

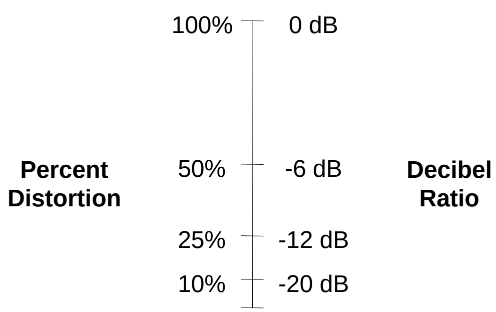
- Indication, filter "out": +2 dB
- Indication, filter "in": -10 dB

There are two methods of measuring 12 SINAD practiced by two-way radio technicians. One is to apply the specified RF level and observe that the DA shows greater than a 12 dB difference from the set level value for 100% distortion. The other method is to apply only enough RF level to cause the DA to show a 12 dB difference. Either method works, but the second is preferred, because the value of RF level is needed for the next test – Signal Displacement Bandwidth.

The procedure for achieving 12 dB SINAD with a Distortion Analyzer follows:

1. Measure receiver distortion. This configures the DA, including tuning of the filter.
2. Switch the DA MODE switch to "Set Level" and adjust INPUT ADJ to indicate +2 dB.
3. Switch DA to "Measure." The meter drops rapidly downward indicating a quite noise free signal.
4. Decrease the RF Level to the receiver under test while observing the DA meter. As the noise in the receiver increases, the meter will deflect less or rise back toward the reference level. When the meter reads –10 dB (12 dB drop from the reference) stop decreasing the RF level.
5. The applied RF level is the 12 dB SINAD Sensitivity Level.

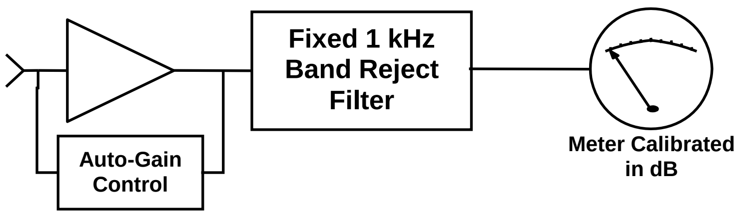
Decibel/Percentage Relationship in Distortion Measurements



SINAD Meter

A SINAD Meter is a specialized distortion analyzer created for measurement of SINAD. The mechanical operations of setting levels and tuning the filter have been eliminated.

SINAD Meter



These instruments use an auto-gain control circuit to perform the function of INPUT ADJ. Operation is adjustment-free over a wide input voltage range. The Notch Filter is fixed at 1000Hz. The source for the 1000 Hz test tone must be within a few hertz of the center of the filter.

If the input to the SINAD meter is greater than specifications for the instrument, the possibility of distortion produced in the instrument exists. Care should be taken not to overdrive the input. Standard receiver tests require that receiver output power be maintained at a specific level when SINAD indications are taken. In practice, if the receiver audio circuits have passed audio distortion, then the level of the receiver audio output can be reduced to meet the requirements of the SINAD meter or one must construct an attenuator to limit the level to the SINAD meter.

Input impedance should not be low so that it affects any circuit, if the instrument is used to probe test points. An input impedance of fifty kilo-ohms or greater is required.

DC/AC Volt/Amp Meter(s)

All standard tests require that equipment under test be supplied with the proper "Standard Test Voltage." Appropriate DC or AC voltmeters are required to set this voltage and to verify that it is maintained during the tests. The required DC metering of voltage and current to the final RF amplifier has been discontinued for many years, but monitoring the voltages and currents are essential for quick troubleshooting.

Some metering capability may be provided by specialized metering test sets recommended for the specific equipment. When essential metering is not provided otherwise, external meters are needed.

Audio Load Resistor

Standard Receiver tests are not performed with a speaker. Instead, they are performed with the receiver terminated by a resistor with its value equal to the specified speaker impedance. Receivers that 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 the rated receiver audio power for extended periods without damage or impedance change.

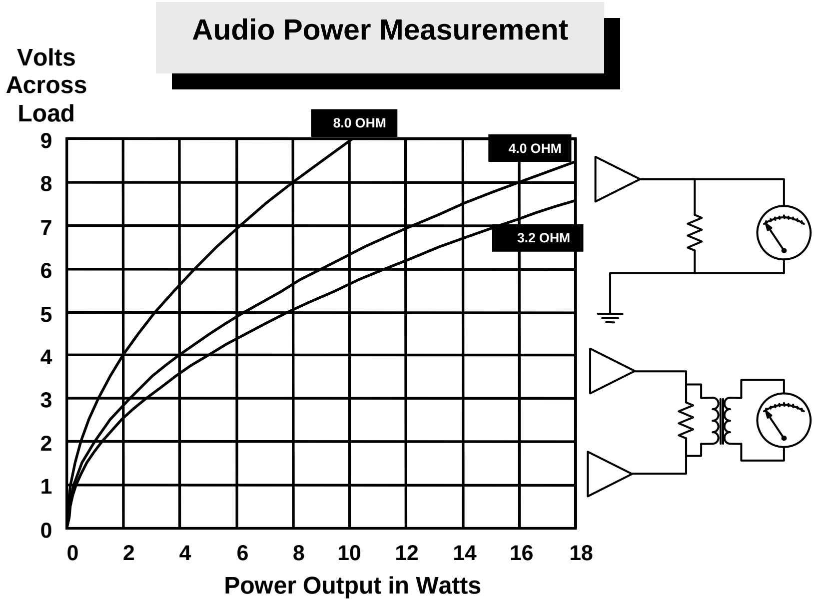
With a load resistor substituted for the speaker, it becomes impossible to listen to the receiver output. This may make troubleshooting inconvenient. Monitoring may be obtained by bridging the Audio Load Resistor with a higher impedance speaker (at least ten times the load resistance). Alternately, a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

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:

$$E = \sqrt{PR}, \text{ where:}$$

E = RMS voltage
P = Power in Watts, and
R = Load resistance in ohms

Voltages across common values of Audio Load Resistors that correspond to a range of power outputs are graphed in the accompanying figure. The graph converts power dissipated in the load to RMS voltage across a load for three common impedances.



Be sure to use a one-to-one isolating transformer between the load and the meters when measuring balanced output circuits - not referenced to ground.

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. However, some transmitter energy must be directed to the Frequency Measuring Equipment and the Deviation Monitor. Direct connection between a transmitter and the test equipment is certainly out of the question and must be avoided. Remember that a transmitter provides an output measured in watts and that sensitive test equipment will be badly damaged when input power approaches a few milliwatts. Loose coupling between the 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 drive 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 approaches to measurements:

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 while proper transmitter termination is maintained. Output at a third "port" is normally attenuated at least 20 dB. Instruments are fed from this port through additional fixed or variable attenuators.

3. Capacitive Couplers used in line between transmitter and RF Wattmeter. Energy is coupled from the "through" path to a "pick-off" port through a small capacitor. This capacitor provides attenuation (to protect the instruments) and isolation (to maintain proper transmitter termination). Unfortunately, loss varies with frequency. Capacitive couplers often include a mechanical adjustment that allows the user to control loss by changing capacity.

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

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.

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 could invalidate any 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 to those specified in the equipment maintenance manual.

Power Supply

The power supply used to perform standard tests must be adjustable between plus and minus 20% of the Standard Test Voltage specified for the equipment and the voltage must be maintain while delivering the required current. The ability to adjust the voltage over the range allows the power supply to more closely simulate the actual voltages incurred in operation and aid in troubleshooting. 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 re-settable 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, the equipment chassis is connected to the grounded battery terminal with 7 feet of #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.

Standard Test Voltages

Nominal Supply Voltage	Operating Current Amperes	Standard Test Voltage
12V DC	Less than 6	13.8
(Also used for 12	6 – 16	13.6
Volt Lead Acid	16 – 36	13.4
Battery – 2.3	36 – 50	13.2
V/Cell)	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

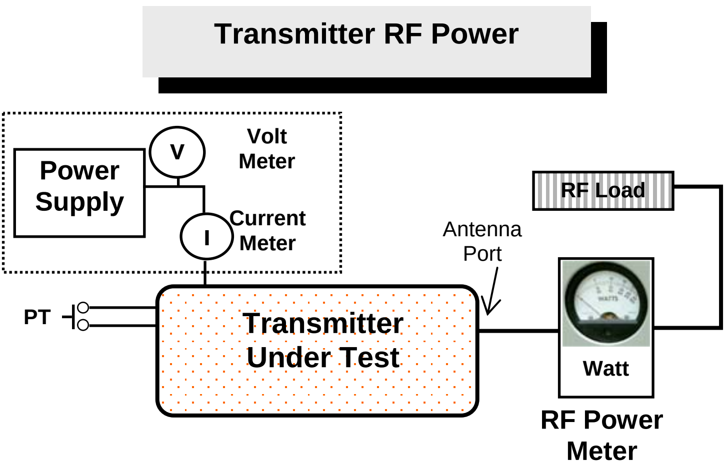
Secondary Cell Voltages for Common Battery Chemistry Types

Cell Chemistry	Nominal Voltage (V/Cell)	Test Voltage (V/Cell)
Nickel-Cadmium (Sealed vent type)	1.2	1.25
Nickel-Cadmium (Gas-venting)	1.2	1.40
Nickel-Metal-Hydride	1.2	1.25
Lithium Ion	3.6	3.75

TRANSMITTER TEST PROCEDURES

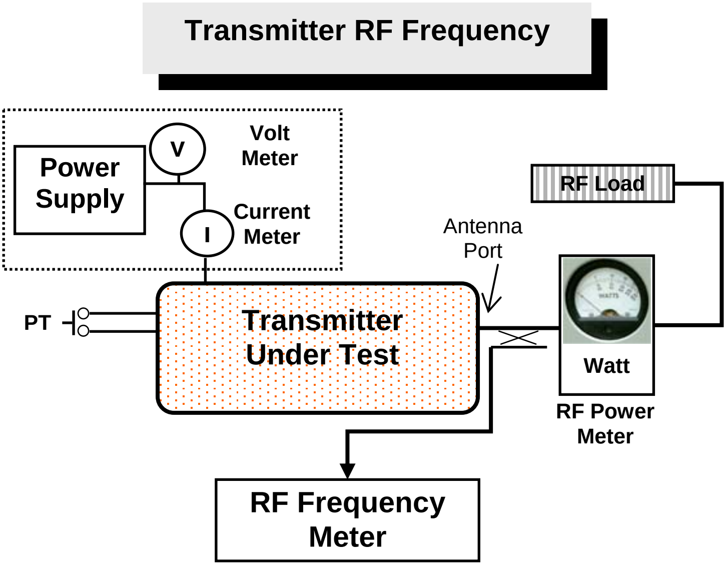
Each transmitter test should be performed sequentially to ensure that the setup of equipment and connections are minimized. A stated test assumes that the previous test was completed satisfactory. All RF cables and terminations are 50-ohms.

Transmitter Power Output



1. Terminate the transmitter with the RF Wattmeter using a short low loss coaxial cable or adapters. Power measurement should be compensated for the loss of the coaxial cable.
2. Supply the transmitter with the Standard Test Voltage using cables supplied with the transmitter or short conductors capable of handling the current of the transmitter without any apparent loss in voltage. Power up the transmitter.
3. Key the transmitter.
4. Measure the power output of the transmitter while monitoring the input voltage and current.
5. Verify that transmitter output power and input current are within transmitter specifications.
6. Unkey the transmitter.

Transmitter Frequency

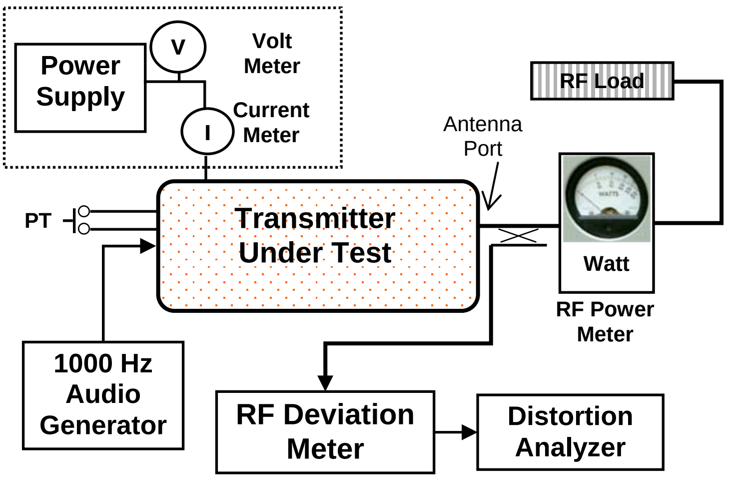


1. Connect the RF frequency meter or counter to the transmitter and RF load using a coupler or indirect coupling if sensitivity of the instrument is sufficient for off the air monitoring.
2. Key the transmitter.
3. Read the Transmitter Frequency (or frequency error) with the Frequency Measuring Equipment.
4. Unkey the transmitter.
5. If necessary, convert the data to the form required for comparison with equipment specifications (and/or governmental regulations).
6. If the frequency is out of tolerance*, verify# that transmitter ambient temperature is within the permissible range. Determine and apply frequency offset that is appropriate for the ambient temperature.
7. If adjustment of transmitter frequency is required, good practices call for adjustments to 10 times better accuracy than specifications.

* See frequency meter comments in test equipment section of this handbook.
# See transmitter maintenance manual

Transmitter Maximum Deviation, Deviation Dissymmetry, Audio Sensitivity and Distortion

Transmitter Maximum Deviation, Deviation Dissymmetry, Audio Sensitivity and Distortion



1. PRELIMINARY

Connect the FM modulation (Deviation) meter to the transmitter and load using a coupler or indirect coupling if sensitivity of the instrument is sufficient for off the air monitoring. Configure the FM modulation meter to measure the required system peak deviation in its most accurate range. Care should be taken for the choice of audio filters and RF bandwidth filters. The ideal choice of audio filter is ≤25 Hz to ≥15 kHz. Generally, the RF bandwidth should be slightly higher than the channel bandwidth under test. A bandwidth that is too narrow will cause measured deviation to be degraded while too wide will allow excess noise to enter into the measurements.

A. Remove Channel Guard (CG) (CTCSS) encoding deviation, if present. (Some communication test sets and modulation analyzers have high pass filters to remove the CG tone. Care should be taken to ensure that the meter is accurate with the filters engaged.)

B. Use a Dummy Microphone Circuit, if required.

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

– FREQUENCY: 1000 Hz

– AUDIO OUTPUT: Voltage specified in the transmitter maintenance manual to set Maximum Transmitter Deviation. If voltage is not specified for maximum transmitter deviation and transmitter microphone audio sensitivity level is stated, then apply ten times greater voltage than the microphone audio sensitivity level. If no voltage is stated, then ascertain the correct voltage by applying sufficient voltage to produce 60% system deviation and then increase the audio level by a factor of ten.

2. MEASURE: TRANSMITTER MAXIMUM DEVIATION

A. Key the transmitter.

B. Observe Deviation in kHz on the Deviation Monitor for both positive and negative peaks. For monitors with scope readout, these readings are available simultaneously. Some instruments have a switch or choice to select between polarities. Still others automatically select the highest without a choice.

C. The higher of the two readings (positive peak or negative peak) is Transmitter Maximum Deviation in kHz. This value should never exceed the system deviation. The value is usually 90% of the system deviation for a 1 kHz test tone. For a 5.0 kHz system deviation, the value would be 4.5 kHz. The recommended* transmitter adjustment procedure may call for some other value.

3. CALCULATE: TRANSMITTER DEVIATION DISSYMMETRY

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

Example: $$\frac{4.5\text{ kHz} - 4.3\text{ kHz}}{4.5\text{ kHz}} \times 100 = 4.4\%$$

* See transmitter maintenance manual

4. MEASURE: TRANSMITTER AUDIO SENSITIVITY

   A. Observe deviation on the peak (positive or negative) that yielded the higher reading when maximum deviation was measured.

   B. Reduce AUDIO OUTPUT of Audio Generator until deviation is reduced to 60 percent of Transmitter System Deviation. This assumes that transmitter maximum deviation is properly adjusted for the system deviation.

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

   D. Unkey the transmitter.

5. MEASURE TRANSMITTER AUDIO DISTORTION

   A. Audio Generator FREQUENCY remains at 1000 Hz.

   B. Audio Generator OUTPUT remains at the voltage that produces 60 percent of Transmitter System Deviation.

   C. Output to the distortion analyzer should be from a de-emphasized output from the deviation meter. Refer to TEST EQUIPMENT, Deviation Monitor (see Table of Contents).

   D. Recheck that transmitter CG is not being encoded. If so, disable the CG or enable the proper monitor filters to remove the CG from the demodulate signal that is sent to the distortion analyzer.

   E. Configure the distortion analyzer or monitor to measure distortion.

   F. Key the transmitter.

   G. When the minimum distortion meter reading is obtained, read Transmitter Audio Distortion in percent.

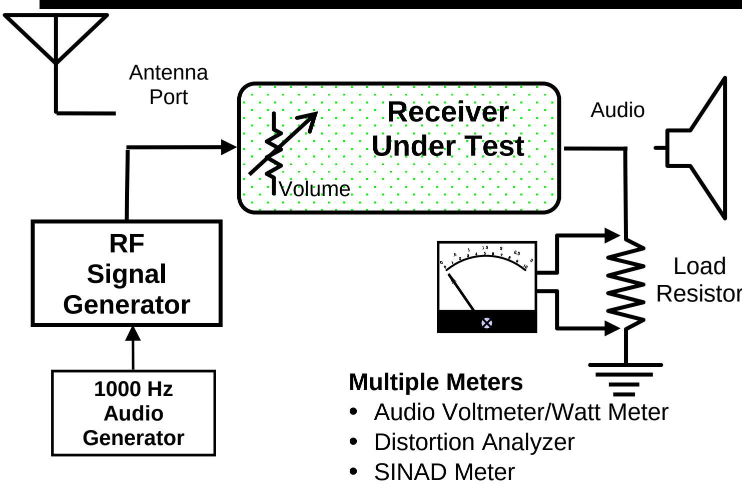
   H. Unkey the transmitter.

RECEIVER TEST PROCEDURES

Each receiver test should be performed sequentially to ensure that the setup of equipment and connections are minimized. A stated test assumes that the previous test was completed satisfactory. All RF cables and terminations are 50-ohms.

Receiver Audio Power & Distortion, 12 dB SINAD Sensitivity, Receiver Signal Displacement Bandwidth, and Squelch Operation

Receiver Audio Power & Distortion, 12 dB SINAD Sensitivity, Receiver Signal Displacement Bandwidth, and Squelch Operation



1. PRELIMINARY

   A. Terminate the receiver with an Audio Load Resistor. Use an isolation transformer if the audio output of the receiver is balanced.

   B. Supply the receiver with the Standard Test Voltage and power on the receiver.

   C. Disable Channel Guard (tone squelch) and noise squelch circuits, if present. It may be necessary to manually hold these functions disabled during the weak RF signal portions of the following tests.

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

- FREQUENCY: Receiver operating frequency
- STANDARD MODULATION: Defined as a test tone of 1000 Hz and a deviation of 60 percent* of the maximum allowable deviation or system deviation.
- RF OUTPUT: 1000 µV (-47 dBm)

2. MEASURE RECEIVER AUDIO POWER AND DISTORTION

A. Configure test equipment to measure audio power or rms voltage.

B. Set the Receiver Audio Power Output to rated power by adjusting the volume control for the desired power or voltage across the speaker load resister. Some receivers have stepped volume controls that may not step directly to the correct setting. Viewing the receiver audio on an oscilloscope and stepping the audio up to a point where audio distortion is visible, then setting the volume to one step below this point will increase the speed of testing. This point should be very near the receiver rated power. If exact testing is desired, the standard modulation can be varied slightly to place the audio level exactly on the rated power. If this is done, one must remember to return the deviation to the standard modulation before continuing on to the SINAD test. (The extra effort of performing to this detail, usually, does not add any value to the tests.) See the figure in the Test Equipment section for "Watts to Volts" conversion or calculate voltage by:

$$Voltage = \sqrt{Power \times Resistance}$$

C. Configure the test equipment to measure audio distortion.

D. Measure receiver audio distortion. It should meet receiver specifications. Usually less than 5 %.

3. MEASURE RECEIVER 12 dB SINAD SENSITIVITY

A. Configure test equipment to measure 12 dB SINAD.

B. Reduce the RF Signal generator RF OUTPUT while observing the SINAD meter. When the SINAD meter indicates 12 dB, record the level of the RF Signal Generator. This is the receiver 12 dB SINAD sensitivity reference. The value should meet or exceed the receiver specifications. Record this value. __________

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* See the Standard Modulation Table in the Transmitter Maximum Deviation comments (see Table of Contents).

4. MEASURE RECEIVER SIGNAL DISPLACEMENT BANDWIDTH

   A. Increase the RF Signal generator RF OUTPUT level by 6 dB (double the voltage) from the SINAD sensitivity reference level.

   B. Notice the SINAD meter is reading a higher number and the noise on the signal is less.

   C. Increase the RF frequency of the RF signal generator until the SINAD meter again displays 12 dB. Record the RF frequency as F_{HI}.____________MHz

   D. Decrease the RF frequency of the RF signal generator below the assigned frequency until the SINAD meter again displays 12 dB. Record the RF frequency as F_{Lo}.__________MHz

   E. Calculate the frequency differences by the following:

      (1) F_{DIFF1} _________ = F_{HI} – assigned frequency

      (2) F_{DIFF2} _________ = assigned frequency - F_{Lo}

   F. The smaller of F_{DIFF1} or F_{DIFF2} is the signal displacement bandwidth of the receiver. It should meet the receiver specifications. This value must be greater than 40% of the rated system deviation (>2 kHz for 5 kHz system).

   G. Return the RF signal generator's frequency to the on channel frequency.

5. MEASURE RECEIVER SQUELCH OPERATION

   A. The receiver and test equipment are setup and configured to measure 12 dB SINAD.

   B. Reduce the RF signal generator RF OUTPUT to zero. Enable the noise squelch circuits, but not the CG decoder. For user adjustable squelch receivers, adjust receiver SQUELCH control slowly until receiver is barely squelched. This is the critical squelch or loose squelch setting. The receiver should be squelched as indicated by no activity on the SINAD meter, AC voltmeter, receiver busy indicator, or monitored receive audio.

   C. Slowly increase RF signal generator RF OUTPUT until the receiver has a continuous audio output (no popping in and out of squelch condition). Observe the RF Signal generator RF OUTPUT level as well as the measured SINAD level. The receiver squelch sensitivity (squelch opening) in RF is read from the RF signal generator RF OUTPUT attenuator or meter. Read the receiver squelch sensitivity level in SINAD from the SINAD meter. The display will be very erratic because of the high level of noise. Use several readings to establish an average value. The values should meet the receiver or the established RF communication system specifications. Record these values. _____ (dBm) RF _____ SINAD

D. Reduce the RF signal generator RF output level until the audio is continuously muted (squelch closing). Record the RF level as read on the RF signal generator output attenuator. ____ (dBm) RF

E. The difference in RF level from squelch opening and squelch closing is the squelch hysteresis. Expect a value of 1 to 3 dB or the specifications for the receiver. It may be necessary to repeat the above steps several times to get valid indications.

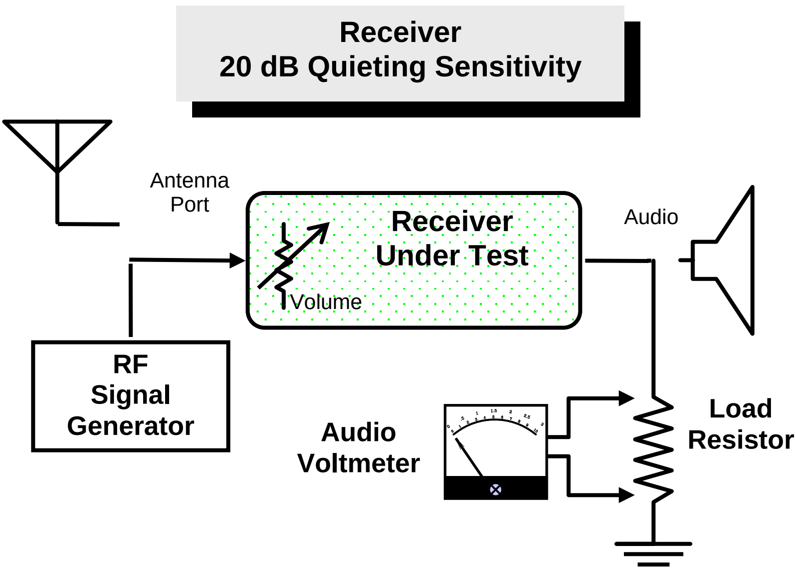
F. Reduce the RF signal generator RF output level to zero.

G. For user adjustable squelch receivers, adjust receiver SQUELCH control to a point that requires the most RF level to open squelch. This is the maximum squelch or the tight squelch setting. The receiver should be squelched as indicated by no activity on the SINAD meter, AC voltmeter, receiver busy indicator, or monitored receive audio.

H. Slowly increase RF signal generator RF output until the receiver has a continuous audio output (no popping in and out of squelch condition). Observe the RF Signal generator RF output level as well as the measured SINAD level. The receiver maximum squelch sensitivity (maximum squelch opening) in RF is read from the RF signal generator output attenuator. Read the receiver squelch sensitivity level in SINAD from the SINAD meter. Record these values. _____ (dBm) RF _____ SINAD The values should meet the receiver's specifications.

Receiver 20 dB Quieting Sensitivity

Often, 20 dB Quieting Sensitivity is not quoted as a receiver specification. The test however is of value when troubleshooting the gain of receiver circuits without using modulation. It can be omitted during PM checks.



1. PRELIMINARY

   A. Terminate the receiver with an Audio Load Resistor. Use an isolation transformer if the audio output of the receiver is balanced.

   B. Supply the receiver with the Standard Test Voltage and power on the receiver.

   C. Disable Channel Guard (tone squelch) and noise squelch circuits, if present. It may be necessary to manually hold these functions disabled during the weak RF signal portions of the following test.

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

   - FREQUENCY: Receiver operating frequency
   - MODULATION: None
   - RF OUTPUT: Initially Zero

E. Set a noise reference level by adjusting receiver VOLUME control for near 25 percent of rated Receiver Audio Power Output (on noise). Use an Audio (AC Volts or dB) Voltmeter. See the figure in the test equipment section for "Watts to Volts" conversion. Pick a value of a whole number, such as .5, 1, or 2, etc. If available, a dB meter scale can be used and set for a 0 dB reference.

2. MEASURE: RECEIVER 20 dB QUIETING SENSITIVITY

A. Increase the RF signal generator RF OUTPUT while observing the Audio (AC or dB) Voltmeter. The reading decreases as RF OUTPUT increases. When voltage is reduced by 20 dB (one-tenth the voltage set as a reference), read Receiver 20 dB Quieting Sensitivity from the RF signal generator RF output attenuator.

B. The value should meet receiver specifications.

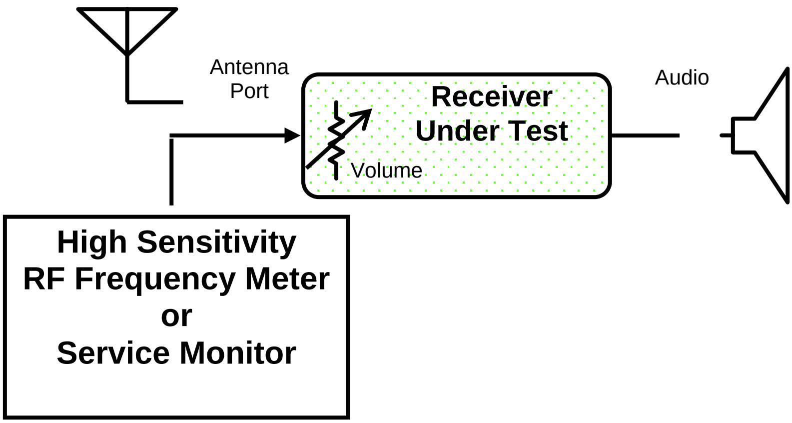
Receiver Frequency Verification

While regulatory agencies, such as the FCC, are not normally interested in receivers' local oscillator frequencies, the frequencies often carry the same specifications as transmitter frequencies. A receiver can pass SINAD when the LO frequencies are out of tolerance. Failure of Signal Displacement Bandwidth usually indicates that the LO is off frequency. In some digital signal systems, this may show up as a weak signal failure before failure of theses standard tests.

Measuring the receiver local oscillator frequencies involve the same concepts and equipment as those for measuring the transmitter frequencies. The major difference is the RF level.

The first LO (Local Oscillator) frequency can usually be verified without opening the receiver, provided you are using test equipment that can measure an "off the air signal." This involves knowing the IF frequency of the receiver and calculating the LO. The first LO is of such a level that a portion escapes out of the antenna port. The following figure shows an arrangement of measurement of the first LO.

Receiver Frequency Measurement
Method 1 - Simplest



1. PRELIMINARY

   A. If unknown, determine the first IF frequency for the receiver.

   B. Calculate the difference and sum of this frequency and the channel frequency.

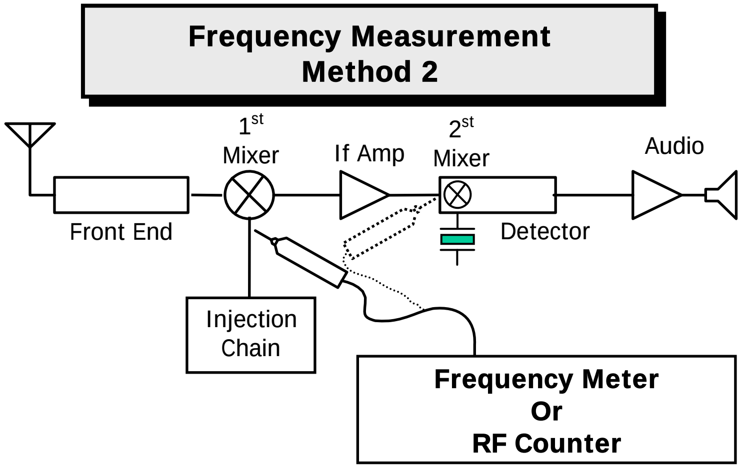
   C. Supply the receiver with the Standard Test Voltage and power on the receiver.

   D. Connect a cable from the most sensitive input of the RF Frequency Meter to the antenna connector of the receiver. Disable any RF attenuators. (For transceivers, be sure not to transmit, as damage to the RF Frequency Meter is sure to occur.)

   E. Configure the RF Frequency Meter to measure the first LO frequency. Use the difference frequency first and if that fails to test properly, repeat the test using the sum frequency.

2. Read the first LO frequency offset from the RF Frequency Meter. While measuring the LO frequency, monitor the audio of the signal or observe the signal strength of the signal to make sure the signal has no noise that will interfere with the measurement. If a sufficient level cannot be obtained the receiver will need to be disassembled to gain better access for testing.

Measuring the receiver first LO with a counter or measuring the other injection frequencies for multiple IF receivers will involve opening the receiver and possibly removing any shields present to gain access to test points.



1. PRELIMINARY

   A. If unknown, determine the injection frequency(s) to be measured.

   B. Remove access covers as necessary to place a probe near the mixer injection point(s). One of the purposes of all that shielding is to reduce this radiation to an acceptable level.

   C. Supply the receiver with the Standard Test Voltage and power on the receiver.

   D. Connect a cable with a loop of insulated wire at the end (A "rubber ducky" antenna on a coaxial cable works well) to the most sensitive input of the RF Frequency Meter. This will be used as a test antenna. Disable any RF attenuators.

   E. Configure the RF Frequency Meter to measure the LO frequency.

3. Position the test antenna close to the injection chain circuit in question. If an RF counter or RF Frequency Meter of limited sensitivity is being used, a 10X scope probe connected directly to the test points may be used. Do not connect directly to a crystal oscillator circuit, as this would most likely cause the circuit not to oscillate.

4. Read the injection frequency offset from the RF Receiver Meter or direct display of the counter.

PERFORMANCE VERIFICATION WITH STANDARD TESTS

Not all testing is done in connection with troubleshooting. Other reasons may include:

- 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 verifying that the equipment involved is doing its job.
- Improving and developing one's skills is also a very important reason for testing.

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 system. The order in which Standard Tests are listed in the troubleshooting charts and test procedures is optimum for checkout efficiency. In some cases, the order is dictated by the tests themselves--one must be passed before another is valid. In other cases, the 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 you are familiar with all controls, the entire sequence requires less than one minute from the time a unit is on the bench and hooked up to the end of tests for a given RF channel. That is a small investment for a lot of assurance!

For receivers, start by verifying noise in the speakers as you disable and enable the squelch circuits and vary the volume 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, Signal Displacement Bandwidth, and Squelch Operation. Again, if your test equipment is well arranged and you are familiar with all controls, the entire sequence takes no more than a few minutes.

TROUBLESHOOTING WITH STANDARD TESTS

The transmitter and receiver troubleshooting charts (last pages in this handbook) give you a systematic troubleshooting process that 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.

Experience has shown that the setup of equipment and connections are the usual cause of a failure. Always double check your setup and use alternate equipment to verify a radio is defective before disassembling and troubleshooting a radio.

When comments are made about adjustments, keep in mind that these adjustments may be physical adjustments in a radio or data stored in the radio during calibration or alignment.

Transmitter Troubleshooting

When Transmitter Power Output fails, a systematic approach to observation and troubleshooting will quickly identify the probable circuits.

First, observe the applied voltage and current. If the voltage is correct and current increases significantly during transmit, then power is being produced. It is not getting to the RF power meter. Verify cables, connections, antenna switching and RF low pass filter. If the applied voltage is correct, but current is lower than expected or no apparent increase while keying, verify the transmitter signal by monitoring with a high sensitivity monitor. If the transmitter functions except for the right amount of power, then one can assume that the problem is in the driver and final amplifier stages.

Troubleshooting in the driver and final amplifier stages, as well as any other circuit, involves checking that all applied levels are correct and gains occur. Verify that proper supply voltage and drive exit. If it does, verify proper tuning or Power Adjust control setting. If driver and final amplifier do not provide the expected gain, go through the RF stages, one by one. Make use of all of the built-in metering points that may be provided. Use an RF voltmeter or Spectrum Analyzer 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 and the transmit signal cannot be verified with a high sensitivity monitor start your investigation at the oscillator stage. Most modern transmitters use a PLL synthesizer circuit to produce the transmit frequency and modulate the signal rather than a single crystal per channel. If the transmitter is crystal controlled, use an oscilloscope, RF voltmeter or spectrum analyzer to make sure it is “running”, and then check the stages that follow, one by one. Synthesized transmitters present many possibilities for exciter failure.

Perform as many tests as possible before starting to troubleshoot by probing into the circuits. Some example questions and evaluations are:

- Is the synthesizer out of lock?
- Does is operate on any other frequency or channel?
- Is the synthesizer shared with the receiver, if so does the receiver work?
- Is programming correct?

If a transmitter fails Transmitter Frequency, adjustment or calibration has to be performed. Refer to the "Transmitter Frequency" discussion in the "INTRODUCTION TO STANDARD TESTS" area for some of the considerations that must be kept in mind. Remember also that the internal power supply voltage feeding an oscillator can and usually does cause frequency changes. This can be verified by varying the test voltage by as little as 10% while keying, if the TX frequency varies with the voltage changes – internal voltage regulators are questionable.

If the transmitter will not "trim" to the correct frequency, a defective crystal is the most likely cause. In compensated oscillators, however, also suspect the compensating components (thermistors and 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 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 working. If it fails, the trouble can lie anywhere between the microphone input and modulator. If Maximum Deviation is too high, it can be adjusted downward with the modulation limiter 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.

Passing Deviation Dissymmetry ensures 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 dissymmetry with audio input reduced to below modulation limiting (deviation less than standard deviation for the system). If dissymmetry stays the same, suspect the modulator (occasionally an amplifier). The modulation limiter should not contribute distortion when operated below the threshold of limiting.

Phase modulated transmitters are prone to dissymmetry problems if not properly tuned. Dissymmetry in the phase modulator is usually corrected by tuning the modulator stage. In multi-frequency transmitters with phase modulators, dissymmetry increases whenever a frequency is selected away from the one to which the modulator is 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 can show a gross lack of audio gain, Audio Sensitivity verifies that gain is correct and confirms that the modulation limiter does limit. Although Maximum Deviation is taken with an audio input, which should produce heavy limiting, the mere fact that one can adjust for modulation limiting does not guarantee that the audio is in heavy limiting (waveform observation when the deviation meter has a scope display does give you that assurance). When a transmitter passes Audio Sensitivity, you know there is sufficient audio gain to produce "standard deviation" (a level below limiting) after the modulation limit control has been set for "system deviation" under maximum (normally heavily limited) conditions. Therefore, passing Audio Sensitivity has two implications:

- Audio gain is adequate.
- Audio was heavily limited when you set the Maximum Deviation.

If Audio Sensitivity fails because it takes too many millivolts of audio to produce "standard deviation," look for low audio gain, but also suspect a modulation limiter that is not limiting. If it takes too few millivolts, suspect that audio gain is abnormally high. It can also be caused by a change in the value of the audio amplifier feedback gain setting components or in the some cases - programming.

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). Transmitter audio stages can often be traced without actually keying the transmitter.

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 operated, you can assume that the majority of the receiver circuitry is in working 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 do not 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 is highly unlikely that any major IF gain or detector problems exist.

What you do not 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 considerably offset (wrong frequency); injection voltage may be low or zero.

The first Standard Test on the chart, Audio Distortion, is taken with a very high RF Signal (1000 µV) and with 60% system 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. At this RF level, a signal should pass through the stages and be detected. Second, with the receiver working end-to-end, you are able to verify or set frequency. Third, the Audio Power test verifies that the receiver will develop full rated audio output power. Fourth, you measure the Audio Distortion. Finally, if you are using a tunable Distortion Analyzer (DA) for distortion and SINAD measurements, the 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. The metering provisions in some receivers help to confirm this condition. If the injection chain seems dead, start your investigation at the oscillator. Troubleshooting the oscillator or synthesizer circuits of the receiver are much the same as the exciter stage of a transmitter, except for no modulation. Refer back to the transmitter comments.

Unless the receiver output appears completely free of noise (as should happen with a 1000 μV input signal), there is no point in trying to measure distortion—you are doomed to failure. There is a gross sensitivity problem. Improve sensitivity until the 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 is a loss of gain somewhere between the detector and the speaker output. You are faced with a simple signal-tracing job. Measurements can be made with a high-impedance AC voltmeter or preferably 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. Distortion at the detector output is always higher than the speaker output of a good receiver. This is because of the 750 μsec de-emphasis of the audio circuits. Using an oscilloscope to observe waveforms is easy; moreover, it will usually pinpoint the trouble areas. Harmonic distortion below 10% is almost impossible to see with an oscilloscope. Gross irregularities in the IF bandpass may show up as excessive distortion. This however is quite unlikely. Crossover distortion found in the earlier FM detector designs and push-pull audio amplifiers, 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. This can be seen very easily with an oscilloscope.

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 many things are right in the receiver:

- Gain and injection are adequate.
- Bandwidth is sufficiently wide to pass marginal signals with 60% system deviation.
- Distortion (already measured) is within reason. It is impossible to achieve 12 dB SINAD specifications if distortion is excessive.

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 circuits.

Gain without any concern for bandwidth is verified by running 20 dB Quieting. Failure of 20 dB Quieting test necessitates troubleshooting the RF path for proper gains. If a receiver passes 20 dB Quieting, it has adequate gain; selectivity related matters must be the problem. Selectivity related matters could be in the form of filters, tuning or injection frequencies off. These can be confirmed by performing the Signal Displacement Bandwidth test.

Signal Displacement 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 "standard deviation," at an RF level slightly above threshold. Selectivity is not too narrow at that level. Even if the receiver failed 12 dB SINAD test, a reference RF level was obtained to verify the Signal Displacement Bandwidth. Failure of Signal Displacement Bandwidth confirms that the selectivity is too narrow. (Remember there is no maximum limit for how wide the Signal Displacement Bandwidth, unless one establishes it as their own standard.)* The most probable cause for failure is the receiver being off frequency. Verify all injection frequencies and adjust if not within tolerance. Another common cause in newer receivers is the wrong bandwidth selected for the channel. Narrow (12.5 kHz) or Wide (20, 25 & 30 kHz) bandwidths should be programmed correctly and testing should be performed to check the proper bandwidth. In rare instances, tuning of the IF matching circuits could contribute or cause a failure of Signal Displacement Bandwidth.

* See the Signal Displacement Bandwidth comments in the Standard Tests section.

Squelch Operation checks 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.

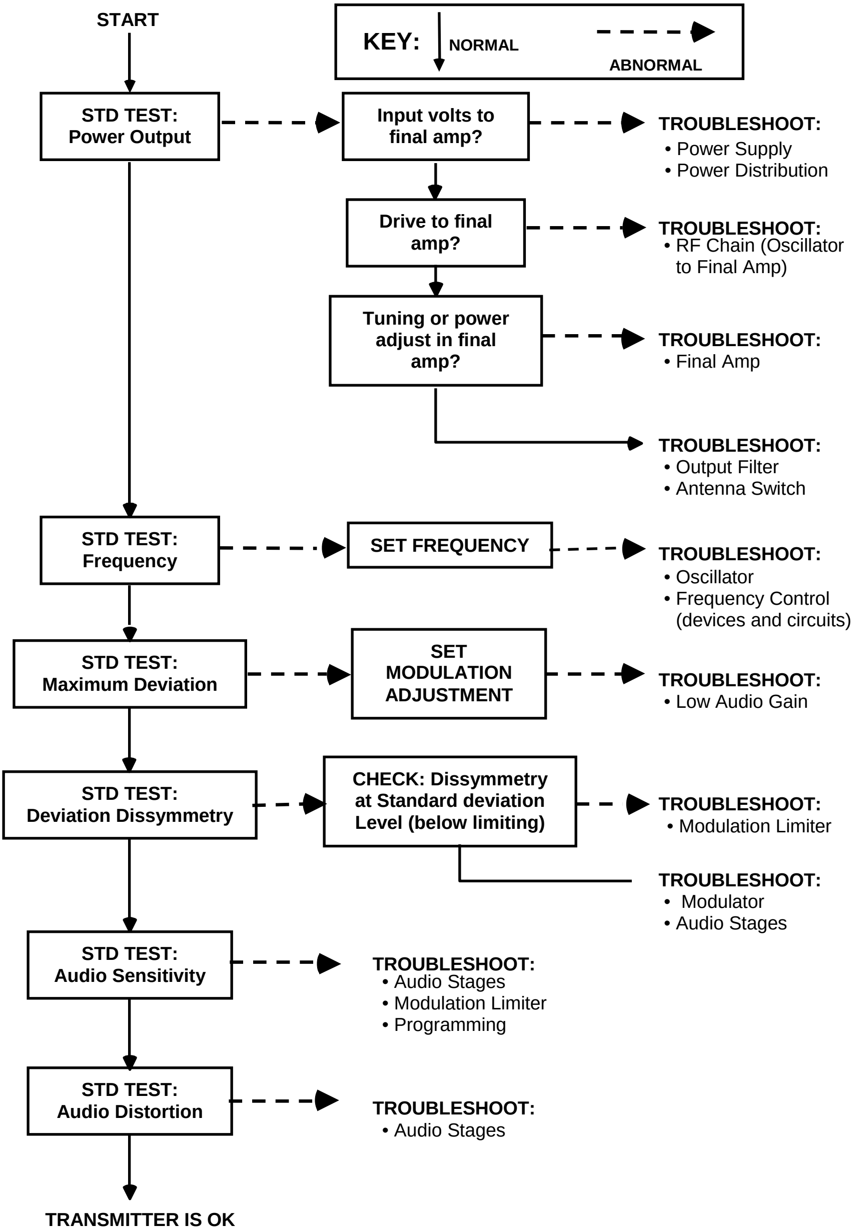
Muting and squelch are used as common terms within TIA documents, but not always in the industry. Squelch terminology always addresses at least the function of noise detection to turn the audio circuits off and on. Muting often refers to the other circuits that "And" with the noise squelch circuits. Examples are CTCSS (CG), paging tones, other selective calling systems and even the algorithms of trunking systems. Be sure that any circuits, which may keep the receiver audio circuits from reacting to the noise squelch circuits, are disabled for test and troubleshooting. Those circuits are tested as a function of "System Testing" of the receiver.

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 Signal Displacement 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 and detector. Operation of the noise detector is checked to make sure that noise is converted to the proper DC voltage. If OK to this point, you must examine the audio control circuits. Typically, these circuits are either on or off - nothing in between. They respond to the techniques used to troubleshoot digital circuits. Somewhere within the circuits, there would be some sort of hysteresis circuit, either in the form of capacitance charging, characteristics of a gate or software.

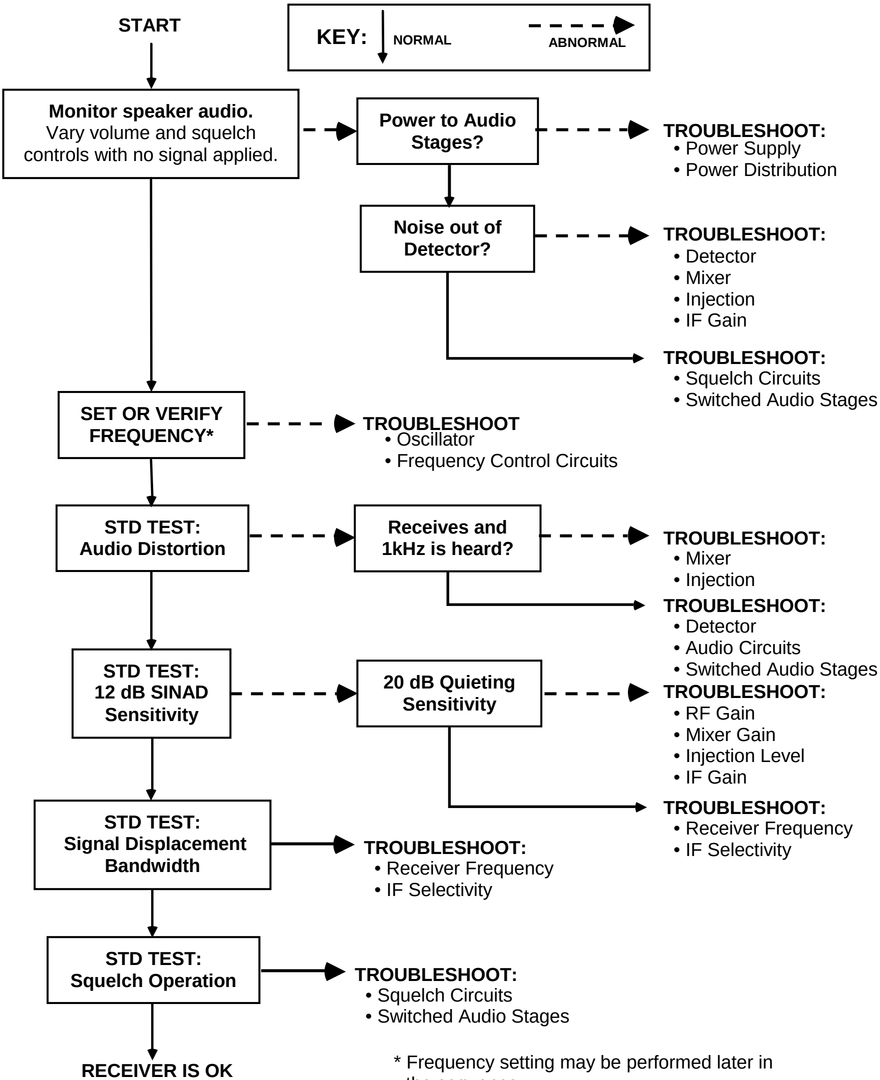
When a receiver fails to unsquelch, but otherwise appears normal, look for trouble in the squelch circuits. If a receiver will not squelch, be sure that the receiver is devoid of gain, selectivity or interference difficulties before attacking the squelch circuits. One form of on channel interference is the receiver responding to a self-quieting signal from within itself. This can be eliminated like any other on channel signal, by simply selecting a different frequency and verifying squelch operation.

Notes

Transmitter Troubleshooting Chart



Receiver Troubleshooting Chart



* Frequency setting may be performed later in the sequence.

Notes

Addendum

This handbook addresses the very basic of two-way transmitter and receiver testing and troubleshooting. Testing, troubleshooting and repair of a radio that can pass these basic tests ensures that the radio can communicate to another good radio in the basic mode of analog non-trunking operation or conventional mode.

System testing of the radio should always be performed before turning the radio over to normal use within a two-way radio communication system. Some examples of tests to perform are:

- Microphone Testing
- Speaker Testing
- Frequency tests on all channels requiring separate adjustments
- Modulation tests on all channels requiring separate adjustments
- CTCSS/CDCSS operation on all used channels
- Selective calling
- Trunking
- User interface
- Scanning and Priority Scanning
- Remote Control
- Etc.

The Two-Way Radio Technician is encouraged to continue to develop ones skills by learning more about testing and using that knowledge in testing and identifying probable causes for failures. This directly translates into savings in cost and just as important, confidence in one's abilities.

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