# ARRL Amateur Radio Interference Assessment Project

**Document: Manual Testing of Field-Strength Levels Using Conventional Receivers**

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This document describes a method to make reasonable measurements of radiated field strength using conventional receivers and commonly available test equipment. This method is not intended to be a substitute for calibrated measurements using EMC test equipment, but it does provide a usefully accurate measurement.

**Equipment needed:**

- A receiver of known sensitivity. The most accurate way to determine the sensitivity of a receiver is to use a calibrated signal generator and an audio voltmeter[1]. It is also reasonable to use the manufacturer's published sensitivity, corrected to a 3 dB S+N/N ratio[2], or ARRL "noise floor" data from the published Product Reviews. To use the formulas on this page, the sensitivity should be expressed in dBm. A typical HF receiver has a noise floor of about -135 dBm in a typical SSB bandwidth of approximately 2500 Hz. It is generally necessary to determine the noise floor on each frequency band that will be measured.
- The bandwidth of the receiver should also be known, by measuring its bandwidth or by using the manufacturer or QST Product Review data[3].
- An antenna of known gain. The gain can be measured, modeled or, with some reliability, you can rely on the manufacturer's published gain figures. You can also use antennas with known gain, such as a half-wave dipole or reference horn

[1] The procedure for doing this is described in a separate document at http://www.arrl.org/~ehare/testproc/testproc.pdf.

[2] This is the level of the noise floor. This is often referred to as the minimum discernable signal (MDS).

[3] The best accuracy for these calculations is obtained if the equivalent rectangular bandwidth of the receiver is known. This is generally reasonably close to the –3 or –6 dB bandwidth of the receiver, depending on the slope of the filter skirts.

antennas. The free-space gain of the antenna should be used for the calculations in this paper.

- Calculated or measured feed-line losses, plus any other losses such as antenna tuners, in-line attenuators, etc.[4]
- A step attenuator. (An attenuator with 10-dB steps is usually adequate.)
- An audio voltmeter with "true-RMS" capability or a computer with a sound card, used as an audio voltmeter
- Optional: A signal generator used to perform receiver calibration.

**Testing steps:**

- Connect the receiver antenna input to the output of the step attenuator. Do not connect the input of the step attenuator to the antenna at this time.
- Set the step attenuator to at least 20 dB. This will terminate the input of the receiver in a 50-ohm load.
- Connect the true-RMS-reading voltmeter to the receiver output (a non-RMS voltmeter will produce a dB or two of error, but can be used with that limitation).
- Power the receiver on, tuned to the frequency of interest. It should be in USB or LSB mode, with its bandwidth set to about 2500-3000 Hz. Adjust the volume to a level that sets the receiver noise from the speaker to a reasonable but relatively low level. (You must have a few dB of headroom so that louder signals will not be overwhelming or cause the receiver audio to clip or saturate.)
- Record the audio level on the AC voltmeter. This voltage represents the receiver's noise floor. This is designated as $V_{terminated}$ in subsequent calculations.
- Connect the antenna to the step attenuator. Adjust the step attenuator so that the actual noise or signals heard in the receiver output are about 6 to 15 dB higher than the level you obtained with no antenna. This can generally be done by an experienced ear, with 10 dB sounding about twice as loud. It is important that the

[4] Coaxial losses can be calculated from coaxial cable manufacturer's published data. The TWL.EXE program, bundled with the ARRL Antenna Book software CD, can be used to estimate coaxial cable losses on any frequency. Information about many cable types can be downloaded from http://www.timesmicrowave.com/aerospace/cable_catalog/

measurement is made in the linear range of the receiver, with no AGC response. Genearlly, if the received level is 10 dB higher than the receiver noise-floor "hiss," the AGC will not be active. If AGC is not active, the S meter will not move at all. For best results, the measurement should be at least 6 dB above the receiver noise floor and at least 10 dB below the point where AGC action begins gain compression in the receiver[5]. A good way to test whether AGC is active is to change the attenuator settings. If the measured voltage changes by the same ratio as the change in attenuator settings, receiver AGC is not affecting the measurement.

- Record the new audio voltage and the step attenuator setting. This is designed as $V_{measured}$.

**Received Signal Level:**

Calculate the actual level of the RSL, at the receiver input. It is not as simple as adding or subtracting dB[6]. The $V_{terminated}$ voltage reading represents the noise floor of the receiver, and the $V_{measured}$ represents the noise floor *plus* the actual signal level. The noise floor must be subtracted from this total to get the actual signal level. This can be done with the formula:

$$\mathbf{RSL_{dbm} = noise\_floor\_dBm + 10log_{10}( V_{measured}^2 \ / \ V_{terminated}^2 - 1)}$$

where $V_{terminated}$ = the voltmeter reading with the receiver input terminated and $V_{measured}$ = the receiver voltmeter with the receiver connected to an antenna (with attenuation set as needed).

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[5] If you want to verify that the receiver is in its linear range, change the attenuation by several dB and repeat the steps. When you run both sets of measured voltages through the following calculations, if the receiver is linear, you will obtain different received signal levels (RSL), but will obtain the same field strength when you factor in the different attenuator settings for each of the two measurements.

[6] Contrary to what many engineers "know," dB can't always be added or subtracted. A power of 10 milliwatts is +10 dBm. 10 dBm + 10 dBm + 10 dBm = 30 milliwatts, or +14.8 dBm. If you added up the dBs, you would incorrectly have +30 dBm, which is 1 watt, a significant error. The formula above converts the relative voltage levels to a dB value that can be subtracted from the noise floor.

The receiver *must* be operating in its linear range, with no AGC action present. This is true for most receivers for levels from 0 to about 20 dB higher than the noise floor. Above that, some receivers will start to AGC compress, throwing off the reading. Adjust the attenuation as necessary to ensure that the receiver is in its linear range.

**Field Strength:**

From this RSL, you can calculate the RMS field strength.

$$\text{DBuV / m} = \text{RSLdbm} + 77.2 + 20\log_{10}(\text{FMHz}) - \text{RcvAntGaindbi}^{7} + \text{dBlosses} + \text{attenuation}$$

$$\text{uV / m} = 10^{(\text{dBuV/m} / 20)}$$

This simple method allows the use of conventional receivers and antennas to make measurements of field strength. It makes far-field assumptions about the way the antenna will interact with the source in the near-field region of large radiators such as power lines, but it does provide useful measurement nonetheless. With higher-gain receive antennas it may slightly underestimate the field strength because the antenna may pick up the direct signal differently than it picks up the signal reflected off ground or other scatterers.

The readings in a residential neighborhood will generally be in the range of –20 dBuV/m for quieter locations to as high as +30 dBuV/m when the receive antenna is located near devices such as computers or other unlicensed radiators.

**Extrapolating to FCC Part 15 limits:**

The FCC Part 15 limits stipulate that measurements be made with a quasi-peak detector below 1 GHz, or an average detector above 1 GHz. The rules stipulate a maximum field strength in the following measurement bandwidths:

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[7] This should be the free-space gain of the antenna.

| Frequency | Detector | Bandwidth |
|---|---|---|
| 9 kHz – 150 kHz | quasi-peak | 100 Hz |
| 150 kHz – 30 MHz | quasi-peak | 9 kHz |
| 30 MHz – 1000 MHz | quasi-peak | 100 kHz |
| 1 GHz – 40 GHz | average | 1 MHz |

In general, calibrated measurements must be made in the appropriate bandwidth because many signals will not be uniform over the entire measurement bandwidth. For example, if a signal being measured were a discrete unmodulated carrier, if a measurement were made in a narrower bandwidth that missed that carrier, the measurement would be totally inaccurate. If the signal being measured had multiple carriers, they could add up to produce a quasi peak signal that was much greater than the average power of the entire emission. Broadband Gaussian noise is somewhere in the middle, with a peak-to-average ratio of about 9.6 dB[8].

However, for signals that are noise-like and reasonably uniformly distributed across the specified measurement bandwidth, it is possible to estimate the quasi-peak value from a measurement made in a smaller bandwidth, with some degree of uncertainty and error. If the signal is noise-like, it can be presumed to have a peak-to-average ratio of 9.5 dB and to have the value vary as $10\log_{10}$(specified bandwidth / actual bandwidth). It is also possible to use a storage oscilloscope or soundcard and the appropriate software to calculate the actual peak-to-average ratio in the measurement bandwidth. This extrapolation would generally not work well if there are significant variations between the measurement bandwidth and the actual bandwidth specified in the C63.4 measurement standard that the rules say to use, but for relatively small differences in bandwidth, such as a 9 kHz measurement being made in a 3 kHz bandwidth by a test engineer that has listened to the signal and determined that the signal is noise-like and that it is uniform across the frequency range, it is possible to make a reasonable estimate of the level of the signal with respect to the levels in the Part 15 rules.

[8] http://www.its.bldrdoc.gov/pub/ntia-rpt/98-355/chap1.pdf

**Documentation:**

This test procedure is in beta testing. It is being sent out to a few select groups. ARRL is looking for feedback and for some initial data from those that are able to make measurements. Feedback, questions or comments about these test methods should be sent to w1rfi@arrl.org and n9gl@arrl.net.

Although it is useful to know the general ambient noise levels affecting Amateur Radio, data gathered by amateurs can have value to the FCC or industry. Engineers analyzing noise data often want to have as much information about the nature of the signal as possible. To ensure that information gathered by amateurs can be widely used, amateurs making measurements should do the following:

1. Take good notes on the nature of the signals you are measuring, possible sources of that signal, a general description of the natural noise you may also hear on the band and a description of the signals that can be identified on the band at the time.
2. Make audio recordings of the sounds of each measurement. The best way to do this is to capture a second or two of audio into a .wav file. This can then be later analyzed using software that does digital-signal processing on the received noise and signals.

ARRL is preparing a data sheet form that can be used to collect and record data in a standardized format.