QST Product Reviews: A Look Behind the Scenes

QST October 1994, pp. 35-38

QST Product Reviews:
A Look Behind The Scenes

Learn how the ARRL Laboratory evaluates new products—and what all those numbers mean to you!

By Mike Gruber, WA1SVF
ARRL Laboratory Engineer

Today's *QST* Product Reviews are better and more comprehensive than ever. They're a tremendous service to any ham interested in new or used equipment. We're always working to improve the quality of our Product Reviews. Recent trends include more products, comparison reviews and increased Lab testing.

Let's take a look at some of the measurements you will see published in a typical product review for an HF transceiver, and discuss how you can use them for evaluating an equipment purchase. Not surprisingly, our tests are broken down into two categories: transmitter tests and receiver tests. We'll consider receivers first.

Receiver Tests

As many newcomers to ham radio have discovered, comparing the performance of one receiver to another is often difficult. The *features* of one receiver may outweigh another, even though its overall *performance* might not be as good. Here is where a little knowledge and some Product Review data can be invaluable.

Some of the more important receiver measurements you'll find in *QST* Product Reviews are sensitivity, blocking dynamic range and two-tone IMD (intermodulation distortion) dynamic range.

Receiver Sensitivity

Sensitivity measures a receiver's ability to hear weak signals. You'll find several methods used to express it. The mode under consideration often determines the best choice. Do not be confused by this—the basic concept is really the same for each. Put simply, receiver sensitivity is the level of input signal required to produce a given signal output. The only variables are the units used to measure the input signal, and the defined receiver output.

Sensitivity is typically expressed in µV, dBm and occasionally in dBµV. You'll see dBm used to describe the power level in dB relative to one milliwatt; dBµV describes the voltage level in dB compared to 1 microvolt.

Logarithmic power units like the dBm are not only very convenient to use when amplifying or attenuating signals, but they're also useful when making comparisons between radios.

One of the most common sensitivity measurements you'll find for CW and SSB receivers is the minimum discernible signal (MDS). MDS is the input level to the receiver that produces an output signal equal to the internally generated receiver noise. Hence, MDS is sometimes referred to as the receiver's *noise floor*. The typical MDS of a modern radio is –135 to –140 dBm with 500 Hz bandwidth.

Receiver sensitivity is also often expressed as 10 dB signal-plus-noise to noise (10 dB [S+N]/N) or 10 dB signal to noise ratio (10 dB S/N). The procedure and measurement are identical to MDS, except that the input signal is increased until the receiver output increases by 10 dB for 10 dB (S+N)/N and 9.5 dB for 10 dB S/N.

AM Sensitivity: AM receiver sensitivity is usually expressed as 10 dB (S+N)/N or 10 dB S/N. The basic procedure is similar to that used to measure MDS, except the signal generator is set for a 30% modulated, 1 kHz test signal. (The modulation in this case is keyed on and off and the signal level is adjusted for the desired increase in the audio output.)

FM Sensitivity: SINAD is the most common sensitivity measurement normally associated with FM receivers. It's an acronym for SIgnal plus Noise And Distortion and is a measure of signal quality:

$$\mathrm{SINAD} = \frac{\text{signal} + \text{noise} + \text{distortion}}{\text{noise} + \text{distortion}}$$

where the ratio is expressed in dB.

Let's take a closer look at SINAD if we consider distortion to be a part of the receiver noise. (Distortion, like noise, is something unwanted added to a desired signal by the receiving system.) If we also assume that the desired signal is much stronger than the noise, SINAD now closely approximates the signal to noise ratio:

$$\mathrm{SINAD} = \frac{\text{signal} + \text{noise} + \text{distortion}}{\text{noise} + \text{distortion}} \approx \frac{\text{signal}}{\text{noise}}$$

where the ratio is expressed in dB.

The most common SINAD spec for amateur receivers is 12 dB SINAD. This corresponds to 25% total harmonic distortion (THD) and a 4:1 S/N:

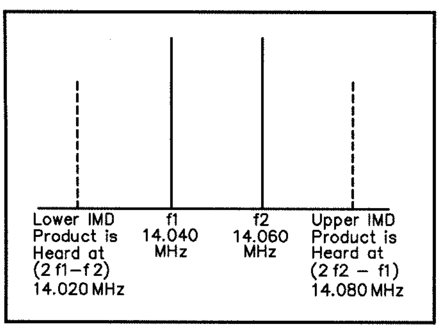

Figure 1—IMD shows up as false signals generated within your receiver. In the example above, a receiver may pick up IMD if it is tuned to 14.020 or 14.080 MHz. These IMD products are produced by the mixing of two strong signals in your radio at 14.040 and 14.060 MHz.

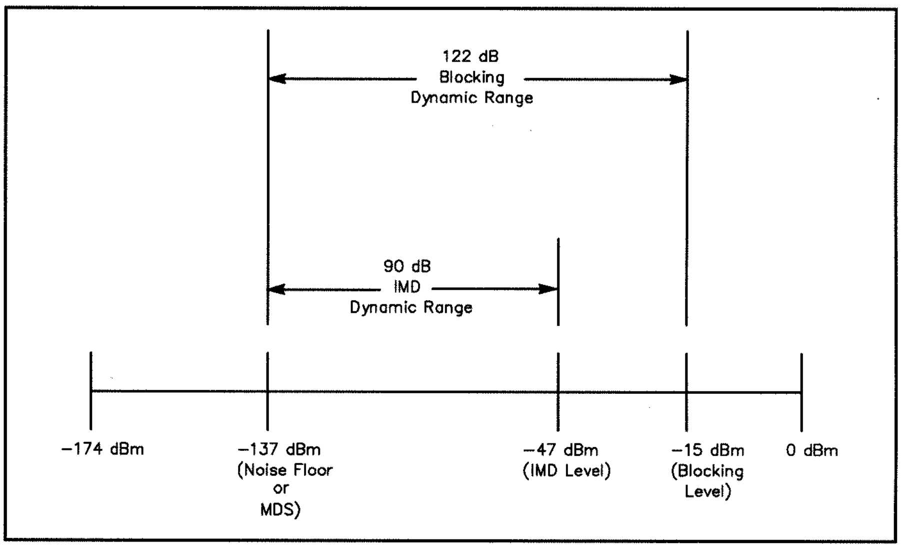

Figure 2—The relationship between MDS and dynamic range.

12 dB SINAD = 20 log (1/[25%]) = 20 log 4

The basic test setup for measuring SINAD is similar to the MDS hook-up. (The only difference is that the audio voltmeter is replaced by a distortion meter.) To measure 12 dB SINAD, the input signal level is adjusted for 25% THD as indicated by the distortion meter. The standard input signal typically used for narrowband FM SINAD measurements (such as used for amateur communication) is 3 kHz peak deviation, modulated at 1000 Hz.

Dynamic Range

Dynamic range is the difference between the weakest signal a receiver can hear, and the strongest signal a receiver can simultaneously accommodate without noticeable degradation in performance. Two types are considered in *QST* product reviews: *blocking dynamic range* (blocking DR) and *third-order intermodulation distortion dynamic range* (IMD DR).

Blocking dynamic range describes a receiver's ability to maintain sensitivity (or not to become desensitized) in the presence of a strong undesired signal on a different frequency. IMD dynamic range, on the other hand, is an indication of a receiver's ability to not generate false signals as a result of the two strong signals on different frequencies outside the receiver's passband. Both types of dynamic range are normally expressed in dB relative to the noise floor.

Evaluating the Dynamic Range Data

Dynamic range can be a major consideration, especially if you're in an urban or RF congested area (like a major city). When the IMD DR is exceeded, false signals begin to appear along with the desired signal (Figure 1). When the blocking DR is exceeded, the receiver begins losing its ability to amplify weak signals. The larger the dynamic range number, the better. Modern radios typically have an IMD dynamic range that is greater than 85 dB, and a blocking dynamic range greater than 120 dB (see Figure 2).

Dynamic range, especially blocking dynamic range, is sometimes reported in our test results as being "noise limited." This means we couldn't make the measurement. Phase noise is masking and interfering with the desensitization or IMD product we're trying to measure. In the case of blocking dynamic range, the normal 1-dB decrease in the desired signal could not be measured due to a 1-dB *increase* in the phase noise. This means the blocking dynamic range is greater than the noise-limited measurement.

A low noise-limited measurement is a clue that the receiver might be phase noisy. A particularly high noise-limited dynamic range indicates both good dynamic and range and low phase noise. In this case, the noise simply won out over the desensitization. If the noise-limited point is not specified, no conclusion can be drawn from the measurement.

While it's true that you can never have too much dynamic range, it's also not necessary to have more than you'll need. For example, with all other parameters equal, a receiver having 85 dB of dynamic range will not perform better than one that has 92 dB—*if only 60 dB is required!* Lots of dynamic range may also come at the expense of reduced sensitivity.

The amount of dynamic range you'll need depends on the presence of strong signals at your receiver's input. Consider all sources, especially nearby transmitters. Your antenna can also affect your dynamic range requirements. Its gain and directivity can enhance a desired signal while simultaneously rejecting the undesired. (As a typical example, consider a Yagi pointing toward a desired station and away from an offending signal source.) Small transmitting loops can reject unwanted signals with their narrow bandwidths and high Q. An antenna tuner can also be helpful in reducing unwanted signals.

Third-Order Intercept Point

Another parameter used to quantify receiver performance in *QST* product reviews is the third-order intercept point (IP3). This is the extrapolated point at which the desired response and the third-order IMD response intersect. Greater IP3 indicates better receiver performance.

Second-Order Intercept Point

We've recently added a new test to the battery: second-order IMD distortion dynamic range. These products, like third-order products, can also be generated within a receiver. In today's busy electromagnetic environment they can become offensive under certain conditions. Consider the case of two strong short-wave broadcast stations, on two different bands, that sum to the frequency of the weak DX you're trying to copy. If their intermod product is strong enough, you may not be able to copy the station through the interference.

Image and IF Rejection

Images are the unwanted results of the mixing process that takes place within a superhetrodyne receiver. They appear as second, false signals that are displaced on your radio dial by twice the local oscillator frequency.

A station operating at a receiver's intermediate frequency (IF) can wreak havoc if its signal is strong enough and the receiver's intermediate rejection is insufficient. The signal will appear across a radio's entire receiving range! Be sure to consider IF rejection when evaluating a transceiver—especially if you have local RF sources at the intermediate frequency.

We test both image and IF rejection in the Lab. We first measure the level that causes the unwanted signal to be at the MDS. Then, we reference this level to the MDS in order to express the measurement in dB.

Audio Power Output

A receiver's audio output capabilities are usually expressed as power (in watts) developed across a given load (usually 4 or 8 Ω) with a specified *total harmonic distortion* (THD). How much audio power do you need? That depends on a variety of factors, including speaker efficiency, ambient noise and personal taste. If you're a mobile operator on a noisy highway and your speaker is wedged against the underside of your car's console, you'll want more audio than someone in a quiet shack with headphones. On the other hand, 1 W of audio can be ear shattering in a small room with an average speaker.

Transmitter Tests

Some of the transmitter measurements reported in *QST* Product Reviews are power output, spectral purity, two-tone IMD, unwanted sideband and carrier suppressions,

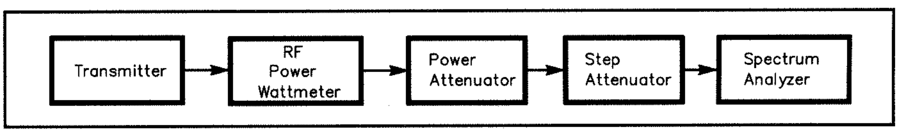

Figure 3—Testing for spectral purity and power output.

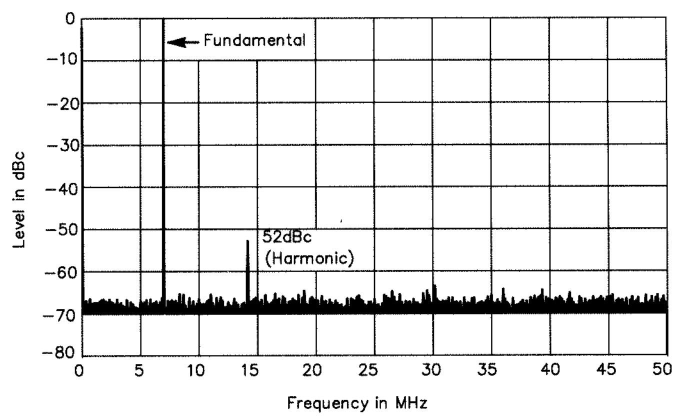

Figure 4—A typical spectral-purity plot.

and keying and turnaround tests.

Power Output

Figure 3 shows the test set-up for power output. It's measured using a laboratory grade wattmeter across each band for each available band and mode. The power attenuator simply serves as a dummy load for this test.

Most amateur transceivers are in the 100 W class. Some of them struggle to get there; others exceed their specification comfortably. These differences are not significant in most cases. The guy on the other end will not be able to hear a 5 or 10-W deviation from a transmitter's 100-W specification.

By the way, don't forget to consider a transmitter's duty cycle rating. Some modes, such as RTTY, are far more demanding than CW or SSB. If you intend to operate RTTY, you may have to reduce power or make short transmissions. At the other end of the spectrum, QRP operators must consider a transmitter's *minimum* power capability. It may not go as low as you'd like.

Spectral Purity

All transmitters emit signals outside their intended frequency range. These signals are called *spurious emissions*—a term that includes all signals that are not the fundamental and its desired modulation. They can include harmonics, parasitics, intermodulation products, noise and frequency conversion products.

We measure spectral purity in the Lab using the hook-up shown in Figure 3. The power attenuator again serves as a dummy load. In addition, it provides an output signal that is attenuated by 30 dB. The step attenuators then further reduce the signal as required for compatibility with the spectrum analyzer and its attenuator.

The spectrum analyzer displays signal amplitude with respect to frequency. Figure 4 shows a typical spectral purity plot obtained with an analyzer. Each vertical division is 10 dB; each horizontal division is 5 MHz. The signal fundamental is at 7.150 (or approximately 1.2 divisions from the left), and the attenuators and analyzer are adjusted to set the fundamental at 0 dB (or the top horizontal line). All other signals can now be referenced to the fundamental and are visible as lower-level pips on the display. The second harmonic at 14.300 MHz, for example, is at –52 dBc (dB referred to the carrier).

Part 97 (the FCC regulations that govern the Amateur Radio service) requires that all transmitters meet standards for the purity of their signals. Spectral purity must be in compliance with these regulations, not just to avoid a QSL from the FCC, but to ensure the transmitter doesn't interfere with other hams and other radio services. The FCC requirement for an HF transmitter operating at 100 W is that all spurs be at least –40 dBc (97.307(d)). The more negative this number, the better. Since our hypothetical transmitter's worst case is –52 dBc, it's spectrally legal. (Other requirements apply for different frequencies and power levels.) All transceivers and transmitters advertised in *QST* must meet the minimum FCC requirements for their frequency and power class.

Two-Tone IMD

Just like your receiver, your transmitter produces IMD distortion products. To measure IMD we use an audio generator. The generator produces two tones, one at 700 Hz and the other at 1,900 Hz. We put the transmitter in the desired SSB mode and modulate it with the two-tone generator. The output is measured by the special PEP-reading wattmeter and observed on the spectrum analyzer.

Figure 5 shows a typical IMD plot. Each vertical division is again 10 dB; each horizontal division is 2 kHz. You can see the two desired signals in the center of the display. All other pips spreading out to the left and right are the odd-order distortion products. In the example shown, the worst-case third-order product is 35 dB below PEP, the worst-case fifth-order product is 39 dB down and the worst-case seventh-order product is down 45 dB.

We test the transmitter in both upper and lower sideband; *QST* Product Reviews always show the worst case. Poor IMD performance can result in unnecessary interference to others on the band and illegal out-of-band products. The greater this number, the better. Typical modern transmitter should have IMD performance better than 25 dB below PEP for the worst case low-order product. High-order products must be much less.

Unwanted Sideband and Carrier Suppression

Single-tone audio-input signals can be used with the same setup as the IMD test to measure unwanted sideband and carrier suppression. To make this measurement, we set the single tone to the 0-dB reference line. The unwanted signal components can then be read directly from the display in dBc.

Unwanted sideband and carrier suppression is important to minimize bandwidth and nearby frequency interference. A modern transmitter should have at least 35 dB of suppression for these parameters. Better than 50 dBc is typical

Keying and Turnaround Tests

Our product review test battery includes three keying and turnaround tests:

- CW keying waveform test
- PTT to SSB/FM RF output test
- Transmit/receive turnaround test time

Each requires an oscilloscope and a keying test generator. Dual-trace scopes are best in most cases, and provide easy-to-read time-delay measurements between keying input and RF (or audio) output signals.

CW Keying Waveform

We measure the CW keying waveform and time delay using a keying test generator (see Figure 6). It is used to repeatedly key the transmitter at a controlled rate—typically 20 ms on and 20 ms off.

PTT to SSB/ FM RF Output Test

For SSB and FM voice modes, a PTT-to-RF-output test is similar to CW keying tests. It measures rise and fall times, as well as the on/off delay times. An audio generator is required in the SSB mode and the transmitter is keyed with the generator connected to the mike input. This can be an important test for some digital modes.

Transmit Receive Turnaround Time Test

Turn-around time is the time it takes for a transceiver to switch from the 50% fall time

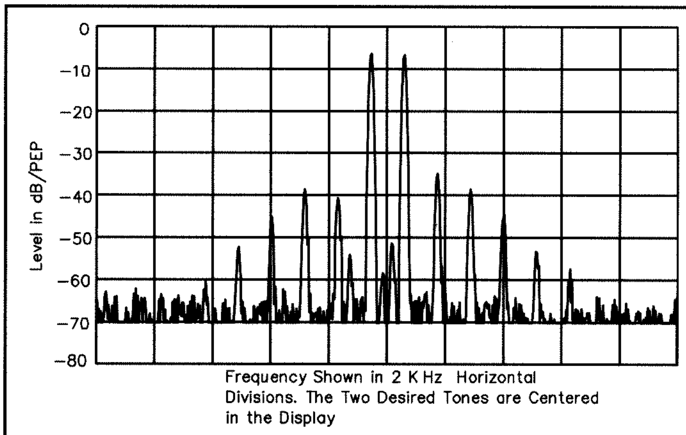

Figure 5—Transmitter IMD testing usually produces a plot like this.

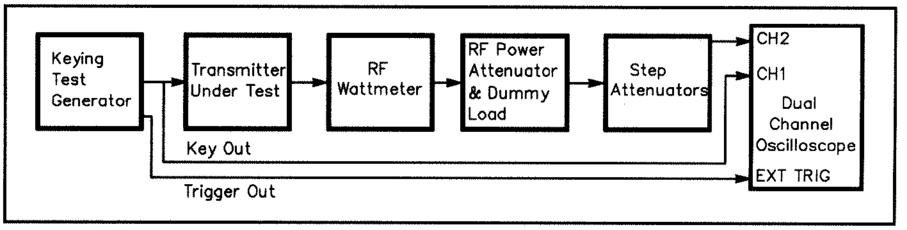

Figure 6—Block diagram of the CW keying waveform test.

Stepping Through the Process

Product Reviews are a team effort requiring a wide range of talent and dedicated individuals. The three primary players typically include the Product Review Editor, the Test Engineer and the Reviewer.

The Product Review Editor oversees the entire review and monitors its progress. The editor, with input from other Headquarters staff and members, first selects the equipment for review. His decision is usually based on anticipated member interest in the item, its uniqueness and its contribution to new technology. The editor then locates a suitable reviewer or reviewers, typically someone with product-related technical expertise. ARRL policy requires reviewers to be either members of the Headquarters staff (except for the Advertising Department) or Technical Advisors (TAs).

The ARRL Purchasing Department obtains all items for Product Reviews. They make every attempt to ensure that the integrity of all equipment is not compromised during its purchase. If a manufacturer, for example, could influence the actual specimen destined for a review, he or she might attempt to substitute a "gold plated" or specially tailored version of the product. To prevent this, the Purchasing Department obtains products off-the-shelf whenever possible and on a competitive-bid basis. They may solicit any number of dealers, and the sale is always made with the understanding that the manufacturer or distributor will not be notified of the purchase.

Whenever a procurement must be made through a manufacturer, or if a review item is particularly sensitive, Purchasing will obtain that item through an unidentified third party. As an added precaution, after making a purchase directly from the manufacturer, the review team compares that product's characteristics to a randomly selected sample.

Product Evaluation

Once an item arrives at Headquarters, the Product Review Editor submits it to the ARRL Lab for testing and evaluation. Depending on the product's complexity, this can take anywhere from several hours to a week. A typical HF transceiver, for example, is subjected to a battery of 21 to 25 tests, depending on its features. More tests are also possible if the product has any special features, functions or specifications. Products of this complexity typically require several days on the test bench.

Once the engineer completes all testing, it's the reviewer's turn. The reviewer is a volunteer who uses and operates the product as if it were his or her own, usually at home (or in his car, if appropriate). The review period usually lasts a month or more. Although doing a review can be fun, it's not easy. During this time, the reviewer must become thoroughly familiar with the product, its manual, its strengths, its weaknesses, and any problems that may have been encountered.

The reviewer's last step is to write a manuscript and forward it to the editor. The editor combines the edited text with any graphics and the test-result table. The table presents the measured performance characteristics along with the manufacturer's specifications and the FCC requirements. The data appears in a standardized format showing both the measured results and manufacturer's specifications.—*WA1SVF*

of a keying pulse to the 50% rise of audio output. Turn-around time is an important consideration with some digital modes. AMTOR, for example, requires a turn-around time of 35 ms or less for long-distance work.

Composite/Phase Noise Test

The composite-noise test measures the phase and amplitude noise, as well as any close-in spurious signals generated by a transmitter. We can assume, however, that nearly all of the noise observed during this test is phase noise. It's the primary noise component in any well-designed transmitter.

Frequency synthesizing circuitry is notorious for generating phase noise. Phase noise often manifests itself as broadband hiss caused by a phase-noisy oscillator chain in the transceiver. You'll hear it when you're tuned to a frequency adjacent to a strong signal.

Composite/phase noise is measured with a spectrum analyzer in the ARRL Lab—but not directly. Doing so would exceed the analyzer's dynamic range capabilities. (There's a tremendous relative difference between the strong desired signal and the low-level noise.) Added circuitry is required to remove the carrier while leaving the noise components unaffected.

The transmitter's CW output signal is converted down to a frequency near 0 Hz, using a signal generator as the local oscillator and an external mixer. This downconverted component of the original signal, as well as any unwanted heterodyne components that are generated by the downconversion process, are then filtered out, leaving only the downconverted signals that result from the noise and spurious signals that were present in the transmitted signal. The noise and spurious signals are then amplified (by a low-noise audio amplifier) and displayed on a spectrum analyzer.

Conclusion

This issue contains the 226th *QST* Product Review. The reviews have grown tremendously in popularity since they first appeared, and the future promises even more growth. New products and technologies will also spawn new challenges. (I can't even imagine what procedures and instrumentation will be required for the 500th review.) We look forward to meeting these challenges and maintaining the standard of excellence you expect in *QST* Product Reviews.