# Receiver Parameters for Contesters

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In some ways the receiver requirements of the contester tend to be the same as for the DXer, although there are some notable exceptions. For example, the contester requires similar signal-handling and selectivity capabilities, among others, but needs somewhat different ergonomics. The DXer can spend time adjusting various controls, while the contester will avoid anything that slows the rate. To this end, there is some argument about the efficiency of menu-driven controls.

Basic RF performance requirements remain somewhat similar for the DXer and the contester, however. This even applies at VHF/UHF, although sensitivity is more important at those frequencies than at HF. Because of the number of signals that have to be handled by the contester's receiver, *dynamic range* has become the magic buzz word. The problem is defining what is meant by the term.

In April/May 2002 *QEX* I wrote an article on the requirements for HF receivers based on a series of received signal-level measurements. The recent review of the Elecraft K3 (see "The Elecraft K3 — First Impressions," *NCJ*, September/October 2007) cites a claimed *blocking* dynamic range of 140 dB. This led me to question the utility of such performance and to prepare this article.

To check the validity of the 2002 measurements, which were made more or less at the peak of the sunspot cycle, they were repeated during a 24 hour portion of the 2007 CQ WW SSB contest.

The results on 7 MHz — "the worst case" in Europe, especially with all the broadcasters —indicate that a dynamic range of about 100 dB is still all that is needed. What is more important is where it starts. Having operated in a number of US locations over the last 25 years (both ends of California, Connecticut, New Hampshire, Iowa, Wisconsin and Illinois), I've always been struck by how relatively quiet the bands are — especially 40 meters — in comparison to how they sound in Europe.

There are four varieties of dynamic range to consider in any receiver. The most obvious is the range of wanted signals it can handle. This is a function of its gain control range — usually the AGC range — which generally easily exceeds 100 dB. The *blocking dynamic range* is the difference between the sensitivity and the input level at which receiver gain starts to decrease. The *intermodulation-limited dynamic range*, usually defined as two-thirds of the difference between noise floor and third-order intercept point, defines the performance of the receiver in the presence of multiple input signals. The *phase noise-limited dynamic range* is a function of the cleanliness of the frequency synthesizer or local oscillator(s). In conjunction with the selectivity-defining filters, it determines performance with respect to strong off-frequency signals. For further explanation of these parameters, see any recent edition of *The ARRL Handbook for Radio Communications*.

Intermodulation distortion (IMD) is reduced theoretically by a factor of 3 dB for each 1 dB the input signal is reduced. In practice, it can be anywhere between 1 and 4 dB, and it can vary depending on the receiver input level. The usual assumption of

**Table 1**
**Number of signals at various noise Levels in 2002 and in 2007 using a dipole at 7 MHz**

| | *Number of Signals, Jan 2002* | | | *Number of Signals, Oct 2007* | | |
|---|---|---|---|---|---|---|
| *Time UTC* | *–10 to –20 dBm* | *–20 to –30 dBm* | *–30 to –40 dBm* | *–10 to –20 dBm* | *–20 to –30 dBm* | *–30 to –40 dBm* |
| 00-01 | | | | | | |
| 01-02 | | | | | | |
| 02-03 | 1 | 12 | 12 | 2 | 3 | 6 |
| 03-04 | | | | 2 | 1 | 8 |
| 04-05 | | | | | | |
| 05-06 | | | | | 1 | 2 |
| 06-07 | | 1 | 4 | | 3 | 2 |
| 07-08 | | | | 1 | 1 | 3 |
| 08-09 | | | | | | |
| 09-10 | | | | | | 2 |
| 10-11 | | | | | | |
| 11-12 | | | | | | |
| 12-13 | | | | | | |
| 13-14 | | | | | | |
| 14-15 | | 1 | 1 | | | 2 |
| 15-16 | | | 2 | | | 2 |
| 16-17 | 1 | 3 | 18 | | 1 | 9 |
| 17-18 | 5 | 5 | 20 | | 5 | 9 |
| 18-19 | 2 | 8 | 23 | | 5 | 10 |
| 19-20 | 1 | 4 | 18 | | | 8 |
| 20-21 | 2 | 6 | 27 | | 3 | 13 |
| 21-22 | | 6 | 25 | | | 13 |
| 22-23 | 1 | 3 | 23 | | 3 | 11 |
| 23-24 | 2 | 5 | 7 | | | |

**Table 2**
**Noise floor and signal levels measured during a 20-hour period in 2007**

| | | *Number of Signals* | | |
|---|---|---|---|---|
| *Time UTC* | *Noise Floor (dBm)* | *–10 to –20 dBm* | *–20 to –30 dBm* | *–30 to –40 dBm* |
| 0215 | –96 | 2 | 3 | 4 |
| 0230 | –100 | | 3 | 6 |
| 0300 | –99 | 1 | 2 | 8 |
| 0315 | –98 | 2 | 1 | 6 |
| 0505 | –102 | | 1 | 2 |
| 0530 | –102 | | 1 | 2 |
| 0610 | –99 | | 3 | 2 |
| 0640 | –103 | | 2 | 2 |
| 0715 | –102 | 1 | 1 | 2 |
| 0730 | –100 | | 1 | 3 |
| 0945 | –100 | | | 2 |
| 1440 | –101 | | | 2 |
| 1530 | –95 | | | 2 |
| 1620 | –99 | | 1 | 8 |
| 1640 | –100 | | 1 | 9 |
| 1700 | –96 | | 5 | 7 |
| 1730 | –95 | | 3 | 9 |
| 1800 | –95 | | 5 | 10 |
| 1920 | –95 | | | 8 |
| 1935 | –102 | | | 5 |
| 2015 | –102 | | 3 | 11 |
| 2045 | –95 | | 1 | 13 |
| 2130 | –100 | | | 13 |
| 2200 | –98 | | 3 | 9 |
| 2215 | –97 | | 2 | 11 |

a 3 dB decrease in IMD for each 1 dB decrease in input level is a good starting point, however.

Phase noise-limited dynamic range (PNDR), sometimes called "reciprocal mixing," is more insidious, however. Phase noise is measured in terms of its power in a 1 Hz bandwidth, so the wider the receiver bandwidth, the greater the phase noise an off-frequency signal causes. It is increased by $10_{log}\ \Delta f$, where $\Delta f$ is the bandwidth. For a 2.5 kHz bandwidth then, the phase noise will be the phase noise at that particular offset from the carrier in dBc/Hz, plus 34 dB. What does this mean?

Assume a receiver with a phase noise performance of –130 dBc/Hz at an offset of 10 kHz and a 2.5 kHz bandwidth. The noise from a signal 10 kHz away from the tuned frequency will be $-130 + 10_{log}\ 2500$ or –96 dB. In other words, a signal 96 dB above the receiver noise floor will raise that noise floor by 3 dB. Unlike the case of IMD, reducing the signal by 1 dB only reduces the noise floor by 1 dB. Although in the case of IMD, two strong signals in the range –20 to –30 dBm produce a limited amount of interference, and many signals between –30 and –40 dBm produce little problem, the phase noise from these signals produces far more problems. Two strong signals between –20 and –30 dBm each will produce phase noise in the above case at between –116 and –126 dBm. Because there are two signals and the noise from each will add, however, the total noise becomes somewhere between –113 and –123 dBm.

Ten signals between –30 and –40 dBm each produce noise at –126 to –136 dBm. Because there are 10 signals, the total noise is in the range –116 to –126 dBm, adding to the –113 to –123 dBm already there. From all this, it can be seen that phase noise adds to the noise floor in an insidious fashion.

Straightforward gain compression or blocking does not present as much of a problem as phase noise, unless the performance is very poor. Measurements show that relatively few occasions exist where 0 dBm appears at the receiver front end, and when such a signal does appear, the phase noise effects cause problems first. There might be exceptions in a multi-multi site, but in those instances, bandpass filters are commonly used to protect the receiver(s).

### The Measurements

Table 1 shows the number of signals at various levels in 2002 and in 2007, measured on a dipole at 7 MHz. The basic noise levels, measured at an SSB bandwidth, correspond reasonably with what would be expected from the ITU-R curves for radio noise in a "quiet rural location." It's interesting to note that these have changed comparatively little in five years. The number of strong signals is significantly lower, however, reflecting worse propagation at the moment (solar minimum between cycles 23 and 24). The noise floor was measured using a Yaesu FT-102 — a receiver having very good phase noise performance, and the levels of the various signals within ±0.5 MHz using a spectrum analyzer. The use of a step attenuator between the antenna and the FT-102 demonstrated that IMD was not a problem, because the noise moved dB for dB with the attenuator.

It can be seen that the requirement for handling a greater number of strong signals corresponds with a higher external noise floor, and that the largest instantaneous difference between unwanted signal and noise is of the order of 92 dB. If phase noise is *not* a limiting factor, then the added noise caused by phase noise should be 10 dB better, or –102dB. In a 2.5 kHz bandwidth this corresponds to a spectral density of –136 dBc/Hz. Most modern transceivers will meet this within about 20 kHz of the tuned frequency.

### What about Receiver IMD?

IMD raises the receiver noise floor, because if you have enough signals, all IMD products tend to form noise, just as adding enough colors yields white light. With two signals, only one IMD product can fall on the wanted frequency, and it may be shown[1] that *n* signals will produce $1.5n^2 - 2.5n + 1$ possible products. The next question is: How good an intercept point is needed?

If we assume two signals at –10 dBm producing an IMD product at –115 (ie, below noise floor on CW), an input intercept point of +42.5 dBm is needed.

The received noise is high enough that a noise floor of –107 dBm to –110 dBm would appear adequate for SSB and some 10 dB lower for CW. Most modern HF receivers are capable of noise figures of around 10 to 15 dB, which corresponds to noise floors in a 500 Hz bandwidth of –137 to –132 dBm. So, an input attenuator of around 15 dB can be used without degrading sensitivity, and this will improve the input intercept point of the receiver by 15 dB. Thus the +42.5 dBm — statistically unlikely to be needed anyway, because the two signals have to be in the correct frequency and temporal relationships to cause interference — becomes +27.5 dBm. Note that this is an absolute worst-case analysis.

Although the larger number of IMD products from signals in the –20 to –30 dBm range is more likely to fall on the wanted channel, they will also be some 30 dB weaker. The reality is that an overall intercept point of around +17 or +18 dBm will suffice *most* of the time, unless really big antennas are used. In that case, the probable remedy is greater attenuation.

Because of CW's narrower bandwidth, IMD noise needs to be lower for this mode than for SSB, while phase noise needs to be better on SSB because of its effective integration over a wider bandwidth.

### So What Do We Need?

There's an old rule: "If you interfere with me, it's your lousy transmitter! If I interfere with you, it's your lousy receiver!" Your receiver may well be able to provide 70 dB rejection of a station 5 kHz away, but unless the IMD and phase noise from the other station are that far down, you *will* get interference. Very few transceivers are that good, especially those employing 12 V PA stages.

From the results depicted in the tables, it seems that something around 100 to 105 dB of total dynamic range is about all that most people will need. There may well be exceptions, especially where there is another amateur station close by, but this is not that common. The majority of modern equipment appears to offer this approximate level of dynamic range performance. The real question is where the dynamic range starts. An antenna attenuator appears to be a useful approach to having a relatively low-cost (and low-power) approach to the receiver front-end problem. High intercept points and low noise floors do not go well with low-power requirements. NCJ

[1] Chadwick, P. E., "Phase Noise, Intermodulation and Dynamic Range," RF Technology Expo, Anaheim, California, 1986.