Blocking Dynamic Range in Receivers

An explanation of the different procedures and definitions that are commonly used for blocking dynamic range (BDR) measurements.

By Leif Åsbrink, SM5BSZ

Introduction

Blocking dynamic range (BDR) may actually mean quite different things at different laboratories. Circumstances and what definition of BDR is being used affect performance comparisons among receivers in the presence of a strong, off-channel interfering signal.

Dynamic range in general is the ratio (or difference in decibels) between the weakest signal a system can handle and the strongest signal the same system can handle simultaneously — without an operator switching attenuators or turning volume potentiometers. The concept is quite general and by no means limited to radio receivers. Human sensors like the ears and the eyes have very large dynamic ranges, for example. The undamaged ear can detect a 1 kHz sound wave at a level of 10^{-12} W/m^2 while the upper limit is about 1 W/m^2, where we start to feel pain. The dynamic range of our ears is thus about 120 dB. Our eyes can detect the light from a star in the dark sky when about ten photons per second reach the retina, which converts to something like 10^{-13} W/m^2. The Sun, with its 300 W/m^2, does not damage our eyes unless we look straight into it.

Another example of dynamic range is the dynamic range of a vinyl music record. It may be on the order of 60 to 80 dB only, much less than the dynamic range of our ears.

The above examples show the dynamic range for a single signal. The corresponding dynamic range for a receiver is not particularly interesting. It relates the strongest on-channel signal the radio can handle, without serious distortion (or damage), to the weakest signal it can receive. We may observe that a local very strong SSB station sounds severely distorted when we tune to it even though the same station does not cause any interference when we listen to other stations on the same band. This is not likely to be any problem to a radio amateur. The example is given just to show the wide meaning of the concept of dynamic range.

The rest of this article will deal with the dynamic range pertinent to situations where a single strong signal is causing interference to the desired sig-

Jaders Prastgard
63505 Eskilstuna
Sweden

nal. This kind of dynamic range — blocking dynamic range (BDR) — may be the most important figure of merit for some radio amateurs while others may find that the interference created by the simultaneous presence of two or more strong signals is the limiting factor. In such cases, the intermodulation-free dynamic range is the number to look for when selecting what receiver to use.

The intermodulation-free dynamic range is discussed frequently in amateur publications. It may be technically challenging to measure properly but there is no controversy about what it means.

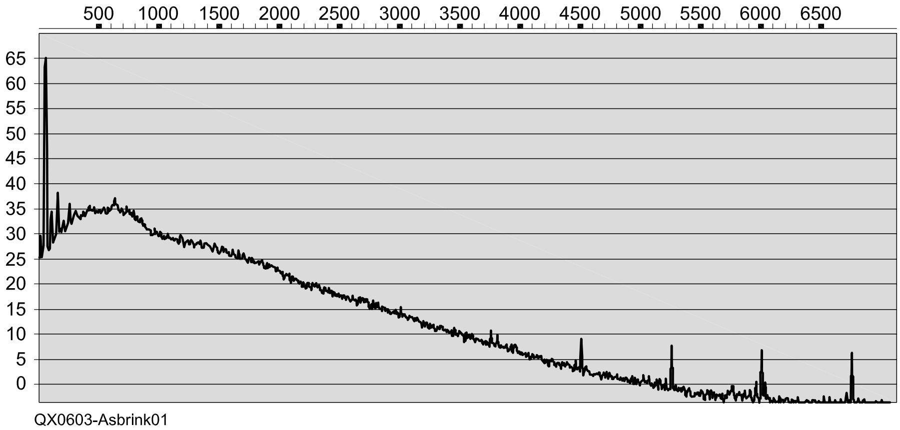

Figure 1 — The loudspeaker output from a Yaesu FT-1000D transceiver with a very leaky transformer close to it causing a fairly strong, but still absolutely inaudible, 50-Hz hum signal.

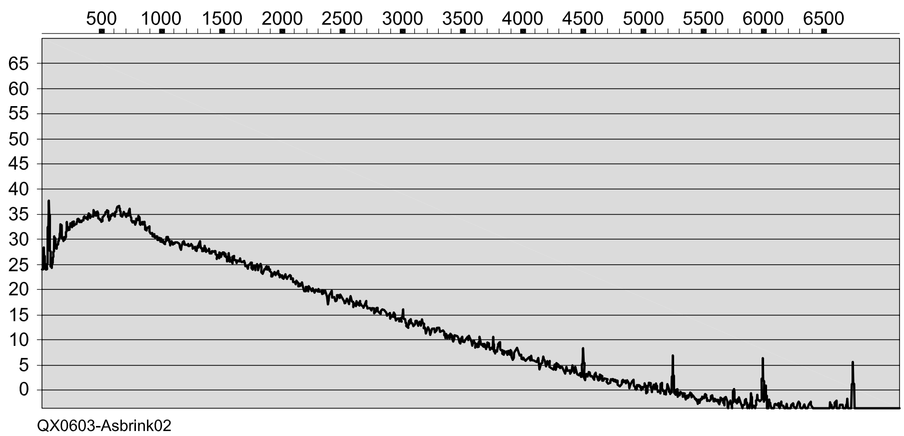

Figure 2 — The loudspeaker output from an FT-1000D with a dummy load at the antenna input. All settings are identical to those of Figure 1.

The Weakest Signal

The weakest signal a receiver can handle is usually taken as the total noise power that reaches the output as measured with a true RMS voltmeter. This means that the low end of the dynamic range is taken as the signal at the antenna input that doubles the output power from the receiver. The measurement has to be done without AGC, and the doubled power output means that the weak signal power equals the noise power at the output. Any room-temperature resistor produces a noise voltage that would transfer –174 dBm/Hz to a matched cold resistor. With the RF preamplifier disabled, a typical HF receiver may produce 20 dB more noise with a room-temperature dummy load at the input than would an ideal receiver that would not add any noise of its own (only amplifying the noise from the dummy load). A receiver adding 20 dB of noise is said to have a noise figure of 20 dB. If the bandwidth were 500 Hz, the noise floor referenced to the antenna input would be –174 + 20 + 27 dBm = –127 dBm. (Note that $10 \log 500 \approx 27$.) This signal level is sometimes improperly called MDS (minimum discernible signal) for such a typical receiver, even though a CW operator would easily copy a signal that is 10 dB weaker.

Picking the noise floor as the low end of the dynamic range is typical for all dynamic ranges, not only in radio receivers. The noise floor power is proportional to the bandwidth and therefore a receiver will have 10 dB more dynamic range when measured at a bandwidth of 200 Hz compared to when it is measured at a bandwidth of 2 kHz. It is the same receiver, though, and the dynamic range differences that depend on bandwidth should not be included when different receivers are compared.

For that reason, receivers should be measured at a standardized bandwidth. It could be 1 Hz, 500 Hz, 2.4 kHz, or something else. Since there is no de-facto standard, each laboratory has to specify what bandwidth they use to allow correct comparisons to results from other labs.

The Strongest Signal

There are two vastly different BDR definitions that may give completely different, although perfectly reproducible, results. Michael Tracy, KC1SX, described them in *QST*.[1] He writes: "BDR as a lab measurement normally refers to the point at which the weak (presumed desired) signal is reduced by 1.0 dB ('blocked') by the presence of a strong (presumed undesired) signal." The procedure followed at the ARRL Lab for BDR measurements is set up to find the point of 1 dB gain loss.[2] A quite different definition defines the strong signal as the signal that causes a predetermined degradation of signal-to-noise ratio (SNR) for a weak signal (1 dB or 3 dB). In some cases, the two different definitions may give the same result; but in other cases, the resulting BDR may differ by 40 dB or more.

The two different phenomena that lie behind the two definitions are called *saturation* and *reciprocal mixing*, although the physical phenomena in the receiver may be something else. A receiver that uses front-end AGC to avoid saturation, and that compensates for the gain loss after the bandwidth-defining filters, will lose sensitivity when the off-channel signal turns the front-end AGC on. As a result, the noise

[1]Notes appear on page 39.

floor will increase to cause a reduced SNR for a weak signal even though the total gain is unchanged. An RF amplifier that is supplied with inadequately decoupled dc voltage or that has a high impedance for audio frequencies on the base and very low impedance for audio frequencies on the emitter will amplitude-modulate the strong off-channel signal. Both these examples would be classified as reciprocal mixing even though the mechanism is quite different from what the classification implies.

The ARRL Lab definition of BDR through the procedure in Note 2 translates to this definition in plain English: "The BDR is the amount above the noise floor for an off-channel signal that degrades the receiver for strong signals." It may be appropriate for crowded HF bands where the desired signal typically is high above the internal noise floor of the receiver. A receiver with a very high number according to this definition is convenient to use because the operator does not have to use an attenuator to shift the dynamic range up and down as conditions change. Radios that reach 150 dB in the ARRL test reports are not uncommon. The other definition translates to this in plain English: "The BDR is the amount above the noise floor for an off-channel signal that degrades SNR for a very weak signal." This BDR is typically about 100 dB.

The first definition is similar to the dynamic range for ears and eyes as defined above. It is the total useful signal range but it does not contain any information about the ability to detect a weak signal in the presence of a strong undesired signal. The second definition is the true dynamic range in the case of a single dominating off-channel signal. It defines *the strongest signal* that may be present simultaneously while *the weakest signal* is detected.

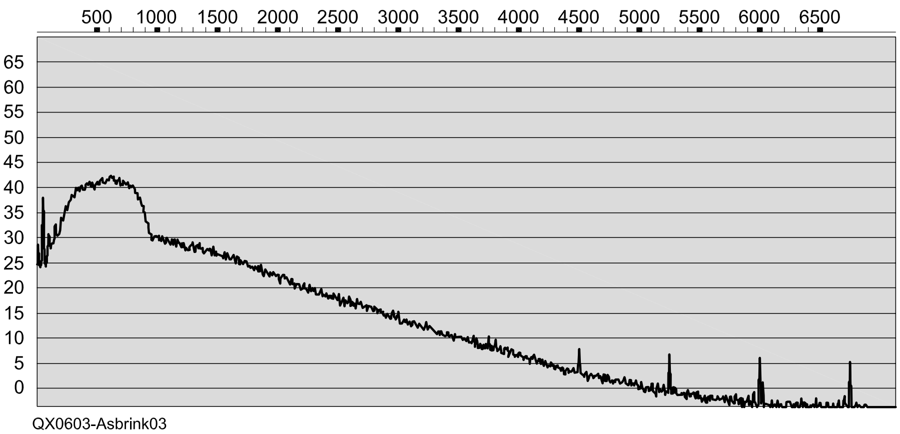

Figure 3 — The loudspeaker output from an FT-1000D with a noise source at the antenna input. All settings are identical to those of Figure 1.

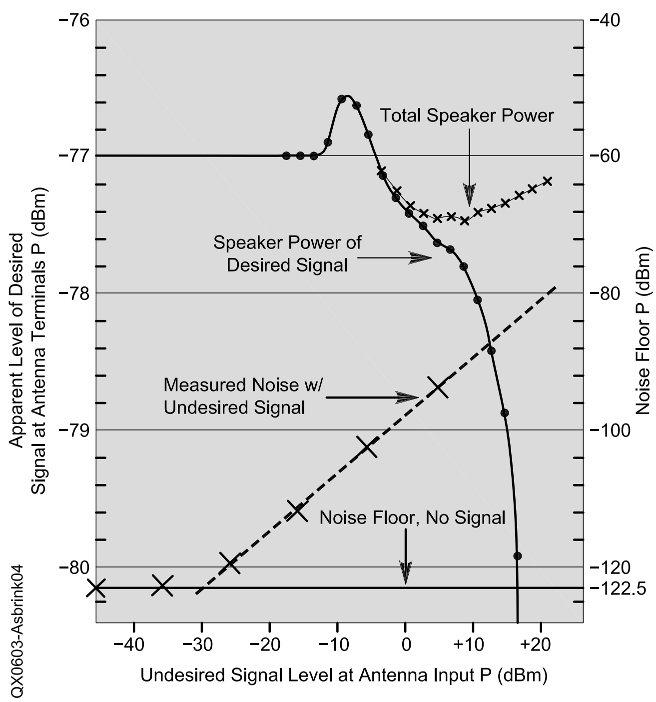

Figure 4 — The loudspeaker output of an FT-1000D with a 14.138-MHz on-channel signal at a level of –77 dBm (10 dB below the on-channel CP1) as a function of the off-channel signal level at 14.158 MHz. The dots are the on-channel signal level measured at 5 Hz bandwidth, the small crosses are the power (10 Hz to 24 kHz) and the big crosses are the power measured without the on-channel signal.

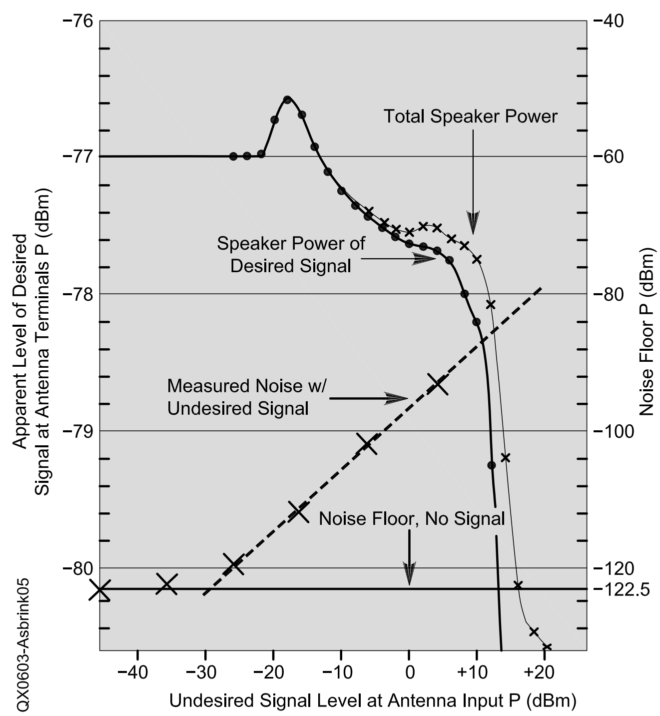

Figure 5 — The loudspeaker output of an FT-1000D with a 14.178 MHz on-channel signal at a level of –77 dBm (10 dB below the on-channel CP1) as a function of the off-channel signal level at 14.158 MHz. The dots are the on-channel signal level measured at 5Hz bandwidth, the small crosses are the power (10 Hz to 24 kHz) and the big crosses are the power measured without the on-channel signal.

Measurement Accuracy Issues with the Weakest Signal

Finding the noise floor by connecting an RMS voltmeter to the audio output may give inaccurate results. The human ear does not respond well to hum from the ac mains frequency of 50 or 60 Hz. Figure 1 shows the loudspeaker output from a Yaesu FT-1000D HF transceiver that had a very leaky transformer placed close to it. This pure 50-Hz hum is absolutely inaudible despite the fact that it is about 30 dB above the noise floor in the spectrum, which has a bin width of 12 Hz. This inaudible 50-Hz hum dominates the loudspeaker signal. It actually lifts the reading of a typical RMS voltmeter by 12 dB and its presence degrades the MDS value by the same amount. The FT-1000D performs absolutely as well with the leaky transformer next to it; there is no audible difference whatsoever and the huge sensitivity difference is an artifact of the measurement procedure.

Even without the leaky transformer, there are some low-frequency spurs in the FT-1000D, as can be seen in Figure 2. This signal is 27 dB weaker than the 50-Hz hum caused by the leaky transformer, so it is only about 2.5% of the total power that reaches the loudspeaker and the error it introduces is only about 0.1 dB. Figures 1 and 2 were recorded in CW mode with the FT-1000D bandwidth set to 500 Hz. It is pretty obvious from Figure 2 that noise outside the desired bandwidth gives a noticeable contribution to the total power seen by an RMS voltmeter. The passband is well visible in Figure 3, where a noise source is connected to the antenna input. From Figure 3 we can estimate the noise floor in a 500-Hz window above the passband to be about 28 dB on the relative dB scale. From Figure 2, we can read the noise floor within the passband as 35 dB. That means that the noise power in the range 900 to 1400 Hz is only 7 dB below the noise power within the desired passband, and therefore causes a reading that is about 20% higher than it would be if a selective voltmeter were used. The noise above the passband is well audible, but it is not really disturbing and it does certainly not degrade the effective sensitivity of the FT-1000D by as much as 20%, as the MDS value would indicate.

By use of exactly the same settings as for Figures 1 to 3: Preamp off (IPO), AGC off, max RF gain, 50% AF gain, 500 Hz bandwidth in CW mode, MDS was measured at 14.120 MHz as described in Note 2 using an RMS voltmeter that was flat from 10 Hz to 24 kHz. The measurement was made with and without the very leaky transformer that makes the difference between Figures 1 and 2. The results are shown in Table 1, which shows the noise power density (NPD) referenced to the antenna input. These settings form kind of standard settings for a transceiver test and they are used in all measurements presented in this article.

The noise power density is 22.2 dB above –174 dBm/Hz, which means that the noise figure of this particular receiver is 22.2 ±1.2 dB with the controls set as in this test. The noise power density can be used to compute the noise power that would pass an ideal filter with a bandwidth of 500 Hz. The result is –124.8 dBm which is 2.3 dB better than the result obtained in the MDS measurement with the RMS voltmeter. The noise power density is a selective measurement and any 50-Hz hum does not affect it at all.

Since the actual detection is done in a much narrower bandwidth than 500 Hz either by machine or by a human being, I argue that the noise power density in the vicinity of the signal is the true noise floor for an MDS measurement. Any wideband noise, hum or high-frequency audio signal that may add several dB to an RMS voltmeter measurement is insignificant — and in those cases where it is audible, there should be a note saying, "This radio suffers from hum or high frequency noise." It may be appropriate to mention here that the mains hum originating in poorly filtered power supplies typically is a pulse train at twice the mains frequency. Contrary to the magnetically coupled pure 50/60-Hz sinewave, 100/120-Hz pulse trains are well audible.

The noise power density can be measured easily with a spectrum analyzer that will give the noise surrounding a carrier in dBc/Hz. With a carrier of known power at the antenna input, the noise power density comes out directly.

Measurement Accuracy Issues with the Strongest Signal

If the BDR definition in terms of SNR loss for a weak signal is chosen, there are no accuracy problems because the definition requires SNR for a weak signal to be monitored. The definition in Note 2, where the reading of an RMS voltmeter is monitored while the off-channel signal is increased, that may lead to unexpected results sometimes.

To illustrate the problems, the BDR of the FT-1000D was measured with the procedure in Note 2. The loudspeaker output was also monitored on a spectrum analyzer on which the level of the on-channel signal was measured. The on-channel response of the FT-1000D is linear from the noise floor at –122.5 dBm up to –70 dBm. The point of 1-dB compression is –67 dBm. Following the procedure in Note 2, the on-channel signal level was set to –77 dBm. Figures 4 and 5 show the result of the measurement at a frequency separation of 20 kHz above and below the desired frequency.

An inspection of Figures 4 and 5 shows that the reciprocal mixing noise is equal to the noise floor power (MDS) for an off-channel signal level of –26 dBm regardless of whether the on-channel signal is above or below the off-channel signal. The dynamic range is therefore –26 dBm – (–122.5 dBm) = 96.5 dB. If the noise floor (MDS) were measured by means of the noise power density, the same dynamic range would result because then the reciprocal mixing noise power density would equal the FT-1000D noise power density at a signal level of –28.3 dBm.

The FT-1000D has lost sensitivity by 3 dB at a signal level of –28.3 dBm although the gain is unaffected up to –22 dBm (20 kHz below) and –14 dBm (20 kHz above) an off-channel signal. The first nonlinear phenomenon that happens is that the gain increases. The point of 1-dB compression as measured with a selective voltmeter is +8 and +10 dBm, respectively. When measuring the loudspeaker output with an RMS voltmeter, 1 dB compression occurs at +12 dBm when the on-channel signal is 20 kHz above the off-channel signal; but when the on-channel signal is 20 kHz below the interference,

Table 1

MDS measured with a wideband RMS voltmeter and noise power in 1 Hz bandwidth as measured with a spectrum analyzer in the loudspeaker output.

	Transformer	
	ON	*OFF*
MDS(dBm)	–110.3	–122.5
NPD(dBm/Hz)	–151.8	–151.8

the reading of the RMS voltmeter remains constant within 0.5 dB all the way up to an interference power level of +20 dBm (100 mW). It would probably remain constant at much higher input levels until the front end was damaged.

It should be quite clear from Figures 4 and 5 that the procedure used up to now at the ARRL Lab may give very inaccurate results because the RMS voltmeter does not distinguish between the desired signal and noise. Using the average from 20 kHz above and 20 kHz below, BDR as defined from the point of 1-dB saturation is 131.5 ±2.2 dB above MDS using the ARRL definition for MDS, or 133.8 ±2.2 dB when MDS is defined in terms of the noise floor power density. The much higher values reported in *QST* is caused by the use of an RMS voltmeter.[3]

Conclusions

When using the concept of dynamic range in Amateur Radio, we should refer to signals present simultaneously at the antenna input. This means that BDR — implying that blocking means that the ability to copy the desired signal as blocked by a strong off-channel signal — for the FT-1000D is 96.5 dB. When the desired signal is placed at –77 dBm (see Note 2), the point of saturation, which was +20 dBm in *QST* (see Note 3) has to be compared to –77 dBm for a dynamic range of 97 dB, not to the MDS value measured under quite different circumstances. The value of 150 dB reported in *QST* is not the dynamic range for two simultaneously present signals. It is the dynamic range for a single signal and is not of much interest to a radio amateur. The point of 1-dB saturation is 133.8 dB above the noise floor, which means that the operator can place the system noise floor up to 37 dB above the internal noise floor of the FT-1000D without serious problems because of gain compression on strong signals. This leaves adequate margin for a VHF enthusiast who uses the FT-1000D together with a transverter that might lift the noise floor by 10 dB and a mast mounted preamplifier that has to lift the noise floor by another 16 dB to get a system noise figure that is within 0.1 dB of the preamplifier itself.

Both BDR definitions convey important information on the usefulness of a receiver. ARRL is considering the use of an AF spectrum analyzer and the reporting of both measurements in future product reviews.

Editor's note: Leif's observations about human vision form an apt analogy to receiver dynamic range. The baseball outfielder who drops a fly ball when the Sun shines in his eyes knows about blocking effects. He employs an attenuator (his sunglasses) to reduce the interference but the attenuation may, in fact, put the image of the desired signal (the baseball) below his noise floor. That's the same as what a front-end AGC does to your receiver: It raises the noise figure and may actually make it harder to recognize the desired signal.

The point is that you must measure the small-signal end of dynamic range under the same interference conditions used to measure the large-signal end. Only then do you truly measure dynamic range. In addition, the bandwidth in which noise-floor power is measured must be accurately known. It's not enough to dial in a nominal 500-Hz filter and assume its effective bandwidth is exactly 500 Hz. An uncertainty of ±150 Hz in bandwidth would result in additional uncertainty of at least 2.6 dB in noise powers between receivers. Passband and stopband shapes affect effective bandwidth. You cannot go by the 3-dB points alone.

As early as 1998, we noted the difference between blocking dynamic range and reciprocal-mixing dynamic range on these pages. Now it is a matter of how previously measured data are corrected or models recharacterized, and procedures updated, including measurement uncertainties. To the best of our abilities, we must adopt procedures that accurately measure real effects in receivers.

A 3rd-order IMD dynamic range measurement on an analog-to-digital converter, for example, may be superfluous when performance is dominated by overload instead. Likewise, another measurement, such as BDR, should not be characterized as "noise-limited" when the noise contribution can be discerned separately from the modeled effect. □□

Notes

1 M. Tracy, KC1SX, "Product Reviews — In Depth, In English," *QST*, Aug 2004, pp 32-36.

2 Ed Hare, KA1CV (now W1RFI), "Swept Receiver Dynamic Range Testing in the ARRL Laboratory," *QEX*, Jun 1996, p 16.

3 Product Review, *QST*, Mar 1991, pp 31-36.

Leif was born in 1944 and licensed in 1961. He holds a PhD in physics and worked with research on molecular physics for 15 years at the Royal Institute of Technology. Since 1981, he has been running his own company developing various electronic products. He is the inventor of the magnetic intermodulation EAS system now owned by Checkpoint. Leif is essentially retired and works mainly with Amateur Radio related technical projects.