All about Receiver Sensitivity

Learn about the different ways receiver sensitivity is measured and specified, and what each specification really means.

BY JOSEPH J. CARR

George was both a professional communications technician and a ham-radio/shortwave enthusiast. He had a brand new general-coverage shortwave receiver that was top-of-the-line for the day (I won't say what model—it'd date me!). George claimed that it was the "... most sensitive radio made . . ." and that it would "... pick up a breath of hot air..." way down in the mud.

While such enthusiastic endorsements are somewhat useful (especially when made by an experienced person), they also evade the question of just what "sensitive" means. In this article we'll provide a useful answer to that elusive question. First, though, let's look at the chief factor that limits receiver sensitivity.

Noise. A radio receiver is a device that must examine the radio portion of the electromagnetic spectrum to find and detect the desired signal. It must also reject undesired signals, man-made noise, and natural noise.

The bottom-line limit to signal detectability is noise, which consists of randomly occurring signals of varying power (or voltage) levels. For that reason noise is handled statistically in radio math. It is necessary to talk about noise in a root-mean-squared (rms) manner because of its randomness. To the listener, noise sounds like a "hissing" tone. A good example of noise can be heard by tuning any receiver (TV, FM, AM, VHF, etc.) to a frequency that is between active stations (with the mute function off, if one is present).

Noise can come from several different sources. There is incoming noise that is picked up by the receiver antenna (for example, noise generated by galactic and solar activity), and noise contributed by the fact that the amplifiers and other active devices in the receiver are not perfect (these are specified by the noise figure of the receiver).

There is also a certain elementary or basic noise contribution that will be present no matter what other noise is present. If the antenna input is terminated in a resistance that is equal to the input impedance so that no external noise enters the system, and the "ideal" internal circuits are so perfect that they contribute no additional noise signals, there will still be a level of noise present in the output. Why? Because of thermal agitation of electrons in the resistance of the input circuitry. In most cases, the input impedance of a receiver is either 50, 75, or 300 ohms, and R would have a value equal to one of these values (as appropriate). The elementary noise is:

$$P_n = 4KTBR$$

Where P_n is the noise power (in watts) at the receiver input, K is Boltzmann's constant (1.38×10^{-23} Joules/°K), T is the temperature in degrees Kelvin, B is the bandwidth in hertz (Hz), and R is the resistance in ohms. To find the noise voltage, take the square root of that equation. For a 1-MHz bandwidth, 50-ohm resistance system, P_n is on the order of 10^{-13} watts, so the noise from this source is not a large number. However, it also cannot be overcome no matter how "ideal" the receiver is.

Figure 1 shows the detection problem graphically. Given a noise signal with an average amplitude N, there are three conditions for signal detection shown. First, the signal at A is undetectable because it is below the noise floor (*i.e.,* it is buried in the noise). Second, signal B is barely detectable because it is at the threshold of noise (*i.e.,* it has an amplitude that is at or near the average noise amplitude). Finally, we have a signal at C that is easily detectable. It's amplitude is clearly above the noise threshold, so the radio receiver will have no trouble detecting the signal and producing a useable output.

What's Sensitivity? A radio receiver's sensitivity is a measure of its ability to pick up extremely small signals. More specifically, the sensitivity is defined as the amount of signal required to achieve a certain condition at the output. So, can we define acceptable sensitivity as the ability to pick up and output very weak signals? No, not quite. First we need to know *how weak* is very weak, and how clean the output should be. Both are highly dependent on the nature of the input signal (AM, FM, SSB, etc.) and the type of output desired (voice, Hi-Fi music, dots and dashes, etc.).

Put another way, a sensitivity specification is based on an operational definition, rather than fundamental physical principles. So sensitivity measurements are highly contextual. They depend on the the type of modulation and the desired output quality.

The nature of the signal (or type of modulation) will help determine the theoretical limits of a receiver's sensitivity (or "how high is up"). The desired output will determine what is *acceptable* sensitivity. For a television receiver, minimal sensitivity should produce a snow-free picture. For an AM or FM broadcast receiver, good sensitivity should produce a clear version of the voice or music signal that modulated the transmitter. For a radiotelephone-communications receiver, the tonal quality or fidelity is less important than it is for a broadcast receiver because only a minimally acceptable clarity of communications is required.

Since the definition of what is "sensitive" depends on the type of receiver in question, how sensitivity is measured depends on the receiver in question. There are many different methods used to measure sensitivity, each suitable for a different form of communication. If the wrong method is used for a certain receiver, it can produce misleading results.

Sensitivity in Context. The sensitivity should be measured with respect to other important parameters such as bandwidth or input impedance to have any relevant meaning. As you might have guessed, which parameters are important and their actual values depends on the context: once again, the signal type and the desired output.

Let's take an example to show the importance of different parameters when measuring the sensitivity of a communications receiver. It might have the sensitivity specified for a given signal-to-noise ratio (or SNR). The SNR can be computed by actually dividing the power of an output signal by the power of the noise present in it, or, more commonly, by computing it in decibels (dB) like this:

$$SNR = 10LOG((S + N)/N)$$

or, expressed in voltage units:

$$SNR = 20LOG((S + N)/N)$$

Typical receiver sensitivity specifications call for various levels of SNR (6 dB, 10 dB, 12 dB, or even 20 dB).

Simple measures of sensitivity are actually not straight SNR, but rather are signal-plus-noise to noise measurements. A more mathematical representation would be:

$$(S + N)/N$$

but that ratio should be converted to decibels. A more sophisticated method used, especially in FM receivers, overcomes some of the limitations of that measurement. These measurements are called SINAD measurements, which stands for "signal plus noise and distortion" and are the principal means for specifying some receiver sensitivities. SINAD—or $(S + N + D)/(N + D)$ converted to decibels—measurements are generally more meaningful than simple signal-plus-noise to noise measurements.

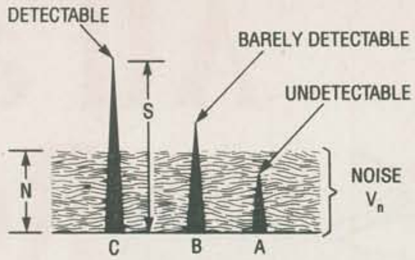

Fig. 1. Here are three signals with some noise. Signal A is undetectable, signal B is marginally detectable, and signal C is easily detectable.

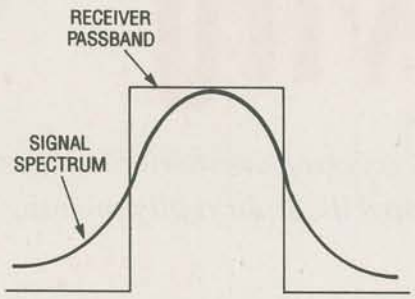

Fig. 2. An ideal match between signal bandwidth and receiver bandwidth results in maximum sensitivity with little or no distortion.

Ways of Specifying Sensitivity. Obviously, noise is clearly a factor in the sensitivity specification of a receiver when measured in this fashion. However, the amount of noise present at the input is directly proportional to the bandwidth of the selective filter of the receiver. Therefore, the bandwidth of the receiver must also be considered. Ideally, the receiver-selectivity controls, which usually adjust the IF amplifier filter, are set to the instantaneous bandwidth required to correctly receive and demodulate the desired input signal; no more, no less (see Fig. 2). If the bandwidth is too high for the received signal, then the noise present goes up, and sensitivity (in terms of SNR) goes down.

Figures 3A and 3B show two different scenario's in which two receivers have the *same* bandwidth, but *vastly different sensitivities.* Keep in mind that the noise term is proportional to the area under the passband curve. Figure 3A has a relatively decent shaped bandpass characteristic, with bandwidth BW. But, because the receiver with the bandwidth curve shown in Fig. 3B has a very poor filter that causes peaks in the passband, (definitely **not** desirable), it can actually produce a lower noise figure. Here, we have "apparent sensitivity" at a cost of significant distortion of the spectrum of the received signal; not good!

To prevent any "creative" specification writing that might result from taking advantage of such situations, several different ways of determining sensitivity have become standards (or near standards). Each "standard" depends on the signal type, the desired signal quality, and usually takes into account any additional important specifications (like bandwidth and input impedance).

For example, in performing a SINAD sensitivity test, one must take into account the signal level, noise level, and the output distortion. Figure 4 shows a typical test set-up. The FM signal generator must be modulated by a 1000-Hz tone to a level of 60% of the peak deviation acceptable to the receiver (peak deviation is typically 5 kHz on communications receivers and 75 kHz on broadcast receivers). The audio signal source must have a very low inherent total harmonic distortion (THD) level. The audio output of the receiver is set to 50% of its rated maximum power level.

The output voltage level is measured under two conditions in the SINAD test. First, the level is measured with switch S1 in the A position. This signal represents the signal, noise, and distortion components. Next, the switch is set to B, so that a 1000 Hz notch filter is in the signal path. This filter takes out the modulation signal (S), leaving only the harmonic distortion and noise components. The SINAD sensitivity is the number of microvolts that will yield an $S + N + D/N + D$ figure of 12 dB. Typical values for 12 dB SINAD sensitivity are stated as 0.1 μV to 0.2 μV.

Another way of specifying sensitivity is the "dBm method." It indicates the input power required to achieve the desired

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SNR in decibels relative to 1-mW dissipated in a 50-ohm resistive load. In other words, 1 mW dissipated in a 50-ohm load represents a signal level of 0 dBm. Typical sensitivities specified in dBm range from −60 dBm to −120 dBm or so. The dBm level of any given signal with power P_{sig} is found from:

$$dBm = 10LOG(P_{sig}/.001)$$

If you want to know the amount of power that a given dBm level represents:

$$P_{sig} = .001 \times 10^{dBm/10}$$

If you need to know how much signal voltage is represented by a specified dBm level, then use:

$$V_{sig} = 7.07\sqrt{P_{sig}}$$

Another unit, the dBmv, is used in some TV-antenna and cable-TV systems, and refers to a measurement in which all signals are relative to a reference level of 1 mV across a 75-ohm load (0 dBmv). The 1-mV level is considered to be the point at which the picture is snow-free.

Sometimes sensitivity is specified in microvolts (μV). This method simply states the number of microvolts, impressed across the input impedance of the receiver (usually 50 ohms), required to achieve the required signal-to-noise ratio.

AM sensitivity is usually specified to achieve a standardized SNR (10 dB is common) using a given percentage of sinusoidal amplitude modulation (30% is typical), of a given audio frequency (400 and 1,000 Hz are common), with the receiver bandwidth set (if it is adjustable) to a certain point. For plain AM receivers, the bandwidth can be just enough to pass the highest significant AM sidebands. However, for broadcast and communications receivers a bandwidth of 6 kHz is common and 8 or 10 kHz for broadcast models. Sensitivities of 1 μV are common on AM receivers.

The sensitivity of a receiver set for SSB or CW operation is generally considerably higher than the same receiver set to the AM mode of operation. One reason for that is that a SSB/CW signal is directly converted to audio and does not pass through an envelope detector as does an AM signal. Second, the bandwidth of the signal is considerably less. The latter factor means that the receiver bandwidth is less, so the noise term (which is a function of bandwidth, among other things) in SNR is also less. Typical values for a 10 dB SNR are 0.02 to 0.1 μV.

An FM receiver must be tested with an FM-signal generator set to some value of frequency deviation that approximates the bandwidth of the typical signals received. For example, a scanner or other FM or PM communications receiver may require a signal that deviates on the order of 2.1-kHz rms, or 3-kHz peak, at an audio rate of 1000 Hz.

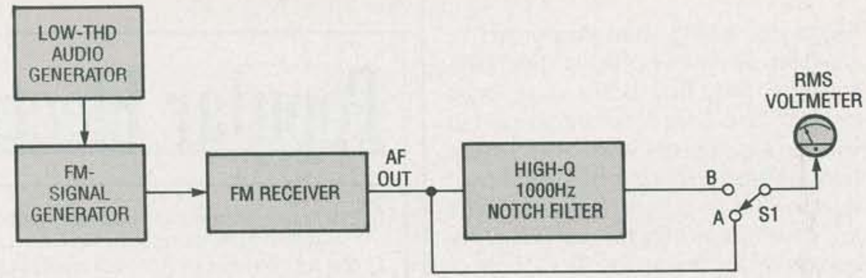


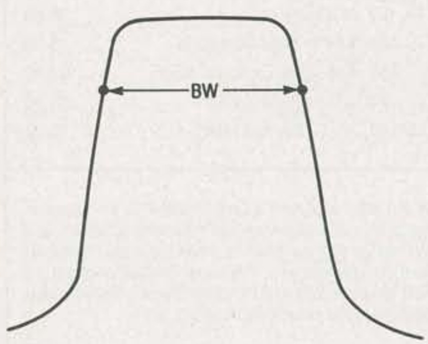
Fig. 4. This is a block diagram of a SINAD sensitivity test set-up. The test is performed in two parts: first with a filter in the signal path and then without a filter.

FM-receiver sensitivity is also sometimes specified for the signal level required to cause 20 dB of output-level "quieting." This method is preferred by some technicians who lack an FM-signal generator because it can be performed with just a CW-signal (*i.e.*, unmodulated) generator. The "quieting" occurs when an unmodulated signal is applied to the input of an FM receiver. Tune the receiver off-channel, and measure the rms value of the output noise ("hiss") voltage. Next, tune a signal generator to the same frequency, and increase the output level until the noise output voltage drops 20 dB. The input signal level that produces this result is called the "20-dB quieting sensitivity," and values on the order of 0.15 μV to 0.25 μV are typical.

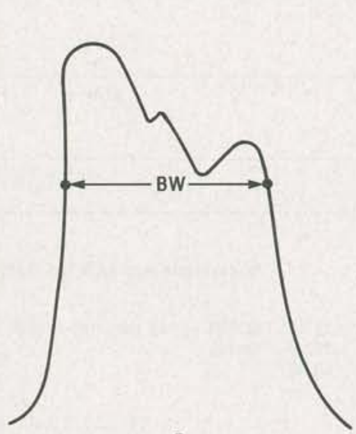
A pulse receiver, such as used in radar and certain other applications, may be specified for a certain "tangential" sensitivity level. This sensitivity is the pulse amplitude that exactly doubles the noise-signal amplitude. Thus, the pulse level is equal to the rms level of the noise in the system.

Conclusion. Receiver sensitivity varies from one model to another, even when the two receivers are nearly the same, for several reasons. One reason is that modulation and bandwidth make a difference. Hence the difference between AM sensitivity, SSB sensitivity, CW sensitivity, and FM sensitivity on exactly the same receiver. Once you appreciate the differences, receiver specification sheets will not be a mystery. Also, you will be able to spot creative "spec" writing on the part of some manufacturers.

For example, a receiver that is used mostly for AM-shortwave listening might be promoted using its CW sensitivity. Why? The narrower CW bandwidth makes the receiver look better. If you are aware of such things you'll know how to avoid comparing apples with oranges when considering the merits of a receiver. ■



A



B

Fig. 3. The pass-band of a good receiver has flat response across the tuned bandwidth (A). The pass-band of a "dog" receiver (B) might yeild a better signal-to-noise ratio.