Radio Receiver Characteristics

In Chpt. 2 of the text we discuss several receiver characteristics of importance. This discussion is applicable to simple receivers that monitor a single frequency for a single modulation. It is equally applicable to receivers that monitor several bands for several modulations. Before we get into the individual blocks and their effects let's assume we have a receiver and would like to characterize its performance.
Obviously the performance for a particular application will depend substantially on the antenna and its environment and on how well it is matched to the receiver. For now, however, we focus in only on the receiver.

**Sensitivity**

This provides an indication of how weak a received signal may still be and provide a useful (specified) output from the receiver. (Note that there are a number of factors that affect the quality of the signal output from the receiver. This is just one.)
General setup used to measure sensitivity:

(Figure from Fig. 2.1 of text.)

- Measurement of AM sensitivity

A typical AM sensitivity definition requires that when the input signal is sinusoidally modulated w percent at x Hz, the receiver bandwidth (if adjustable), having been set to y kHz, shall be adjusted to
produce an output S/N of $\approx$ 2 decibels, and the resulting signal generator open-circuit voltage level shall be the sensitivity of the receiver.

Example:
Assume we wish to measure the AM sensitivity of an HF receiver at 29 MHz.

Steps:
1) Setup the receiver
   a) Set the carrier frequency.
   b) Select 6kHz bandwidth.
   c) Select automatic or manual on the gain control.
   d) Set AGC time constant to normal AM.
e) Turn BFO off.
   ↑
   Beat Frequency Oscillator

f) Set \( f_{\text{rf}} \) gain control (if manual) to prevent overload.

g) Set audio level to appropriate value.

[Notice the number of settings involved. A high quality communication receiver will permit adjustments of the parameters as indicated.]

2) Turn the signal generator on and set to 30\(^\circ\) modulation at 1 kHz modulation. Start with low output, i.e., 1 \( \mu \)V or so. (1 \( \mu \)V open circuit

\[ \Rightarrow \frac{(0.5 \mu V)^2}{50} \text{ W or } -143 \text{ dBm} \]
3) While the audio output meter is observed switch off generator modulation. Record output levels with the modulation on and with it off. Adjust the signal generator level until the difference between the two is 9.5 dB. That is, $10 \log \left( \frac{S+N}{N} \right) = 9.5 \text{dB}$

$$\Rightarrow 10 \log \left( \frac{S}{N} \right) \approx 10 \text{dB}$$

4) The signal generator output is read to give sensitivity.

- Measurement of SSB and CW sensitivity

A receiver for SSB and CW can be much more sensitive than one for AM. This is for several reasons:
1) In a simple AM receiver (with envelope demodulation) a nonlinear transformation enhances the effect of noise.

2) Much less receiver bandwidth is needed for SSB (and CW).

3) There is no carrier power for SSB.

For this measurement the AGC is disabled and the output level is measured with the signal generator on and again with it off. The signal generator frequency is offset from the
receiver rf frequency by the modulating frequency.

Example:

1 kHz modulation is used.
Receiver bandwidth is set to 3 kHz. Receiver frequency is 29 MHz and signal generator frequency is 29.001 MHz.

Adjust the signal generator until $10 \log \left( \frac{S+N}{N} \right) = 9.5$ dB, where $S+N$ is the measurement with the generator on and $N$ is the measurement with the generator off.
The resulting signal generator level gives the measure of sensitivity. Sensitivity for a good receiver at the 50Ω input is 0.1 to 0.3μV.

Another technique that can be used (and often is for FM receivers) takes into account all internal noise sources and distortion. In this case we measure signal-plus-noise-plus-distortion (SINAD). The measurement is approximately the same as the ones described before but in this case the signal generator modulation is not turned off.
Rather a selective band-reject filter (tuned to the modulation frequency) is switched in and out prior to the audio level meter.

Measurement of FM sensitivity

An FM signal generator is used at the input to the test circuit. Sensitivity is measured at a specified deviation. For commercial
communications receivers a peak deviation of 2.1 kHz rms (3 kHz peak) at a 1 kHz rate is common. The measurement is nearly the same as was used for SSB sensitivity; only in this case the measurements are made with and without the notch filter (instead of with the signal generator on and off). For a 12-dB S/N ratio, a good receiver has a 0.1 - 0.2 μV sensitivity.

Other measurements relating to sensitivity:

1. Quieting sensitivity - The output level is measured in
the absence of a signal. Then an unmodulated signal is applied and the level is increased until the output noise level is decreased by a predetermined value, usually 20 dB. This is called the quieting sensitivity and it may be $0.15 - 0.25 \mu V$ for a good receiver.

2. Ultimate S/N

Here S/N is measured in the usual way, only the generator signal level is adjusted until the S/N levels off. This can provide information of residual system noise. For example, for
a residual FM (in the synthesizer) of 3 Hz, S/N is limited to

\[ 20 \log \left( \frac{3 \text{kHz}}{3 \text{Hz}} \right) = 60 \text{dB} \]

**Noise Figure (NF)**

This is an alternative way of describing sensitivity. Unlike the above definitions, NF does not depend on any specific signal characteristics.

Output of

Set up IF or linear demodulator

For this measurement the following steps are taken:

1) The receiver is tuned to the appropriate frequency and bandwidth (AGC is off).
2) The output level is measured with the gaussian generator off. Then the generator is turned on and adjusted until the output level has risen 3dB.

3) The setting on the gaussian source is read as the noise figure.

Note that noise factor is defined as

\[
F = \frac{\left( \frac{S_{\text{receiving}}}{N_{\text{receiving}}} \right)}{\left( \frac{S_{\text{output}}}{N_{\text{output}}} \right)}
\]

\text{Noise Figure (NF) is}

\[NF = 10 \log(F)\]

The noise factor is always \( \geq 1 \) (ideally) since the receiver at best adds no noise.
A variety of types of noise mechanisms exist including:

1) thermal noise \( (N = kT/B) \)
2) shot noise (similar to thermal noise)
3) 1/f noise (also called flicker noise)
4) Barkhausen noise (in magnetic materials)

Selectivity

This is a property of a receiver that allows it to separate a signal or signals on one frequency from those on other frequencies. This is especially important for cellular communications, cordless phones, etc. where user density is high.
A trade-off is involved: the selective circuits must be sharp enough to suppress interference from adjacent channels and spurious responses. But they must be broad enough to pass the highest sideband frequencies with acceptable distortion in amplitude and phase.

Quantitatively, selectivity is the bandwidth for which a test signal $x$ decibels stronger than the minimum acceptable signal at nominal frequency is reduced to the level of that signal. Nonlinearities can affect the measurement of selectivity so care is needed.
These nonlinearities include: overload, modulation distortion, spurious signals, and spurious responses. Distortion can also occur in demodulators. To check for the presence of distortion it is good to vary the signal level to see if there is a dB for dB change between input and output.

**Dynamic range**

A receiver operates within a predefined level of performance only for a range of input powers. On the low power input side, the level of performance is defined in terms of the
minimum detectable signal (MDS).

\[ \text{MDS} = kTBnF \]

noise bandwidth

noise

Boltzmann's constant factor

It is often specified otherwise, e.g., in terms of minimum acceptable S/N at the output.

On the strong power input side the acceptable level of performance may relate to a tolerable level of distortion at the output.

The dynamic range is then defined as the difference (in dB) between strongest acceptable input power and weakest acceptable input power.

Often this isn't a satisfactory definition since
strong signals can cause degradation in ways other than simply distortion of the intended signal. A more commonly used definition for dynamic range refers to the ratio of the level of a strong out-of-band signal that in some way degrades signal performance of the receiver to a very weak signal. As we'll see later, the distortion effects can be expressed as a Taylor series where each term has the form $(A_1 \sin 2\pi f_1 t + A_2 \sin 2\pi f_2 t)^n$. $f_1$ and $f_2$ are frequencies of two arbitrary signals input to the receiver. For $n$ odd,
particularly $n=3$, $f$, and $f_z$ can be close to the frequency of the desired signal such that

$m f_1 \pm (n-m) f_z$ has frequency of the desired signal for some $m$ between 0 and $n$. This is called intermodulation (IM) where signals outside of the monitored channel combine nonlinearly to produce a frequency on the monitored channel. Odd-order IM products generally limit the dynamic range significantly.

Aside: For $n=2$ we have

$$\left( \cos 2\pi f_1 t + \cos 2\pi f_2 t \right)^2 = \cos^2 2\pi f_1 t + \frac{1}{2} + \frac{1}{2} \cos \left( 2 \left( 2\pi f_1 t \right) \right)$$
\[
\begin{align*}
&+ \frac{1}{2} \cos(2\pi f_1 t) \cos(2\pi f_2 t) \\
&\quad + \frac{1}{2} \cos(2\pi (f_1 + f_2) t) \\
&\quad + \frac{1}{2} \cos(2\pi (f_1 - f_2) t) \\
&\quad + \frac{\cos^2 2\pi f_2 t}{\frac{1}{2} + \frac{1}{2} \cos(2(2\pi f_2 t))}
\end{align*}
\]

Looking at the expression $mf_1 \pm (n-m)f_2$

$m = 0 \quad \Rightarrow \quad 2f_2$

$m = 1 \quad \Rightarrow \quad f_1 \pm f_2$

$m = 2 \quad \Rightarrow \quad 2f_1$

$n = 3$ distortion term is much more difficult to deal with.
\[ n = 3 \quad \text{terms:} \]
\[ \left( \cos 2\pi f_1 t + \cos 2\pi f_2 t \right)^3 \]
\[ = \cos^3 (2\pi f_1 t) \]
\[ + \frac{3}{4} \cos (2\pi f_1 t) + \frac{1}{4} \cos (3(2\pi f_1 t)) \]
\[ + 3 \cos^2 (2\pi f_1 t) \cos (2\pi f_2 t) \]
\[ \frac{3}{2} \cos (2\pi f_1 t) + \frac{3}{4} \cos (2\pi (2f_1 - f_2) t) \]
\[ + \frac{3}{4} \cos (2\pi (2f_1 + f_2) t) \]
\[ + 3 \cos^2 (2\pi f_2 t) \cos (2\pi f_1 t) \]
\[ \frac{3}{2} \cos (2\pi f_2 t) + \frac{3}{4} \cos (2\pi (2f_2 - f_1) t) \]
\[ + \frac{3}{4} \cos (2\pi (2f_2 + f_1) t) \]
\[ + \cos^3 (2\pi f_2 t) \]
\[ \frac{3}{4} \cos (2\pi f_2 t) + \frac{1}{4} \cos (3(2\pi f_2 t)) \]
Those frequency terms can be obtained from:

\[ mf_1 \pm (n-m)f_2 \]

- \( m=0 \) \( \Rightarrow \) \( 3f_2 \)
- \( m=1 \) \( \Rightarrow \) \( f_1 \pm 2f_2 \)
- \( m=2 \) \( \Rightarrow \) \( 2f_1 \pm f_2 \)
- \( m=3 \) \( \Rightarrow \) \( 3f_1 \)

The major problem with odd components is nearby (frequency) signals that combine so as to produce a signal at the tuned frequency.
A commonly accepted definition for dynamic range in terms of $IP_3$ is
$DR = \frac{2}{3} \left[ \frac{IP_3}{(\text{in})} - MDS \right]$.

Desensitization

Recall that $n$ = even distortion components include a dc term. For large distortion this term may mix with (be multiplied times) the intended signal leading to a modification in the effective gain of the receiver.