Radio receiver dynamic range

- a look at the overall performance of a receiver

Sensitivity is one of the main specifications of any radio receiver. However the sensitivity of a set is by no means the whole story. The specification for a set may show it to have an exceedingly good level of sensitivity, but when it is connected to an antenna its performance may be very disappointing because it is easily overloaded when strong signals are present, and this may impair its ability to receive weak signals.

The overall dynamic range of the receiver is very important. It is just as important for a set to be able to handle strong signals well as it is to be able to pick up weak ones. This becomes very important when trying to pick up weak signals in the presence of nearby strong ones. Under these circumstances a set with a poor dynamic range may not be able to hear the weak stations picked up by a less sensitive set with a better dynamic range. Problems like blocking, inter-modulation distortion and the like within the receiver may mask out the weak signals, despite the set having a very good level of sensitivity.

What is dynamic range?

The dynamic range of a receiver is essentially the range of signal levels over which it can operate. The low end of the range is governed by its sensitivity whilst at the high end it is governed by its overload or strong signal handling performance. Specifications generally use figures based on either the inter-modulation performance or the blocking performance. Unfortunately it is not always possible to compare one set with another because dynamic range like many other parameters can be quoted in a number of ways. However to gain an idea of exactly what the dynamic range of a receiver means it is worth looking at the ways in which the measurements are made to determine the range of the receiver.

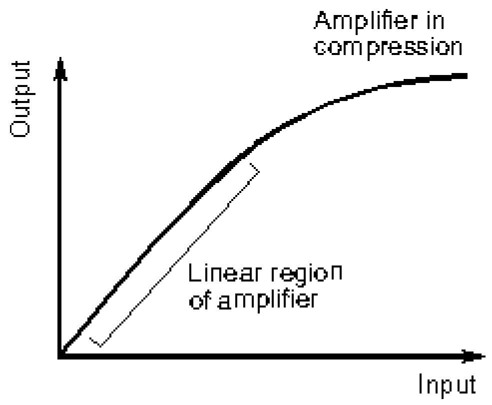
Sensitivity

The first specification to investigate is the sensitivity of a set. The main limiting factor in any receiver is the noise generated. For most applications either the signal to noise ratio or the noise figure is used as described in a previous issue of MT. However for dynamic range specifications a figure called the minimum discernible signal (MDS) is often used. This is normally taken as a signal equal in strength to the noise level. As the noise level is dependent upon the bandwidth used, this also has to be mentioned in the specification. Normally the level of the level of the MDS is given in dBm i.e. dB relative to a milliwatt and typical values are around -135 dBm in a 3 kHz bandwidth.

Strong signal handling

Although the sensitivity is important the way in which a receiver handles strong signals is also very important. Here the overload performance governs how well the receiver performance.

In the ideal world the output of an amplifier would be proportional to the input for all signal levels. However amplifiers only have a limited output capability and it is found that beyond a certain level the output falls below the required level because it cannot handle the large levels required of it. This gives a characteristic like that shown in Fig. 1. From this it can be seen that amplifiers are linear for the lower part of the characteristic, but as the output stages are unable to handle the higher power levels the signals starts to become compressed as seen by the curve in the characteristic.



A typical amplifier characteristic

The fact that the amplifier is non-linear does not create a major problem in itself. However the side effects do. When a signal is passed through a non-linear element there are two main effects which are noticed. The first is that harmonics are generated. Fortunately these are unlikely to cause a major problem. For a harmonic to fall near the frequency being received, a signal at half the received frequency must enter the amplifier. The front end tuning should reduce this by a sufficient degree for it not to be a noticeable problem under most circumstances.

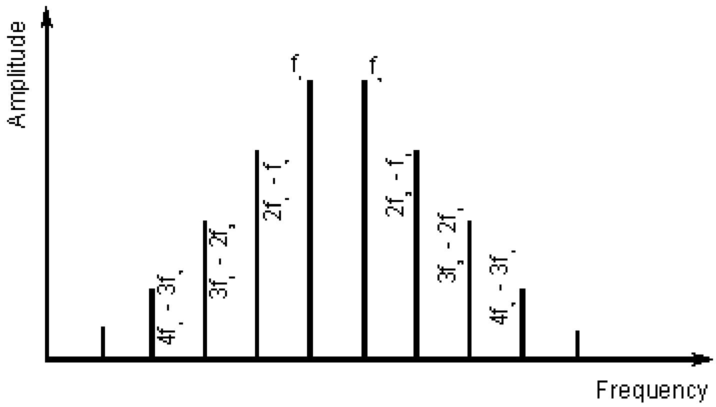
The other problem that can be noticed is that signals mix together to form unwanted products. These again are unlikely to cause a problem because any signals which could mix together should be removed sufficiently by the front end tuning. Instead problems occur when harmonics of in-band signals mix together.

Third order products

Problems occur when harmonics of in-band signals mix together. It is found that a comb of signals can be produced as shown in Figure 2, and these may just fall on the same frequency as a weak and intersting station, thereby masking it out so it cannot be heard.

It is simple to calculate the frequencies where the spurious signals will fall. If the input frequencies are f_1 and f_2, then the new frequencies produced will be at $2f_1 - f_2$, $3f_1 - 2f_2$, $4f_1 - 3f_2$ and so forth. On the other side of the two main or original signals products are produced at $2f_2 - f_1$, $3f_2 - 2f_2$, $4f_2 - 3f_1$ and so forth as shown in the diagram. These are known as odd order inter-modulation products. Two times one signal plus one times another makes a third order product, three times one plus two times another is a fifth order product and so forth. It can be seen from the diagram that the signals either side of the main signals are first the third order product, then fifth, seventh and so forth.

To take an example with some real figures. If large signals appear at frequencies of 30.0 MHz and 30.01 MHz, then the inter-modulation products will appear at 30.02, 30.03, 30.4 ...MHz and 29.99, 29.98, 29.97 MHz.



Inter-modulation products

Blocking

Another problem that can occur when a strong signal is present is known as blocking. As the name implies it is possible for a strong signal to block or at least reduce the sensitivity of a receiver. The effect can be noticed when listening to a relatively weak station and a nearby transmitter starts to radiate, and the wanted signal reduces in strength. The effect is caused when the front-end amplifier starts to run into compression. When this occurs the strongest signal tends to "capture" the amplifier reducing the strength of the other signals. The effect is the same as the capture effect associated with FM signals.

The amount of blocking is obviously dependent upon the level of the signal. It also depends on how far off channel the strong signal is. The further away, the more it will be reduced by the front end tuning and the less the effect will be. Normally blocking is quoted as the level of the unwanted signal at a given offset (normally 20 kHz) to give a 3 dB reduction in gain.

Dynamic range definition

When looking at dynamic range specifications, care must be taken when interpreting them. The MDS at the low signal end should be viewed carefully, but the limiting factors at the top end show a much greater variation tin the way they are specified. Where blocking is used a reduction of 3 dB sensitivity is normally specified, but in some cases may be 1 dB used. Where the inter-modulation products are chosen as the limiting point the input signal level for them to be the same as the MDS is often taken. However whatever specification is given, care should be taken to interpret the figures as they may be subtlety different in the way they are measured from one receiver to the next.

To gain a feel for the figures which may be obtained where inter-modulation is the limiting factor figures of between 80 and 90 dB range are typical, and where blocking is the limiting factor figures around 115 dB are generally achieved in a good receiver.

Designing for optimum performance

It is not an easy task to design a highly sensitive receiver that also has a wide dynamic range. To achieve this performance a number of methods can be used. The front-end stage is the most critical in terms of noise performance. It should be optimised for noise performance rather than gain. Input impedance matching is critical for this. It is interesting to note that the optimum match does not correspond exactly with the best noise performance. The amplifier should also have a relatively high output capability to ensure it does not overload. The mixer is also critical to the overload performance. To ensure the mixer is not overloaded there should not be excessive gain preceding it. A high level mixer should also be used (i.e. one designed to accept a high-level local oscillator signal). In this way it can tolerate high input signals without degradation in performance. Care should be taken in the later stages of the receiver to ensure that they can tolerate the level of signals likely to be encountered. A good AGC system also helps prevent overloading and the generation of unwanted spurious signals.

A receiver with a good dynamic range will be able to give a far better account of itself under exacting conditions than one designed purely for optimum sensitivity.