Receiver Intermodulation Distortion (IMD) and Roofing Filters

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Following the Antenna connection, in a **Transceiver** (**Trans**mitter / Re**ceiver**), there is an ***Parallel Inductive –Capacitive (LC) Band Pass Filter (BPF)*** in the Receiver section, which is usually as wide as the entire band or even wider.

The Transceiver's Receiver stage first mixer has a large quantity of signals at it's input while trying to separate out one signal for reception.

1. The function and the design of the first mixer circuit gives it the ability to handle signals without excessive **Intermodulation Distortion (IMD).**
2. The first mixer circuit does have a limit though, above which there is an IMD level, which becomes stronger than the **Noise Floor (NF).**
3. The difference between the IMD and NF levels is known as the Dynamic Range (DR).
4. The DR characteristic is generally measured with just two signals of the same strength and some particular frequency spacing. For two signals within the operating band, this is called the **3rd Order IMD-DR (IM3-DR).**
5. ***When signal spacing is much greater than the BPF Band Width (BW), the first mixer and any other early stages determine the dynamic range of the receiver.***

Most high-end Transceivers today have a IMD-DR in the area of '87 dB - 110 dB' for a signal spacing of '20 kHz' or more. As the signal spacing decreases, at some point they will fall into the bandpass of the filter and they will then infringe on the following second mixer and IF stages, which will create IMD at much lower levels. Thus for closely spaced signals the receiver dynamic range drops dramatically to maybe '60 dB' or '70 dB'. ***The transition width from the first mixer dynamic range limit to the second mixer limit is determined by the bandwidth of the filter.***

Let's assume we have a Transceiver with '100 dB' of Dynamic Range (DR) and a NF of '–135 dBm' for signals spaced '20 kHz' apart. This means there are two signals, one off tune by '20 kHz' and the second one off tune by '40 kHz' and they create a false response on the tuned frequency when their level is '–35 dBm' or '100 dB' above the noise floor. How strong is that? Well, an 'S9' meter reading in a typical Transceiver is '–73 dBm' (50.1 uV), so these signals are '38 dB' above 'S9'. Any signals weaker then that will cause no problem for these or wider signal spacing.

There are two basic designs for modern Transceivers.

1. The **__first design__** is those Transceivers **with only the MF (160 Meter) & HF (80 - 10 Meter) Amateur Radio Bands.**
    a. The **First IF, is typically between '4 MHz' and '10 MHz'.**
    b. These filters are easy to make and have been available for many years.

2. The **__second design__** are those Transceivers **which also include one or more of the VHF Amateur Radio Bands, well above '30 MHz'**. **Which are usually called "__Up Conversion__" Transceivers.**
    a. The **First IF, is at VHF, somewhere in the '40 MHz' to '75 MHz' region.**
    b. Narrow bandwidth VHF filters have not been available until recently, so the Transceivers with VHF IFs typically use '10 kHz' to '20 kHz" wide filters.

The ability of a Transceiver to ignore strong signals near the tuned frequency is greatly enhanced by a '__Roofing Filter__'.

A roofing filter is the __current buzzword__ in high-end Transceivers. Just what does it mean? Basically, a 'Roofing Filter' is simply the 'First Intermediate Frequency (IF) Band Pass Filter (BPF)' in a Transceiver. All of which are "__Crystal Filters__", either __discrete__ or __monolithic__ types. It is usually placed as close to the first mixer as possible in order to be effective.

The term 'Roofing' stems from the fact that it protects the rest of the Transceivers Receiver Section following it from signals out of the bandpass. Ideally, the final desired selectivity should be in the First Intermediate Frequency (IF) to protect the following high gain stages from strong out of band signals. At the lower IF's it is possible to use filters as narrow as '250 Hz'. At VHF it is not yet possible to make practical filters that narrow. '3 kHz' or '4 kHz' is about as narrow as they go in the VHF region.

The goal of the First Intermediate Frequency (IF) 'Roofing Filter' is to reduce the bandpass to about '6 kHz - 20 kHz', so that overloading and distortion in the following amplifier stages and mixers stages are reduced.

The Receiver's bandwidth is not determined by the First Intermediate Frequency (IF) 'Roofing Filter' but by a following crystal, mechanical or DSP filter. These allow a much better filtering curve than a roofing filter, which often uses a high 1st IF of higher than '40 MHz'. It should be noted that while a '6 kHz - 20 kHz' roofing filter is acceptable for general purpose MF / HF radio reception. **Demanding uses like listening to weak CW or SSB signals require the use of First Intermediate Frequency (IF) 'Roofing Filter' that has a much smaller bandwidth appropriate to the reception mode in use. A '250 Hz', '500 Hz', or '1.8 kHz' would be acceptable values. __These also require that the receiver uses a low first IF perhaps '9 MHz' or '11 MHz'.__**

Suppose the dynamic range within the roofing filter bandwidth is only '70 dB' and the filter is '12 kHz' wide, two signals spaced at '3 kHz' or less will fall inside this filter, and if they are '70 – 135 = -65 dBm' or stronger, they will cause IMD signals in the bandpass. This is only 'S9 +8 dB' per signal. In a Transceiver used in a contest it is possible to have several signals in the '+ / - 6 kHz' range around your tuned frequency which are stronger than 'S9 +8 dB', and this is why we hear false signals under those conditions.

Narrowing the 'Roofing Filter' has no effect on widely spaced signals, as the IMD is earlier in the signal chain of the receiver. However, it can improve the receiver performance for close-in signals. In the above example, if we reduce the roofing filter bandwidth to '4 kHz', the widest separation, which will cause a problem, becomes '1 kHz' instead of '3 kHz'. This can reduce the interference substantially in crowded band conditions. **So it's apparent that signals spaced at the roofing filter bandwidth divided by '4' is the minimum spacing at which the dynamic range of the Transceiver will be improved.** Shall we go as narrow as possible? Suppose we use a '250 Hz' roofing filter, signal spacing down to '62.5 Hz' will be improved. Doesn't this seem a bit close to operate next to your neighbor in a contest? I think the DX station would have some difficulty trying to copy one of you and not the other. What is reasonable? Maybe something which starts attenuating at signal spacings of '100 Hz' makes sense. This is a roofing filter with '400 Hz' bandwidth. The other advantage of making the filter a bit wider is that the insertion loss is not as great. Insertion loss can reduce the sensitivity of the Transceiver.

Is an '8-pole' filter necessary? How does a '4-pole' filter compare? One difference between the two filters is insertion loss. For a '500 Hz' filter this difference can be about '5 dB' for a '9 MHz' filter.

The receiver overall gain should be kept fairly constant as filter bandwidths change to preserve the Automatic Gain Control (AGC) characteristics and to keep the "S" meter reading constant.

Also, the receiver NF can suffer if there is a gain reduction close to the front end. **We need to insert an amplifier or otherwise change the gain to make up for the extra filter loss when a narrow '8-pole' filter is selected**. This can reduce the dynamic range of the Transceiver.

So '4 pole' filters have an advantage, particularly for narrow bandwidths, even though the selectivity is not as good for signals falling down the skirts. There is less advantage in going to a wider filter such as a '2400 Hz' bandwidth.

For example, a '10 pole', '2400 Hz' filter has an insertion loss of about '2.2 dB', while the '4-pole' filter with the same bandwidth has a loss of '1 dB'. The difference of '1.2 dB' is small enough that it could be ignored and the '10-pole' filter would provide better off-channel rejection.

Thus for the SSB bandwidths a good '8' or '10 pole' filter will outperform a '4 pole' filter, ***but for the narrow bandwidths the simpler filter is best***.