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A Few Words About Intermodulation Dynamic Range (IMDDR) and Roofing Filters

"Roofing filter" is the current buzzword in high-end radios. Just what does it mean? Basically, a roofing filter is simply the first IF filter in a radio. It is usually placed as close to the first mixer as possible to be effective. The term "roofing" means that it protects the rest of the radio following it from out of the passband signals.

Modern radios are two basic designs: radios with only ham bands use a first IF in the HF region, typically between 4 and 10 MHz, or radios that have their first IF in the VHF region, well above 30 MHz. The latter are usually called "Up Conversion" radios. Let's examine some of the advantages of each.

The Orion, K2, and Omni are like the first type. The Yaesu, Kenwood, and Icom radios are like the second.

The first IF in the Orion is in the HF region. These filters are easy to make and have been available for many years. In the up conversion radios, the first IF is at VHF, somewhere in the 40 to 75 MHz region. All are crystal filters, either discrete or monolithic types. Narrow bandwidth VHF filters have not been available until recently, so the radios with VHF IFs typically use 10 to 20 kHz wide filters.

The ability of a radio to ignore strong signals near the tuned frequency is greatly enhanced by a roofing filter. Ideally, the final desired selectivity should be in the first IF to protect the following high-gain stages from strong out-of-band signals. At the lower IFs it is possible to use filters as narrow as 250 Hz. At VHF it is not yet possible to make practical filters that narrow. Three or four kHz is about as narrow as they go in the VHF region.

Roofing Filters and Dynamic Range

Following the antenna connection, most radios have an LC bandpass filter. This filter is usually as wide as an amateur band or even wider. So, the first mixer may have tens or hundreds of signals at its input while you are trying to separate out one signal for copy. The ability of the first mixer to handle these signals without excessive intermodulation is a function of its circuit design. It does have a limit, above which there is intermodulation that becomes stronger than the noise floor of the radio. The difference between these two levels is known as the dynamic range. This 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 third-order dynamic range. When the signal spacing is much greater than the roofing filter bandwidth, the dynamic range of the radio is determined by the first mixer and any other early stages.

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Most high-end radios today have a dynamic range in the area of 95 to 105 dB for signal spacing of 20 kHz or more. As the signal spacing decreases, at some point they fall into the passband of the roofing filter. They then impinge on the following second mixer and IF stages, which will create intermodulation at much lower levels. Thus for closely spaced signals, the receiver dynamic range drops dramatically to maybe 60 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 roofing filter.

Let's make some guesses as to the signal levels involved here. Assume we have a radio with 100 dB dynamic range and a noise floor of -135 dBm for signals spaced 20 kHz. This means there are two signals – one off tune by 20 kHz and the second 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, S9 in a typical radio is -73 dBm, so these signals are 38 dB above S9. Any signals weaker that that will cause no problem for these or wider signal spacings.

Now, suppose the dynamic range within the roofing filter bandwidth is only 70 dB and the filter is 12 kHz wide (as it is in the FT-1000MP). 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 intermodulation signals in the passband. This is only S9 +8 dB per signal. In a radio contest it is possible to have several signals in the +/- 6 kHz band around your tuned frequency that 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 intermodulation takes place earlier in the signal chain of the receiver. However, it can improve the receiver performance for close-in signals. In the preceding example, if we reduce the roofing filter bandwidth to 4 kHz, as the Inrad Roofing Filter mod does, the widest separation that causes a problem becomes 1 kHz instead of 3. 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 radio is improved.

Shall we go as narrow as possible? Suppose we use a 250 Hz roofing filter. Signal spacings down to 62.5 Hz is 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 that 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 radio.

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 a difference of about 5 dB for a 9 MHz filter. The receiver overall gain should be kept fairly constant as filter bandwidths change to preserve the AGC characteristics and to keep the S meter reading constant. Also, the receiver noise floor can suffer if a gain reduction is 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 radio, as has been seen in the Orion performance numbers in the ARRL review.

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, Inrad's 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.

Roofing filter products

Ten Tec Orion: Some time ago, after much discussion with W4ZV, we introduced a 4-pole, 600 Hz bandwidth filter kit centered at 9001.5 kHz for the Orion. This filter was centered on the SSB frequency so it could be put into the 1.8 or 1.0 kHz slots in the Orion, allowing the use of a narrow roofing filter without needing the extra amplifier that is switched in when selecting 500 or 250 Hz bandwidths. As a result the dynamic range for close in signals is dramatically improved.

Here is what Rob Sherwood said about this filter compared to the Ten Tec 1.0 unit. "At 2 kHz spacing, the improvement (in dynamic range) is on the order of 6 to 7 dB. At 1 kHz spacing the improvement is closer to 10 dB."

We have discontinued the kit (it was our reference #352) in favor of a completely assembled unit that is ready to plug in and it is our reference #762.

Yaesu FT-1000MP series: Earlier this year we located a source that can produce good filters at 70.455 MHz and other VHF frequencies. We procured some and ran numerous tests. Initial results were promising and a mod board was designed before the Dayton Hamvention. A run of 100 units was completed and we tested and documented each unit. Customers receiving these filters were asked to report their findings. Some of those comments are reproduced below.

"I have been doing A/B tests with the Orion and the FT1000MP in crowded large interfering signal conditions. I must say the FT1000MP is doing a very excellent job – and earlier tests clearly showed the superiority of the Orion in those kinds of conditions. The real eye-opener was when I tuned across my neighbor ham's signal, which was pegging the S-meter at 80 over. I had been listening just below his frequency for awhile and had not even realized he was on the air. "

"I have turned on the noise blanker in the presence of the local strong signals, and can hear no products when they are tuned outside the passband of the filter. I consider the price a real bargain. You disproved the prevailing theory that 70 MHz roofing filters were impractical. Keep up the good work."

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"It appears that the rig is less touchy to big signals when tuning around the band with the wide filter open. Looks like a keeper..."

About the noise blanker..."I do notice the shotgun effect I used to get from the NB is now almost totally gone. The difference here was phenomenal!!"

"Without any attenuation and IPO on, the sub receiver of course still shows the intermod etc - but the main RX is clean. So I am a very happy customer."

In Europe...."initial subjective listening on 20M SSB with 10 to 20+ dB over 9 European signals crowding the band indicates improved close-in strong signal capabilities."

During Field Day: "I could walk over to the other stations and hear the difference between the stock FT-1000's and my Inrad equipped FT-1000. Does the roofing filter make a difference.....YES! Would I do it again......YES! Does the Roofing Filter give me an advantage? YES! PS: Don't tell my competition about your Roofing Filter, I need all the advantages I can get."

Testing was also done at an independent laboratory (not ours) and a sample of the performance obtained with our mod installed is shown below.

Signal Spacing	Blocking DR	IMDDR
20 kHz	146 dB	93 dB
5 kHz	130 dB	89 dB

If these performance parameters are important to you, indications are that you can save from $1500 to almost $9000 by keeping your FT-1000MP, installing this mod, and not buying a new radio.

Performance data for the original radio and as modified are shown in the following plot. These curves are plots made by injecting a signal into the radio antenna connector at 7 MHz and detecting the resulting signal at the output of the RF board on 70.455 MHz.

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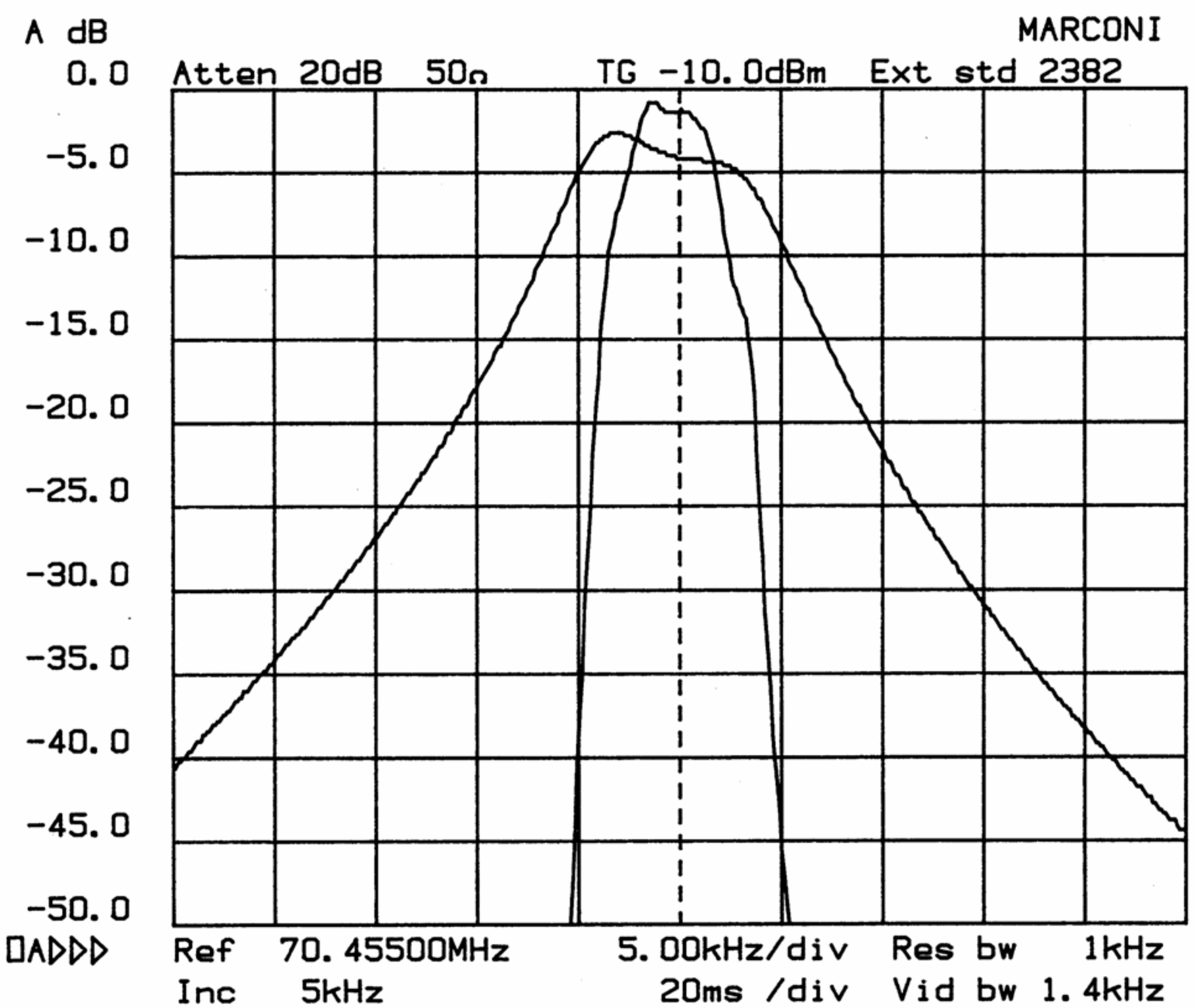

The wider trace is the unmodified RF board response and the narrow trace is after the Inrad mod is installed. There is a small increase in gain that has a slight effect on lowering the noise floor.

What can you expect from this mod?

Less IMD in crowded band conditions, particularly from stations at offset frequencies of 2 to 10 kHz either side of the operating frequency.

Will it defeat the noise blanker?

No, the roofing filter is in the circuit before the noise blanker sample is taken. The filter delay is added to both signal and noise.

Will this mod allow for wide band SSB?

No, the roofing filter will determine the overall widest bandwidth of the receiver, which is about 4 kHz wide. It will also limit the bandwidth of AM signals when both sidebands are being detected. The sub receiver is not altered and can still be used for the wider bandwidth modes.

Why not make the bandwidth narrower for CW use?

It is quite difficult to make narrow filters at 70 MHz. There is quite a bit of variation from unit to unit, so we have chosen a bandwidth that will work for SSB and CW even with the worst-case variation in bandwidth.

If 6 poles work so well, why not 8 poles?

The most important part of the filter characteristic is from the pass-band on down to about -30 dB on either side of center. Eight poles would provide much better stop-band isolation, but it's not required in a roofing filter and would make no noticeable improvement in IMD performance.

Who can benefit from installing this mod?

Operators who experience lots of strong signals which are close together in frequency. This would include contesters with big antennas, people with really good antennas and a good location, and dxpeditioners who get large pileups. Casual operators would probably not notice any difference in receiver performance.

Ten Tec Omni VI series: We are presently working on a roofing filter mod for the Omni VI+ radios. Plans are not quite formalized yet, but some preliminary data from our lab is shown below.

Signal Spacing	IMDDR	Filter Bandwidth
20 kHz	100 dB	2800 kHz
5 kHz	93 dB	2800 Hz
20 kHz	100 dB	400 Hz
5 kHz	100 dB	400 Hz
1 kHz	90 dB	400 Hz

We hope to make this unit available in the late fall or winter of this year.

IC-765 and IC-781: Sample filters for feasibility testing are on order and will be here in August. Stay tuned……

Other radios: **As time permits.**