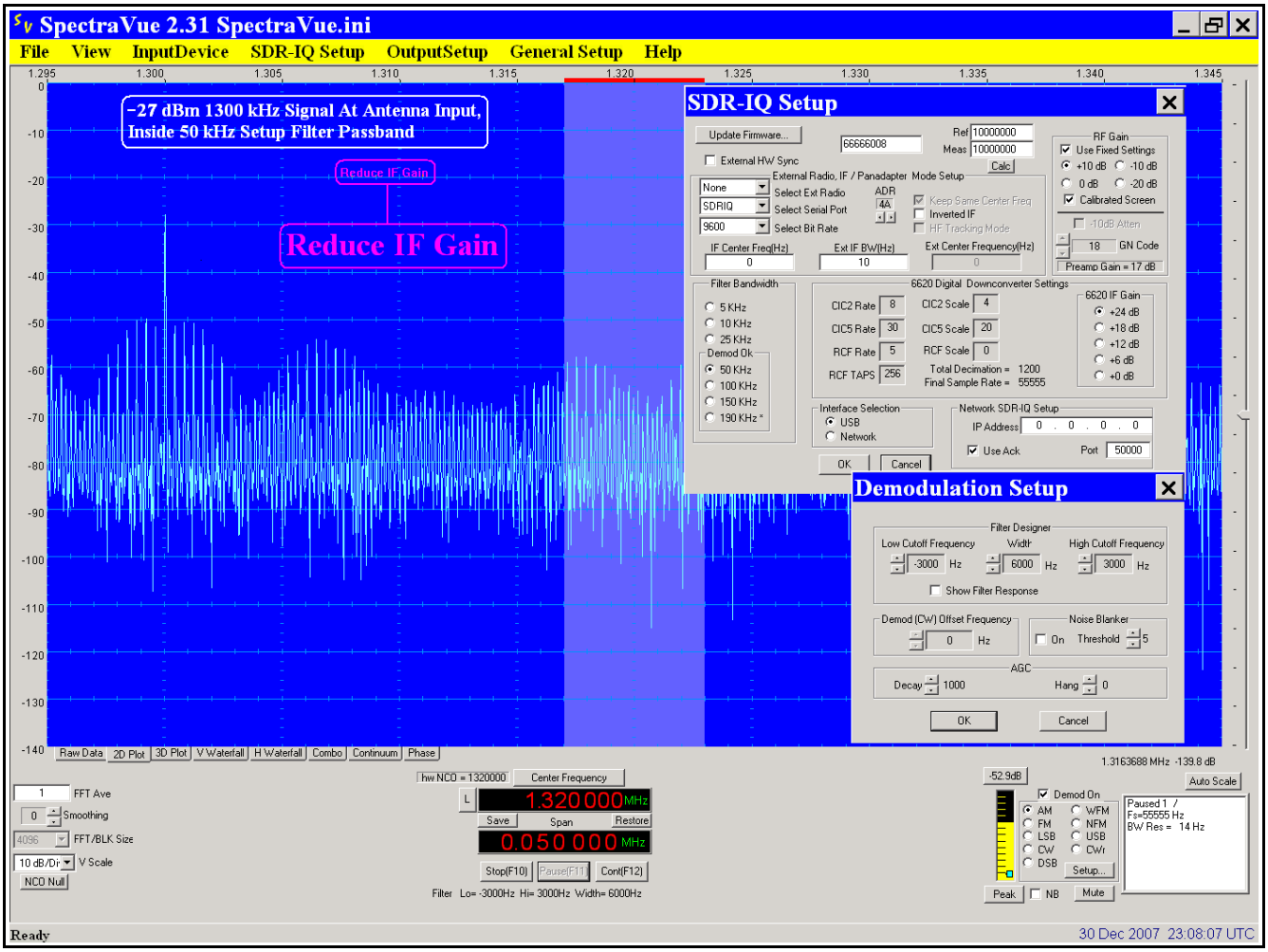
SDR-IQ Overload Characteristics

Dallas Lankford, 1/14/08

One of the reasons that digital down conversion receivers like the SDR-IQ are attractive is that they are capable of recording substantial segments of the RF spectrum to WAV files which can be played back later with the SDR software as if one were listening to the original spectrum segment. One can tune around in the recorded spectrum, change mode, change bandwidth, change AGC decay and hang release times, and generally change almost any receiver parameter of importance for DXing that could have been changed when the spectrum segment was being recorded. With the SDR-IQ the maximum recording segment width is 192 kHz. The SDR-IQ also has other attractive features, including AM filters with steep skirts adjustable in 100 Hz steps from 200 Hz to 20 kHz, USB and LSB filters with steep skirts adjustable in 100 Hz steps from 1 kHz to 24 kHz, CW and FM filters too, AGC times adjustable from 100 mS to 10 Sec for 90% decay in 100 mS steps, and so on. However, the SDR-IQ has certain overload characteristic which are unlike anything ever encountered in an analog receiver or even in a DSP receiver with an analog front end which may make it unsuitable for DXers in high RF environments. Below these unusual SDR-IQ overload characteristics are cataloged and discussed.

The SDR-IQ has two filters, a Setup Filter (user selectable 50, 100, 150, and 190 kHz bandwidths), and a Demodulation Filter (user selectable 0.2 – 20 kHz bandwidths in AM mode). This is like having a roofing filter (the Setup Filter) followed by an IF filter (the Demodulation Filter). A 50 kHz bandwidth Setup Filter and 6 kHz AM Demodulation Filter were used for the measurements described below. An HP 8640B signal generator was used for these tests. It was found that if a signal greater than -27 dBm at the antenna input of the SDR-IQ was inside the Setup



Filter passband (as in the display above), then the SDR-IQ overloaded as shown in the display below and the error message "Reduce IF Gain" was displayed. This displayed message is pink in color (I use custom colors for my SDR-IQ) in the display above and is quite small. A much larger pink error message was added to the figure above and both of them were circled. The SDR-IQ specifications state "Clipping RF level (Max Gain): -4 dBm (TBD)." Strictly speaking the above -27 dBm level is not clipping (and the red LED clipping light did not turn on). However, the SDR-IQ is unusable when the Reduce IF Gain message occurs.

What this means is that if there are one or more sufficiently strong local signals which produce -27 dBm or greater at an SDR-IQ antenna input, the SDR-IQ will overload as described above when one or more of the -27 dBm signals are inside the Setup Filter passband. Yes, you can reduce the IF gain, but that reduces the SDR-IQ sensitivity which may not be an acceptable solution for many DXers. For example, with +24 dB IF gain (the maximum available) and +10 dB RF Gain (the maximum available), the SDR-IQ AM sensitivity for a 6 kHz BW and 400 Hz 30% modulation was 2.2 μV for a 10 dB S+N/N ratio. If the IF Gain was reduced by 6 dB to 18 dBm then the AM sensitivity was reduced to a somewhat deaf 4.4 μV. And if the IF Gain was further reduced, the sensitivity was further degraded by a corresponding amount. Analog receivers do not have such catastrophic failures due to overload at such relatively low signal levels.

If a strong signal is outside the Setup Filter passband of an SDR-IQ, then the strong signal handling performance was better when using the HP 8640B. There were no error messages or red LED clipping indication for a -12 dBm 1300 kHz signal at the antenna input of the SDR-IQ with a 50 kHz Setup Filter bandwidth centered at 1330 kHz (the -12 dBm signal was only 5 kHz less than the lower passband limit of 1305 kHz). When the signal level was increased to -11 dBm at the antenna input, the red LED clipping light came on, but there was no error message as in the previous case when the signal was inside the passband of the Setup Filter. With the -12 dBm signal (at the antenna input of the SDR-IQ) outside the Setup Filter passband, sensitivity was the same as if there were no strong signal at all. However, when clipping began at about -11 dBm, as the level of the strong signal outside the passband was increased, sensitivity inside the passband was decreased by about the same amount in dB. For example, a -2 dBm signal at the antenna input of the SDR-IQ outside the Setup Filter passband reduced the SDR-IQ sensitivity (inside the Setup Filter passband) from about 2.2 μV to about 7 μV. Also, spurious signals similar to those in the figure above begin to rise out of the noise floor at some frequencies as the clipping level was increased above its threshold.

While the tests above were conducted for 50 kHz Setup Filter bandwidths, similar results were obtained with other Setup Filter bandwidths.

LW, MW, and SW signal levels at my location are low enough so that I rarely experience overload or clipping, even with a 10 dB gain preamp, which I often use. But SDR-IQ overloading can be a problem for MW DXers in urban areas of the USA and in Europe and elsewhere where MW transmitter powers are much higher than in the USA. If you do experience overloading with your SDR-IQ, perhaps you can eliminate the overloading by adjusting the tuning of your SDR-IQ and/or the Setup Filter bandwidth so that the strong signal(s) which overload(s) your SDR-IQ is(are) outside the Setup Filter passband.

But then again, maybe not. Last night (1/4/08) I experienced my first occurrence of "real world" overloading. I was using an active whip antenna and a 10 dB gain Norton amp, listening in the 60 meter band, when intermittent flashes of the "Reduce IF Gain" overload message began to appear. The red LED clipping indicator of the SDR-IQ was also flashing intermittently in sync with the "Reduce IF Gain" message. The culprits were found to be two strong religious broadcasters in the 90 meter band whose signals were about -30 dBm at the antenna input of the SDR-IQ, but which occasional rose briefly to higher levels. I tuned down to the MW band and found that the error message and red LED continued to flash, due, presumably, to the 90 meter band signals.. These observations demonstrate that the SDR-IQ can clip with signals as low as about -29 dBm at its antenna input. Bjarne Mjelde told me that similar overloading and clipping with his SDR-IQ has occurred in the MW band at Kongsfjord, Norway due to strong Russian signals off the back lobe of his North American beverage. So much for the manufacturer's stated clipping specifications. Apparently in the "real world" your SDR-IQ will clip at much lower levels. Note that in the "real world" clipping occurred at -29 dBm regardless of whether the strong signal was inside or outside the Setup Filter passband. Why there are such substantial differences between the "real world" and "laboratory settings" I do not know.

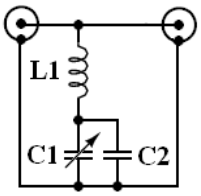
Up to now at my location no MW signals have caused my SDR-IQ to overload provided a reasonable antenna and reasonable preamplification were used. However, other SDR-IQ owners who regularly experience higher MW signal levels than I do have reported SDR-IQ clipping. It occurred to me that one way to simulate higher MW signals was to add another Norton amp. I did this and also inserted a precision rotary attenuator with 1 dB steps so that I could adjust th gain, and hence the signals levels, precisely in order to determine "real world" MW band clipping levels. Surprisingly I found that the SDR-IQ began to clip (red LED flashing on and off and Reduce IF Gain message) with signals of amplitude as little as -35 dBm at the antenna input of the SDR-IQ. Apparently clipping can occur at even lower signal levels than the -29 dBm observed in the case of the two 90 meter band signals discussed above.

Perhaps in the future digital down conversion SDR's will have better strong signal handling performance.

If overloading is caused by a single MW signal, one of the notch filters below may solve your problem. Notch depth generally is slightly greater than 30 dB. Insertion loss depends on the notch frequency and the frequency difference between the notch frequency and the desired frequency. The high C to L ratio is necessary to obtain the 30 dB depth. There is no other way to obtain satisfactory notch depth. If, for example, you use a standard 365 pF air variable and 290 µH inductor to tune the entire MW band, you will get about 3 dB notch depth at the high end and about 10 dB notch depth at the low end of the MW band. The 1500 pF air variable capacitor is a triple section 500 pF per section wired in parallel. Such capacitors are available from Antique Electronics Supply for about $30. Buying off the shelf inductors from your favorite snake oil salesman may not produce the desired results. Fixed capacitors should be mica capacitors. Disc ceramic or other kinds of capacitors may not produce the desired results.

MW Notch Filters

Dallas Lankford, 1/12/08

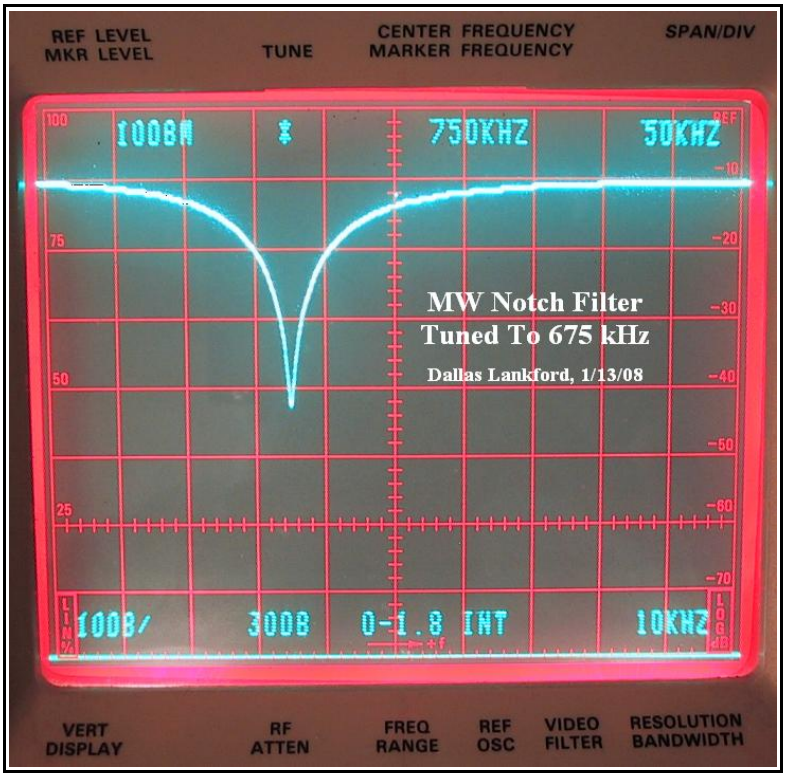


50 Ω input and output

C1 = 1500 pF

tuning range	L1	C2
510 - 675 kHz	29 µH	1820 pF
620 - 850 kHz	22 µH	1470 pF
730 - 1020 kHz	17 µH	1330 pF
910 - 1460 kHz	12 µH	1000 pF
1190 - 1920 kHz	8 µH	820 pF

L1 was made with an Amidon T-106-15 using #20 enameled copper wire with 28, 24, 20, 16, and 12 turns respectively. A band switched version was made using a 5 position 2 pole rotary switch and a single tapped T-106-15.

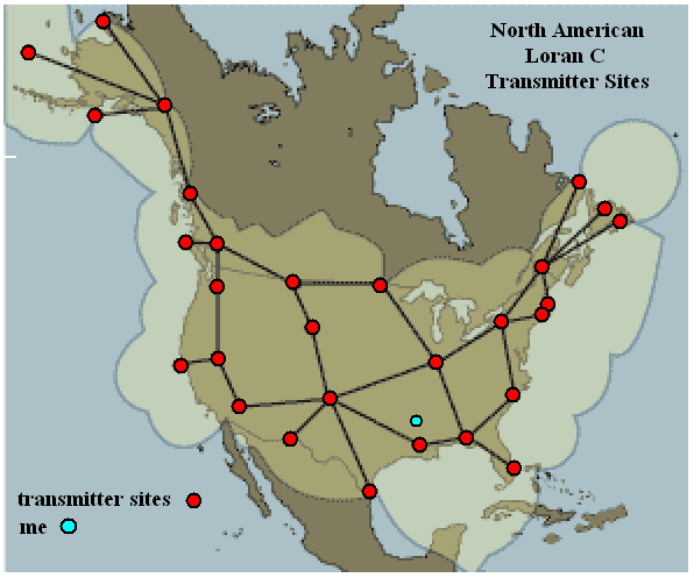


They say a picture is worth a 1000 words, so above right is a picture of a spectrum analyzer with sweep generator sweeping one of the MW notch filters described above, the one which tunes 620 – 850 kHz. The sweep generator output level was 0 dBm and the spectrum analyzer display was set for a reference level of 10 dBm for easy viewing of the Tektronix 495P on screen parameters. According to "real world" measurements the -2 dB bandwidth is about +/- 150 kHz, although the spectrum analyzer sweep indicates about +/- 200 kHz. The 1190 – 1920 kHz notch filter has a wider -2 dB bandwidth, about +/- 300 kHz.

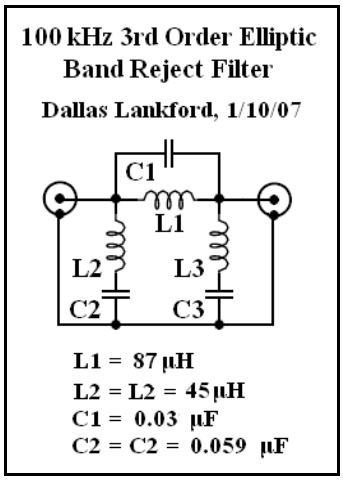
There are also spurious responses associated with the Setup Filter which depend on the Setup Filter bandwidth. For

example, with a strong signal outside the 50 kHz Setup Filter passband, there are spurs at approximately +/- 55, +/- 111, and +/- 166 kHz away from the strong signal. For a 150 kHz Setup Filter the spurs are at approximately +/- 156 and +/- 318 kHz away from the strong signal.

And the Setup Filter influences the Noise Blanker performance. If the Setup Filter passband contains only signals which are about the same amplitude as pulse noise in the Setup Filter passband, then the Noise Blanker is quite effective and blanks the noise well. But when a signal considerably stronger than the noise is inside the Setup Filter passband, it disables the Noise Blanker; the noise is not blanked. The minimum Setup Filter bandwidth is 50 kHz for demodulated signals, so the Noise Blanker is generally ineffective because of amplitude variation of signals in the Setup Filter passband. You can easily verify that the Noise Blanker is effective when strong signals do not disable it by tuning to a frequency where there is pulse noise, even power line noise, but no strong signals nearby. In this case when you toggle the Noise Blanker on and off you will hear and see the Noise Blanker blank the noise.



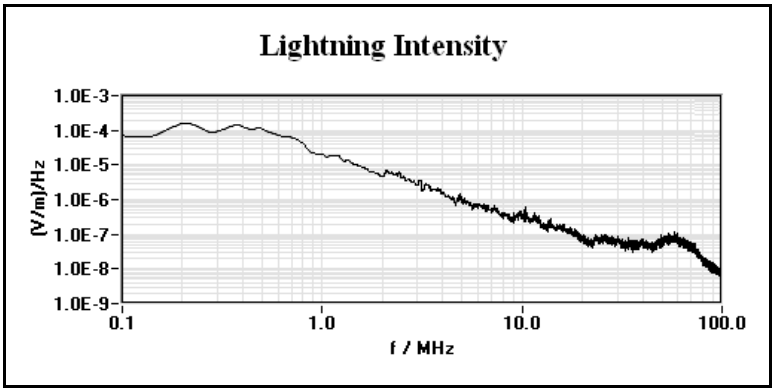
Depending on the proximity of the nearest Loran C transmitter and the signal levels delivered by your antenna, an SDR-IQ can have overload and clipping problems due to the Loran C transmitter. For example, at my location when I turn on the noise blanker at, say, 180 kHz looking for a weak nighttime European broadcaster, a Loran C signal appears. Regardless of where you live in the continental USA you may not be sufficiently far away from a Loran C transmitter to avoid SDR-IQ noise blanker problems due to Loran C; see the North American Loran C Transmitter Sites Map at right.

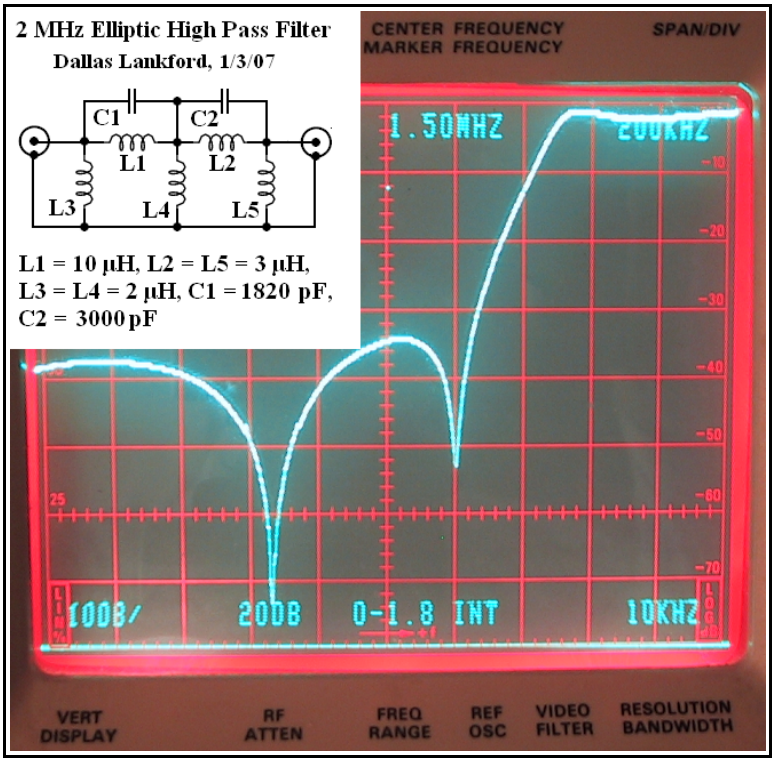


At my location, which is not all that far from the nearest Loran C transmitting antenna, a simplified 3rd order 100 kHz elliptic band reject filter has been sufficient for eliminating my SDR-IQ overloading due to Loran C. A schematic of the filter I developed is given below right. The inductors were inexpensive off the shelf inductors available from Mouser. The capacitors were made by paralleling disc ceramic capacitors which I had on hand, some purchased in the past from Mouser, and others bought at hamfests over the years. L1 was marked as a 100 µH inductor, and L2 and L3 were marked as 47 µH, but they measured 87 µH and 45 µH respectively using an AADE digital inductance meter. The capacitor values may be calculated from the formula for LC resonance, namely $f = 1/2\pi SQRT(LC)$. Both sides of the LC resonant frequency formula are squared from which it is found that $C = 1/4\pi^2 f^2 L$ where f is in Hertz and L is in Henrys. For example, taking L1 = 87 µH we have $C = 1/4\pi^2 100{,}000^2 0.000087 = 0.000000029$ F = 0.029 µF. The AADE inductance meter also measures capacitance, so it was used to make a 0.029 µF capacitor by paralleling capacitors of lower value. The 100 kHz elliptic band reject filter obtained in this manner was not perfectly symmetric about 100 kHz, but it was more than satisfactory with greater than 70 dB attenuation at100 kHz While examining the filter shape with a signal generator and spectrum analyzer I found that 0.03 µF gave a slightly better shape, so that is what I specified in the schematic figure at right. However, the improvement was probably due to error in my digital capacitance meter (with a meter indication of 0.03 µF the capacitance was actually, say, 0.0293 µF). The other values were arrived at similarly.

Static causes overload? Not in an analog receiver or DSP receiver with analog front end to the best of my knowledge. But much to my surprise it does for an SDR-IQ. Listening in and around the MW band as a thunderstorm passed by I

observed the red LED clipping indicator flashing on (and off) followed by a slightly delayed audible static burst from the SDR-IQ. When there were multiple static bursts, they were preceded by multiple red LED flashes. As in the case of Loran C, whether a lightning storm will cause your SDR-IQ to clip will depend on the proximity of the storm and the signal levels delivered by your antenna. It has been said that the field strength of lightning tends to approach a maximum about 5, decreases approximately as 1/f as the frequency approaches 100 MHz, and then presumably decreases slowly for higher frequencies. The figure above and others do not exactly agree with that statement, but then such results are approximations. If we accept the figure below as typical, then as the frequency increases from 100 kHz to 1 MHz, the intensity of received static tends to decrease by 20 dB, and from 1 MHz to 10 MHz it decreases by another 20 dB. A somewhat curious feature of the SDR-IQ, presumably for MW band attenuation, is a 5 MHz high pass filter which is switched in and out automatically. I observed that for all frequencies below 5.000000 MHz, the red clipping LED flashed on and off in near sync with static crashes. But that for all frequencies greater than or equal to 5.000000 MHz, the red light no longer flashed, although the static crashes sounded just as strong as before (though, of course, much weaker on the spectrum display, than, say, at 200 kHz). What happened? When tuned below 5.000000 MHz the SDR-IQ was broadband and received strong lightning impulses just as if it was tuned to, say, 200 kHz. But when tuned above 5.000000 MHz the SDR-IQ switched a high pass filter into the signal path at the antenna input which attenuated the stronger lower frequency lightning strokes and so clipping no longer occurred. To verify that the SDR-IQ 5 MHz low pass filter was responsible for eliminating lightning crash overload above 5 MHz, I built an external 2 MHz elliptic high pass filter and used it to eliminate static overload for frequencies between 2 and 5 MHz as well as all frequencies above 5 MHz; see the figure above. It is usually impossible to eliminate SDR-IQ static overload throughout the entire MW band with a 530 kHz elliptic high pass filter because the signal strength of lightning strokes tends to be about 20 dB greater at 500 kHz than at 2 MHz. Pity. I recall with fondness logging Rome 2 on 845 kHz many years ago in Austin, Texas during an intense thunderstorm with my HQ-180A and 2 foot air core loop. That probably could not have been done with an SDR-IQ. The 2 MHz high pass filter above should also eliminate most overloading of the SDR-IQ in the 2 to 5 MHz range due to strong MW band signals.





After Bjarne reviewed a draft of this article he suggested that the Setup Filter may not actually be a filter so that my analogy of the Setup Filter with a roofing filter may not be correct. He has a good point in view of our experiences with "real world" overload. But on the other hand, that does not explain the laboratory measurements of SDR-IQ overload. Whatever the case, the SDR-IQ overload signal level at the antenna is less than the manufacturer's specifications for laboratory measurements and considerably less than the manufacturer's specifications for the "real world."