CW Notching Filter for Field Day Use

Figure 1 - USRX Filter assembly

As probably everyone in the Club knows by now, the 20-meter Phone team had a terrible problem at Field Day 2024 with 20-meter CW QRM from the close-by 20-meter CW team. Of course, this was nothing new – it has been happening for many years. It is just that I found it particularly annoying, seeing as how it was my first Field Day effort either as an operator or as a band chair. I made up my mind to do something about it, so when **Frank Romeo N3PUU** sent an article to me (of unknown provenance at the time), I read it with great interest.

That article, it tuns out, was written by **Nelson Sollenberger KA2C** and was published on his website www.ka2c.com as well as in various ARRL publications. Nelson, who is fortunate enough to live on a gorgeous farm just west of Chambersburg, PA, has penned several articles dealing with filters, QRM, and Field Day operations.

After reading several articles on the topic, I decided to emulate his Ultra-Sharp Receive Filter (USRX Filter – Figure 1) in a 20-meter version as a means of blocking the 20-meter CW QRM during this year's Field Day event.

The project began with first ensuring that I had a thorough understanding of just what I was going to build, what was needed for the build, and how it would work. Simply put, the filter is comprised of a three-stage series of separate filters, all tuned for the same frequency range, specifically 14.000MHz to 14.150MHz. Each separate filter stage would occupy its own compartment in an aluminum enclosure, using 700pF silver-mica capacitors to couple the RX signal from stage to stage. The individual filter stages each would consist of a solenoidal-wound air-core coil of about 4µH inductance, in series with about 31pF of capacitance. The capacitance was achieved by a combination of a 22pF fixed silver mica capacitor in parallel with a 2-18pF air gap variable capacitor.

The specific resonant frequency of the filter can be calculated using the standard equation for resonant frequency:

$$f_{RES} = \frac{1}{2\pi\sqrt{LC}}$$

where:

f_{RES} = the resonant frequency;

L = the inductance in henrys; and

C = the capacitance in farads.

Substituting our target values for the variables in the equation, we get:

$$f_{RES} = \frac{1}{6.28 \times \sqrt{(4 \times 10^{-6}) \times (31 \times 10^{-12})}}.$$

Simplifying that equation, we end up with the following:

$$f_{RES} = \frac{1}{6.28 \times \sqrt{124 \times 10^{-18}}}$$

or:

$$f_{RES} = \frac{1}{6.28 \times 0.000000011}$$

or:

$$f_{RES} = \frac{1}{0.00000007}$$

or:

$$f_{RES} = 14{,}299{,}785 Hz \ or \ 14.300 MHz .$$

Several factors came into play during the construction of this filter. First off was the Q of the various components used. High Q parts were highly desirable, and I did my best to source some high Q off-the-shelf NOS coils, but to no avail. I ended up having to wind my own coils and hope for the best there. I was concerned about the Q of my home-brewed coils, but it turned out that they were quite respectable. Q is determined by dividing the reactance by the resistance. For a resonant circuit, because the inductive reactance and capacitive reactance are by definition equal to each other, we can use either value in determining the Q of that resonant circuit. I wanted to start with a decent coil, though, so I set out to determine the Q of my home-brewed coils. Starting with the measured resistance of the coil, as obtained using my Ascel Electronics Æ20218 Milliohm Meter, we have a value of 0.098Ω.

That value is the DC resistance of the wire in one of my coils. Based on the published value ([Wire Resistance at Various Frequencies - http://ve3efc.ca/wireohms.htm](http://ve3efc.ca/wireohms.htm)) for the DC resistance of a one-hundred-foot long 18AWG solid wire being 0.69Ω, we can calculate that the length of wire in my coil is 7.0402 feet (0.69 divided by 0.098). Using that length value and again referring to the published resistance value of that same 18AWG wire, we can extrapolate that at 14.300MHz, a 100-foot resistance would be 10.22Ω, or 0.1022Ω per foot. Finally, we multiply our length of 7.0408 feet by 0.1022Ω per foot to derive a 14.300MHz RF resistance of 0.720Ω for my coil. Remember that number…

Next, we must calculate the inductive reactance of the coil, which measured out to be 3.78µH after final trimming. Based on the 14.300MHz resonant frequency, we come up with an inductive reactance of ≈339.46Ω as follows:

$$X_L = 2\pi f L$$

or:

$$X_L = 6.28 \times 14300000Hz \, x \, 0.00000378H$$

or:

$$X_L = 6.28 \times 54.054$$

or:

$$X_L = 339.45912\Omega \, .$$

Finally, we divide the inductive reactance of ≈339.46Ω by the resistance of 0.720Ω and we get a resulting Q factor of 471.5, or ≈472. That is a respectable value under these circumstances. In his article, Nelson Sollenberger stated that a one-inch diameter air-core coil of about an inch in length can achieve Q factors of about 500 to 600, so I was very happy with my calculated value and therefore with the Q of my coils.

In order to reliably wind coils with a high degree of repeatability, I decided to “invent” a system of support members for the windings. I started out by designing a 3-D printable strip that has a series of notches spaced one wire’s diameter of 0.045” apart. The wire used for the coils was a 155°C-rated enamel-coated 18AWG magnet wire. This wire, while fairly heavy at 0.045” diameter, was nonetheless quite pliable and it would wind nicely. To support the printed plastic strips, of which four were used, I designed a cylindrical core with longitudinal slots into which the notched strips would fit. I lined up the strips all flush at one end of the core and wound the wire, shifting down one notch at each full turn. The result was a coil with parallel windings that jog down a bit on one side. After winding fifteen turns (I anticipated needing thirteen turns based on my calculations), and having left two-inch tails on each end of the coil, I secured the wire to the strips by applying hot glue along each strip, smearing it into the notches with a putty knife while the glue was still soft. Once all four strips had been glued and the glue was completely set, I simply pushed the core out from the middle of the coil, producing an air-core coil. This, of course was repeated twice to form a total of three such identical coils.

After the coils were wound, it was time to trim them to the desired inductance of between 3.5µH and 4.0µH. I ended up with twelve and a half turns on each coil, yielding a final coil inductance of 3.78µH. I then shortened the wire tails to about an inch long each, and removed the enamel coating from the last half-inch of each tail for soldering purposes.

I have to throw out some kudos to **Rich Subers W2RHS** first for doing all of my 3D printing, but also for suggesting the slotted core that was used to hold the notched strips for winding the coils. A simple yet ingenious idea that worked beautifully.

Each of the notched strips was printed with a series of transverse holes through the body of the strip, with the intention of using the holes for mounting the coils in place inside the filter enclosure. That was, in fact, exactly how the coils were secured to the enclosure, using a pair of Keystone 800-series single-lug terminal strips to mount each coil, securing the coil between the terminal lugs by inserting a machine screw through the terminal lugs and the notched strip, and then placing a KEPS nut onto the machine screw. For those who may not be familiar with the term, a *KEPS nut* is basically a standard hex nut with a captive but rotatable externally-toothed lock washer attached. The use of these nuts simplifies the assembly process and reduces the parts piece count.

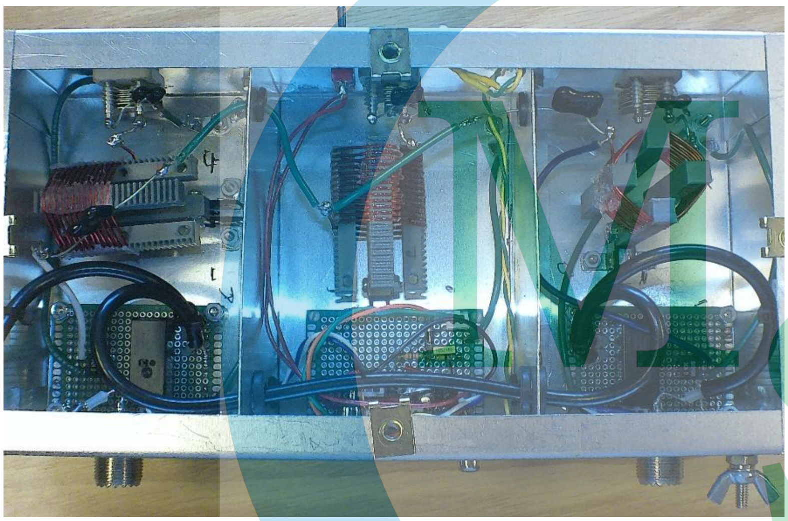

Figure 2 - Working parts of USRX Filter

An important consideration when installing the coils was that each coil was installed with the longitudinal axis of the coil in a different plane of orientation, one being mounted *horizontally along* the length of the enclosure, the second being mounted *horizontally across* the length of the enclosure, and the third being installed *vertically* on end within the enclosure (Figure 2). This is done so that there is minimal magnetic transfer between the three coils, as each field is then in a different plane.

Moving on to the capacitors, it must be understood that the ideal situation had three-quarters of the filter's required capacitance being made up by the value of the fixed capacitor, with the remaining 25% coming from a variable capacitor. Nelson suggested the use of surplus Johnson air variables, and I was fortunate enough to source three of them of suitable value from Surplus Sales of Nebraska. However, the capacitors purchased were of a 12-30pF value, somewhat higher than that which I needed. Optimally, we should have the variable capacitor operating at about the center of its adjustment range in practice. Having settled on 22pF fixed capacitors, I needed about 9pF from the variable capacitors. As a result, I modified these three capacitors by removing two of the five fixed plates (one at a time, measuring the value after each removal), resulting in variable capacitors having a 2-18pF value range. This would then ideally put the final desired value of about 9pF very close to the center of the adjustment range.

A schematic diagram of the filter assembly is shown in Figure 4. Refer to that illustration as you follow along with the upcoming discussion of the operation of the filter unit. The filter has two operating modes – RX and BYP – or *receive* and *bypass*. The BYP mode is the operational mode in use during any transmission from the transceiver. The RX mode is in use whenever the filter is switched to the RX switch position with power applied and the transceiver is in its receive mode. Note that the BYP mode is the power-off fail-safe mode. This is intended to help to prevent the transmitted RF signal from finding its way into the filter circuit.

The filter enclosure, as already mentioned, is divided into three compartments, one for each of the three filter sections. That division is accomplished by the installation of aluminum divider panels that are cut to fit snugly between the front and back walls of the enclosure, and are the full height of the interior of the enclosure. Machine screws and KEPS nuts are used to secure the panels in place, as well as to secure most of the other parts and components within the filter enclosure. While sheet metal screws could have been used, and may well have been easier to install, they would certainly not have been as kind to the hands and fingers that needed to reach within and work inside the enclosure.

Each of the three compartments has a circuit board installed. In this prototypical version of the filter unit, protoboards were used instead of having custom PCB's made. Future versions will likely have the already-designed PCB's installed. The two end compartments each have a relay board, while the center compartment contains a control board.

During BYP operation, the RF output signal from the transceiver enters the enclosure via a coaxial cable connected to the TRANSCEIVER SO-239 connector (Figure 3). From there, the signal is routed on a short length of RG-58 coaxial cable to the relay board in that filter compartment. The RF output signal then passes through the normally-closed (NC) and common (COM) terminals of the relay and directly out to a transverse length of RG-58 cable, which carries the signal to the relay board in the opposite end compartment. There, the signal passes through the COM and NC terminals of the relay in that compartment, and then is passed out to the rear-panel ANTENNA SO-239

Figure 3 - Rear panel view

connector and off to the transmit antenna.

Control of the filter unit is provided by the transceiver RF amplifier control port (*e.g.,* the SEND port on Icom radios), which is usually an RCA jack on the back of the transceiver, and is taken to ground when the mic is keyed. This action would often be used to key an

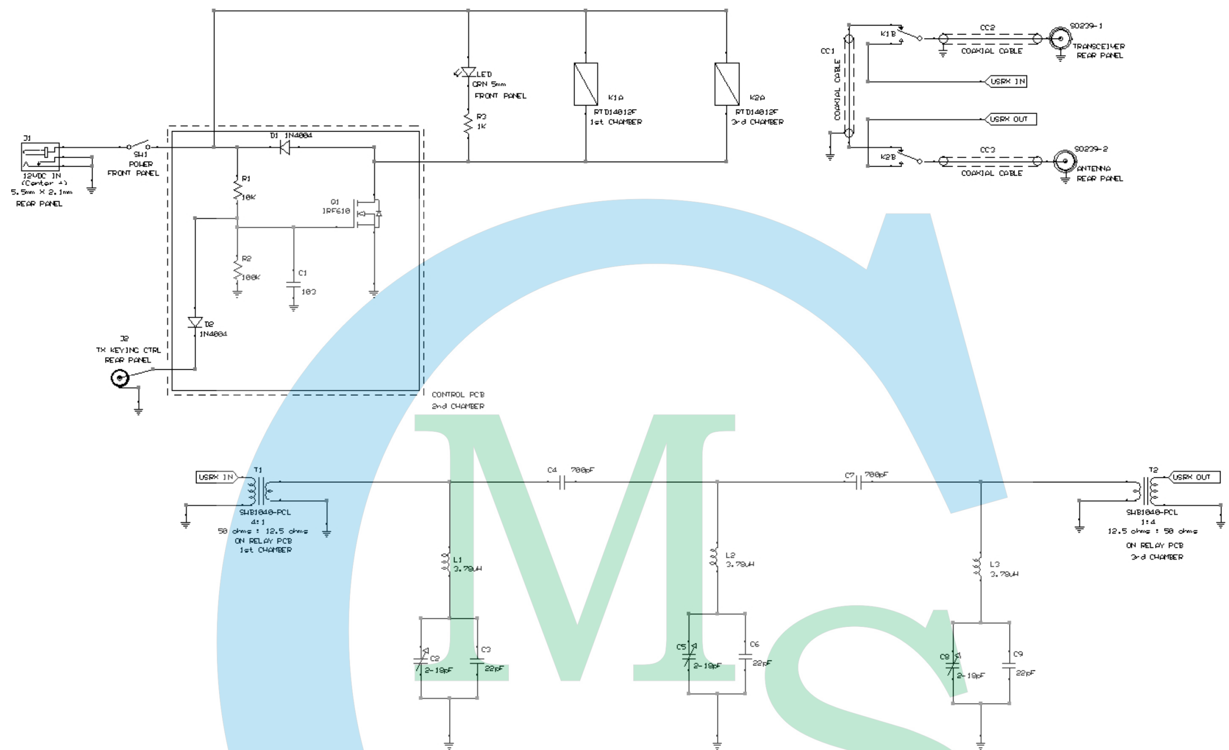

Figure 4 - USRX Filter schematic diagram

RF amplifier to its active state for transmission. In the case of this filter unit, power-on at-rest state has the filter unit in its RX mode, with the relays on the two relay boards pulled into their active or switched state. Thus, in the RX mode, the relays are both switched “on” so that their COM terminals are actively connected to their normally-open (NO) terminals. This provides a receive signal path from the receive antenna into the filter unit at the ANTENNA SO-239 connector, through the short RG-58 connecting cable and to the relay board. On the relay board, the RX signal is routed through the now-closed COM and NO terminals and out to a four-to-one step-down transformer, where the 50Ω impedance is dropped to a more suitable 12.5Ω for the filter circuit. From the transformer, the RX signal is routed to the three parallel filter sections via the 700pF coupling capacitors. The low end of the 20-meter signal is shunted off to ground via the filter sections, while the upper end of the band is passed on to the opposite relay board, where it passes through a reversal of the impedance-matching transformer (now a one-to-four step-up transformer), bringing the impedance back up to the 50Ω level on its way to the relay. At the relay, the RX signal passes through the NO and COM terminals and on to the short RG-58 connecting cable, by which it is carried to the TRANSCEIVER SO-239 connector and thence on to the transceiver.

The filter mode is indicated by a green LED on the filter front panel. An illuminated LED indicates that the filter is in its RX mode, and the LED should go out as soon as the mic is keyed, switching it to the BYP mode instead.

The transformers used in this build are the closest thing that I could find to the specific model recommended in Nelson Sollenberger's article. His recommendation was for the CoilCraft WB4-6L transformer, of which there was zero stock worldwide. Instead, I sourced the CoilCraft SWB1040-PCL, a miniature transformer with almost identical characteristics and the same physical size and form factor. I could see no reason why it should not work in the circuit, and it turns out that I was correct.

A few words about these transformers are called for here and now. These devices – both part numbers – are rated at a mere 250mW and are therefore ill-suited for handling the transmit power of the transceiver at any level at all. Therefore, the filter design was such that the default or power-off condition would route the transmit power directly through the filter unit on a bypassing coaxial cable, basically carrying the signal from the TRANSCEIVER SO-239 connector to the ANTENNA SO-239, without ever going near the transformers. However, this depends upon proper operation of the Potter and Brumfield RTD14012F relays. These relays, while having a nominal twelve-volt coil, operate quite well when powered from the ubiquitous 13.8VDC so prevalent on the ham bench today. While the engage time is a bit slower than is the release time – eight milliseconds for engage compared to six milliseconds for release – the relay timing is still quick enough to do the job.

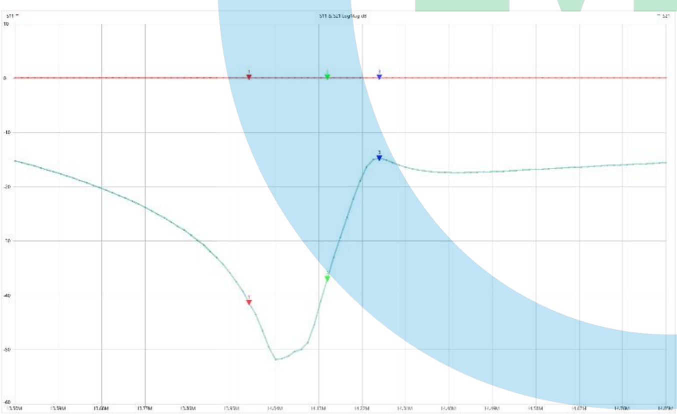

Figure 5 - Performance curve of the filter

Now that you have seen an explanation of the filter's basic operation, it should become quite evident that this filter unit is capable of eliminating the CW QRM about which I was so concerned.

Tuning of the filter unit was done using a NanoVNA H4 that was properly calibrated and set with a stimulus range of 13.5MHz to 14.85MHz, thus encompassing the entire 20-meter band. The illustration at Figure 5 depicts the performance curve of the tuned filter. As can be seen, the final attenuation of the CW segment of the band was more than 50dB. In practice, it worked quite well, though I was not thrilled with the resultant attenuation across the remainder of the band. However, that attenuation did not stop the team from making a good number of QSO's.

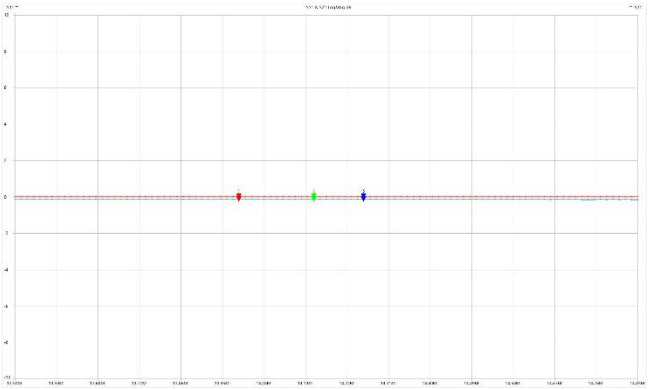

Figure 6 - Filter insertion loss

The Figure 6 illustration depicts the performance in the transmit mode, where the insertion loss was on the order of ≈100mdB (or 0.1dB). That loss was the result of the signal passing through the relay contacts, which is unavoidable under the circumstances.

In both Figure 5 and Figure 6, the frequencies marked are approximately 14.0MHz, 14.15MHz, and 14.25MHz respectively.

It is my recommendation that the Club seriously consider building a series of these filter units for the other operational bands utilized on Field Day, specifically 80-meters, 40-meters, 15-meters, 10-meters, and even 6-meters. In the 40m and 80m versions, the coils utilized would be toroidal coils, while the other bands would need solenoidal air-core coils as used in the 20-meter version. If this filter worked so well for me on 20-meters, it should perform equally well on the other bands.