Combline Filters for VHF and UHF

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RF pollution is rampant at good portable locations on mountaintops and other high places – anywhere accessible is populated with cellphone towers, TV and FM broadcast stations, two-way radio and pager transmitters, and even amateur repeaters. Most of these are high power, producing signals strong enough to seriously overload the VHF and UHF transceivers we use for contest operation or microwave liaison. The problem often manifests itself as a very high noise level.

In August 2013, we were operating the 10 GHz & Up Contest from the top of Mt. Mansfield in Vermont, right next to the building with most of the TV and FM transmitters. Our two-meter liaison transceiver was suffering from a very high noise level, so we could only hear strong signals – not much good for working DX. Fortunately, N1JEZ had asked me to bring a filter. We put my combline filter in line and eliminated the excess noise. On previous expeditions, we didn't have a filter and suffered the consequences with noise, birdies, and interference.

The advent of broadband MMIC preamps acerbates the problem. Unfiltered, they would be a disaster on a mountaintop like Mt. Mansfield. Even at my QTH, 42 km away from Mt. Mansfield but line-of-sight, the strongest FM broadcast station, at 107.9 MHz, is -17 dBm on an FM turnstile antenna. Amplified by 25 dB or more, this is more power than most receivers can handle, even out of band.

Combline Filters in Stripline

I was inspired by a QST article by Reed Fisher, W2CQH, from 1968: "Combline V.H.F. Bandpass Filters." Making one had been on my "to do" list for years, but I finally got around to it in 2010 after other mountaintop noise and interference problems.

A combline filter uses parallel transmission line resonators less than a quarter-wave long, loaded by capacitance at the open end. This allows tuning over a range of frequencies by varying the capacitance. Typical electrical length of the resonators is between 30 and 60 electrical degrees; a quarter-wavelength is 90 degrees.

The W2CQH version uses three parallel stripline resonators tuned by air trimmer capacitors, with two additional by air trimmer capacitors input and output coupling. I didn't like the coupling capacitors for two reasons: they add two additional adjustments, making it hard to tune the filter without good swept test equipment, and, more important, the capacitors are hard to find. In

1968, they were inexpensive and available at your local radio-electronics store; now, I am lucky to find three usable capacitors between the junk box and scrounging at hamfests. Surplus capacitors from Russia are appearing on ebay at fairly reasonable prices.

So I opted for stripline construction with tapped input and output coupling, as sketched in Figure 1, but I needed to determine the tap point. Today we can do this in software – **Ansoft Designer SV** (Student Version) CDs were handed out at VHF and microwave conferences a few years ago, and a Filter Design Wizard is included. Calculating a combline bandpass filter in stripline is pretty straightforward, just plug in the desired frequency and bandwidth and guess at few other parameters. Then it's a matter of fiddling the dimensions, strip impedances, and electrical length so it fits in the desired box or chassis. Design procedure is given in Part 2 below.

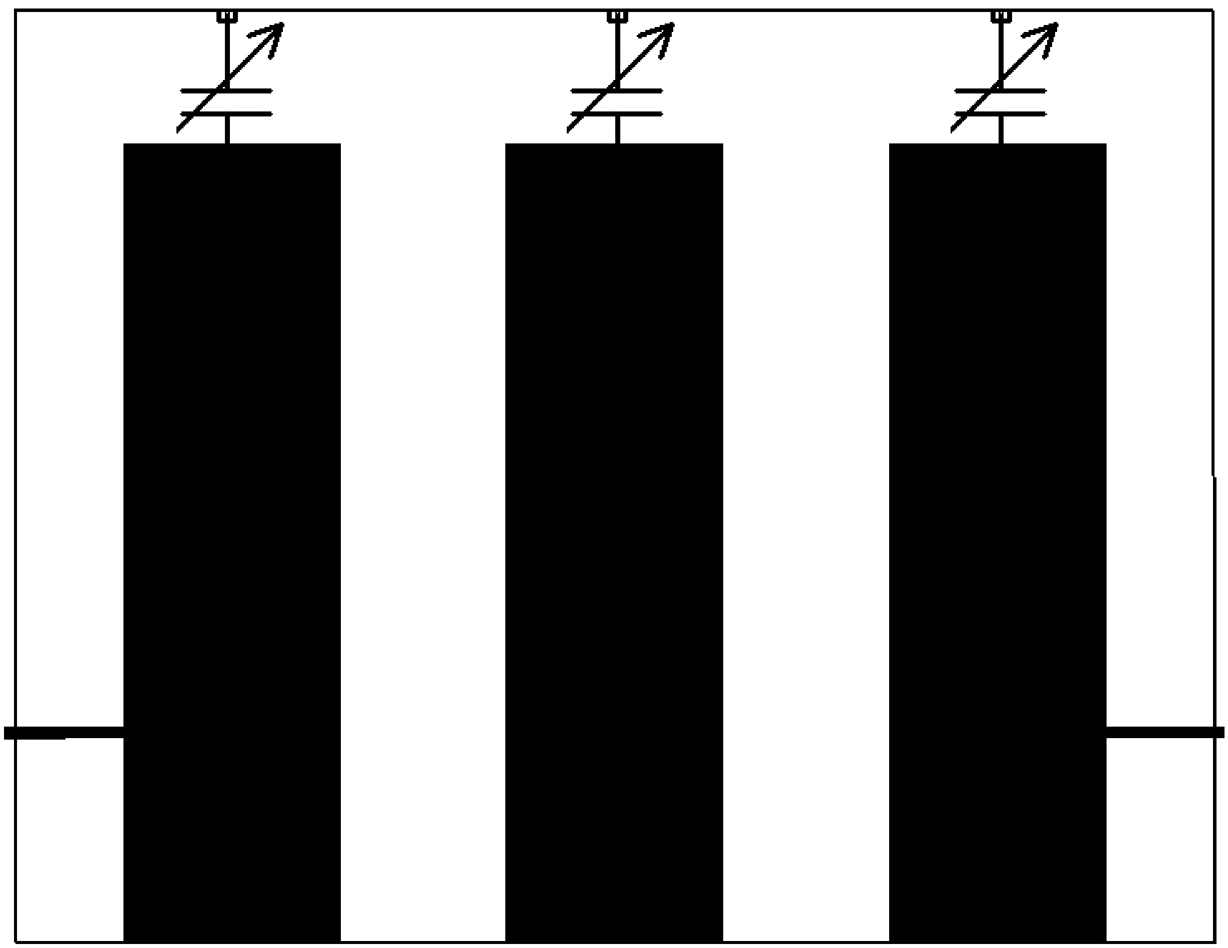

Figure 1 – Sketch of Combline Filter in Stripline

The electrical design is only part of the project. A good, sharp filter must be mechanically robust to stay on frequency, especially for rover work. For low loss, high Q is important – wide striplines with good contact to ground at the bottom, the high-current point. W2CQH used copper resonators in an aluminum chassis, a combination that is asking for corrosion. I chose to stick to aluminum resonators, probably with slightly higher loss, instead. Aluminum is extremely difficult to solder, so all connections are made with #4 tinned solder lugs (I bought a box of 1000 years ago) and stainless-steel hardware, metals that are least likely to interact with aluminum. For the box, I had some inexpensive nested aluminum boxes made in India (look for Stalwart U3789 online or at Amazon – three useful boxes with lids). I used the largest size, about 220x145x60 mm for the 144 MHz filter.

The assembled filter is shown in Figure 2 – three narrow strips with air trimmer capacitors at one end, input and output tap points to BNC connectors.

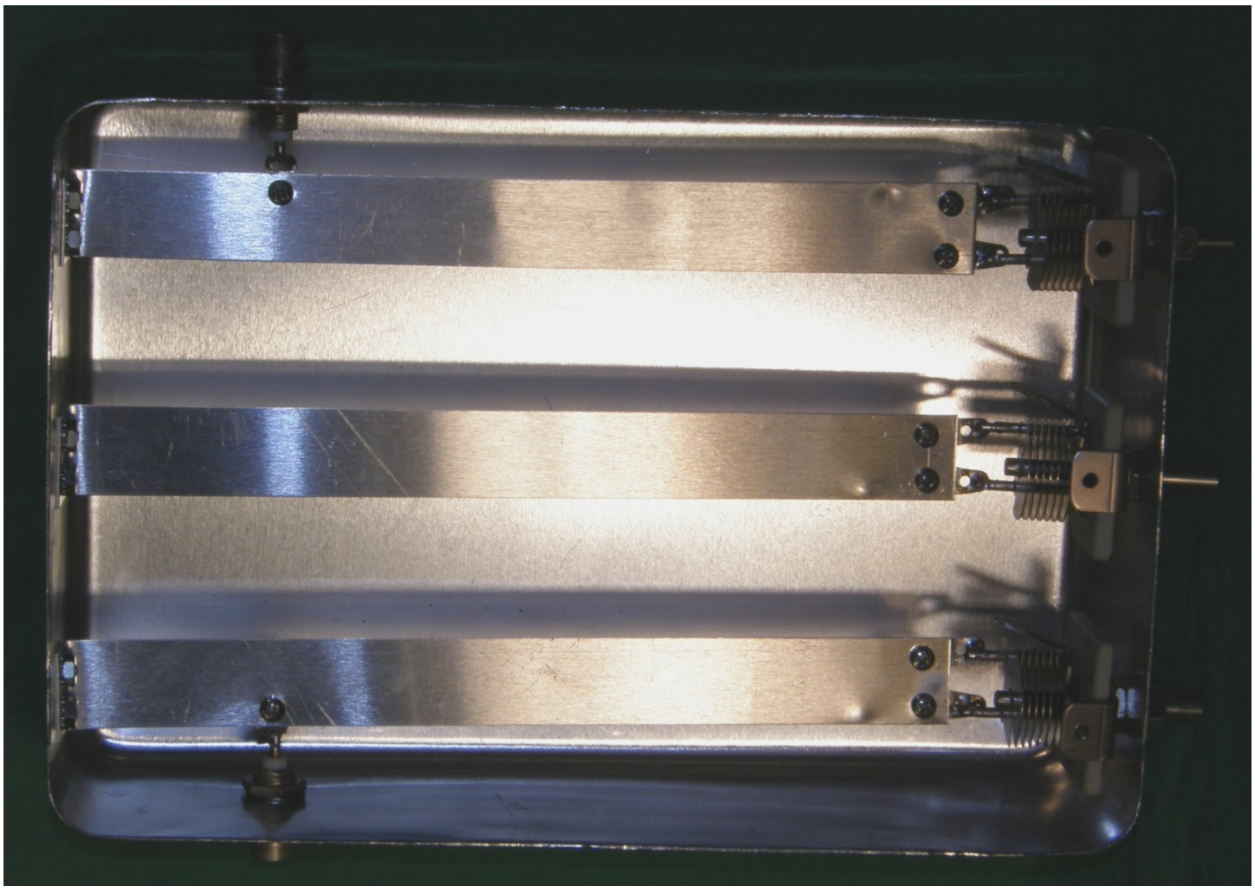

Figure 2 – Combline Filter for 144 MHz

Initial tests suggested that the Filter Design Wizard doesn't work very well (the expensive professional version of **Ansoft Designer** has the same Filter Design Wizard). After careful tuning, the best response I could get is shown in Figure 3. Bandwidth is nearly twice the design goal, and the filter is obviously over-coupled. This suggests that the tap position is incorrect – the Filter Design Wizard gets it wrong. Further tests confirmed this error.

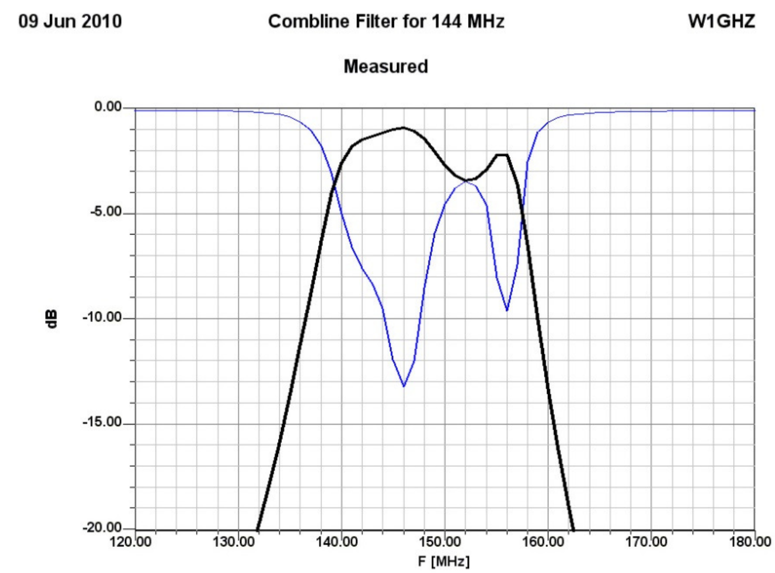

Figure 3 – Initial Performance of 144 MHz Combline Filter in Figure 2

Improvement would be easy by starting over, but I had already done the hard metalwork here, so I wanted to try and fix this one. At the time, I had access to Ansoft **HFSS** software (www.ansys.com) so I was able to simulate a full 3D model of the filter and adjust dimensions. What I found was that coupling is increased by moving the tap point closer to ground – the opposite of my intuition. Eventually I found a compromise of narrower striplines and a tap point farther from ground, but not too far from the connectors, which worked without drilling additional holes. The response of the improved version is shown in Figure 4, with narrower bandwidth (about 13 MHz), lower loss (about 0.6 dB), better return loss, and a smooth passband.

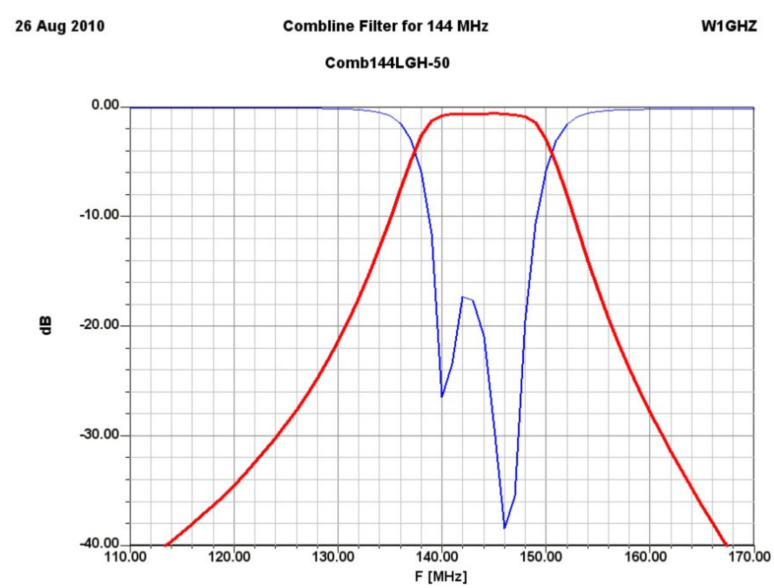

Figure 4 - Performance of 144 MHz Combline Filter in Figure 2 after modifications

Other bands

After fixing the two-meter filter, it felt like I had a good handle on designing combline filters – do the basic design quickly in **Ansoft Designer SV**, then use **Ansoft HFSS** to adjust the tap point. I did paper designs for other VHF and UHF bands and recorded them in my notebook, but didn't get around to building them until recently. The real impetus was our experience on Mt. Mansfield last summer.

222 MHz

A filter for 222 MHz was the first priority, since the FCC had decided to move TV channel 44 (analog) to DTV channel 13, 210 to 216 MHz. My noise level increases by 16 dB when pointed at Mt. Mansfield. For this filter I chose the middle size of nested aluminum box (Stalwart U3789), about 202x129x54 mm. The striplines in this version, Figure 5, are parallel to the short dimension of the box, allowing for wide strips spaced farther apart for narrower bandwidth.

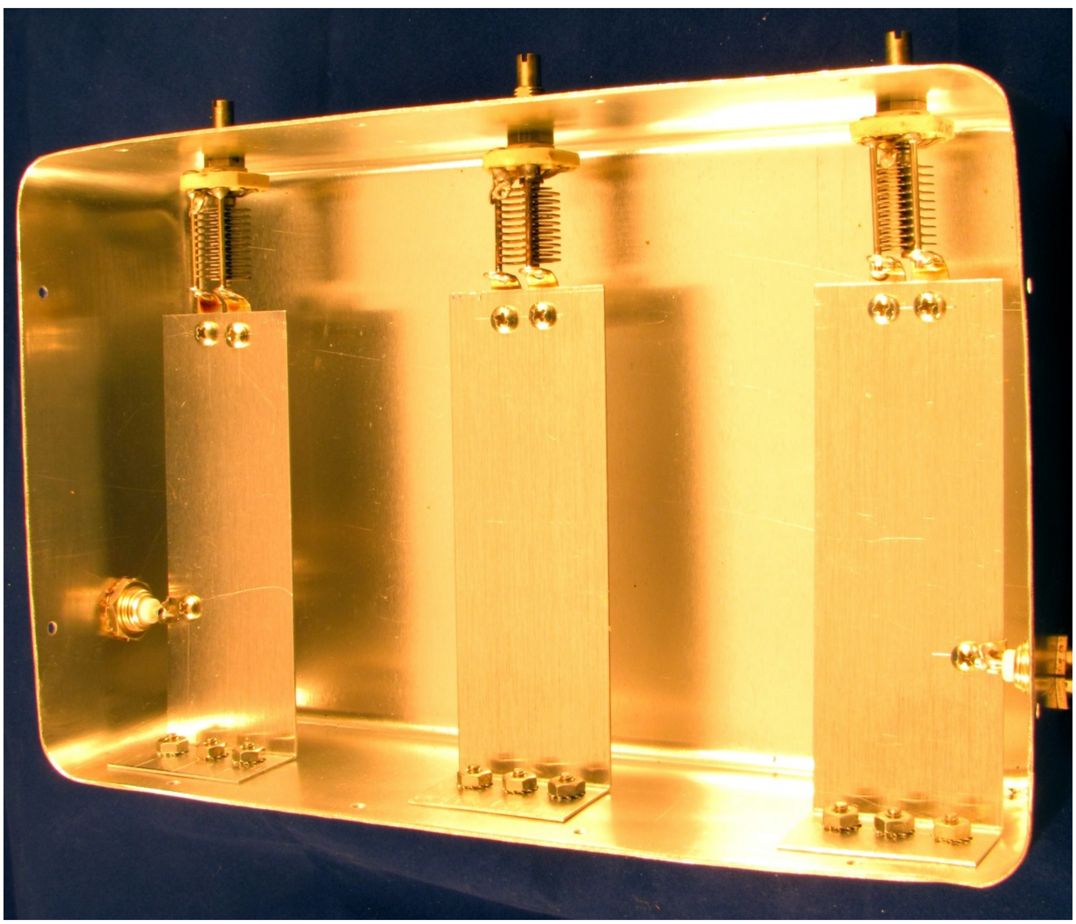

Figure 5 – Combline Filter for 222 MHz

Performance of this filter is shown in Figure 6. The bandwidth is narrower than the 144 MHz filter, about 8 MHz with a smooth passband, but loss is slightly higher, about 1.1 dB. We expect narrower filters to have more loss for the same resonator Q – since the filters have similar construction, Q should be about the same.

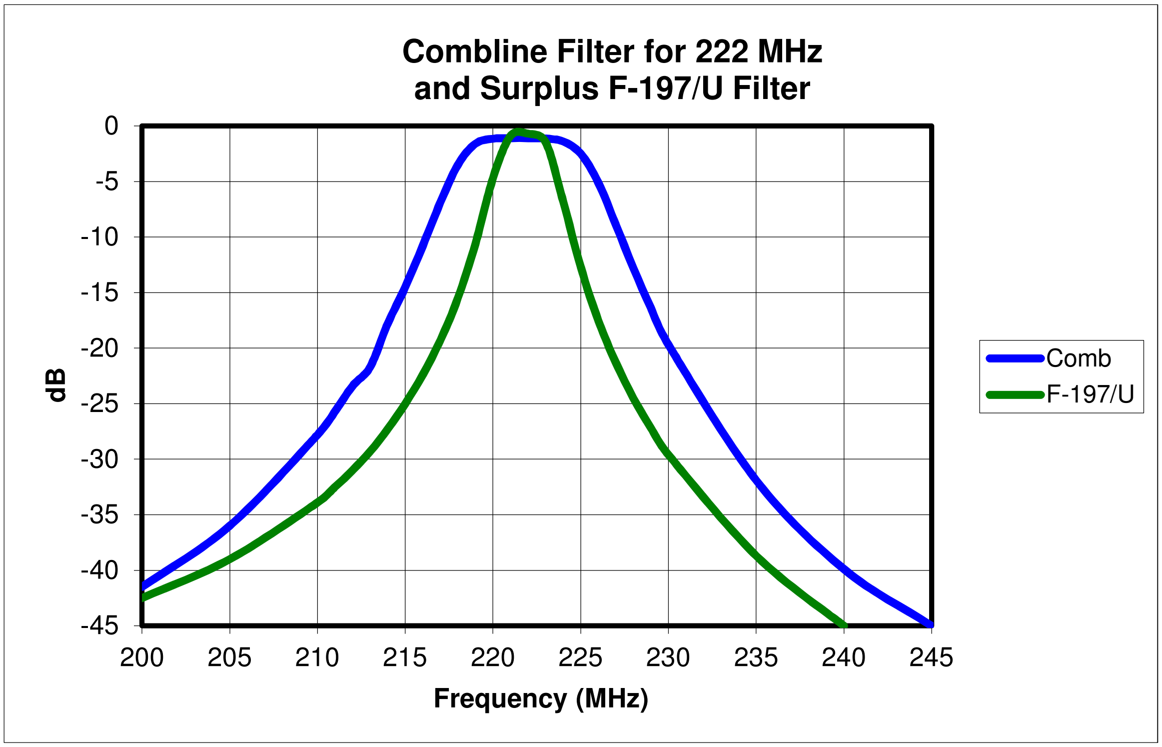

Figure 6 – Performance of 222 MHz filters

For comparison, I found the filter shown in Figure 7 in my barn, marked "Signal Corps, Filter, Band Pass F-197U." I picked this up at a hamfest some years ago. The seller told me it had high loss and needed modification to be usable, and I never did anything about it. I tuned it to 222 MHz and measured the performance, also shown in Figure 6. The bandwidth is narrower than the combline filter *and* the loss is lower, about 0.7 dB. It also has a lot more rejection at 216 MHz than the combline filter. Those big gold-plated cavities have higher Q than the aluminum striplines and trimmer capacitors.

Do these filters help with the noise level? With the surplus filter, the noise increase in the direction of Mt. Mansfield is reduced to 2 dB rather than 16 dB. But with the combline filter, with 10 dB less rejection, the noise increase is 3 dB. We can infer that most of the noise is coming from sources other than the channel 13 DTV transmitter. And either filter is a big improvement.

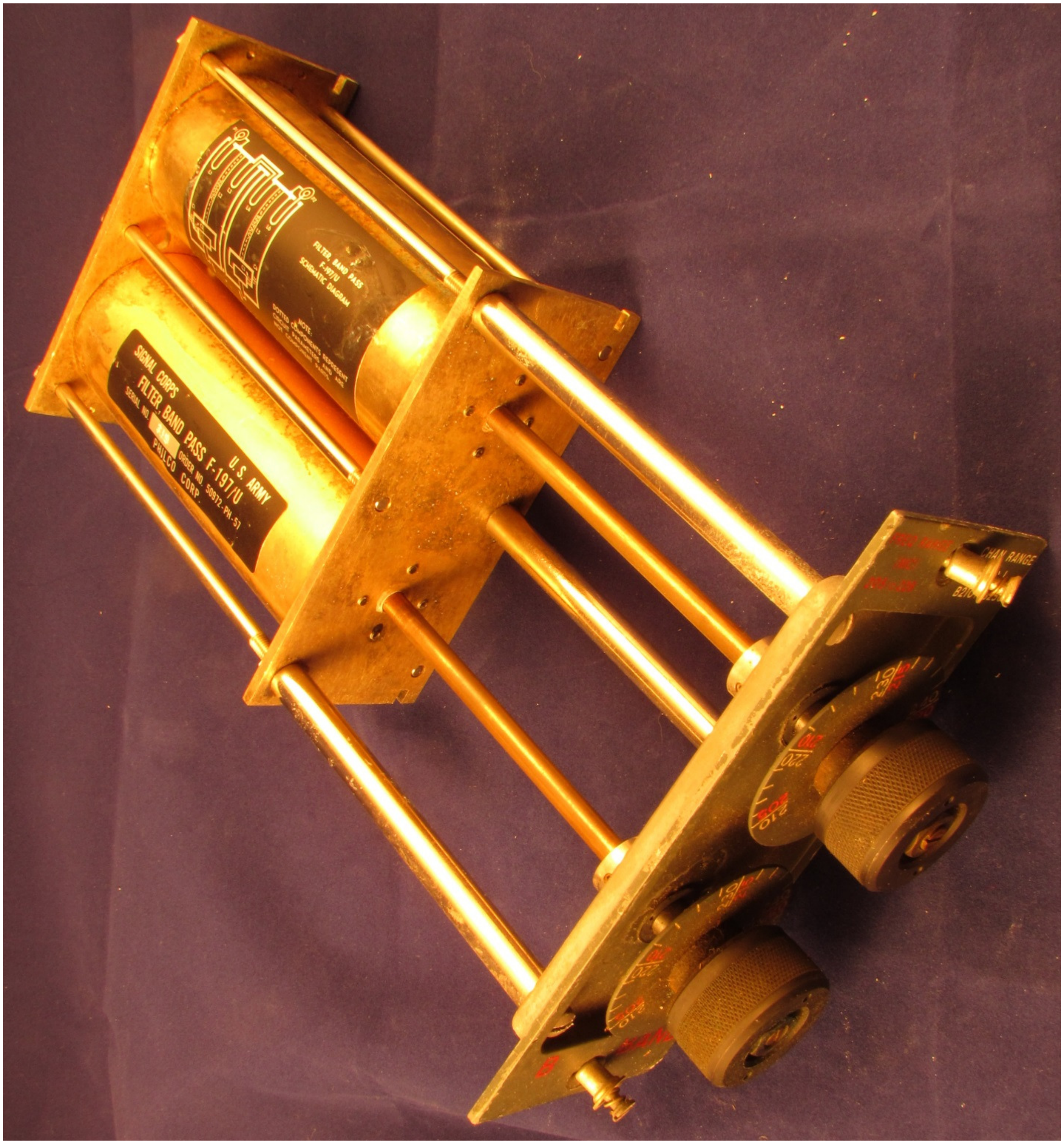

Figure 7 – Surplus Filter, Band Pass F-197/U

432 MHz

For 432 MHz, I had calculated filter dimensions for the smallest nested box (Stalwart U3789), which is about 176x99x43 mm. I had also calculated dimensions for a diecast aluminum box, the Hammond 1590-BB, with inside dimensions about 115x90x30 mm. The diecast box seems a lot more robust, so I went with that one first. The filter is shown in Figure 8. Because the height of the diecast box is much shorter than the others, the striplines are narrower, but the spacing is still proportionately large for narrow bandwidth.

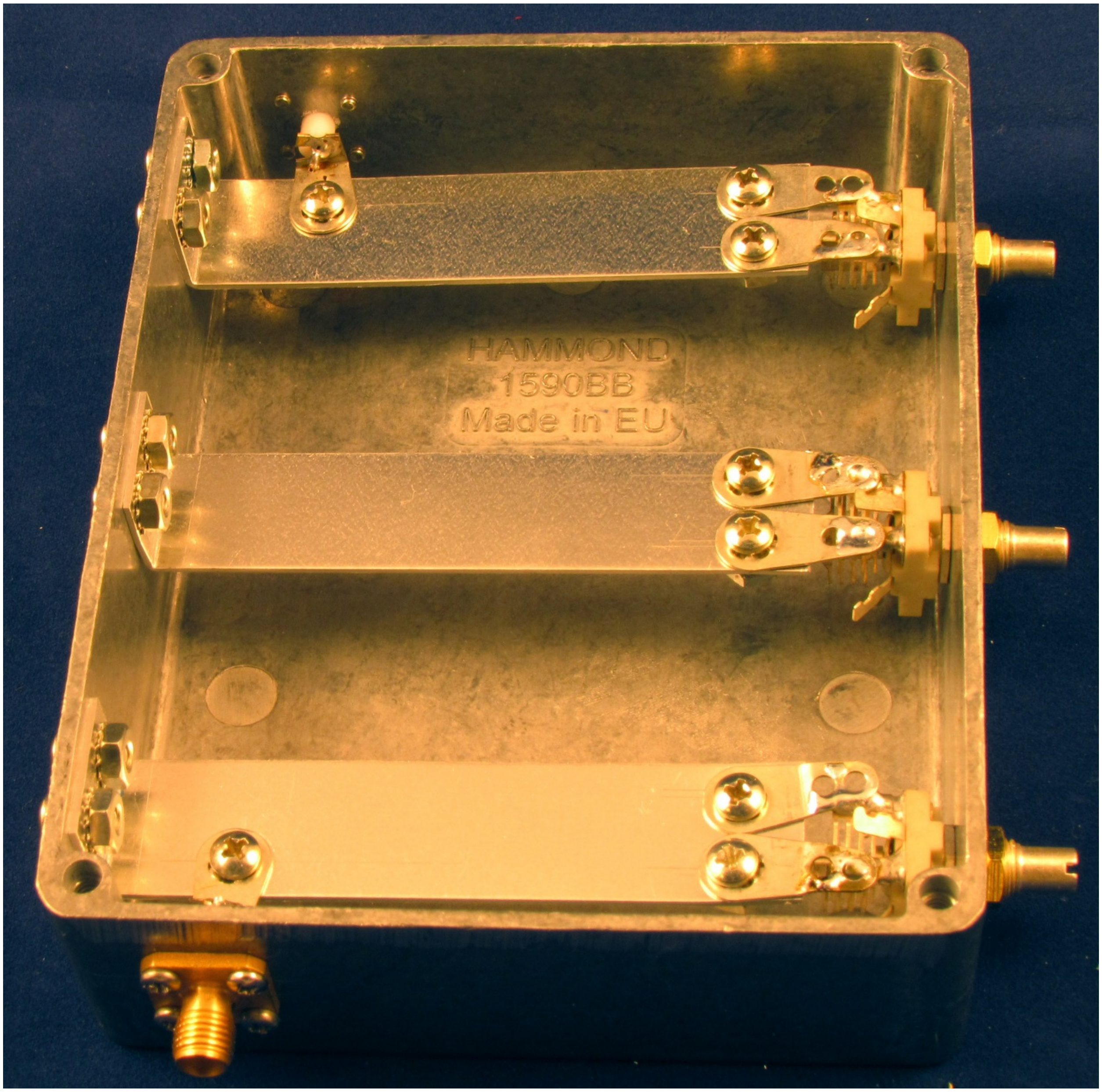

Figure 8 – Combline filter for 432 MHz in diecast box

Performance of the 432 MHz combline filter is shown in Figure 9. This one is also quite sharp, with a smooth bandwidth of about 11 MHz, and loss of about 1.25 dB.

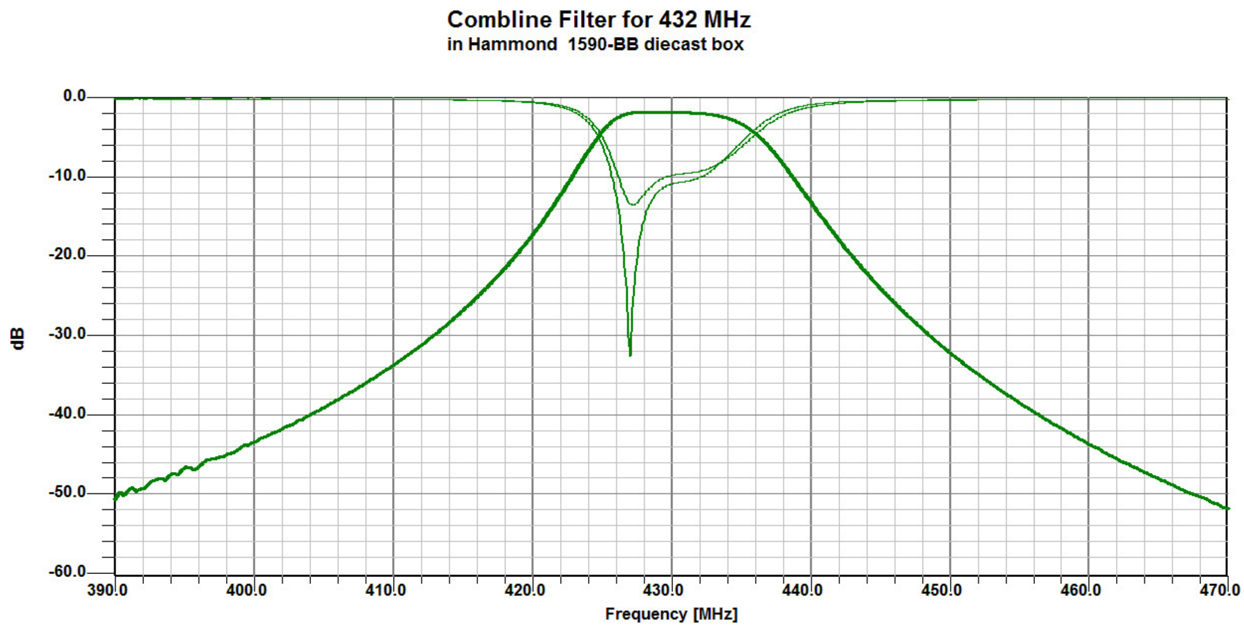

Figure 9 – Performance of Combline Filter for 432 MHz in diecast box

Since I had drilled the holes and cut the striplines for the other 432 MHz combline filter, in the small nested aluminum box (Stalwart U3789), I later went back and assembled that one as well – the assembly process is a bit fiddly and takes some time to get all the solder lugs lined up just right. The completed filter is shown in Figure 10.

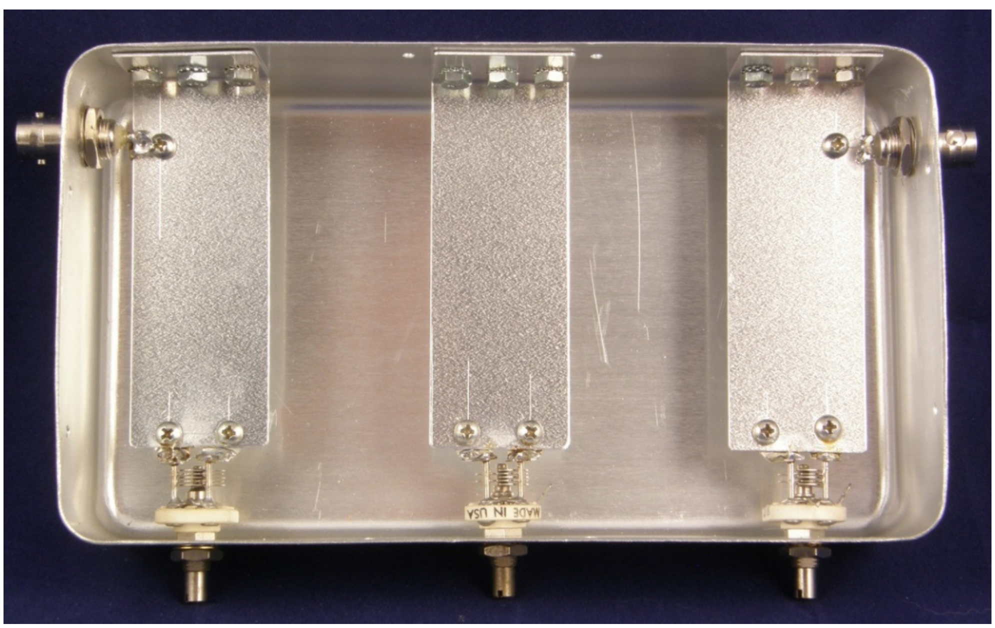

Figure 10 – Combline Filter for 432 MHz in small Stalwart nested box

Once the lid is screwed on securely to provide rigidity, tuneup was smooth. Performance is shown in Figure 11. This one is also quite sharp, with a smooth bandwidth of about 13 MHz, and loss of about 1.4 dB, not quite as good as the version in the diecast box.

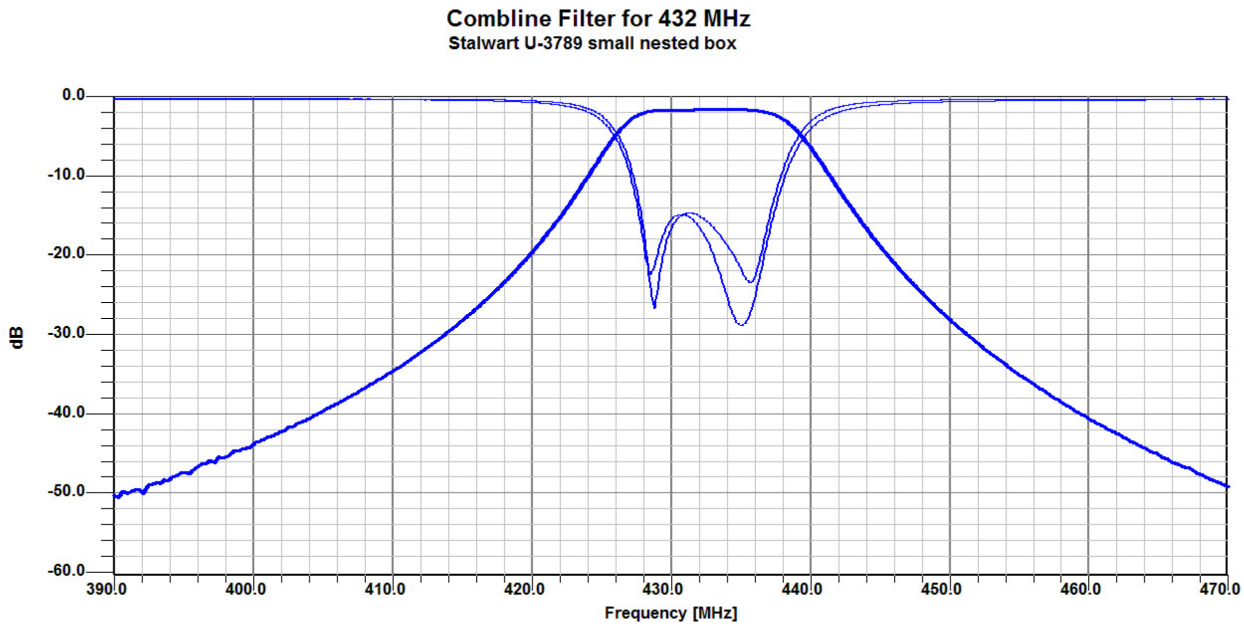

Figure 11 – Performance of Combline Filter for 432 MHz in small Stalwart nested box

Since the resonators in a combline filter are not a full quarter-wavelength, they do not have responses at frequencies that are odd harmonics of the passband, unlike some other filter types. Figure 12 shows that these filters are free of spurious responses up to about 1.5 GHz and have very good rejection up to that frequency.

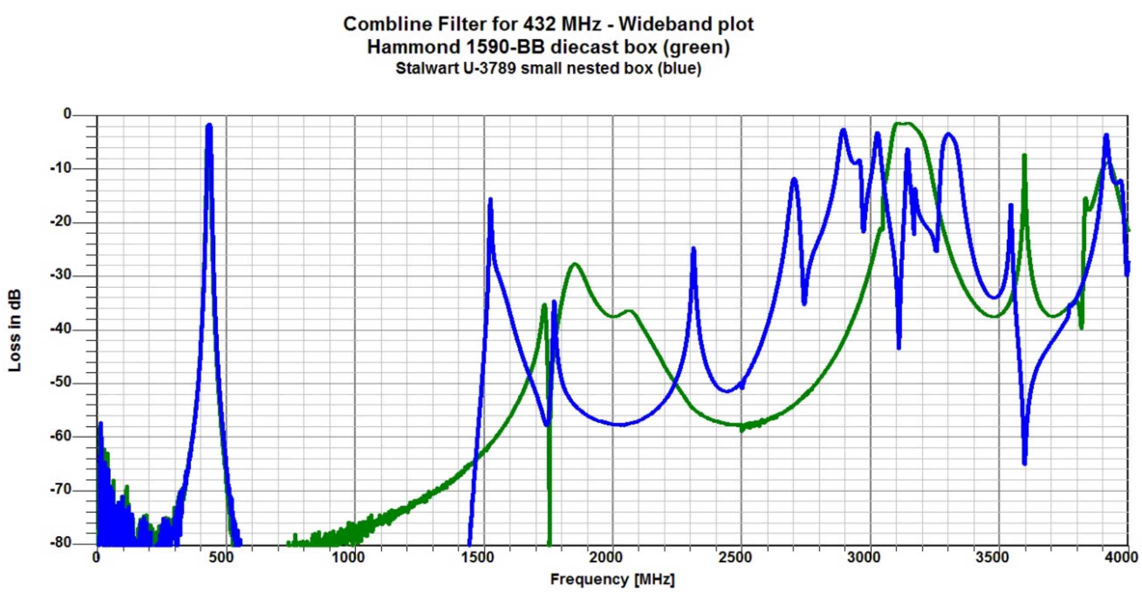

Figure 12 - Performance of the 432 MHz Combline Filters over a wide frequency range

144 MHz

Since the first 144 MHz combline filter was a compromise and the bandwidth was not as narrow as I had intended, I calculated new dimensions in the large Stalwart box. I also calculated dimensions for a chassis like the one W2CQH used, a Bud AC-406, 9x7x2 inches. I chose to build the one in the chassis, shown in Figure 12.

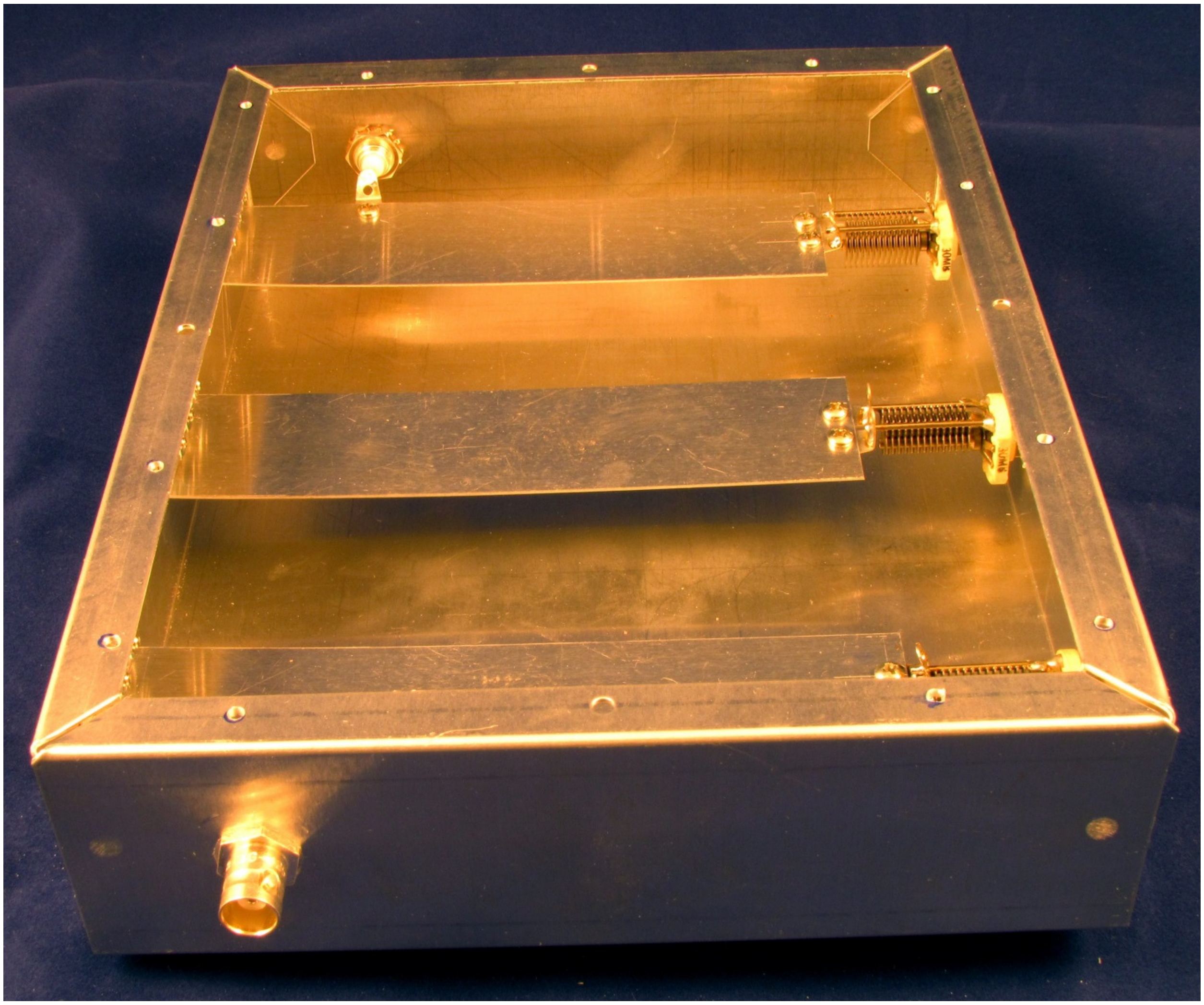

Figure 13 – Combline Filter for 144 MHz in Bud AC-406 Chassis

This filter is very sharp, with a bandwidth of about 2.5 MHz. The price for the narrow bandwidth is slightly higher loss, about 1.7 dB. The smooth response is shown in Figure 14. This filter was simply tuned for minimum loss at 144.2 MHz, since my sweeper was acting up and I couldn't sweep the response while tuning.

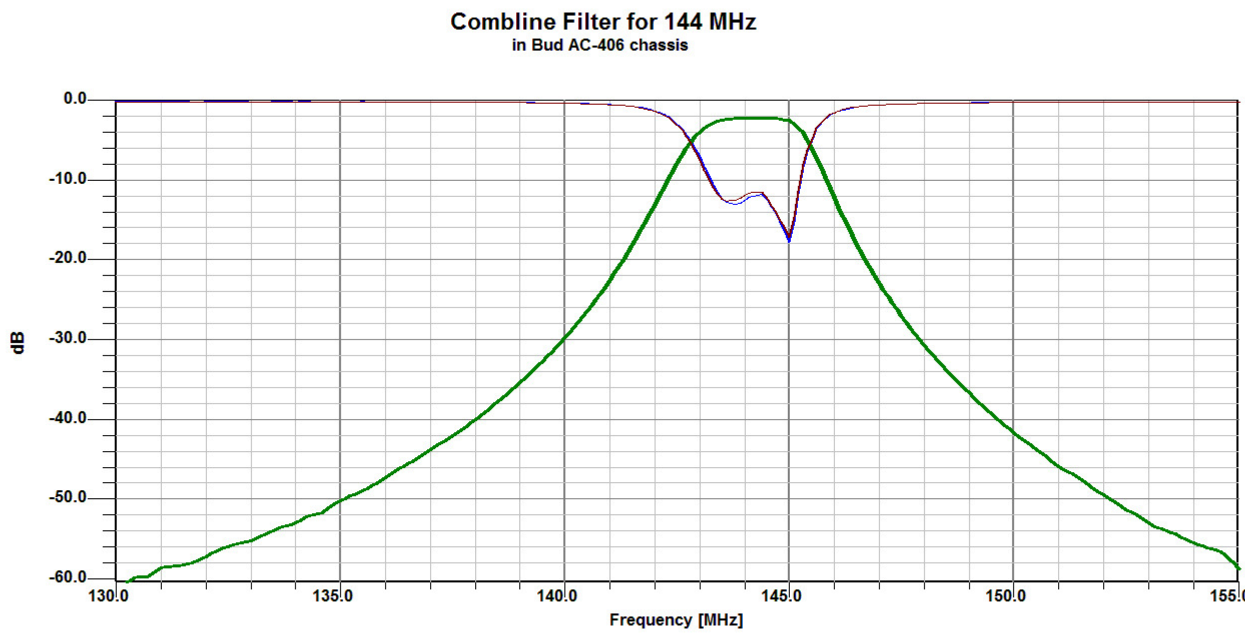

Figure 14 – Performance of Combline Filter for 144 MHz pictured in Figure 13

Like the 432 MHz filters, the 144 MHz combline filter has excellent out-of-band rejection, with no spurious responses below 750 MHz, as shown in Figure 15. This filter can effectively block all broadcast radio and TV frequencies from your receiver.

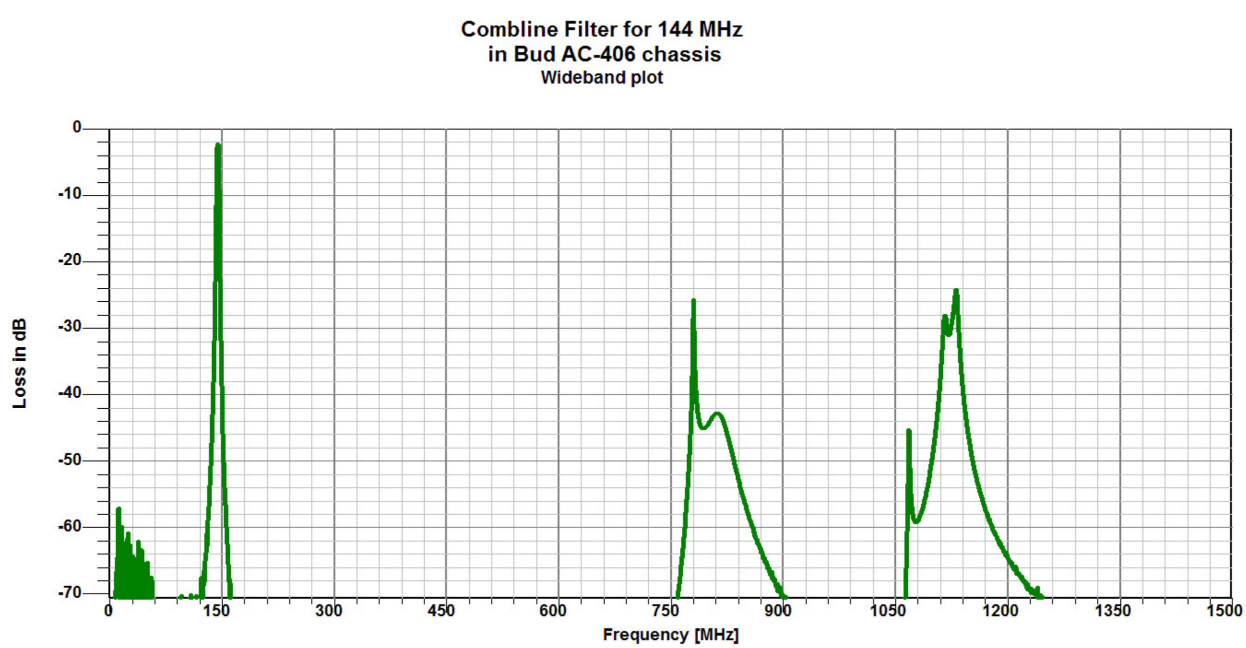

Figure 15 - Performance of the 144 MHz Combline Filter over a wide frequency range

50 MHz

For 50 MHz, W2CQH used the same Bud AC-406 chassis, 9x7x2 inches, but rotated 90 degrees, so the striplines are longer. I calculated dimension for a tapped combline filter in this chassis, but it seemed a bit cramped, so I chose a slightly larger chassis, the Bud AC-1418, 10x8x2.5 inches. With the chassis oriented so that the striplines are in the long dimension, **Ansoft Designer SV** calculated a capacitance of 135 pf for the outside resonators, and about 10% less for the center resonator. I didn't have anything this large available, so I looked on ebay and found some 140 pf air trimmer capacitors from Russia.

After the capacitors arrived, I drilled the chassis and cut the striplines with tinsnips, then assembled the filter, shown in Figure 16.

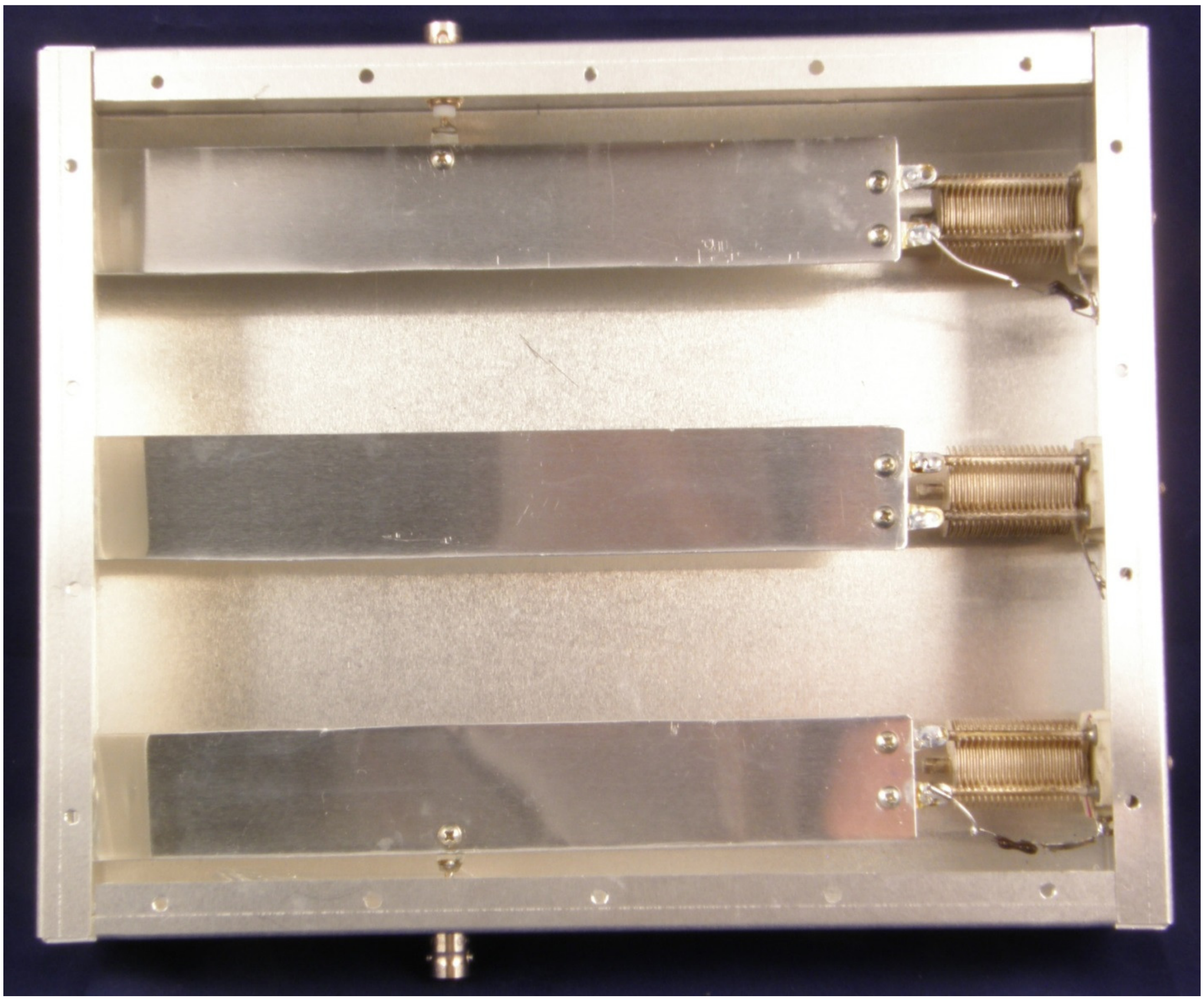

Figure 16 – Combline Filter for 50 MHz

Initial testing showed that the filter would not tune below 52 MHz. The problem was the capacitors – they are much longer than I had estimated, so the striplines are shorter, about 198 mm. Recalculating with the new length suggested that 150 pf is required for 50 MHz, so I put a 15 pf silver mica capacitor in parallel with each end capacitor – less capacitance is required for the center resonator. Now the filter tunes down to about 48 MHz. Final tuning at 50 MHz yielded the performance shown in Figure 17, nice and sharp with about 3 MHz bandwidth. Insertion loss is about 0.75 dB, so the silver mica capacitors are OK at 50 MHz. It might even be preferable to use smaller air trimmer capacitors with more fixed capacitance.

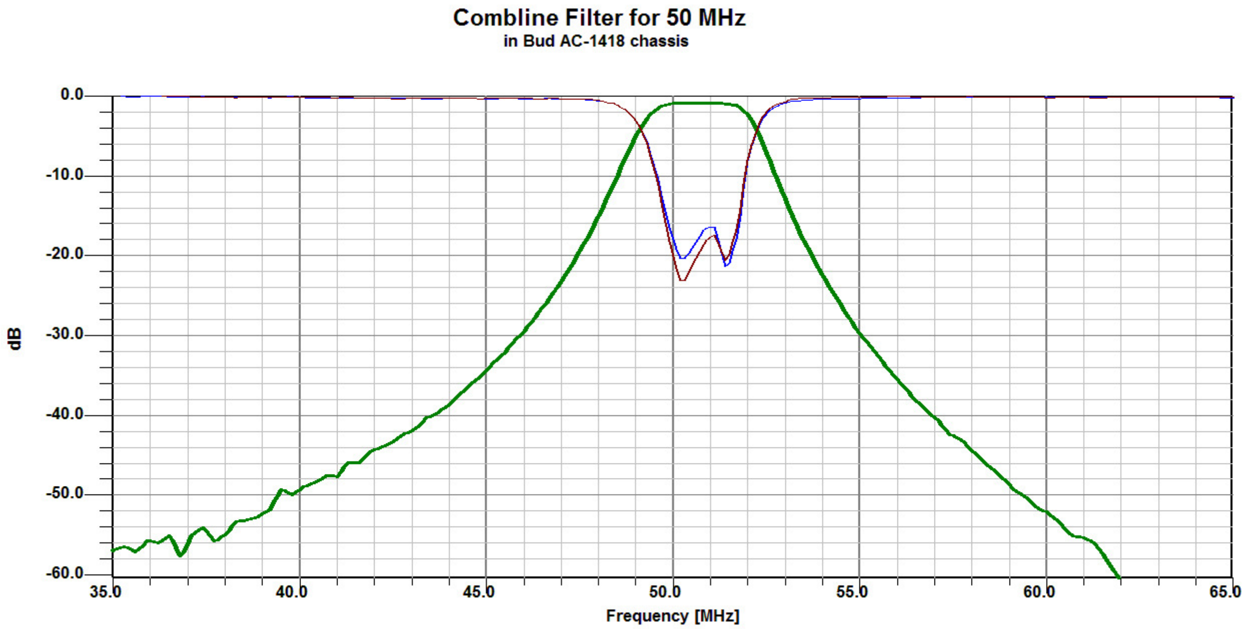

Figure 17 – Performance of Combline Filter for 50 MHz

Like the 144 and 432 MHz filters, the 50 MHz combline filter has excellent out-of-band rejection, with no spurious responses below 700 MHz, as shown in Figure 18. This filter can effectively block all broadcast radio and TV frequencies from your receiver.

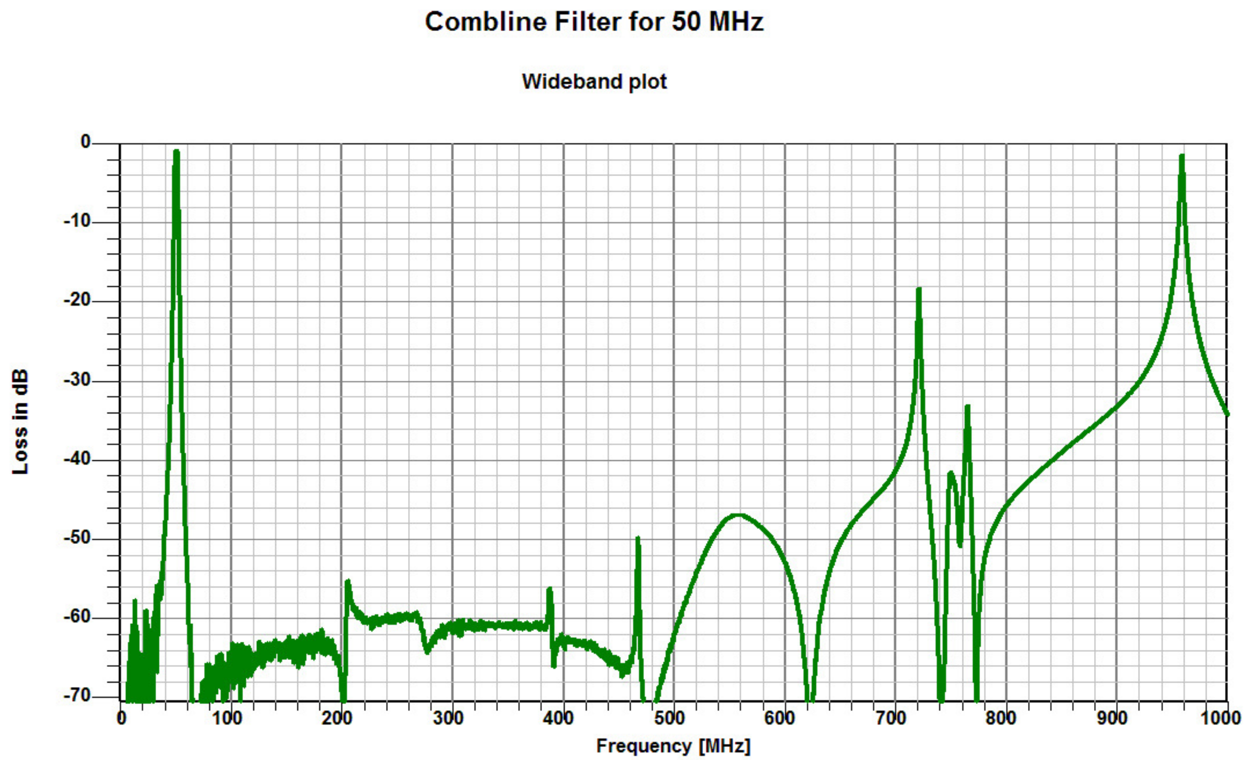

Figure 18 - Performance of the 50 MHz Combline Filter over a wide frequency range

Construction

Making these filters is mostly careful metalworking, but not any fancy equipment. A drill and tinsnips should be enough to do the job. Mark the box holes carefully – I make rough measurements with a ruler and Sharpie, so I can erase mistakes. When it looks right, then I scribe hole locations with a digital caliper. Centerpunch the hole locations, then drill or punch the holes. I find that a hand punch makes cleaner holes in sheet metal where it fits, otherwise brad-point drills are recommended. Deburr everything.

Cut the striplines to the desired width, but leave them long. Bend the last half-inch to a right angle, in a vise if you don't have a bender. Put a capacitor in place, fit a stripline, and eyeball the length. Cut to length, make the holes in the striplines, and see if it all fits with solder lugs. If not, cut another stripline. The capacitor end of the stripline should fit something line Figure 19.

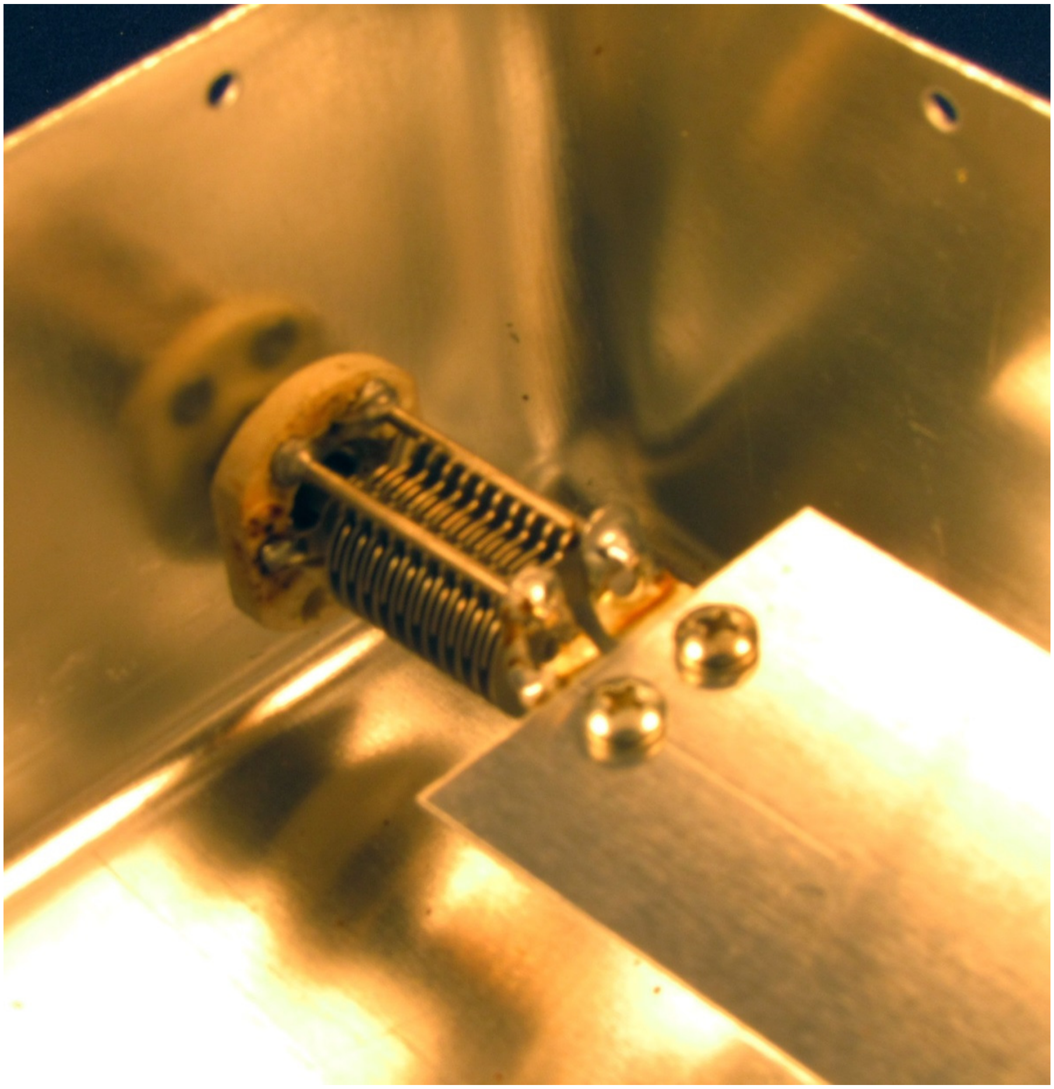

Figure 19 – Closeup of tuning capacitor assembly

Before assembly, clean everything, first with denatured alcohol to remove grease, then rinse with water. Good contact depends on clean surfaces. The ground end of the stripline and the connector tap point should fit something like Figure 20.

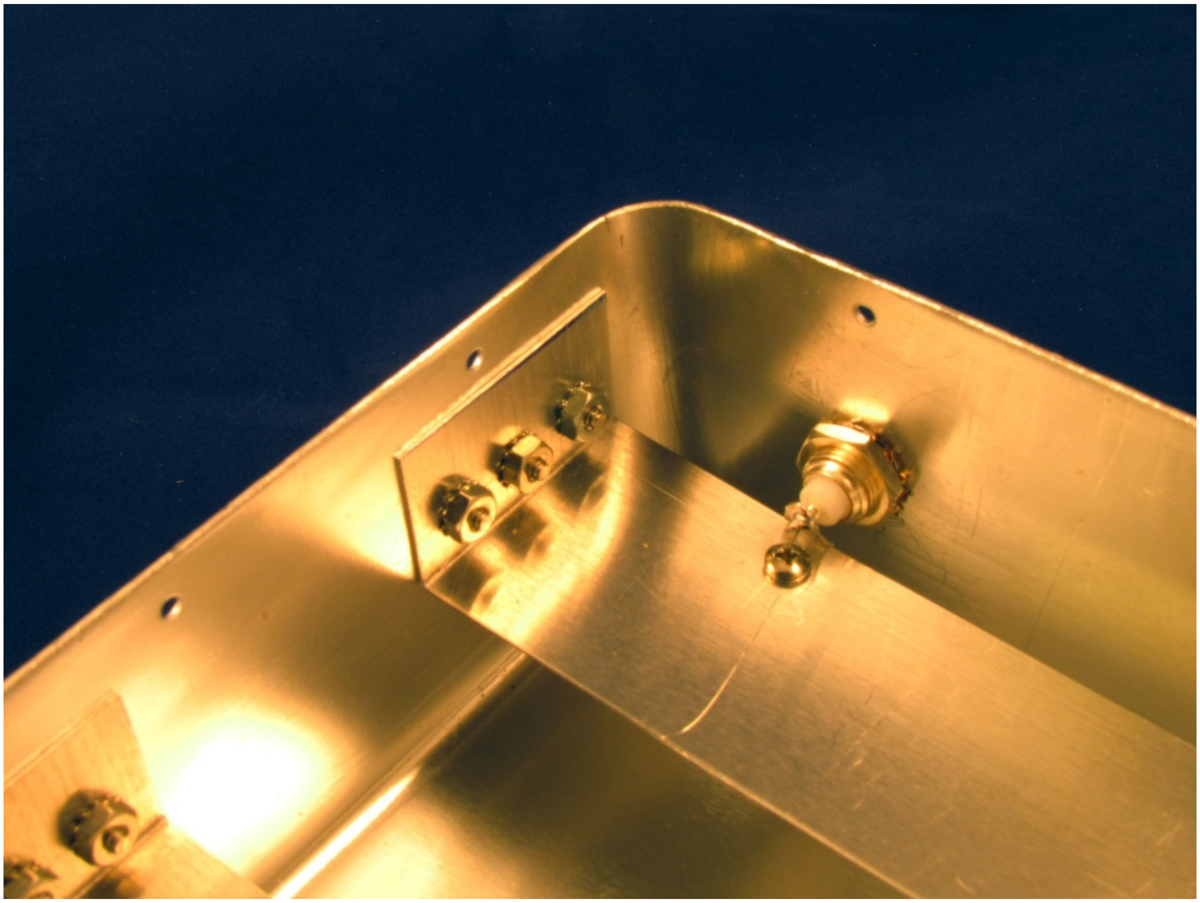

Figure 20 – Closeup of stripline grounding and connector tap

One final note about the tap point: the ground screws are not right at the corner, so the actual contact point is uncertain. This doesn't matter for resonance, since the capacitor tunes it out, but it can affect the electrical distance to the tap point. Adding a couple of extra tap holes in the resonators, perhaps 5 mm on each side of the specified distance, might make fine adjustment easier if you are fussy. A couple of small holes won't affect performance at all.

Tuning

If you have a sweep generator, tuneup is easier – you can see the response and adjust the shape as desired. The best indicator is the Return Loss or VSWR. It should be possible to achieve Return Loss better than 20 dB over at least the important part of the bandwidth, with good transmission passband shape as well.

If you don't have a sweeper, just apply a signal near the calling frequency or other desired center frequency and tune for maximum output and minimum VSWR. Then check other frequencies to be sure the whole range you intend to use is covered – only a few hundred KHz for most weak-signal operation.

The filters can also be tuned to other frequencies outside the ham bands if needed. For instance, the 144 MHz version can be tuned up to 220 MHz, or the 50 MHz version to 70 MHz to listen for 4 meter signals from Europe.

Summary

For mountaintop operation, a filter is essential. At my home QTH, line-of-sight to many broadcast transmitters, filters make a big difference, and I use one on each band to reduce the number of spurious signals. For the VHF bands, I use a filter between the antenna and preamp – my broadband MMIC preamps[2] have a noise figure near 0.5 dB, so the total noise figure with the filter is under 2 dB, quite adequate for terrestrial work. For higher bands, the filter follows the preamp.

These combline filters with stripline construction provide very good performance and may be built with modest metal-working skills. Dimensions are included in the table below. The cost should be significantly less than commercial products and performance is better than most, if not all, available filters.

Acknowledgement

All of the pretty performance plots are from data measured with a Rohde & Schwarz ZVA50 Vector Network Analyzer[3] kindly provided by Greg Bonaguide, WA1VUG, for measurements at several VHF conferences. Otherwise, my measurements are made by hand over a limited range, like Figure 6.

References

1. Reed Fisher, W2CQH, "Combline V.H.F. Bandpass Filters," ***QST***, December 1968, pp. 44-45.
2. Paul Wade, W1GHZ, "Simple Cheap MMIC Preamps," *Proceedings of the 48th Conference of the Central States VHF Society*, ARRL, 2014, pp. 204-214.
3. http://www.rohde-schwarz.com/