Altoids Tin Filters

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Several years ago, I described a series of "Multiband Microwave Transverters for the Rover - *Simple and Cheap* " (www.w1ghz.org), with several later enhancements. These have proved popular; I hope they have gotten some hams on new microwave bands. I did warn that they were adequate for a simple QRP station, but would need more filtering when augmented with amplifiers.

My suggestion was for "real metal filters," but no concrete suggestions. Unless you are lucky with surplus finds, good filters are hard to make or expensive to buy. Even with some decent machine tools, filters take time and care, but the results are usually rewarding.

I was recently inspired by bad weather and too much broken equipment needing repair to try building some simple, inexpensive filters. The goal is a filter with good performance with minimal cost that can be built in a couple of hours with modest tools.

Filter design

Filter design software, no matter what the cost, yields a set of dimensions that meet some performance specifications. This is only half of the problem; the other half is making it realizable within practical limitations – can I build it? The practical limitations and capabilities could range anywhere from a shop with a 6-axis CNC machine to a drill and soldering iron on the kitchen table. Most hams are somewhere in between, but closer to the latter.

Since these transverters are QRP rigs, aren't we required to use an Altoids tin somewhere? Can we build a decent filter in an Altoids tin?

A good filter type for UHF and microwaves is the combline filter. I use a printed version in my LO boards. The 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.

Once the resonator length is chosen, the type and impedance of the transmission line resonators is estimated. Then the resonator spacing and required tuning capacitance may be calculated – usually by software except in very simple cases. If we are trying to fit into an available enclosure, like the Altoids tin, the choices may be limited and require some trial-and-error tradeoffs to fit.

Altoids filter

Figure 1 – 432 MHz Combline filter in Altoids tin

A simple way to make a transmission line resonator is a cylinder between two flat plates, known as slabline. For the cylinder, I use the outer conductor of common semi-rigid coax, 0.141 inches in diameter, such as UT-141. Then the inner conductor provides the capacitor, sliding out to adjust the capacitance – approximately 2.4 pf per inch. The outer conductor is soldered to the tin wall at one end, and the inner conductor to the other end after tuning, making a reasonably rigid assembly.

Several configurations of input and output connections are commonly used, but most straightforward is to tap the end resonators near the ground end. This configuration does not permit easy adjustment, but once the correct tap point is known, adjustment is not needed.

The minimum number of resonators for decent filter shape is three. More resonators provide better filter shape but make tuning more difficult, especially with limited test equipment.

A few trial calculations suggested that the lowest ham band frequency that would fit in an Altoids tin is about 432 MHz. The resonators are about 46 degrees long, and require about 4 pf to resonate. Lower bands would require more capacitance than the coax can provide. Calculated characteristic impedance of the semi-rigid coax resonators is 116 ohms. A lower impedance might be desirable, but would require larger, more expensive coax than the readily available 0.141 inch diameter.

Since I needed a 432 MHz filter for another project, I put one together - construction details below. The filter is shown in Figure 1, and the performance in Figure 2. Loss is about 1 dB, and bandwidth is about 36 MHz, with the common LO frequency of 404 MHz about 15 dB down. A narrower filter would be desirable, but would require wider spacing between the resonators, and there isn't room in the Altoids tin, especially with the rounded corners.

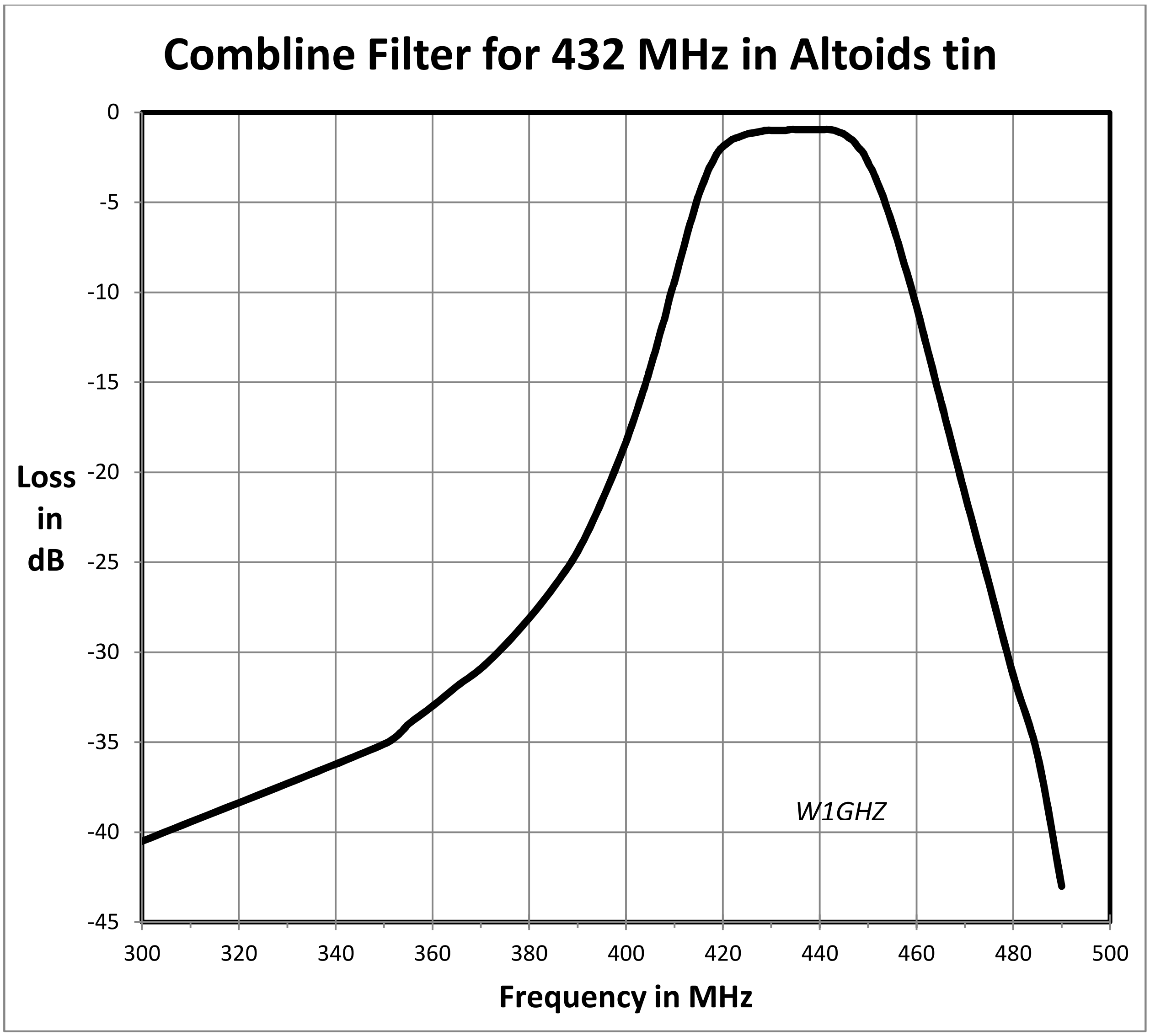

Figure 2 – Performance of 432 MHz Combline Filter

Tuning is a bit tricky, involving pulling one center conductor with a pair of pliers while holding the other two center conductors with other fingers so they make connection to the box. This is repeated for each conductor in turn until the desired performance achieved - then the inner conductors are soldered to the box. Tuning a filter is a series of tradeoffs, and is easier with a swept-frequency setup. The tuning starts around 300 MHz with the inner conductor only pulled out a small amount, perhaps 1/2 inch, but moves up smoothly to 432 MHz or a bit higher – this filter could be tuned to any frequency in this range, perhaps for an LO frequency.

902 MHz Filter

The 432 MHz filter demonstrates that the Altoids filter is feasible - now what about higher frequencies? Rotating the Altoids tin so the resonators fit the short dimension, as shown in Figure 3, makes the length about 57 degrees at 902 MHz. Much less capacitance is required, roughly 1.5 pf, so the inner conductor is nearly all the way out and tuning is much more finicky. The tuning starts about 600 MHz before the inner conductor is pulled out, so it could be tuned to any frequency in between, if needed.

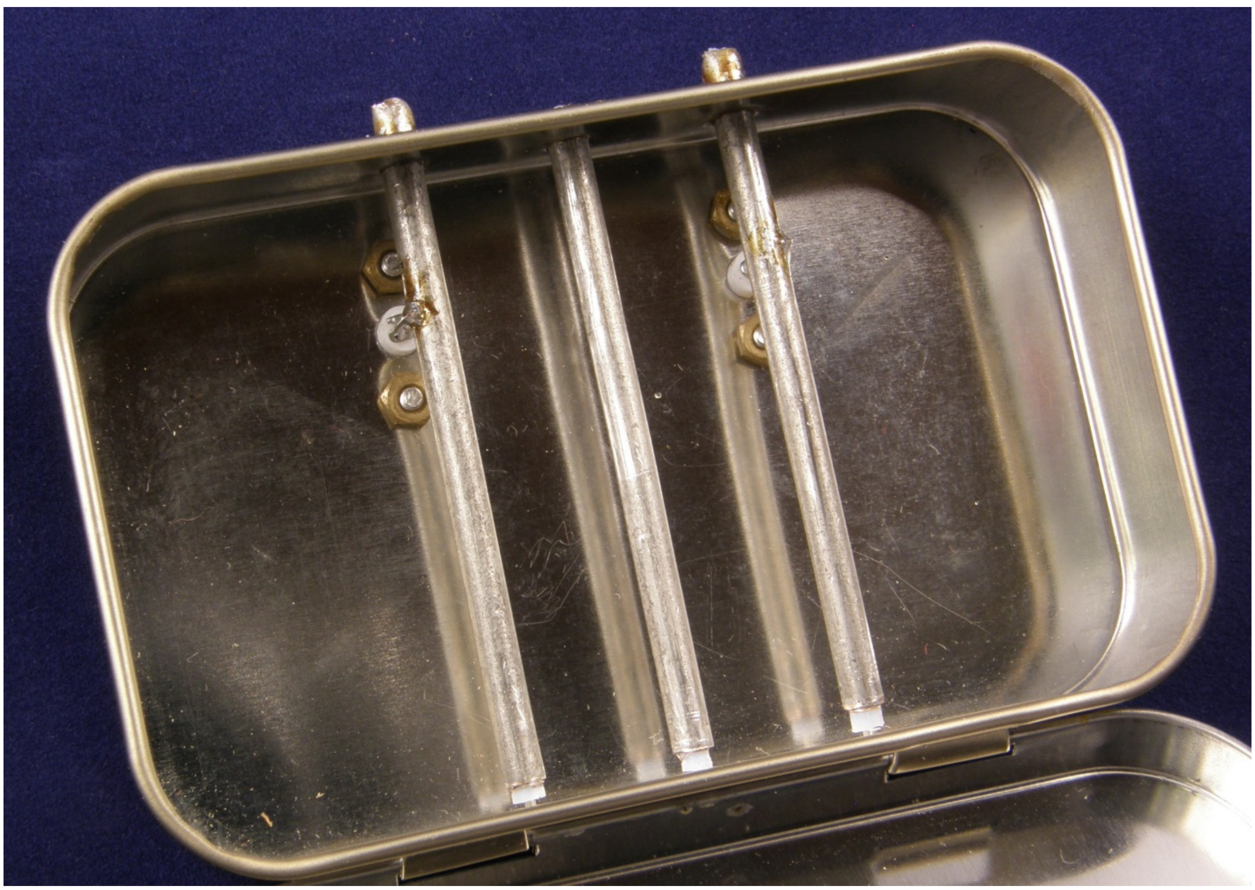

Figure 3 – 902 MHz Combline filter in Altoids tin

Performance is shown in Figure 4, with a loss of about 1 dB and a bandwidth of about 80 MHz. The filter shape isn't as pretty because I chose to improve the VSWR at 902 MHz rather than worry about loss over the whole bandwidth.

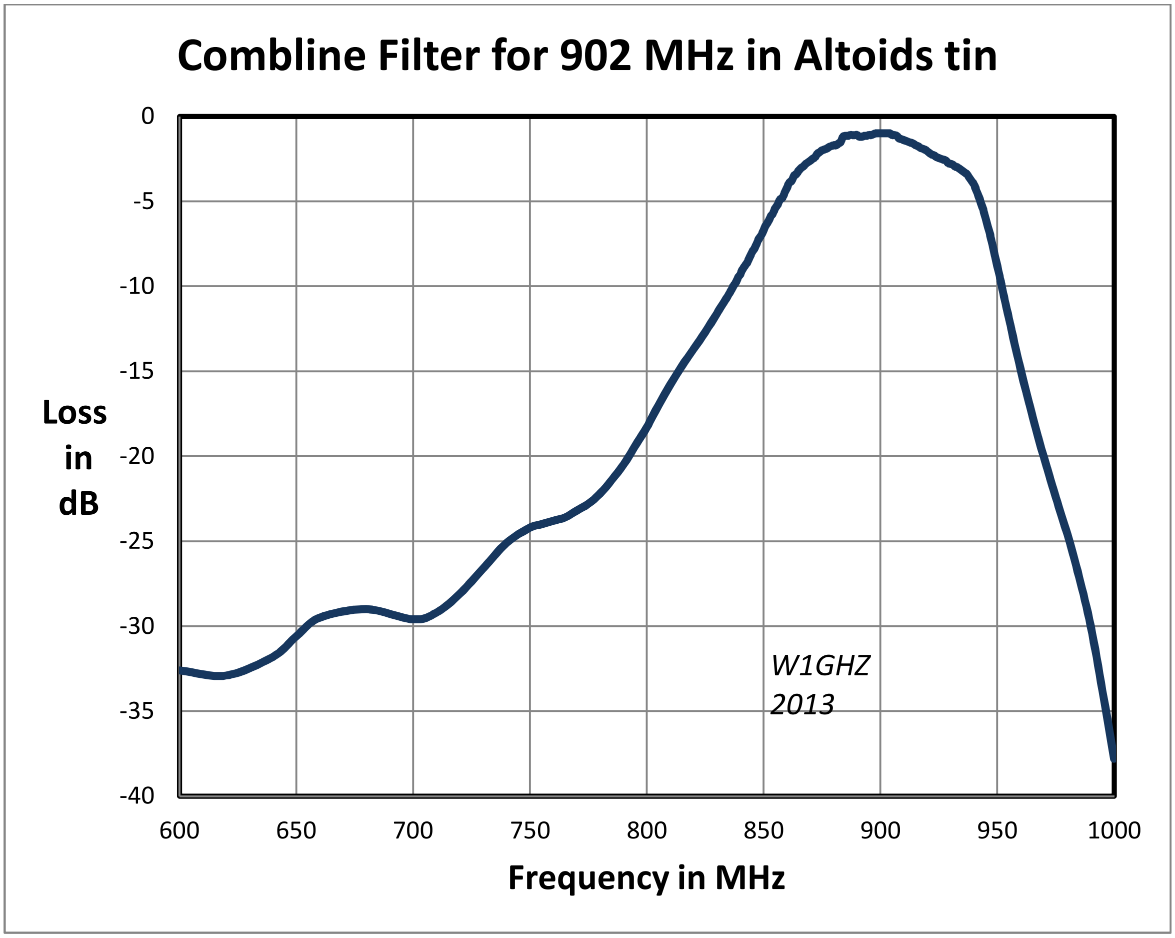

Figure 4 – Performance of 902 MHz Combline Filter

For the higher frequency, there is room in the Altoids tin make the filter sharper by increasing the spacing between resonators or to add an additional resonator. Either would make the tuning more difficult, and increase the loss – tinned steel isn't the highest Q material.

1296 MHz and 1152 MHz Interdigital Filter

The width of the Altoids tin is a quarter-wavelength at 1282 MHz, so resonators for 1296 MHz would be 90 degrees long; unfortunately, this will make a bandstop filter rather than bandpass. Instead, we can flip the center resonator to make an interdigital filter, so that the center resonator grounded at the opposite the grounded end of the adjacent resonators.

I made two interdigital filters with tapped inputs, one for 1296 MHz and one for 1152 MHz for the LO frequency. Both were difficult to tune, especially at 1296 where the resonators are close to ½ wavelength long and only a tiny bit of additional capacitance is possible. The best tuning resulted in a lumpy passband shape and very poor input and output VSWR. The high VSWR resulted in high loss, since most of the power is reflected. The performance curves are included in Figures 5 and 9.

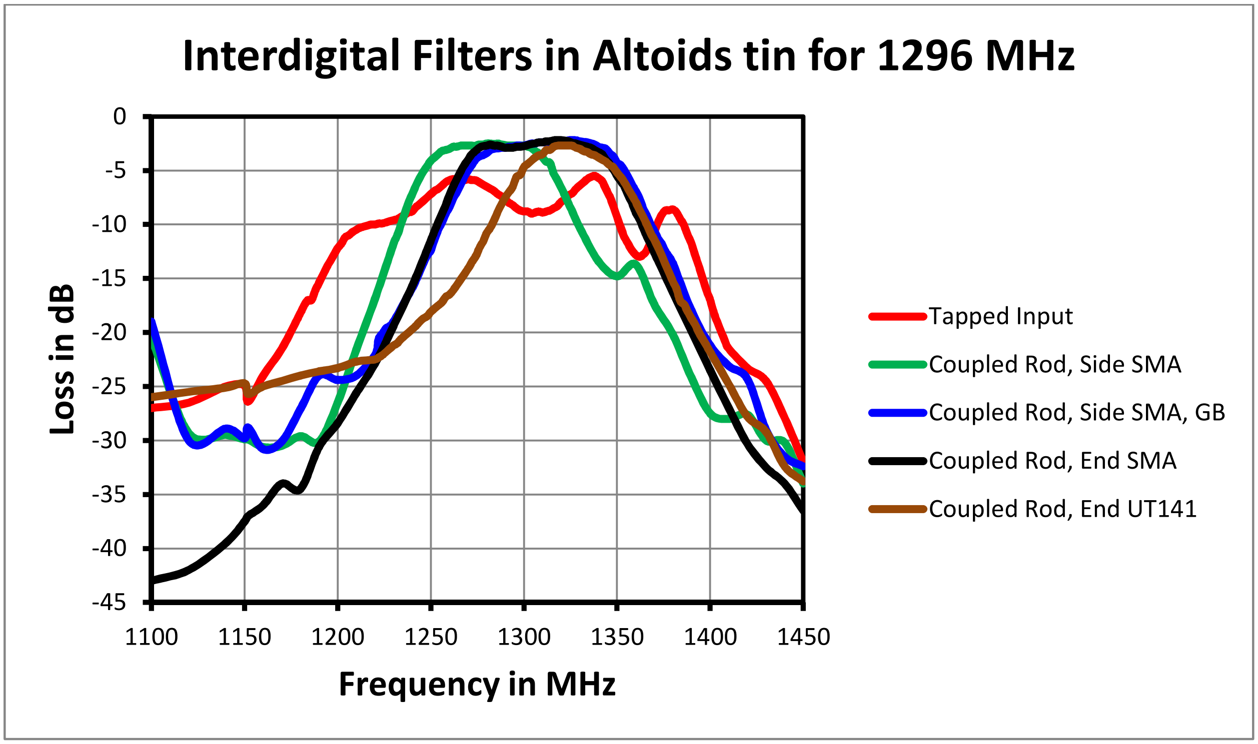

Figure 5 – Performance of 1296 MHz Interdigital Filters

When I made the printed filters for my Cheap and Simple Rover Transverters, I found that side coupled inputs and outputs provided better performance than tapped input and output. There is room in the Altoids tin for additional rods for coupling, and the semi-rigid cable is inexpensive, so I calculated the spacings for side coupling rods and built a couple. The first attempt, in Figure 6, mounted the SMA connectors in the bottom of the box with a wire up to the open end of the coupling rod from the side. Performance of this version, also included in Figures 5, is much better, with good filter shape and improved VSWR. An additional advantage is that very little tuning is needed – the resonators are just about ½ wavelength without capacitance, so only a short stub of center conductor is left to provide mechanical support.

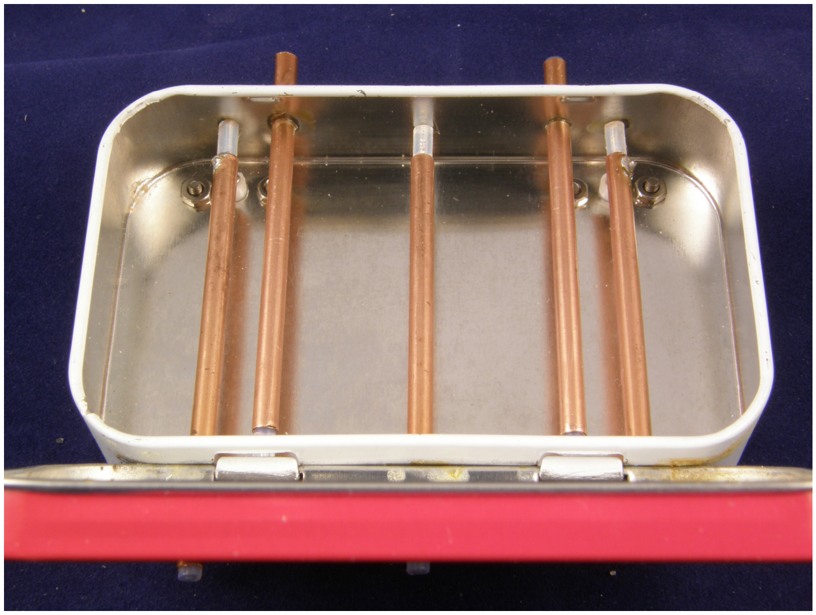

Figure 6 – Interdigital filter with coupled-rod input and side connectors

The 1296 MHz filters in Figure 6 with the side SMA connectors show limited out-of-band rejection in Figure 5, only about 30 dB. I wondered if stray coupling was occurring between the SMA connectors. One solution is to put the SMA connectors in line with the rods, as shown in Figure 7. Figure 5 shows a nice filter shape for this version with much better out-of-band rejection. Rejection of the 1152 MHz LO frequency is better also. This one also requires no tuning – the rods are resonant near 1296 MHz.

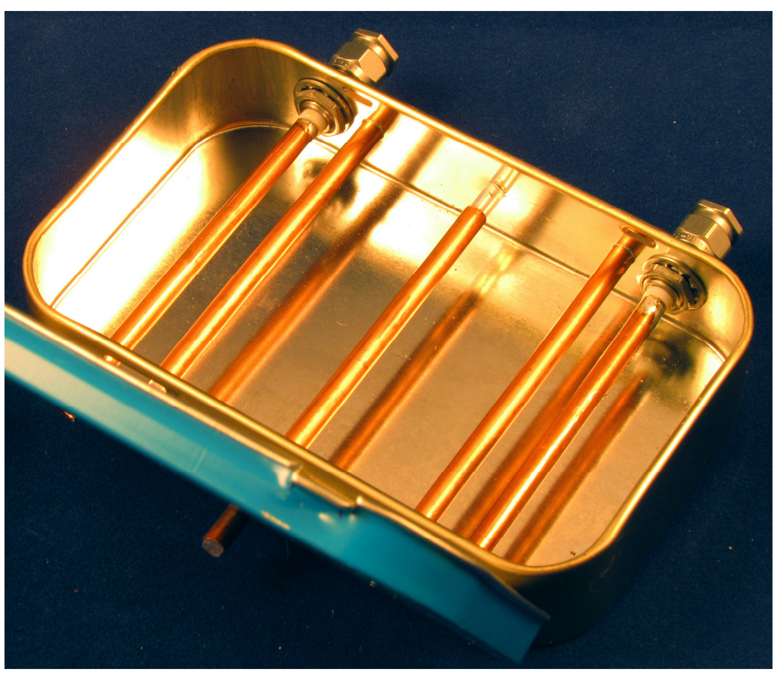

Figure 7 - Interdigital filter with coupled-rod input and end connectors

I used male SMA connectors for the version in Figure 7 since they were the only ones I had on hand that fit in the space, and I only had two. Male connectors are fine for connecting directly to another module, but most short cables have male connectors, limiting options. Since we are already soldering semi-rigid cable to the box, why not use cable for the input and output, connecting directly to adjacent modules. With no tuning, this one is centered slightly high in frequency in Figure 5 – I cut the resonators slightly too short so the response is about 2 dB down at 1296 MHz. The center frequency could be moved down by adjusting the center conductor, but I soldered them without testing thoroughly.

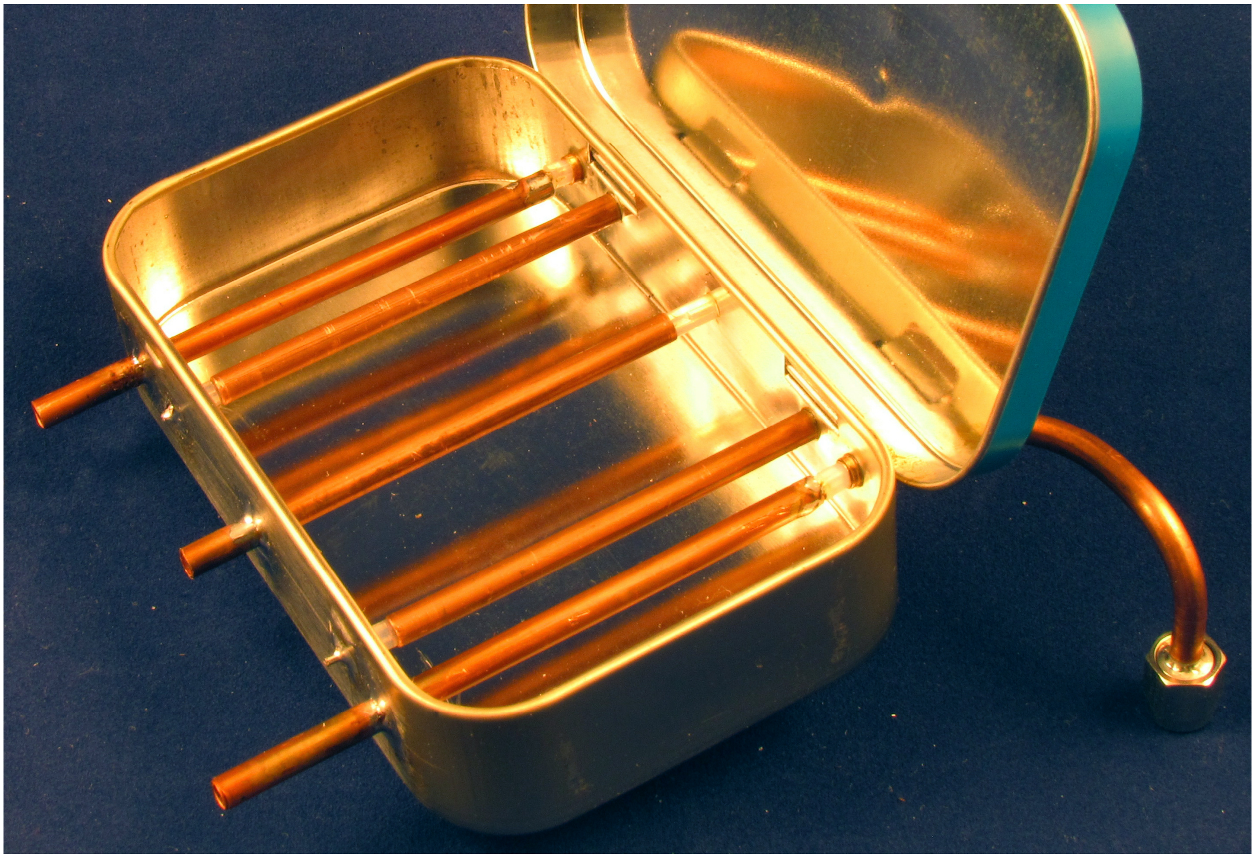

Figure 8 - Interdigital filter with coupled-rod input and semi-rigid cable end connections

Interdigital filters for 1152 MHz are identical to the 1296 MHz filters, except that part of the center conductor is left inside the outer conductor to provide capacitance to lower the resonant frequency. It should be possible to tune these interdigital filters as low as 750 MHz with the center conductor. The curve in Figure 9 labeled "Coupled Rods" is for a filter very similar to the one in Figure 7.

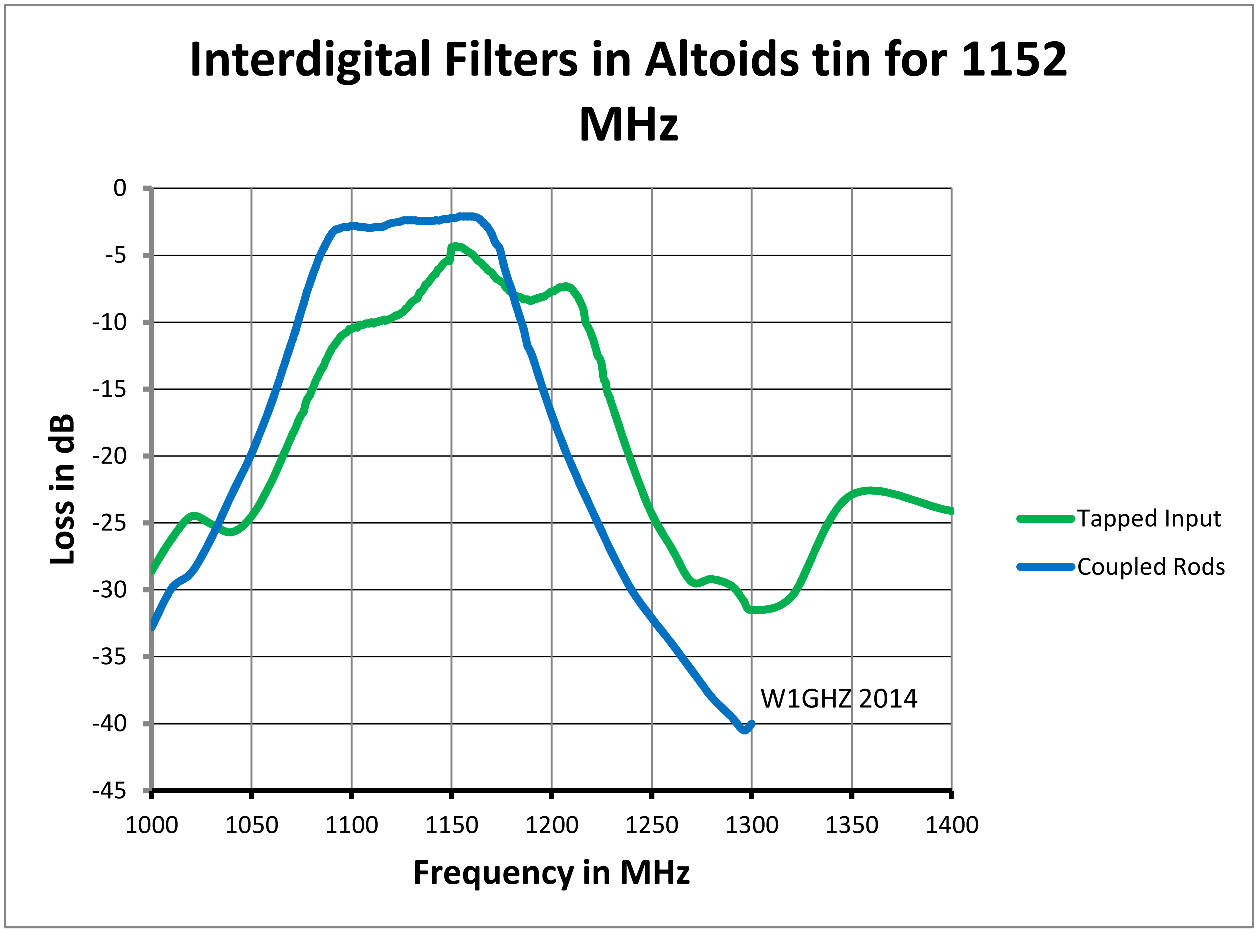

Figure 9 – Performance of Interdigital Filters tuned to 1152 MHz

Filter Construction

The Altoids tin is made of very thin steel, easily soldered with a medium-sized iron, but the paint must be removed first. I use an abrasive wheel (Scotch-Brite Paint and Rust Stripper) in a drill or drill press, which removes paint quickly without tearing up the metal. Then it is a matter of marking and drilling the holes. I mark them with a cheap caliper used as a scribe, prick the hole location with a scriber, then drill a very small hole, #60 or 1 mm at each location. Then I use brad point drill bits which make a clean hole in thin metal. Sets are sold for woodworking (www.woodcraft.com), but only two sizes are needed for these filters: 9/64" for the semi-rigid coax and 5/32" for the SMA connectors.

Figure 10 – Preparing semi-rigid coax with miniature tubing cutter

For the semi-rigid coax, the best tool is a miniature tubing cutter. As shown in Figure 10, the tubing cutter is used to nick the outer conductor just enough so it snaps instead of bending. Nick it again about a half-inch away, snap it again, then pull the short section of outer conductor off with pliers. Make a cut all the way around the Teflon at the desired location; the goal is to leave enough to push the exposed Teflon against the wall of the box and control the length of the resonator. Next, pull off the end of the Teflon, leaving a short length of inner conductor exposed. Then clamp the coax in a vise with V-jaws (which also straighten any small bends in the coax) and pull on the inner conductor with pliers (Figure 11) until it starts to move, but leave it in the coax for tuning. Trim the end of the inner conductor slightly to remove any burr.

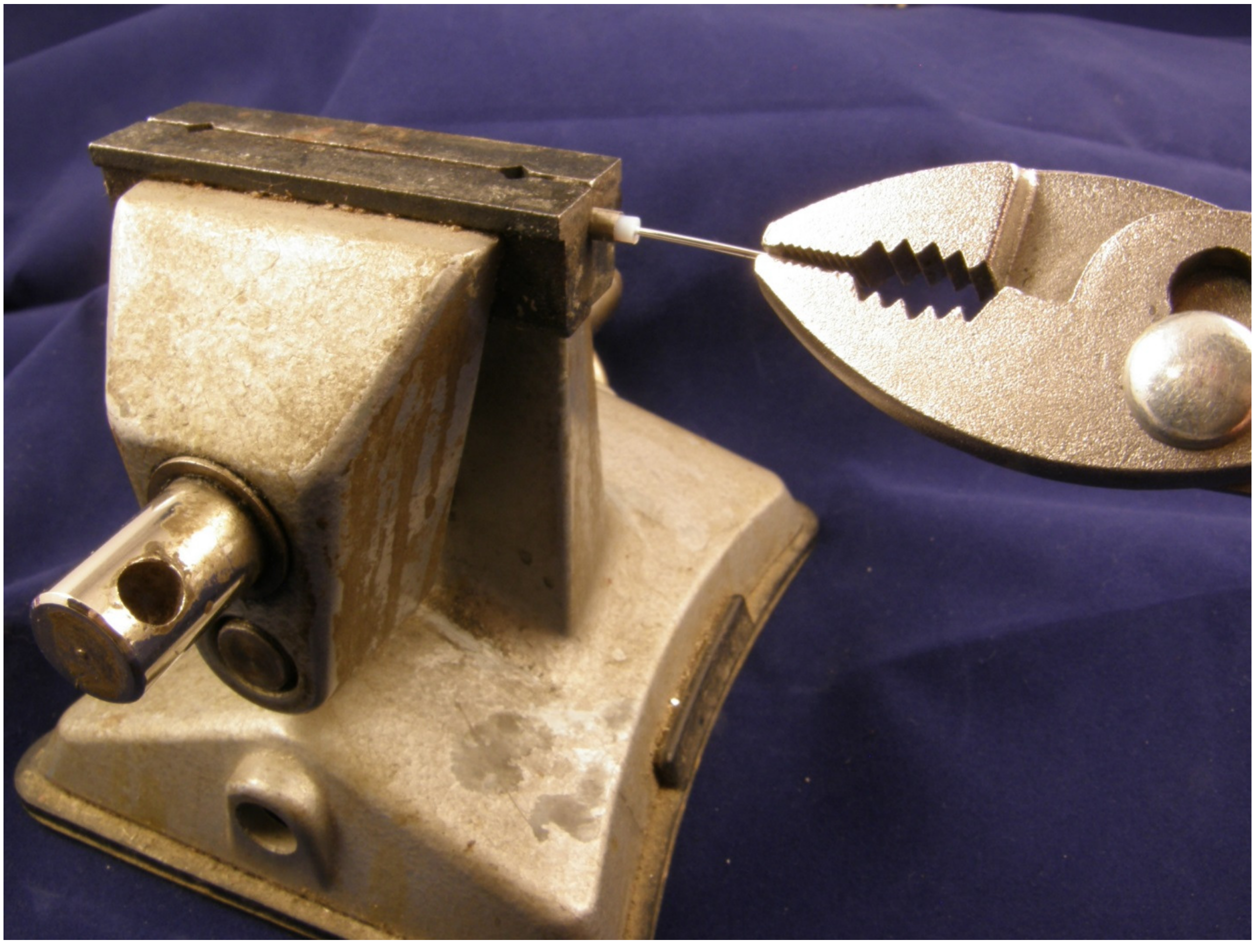

Figure 11 – Pulling out center conductor of semi-rigid coax

Install the SMA connectors in the Altoids box, then add the input and output wires and push them aside. Now it is time to install the resonators. The 0.141" diameter coax is a very tight fit in the 0.140" diameter holes, but the thin metal gives enough so it slides in tightly and stays put.

At the far end, guide the inner conductor through the small hole and adjust for the desired resonator length. When all three resonators are in place, apply a bit of paste flux around them on the outside of the box only, and then solder them in place at the ground end only.

For the comb filters, solder the input and output wires to the resonator tap points with small dab of paste flux. Clean up flux and close the lid, and the filter is ready for tuning.

For the interdigital filters with coupling rods, remove the center conductor completely, then pull the Teflon out enough so that one end of the semi-rigid coax is empty. Inset the empty end toward the connector, apply a small dab of paste flux, and solder the open end to the connector or input cable.

Connect the filter to a detector and a signal generator, preferably a swept-frequency setup. Of course, if you have a network analyzer, that's even better. Tuning is a matter of pulling (or pushing if needed) one center conductor with a pair of pliers; once the center conductor is started, as shown in Figure 11, it becomes easier to move and the vise is no longer necessary. While tuning one resonator, hold the other two center conductors with other fingers so they make connection to the box. Repeat for each conductor in turn until the desired performance achieved - then the inner conductors are soldered to the box. For fine tuning and final compromise, VSWR may be more sensitive than loss.

Dimensions

432 MHz combline filter: resonators are 16.7 mm center to center, input and output taps at 19.5 mm from ground end. Resonator length = 2 mm less than Altoids long dimension.

902 MHz combline filter: resonators are 17 mm center to center, input and output taps at 11 mm from ground end. Resonator length = 2 mm less than Altoids long dimension.

1296 MHz interdigital filter: resonators are 21.2 mm center to center. Coupling rods are 8.8 mm center to center from outside resonators. Center resonator length = 4.3mm less than Altoids short dimension. Outside resonator length = 3.7mm less than Altoids short dimension. Coupling-rod length as needed to reach connector, roughly same as outside resonator.

Summary

These simple filters are easy to build and cost very little, even if you have to buy the Altoids. The 1296 MHz version will work with no tuning required. The filters can help clean up your signal, reduce birdies, and sweeten your breath at the same time.

Acknowledgement

Thanks to Ken, W1RIL, who provided me with a large bag of Altoids tins.