An Easily Built VHF Bandpass Filter

Introduction

Super-heterodyne systems are largely defined by the filters they use. Interesting measurement equipment, transmitters, or receivers can be built if we can fabricate effective VHF bandpass filters with a fractional bandwidth of 1% or less. The filter described in this note, although not unique, is easily duplicated. It operates at 260 MHz with a bandwidth under 2 MHz, uses readily available components, and can be built with standard hand tools. The circuit resembles an earlier effort that was not as easily duplicated or extended to other frequencies. (ref. 1) This filter can be extended to any frequency in the 30 to 300 MHz VHF spectrum and even higher.

The filter, a triple tuned circuit, is shown in the schematic of Fig. 1. No component values are included, for many are not easily measured or realized as lumped components.

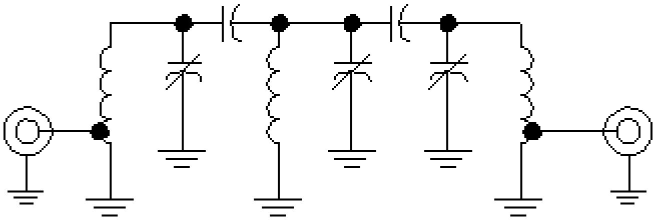


Fig. 1. Approximate representation of a three section VHF bandpass filter.

The physical basis for this filter is a small cast aluminum box, the Hammond 1590A. One box houses each resonator or tuned circuit with three bolted to each other to form a triple tuned circuit. The middle box is rotated with the lid coplanar with the bottom of the end boxes, useful with boxes using sloped walls. Coupling between resonators is realized with wires soldered to an end resonator. The wire is extended through a small hole into the middle resonator. Teflon “spaghetti” insulates the coupling wire from the box. The wire position in the middle cavity is adjusted to establish coupling.

Although we can calculate many of the details related to this filter, careful experimental methods are needed to actually build it. The measurements are a necessary part of the construction and should not be omitted, even if they are somewhat tedious.

Resonator Measurements

Our experiment begins with evaluation of a single resonator. Resonant frequency and unloaded Q are measured with a signal generator (ref. 2) and power meter (ref. 3). The unloaded Q should be 300 or higher if we are to eventually build a filter with a 1% bandwidth (filter Q=100.) Both measurements use the scheme of Fig. 2A. Small capacitors couple energy into and out of the tuned circuit. These are no more than pieces of wire, or probes, extending into the box from coaxial connectors, making Fig. 2B more descriptive. I used probe wire lengths of about 1 to 2 cm in my measurements. The box lid should be attached during measurements.

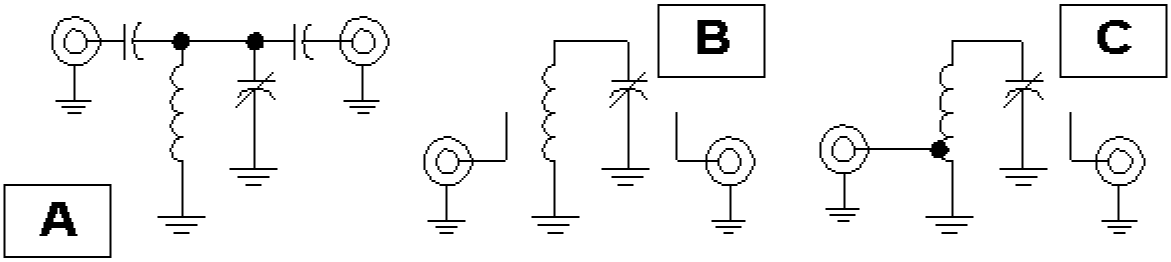


Fig. 2. A single resonator is evaluated with probes that capacitively couple energy to the LC. The traditional circuit at A is perhaps better illustrated with the form at B. Part C shows the attachment for loaded bandwidth measurement.

We found that the better resonator Q occurred with tuned circuits using low capacitance and high inductance. Multiple turn glass trimmer capacitors from the junk box were used, adjusted to C of about 1 pF. Exact capacitor type is not important, although the Q should be high. These parts had Q>1000 at VHF. The inductors were fabricated from #12 bare copper wire attached to the box bottoms with a LARGE solder lug. A slight bend in the lug positions the coil away from the box bottom. For 260 MHz operation, my inductor consisted of 3.75 turns wound on a 5/8 inch diameter piece of aluminum tubing. Spacing was about 4 turns per inch. The coil is bent into final position before the lead from the fragile glass capacitor is attached to the end. A smaller wire is soldered at the 2.75 turn point and routed through a hole to the next resonator before final measurements. The two probe measurement of Fig. 2B produced a response represented by Fig. 3 with typical a bandwidth of 0.67 MHz for Qu=390 at 260 MHz. Although we treated this resonator as a traditional inductor-capacitor, we discovered later that it is actually a helical resonator, a familiar revelation for VHF experiments.

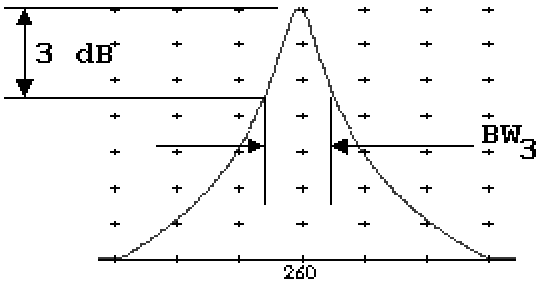


Fig. 3. Q measurement response.

Qu values as high as 500 were obtained with 0.75 inch ID coils. However, that size was very difficult to use with the Hammond 1590A box. The Qu produced by #12 wire was significantly higher than with #14. We have used the larger #10 wire for even higher Q UHF (500 MHz) resonators. Silver plating of both the coil and the enclosure can take Qu to values over 1000 at UHF.

The two end resonator coils are wound with opposite sense. This allows a true mirror image to be used, simplifying the chore of making the ends electrically identical.

Tuning the Filter

A filter can now be built with these high Q resonators. A central filter concept allows this: **A bandpass filter is defined by establishing the loaded Q of the end sections and the coupling between adjacent resonators.** If we seek to build a Butterworth filter with this concept, we find that the loaded Q of an end section should equal that of the final filter. Hence, loaded end section bandwidth will equal filter bandwidth. The test setup we use here is that of Fig. 2C where a 50 Ohm termination is attached to the inductor tap. A probe is used to determine loaded bandwidth. This was done with the end resonators, again producing a response like Fig. 3, but now with a wider bandwidth. Adjusting the tap to about 0.75 inch from the solder lug produced a loaded bandwidth of 4.4 MHz. This is shown in a photo. This bandwidth was too high. Dropping the tap to about ¼ inch from the solder lug produced a bandwidth of 2.5 MHz in each end resonator. The measurements should be done with the box lids attached.

The total filter was then examined. Coupling was adjusted and the three resonators were adjusted for a peak response with an input of 260 MHz. The signal generator was then tuned over a wide range (200 to 350 MHz, or more.) This revealed a response with three peaks, indicating severe over coupling. This step is vital; don't skip it!

The length of the coupling wires (shown in a photograph) were then reduced, causing the extra peaks to approach the desired frequency. Eventually, a single peak was obtained, resulting in a useful bandpass filter with a bandwidth of 2.43 MHz and insertion loss of 4.3 dB.

This filter was not selective enough for my application, so the adjustments were repeated. Attaching the tap wire next to the top of the solder lug produced a loaded bandwidth of about 1 MHz in each end. (Soldering is less difficult when the bolt through the lug is removed and a paper scrap is inserted between the lug and box.) Coupling probe lengths were again reduced to produce a filter with B=1.6 MHz. This design was selective enough for my application, but now had an IL of 8 dB.

Coupling can be adjusted while examining nothing more than the final filter response. However, a much better method uses a two probe excitation of an end resonator, shown in Fig. 4. The two probes in resonator 1 are attached to the signal generator and power meter. Resonators 2 and 3 are then severely detuned. Resonator 1 is peaked at the center frequency, here 260 MHz. Resonator 2 is then tuned to secure a response dip. The signal generator is then tuned to examine the result, shown in Fig. 4B. The separation of the two peaks is a measure of coupling. The spacing, S, should ideally be S=BW3/1.414 for a Butterworth filter shape. These extremely useful methods are attributed to Dishal.(ref. 4)

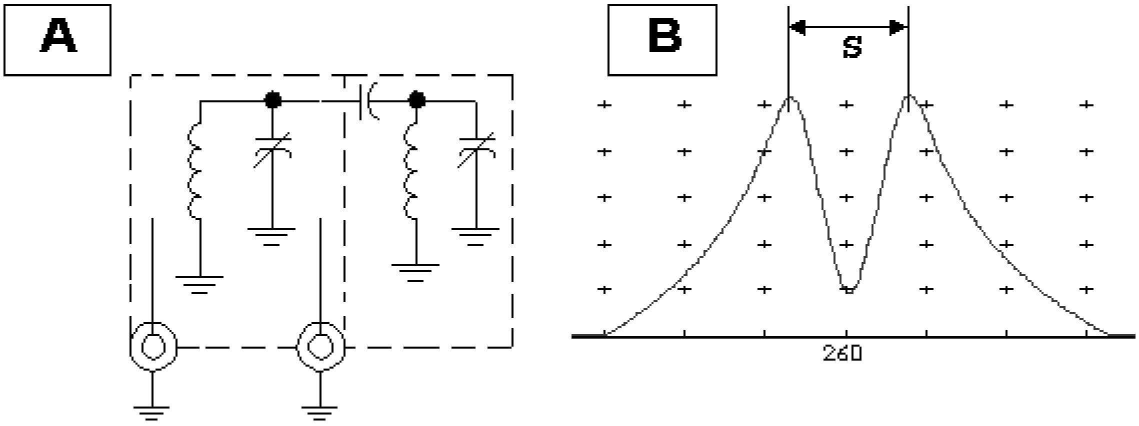


Fig. 4. Adjusting coupling via the Dishal method.

It is also interesting to extend the Dishal experiment with one further step. Repeat the two probe examination by tuning the first resonator for a peak, followed by a null with the second. Then tune the third for a peak. A sweep then reveals three peaks.

A significant utility of the Dishal methods lies in computer simulations. A filter can be designed using unrealistic component values. That filter is then studied with the computer to establish the loading and coupling responses. The frequency separations are then parameters that can be realized with adjustment of the practical filter.

Results

The results presented so far were obtained in a modest home lab. More refined measurements were done with the assistance of K7TAU and KK7B at TriQuint Semiconductor. Fig. 5 shows the filter response when measured with an HP-8753D network analyzer. Measurement with a signal generator and spectrum analyzer further confirm the excellent stopband attenuation. An insertion loss of 10 dB is shown, but 2 dB of that is attributed to about 3 feet of coaxial cable.

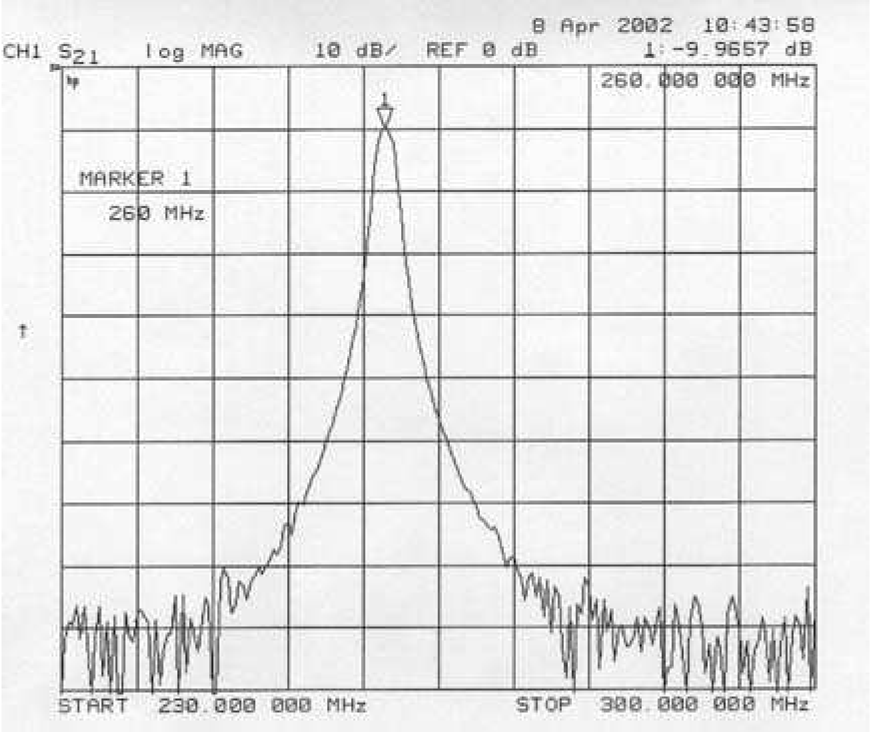


Fig. 5. Network analyzer sweep of the filter response.

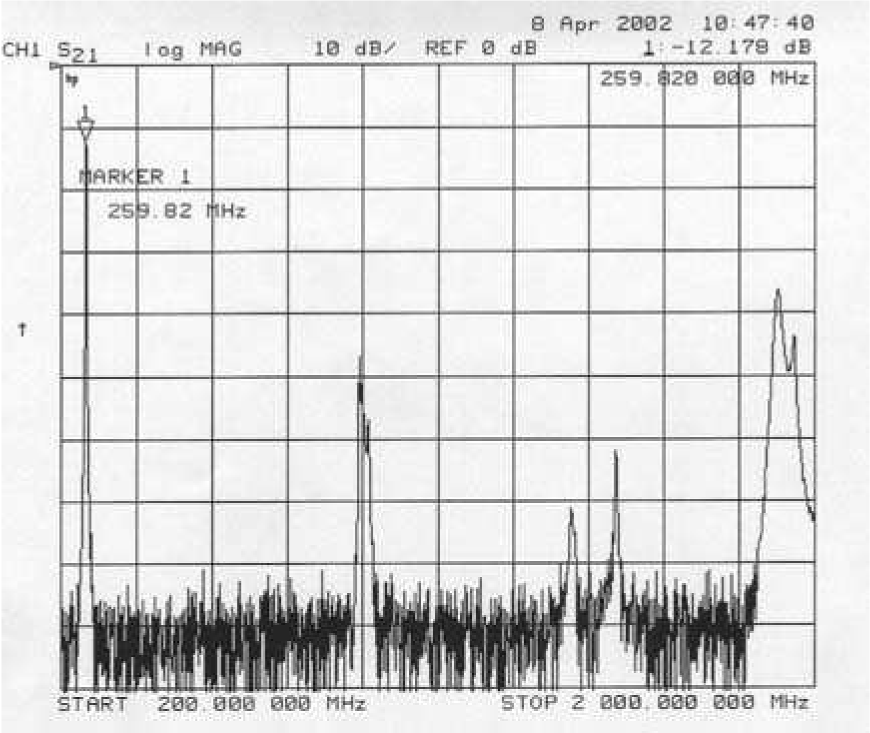


Fig. 6. Wide frequency sweep of the filter showing reentrant modes indicating the helical resonator characteristics.

Figure 6 is like the first sweep, but extends to 2 GHz. A response at 910 MHz represents a frequency where helical resonators are ¾ wavelength in extent. The 5/4 wavelength response is also evident. The rather strong response around 1.9 GHz is probably the result of resonance within the Hammond box and has little to do with anything in the enclosures.

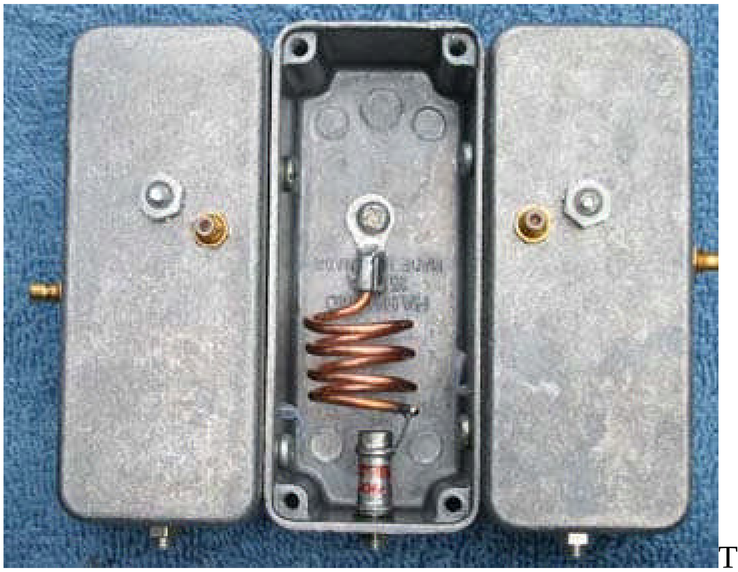
Applications and conclusions.

The ability to build VHF filters with a bandwidth of 1% or less can greatly ease the construction of VHF equipment. For example, such a filter between a low noise amplifier and a strong mixer would allow construction of a single conversion receiver for the 144 MHz band with an IF around 9 or 10 MHz where homebrew crystal filters are easily built. A similar filter will form the basis for a matching transmitter. The same ideas are easily extended to 432 MHz, although higher unloaded Q values will be required.

The 260 MHz filter presented here will be used in a spectrum analyzer. A POS-535 VCO from MiniCircuits will sweep from 260 to 460 MHz to heterodyne signals in the 0 to 200 MHz area to a first IF of 260 MHz. This will then be converted to 10 MHz with a simple 250 MHz local oscillator. The analyzer is similar one described earlier, but is now suitable for examination of 144 MHz systems. (ref 5)

The filter we have built used an available Hammond box. The experimenter with a more refined machine shop at his or her disposal has much greater freedom in fabricating critical filters.

View of an end resonator. Note the "pilot" holes in the box that were used when drilling holes for mounting the boxes together and for coupling. Small holes like this are not a problem for signal leakage.



The "bottom" of the filter showing the interior of the middle resonator. Probes are attached to the extra coax connectors in the end resonators. These holes will eventually be used to mount the filter. The small coupling wires are seen where they enter from the end resonators. They become even shorter for the narrower bandwidth filter configuration.

This information is presented to illustrate the methods that can be used by the experimenters in building his or her own bandpass filters at VHF. No components values are given for the variable capacitors we used, for that does not matter. We only provided turns information, wire sizes, and coil diameters because they impacted our measured results, as presented. This filter is not intended for exact duplication.

It should be a simple chore to build a three section bandpass filter for 110 MHz with the methods presented. A filter bandwidth of 1 MHz or less should be easily within reach, offering excellent performance in the 1998 spectrum analyzer. A design of this sort will be larger than the original, but less ambiguous in it's realization.

References:

1. Hayward, "Extending the Double-Tuned Circuit to Three Resonators," QEX, Mar/Apr 1998.

2. A surplus HP-8654 generator was used in my experiments. Many high quality generators are available at hamfests and via E-Bay and one is recommended, especially for VHF experiments. A frequency counter is also useful, but be careful, for radiation from the counter can compromise measurements.

3. Hayward and Larkin, "Simple RF-Power Measurement," QST, June, 2001.

4. Dishal, M., "Alignment and Adjustment of Synchronously Tuned Multiple-Resonant-Circuit Filters," Elec. Commun., pp. 154-164, June, 1952. Also see Hayward, "Introduction to Radio Frequency Design," ARRL, 1994, pp95-101.

5. Hayward and White, "A Spectrum Analyzer for the Radio Amateur," QST, August and September, 1998.