W1GHZ

MICROWAVELENGTHS

Microwave Filters

Anyone who has operated from a high place with lots of RF installations understands the need for filtering, and probably didn't have enough. All radio equipment, except perhaps simple oscillators like a Gunnplexer, needs filtering, both to reject undesired signals from the receiver and to prevent transmitting out of band.

All microwave transverters need filters, both to prevent unwanted radiation of LO and images, and to reject receiver images. Without good image rejection, the receiver sees twice as much noise but no additional signal, so the minimum possible[1] noise figure is 3 dB, no matter how good a preamp is used. Things could be even worse if there happens to be an interfering signal at the image frequency.

Cavities

At low frequencies, filters are comprised of inductors and capacitors. For VHF, cavities like the one in Figure 1 are often used. A cavity is just a single resonant circuit, just like an LC resonator, with the same limitation: increased selectivity is accompanied by increased losses. Making a cavity larger can improve the unloaded Q, a measure of the inherent loss, and minimize loss for a desired selectivity.

Wavelengths at microwave frequencies are small, so the cavities must also be small — a quarter-wavelength cavity can only be a quarter-wavelength long, and must be smaller in other directions to prevent other resonances. Thus, we must consider other types of filters; fortunately, the small wavelength allows us to make more sophisticated filters in a reasonable size.

Better filters have multiple resonators, usually coupled together so they interact. By varying the coupling between resonators, the filter characteristics may be controlled. Figure 2 shows a simple example, a classic double-tuned circuit. The two resonators are shown as LC resonators, but can be any resonant structure. The coupling is shown as a capacitor connecting the two resonators, but could also be an inductor, mutual coupling of the magnetic fields of the two inductors, or a hole between waveguide sections. The insertion loss is plotted in Figure 2 for several values of coupling capacitors. As the coupling is increased, from undercoupled to overcoupled, by increasing the coupling capacitor, the bandwidth of the passband (the frequency range with very low insertion loss) increases. In the overcoupled case, there is some ripple in the passband. However, the shape of the skirts, just outside the passband, does not change. In order to make the skirts steeper, for more rejection of an unwanted frequency, more resonators are required.

Shaping

With multiple resonators, the shape of the filter response may be tailored as needed, by choosing the right number of resonators and the coupling between them. A common microwave filter is the interdigital filter shown in Figure 3, consisting of resonant rods, each an electrical quarter-wave long, with the spacing between them controlling the coupling. The screw at the open end of the rod is a capacitor for fine-tuning.

A comb-line filter is similar, but with all the rods pointing in the same direction. For VHF and UHF, helical filters are similar, with the quarter-wave resonator wound into a helix.

The hairpin filters used in some "no-tune" microwave transverters are a printed circuit type, shown in Figure 4. Each hairpin resonator is an electrical half wave, rather than a quarter wave, to eliminate the need for grounding one end so that the resonators can be printed on a common printed circuit board. The coupling occurs between the edges of the resonators.

Even the crystal ladder filter, popular in homebrew QRP rigs, is electrically equivalent to these filters. The very high Q of crystal resonators makes it possible to make very narrow filters.

The double-tuned circuit is simple enough to analyze by hand, but complex filters are not. Old-time microwave engineers

[1]P. Wade, N1BWT, "NOISE: Measurement and Generation," *QEX*, Nov 1996, pp 3-12. **www.w1ghz.org/noise/noise99.pdf**.

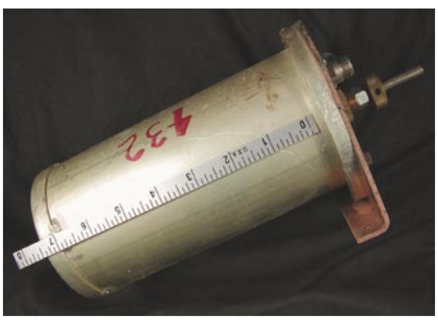

Figure 1 — Cavity filter for 432 MHz.

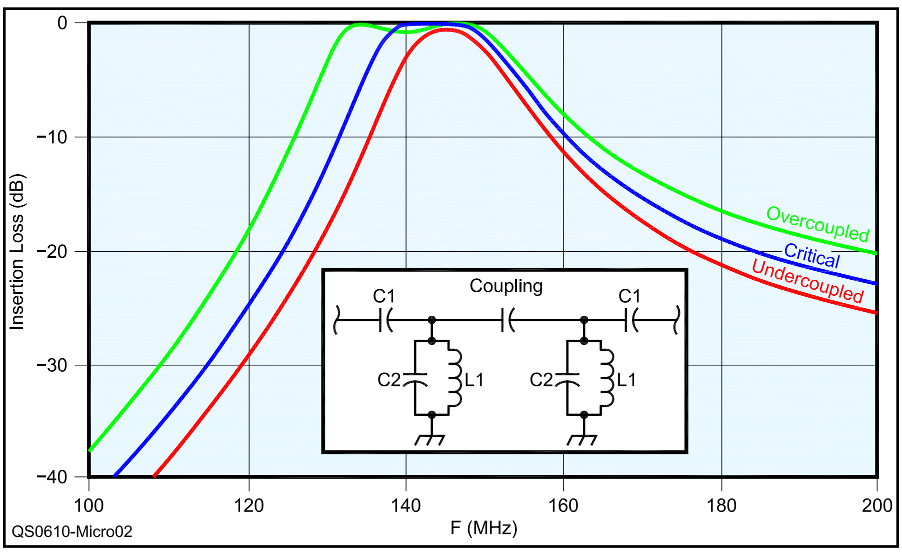

Figure 2 — Classic double-tuned circuit and frequency response.

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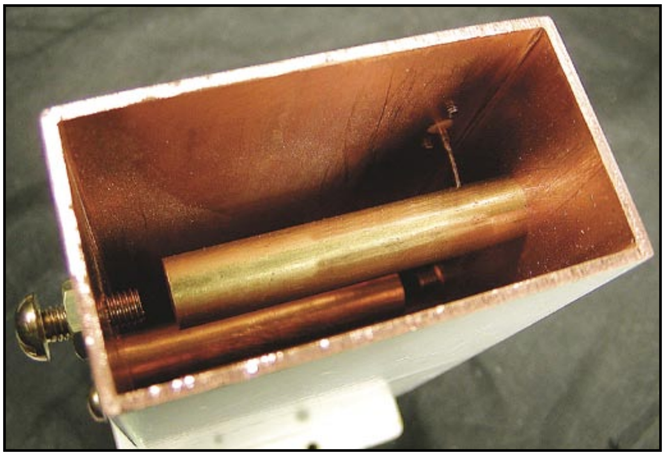

Figure 3 — Interdigital filter built in section of scrap waveguide.

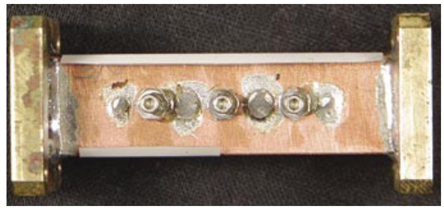

Figure 5 — External view of a 24 GHz waveguide filter made by W2PED.

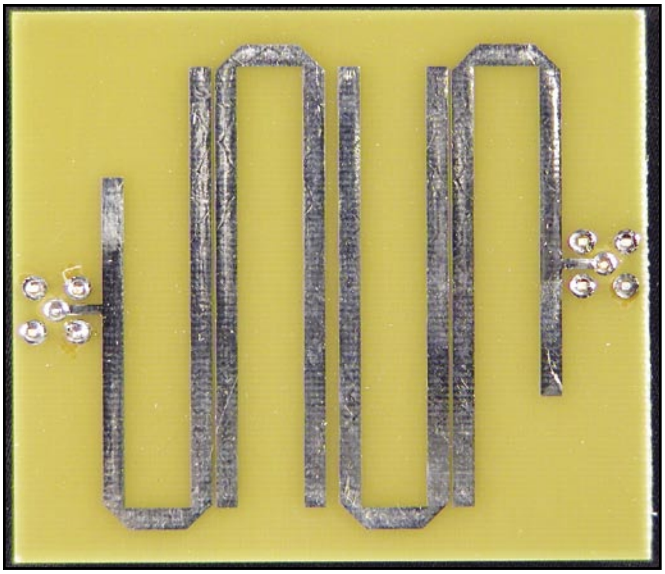

Figure 4 — Hairpin filter on printed-circuit board.

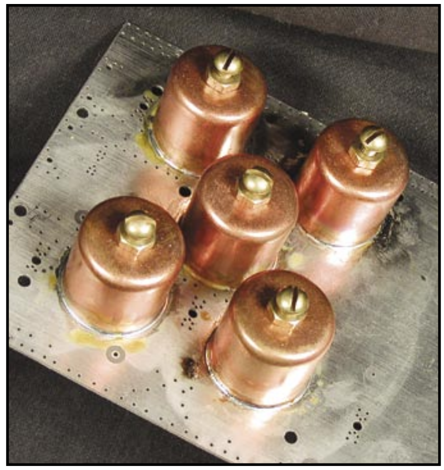

Figure 6 — Transverter for 5760 MHz uses five pipe-cap resonators.

had books of graphs and tables, but today, everyone has a personal computer — all we need is software. One of my favorites is the "Filter Design Wizard" in Ansoft Designer software — you can download a free Student Version from **www.ansoft.com** and give it a try. Trial designs can yield quite a bit of insight into filter design and behavior, with no metalwork needed — unless you come up with a good one and can't resist building it. Other software vendors also offer free versions with limited capabilities which are adequate for most ham use.

Software

Some amateur programs have been developed for specific filter types. A good one for interdigital filters, *INTFIL*, was originated by N6JH;[2] a version is available on my Web page, **www.w1ghz.org**. I used this program to design a series of interdigital filters using waveguide stock as the mechanical structure, like the one in Figure 3.[3]

True waveguide filters separate a length of waveguide into a series of resonant cavities. The cavities are separated by an iris, a thin wall with a hole for coupling, or by a post, where the post acts as an inductive coupling as well as an electrical wall. A post-type filter is shown in Figure 5. Waveguide has very low losses, so the cavities can have extremely high Q, and can make incredible filters. Good designs by N6GN[4,5] and N6CA[6] for 10 GHz and 5.7 GHz have been published. A program by WA4LPR, *WGFIL*, can design both iris and post filters.[7]

Another popular filter in amateur microwave designs is the pipe cap. A common copper plumbing pipe cap with a tuning screw acts as a single resonator. Rather than couple the resonators, they are separated by MMIC amplifiers, so each may be tuned independently, but the filter responses add together for better selectivity. This technique, called synchronous tuning, works as well as it did in TRF receivers before the superhet was invented. Figure 6 shows a section of my 5760 transverter with pipe-cap filtering: two resonators for the LO, two for the transmitter, and one for the receiver.

Filters are one of the essential building blocks for microwave transverters. In future Microwavelengths, we will examine the other essentials, then put them all together into a complete transverter. Perhaps the one I build will be ready to lend out next summer and get someone new on the microwavelengths. And, if you follow along, we'll see you on the band too.

[2]J. Hinshaw, N6JH, and S. Monemzadeh, "Computer-Aided Interdigital Bandpass Filter Design," *ham radio*, Jan 1985, pp 12-26.

[3]P. Wade, N1BWT, "Waveguide Interdigital Filters," *QEX*, Jan/Feb 1999, pp 3-8.

[4]G. Elmore, N6GN, "A Simple and Effective Filter for the 10-GHz Band," *QEX*, Jul 1987, pp 3-5.

[5]**www.w1ghz.org/10g/6gwgfilt.gif**.

[6]C. Angle, N6CA, "10368 MHz post coupled band pass filter for a 28 MHz IF," **www.ham-radio.com/n6ca/microwave/filters/10368-28bpf.html**.

[7]D. G. Sweeney, WA4LPR, "Design and Construction of Waveguide Bandpass Filters," *Proceedings of Microwave Update '89*, ARRL, 1989, pp 124-132. **www.ham-radio.com/sbms/techpapers/waveguide_filters/wgfiltrs.html**.