CARR'S CORNER

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Frequency Selective Filters for UHF and Up

A filter is a device or circuit that selectively discriminates against some frequencies, while favoring other frequencies. The cluster of favored frequencies is called the *passband* while the rejected frequencies are called the *stopband*. The filter operates by providing a large attenuation for stopband frequencies, and a minimum attenuation (ideally zero) for passband frequencies.

There are four general classes of filter that we will consider here: *low-pass, high-pass, bandpass and bandstop.*

The low-pass filter (LPF) characteristic (Figure 1A) shows that the filter passes frequencies from DC or near-DC to some *cut-off frequency* (F_c). The attenuation increases above the cut-off frequency until the maximum stopband value is reached. The filter *skirt* is the transition region between the passband and full stopband. The steepness of the skirt slope defines the filter quality.

The skirt slope is usually specified in terms of decibels of attenuation per octave (2:1 frequency change) or per decade (10:1 frequency change), i.e. dB/octave or dB/decade. If, for example, a low-pass filter is specified to exhibit a 10 dB/octave slope for a 200 MHz cut-off frequency, the attenuation at 400 MHz is 10 dB greater than the attenuation at 200 MHz, and at 800 MHz it is 20 dB greater than the 200 MHz value.

The cut-off frequency is defined as the frequency at which the response falls off -3 dB from its passband response. Because the passband response isn't smooth, however, the average attenuation value is used, and the cut-off frequency is found at the point where the attenuation figure increases three decibels (see "3 dB" point in Figure 1A).

The high-pass filter (HPF) has a response curve that is the inverse "mirror image" of the LPF response (see Figure 1B). The attenuation is very high below the cut-off frequency, and minimum above the cut-off frequency. As was true in the LPF case, the HPF has a skirt or transition region between the stopband and the passband.

The bandpass filter (BPF) is a combination of the LPF and HPF responses in which the respective cut-off frequencies are different (see Figure 1C). In the BPF there is a high attenuation stopband above and below the minimum attenuation passband region.

The passband bandwidth is defined as the frequency difference between the upper cut-off frequency (F_H) and lower cut-off frequency (F_L) on the response curve ([F_H - F_L in Figure 1C). This expression of bandwidth is usually called the "3-dB bandwidth" and is often abbreviated in data sheets and specifications as "BW3-dB."

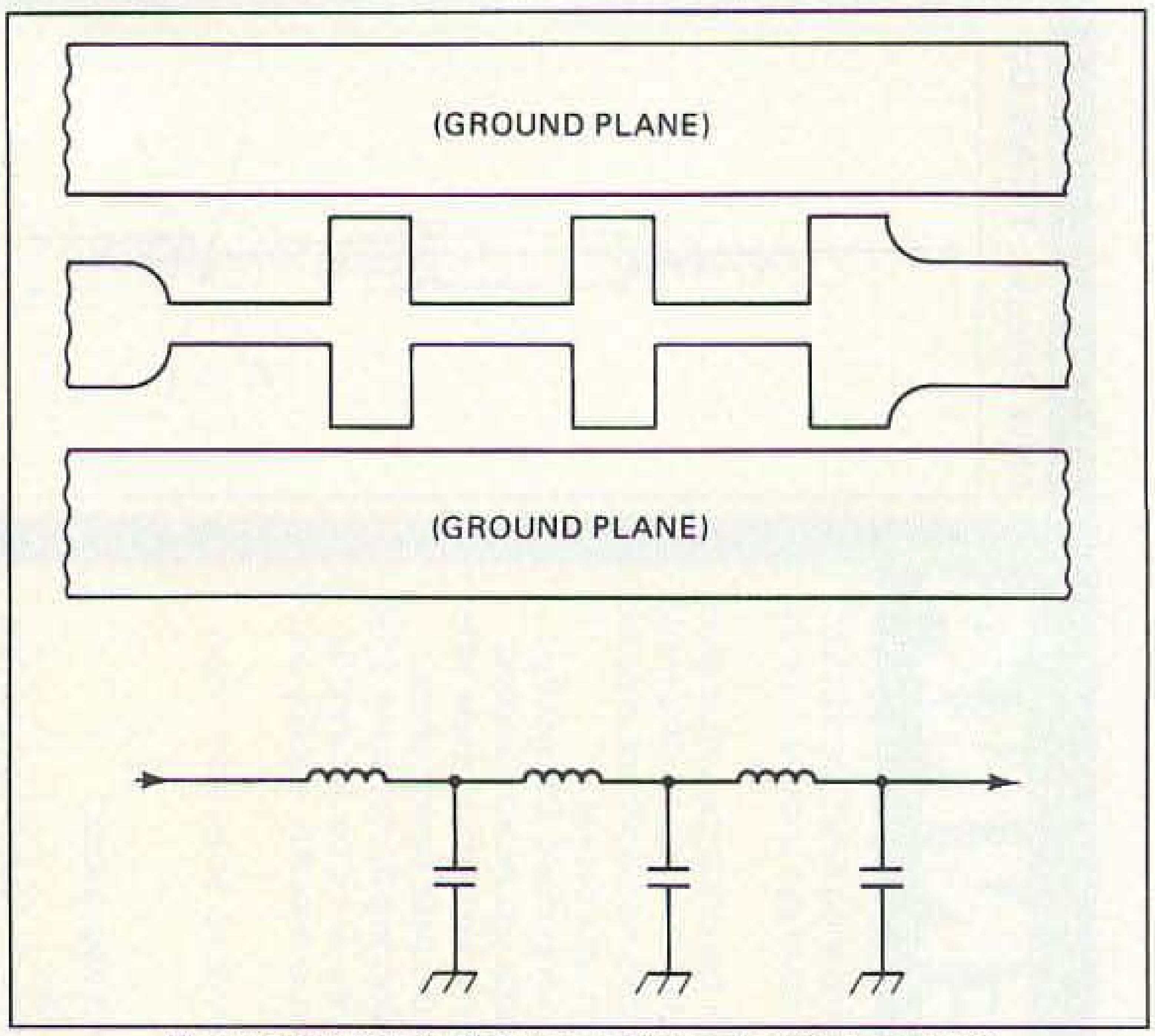

Figure 2. Printed circuit low-pass filter and equivalent circuit.

The upper and lower skirts define the sharpness of the cut-off characteristic between the passband and the two stopbands. This parameter is defined by the *shape factor,* which is the ratio of the 60 dB bandwidth to the 3-dB bandwidth. In terms of Figure 1C, the shape factor (SF) is:

$$S.F. = \frac{F_2 - F_1}{F_H - F_L} \qquad (1)$$

or,

$$S.F. = \frac{BW_{60\,dB}}{BW_{3\,dB}} \qquad (2)$$

The *figure of merit* or *quality factor* ("Q") of a bandpass filter is defined as the ratio of center frequency to the 3-dB bandwidth:

$$Q = \frac{F_C}{BW_{3\,dB}} \qquad (3)$$

The Q and the shape factor must be considered in selecting or designing microwave filter circuits. The most obvious factor is the relative position of other-frequency signals compared with the center frequency of the filter. Also, the bandwidth must be sufficient to properly pass the spectrum of the expected signals without also being so wide that other signals and excess noise signals are also admitted. For fast rise-time signals (such as pulses or digital signals), a filter that is too narrow (i.e. too high Q) will "ring" in the same manner as in LC resonant "tank" circuits.

The passband of an ideal filter is perfectly "flat" (i.e. constant attenuation) for all frequencies between the cut-off frequencies. But in real filters this ideal condition is never met, so a certain *ripple factor* (see Figure 1C) exists within the passband. In high quality filters the passband ripple will be on the order of 0.1 dB to 0.5 dB, although in some cases a larger ripple (e.g. 1 dB) factor will be acceptable.

The *insertion loss* of a filter is the attenuation of signals inside the passband. Ideally, the insertion loss is zero, but that is not achievable. In most designs, the better the shape factor, or the higher the Q, the worse the insertion loss. This phenomenon is due to the fact that such filters usually have more elements or "poles" than lesser types, so therefore show greater in-band loss. Many circuit designers opt for a pre-filter or post-filter amplifier to make up for insertion loss.

The bandstop filter (BSP) is the inverse of the bandpass filter. The attenuation is greatest between the cut-off frequencies (see Figure 1D). At frequencies above and below the stopband signals are passed with minimal "insertion loss" attenuation. The purpose of a

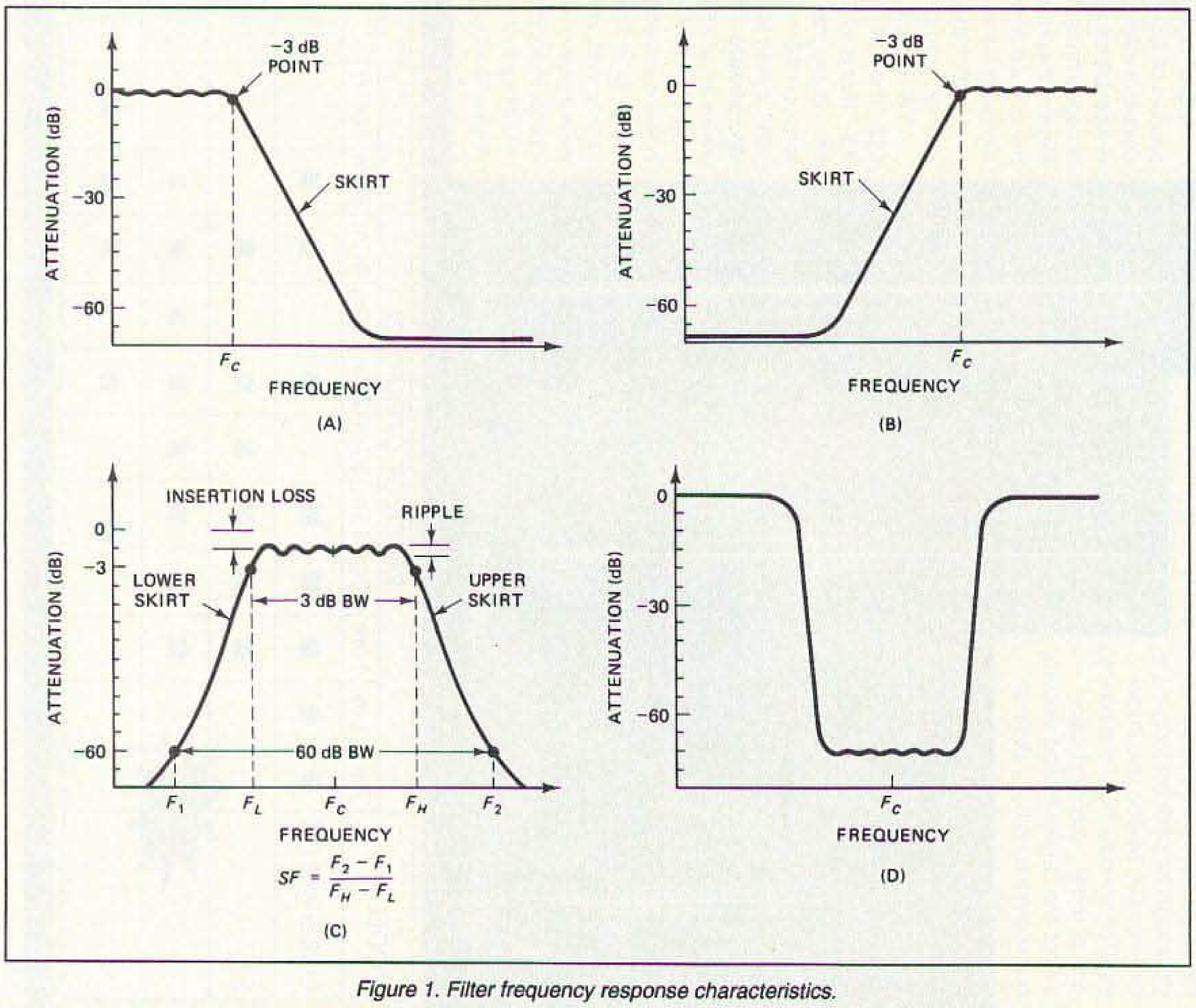

Figure 1. Filter frequency response characteristics.

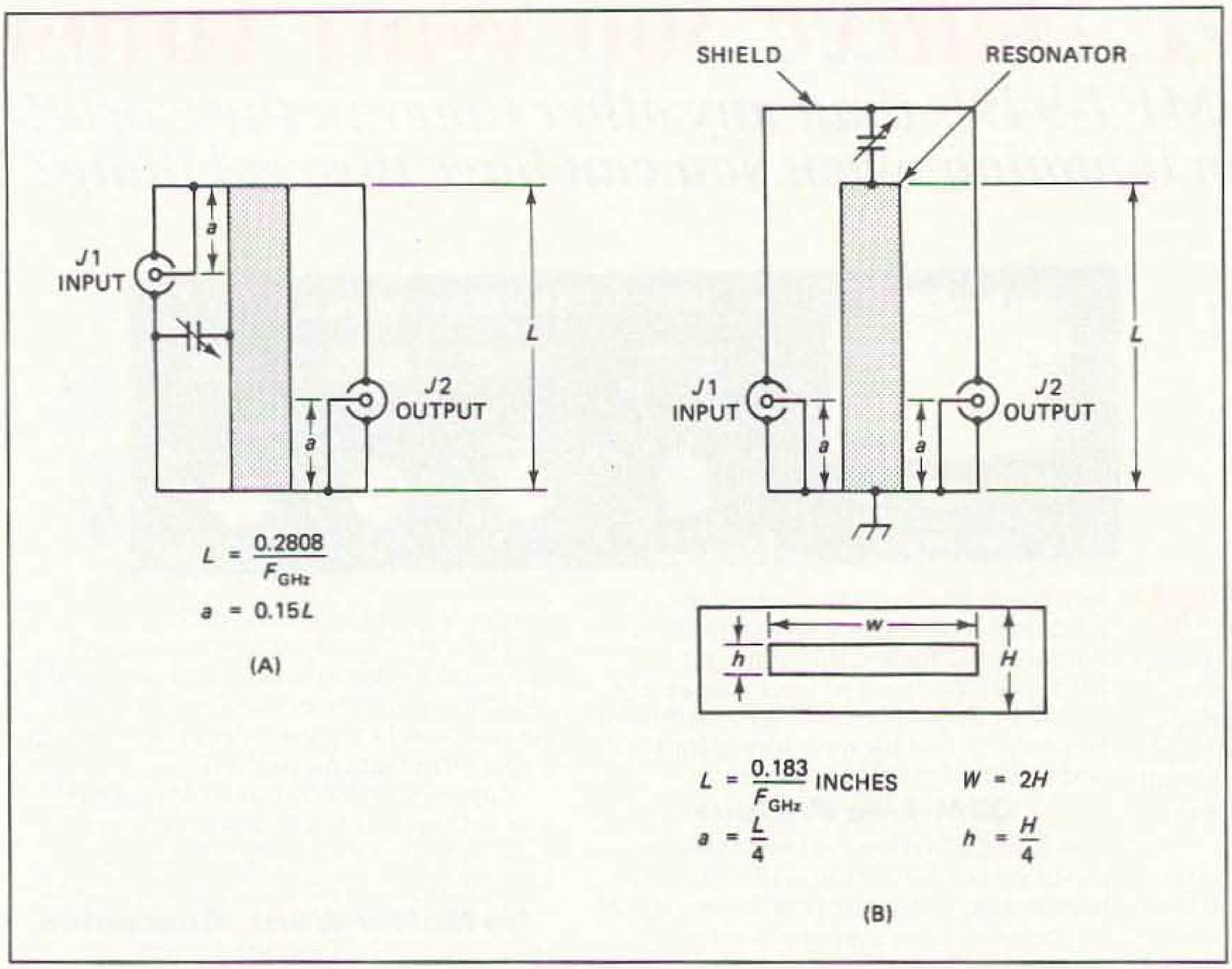

Figure 3. Stripline filters.

bandstop filter is to remove offending signals. An example is in communications systems where transmitters and receivers on two different frequencies are co-located at the same site. A receiver on frequency F1 will have a front-end bandstop filter on frequency F2, i.e. on the frequency of the co-located transmitter.

Typical UHF/Microwave Filters

At frequencies lower than microwave bands filters are often designed using lumped inductance and capacitance (L and C) components. In the microwave bands implementation of filters is through printed circuit stripline or (in UHF and low microwave bands) chip components. Figure 2 shows a microwave stripline implementation of a low-pass filter (HPF, BPF and BSP designs use the same methods but with different layouts).

As microwave frequencies increase the dimensions of the stripline components get smaller, eventually becoming too small to either carry required load currents or to be easily built using ordinary printed circuit techniques. But stripline width is a function of system impedance as well as frequency. As a result, microwave filter designers often design a filter for a lower input and/or output impedance than is required by the system, and then provide impedance matching networks to renormalize the circuit. For example, in a 50-ohm system the filter may be designed for 20-ohm termination impedances, with a 50:20-ohm impedance transformation provided at the input and output terminals. The resultant filter will have wider (more easily built) stripline tracks.

Two forms of resonant stripline bandpass filter are shown in Figure 3. The half-wavelength version is shown in Figure 3A, and the quarter-wavelength version in Figure 3B. This is a form of transmission line filter, and is usually built inside of a shielded container. At one time, one would cut metal strips (see older editions of *The ARRL Radio Amateur's Handbook* for examples) for the resonator (shaded area), but today an appropriate section of printed circuit board stripline can be substituted.

Another form of stripline filter is the interdigial design shown in Figure 4. This type of filter consists of a series of quarter-wavelength stripline transmission line segments. This sort of filter can be used well into the microwave region and are well suited to MMIC and hybrid circuit designs.

Figure 5 shows several forms of waveguide frequency selective filters. The cut-off frequency of waveguide is a function of crossectional dimensions. Similarly, inductive and capactive circuit action is found through the use of restrictive "irises" in a segment of waveguide. In Figure 5A we see the stepped or staircase bandpass filter. In this design, critically dimensioned steps are machined into the internal surfaces of a section of waveguide.

A cavity-type series resonant bandpass filter is shown in Figure 3B. Using a re-entrant resonant cavity, this filter allows passage of signals with a frequency around the resonant frequency. A parallel resonant cavity bandpass filter is shown in Figure 3C. This particular version is tunable by virtue of the volume-changing tuning disk inside of the cavity.

Conclusion

Filter circuits for VHF, UHF and our lower microwave bands need not be too complex to be effective. In some cases, filter elements can be purchased. Digi-Key (POB 677, Thief River Falls, MN) sells Toko helical resonators for VHF/UHF bands. Also, the advertisers in this magazine are sources of some forms of filter elements and parts. Finally, you can build them yourself.

I can be contacted at P.O. Box 1099, Falls Church, VA.

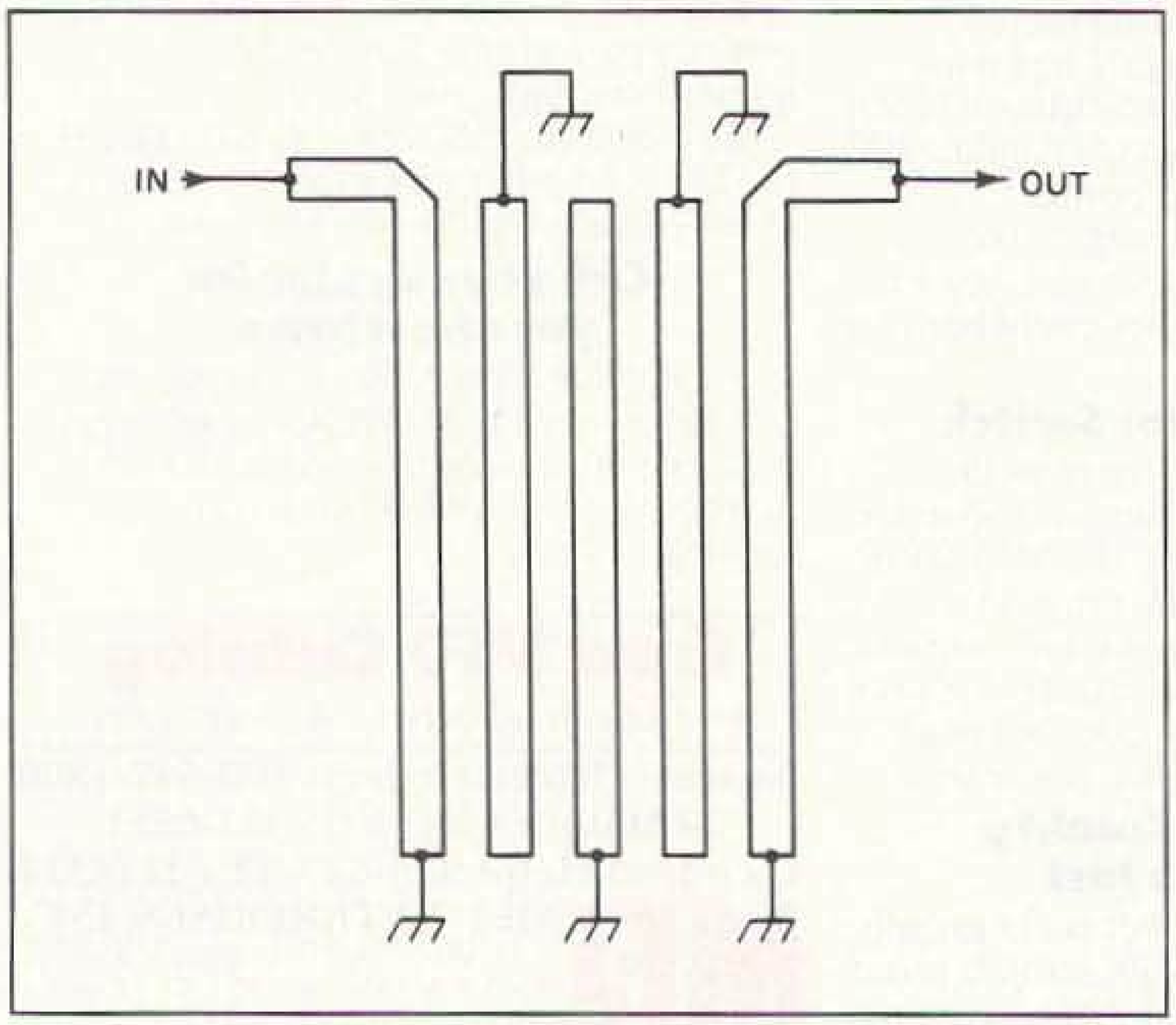

Figure 4. Inter-digital filter.

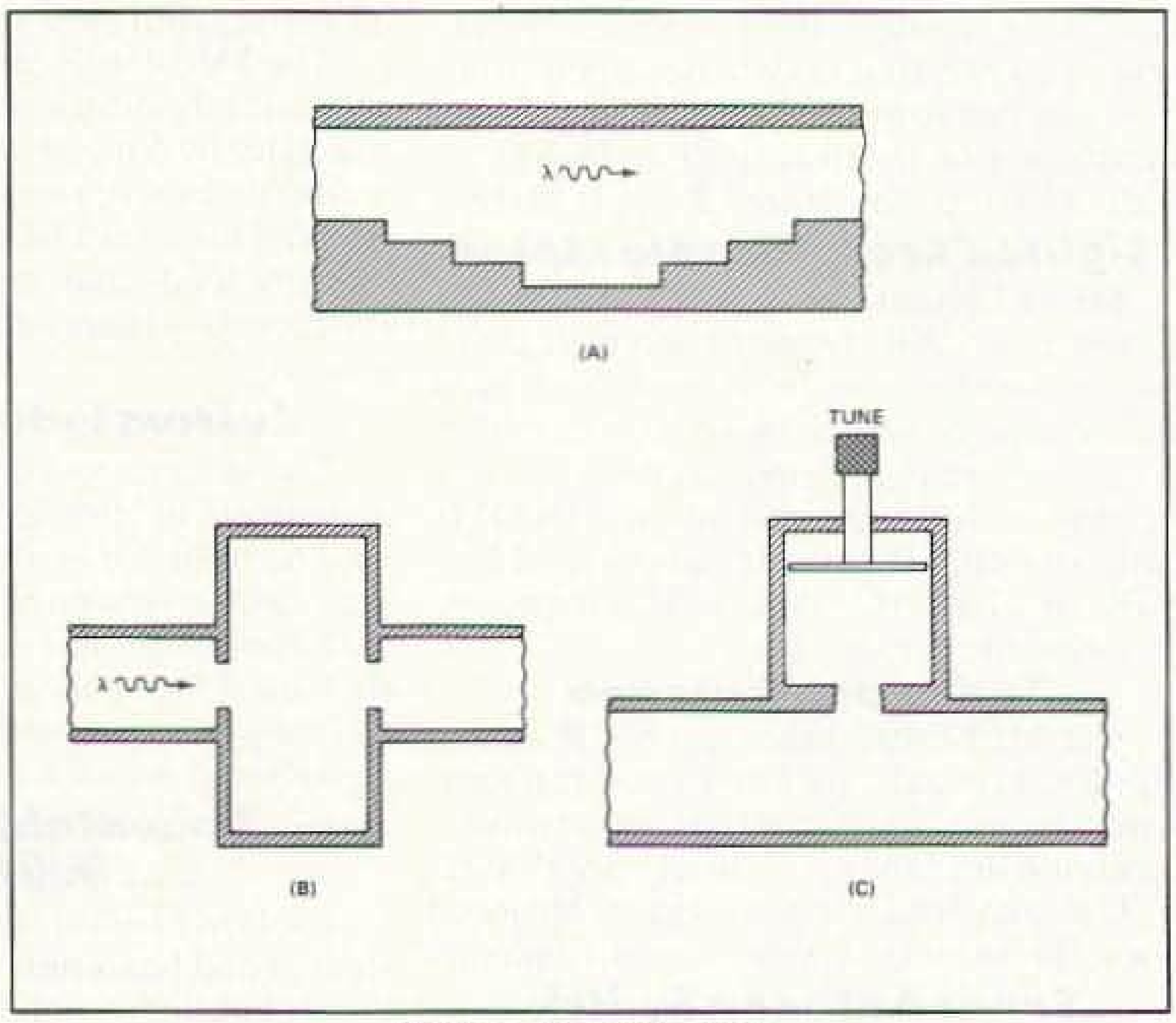

Figure 5. Microwave filters.