Understanding Filter Types and Their Characteristics

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As one of the fundamental signal processing components in RF and microwave circuits, filters play a critical role in determining any system's ultimate performance. Since the electromagnetic spectrum has become more and more densely populated, filter performance has taken on greater significance than ever because interference rejection is of paramount importance. To the uninitiated, filters can seem strikingly simple, since they are passive components that perform a single function: to reject RF energy either below or above a specific frequency or range of frequencies or both. However, the truth lies elsewhere, since there are not only multiple types of filters but multiple response types, and descriptions of both are the subject of thousands of technical papers and several textbooks.

Specifying a particular filter for a given system invariably requires a trade-off between a wide variety of factors, including power handling, Q factor, insertion loss, intended operating frequency, size, packaging and mounting, manufacturability, and many other parameters. Consequently, rather than providing a highly-academic discussion about filter designs and characteristics, the goal of this article is to provide a simple, thumbnail sketch of the most popular filter types (LC, ceramic, cavity, Surface Acoustic Wave (SAW), crystal, and helical) along with the advantages and disadvantages of each in various applications. Armed with this information, designers can be better equipped to make realistic decisions when specifying a filter and contacting a filter manufacturer such as Anatech Electronics, Inc.

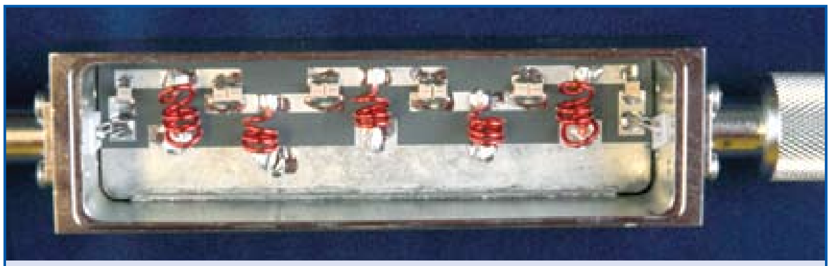

Figure 1: A typical LC filter

Figure 2: A cavity filter and smaller LC filter

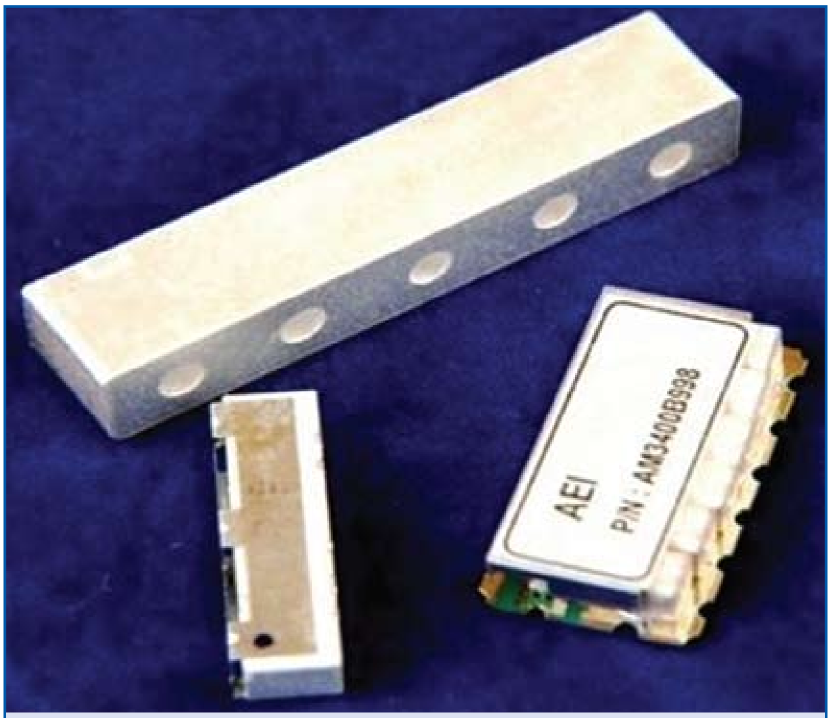

Figure 3: A group of ceramic filters

LC or Lumped-Element Filters

LC filters are lumped-element (also called lumped-component) types that can be specified in low-pass, bandpass, bandstop, high-pass, or diplexer configurations and are available for frequencies ranging from below 100 kHz to slightly above 3 GHz (**Figure 1**). The resonators in an LC filter consist of inductors and capacitors in either series or parallel resonant circuits. They range in size from about 0.5 in. at high frequencies to 26 in. at low frequencies, their size being dictated by the size of their capacitors, inductors, and power handling.

LC filters have a variety of advantages, the benefits of which vary depending on the application for which they are being considered. They are a good choice, for example, at frequencies between 500 MHz and 1 GHz, because their size remains reasonable compared to other filter types, and they are the best choice for very low frequencies, where cavity filters would be too large and they can achieve high performance.

For example, an LC filter with a center frequency of 500 MHz would typically be one third the size of a cavity filter (**Figure 2**). They can be made to provide the widest range of filter responses, including Chebyshev, elliptical, Bessel, Butterworth, constant-impedance, and constant group delay, and deliver a steep transition from passband to the rejection points. It is also relatively easy to shift the center frequency of LC filters, since this is achieved by changing the inductance of the coil and requires no machining. LC filters are also very versatile from a mechanical standpoint, and can support many types of connectors in various combinations, as well as drop-in, printed circuit board, and surface mounting.

Many case styles can be accommodated to meet the needs of specific physical environments as well. They inherently have low insertion loss and can handle RF power levels as high as 500 W, and in special cases even more.

However, LC filters cannot achieve extremely narrow bandwidths because of the coupling between elements, and a Q factor limitation. In addition, at frequencies above about 2 GHz, the inductors and capacitors become very small and impractical to fabricate.

Their power handling ability

is defined by the physical characteristics of their elements and is thus somewhat limited. Although they can be made with up to 14 sections, their insertion loss increases significantly when many sections are needed, and they can be complex when steep rejection skirts are required. Finally, the labor-intensive nature of LC filters makes them comparatively expensive.

Ceramic Filters

Ceramic filters (Figure 3) use quarter-wavelength resonators as their main tuning elements, are best suited for frequencies between 400 MHz and 6 GHz, and can be fabricated in bandpass or bandstop configurations. The most prevalent type is the bandpass.

Their size depends on the dielectric constant of the ceramic resonator, which in most cases ranges between 30 and 90. The lower the dielectric constant, the larger the resonator and the better the temperature coefficient, and vise versa. Ceramic filters can be made from discrete ceramic resonators or as a monoblock in which the resonators are made from a single piece of ceramic. Their advantages include good insertion loss, low cost, comparatively small size, and the ability to be mass produced cost-effectively in large numbers.

However, ceramic filters can be designed for a relatively narrow range of frequencies, can handle RF input power of only 5 W, and have the potential for temperature instability when constructed with ceramics having high dielectric constants. In addition, their construction allows them to be suitable only for surface mounting, and they require a considerable amount of care during assembly to ensure good adhesion to ground. It is also very difficult to modify or shift the frequency of ceramic filters once they are tuned.

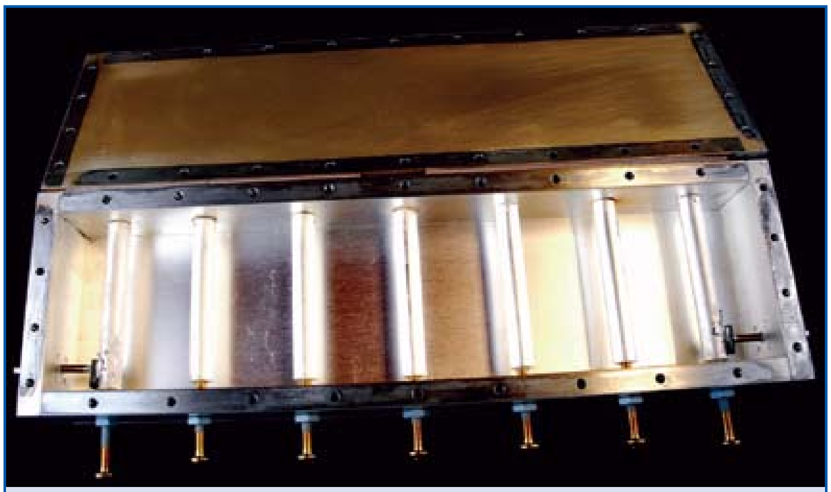

Figure 4: Inside a cavity filter

Figure 5: Size comparison between cavity and ceramic filters

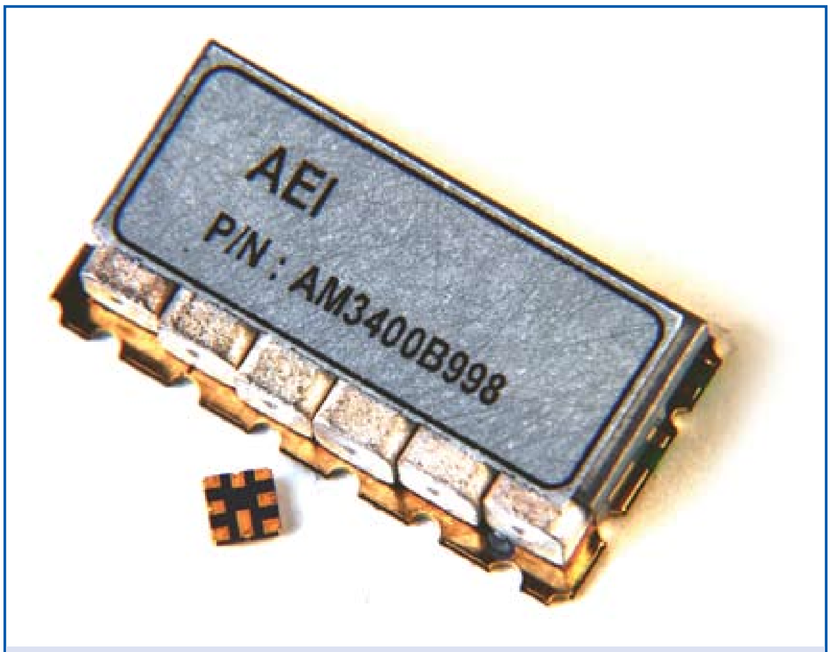

Figure 6: SAW filter compared to ceramic filter

Cavity Filters

This extremely common type of filter is usable at frequencies between 20 MHz and 30 GHz or even higher, and can be specified in bandpass and notch configurations. It consists of a quarter-wavelength resonator typically machined from aluminum and usually in an air dielectric, the result being very large compared with ceramic filters, for example, as shown in Figure 4.

The advantages of cavity filters include high power handling ability with the norm being about 500 W, low insertion loss, very high performance, and the ability to be manufactured in medium to large quantities although at relatively high cost. On the downside, they are comparatively large (Figure 5), cannot be used at very low frequencies, and generally can only be supplied in a connectorized module.

A coupled resonator structure is employed when narrow bandwidth is required. Moderate bandwidths are accomplished with a combline structure, and when wider bandwidths require an interdigital type configuration. Recent advances in cavity filter design allow them to achieve extremely high performance, with a transition from passband to stopband as low as 1 MHz in a filter centered at 800 MHz, for example.

Surface Acoustic Wave (SAW) Filters

Compared to "traditional" filter types, which are typically hand-made devices, SAW filters are made using a photolithographic process. They vary in size from being extremely small with a very low profile (2 x 2 x 2 mm), to about 25 x 12 x 2 mm (size also depends on the number of sections and required performance), and can be manufactured in very large quantities at low cost (Figure 6). This has led to their becoming a staple in virtually every portable wireless-enabled device. They are made from piezoelectric crystal and employ multiple conductors that are calculated to resonate at a specific frequency.

The signal propagates from one conductor to the other, and depending on the number of electrodes and the distance between them, the filter will achieve a specified bandwidth and level of performance. SAW filters are limited to bandpass and duplexer configurations at frequencies from 30 MHz to about 3 GHz, and can achieve very narrow bandwidths, with very low group delay variation.

That said, their overall performance, especially insertion loss, is inferior to other types of filters, they can handle only very low-power levels, and like all "wafer-scale" devices, their characteristics cannot be changed after fabrication.

Crystal Filters

Crystal filters consist of crystal resonators, each one made from a single piezoelectric resonance material (Figure 7). They provide a precisely-defined fixed center frequency and achieve extremely high Q factors (in the tens of thousands), which allows them to achieve extremely narrow bandwidths of only a few kilohertz.

Crystal filters are typically employed in intermediate frequency (IF) stages of receivers (70 and 140 MHz), and can be specified at frequencies from about 300 kHz to about 225 MHz. They are usually available in bandpass or notch configurations and in Chebyshev or Butterworth topologies.

Crystal filters are primarily used for single-band applications such as a receiver operating at one frequency, which the filter passes while rejecting all others with high precision. They also inherently have high temperature stability. However, crystal filters can handle power levels of only about 10 W, are very difficult to tune, are typically expensive, and exhibit relatively high insertion loss.

Figure 7: Inside a crystal filter

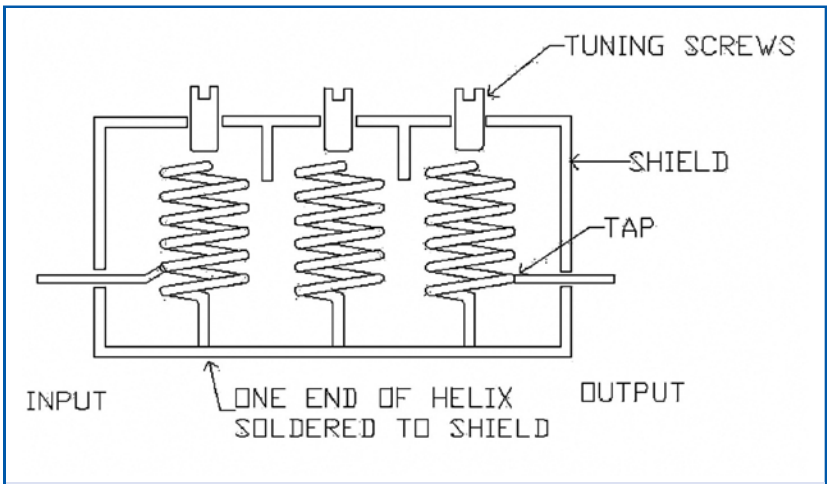

Figure 8: Helical filter structure

Helical Filters

Helical filters are lumped-element types that can be made to operate at frequencies between 45 MHz and 3 GHz and are limited to the bandpass configuration. They consist of a series of cavities that are magnetically coupled, each cavity consisting of a coil soldered to ground on one side and a tuning capacitor on the other (Figure 8). The length of the unfurled coil is equal to one-quarter wavelength at the filter's center frequency.

Their advantage over LC filters is in their bandwidth versus insertion loss. They also have much higher Q than conventional lumped-element types, produce comparatively little stray coupling, and are easy to adjust. When compared to a SAW filter, for example, they offer much lower insertion loss and lower impedance. Their simple design enables smaller quantities to be produced economically with fast delivery. The factors determining the size of a helical filter include frequency and bandwidth. Narrow bandwidths require larger structures to achieve higher resonator Q, and filter size decreases as frequency increases. Their limitations include RF power handling ability of only 5 W, and a relatively narrow frequency range of 45 MHz to 3 GHz.

Summary

As should be obvious at this point, specifying the most appropriate filter for a given application is not as simple as might be expected, and the ultimate decision requires careful examination of many factors. Fortunately, filter manufacturers such as Anatech Electronics help designers make these decisions every day and can provide quick solutions to even the most complex problems that can otherwise consume lots of time. For more information, visit www.anatech-electronics.com.

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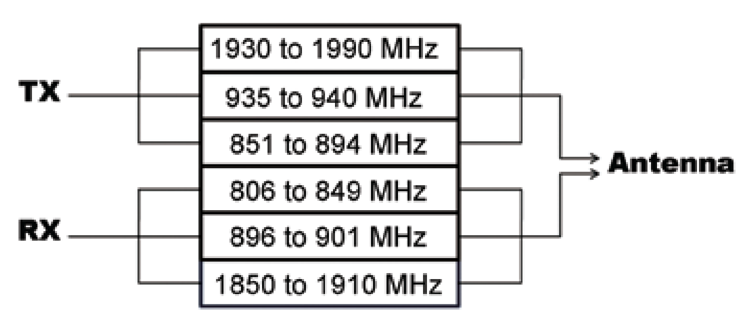
Multi-band Combiners Reduce Cell Site Complexity

For most of the relatively short history of the wireless industry, cell sites looked relatively simple judging from the uncluttered appearance of their towers and antennas, and collocated sites were comparatively few. Today, collocated sites are the norm, and it is common to have four or five different services transmitting and receiving from a single tower, each one using multiple frequencies. This presents a challenge for wireless carriers, who must find a way to accommodate all the signals from the multiple bands in their networks using the least amount of combining and dividing networks.



Anatech's AD800-900-1800TR288 multiband combiner/splitter is well suited for this task. It allows carriers to a single antenna for both transmit and receive signals in the 800 and 900 MHz SMR and 1800 MHz PCS bands while maintaining the required amount of isolation between transmit and receive signals in each band. A graphic depiction of its functions is shown in the figure.

The AD800-900-1800TR288 can considerably reduce the amount of hardware required to handle all three bands. It is constructed using high-performance cavity bandpass filters that have extremely high rejection, handles 20 W of average power, and measures only 16.2 x 9 x 2.6 in. Rejection of transmit signals in the receive path (and vice versa) in any band is at least 45 dB and ranges as high as 65 dB at the higher frequencies. More information is available at www.anatechelectronics.com.

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