Ceramic Bandpass Filters — Boon or Bane?

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In recent years, the electronics industry has seen important technological advances superimposed upon an emerging commercial market place. The ceramic bandpass filter has become a reality and has found its niche in wireless communications equipment. This new version of coaxial bandpass filters has become feasible due to the miracle of new ceramic materials. They provide high dielectric constants, low loss tangents and markedly improved temperature stability. The ceramic bandpass filter has achieved dramatic unit cost reduction via a new and novel manufacturing process.

In this tutorial article, some of the basic capabilities and limitations of ceramic bandpass filters will be discussed.

Filter capabilities

Bandpass filter insertion loss, due to dissipation, can be computed readily [1]:

$$L = 4.343(Q_T/Q_{UL}) \times \text{sum of } g \text{ values from 1 to } n \quad (1)$$

where

L = filter insertion loss, due to dissipation, at the filter center frequency in dB.
Q_T = filter total Q
= filter center frequency/filter normalizing bandwidth
Q_{UL} = resonator overall unloaded Q
g values refer to normalized circuit elements from the low pass prototype
n = number of resonators or poles

The low pass prototype can be normalized to a ripple bandwidth, a 3 dB bandwidth, or some other selected bandwidth. The filter insertion loss is inversely proportional to the resonator unloaded Q.

The ceramic bandpass filter usually uses quarter-wave coaxial resonators in a combline configuration in which adjacent resonators have common short-circuit and open-circuit reference planes. Each resonator is fabricated by a metallization process in which copper conductors are deposited on a high dielectric constant ceramic. Conductor thickness should be greater than three skin depths. By using nominal 90-degree resonators, unloaded Q degradation due to resonator foreshortening is not encountered, as shown in Table 1.

Typical ceramic resonator dielectric constants of 20 to 90 have resulted in resonator physical lengths reduced by a factor of 4.473 to 9.487. Resonator cross sections use square outer conductors with rounded corners, along with round inner conductors. Typical outer conductor sizes range from 12 millimeters down to 2 millimeters. Resonator quality is quantified by overall unloaded Q [1].

$$Q_{UL} = 1/Q_C \text{ plus } 1/Q_D \quad (2)$$

where Q_C is the conductor unloaded Q and Q_D is the dielectric unloaded Q (the reciprocal of loss tangent).

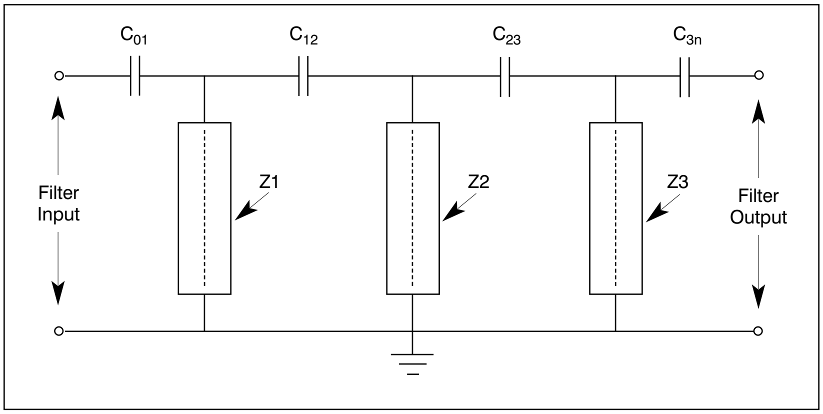
Conductor unloaded Q is primarily a function of resonator size (cross section), metallic conductivity and metallic surface finish. For a conductor unloaded Q of 1,000 and a dielectric unloaded Q of 10,000 (loss tangent = 0.0001), the overall unloaded Q is reduced from 1,000 to 909.1 This illustrates the rather modest degradation of overall resonator unloaded Q due to the loss tangent of the ceramic resonator dielectric.

Two or more ceramic resonators are cascaded to form a direct coupled multi-resonator bandpass filter. Capacitive input, output and interstage couplings are used similar to a top-CLC lumped element bandpass filter. A simplified filter schematic is shown in Figure 1. Each individual resonator is affected by reactive loading from adjacent couplings and open-ended capacitive fringing. Resonator center frequencies are factory adjusted to a specified center frequency. This is achieved by trimming of metallization and solder modification of the short circuit reference planes.

The high dielectric constant ceramics reduce the res-

Resonator Length (degrees)	Unloaded Q Degradation
30	0.25
45	0.5
60	0.75
90	1.0

▲ **Table 1. Unloaded *Q* degradation for combline resonators of different lengths.**



▲ **Figure 1. Simplified schematic for a three pole ceramic bandpass filter.**

onator operating impedances. Typical resonator impedance levels are 5 to 15 ohms. For a resonator (neglecting rounded corners), impedance is given by [2]:

$$Z_0 = \left[\frac{60}{\sqrt{\varepsilon_r}}\right] \ln\left(1.0787\frac{D}{d}\right), \quad \text{for } \frac{D}{d} > 0.9 \qquad (3)$$

where

Z_0 = characteristic impedance of the resonator in ohms
ε_r = ceramic dielectric constant
D = side of square outer conductor in inches
d = diameter of round inner conductor in inches

Ceramic bandpass filters have typical bandwidths of 1 to 5 percent. Center frequency tolerances are usually plus or minus 0.2 percent to plus or minus 1 percent. The temperature stable ceramic bandpass filters have thermal sensitivities less than 5 ppm/degree C. This is substantially better than air dielectric combline bandpass filters using milled block construction.

Ceramic bandpass filters achieve cost savings by avoiding coaxial input and output connectors. Input and output filter interfaces include flat pack surface mount, printed circuit board surface mount and through-hole pins for drop in printed circuit board mounting. Diligent solder techniques are needed when mounting ceramic bandpass filters on the next higher assembly. Proximity of ceramic bandpass filters to adjacent units must be examined to avoid spurious couplings to filter input/output and locations where resonator metallizations have been removed.

Dielectric Constant ε_r	TE_{11} Mode Cutoff Frequency (GHz)
1	15.02
20	3.359
37	2.469
90	1.583

▲ **Table 2. TE_{11} mode cutoff frequency for selected values of resonator dielectric constant.**

Filter limitations

Commercially available ceramic bandpass filter specifications usually do not include some specifications provided with other coaxial bandpass filters:

- A central usable passband
- Passband amplitude response
- Passband return loss (VSWR) response
- Location of filter spurious passbands
- Filter average and peak power handling

A ceramic bandpass filter with input and output VSWRs of 2.0 (return loss of 9.54 dB) has a reflection loss of 0.51 dB. Overall filter insertion loss includes both the reflection loss and the previously cited dissipation loss due to resonator finite overall unloaded Qs. If source and load VSWRs are also 2.0, a worst case multiplication of VSWRs could result in an overall VSWR of 8.0. This corresponds to an overall reflection loss of 4.03 dB, which is not necessarily trivial.

All coaxial bandpass filters have an upper frequency limit where unique dominant (TEM) mode operation no longer exists. The TE_{11} circumferential mode is the first higher mode for coaxial lines. Assuming ceramic resonator square outer conductor dimension D is replaced by a round outer conductor with diameter D, the higher mode cutoff frequency can be readily computed by [2]:

$$F = \left(\frac{7.51}{\sqrt{\varepsilon_r}}\right)\left(\frac{1}{D+d}\right) \qquad (4)$$

where F = TE_{11} mode cutoff frequency in GHz.

Assuming D = 0.375 inch and d = 0.125 inch, then equation (4) becomes:

$$F = \left(\frac{15.02}{\sqrt{\varepsilon_r}}\right)$$

Letting ε_r = selected values, F is shown in Table 2.

For a ceramic bandpass filter operating at 5 GHz and a dielectric constant of 20, resonator cross section dimensions must be reduced to raise the TE_{11} mode cutoff frequency past the upper limit of the filter stopband. This size reduction is accompanied by a corresponding decrease in conductor unloaded Q and increase in filter insertion loss at the center frequency.

It should also be noted that nominal 90-degree (quarter-wave) ceramic resonators will have a first TEM spurious passband at three times the filter center frequency when the resonator electrical length is 270 degrees. Air dielectric foreshortened 45-degree combline resonators will have their first TEM spurious passband at six times the filter center frequency.

Capacitive couplings in ceramic bandpass filters are quite frequency sensitive and provide sharper selectivity below resonance than above resonance. Ceramic bandpass filters are not field tunable to a different center frequency. They are factory trimmed to a fixed center frequency and must be replaced by a different filter upon change of center frequency. Ceramic bandpass filters are not field repairable and are throw-away components when they fail. Air dielectric combline bandpass filters can be designed for field tunability and repairability. They also can provide larger percentage bandwidths than ceramic bandpass filters.

The future

Ultimate low cost bandpass filter design will certainly use active filters. This is compatible with integration at the overall system level. Of course, production volume must be sufficient to justify the nonrecurring costs. Implementation will probably start at lower UHF before moving up to microwave frequencies. Sometime in the future, ceramic bandpass filter replacement could begin. Until then, ceramic bandpass filters are here to stay.

Conclusions

Ceramic bandpass filters provide an adequate low cost solution to the needs of wireless communications and related equipment. This is enhanced by important advances in miniaturization and thermal stability. The limitations of ceramic bandpass filters must be carefully scrutinized before attempting to use them in applications with more stringent transmission requirements, such as high speed digital data and video. ■

References

1. G.L. Matthaei, L. Young and E.M.T. Jones, *Microwave Filters, Impedance Matching Networks, and Coupling Structures*, McGraw-Hill, 1964, pp. 154, 166.

2. R. Rhea, *HF Filter Design and Computer Simulation*, Noble Publishing, 1994, pp. 83, 94.

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