# Triple-mode ceramic the key in ultra-compact filter research

**To meet the space limitations of tomorrow's cellular base stations, Radio Frequency Systems is researching an ultra-compact hybrid filter technology based on a low-loss dielectric ceramic.**

With the deployment of 'micro' base stations and the co-location of multiple cellular services, the challenge is on to fit more and more equipment into a shrinking amount of space. One component that can occupy a significant fraction of base station volume is the RF bandpass filter, increasingly introduced to control interference and improve quality of service. As a result, base station manufacturers are demanding RF filter technologies that are both less costly and more compact, while continuing to meet stringent base station RF performance specifications.



Perhaps the most logical means of minimizing the size of an RF bandpass filter is to minimize the volume allocated to the resonant chambers—or cavities—that determine the pass band and selectivity of the filter. The use of low-loss dielectric ceramics has proven useful in this regard, by allowing the development of multi-mode filters—essentially where a single cavity supports two or three resonant modes (or poles).

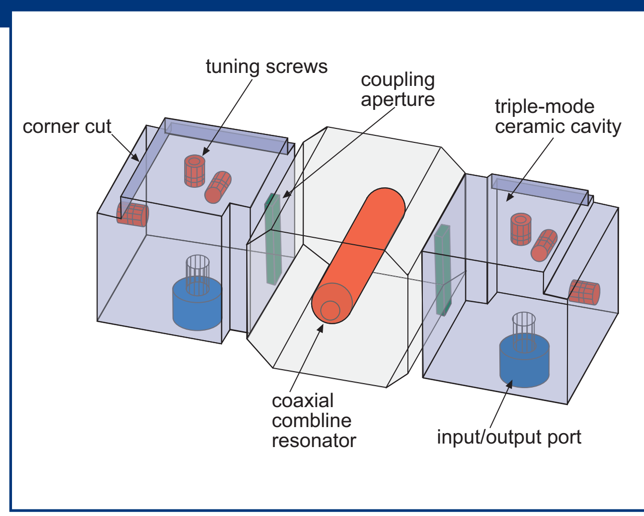
A 'dielectric-loaded' multi-mode cavity offers a compact filter with a high quality factor (Q). However, the resonator volume can be even further reduced by making the entire multi-mode cavity out of the low-loss ceramic dielectric. In this case, the metallic housing is replaced by metallic plating of the ceramic and—although the Q is sacrificed to some extent—it remains in the range of typical metallic coaxial resonators that are commonly used in base station filters.

Such use of low-loss dielectric ceramics for triple-mode cavities means that the size of the resonator can be scaled down by as much as the square root of the dielectric constant, relative to an air-filled cavity resonant at the same mode. In addition, power handling is relatively high because there are no air gaps, and because the majority of the power loss in the filter is resistive loss at the resonator surface and can easily be dissipated.

## Seven-pole UMTS filter

Radio Frequency Systems has applied these principles to develop a proposed ultra-compact RF bandpass filter for universal mobile telecommunications system (UMTS) base station applications. The seven-pole hybrid filter comprises a metallic coaxial combline resonator sandwiched between two triple-mode plated ceramic resonators, each with three orthogonal modes (Figure 1). The two types of resonators form a hybrid structure, which is used to address the poor spurious performance that is typical of multi-mode filters based on dielectric ceramic.

Figure 1: Configuration of the seven-pole triple-mode ceramic block-based hybrid structure

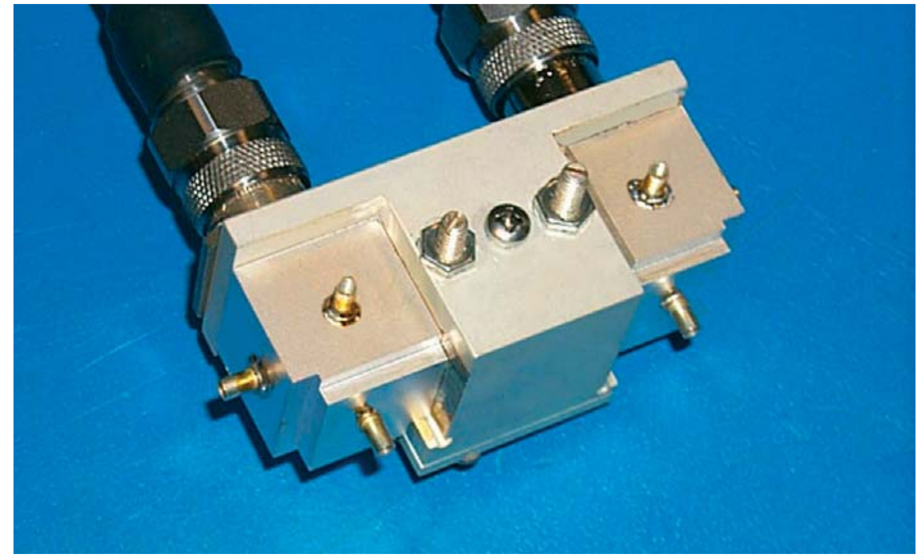



Using various computer simulation techniques, the proposed UMTS filter was designed to accommodate a pass band of 1920-1980 MHz, with greater than 70-dB rejection below 1880 MHz and better than 95-dB rejection above 2110 MHz. Insertion loss and return loss were designed to be less than 1 dB and less than -20 dB respectively. The ideal response of the seven-pole filter from the filter synthesis program is shown in Figure 2A.

The resonant frequencies of the three orthogonal modes in each triple-mode cavity are determined by the dimensions of each side of the plated ceramic block. Each corner cut, as shown in Figure 1, then determines the coupling coefficient between two orthogonal modes. Excitement of each triple-mode ceramic block is achieved via a probe; the dimensions of the hole into which this is inserted determines the input/output coupling. Coupling between the third mode of each triple-mode cavity and the central coaxial resonator is achieved using an aperture of specific dimensions.

## Double optimization

Optimization of the overall triple-mode cavity dimensions was achieved using a combination of two techniques: a finite element method (FEM)-based three-dimensional electromagnetic simulator, and RFS-developed filter synthesis software based on circuit modelling network theory. By matching the two responses, the resonant frequency and the coupling parameters of the filter model in the three-dimensional simulator were determined.

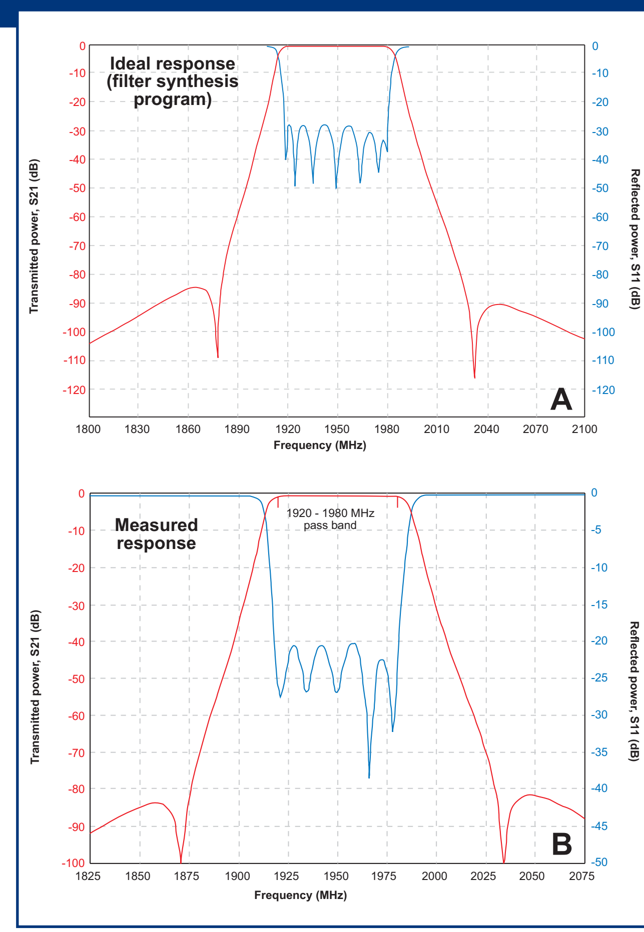


Culmination of the research: the assembled hybrid seven-pole filter, showing three tuning screws on the triple-mode blocks

Based on the simulations, the resonant frequencies and intermode couplings of the triple-mode cavities were optimized by changing the dimensions of the ceramic block faces and corner cuts respectively. Similarly, the coupling between the ceramic cavities and the coaxial resonator was adjusted by changing the aperture dimensions. After a few iterations, all the desired resonant frequencies and the coupling parameters were achieved.



Figure 2: Ideal response (A) and measured in-band response (B) of the seven-pole hybrid filter




In order to provide independent tuning of each resonant frequency of the triple-mode ceramic cavities, a custom-designed tuning screw has been inserted into the centre of each face on each block. The coupling between the triple-mode block and the coaxial resonator can also be tuned by tuning screws at the bottom of the coaxial resonator. This tuning functionality also allows the entire filter pass band to be tuned by approximately 15 MHz.

## A third the volume

The assembled hybrid seven-pole filter is shown left. The measured filter response shown in Figure 2B matches very well with the simulated filter response (Figure 2A). As specified by the design parameters, the return loss is better than 20 dB across the band and the insertion loss at the centre frequency is 0.51 dB. The insertion loss at the edges of the 60-MHz band is less than 1 dB. The filter also meets all the rejection requirements.

The overall average resonator Q measured for the filter is approximately 2300, which Q is approximately 15 per cent lower than the simulated Q. The difference is believed to be due to the conductivity of the silver plating being less than that of pure silver, as was assumed in the simulation. The wideband response of the filter was also measured, with the closest spur recorded at 2.44 GHz. Due to the hybrid structure of the filter, this spur was depressed 28-dB compared with the desired pass band signal—a spurious performance improvement of almost 20 dB over a filter without a hybrid structure.

With final dimensions of just 75 by 36 by 33 millimetres (excluding tuning screws), the proposed triple-mode ceramic-based hybrid seven-pole filter is less than one-third the size of a traditional metallic coaxial combline filter. In addition, it meets the stringent performance requirements demanded by UMTS base station manufacturers and cellular operators, ensuring that it has a good potential for base station application.

**This article is based on the paper 'A compact triple-mode plated ceramic block based hybrid filter for base station applications', by Mohammed M Rahman, Weili Wang and William D Wilber of Radio Frequency Systems.**
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