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# Monolithic Integrated Ceramic Waveguide Filters

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**Abstract — Design techniques for a new class of integrated monolithic high permittivity ceramic waveguide filters are presented. These filters enable a size reduction of 50% compared to air-filled TEM filters with the same unloaded Q-Factor. Designs for both chebyshev and asymmetric generalized chebyshev filter are presented, with experimental results for an 1800 MHz chebyshev filter showing excellent agreement with theory.**

**Index Terms — Ceramic filter, microwave waveguide filters, Miniaturization.**

## I. INTRODUCTION

Cellular radio base stations routinely use TEM filters and multiplexers. These filters are relatively simple to manufacture and offer high Q and good spurious performance, although they use significant physical volume [1]. There is significant pressure for future systems to increase the number of filters and consequently a reduction in size without compromising electrical performance is required. In this paper, we present new designs for ceramic loaded rectangular waveguide filters. These offer for a given unloaded Q a reduction in size of 50% or more. The filters consist of mono-blocks of high permittivity ($\varepsilon_r$=45) ceramic with various through holes to realize the complex inter-resonator couplings for both in-line and cross coupled filters. The exterior surface is metallized with conductive ink. Experimental results are presented for a chebyshev design with EM simulations for more complex designs.

## II. CERAMIC WAVEGUIDE RESONATOR

Consider the resonator shown in Fig.1 (ii), consisting of a solid rectangular block of high permittivity ceramic, with the exterior metalized. The resonant frequency and Q-Factor of waveguide modes are readily computed from [2]. For the fundamental $TE_{101}$ mode, as the dielectric constant is increased then the physical dimensions and unloaded Q decrease as $\sqrt{\epsilon_r}$ [3].

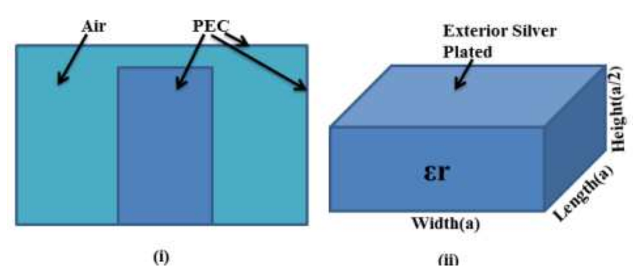


Fig. 1. (i) Coaxial Resonator (ii) Ceramic waveguide Resonator

A numerical simulation of a comparison between an air filled coaxial resonator (Fig.1) and the ceramic waveguide resonator for a resonant frequency of 1GHz is shown in Fig.2.

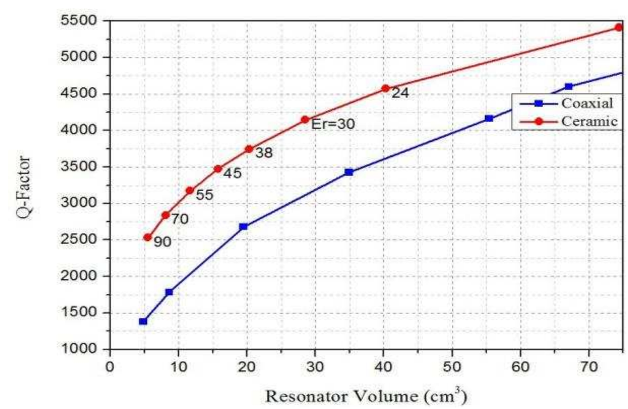


Fig. 2. Q vs Volume comparison between comb-line coaxial and ceramic waveguide resonator

This demonstrates that the dielectric waveguide offers a potential size reduction of 50% when compared with air- filled coaxial comb-line resonators with the same Q-Factor.

## III. CHEBYSHEV FILTER REALIZATION

A six pole ceramic waveguide filter with the following specification was designed using λg/2 resonators separated by metalized holes in ceramic.

| | | |
|---|---|---|
| Centre frequency | : | 1842MHz |
| Bandwidth | : | 75MHz |
| Max Insertion loss | : | 0.7dB |
| Ceramic Permittivity | : | 45 |

The holes provide inductive inter-resonator couplings and the design technique described in [4] may be used. Adjustment in inverter susceptances can be achieved with fixed number of holes of fixed diameter by varying the distance among them [5]. Inductive holes are placed symmetrically across the waveguide broad dimension in order to suppress the higher order modes. The equivalent circuit of a six pole chebyshev ceramic waveguide filter is shown in Fig.3.

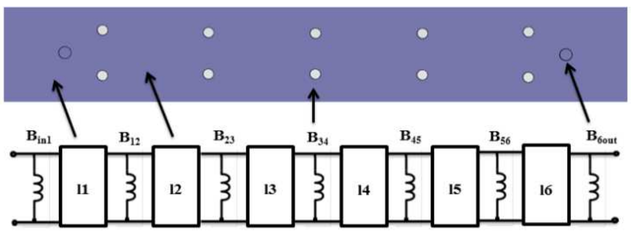


Fig. 3. Six pole ceramic waveguide filter equivalent circuit

The structure is silver plated except for the input /output coupling probe positions. Input /output coupling is achieved using coaxial probes. The probe position from the shorted back end, diameter and depth inside the waveguide determine the amount of coupling achieved, bandwidth and center frequency. Comparison of HFSS simulation and measured filter response is given in Fig.4.

Practical issues for fabrication are; the ceramic material used was Barium titanate with $\varepsilon_r$ = 45 and tan$\delta$ =0.00004. The ceramic was fired and pressed and details were added by machining. The surface finish was 0.5μm. The metallic coating was a silver loaded ink which was sprayed on to the ceramic; it had a conductivity of 4.4x1e7 s/m.

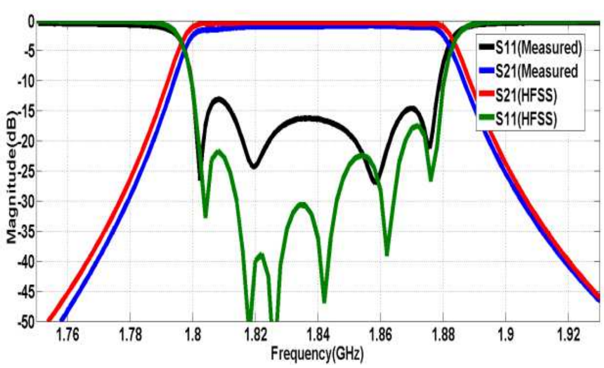


Fig. 4. Six pole chebyshev filter response without tuning screws

Fig.5 shows the closer view of pass band insertion loss of the simulated and measured filter response.

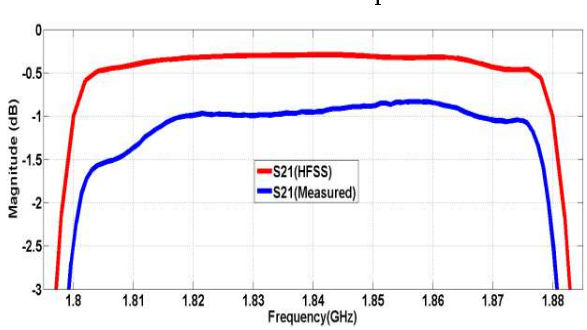


Fig. 5. Six pole chebyshev filter response without tuning screws

Simulations give a resonator Q-factor of 2400 however the measured pass band insertion loss was higher than the simulated loss. This was mainly due to leakage at the input and output and also slightly due to reflection, as there were no tuning screws in the filter. This is being corrected in future designs. A photograph of the fabricated filter is shown in Fig.6.

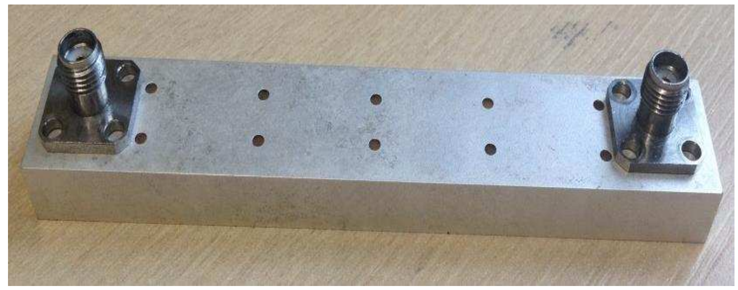

Fig. 6. Fabricated six pole chebyshev ceramic waveguide filter

## IV. Generalized Chebyshev Waveguide Filter with Cross Couplings

A more complex design of a six section cross coupled ceramic waveguide filter operating at DCS uplink frequency was designed using cross coupled triplet to meet the following specifications.

| | | |
|---|---|---|
| Centre frequency | : | 1730MHz |
| Bandwidth | : | 60MHz |
| Max insertion loss | : | 0.7 dB |
| Ceramic Permittivity | : | 45 |
| Rejection | : | 80 dB at 1845MHz |

The coupling matrix for the generalized chebyshev filter was derived with the method described in [6] and is given below.

| | S | 1 | 2 | 3 | 4 | 5 | 6 | L |
|---|---|---|---|---|---|---|---|---|
| S | 0 | 1.0637 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 1.0637 | 0.0054 | 0.8916 | 0.1218 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0.8916 | −0.1642 | 0.6242 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0.1218 | 0.6242 | 0.0284 | 0.5998 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0.5998 | 0.0114 | 0.6324 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0.6324 | 0.0068 | 0.8999 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0.8999 | 0.0054 | 1.0637 |
| L | 0 | 0 | 0 | 0 | 0 | 0 | 1.0637 | 0 |

A transmission zero at the high side of pass band is produced by introducing an inductive cross coupling from resonator 1 to resonator 3 to achieve specified out of band rejection level. In a ceramic waveguide filter all positive cross couplings can be achieved by metal plated through holes. The position of transmission zero above the pass band can be controlled by varying the distance and radius of through holes placed between resonator 1 and 3. The stronger is the cross coupling, the closer is the transmission zero to the pass band.

The input and output couplings are achieved by 50 ohm coaxial probes. The Probe diameter, depth inside the waveguide, its distance from the shorted backend and offset from center determines its coupling bandwidth, power handling and center frequency. Fig.7 shows the final layout of the cross coupled generalized chebyshev filter designed to operate at DCS uplink frequency band.

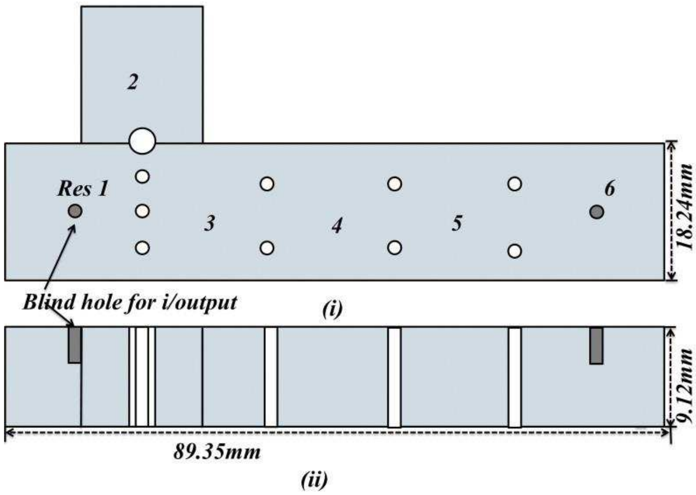


Fig. 7. Generalized chebyshev Cross Coupled ceramic waveguide Filter (i) Top view (ii) Cross sectional view

Fig.8 and Fig.9 show the simulated response of a six section cross coupled ceramic waveguide filter with a transmission zeros at upper side of the pass band.

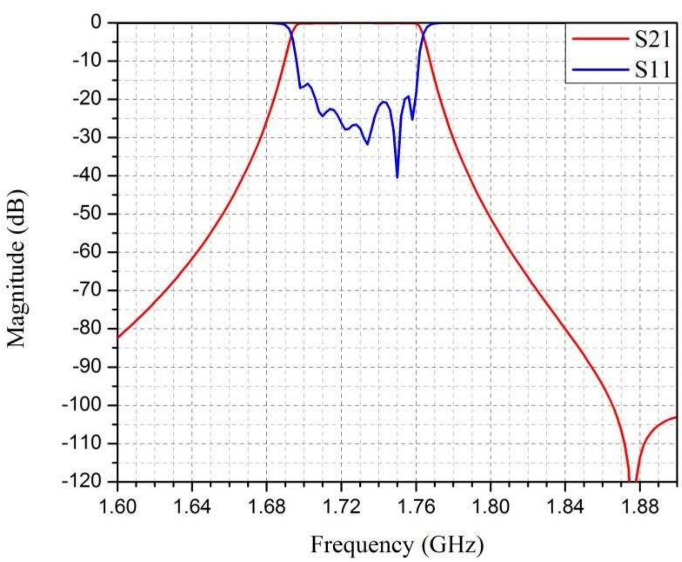


Fig. 8. Cross coupled ceramic filter response (HFSS Simulation)

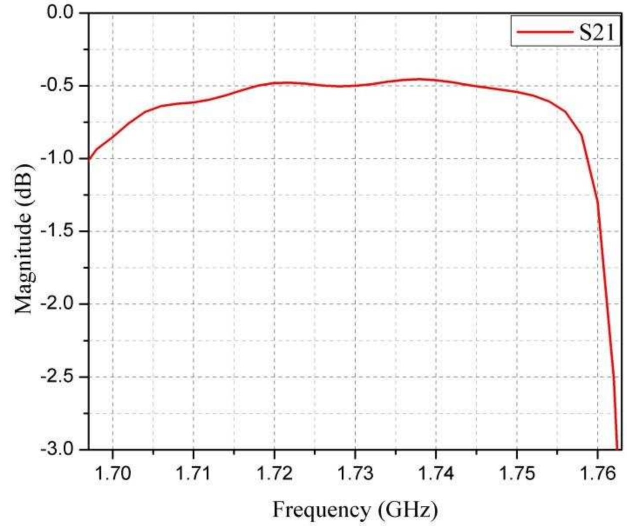


Fig. 9. Cross coupled ceramic filter pass band response (HFSS simulation)

## V. CONCLUSION

The design of miniaturized integrated ceramic waveguide filters is presented in this paper. A monolithic six pole chebyshev and a cross coupled generalized chebyshev ceramic waveguide filter were designed. Potential volume reduction of 50% is achieved as compared to conventional coaxial filters using high permittivity ceramics. Measured results are in good agreement with the simulated results with the one exception of pass band loss where leakage at input and output will be taken account of in future designs. A further publication will address this plus other design aspects including tuning, interfaces, temperature performance and power handling.

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