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Bakr, MS, Luhaib, S and Hunter, IC orcid.org/0000-0002-4246-6971 (2017) A Novel Dielectric-Loaded Dual-Mode Cavity for Cellular Base Station Applications. In: 2016 46th European Microwave Conference. European Microwave Conference 2016 (EUMW), 04-06 Oct 2016, London, UK. IEEE (European Microwave Association) . ISBN 978-2-87487-043-9

https://doi.org/10.1109/EuMC.2016.7824455

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A Novel Dielectric-Loaded Dual-Mode Cavity for Cellular Base Station Applications

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***Abstract*—A new class of dual mode dielectric resonator filter for mobile communication systems is presented. The proposed resonator exhibits high unloaded quality factor and reasonably wide spurious operating window. Based on this cavity, a 4-pole dual-mode Generalised Chebyshev filter is developed and fabricated in the stacked configuration. An unexpected spurious mode is appeared at 2.3 GHz due to improper coupling. A coupling technique for eliminating the unexpected spurious resonance is proposed. The obtained experimental and measured results with an asymmetric transmission zeros confirm the validity of the proposed resonator for releasing filters for cellular-radio base stations.**

***Index Terms*—Dual-mode filters, Dielectric resonator, Cellular-radio base stations, Band pass filters, Miniaturization.**

I. Introduction

The demand of data traffic is increasing rapidly due to the rapid development of smart phones and tablets. Currently, there is an intensive effort to develop the cellular infrastructure to support the rapid data traffic flood initiated by wireless devices. Typical cellular base stations locating their transceivers at the base mast in which they are connected to the antennas at the top mast by long coaxial cables. As a consequence, a significant portion of the signal is attenuated in the lengthy coaxial cables. One way to reduce this significant energy loss is by placing the transceivers at the top mast alongside the antenna. This could be achieved by miniaturizing cellular base station components. Moreover, the increasing need for installing new cellular base stations and co-sitting them with the existing ones will add further constrains on filters [1].

Filters are used to separate the desired electromagnetic signals from unwanted interference. Thus, the biggest challenge for achieving the desired BS configuration is the reduction of microwave filter mass and size without affecting its electrical performance, which is the core objective of this research work. Today, EM simulation is a necessary tool of modern cavity filter design. Complete filter structures can be easily modelled and optimized in the EM domain using an EM simulator, and that significantly reduced the number of hardware prototypes that have to be built and tuned. Infrequently, unexpected spurious couplings might appear in the virtual EM prototypes due to improper couplings. These spurious couplings might appear very close to the fundamental frequency preventing the designer from tuning the filter to the desired response. In addition, such spurious would be difficult and expensive to diagnose after the hardware is built. Recent development in dielectric resonator filters have shown a possibility of significant reduction in size and weight for cellular radio-base station and satellite applications. Further reduction can be achieved through the use of dual-mode dielectric resonators, as reported by Fiedziuszko [2]. Dual-mode bandpass filters possess considerable advantages over conventional TEM or coaxial-line resonators, the usual adopted solution over the years, especially where volume and mass are critical [3].

This paper presents a novel dielectric loaded dual-mode cavity for cellular base-station applications. The proposed configuration offers a significant size reduction, high quality factor and acceptable spurious window. The proposed dual-mode dielectric resonator filter consists of a puck of circular ceramic of high dielectric constant suspended in a cylindrical metallic enclosure and short-circuited from the sidewalls. A four pole filter, with asymmetric response, is realized displaying the validity of the proposed approach. Moreover, a new coupling configuration to suppress the unexpected spurious coupling for dual-mode dielectric loaded cavity structures is proposed. The origin of the spurious resonance can be divided into two categories: the first one is believed to be generated by the improper input/output couplings while the other type of spurious resonance is generated by higher order resonant modes in the filter cavity.

II. The Dual-Mode Ceramic Resonator Cavity Structure and Resonance

A side view schematic of the proposed cavity is reported in figure 1. The proposed dual-mode dielectric loaded cavity structure is based on circular waveguide where TE_{11} is exploited. It consists of a puck of circular ceramic of high dielectric constant suspended in cylindrical metallic enclosure, waveguide cavity below cut-off, and short-circuited from the sidewalls miniaturizing the filter size significantly while maintaining a good electrical performance. Firstly, the resonator higher order modes are obtained by using a full-wave EM simulator applying Eigen mode solution.It is seen in table I that the unloaded resonator exhibits a fundamental resonant frequency of 1.87 GHz with Q_u of 4846 and a spurious separation of 760 MHz between the fundamental frequency and the first higher order mode.

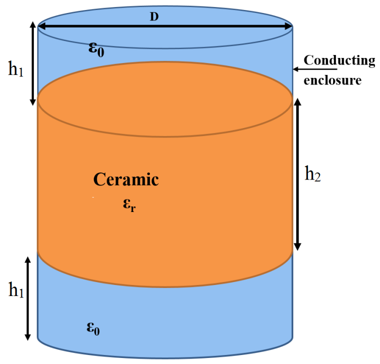
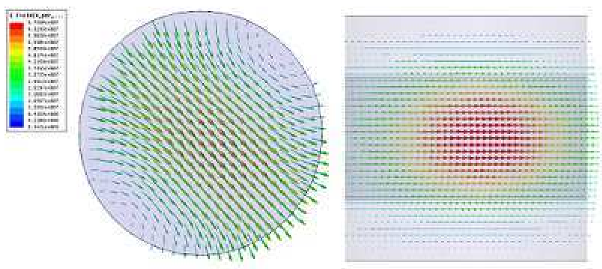


Fig. 1. The proposed DR cavity configuration.

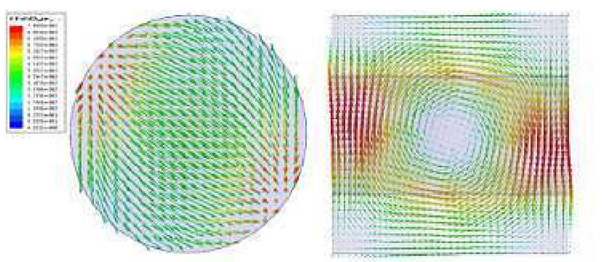
TABLE I
FIRST SIX RESONANT MODES OF THE PROPOSED DIELECTRIC PUCK

Mode N0.	Name	Frequency(GHz)	Quality factor
1	TE_{11}	1.87	4846
2	TE_{11}	1.87	4846
3	TE_{21}	2.63	4519
4	TE_{21}	2.63	4519
5	TM_{01}	2.78	6951
6	TE_{01}	3.16	8749

The field patterns for the orthogonal polarised degenerate TE_{11} mode is shown in figure 2.



(a)



(b)

Fig. 2. Field distribution of TE_{11} dual mode (a) E-field plots (b) H-field plots

Coupling between these two orthogonal degenerate modes can be achieved by presenting a proper field perturbation positioned at 45^0 with respect to the direction of the orthogonal polarized fields. Perturbation is possible by introducing a hole or a slot within the puck or using a tuning screws located vertically or horizontally in the DR surroundings.

III. The Dual-Mode Ceramic Resonator Cavity Coupling

The coupling between the two orthogonal TE_{11} degenerate modes is realized by using screws or through holes at 45^0 with respect to the polarization axis. Input/output coaxial probes and intra-cavity coupling screws are located with near approximate distance to the dielectric resonator since most of the EM field is confined within the dielectric resonator, a ceramic of ϵ_r=45 and tangential loss of 0.00004 is used. Figure 3 shows the coupling configuration using coaxial probes for input/output coupling.The coupling values can be controlled by adjusting the dimensions and penetration depth of input/output coupling probes and inner-cavity coupling by means of screw or through-holes.

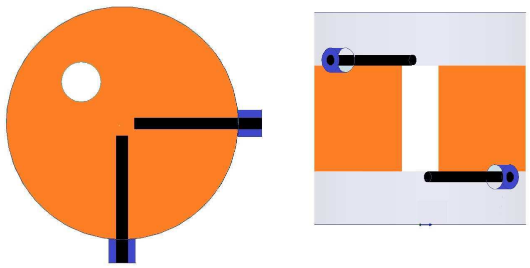


Fig. 3. Two-pole dual-mode filter structure

IV. Filter Design

The simulated response of the fourth order dual-mode bandpass filter in stacked configuration is presented in figure 5. The coupling between the two cavities is achieved by using a metallic wire for intra-cavity coupling since the field decays with near approximate distance from the puck as shown in figure 4.

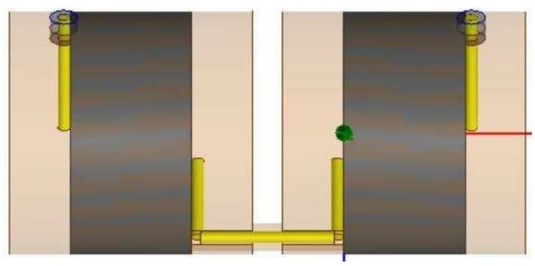


Fig. 4. Four-pole dual-mode filter structure in stacked configuration

The simulated response exhibits a BW of 58 MHz at 3 dB and insertion loss of less than 0.2 dB. Furthermore, it is observed in figure 5 that an unexpected spurious resonance is appeared at 2.3 GHz, non-existent in the results obtained from Eigenmode solver HFSS, very near to the fundamental frequency. It is believed that the appearance of this unexpected resonance is due to the improper coupling technique used.

Figure 6 shows the non-existence of the aforementioned spurious coupling when loop-current is used for input/output couplings. However, the in-band performance is poor due to the insufficient coupling provided since most of the elecomagnetic field, in particular the E-field, in confined in the middle of the dielectric puck as shown in figure 2.

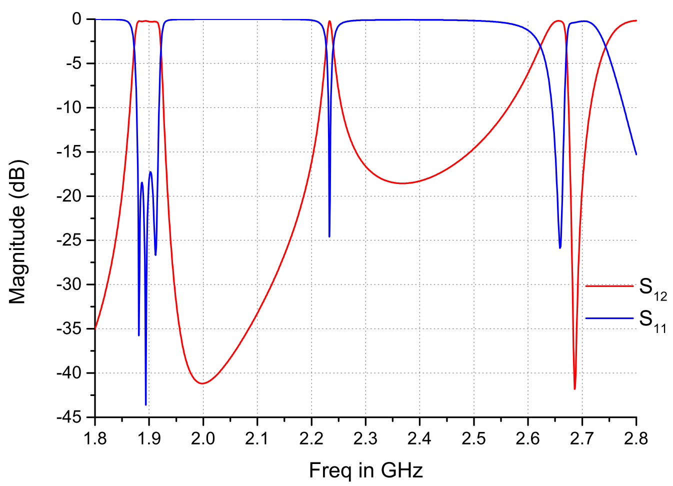


Fig. 5. Four-pole dual-mode filter simulated response in stacked configuration

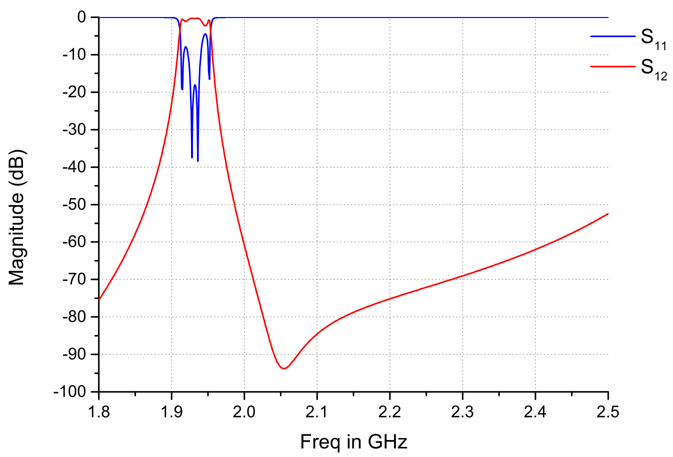


Fig. 6. The proposed filter response, loop-current I/O coupling

V. Transmission Zeros Realisation

The proposed filter offers a simple implementation of generalized Chebyshev response where transmission zeros are required on high/low side of the passband, typical for providing high isolation between adjacent channels in cellular basestations. Transmission zeros can be realized by creating a multipath between the non-adjacent resonators, cross-coupling, to produce destructive interference at finite desired frequencies increasing the filter selectivity. This is achieved by means of changing the angle between input/output couplings and intracavity couplings [4]. The obtained asymmetric response is presented in figure 7.

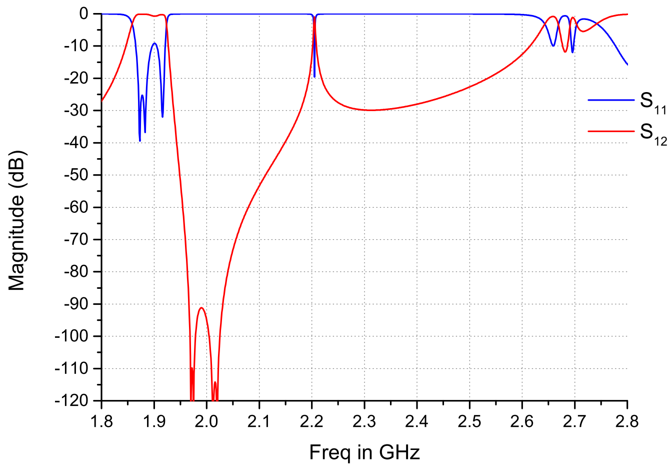


Fig. 7. Four-pole dual-mode filter simulated response with four transmission zeros on the upper passband edge

VI. The Proposed Approaches for the Suppression of the Unexpected Spurious

The basic goal is to improve the rejection band performance by suppressing the unexpected spurious related to improper input/output couplings. In the following, a brief description of two proposed approaches to improve the upper stop band performance is provided.

A. First Approach

This approach considers replacing the air-filled through hole for coupling between the two orthogonal TE_{11} degenerate modes by a dielectric-filled through hole. The dielectric constant of the dielectric-filled through holes is optimized from to 49 by a step-width of 7. This resultant in suppressing the unexpected spurious coupling by loading the resonator subduing the unexpected coupling as shown in figure 8. Tuning screws can be used to compensate the shifting in the center frequency when this approach is considered.

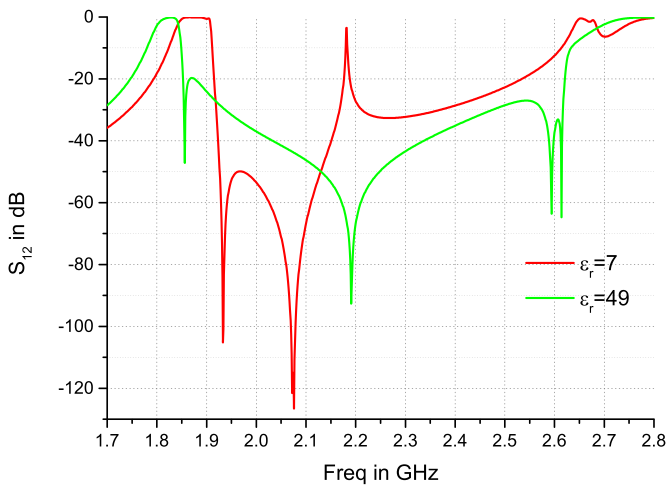


Fig. 8. Filter response of the coupling technique proposed in approach 1

B. Second Approach

In this approach, a new coupling technique is used to suppress the unexpected resonance at 2.3 GHz. A three through half-circle slots at the resonator edges are introduced as follow: a slot at 45^0 for coupling between the two orthogonal modes. In addition, another two slots are introduced close to the input/output and intra-cavity couplings in order to minimize the effect of the unexpected resonance due to improper coupling by benefit from the capacitance effect produced. The simulated response can be seen in figure 9.

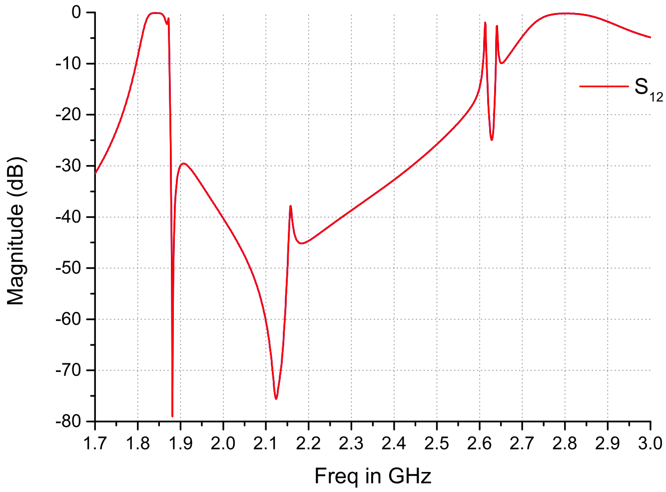


Fig. 9. . Filter response of the coupling technique proposed in approach 2

VII. Experimental Results

A copper prototype cavity of height of 45 mm and diameter of 30 mm has been fabricated. The dielectric resonator was chosen with ceramic material ($\epsilon_r = 44 - 45$) and tangent loss of 4×10^{-5}, shown in figure 10.

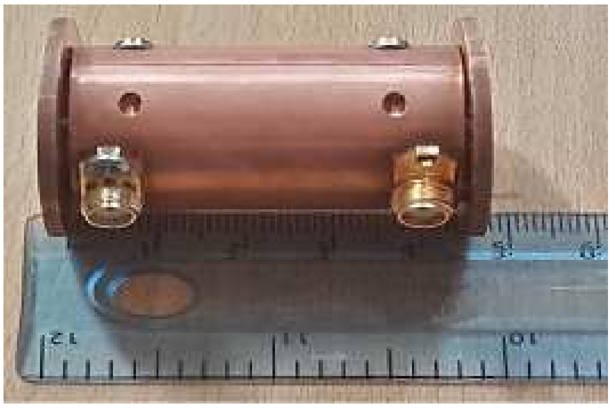


Fig. 10. Fabricated 4th degree dual-mode bandpass filter

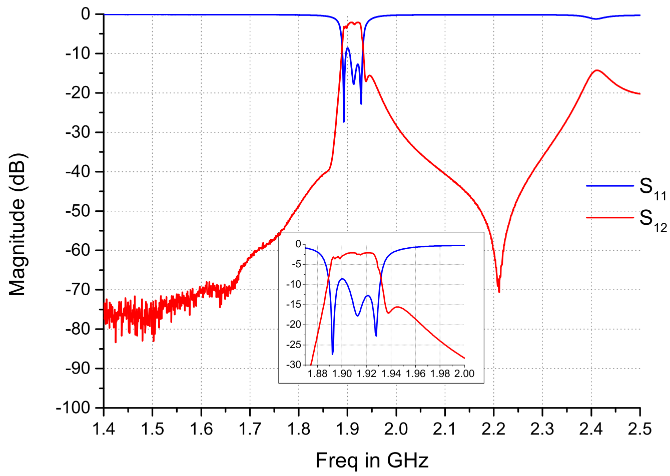


Fig. 11. Measured response wide spurious window

The measured result exhibits a 13 MHz increase in the center frequency, due to the damage caused to the ceramic puck during fabrication, and has an insertion loss of 2.1 dB mainly related to the imperfect contact between the ceramic puck and the cavity walls, fabrication tolerance. This can be improved by retesting the filter with undamaged ceramics, using silver probes/wires for Input/Output and intra-cavity couplings with accurate dimensions, and ensure a nearly perfect contact between the ceramic puck and the cavity walls. In addition, two transmission zeros are add at 2.2 enabling asymmetric response at the passband upper edge. The measured response is presented in figure 11. Finally, the fabricated filter is currently being optimized to obtain better results. In addition, the use of iris for intra-cavity coupling is being investigated.

VIII. Conclusion

The novel dielectric-loaded dual-mode cavity filter for cellular-base station applications with good electrical performance in simple miniaturized inexpensive structure is described in this paper. The proposed cylindrical cavity consists of a circular ceramic puck of high permittivity suspended in a cylindrical metallic enclosure and short-circuited from the sidewalls. The proposed resonator exhibits high unloaded quality factor and reasonably wide spurious operating window. Based on this cavity, a 4-pole dual-mode Generalised Chebyshev is developed and fabricated in stacked configuration. Two approaches are proposed to suppress the appearance of unexpected resonance due to improper couplings. Transmission zeros are added at arbitrary frequencies to improve the stopband attenuation performance. The obtained experimental and measured results confirm the validity of the proposed resonator for releasing filters for cellular-radio base stations.

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