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Miniature Triple-Mode Dielectric Resonator Filters

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***Abstract*—This paper presents a new class of triple mode dielectric resonator filters. These devices use dielectric-loaded cavities with unloaded Q-factor of 3000-5000 and reasonable spurious free window. The proposed structure is less than one quarter of the physical volume of TEM filters of the same Q. A finite element method solver for electromagnetic structures (HFSS) is used to study the main properties of this resonator. Fundamental design rules for a bandpass filter have been presented. A three pole bandpass filter was designed, fabricated and measured to verify the proposed approach.**

***Index Terms*—Miniature filters, triple-mode filters, dielectric resonators.**

I. Introduction

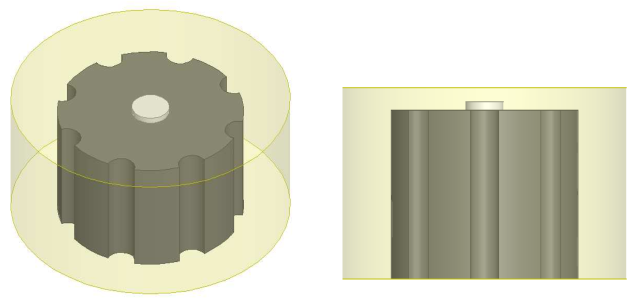
The continuous development of modern telecommunication systems drives the needs for more efficient use of the limited available RF spectrum. Wireless systems require compact filters with stringent electrical performance to replace the traditional bulky TEM filters. Dual and multi-mode dielectric resonator filters are finding increasing interest because of their good temperature stability, low loss and compact size.

In 1951, Li introduced the first multi-mode cavity microwave filters [1]. Since then, many filter designs employing dual and triple mode resonators have been reported. In [2], [3], [4], cubical and spherical structures were proposed to design triple mode resonators, in which triply degenerate resonances occur is three dimensions. Another approach was reported in [5], [6] where the geometry of the resonator is optimised to obtain three degenerate modes e.g. HE and TM modes. In this paper, the latter approach is followed.

II. Triple-Mode Dielectric-Loaded Cavities

In this paper, a novel miniature triple mode dielectric resonator filter that is suitable for base radio station applications is presented. The filter uses a triple mode dielectric-loaded cavity structure (Fig. 1). A significant size reduction is achievable compared to TEM filters, less than one quarter of the physical volume, with the same unloaded Q. The resonator consists of a longitudinally grooved cylindrical ceramic puck that is placed inside a metallic housing. The lower flat surface of the ceramic puck is in direct contact with the base of the metallic housing. A finite-element method field simulator (HFSS) is used to study the E and H-field patterns of the first three modes of the resonator.

The metallic housing height is chosen to be slightly larger than the puck height. The effect of reducing the cavity height is to drive the TM_{01} mode down in frequency while not significantly changing the frequency of the fundamental degenerate HE_{11} mode (Fig. 2). However, it does reduce the Q of the resonator, in particular the TM_{01} mode, as shown in Fig. 3. It is also noted that the E field of the three resonances is maximum near the top flat surface of the resonator where the E field density of the TM_{01} mode is significantly larger than the degenerate HE_{11} mode. This drives down the TM_{01} down in frequency and facilities strong inter-resonator couplings between the three modes, which is required for base-station filters. Likewise, the effect of adjusting the resonator diameter, where the cavity diameter is defined as D=30mm, is presented in Fig. 4. Increase the resonator diameter drives the three modes down in frequency. The unloaded Q of the degenerate mode is significantly improved. It is noticed that the Q factor of the TM_{01} mode is reasonably constant for small D/d ratio as depicted in Fig. 5. The mode and unloaded Q charts are used to design a three-pole bandpass filter using the proposed resonator.



(a) (b)

Fig. 1. Schematic of the proposed triple mode dielectric resonator (a) 3D view (b) cross section view.

III. Filter Design

The proposed structure resonant frequency and Q-factor is mainly determined by the ceramic puck dielectric constant and diameter, and the metallic housing height and diameter. A resonator was constructed with a 20mm diameter and 10mm height of ceramic puck with permittivity of 44 and loss tangent of 4×10^{-5} in a cylindrical copper cavity with internal dimensions of 30mm diameter and 11.35mm height with electrical conductivity of an $4{\times}10^7$ S/m. The fundamental frequency was 2.5 GHz with unloaded Q of 3800. The first

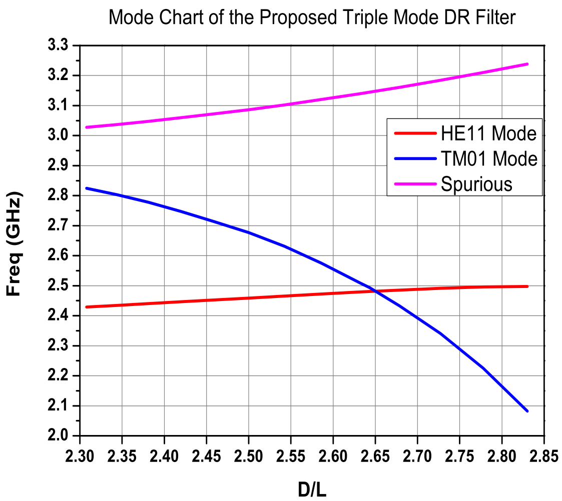


Fig. 2. Mode chart of the triple mode structure as a function of the cavity diameter (D) to the cavity height (L) where D=30mm.

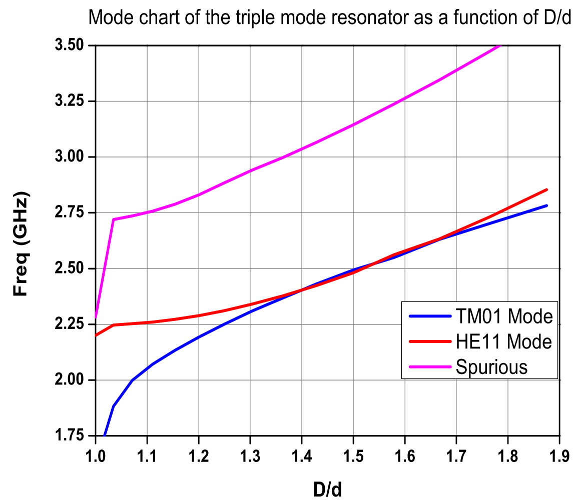


Fig. 4. Mode chart of the triple mode structure as a function of the cavity diameter (D) to the ceramic puck diameter (d) where D=30mm.

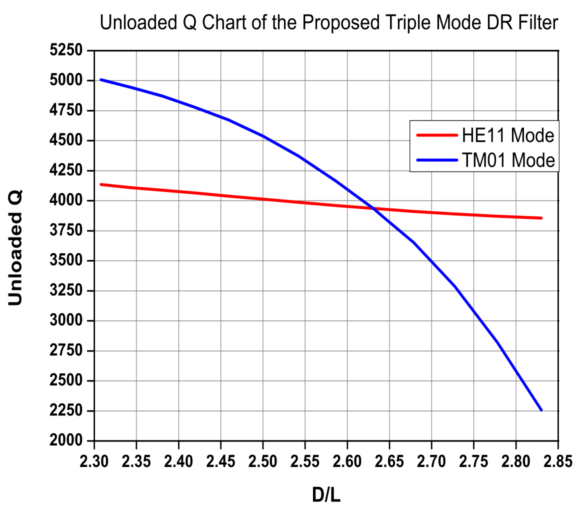


Fig. 3. Unloaded Q chart of the triple mode structure as a function of the cavity diameter (D) to the cavity height (L) where D=30mm.

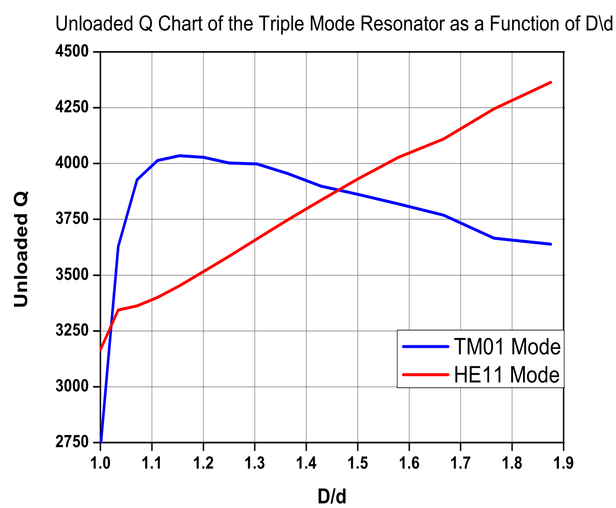


Fig. 5. Unloaded Q chart of the triple mode structure as a function of the cavity diameter (D) to the ceramic puck diameter (d) where D=30mm.

spurious mode happened 650 MHz above the fundamental resonances.

TABLE I
RESONANT FREQUENCIES AND COUPLING COEFFICIENTS OF THE 3-POLE FILTER

Resonant Frequency (GHz)	Coupling Coefficient (MHz)	Non-Adjacent Coupling Coefficient (MHz)
f_1 = 2.48	R_{i1} = 45.44	M_{13} = 33.71
f_2 = 2.5	M_{12} = -2.03	M_{i3} = -32.51
f_3 = 2.52	M_{23} = 33.71	M_{o3} =-32.51
	R_{o2} = 45.44	

The individual coupling needed to design a three pole bandpass filter may be better understood by looking at the E-field of each of the triple modes. A schematic diagram of the input and output couplings and frequency tuning mechanism is shown in Fig. 6. The height of the input and output coupling posts are close to the height of the cavity to enable correct couplings to the first three modes, mainly TM_{01} mode. Longitudinal grooves are placed symmetrically around the circumference of the ceramic puck to facilitate stronger coupling from input and output to three modes, mainly the degenerate HE_{11} modes. The internal coupling between the degenerate HE_{11} mode is negligible as the structure is symmetric and no discontinuity is introduced to perturb the degenerate mode. However, strong couplings

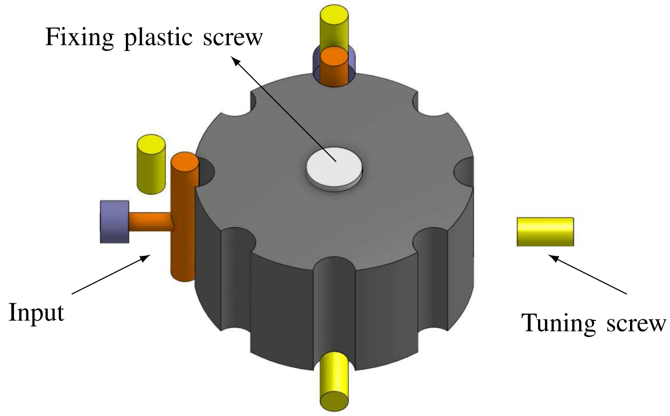


Fig. 6. Schematic of the input/output coupling structure.

between the degenerate HE_{11} mode and TM_{01} mode seem to exist. This provides cross couplings realising two real frequency transmission zeros. The filter coupling scheme can be represented as two cascaded triplets as shown in Fig.8. The resonant frequency and the coupling coefficients between adjacent and non-adjacent resonators is shown in table I.

A prototype bandpass filter has been designed, fabricated and measured to validate the proposed approach. The basic specification was chosen as 50 MHz ripple bandwidth at 2.5 GHz centre frequency with insertion loss less than 0.17 dB and out of band rejection of 25 dB at 2.46 GHz. A three pole generalised Chebyshev filter with two real frequency transmission zeros on the lower side is required to meet the chosen specifications. The prototype was synthesised as two cascaded triplets as shown in Fig. 7. The frequency response of the synthesised and EM simulation is shown in Fig. 8. A photograph of the fabricated prototype is shown in Fig. 9. The measured frequency response is shown in Fig. 10. The filter response was measured as a function of temperature in the range 15 to 65 C°. The total frequency deviation with temperature was only 0.4 MHz.

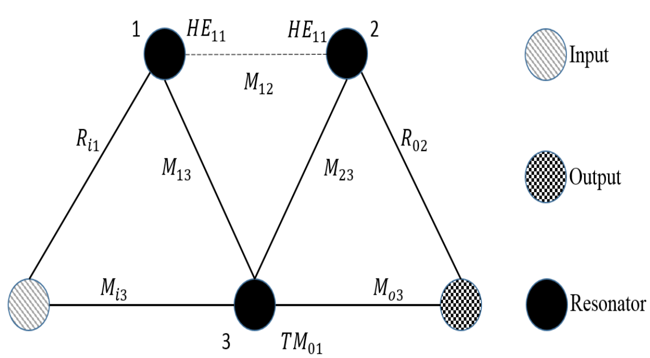


Fig. 7. Coupling Scheme of the proposed triple mode filter.

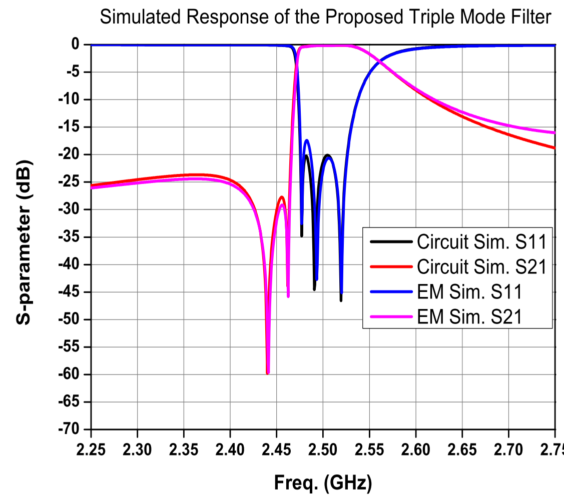


Fig. 8. Frequency response EM vs circuit simulation.

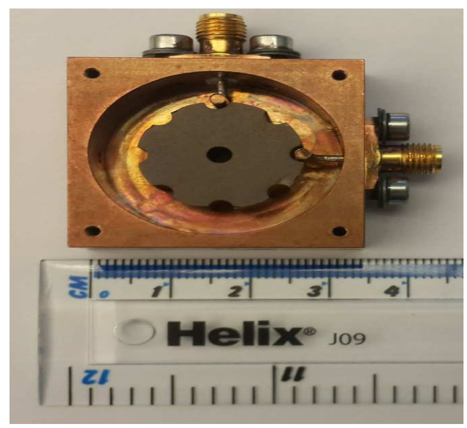


Fig. 9. Fabricated three-pole triple mode dielectric filter.

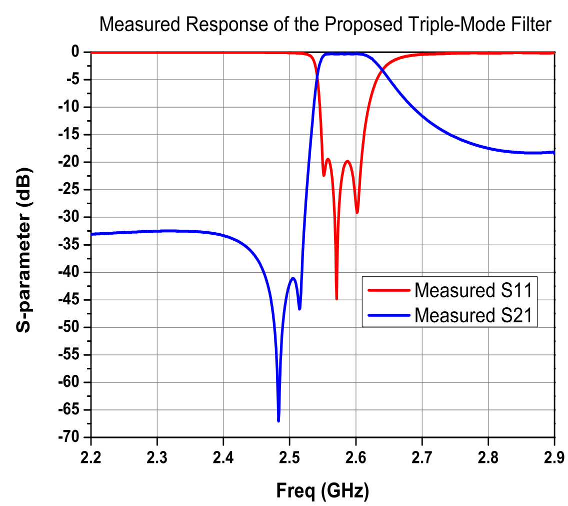


Fig. 10. Measured frequency response of the three-pole triple mode filter

IV. Conclusion

A new class of triple-mode dielectric resonator filters has been described. They offer the advantages of significant size reduction, less than one quarter, when compared with TEM filters. The spurious free response of the proposed filter is good, i.e. the first spurious mode happened 650 MHz above the fundamental resonances. The filters can be implemented as cascaded triplets enabling the realisation of real-frequency transmission zeros. A prototype bandpass filter has been designed, fabricated and tested validating the proposed approach. A detailed study of these devices is being carried out to build filters with high orders, and controllable bandwidth and real frequency transmission zeros. In addition, a detailed study to analyse the power-handling capability of the proposed filter is being carried out.

Acknowledgment

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