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Dual-Mode Dual-band Conductor-Loaded Dielectric Resonator Filters

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***Abstract*—A new class of dual-mode dual-band microwave filters is presented. Conductor-loaded dielectric resonators are used as a basic building blocks for these devices. The proposed resonator enables the realization of microwave filters with unloaded quality factors of 1000-4000 with good spurious performance and significant reduced size, e.g. less than the half physical size, compared to TEM filters. The basic properties of the proposed resonator have been studied and examined with the help of a finite element method solver (HFSS2015). A design example of a dual-mode dual-band bandpass filter with maximum transmission zeros for mobile communications is developed.**

I. Introduction

Emerging wireless communication technologies demand compact RF/Microwave systems with acceptable electrical performance. This enables the deployment of larger number of cellular base stations to meet the increasing demand of high data traffic. Therefore, various filter designs have been introduced in the past years to replace bulky microwave filters such as combline and single-mode dielectric resonator filters [1] [6]. Multi-mode dielectric resonator filters have been received a great attention in academia and industry due to their attractive feature of enabling further size reduction while maintaining good electrical performance.

The concept of dual-mode dielectric resonator filter was first coined in 1980 [1]. Ever since, several filter designs utilizing dual, triple and quad mode resonators have been presented [2] [6]. One of the reported dual-mode resonators was done by Hunter et al. [3], a conductor loaded dielectric resonator placed in a metallic housing was studied. To drive the fundamental frequency down while maintaining a good unloaded quality factor, the bottom and top surfaces of the cylindrical ceramic puck were short-circuited by the metallic housing and disc respectively enabling significant size reduction compared to TEM filters. On the other hand, Memarian et al. [6] studied the possibility of obtaining dual-band filters using the half-cut cylindrical dielectric resonators in which the orthogonal degenerate modes are separated to realize dual-band resonator filter with independent control of each band center frequency maintaining good electrical performance and compact size. However, to the author knowledge, dual-mode dual-band dielectric resonator filters have not been studied in the literature.

In this paper, a new class of dual-mode dual-band conductor-loaded dielectric resonator filter is presented. The basic resonator structure is based on the work presented by Hunter et al. [3]. The reported resonator structure is modified to obtain dual-mode dual-band resonators within the same cavity size. The proposed resonator exhibits compact size with acceptable electrical performance. To the author knowledge, this is the first time to highlight the possibility of attaining dual-mode dual-band dielectric resonator structure with compact size and high unloaded quality factor.

II. Dual-Mode Dual-band Conductor-Loaded Dielectric Resonator

Fig. 1 shows the configuration of the new class of dual-mode dual-band conductor-loaded dielectric resonator.

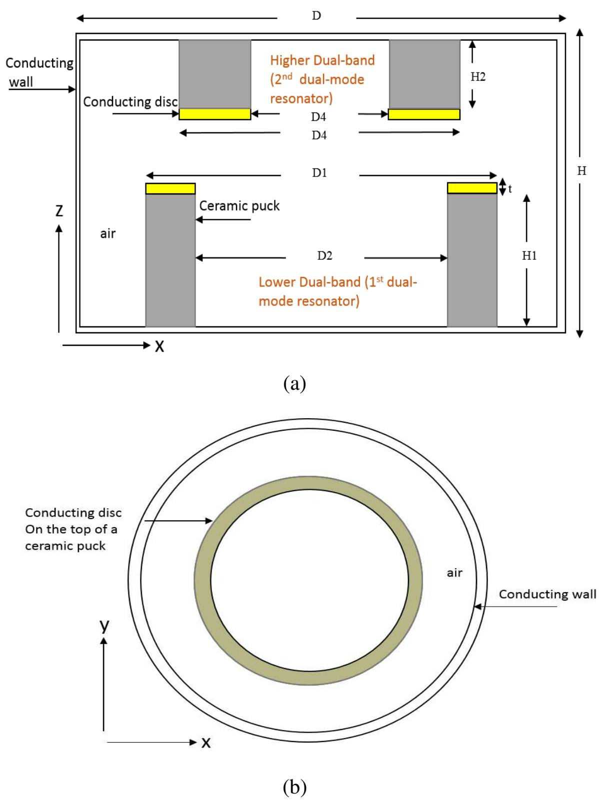
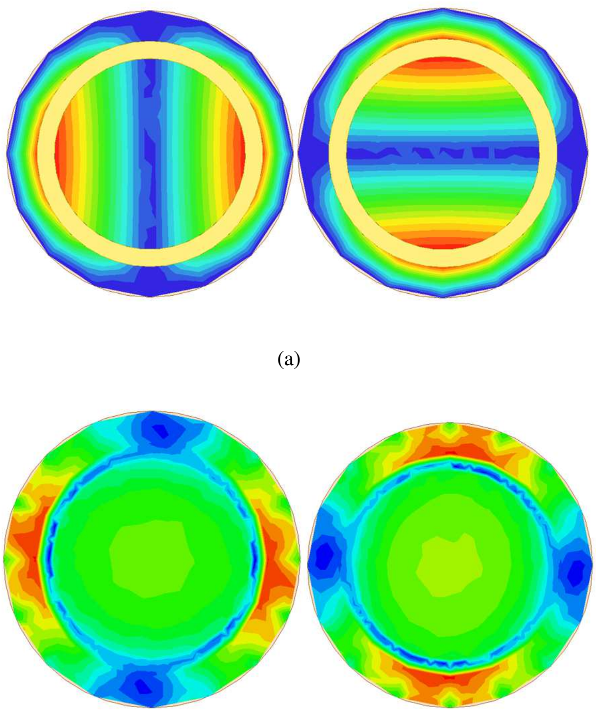


Fig. 1. Dual-mode dual-band conductor-loaded dielectric resonator (a) cross-section view. (b) Top view.

The proposed resonator consists of two cylindrical ceramic pucks aligned on the z-axis opposite to each other. The top flat surfaces of the two ceramic pucks are coated with a metallic disc while the bottom flat surfaces are short-circuited by the base of the cylindrical metallic housing. The fundamental resonances of the ceramic pucks is the orthogonal HE_{11} mode (TM_{11} like-mode) due to the presence of the metallic discs on the top surfaces of the ceramic pucks. The consequence of the presence of the metallic disc is to drive the fundamental resonance down with no significant effect on the higher order modes. In order to drive the fundamental frequency further down, a circular hole is introduced in the metallic disc as shown in Fig. 1. This leads to degrade the resonator the unloaded quality factor. The resonator spurious performance is significantly improved by introducing a circular hole in the middle of each dielectric puck since the E field of the fundamental resonances are nearly zero along the axis. The resonant frequency of each dual-band is mainly determined by the permittivity and diameter of the dielectric puck and metallic disc since the E field of the fundamental modes are maximum near the disc circumference, see Fig. 2(a).



(a)

(b)

Fig. 2. (a) Electric and (b) Magnetic field distribution of the fundamental modes across the transverse plane (x-y plane) at the interface between the dielectric puck and metallic disk.

On the other hand, the unloaded quality factor is mainly determined by the ceramic puck height, the diameter of the circular hole in the metallic disc and the cavity diameter. It is worthy to note that by optimizing the aforementioned parameters to increase the Q_u, the spurious performance may significantly degrade. Therefore, a trade-off between the resonator unloaded quality factor and spurious performance must be made. The concept of dual-mode dual-band filter is attainable because of the absence of E field along the resonator axis. This enables the designer to mirror the dielectric resonator configuration in the same cavity introducing another band without increasing the cavity size. The fundamental resonance of each dual-band is mainly controlled by the ceramic puck permittivity, diameter and the metallic disc diameter, as depicted in Fig. 1(a). This facilities independent control of each dual-band center frequency and unloaded quality factor. Table I shows the first five resonant modes of the proposed resonator. In the following section, a design example is presented to demonstrate the validity of the proposed concept.

TABLE I
THE FIRST FIVE RESONANT MODES OF THE PROPOSED RESONATOR

Mode No.	Single or Dual	Name	Resonant Frequency (GHz)	Unloaded Quality factor Q_u
1	Dual	$HE_{11\delta}$	1.953	2189
2	Dual	$HE_{11\delta}$	2.306	2026
3	Dual	$HE_{21\delta}$	3.382	2979
4	Dual	$HE_{21\delta}$	3.541	3147
5	Single	TE_{011}	4.157	5371

III. FILTER DESIGN

The proposed dual-mode dual-band resonator was built using ceramic pucks of permittivity of 43 and tangent loss of 4×10^{-5} in a copper cavity of D=30mm and H=22mm. The silver-plated metallic discs were 11.8mm (D1) and 8mm (D4) in diameter respectively with 2mm thickness (t) to reduce the current loss in the disc edges. The fundamental frequency of each one of the dual-bands was 1.953 GHz and 2.306 GHz with unloaded quality factor of 2189 and 2026 respectively. The first spurious window was the $HE_{21\delta}$ mode and this occurred 1.43 GHz and 1.08 GHz respectively above the fundamental resonances. The circular hole along axis of the ceramic pucks were 10mm (D2) and 6mm (D4) with height of 12mm (H1) and 4mm (H2) respectively. The first five modes, their resonant frequencies and unloaded quality factors can be seen in Table I. In addition, the electric and magnetic field distribution of the fundamental resonance of each band across the transverse plane (x-y) is shown in Fig. 2.

In this design example, the coupling between the orthogonal dual-mode of each band is achieved by introducing a slot in the metallic disc at $45°$. In order to increase the coupling bandwidth between the two orthogonal modes, the slot depth may be increased. The input and output coupling configuration is depicted in Fig. 3. It can be represented as capacitive probe configurations with shunt inductances utilizing the strong radial E field near the disc's circumferences. This enables the correct input-output coupling to the two bands without the need for tuning screws. In addition, maximum number of transmission zeros are obtained due to the direct coupling between the input/output probes and cross coupling between the orthogonal modes of the dual-band.

The designed dual-mode dual-band bandpass filter prototype exhibits a bandwidth (at 3-dB) of 2% and 1.2% at 1.92 GHz

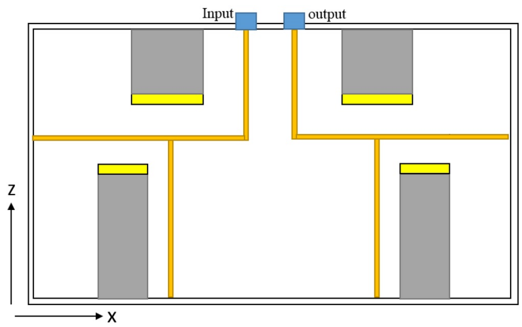


Fig. 3. Input-output coupling mechanism.

and 2.2 GHz respectively with insertion loss 0.23 dB and 0.47 dB respectively. The designed prototype has maximum number of transmission zeros (four transmission zeros) with one transmission zero on the low and high sides of each band enabling a high rejection band performance. The simulated response of designed dual-mode dual-bands bandpass filter is shown in Fig. 4. In addition, the wide spurious performance of the bandpass filter is depicted in Fig. 5.

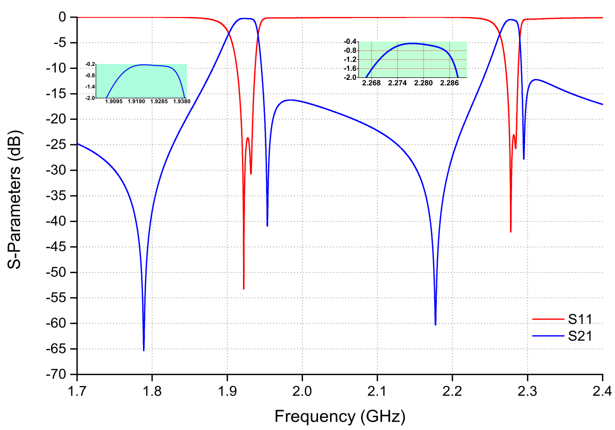


Fig. 4. Simulated response of prototype filter.

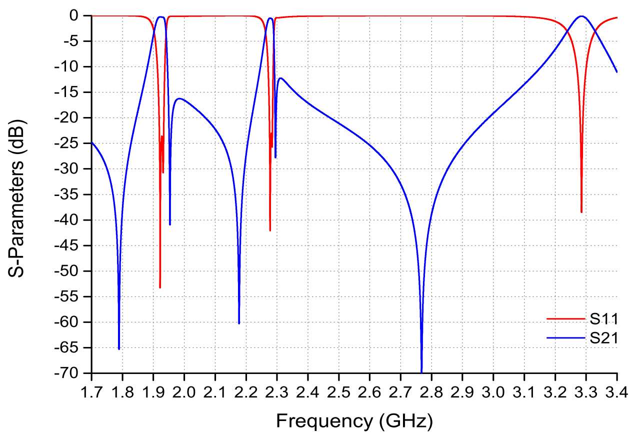


Fig. 5. Simulated spurious performance of prototype filter.

IV. Conclusion

A new class of dual-mode dual-band conductor-loaded dielectric resonator filter has been studied. This resonator enables the realization of compact filters with acceptable unloaded quality factor utilizing the dual-mode dual-band feature. In addition, the spurious window performance is very good. A prototype filter has been developed demonstrating the importance and applicability of the proposed resonator for mobile communications. Finally, the measured results of the presented prototype will be available soon and a detailed study of the structure is being conducted for building higher order filters.

V. Acknowledgement

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