

Miniaturized Dual-Band TM-Mode Dielectric Filter and Its Reconfiguration Capabilities

Abdulrahman Widaa^{#1}, Michael Höft^{#2}

[#]Chair of Microwave Engineering, Kiel University, Kiel, Germany

{¹aw, ²mh}@tf.uni-kiel.de

Abstract—A new miniaturized C-band dual-band dual-mode filter is reported in this paper using TM mode dielectric resonators. The filter is realized in planar topology to offer easy tuning and assembly for the applications of reconfigurable filters. High isolation between the two channels is obtained through the introduction of an inter-band transmission zero. Also, two asymmetrical transmission zeros are generated to enhance the out-of-band rejections. Both passbands can be tuned either simultaneously at the same time, or independently. A two-pole dual-band dual-mode TM dielectric filter is designed, implemented, and measured with the investigation of its tuning capabilities.

Keywords—Bandpass filter, dual-band, dual-mode, dielectric resonator, tunable filter.

I. INTRODUCTION

Dual-band bandpass filters (DBBPFs) have received growing demand in recent years with the exponential development in multi-standard, multi-band communication systems [1]. In the same context, the proposal of tunable dual-band bandpass filters is of focal importance for future frequency-agile and software-defined radios [2]. Those applications have strict requirements of high-performance, low-loss, and compact dual-band filter structures with reconfigurable frequency plans. Unfortunately, despite planar dual-band filters are easy to design and offer very compact structures, they suffer from high losses and limited power handling capabilities. On the other side, empty waveguide structures have key features of high unloaded quality factor (Q_u) and high-power performance. Nevertheless, their large, bulky size makes them an unfavourable solution for the design of miniaturized fixed/tunable dual-band filters.

Considering the above drawbacks of planar and waveguide configurations, dual-band dielectric bandpass filters are getting increasing attention because of their desirable advantages of high Q_u , compact size, and compatibility with high-power levels. Couple of dual-band dielectric filters were presented in the open literature using different types of dielectric resonators (DRs) with fixed passbands [3]–[7]. Among all, TM mode dielectric resonators offer more compactness, better spurious performance, and mechanically-stable structures. To benefit from these attractive features, [6] presented a highly miniaturized, high- Q_u DBBPF using dual-mode TM mode dielectric resonators in a transversal configuration. Unfortunately, this structure is not suitable for the realization of tunable filters since the resonant frequency cannot be tuned efficiently because the resonators cannot be accessed due to the transversal topology. Therefore, there is an

essential need for alternative compact TM mode DBBPFs suitable for reconfigurable filter designs.

This paper introduces a miniaturized reconfigurable dual-band dual-mode TM mode dielectric filter. Firstly, a new planar configuration of dual-band TM mode filters is presented [7]. Then, the tuning capabilities of the proposed dual-band filter are explored for the applications of tunable filters.

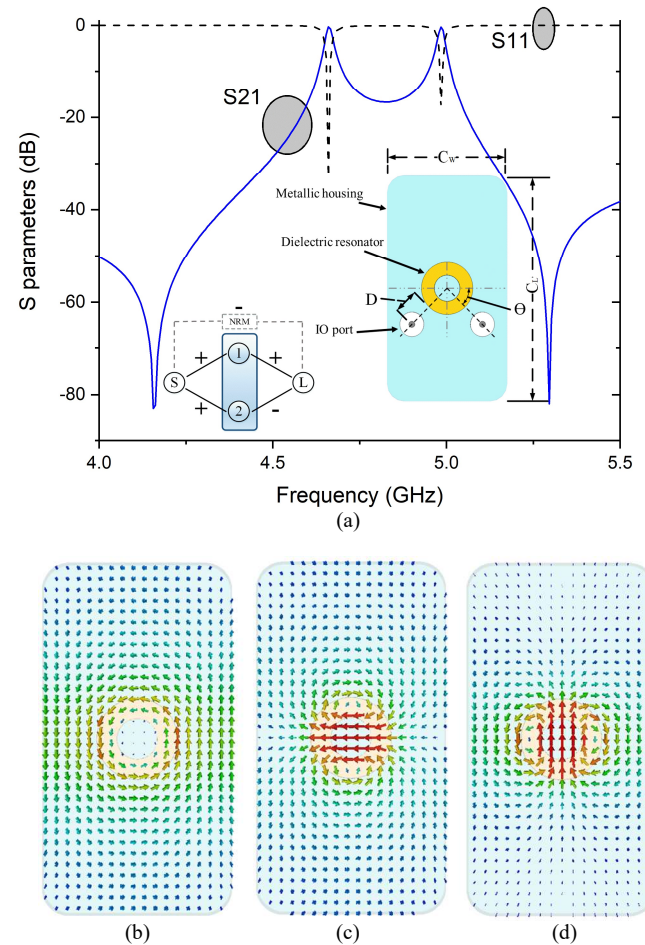


Fig.1. Dual-response TM mode DR cavity. S-parameter response of a dual-band configuration and its corresponding coupling route. Dual-band response is obtained by $C_L > C_W$ ($f_{TM120} = 4.66$ GHz, $f_{TM210} = 4.98$ GHz). Inter-band TZ is introduced (sign change of M_{21} causing a phase reversal). Two TZs are introduced by the mean of the nonresonating TM₁₁₀ mode bypass source-load coupling (NRM). The TM mode dielectric resonator has outer diameter $D = 8$ mm, inner diameter $d = 4$ mm, height $h = 6$ mm, and dielectric constant $\epsilon_r = 45$. (b) H-field, TM₁₁₀. (c) H-field, TM₁₂₀. (d) H-field, TM₂₁₀.

II. CONCEPT AND DESIGN

Originally, TM mode DR filters are designed using the fundamental TM₁₁₀ mode. Recently, the orthogonal degenerate modes TM₁₂₀ and TM₂₁₀ were utilized to design highly miniaturized dual-mode TM mode dielectric filters in [8]. Similarly, the dual-mode response can be changed to a dual-band response by moving any of the orthogonal modes away from the other one. Fig. 1 depicts the basic dual-band dual-mode cavity and its H-field distributions of the fundamental TM₁₁₀ mode, and the orthogonal degenerate modes TM₁₂₀, TM₂₁₀. As shown, each of the orthogonal modes is propagating mainly along one axis of the cavity (TM₁₂₀ along the length axis (C_L), TM₂₁₀ along the width axis (C_W)). Consequently, dual-band response is realized by reducing the width of the metallic cavity (C_W) pushing TM₂₁₀ to a higher frequency. The coupling topology of the dual-band response is represented similar to the conventional doublet structures [9] as shown in Fig. 1(a). Also, the nonresonating TM₁₁₀ mode (NRM) is employed to create a source-load (S-L) coupling path generating two transmission zeros [10]. The IO feeding is realized using SMA probes. The IO feedings are positioned at an angle (Θ) of 45° to excite both modes equally. If Θ < 45°, then the IO pins are more coupled to TM₂₁₀, while they'll be more coupled to TM₁₂₀ in case of Θ > 45°. The coupling strength is adjusted through the angular distance between the resonator and the feeding pin (D).

Interestingly, the orthogonal distribution nature of the fields inside the dual-mode cavity features more frequency tuning flexibility. As can be seen in Fig. 2, tuning screws can be properly positioned to control either both modes simultaneously, or individual modes separately.

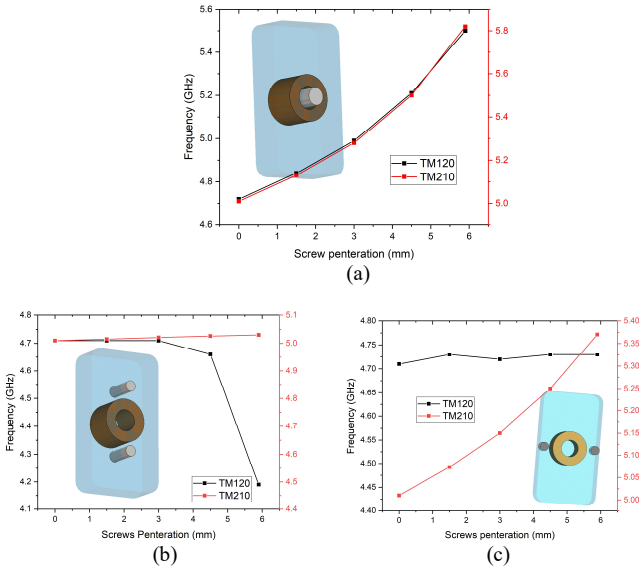


Fig. 2. Relation between TM₁₂₀, TM₂₁₀ modes and tuning screws at different locations. (a). A single tuning screw in the centre. (b). Two longitudinally-positioned screws. (c). Two laterally-positioned screws. Dimensions and specifications are the same as those in Fig. 1.

Similarly, the above dual-response cavity can be expanded to introduce dual-band dual-mode TM mode filters in planar configuration. For example, this section introduces a two-pole

dual-band bandpass filter. The design process begins by defining the required specifications of each band (f_1 , f_2) individually, and extracting the corresponding matrixes using the standard synthesis procedure [11]. Then, the overall matrix is optimized with the inclusion of any additional transmission zeros [7], [10]. Afterwards, the required external quality factors (Q_{ext_1} , Q_{ext_2}) and physical coupling coefficients ($K_{1,3}$, $K_{2,4}$) are calculated using:

$$Q_{\text{ext}_1} = \frac{f_1}{ABW_1 \times (m_{s1})^2}, \quad Q_{\text{ext}_2} = \frac{f_2}{ABW_2 \times (m_{s2})^2} \quad (1)$$

$$K_{1,3} = \frac{ABW_1 \times m_{1,3}}{f_1}, \quad K_{2,4} = \frac{ABW_2 \times m_{2,4}}{f_2} \quad (2)$$

where ABW_1 and ABW_2 are the absolute bandwidth of the first (lower) and second (upper) bands, respectively. The dual-band BPF is designed to operate at 4.46 GHz with absolute bandwidth (ABW_1) of 38 MHz, and 4.82 GHz with 26 MHz of bandwidth (ABW_2). The corresponding coupling route and optimized overall coupling matrix are shown in Fig. 3. Both inter-band and out-band transmission zeros (TZs) are introduced to increase the isolation between the two channels and improve the out-of-band rejection characteristics. The inter-band TZ is realized by inducing a phase reversal between the two modes at the output side ($M_{S2}=M_{4L}$, $M_{S1}=-M_{3L}$). Whereas the nonresonating TM₁₁₀ mode is employed effectively to introduce two asymmetrical TZs at both sides of the dual-band filter without the need for any further cross-coupling setups.

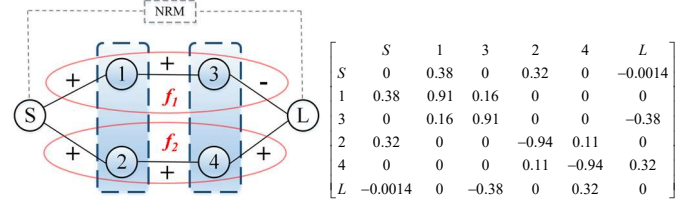


Fig. 3. Coupling scheme of the proposed two-pole dual-band dual-mode TM mode dielectric filter.

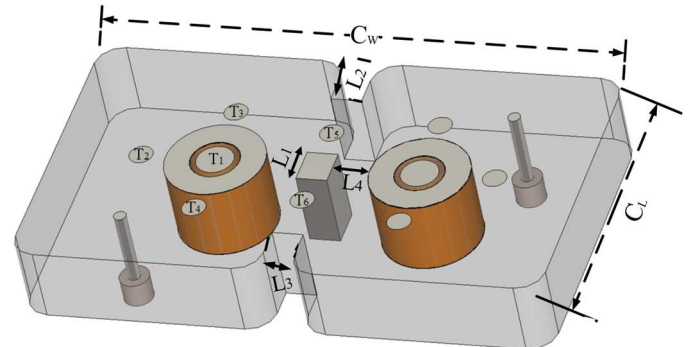


Fig. 4. 3D view of the proposed two-pole dual-band dual-mode TM mode DR filter. Dimensions (in mm): $C_W = 40.5$, $C_L = 26$, $L_1 = 3$, $L_2 = 3$, $L_3 = 2.5$, $L_4 = 3$.

In the next step, the designed dual-band bandpass filter is realized using the proposed planar dual-mode TM mode configuration as shown in Fig. 4. The both orthogonal modes

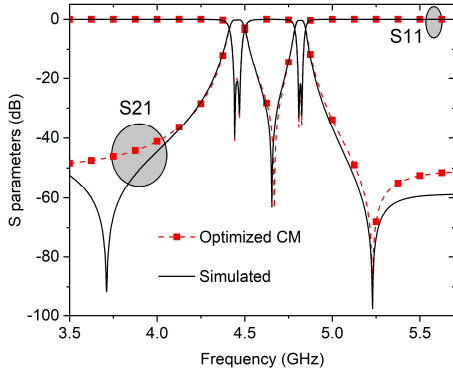


Fig. 5. Simulated S parameters and optimized coupling matrix (CM) of the proposed 2nd-order dual-band dual-mode TM mode BPF.

TM₁₂₀ and TM₂₁₀ are excited simultaneously through inductive feeding pins positioned with an angle $\Theta = 45^\circ$ and angular distance $D = 8$ mm. The lower passband is constructed by the resonating TM₁₂₀ mode, while the upper channel is built through the degenerate TM₂₁₀ mode. The required inter-resonator couplings $K_{1,3}$ and $K_{2,4}$ are obtained using inductive irises with a central inductive post. $K_{1,3}$ is more controlled by L_2 since the TM₁₂₀ is more distributed on the sides, while the post length (L_1) mainly controls the $K_{2,4}$ since it's located at the peak of the TM₂₁₀ fields. This indicates also that the central post is also used to adjust the resonant frequency of the upper channel. Both inter-band and out-band TZs are successfully created. The required change in the sign of M_{3L} to introduce inter-band TZ is obtained by positioning the output feeding pin opposite to the input pin (180° phase change of TM₁₂₀). Similarly, this 180° in the output side creates a negative S-L coupling path through the nonresonating TM₁₁₀ mode generating two asymmetrical TZs.

One of the key motivations behind the proposal of the above planar topology of dual-band TM mode filters is to ease the tuning process for reconfigurable filters applications. It is worth reminding that tuning is more feasible in TM mode DR components than in others. Simple screws/rods (see Fig. 4) can be used to tune both the resonant frequency and bandwidth. T_1 screw is used to tune the resonant frequency of both passbands at the same time. Here, unlike TM₁₁₀ mode, H-field is the maximum in the centre of the DR while E-field is stronger in the surrounding (refer to Fig. 1). This means that the frequency will be shifted up with the intrusion of the tuning element (T_1). Also, considering that the TM₁₂₀ and TM₂₁₀ modes propagate orthogonally to each other, T_3 and T_4 are used to check the independent reconfiguration of the lower passband (TM₁₂₀), and T_2 is utilized to tune the upper passband (TM₂₁₀). In these cases, the frequency will decrease with the insertion of the tuning screw since the E-field is maximum, as mentioned earlier. T_5 , T_6 can be used to tune the inter-resonator couplings.

III. EXPERIMENTAL RESULTS

A two-pole dual-band dual-mode TM mode dielectric filter is implemented and measured to verify the proposed planar configuration and investigate its tuning capabilities. An E6045

TM mode dielectric resonator from EXXELIA is used ($\epsilon_r = 45$, Q-factor = 8000 @ 5 GHz) with outer diameter = 8 mm, inner diameter = 4 mm, height = 6 mm. The filter parts are assembled and the dielectric resonators are soldered to a copper metallic housing. The filter has a very compact structure of $40.5 \times 26 \times 5.9$ mm³ providing > 70% volume saving in comparison with the conventional waveguide technology. A photograph and the measured S parameter responses of the implemented DBBPF are depicted in Fig. 6. The first passband is centred at 4.46 GHz with fractional bandwidth (FBW) of 1.05% and Q_u of 1000. While the higher passband operates at 4.94 GHz with FBW of 0.57% and Q_u equals 950. As can be seen, high inter-band isolation and out-of-band rejections are obtained. An Inter-band transmission zero is introduced providing a high 60 dB isolation between the two passbands. Two asymmetrical TZs are generated below and above the filter passbands at 3.75 GHz and 5.75 GHz, respectively. Also, the frequency tuning capabilities of the fabricated dual-band filter are demonstrated in Fig. 7. Firstly, both passbands are reconfigured at the same time (Fig. 7(a))

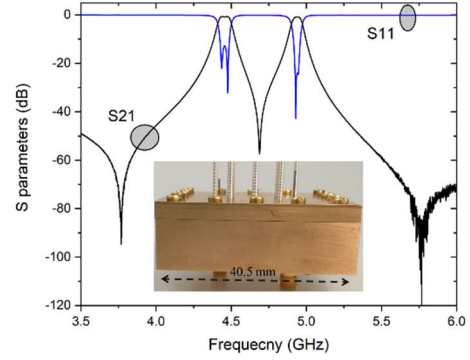


Fig. 6. Photograph and measured results of the two-pole dual-band dual-mode TM mode dielectric filter.

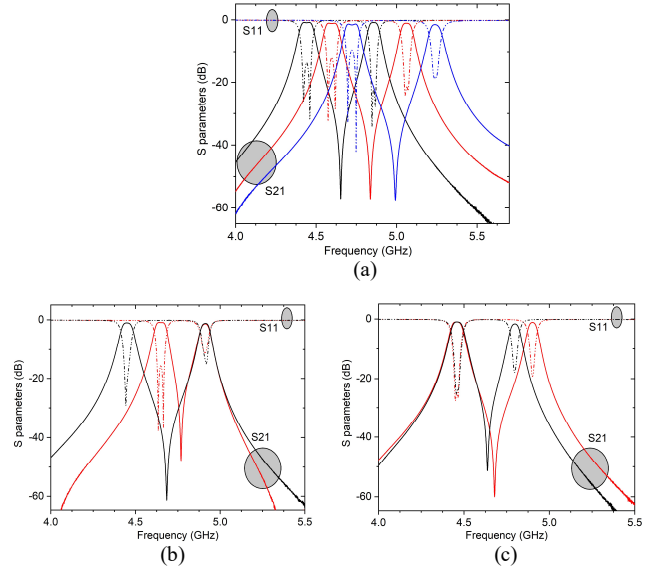


Fig. 7. Measured reconfigurable responses of the dual-band dual-mode TM mode filter. (a). Both passbands tuning. (b). Lower-passband tuning. (c). Higher-passband tuning.

showing a 260 MHz tuning band from 4.46 GHz to 4.72 GHz at the lower channel and from 4.85 GHz to 5.24 GHz at the upper passband with a tuning window of 390 MHz. Furthermore, each passband is reconfigured independently. Fig. 7(b) demonstrates a 200 MHz tuning band at the lower passband from 4.65 GHz – 4.45 GHz, while the upper channel remains fixed at 4.92 GHz. Contrary, in Fig. 7(c), the lower channel stays at 4.46 GHz, while the upper passband is tuned over 100 MHz window from 4.90 GHz to 4.80 GHz.

IV. CONCLUSION

A new inline planar configuration of miniaturized dual-band TM mode DR filters was introduced for the advantages of easy tuning, assembly, and production. Both inter-band and outer-band transmission zeros were introduced offering higher isolation between the passbands and enhanced selectivity. The tuning capabilities of the presented filter were investigated for tunable filters applications. The two passbands can be tuned either simultaneously or independent from each other.

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