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Very Compact Diplexer Based on Dual-Mode Dielectric TM-Mode Resonators

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***Abstract*—A very compact in-line C-band diplexer is reported in this paper based on dual-mode dielectric TM-mode resonators in planar coupling configuration. In addition to the advantages of substantial volume-saving and easy assembly, the proposed diplexer features high quality factor, enhanced spurious performance, high-power handling, and efficient tuning process with independent control of each passband. For verification purposes, a C-band diplexer is designed, implemented, and tested. The final assembled diplexer unit has a compact overall volume of 43×40×15.9 mm^3. It operates at 4.73 GHz and 5.03 GHz with same bandwidth of 24 MHz, an insertion loss better than 0.9 dB, and a return loss higher than 21 dB. Additionally, high-power breakdown analysis shows that the introduced diplexer can handle high levels of input power up to 5200 watts.**

***Index Terms*—Compact, dielectric resonators, diplexer, dual-mode, TM-mode**

I. Introduction

HIGH-Q, compact, and high-power diplexers are an essential component of every multi-band transceiver in a broad range of high-performance evolving applications, including cellular base stations and satellite payloads. Accordingly, many diplexers were presented in the open literature based on various planar and waveguide technologies. In particular, loaded-waveguide diplexers have gained an increasing amount of attention because of their desirable features of more size miniaturization, high-Q, and good power handling capabilities [1]- [9]. For example, [1] presented an L-band combline diplexer for space applications with input power up to 1800 watts. Also, a couple of dielectric diplexers were introduced to offer more size compactness and lower losses than coaxial ones based on triple-mode resonators [5], customized corner-cut [6], oval [7] dual-mode HE resonators, and TM_{010} mode resonators [8], [9]. Among all, TM_{010} dielectric resonators have highly desirable advantages of substantial volume-saving, mechanical stability, enhanced high-power performance, and wider spurious-free bands. Hence, they were employed successfully in high-performance terrestrial and satellite filtering components as in [8]- [11]. The authors in [8] and [9] recently introduced compact L-band TM_{010} dielectric diplexers for high-power space applications up to 768 W. Also, besides the single-mode TM_{010} mode, the orthogonal modes TM_{120} and TM_{210} were utilized to design very compact dual-mode and dual-band filters [12]- [15]. For instance, we recently introduced a miniaturized in-line TM-mode dual-band filter in a planar configuration suitable for mass production [14]. Similarly, diplexers can be designed to benefit from these highly desirable merits.

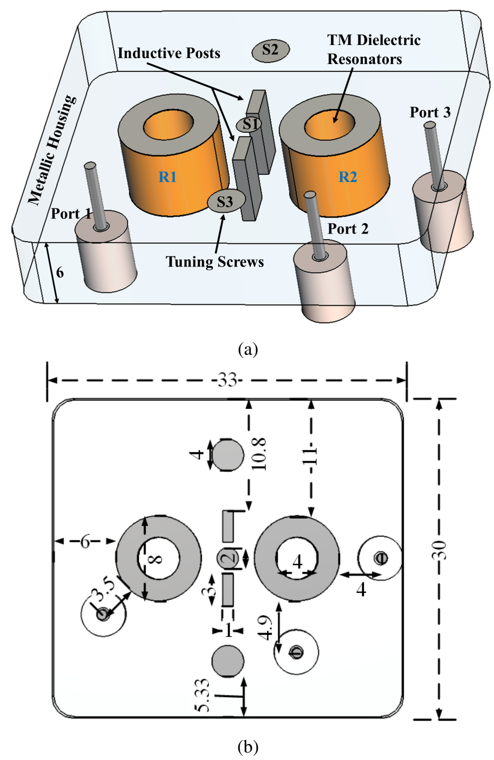

Fig. 1. Proposed compact dielectric TM-mode diplexer. (a). Perspective view and (b). top view. All dimensions are in mm unit.

In this letter, a very compact C-band diplexer based on dual-mode TM-mode dielectric resonators is presented, for the first time. The use of high dielectric constant dual-mode TM-mode dielectric resonators attributes a substantial volume saving in comparison with conventional waveguide technology. Also, the proposed diplexer eliminates the need for coupling junctions featuring more compactness, handling of higher power levels, and a simpler design procedure. Furthermore, the diplexer is designed in an in-line planar coupling configuration that advantageously provides easy tuning and assembly. Thanks to the planar topology and the properly designed inter-resonator (IR) coupling irises, all the input-output couplings, resonant frequencies, and inter-resonator couplings can be controlled effectively and independently.

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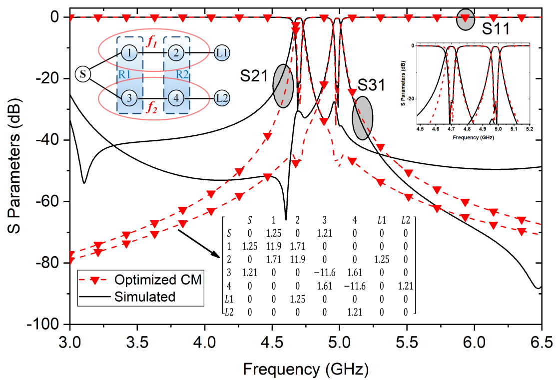


Fig. 2. Coupling scheme, optimized coupling matrix (redline), and CST EM simulated S-parameters (blackline).

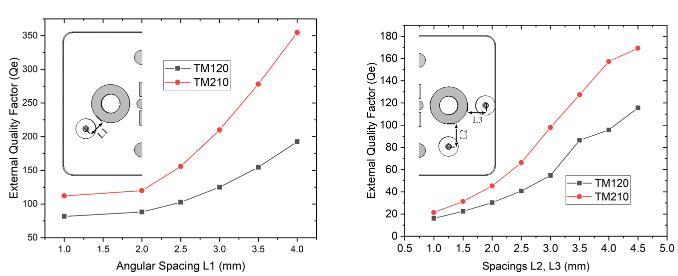
II. Diplexer Design

A. Specifications and Configuration

The configuration, coupling topology, and CST EM simulations of the proposed compact dielectric TM-mode diplexer are depicted in Fig. 1 and Fig. 2, respectively. The design is based on second-order filters operating at 4.7 GHz (f_1) and 4.98 GHz (f_2) with similar bandwidth of 24 MHz. The design procedure begins with the synthesis and optimization of the corresponding coupling matrix based on the required specifications following the method detailed in [14]. Then, the required inter-resonator couplings and input-output couplings are calculated (K_{12}= 0.009, K_{34}= 0.008, Q_{e1}= 129, Q_{e2}= 137.7). The receiver (RX) and transmitter (TX) channels (f_1, f_2) are realized using the two orthogonal modes TM_{120} and TM_{210} [12], respectively. At the input side (port 1), the feeding pin is positioned at an angle 45° to couple with both modes simultaneously. Then, two orthogonal outputs (port 2, port 3) are used to couple the RX (TM_{120}) and TX (TM_{210}) channels separately and independently. Two inductive posts are used the realize the required inter-resonator couplings for each channel.

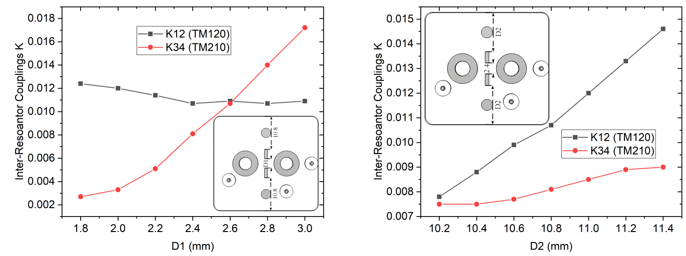
B. Input-Output Couplings

The input and outputs feedings are realized using inductive wires (grounded at the top side of the housing) soldered on SMA (Sub-Miniature) connectors as shown in Fig. 1. The input feeding (port 1) is firstly positioned at angle 45° to be coupled to both orthogonal modes (TM_{120}, TM_{210}). Then, the coupling strengths are adjusted through the angular spacing



(a) (b)

Fig. 3. External quality factor of TM_{120} and TM_{210} modes in relation to the IO feeding probes. (a). The dependence of both modes on the angular spacing L_1. (b). TM_{120} and spacing L_2, TM_{210} and spacing L_3. All dimensions are in mm unit.



(a) (b)

Fig. 4. Relationship between the physical coupling coefficients of TM_{120} and TM_{210} modes and (a) the gap between the two posts D_1, and (b) the distance between the posts and the sidewalls of the cavity (D_2). All dimensions are in mm unit.

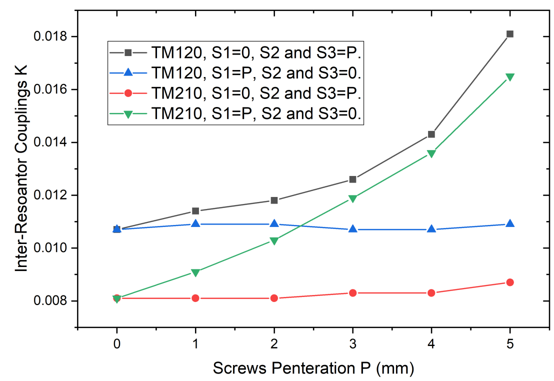


Fig. 5. Inter-resonator couplings relation to the tuning screws' (S1, S2, S3) penetration (refer to Fig. 1).

between the first resonator and the input feeding (L_1) as depicted in Fig. 3(a). At the output side, two perpendicularly positioned feeding probes are used to couple each of the orthogonal modes separately. The first output (port 2) is used to feed only the receiver channel (TM_{120}) and the second output (port 3) is used to couple the transmitter channel (TM_{210}). The corresponding coupling strengths are controlled through the gap between the second resonator and the feeding pins (L_2 for TM_{120} channel, and L_3 for TM_{210} passband) as can be seen in Fig. 3(b).

C. Inter-Resonator Couplings

It was shown earlier in [14] that a single central inductive post is employed to obtain the required couplings for dual channels at the same time. Here, we alternatively propose two inductive posts instead of the single central post to provide more flexibility and degree of freedom in realizing the required inter-resonator couplings for both modes more independently. As shown in Fig. 4, the required IR couplings are obtained by adjusting the gap between the two posts (D_1) and the distance between the posts and the sidewalls of the cavity (D_2). The IR coupling of TX channel (TM_{210}) is mainly controlled by D_1 (see Fig. 4(a)) since the TM_{210} mode resonates in the middle of the cavity. On the other hand, as the TM_{120} mode propagates mainly at the sides, the coupling of the RX channel (TM_{120}) is adjusted using D_2 as demonstrated in Fig. 4(b).

Especially for such multi-mode designs, tuning screws might be essential to obtain the required responses and compensate for any assembly and fabrication tolerances. It was

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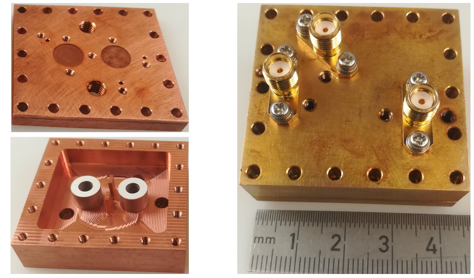
demonstrated in [15] that such planar TM-mode-based configurations allow efficient tuning of resonant frequencies either simultaneously or independently. Additionally, and thanks to the proposed two-post iris structure here, tuning screws (S1, S2, and S3 in Fig. 1) can be added to control the inter-resonator coupling of each channel independently as can be seen in Fig. 5. This is a key advantage of the proposed structure. It worth to note that higher-order diplexers can be designed further effectively following the same design procedure.

III. Experimental Results

A prototype is manufactured, assembled, and measured to verify the proposed very compact diplexer design. The disassembled components and the final assembled diplexer are exhibited in Fig. 6. The TM-mode dielectric resonators are E6045 (DK = 45, Q-factor = 8000 @ 5 GHz) from EXXELIA [16] with outer diameter = 8 mm, inner diameter = 4 mm, and length = 6 mm. The metallic housing and lid were manufactured using copper metal. The diplexer is then assembled and the DRs were soldered with the metallic cavities using a silver paste. The diplexer prototype has a compact overall volume of 43×40×15.9 mm^3 offering a substantial volume-saving in comparison with the conventional empty-waveguide structures. Fig. 7 illustrates the measured S-parameter responses of the implemented compact diplexer showing a good agreement with the re-optimized simulations considering the dielectric constant uncertainty (DK≈44.2) and assembly tolerances. The first channel (f_1) operates at 4.73 GHz with an insertion loss better than 0.7 dB, while the second passband (f_2) is centered at 5.03 GHz, with an insertion loss of less than 0.9 dB. Both passbands have similar BW of 24 MHz with a return loss better than 21 dB. The estimated quality factor of the manufactured prototype is 1500 (≈50% of simulation), and the isolation between the two channels is higher than 31 dB. Tuning screws were considered in the manufactured prototype, but were not used as the frequency shift is small (less than 1%) and we also do not want to introduce additional losses. Also, the high-power handling capabilities of the introduced diplexer were evaluated using the Spark3D tool. The diplexer has no multipactor discharge breakdowns up to 4700 W at the RX channel and 5200 W at the TX channel. Here, it should be noted that hardware limitations (e.g. SMA connectors) and thermal tests are still needed for complete high-power analysis, especially due to the instability issues of such TM-mode structures over temperature [9]. Table I summarizes a comparison between the proposed diplexer and similar designs, featuring a very compact structure, higher quality factor, spurious-free band better than 1.9 GHz (lower spurious 2.82 GHz, upper spurious 7.07 GHz), and high power levels up to 5200 W. Furthermore, the planar coupling configuration of the presented diplexer brings highly desirable advantages of easy assembly, integration, and tuning where the operation frequencies and inter-resonator couplings of the diplexer channels can be tuned independently. The isolation of the diplexer prototype is higher than 31 dB which is better than [5] and comparably similar to [6] and [8]. Alternatively, single-mode resonators can be added at the outputs to enhance the isolation similar to [2].



(a) (b)

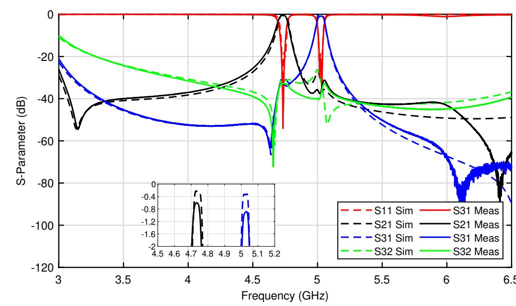


Fig. 7. Measured results of the proposed very compact TM-mode DR diplexer.

TABLE I. Comparison with Similar Coaxial/Dielectric-Loaded Waveguide Diplexer Designs

Ref.	[2]	[5]	[6]	[8]	**This work**
f_0 (GHz)	1/1.8	2.55/2.66	1.52/1.64	1.54/1.65	**4.73/5.03**
Order	4/4	3/3	2/2	3/3	**2/2**
FBW (%)	16/6	3.8/3.5	0.85/1.1	2.74/2.96	**0.51/0.48**
IL (dB)	0.72/0.55	0.63/1.1	0.8/0.5	0.17/0.31	**0.7/0.9**
Isolation (dB)	> 50	20	33	≥ 30	$>$ **31**
Size (λ_g^3)	0.0383	0.2653	0.01344	0.0633†	**0.021**
Q_u	190/650	1080/670	810/1050	2000	**1500**
Vol. (cm^3)	1035.26	432	106.24	468†	**5.94**
Q_u/Vol. (cm^{-3})	0.63	2.5	9.88	4.27	**252.53**

(Ref.=Reference, λ_g= Guided wavelength at the lower operation channel, Vol.=Volume). †Metallic wall thickness included.

IV. Conclusion

This letter has presented a new class of very compact in-line diplexers based on dual-mode dielectric TM-mode resonators in planar coupling configuration. The proposed diplexer has many desirable advantages including substantial volume-saving, high quality factor, good spurious performance, and high-power handling capabilities. Besides, thanks to the planar configuration and the proposed two-post iris structure, the introduced diplexer features easy assembly and an efficient, independent tuning process for both transmission and reception channels.

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