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RESEARCH PAPER

Compact diplexers and triplexers implemented with dual-mode cavities

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In this paper, the design of compact diplexers and triplexers with dual-mode cavities is presented. Such devices are composed of coupled resonators without additional waveguide element, leading to a more compact architecture. Two topologies of compact diplexers are implemented and compared to a standard manifold diplexer. A hardware prototype is fabricated and measured for experimental verification. A compact triplexer is finally introduced for extending the concept to more than three ports.

Keywords: Filters, Passive components and circuits

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I. INTRODUCTION

Microwave multiplexers are widely used in space and terrestrial communication systems, and special attention is paid to reduce their size and weight.

Traditionally, microwave multiplexers include several elements such as power dividers, circulators or manifold networks for connecting channel filters [1–3]. These additional elements allow a separate design of each channel; however, they contribute to increased size and weight and also have a non-negligible impact on electrical performances (insertion loss, power handling, etc.). In the case of manifold multiplexing, optimization of waveguide elements is required to meet the electrical specifications, and this could be computationally extensive when a high number of channels are considered.

To suppress waveguide junctions in multiplexing networks, compact microwave multiplexers exclusively composed of coupled resonators have been introduced [4–10]. This new concept allows a large reduction of size and weight compared to conventional microwave multiplexers. Moreover, compact multiplexers offer additional flexibility compared to other multiplexing networks, since coupling between different channels is now possible [8].

For designing such compact multiplexers, analytical methods for evaluating characteristic polynomials and generalized coupling matrix of microwave multiport networks have been developed. These methods have been validated and several prototypes of diplexers and triplexers have been manufactured using a variety of technologies [6–10], but up to our knowledge, only using single-mode resonators.

In this paper, for more compactness, a dual-mode implementation of microwave diplexers and triplexers is proposed. These devices are designed to be consistent with an output multiplexer for satellite payload. Consequently, for a matter of power handling and quality factor, empty cavities working on their TE_{113} dual mode are used for their implementation.

Two topologies of compact diplexers are proposed and compared to a manifold diplexer in terms of electrical performance and integration. Compared to our previous works [4, 5], the current paper provides measurements on a compact diplexer prototype and the design of a compact triplexer to generalize the approach.

II. MANIFOLD DIPLEXER

For reference, a manifold diplexer consisting of two dual-mode cavity filters coupled with waveguide sections has been designed. The electrical specifications for each channel are: a return loss of 20 dB and an out-of-band rejection of 8 dB at ± 45 MHz and 18 dB at ± 55 MHz from the center frequency. The two 72-MHz channels are centered at 10.741 and 10.821 GHz, respectively.

To reach the electrical specifications, each channel requires a five-pole quasi-elliptic function with two transmission zeros at $\omega_{1,2} = \pm 1.33$ rad/s.

For dimensioning such a structure, we applied a classical approach that consists of designing channel filters independently, then optimizing the whole diplexer structure. The manifold diplexer is shown in Fig. 1 and the optimized electromagnetic (EM) response is shown in Fig. 2. The insertion loss is found to be 0.28 dB and the diplexer structure is contained in parallelepiped occupying $37.5 \times 2.65 \times 2.65 = 263$ cm^3.

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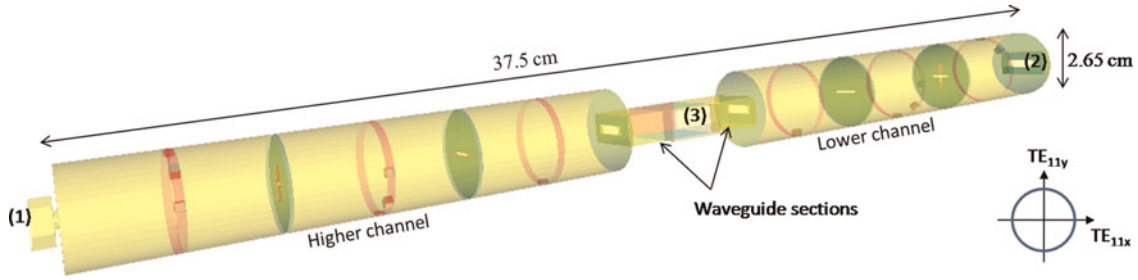


Fig. 1. EM model of the manifold diplexer.

III. COMPACT DIPLEXER: FIRST TOPOLOGY

The first topology of compact diplexer is shown in Fig. 3. This topology is directly derived from the classical architecture of the microwave diplexer. Indeed, the structure consists of two independent paths (resonators 1–5 and resonators 6–10), and the common port L excites the two paths simultaneously.

To calculate the generalized coupling matrix of the diplexer, we did not calculate the characteristic polynomials as in [6, 7], but we directly optimized the coupling matrix with a circuit software. After optimization, we obtained a transfer function as shown in Fig. 4. The generalized coupling matrix, given in equation (1) is normalized with respect to a center frequency of 10.781 GHz and a passband of 72 MHz covering the two passbands of the diplexer. For implementing this topology in dual-mode cavities, we used the same approach as for classical filters [11]. The EM structure corresponding to the first topology is shown in Fig. 5. For feeding simultaneously resonators 5 and 6 by the common port L, a coupling iris was placed at 45° from the two orthogonal polarizations (TE_{11x} and TE_{11y}). To avoid deep penetration of the screws into the cavity and to keep the symmetry, we used diametrically opposed screws in the middle cavity. Moreover, the screws and the iris are not placed on the same maxima of electric field (TE113) to reduce the sensitivity of the structure.

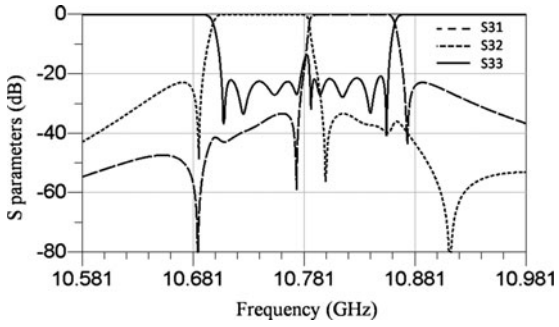


Fig. 2. Optimized EM response of the manifold diplexer.

A) Lower channel path

Considering one-half of the structure closed by a perfect electric conductor (PEC), and, placing the excitation so as to excite only one polarization as shown in Fig. 6, we were able to tune the lower channel segment iteratively by using a coupling matrix identification approach [12, 13]. The EM response was identified to be a transfer function with five poles and two transmission zeros and the corresponding coupling matrix was compared to the second half of the generalized coupling matrix.

	S1	S2	1	2	3	4	5	6	7	8	9	10	L
S1	0.000	0.000	1.054	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
S2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.054	0.000
1	1.054	0.000	1.100	0.826	0.000	−0.305	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.826	1.056	0.809	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.809	1.130	0.542	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	−0.305	0.000	0.542	1.200	0.792	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.792	1.595	0.000	0.000	0.000	0.000	0.000	1.040
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	−1.595	0.792	0.000	0.000	0.000	1.040
7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.792	−1.200	0.542	0.000	−0.305	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.542	−1.130	0.809	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.809	−1.056	0.826	0.000
10	0.000	1.054	0.000	0.000	0.000	0.000	0.000	0.000	−0.305	0.000	0.826	−1.100	0.000
L	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(1)

For dimensioning the structure shown in Fig. 5, we divided it into three parts. The two channel paths and the common center cavity were designed separately and the whole structure was finally slightly optimized.

B) Higher channel path

The same segment was used to tune the higher channel. In this case, the dimensions were calculated by comparing the

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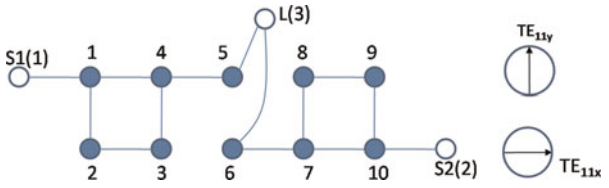


Fig. 3. First coupling topology for realizing the compact diplexer.

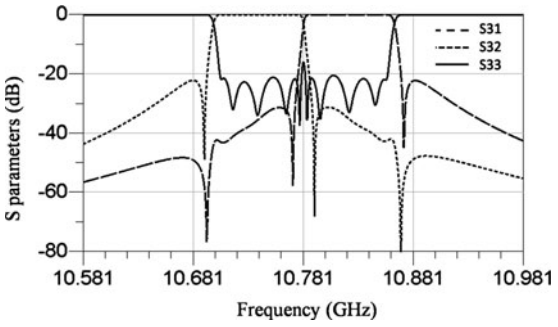


Fig. 4. Optimized circuit response for the first coupling topology.

extracted coupling matrix to the first half of the generalized coupling matrix.

C) Common cavity

To precisely tune the structure, a pre-dimensioning of the common (center) cavity with the excitation placed at 45° from the two polarizations was necessary. The considered segment in this case is described in Fig. 7(a). The dimensions of this segment were initialized by identification of the equivalent circuit presented in Fig. 7(b), where resonators 5 and 6 represent the two orthogonal polarizations in the common cavity. The coupling between these two polarizations has to be null; however, the feeding element (coupling iris) placed at 45° creates inevitably an undesirable coupling. To balance this magnetic coupling, we introduced additional screws placed also at 45° from the two polarizations as shown in Fig. 8. The electric coupling realized with the additional screws cancels the undesirable coupling. The other (desirable) couplings in this segment are adjusted by tuning the iris length and the other screws.

D) Compact diplexer

Once the three segments were dimensioned, the whole structure was analyzed. The response shown in Fig. 9(a) is close to the desired one; however, a fine tuning of the whole structure

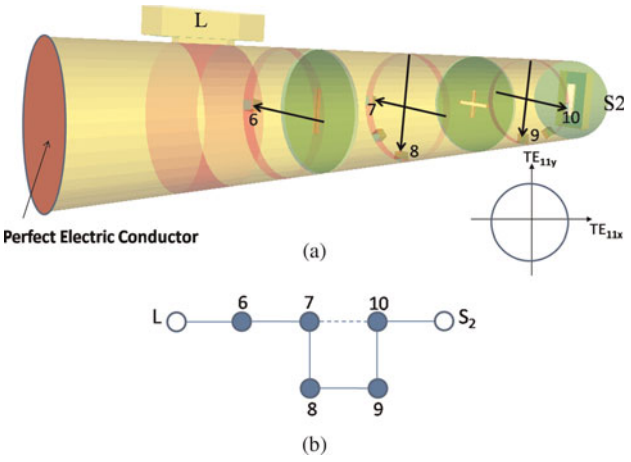


Fig. 6. (a) EM structure for dimensioning the lower channel path and (b) equivalent coupling topology.

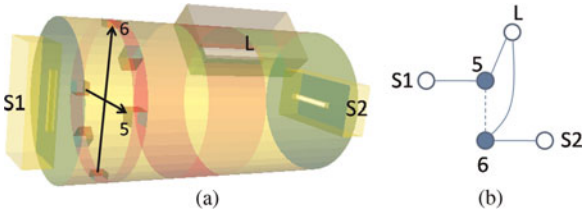


Fig. 7. (a) EM structure for dimensioning the common cavity and (b) equivalent coupling topology.

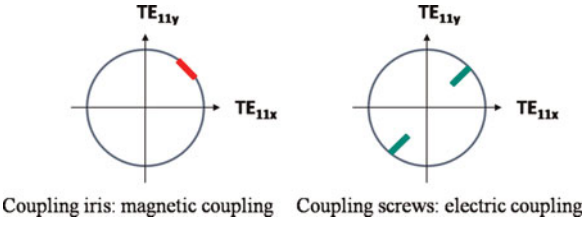


Fig. 8. Compensation of the parasitic coupling due to excitation.

remained necessary to satisfy the specifications, especially in terms of return loss. The optimized response of the compact diplexer is shown in Fig. 9(b). The insertion loss is 0.27 dB and the structure occupies $26.53 \times 2.65 \times 2.65 = 186\ \text{cm}^3$.

Compared to our previous work [4], the common cavity has been pre-dimensioned for more accurate design and, thanks to additional tuning screws; the spurious resonances have been eliminated by improving the overall performance of this compact diplexer configuration.

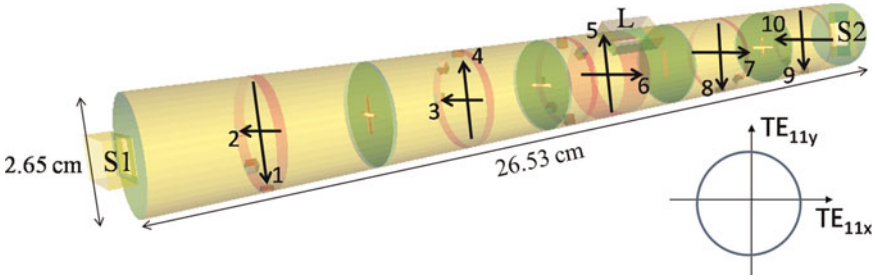


Fig. 5. EM structure of compact diplexer with the first coupling topology.

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IV. COMPACT DIPLEXER: SECOND TOPOLOGY

For facilitating the dual-mode implementation, a second topology described in Fig. 10 has been proposed [4]. With this topology, the common port L excites a single resonator. Consequently, the magnetic iris is now placed orthogonal to polarization TE_{11x} as shown in Fig. 11.

The design begins with the synthesis of the generalized coupling matrix. The coupling matrix given in equation (2) was obtained by circuital optimization and the corresponding responses shown in Fig. 12, satisfies the desired electrical specifications. The coupling matrix is normalized with respect to a center frequency of 10.781 GHz and a passband of 72 MHz. One can note that coupling M_{56} is almost double than other couplings. This is due to this particular topology where resonators 5 and 6 are shared by the two paths corresponding to the two passbands; consequently, this coupling covers the whole band of the diplexer (152 MHz). Besides, comparing the circuit responses in Fig. 4 and Fig. 12, one can see that transmission zeros due to channel interactions have disappeared in this configuration. Therefore, the second topology is less attractive in terms of channel isolation and out-of-band rejection.

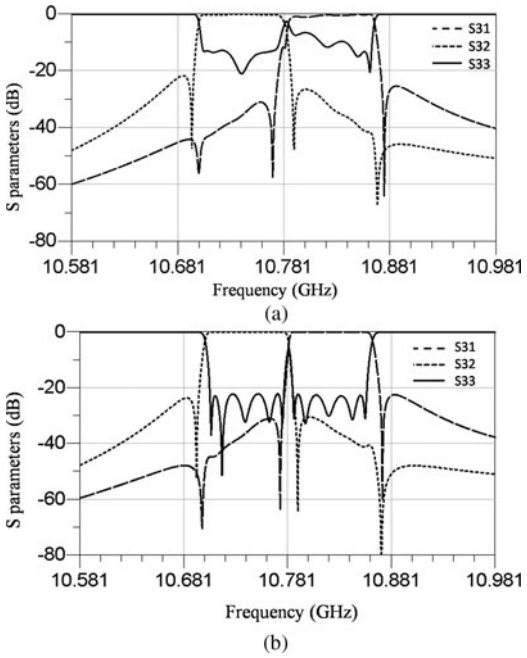


Fig. 9. EM response of the first compact diplexer: (a) before fine tuning and (b) after fine tuning.

	S1	S2	1	2	3	4	5	6	7	8	9	10	L
S1	0.000	0.000	1.247	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
S2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.247	0.000
1	1.247	0.000	1.102	1.014	0.000	−0.324	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	1.014	1.102	0.820	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.820	1.077	0.537	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	−0.324	0.000	0.537	0.962	0.840	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.840	−0.020	1.555	0.840	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	1.555	−0.011	0.000	0.000	0.000	0.000	1.274
7	0.000	0.000	0.000	0.000	0.000	0.000	0.840	0.000	−0.962	0.537	0.000	−0.324	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.537	−1.077	0.820	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.820	−1.102	1.014	0.000
10	0.000	1.247	0.000	0.000	0.000	0.000	0.000	0.000	−0.324	0.000	1.014	−1.102	0.000
L	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.274	0.000	0.000	0.000	0.000	0.000

(2)

After this circuital optimization, the diplexer dimensions have to be determined; however, only two segments have to be considered since the center cavity is common to the two paths.

A) Lower channel path

The segment used for initializing the dimensions of the lower channel is shown in Fig. 13. This segment is built with one-half of the whole structure and the other half is replaced by a PEC. The segment was tuned by coupling matrix identification [12, 13] and the response was identified to be a transfer function with six poles and two transmission zeros, comparing the corresponding coupling matrix to the second half of the generalized coupling matrix.

B) Higher channel path

The same segment was used to tune the higher channel. In this case, the dimensions were adjusted with respect to the first half of the generalized coupling matrix.

C) Compact diplexer

Finally, a global optimization of the whole structure was necessary to satisfy the specifications especially in terms of

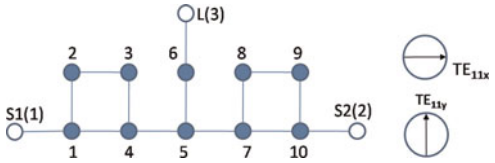


Fig. 10. Second coupling topology for realizing the compact diplexer.

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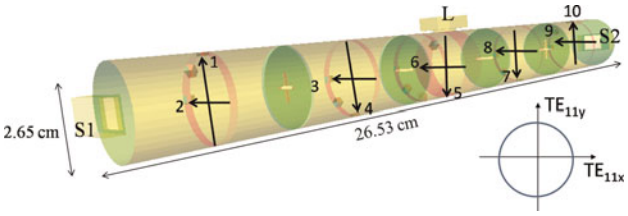


Fig. 11. EM structure of compact diplexer with the second topology.

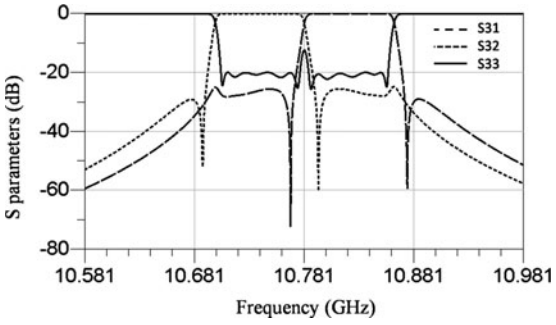


Fig. 12. Optimized circuit response for the second topology.

return loss. The EM response of the diplexer in this topology is shown in Fig. 14 before and after optimization. In this configuration, insertion loss is also found to be 0.27 dB and the volume occupation is similar to our previous topology (186 cm^3).

V. EXPERIMENTS

For validating the design of compact diplexers in dual-mode cavities, a hardware prototype was fabricated as shown in Fig. 15. The second topology was preferred for facilitating implementation and tuning. The cavities are silver plated for increasing the electrical conductivity.

The two channel paths were separately preset using coupling matrix identification to facilitate the tuning. The whole diplexer is then assembled and finely tuned. The measured response displayed in Fig. 16 is in good accordance with the

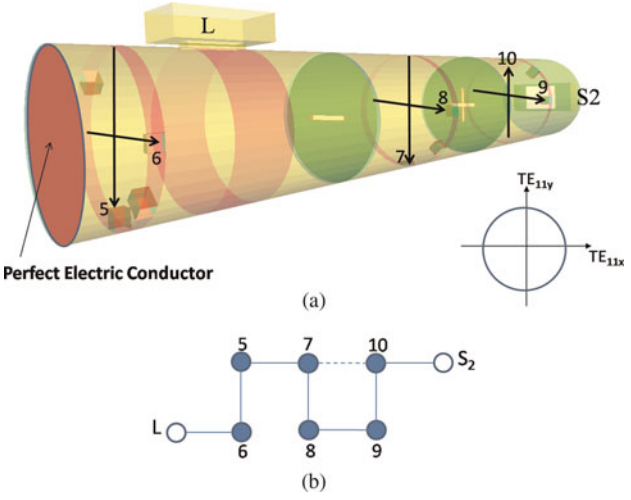


Fig. 13. (a) EM structure for dimensioning the lower channel path (second topology) and (b) equivalent coupling topology.

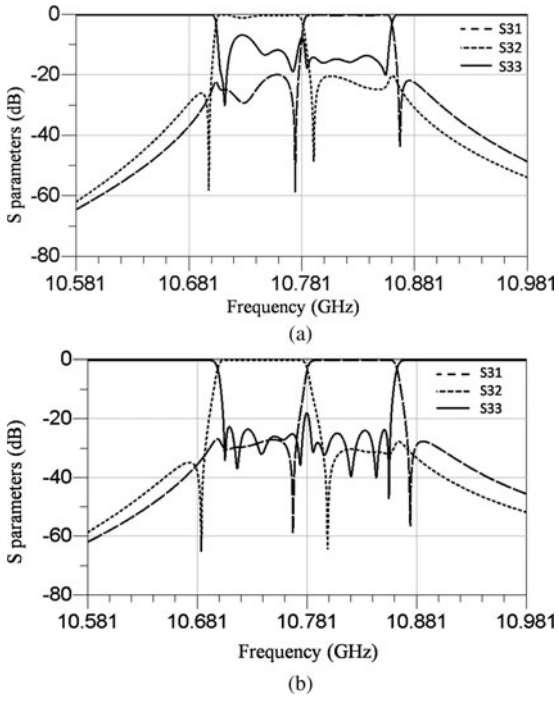


Fig. 14. EM optimized response of the second compact diplexer: (a) before fine tuning and (b) after fine tuning.

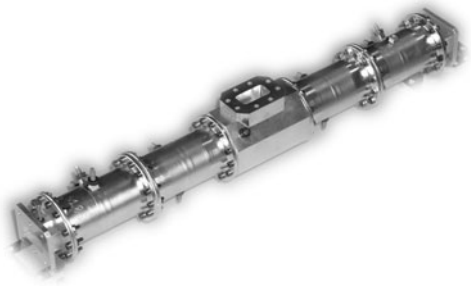


Fig. 15. Photography of the fabricated diplexer.

simulation. Insertion losses are 0.38 dB in the lower channel and 0.36 dB in the higher channel.

VI. COMPACT TRIPLEXER

For extending the approach to more than three ports, a compact triplexer with contiguous channels is proposed.

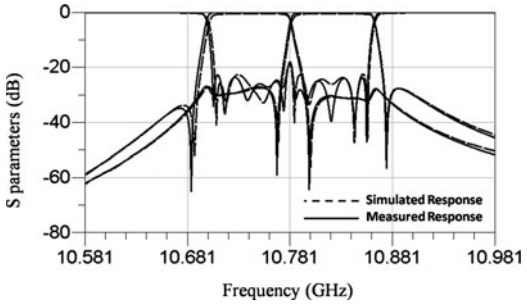


Fig. 16. Measured (solid line) and simulated (dashed line) diplexer response.

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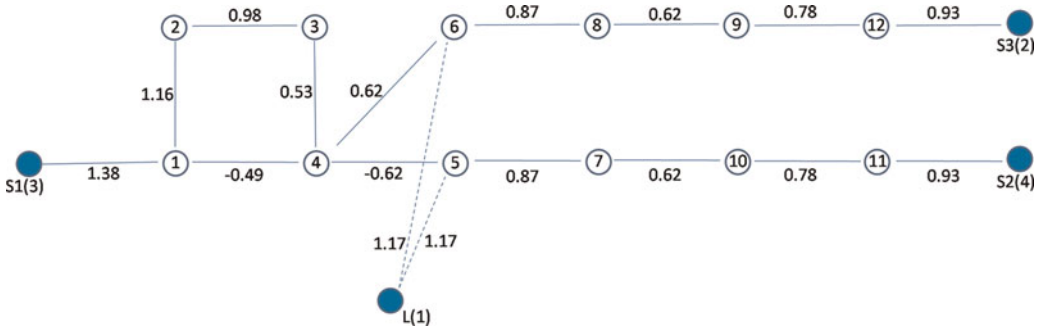


Fig. 17. Coupling topology for realizing the compact triplexer. $M_{11} = M_{22} = M_{33} = M_{44} = 0$, $M_{55} = -M_{66} = 2.32$, $M_{77} = -M_{88} = 2.25$, $M_{99} = -M_{1010} = -2.24$, and $M_{1111} = -M_{1212} = 2.23$.

The three 72-MHz channels are centered at 10.701, 10.781, and 10.861 GHz, respectively. The return loss is expected to be 18 dB in each channel, and the out-of-band rejection is at least 15 dB at ± 58 MHz from the center frequency. The triplexer is synthesized through circuit optimization. Four pole channels are necessary for attaining the out-of-band rejections and two transmission zeros are added in the middle channel for increasing isolation between channels.

Fig. 17 shows the optimized coupling topology. Synthesized coupling values are reported in the coupling diagram and self-couplings are given in the figure caption. All these couplings are normalized with respect to a center frequency of 10.781 GHz and a passband of 72 MHz. One can distinguish easily the three channel paths: the lower channel path is composed of resonators 6, 8, 9, and 12; the higher channel path is composed of resonators 5, 7, 10, and 11; and the middle channel path is composed of resonators 1, 2, 3, and 4. The latter channel requires a coupling between resonators 1 and 4 to realize the pair of transmission zeros. Moreover, one can remark that couplings and self-couplings are symmetrically arranged because of the symmetry in the electrical specifications.

The corresponding transfer function is shown in Fig. 18. Additional transmission zeros are observed in the passbands of opposite channels, improving the isolation between them. The location of such incomplete transmission zeros depends on couplings between resonators of lower and higher channels (M_{56}, M_{78}, etc.).

The implementation in dual-mode cavities is shown in Fig. 19. To couple resonator 4 to resonators 5 and 6, dual-mode polarizations were rotated by 45° with respect to polarizations TE_{11x} and TE_{11y}. For simultaneously feeding resonators 5 and 6 by the common port L, a coupling iris was placed at 45° from the two polarizations 5 and 6 are depicted in Fig. 19.

For dimensioning the structure, each channel path has been separately designed. Moreover, for obtaining an accurate dimensioning, an additional segment was used to precisely evaluate couplings between resonators 4, 5, and 6. Finally, the whole structure was finally optimized.

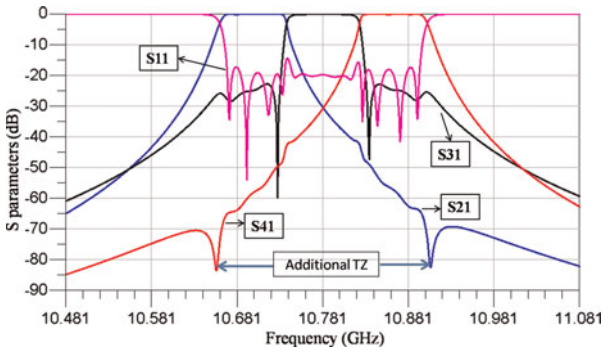


Fig. 18. Optimized circuit response for the compact triplexer.

A) Higher channel path

The segment used for initializing dimensions of the higher channel path is shown in Fig. 20. This segment corresponds to the right half of the whole structure. The two first cavities were replaced by a PEC. Moreover, the coupling iris of common port L is placed so as to excite only one polarization. The port corresponding to the lower channel path is replaced by a matched load condition ($\rho = 0$).

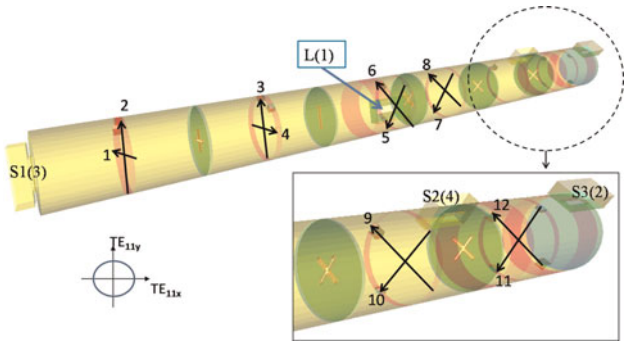


Fig. 19. EM model of the compact triplexer.

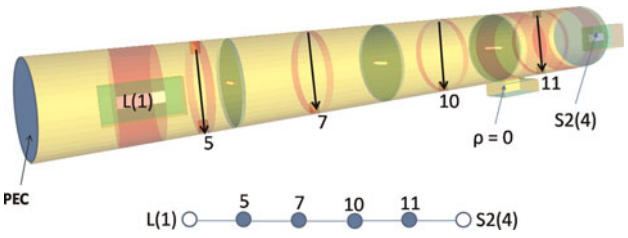


Fig. 20. EM structure for dimensioning the higher channel path and its equivalent coupling topology.

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B) Lower channel path

The same segment was used to tune the lower channel. In this case, the lower channel port S3(2) is considered, and tuning screws are dimensioned for adjusting resonant frequencies.

C) Segment used for tuning couplings between resonators 4, 5, and 6

As for the first topology of compact diplexers, a pre-dimensioning of the common cavity with the excitation placed at 45° from the two polarizations (5 and 6) was necessary. Moreover, for initializing precisely dimensions of the iris realizing couplings M_{45} and M_{46}, the segment described in Fig. 21 was considered.

D) Middle channel path

The segment used for dimensioning the middle channel is shown in Fig. 22. This segment is built with the two first cavities.

All these segments were tuned by coupling matrix identification [12, 13]. For each segment, the response was identified to be the transfer function corresponding to its equivalent coupling topology. The identified couplings were compared to the corresponding desired ones shown in Fig. 17.

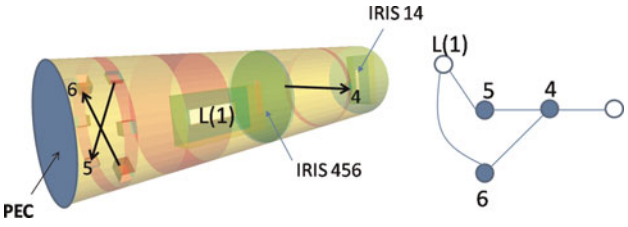


Fig. 21. EM structure for dimensioning the middle cavity and its equivalent coupling topology.

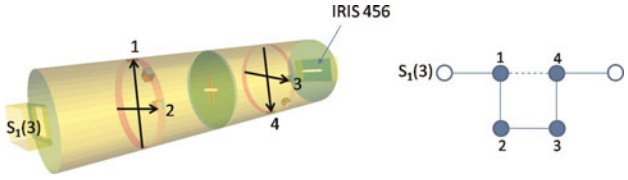


Fig. 22. EM structure for dimensioning the middle channel path and its equivalent coupling topology.

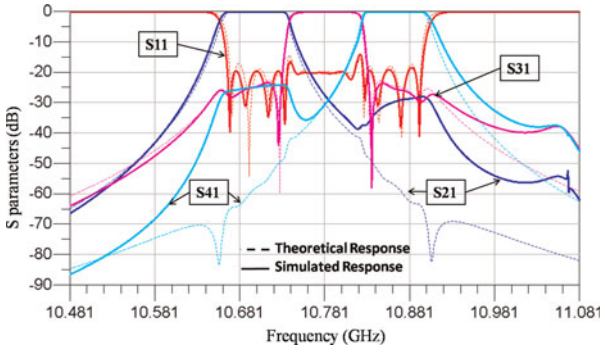


Fig. 23. Simulated (solid line) and theoretical (dashed line) triplexer response.

E) Compact triplexer

Once the segments have been dimensioned, the whole structure was analyzed. The response after the segmentation stage is close to the desired one; however, a fine tuning of the whole structure remained necessary. The optimized response, compared to the theoretical one, is shown in Fig. 23. One can observe that additional transmission zeros have disappeared on the simulated response. This is due to weak couplings between resonators of lower and higher channels (M_{56}, M_{78}, etc.).

VII. CONCLUSION

In this paper, several topologies for realizing compact microwave diplexers and triplexers in dual-mode cavities have been proposed. These devices are exclusively composed of coupled resonators and their designs have been described in detail. The approach has also been illustrated by a fabricated prototype.

The first compact diplexer, which is inspired by classical diplexer architecture, is more attractive in terms of out-of-band rejection since it presents an increased selectivity. Nevertheless, it requires a careful design for dimensioning properly the cavity supporting the common port.

The second topology excites a single resonator at the common port. Implementing this configuration is more comfortable; however, the selectivity is reduced compared to the first topology. Measurements of a hardware prototype are in good accord with the theoretical design.

The two first topologies have been compared with a manifold diplexer. The diplexers allow reducing volume occupation by 29%, whereas electrical performances in terms of insertion loss and out-of-band rejection (first topology) are comparable.

Finally, the approach was extended to four-port devices for realizing compact triplexers.

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