Modified CSRRs in SIW technology for passband improvement

Javier Martínez[1], Ángela Coves[1], Ángel A. San-Blas[1], Enrique Bronchalo[1], Maurizio Bozzi[2]
[1] Departamento de Ingeniería de Comunicaciones-I3E, Universidad Miguel Hernández de Elche,
Elche, Spain, angela.coves@umh.es
[2] Department of Electrical, Computer and Biomedical Engineering, University of Pavia, Italy

***Abstract*—In this paper, a substrate integrated waveguide (SIW) loaded with three pairs of modified complementary split-ring resonators (CSRRs) is presented, in which the subwavelength waveguide passband can be significantly increased due to the appearance of new electromagnetic couplings between the different resonators. The obtained results are compared to those provided by a more classical topology based on CSRRs periodically etched along the waveguide wall, showing a significant bandwidth improvement, while maintaining a good matching level.**

Index Terms—*resonator, substrate integrated waveguide, electromagnetic coupling.*

I. INTRODUCTION

During the last decade, microwave filters based on substrate integrated waveguide (SIW) technology have been widely studied, due to its versatility, low cost and simplicity of manufacture [1]-[3]. The study of these filters aims for the easy integration with other circuits and of waveguides for low radiation losses of the structures. However, the physical sizes of SIW circuits and components are typically larger than those of the microstrip or coplanar waveguide counterparts. In this respect, SIW lacks advantage in size for practical applications, especially for applications operating at the radio frequency (RF) or low-frequency region of microwave [4], [5].

In order to reduce the large physical size of SIW, several approaches have been developed over the past decade. Among all the reported size miniaturization methods, the evanescent mode propagation supported by SIW section loaded with metamaterials is an attractive one since it can realize guided wave operation below the characteristic cutoff frequency of the dominant mode in the conventional SIW [6], [7]. Resonators as Complementary Split Ring Resonators (CSRRs) have been used for this purpose since they can resonate below the cutoff frequency of the empty waveguide [8]-[10], which results in an attractive feature to obtain bandpass filters while compressing the transversal dimension of the waveguide. This transversal compression is crucial in practical applications; for example, in communications systems where the space to feed antenna arrays is limited. Therefore, to have waveguides that operate below the cut-off frequency is needed to reduce the levels of grating lobes. However, the use of CSRRs usually results in a very narrowband response since the frequency resonances of the rings are very close to each other.

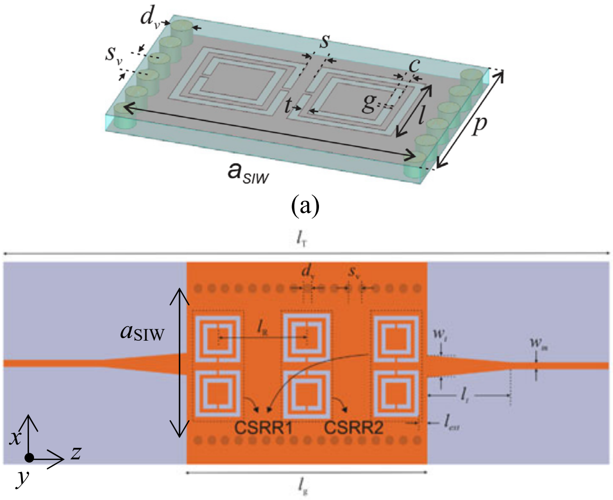
In this work, we demonstrate that modifying the rings, by dividing them into smaller resonators by means of the insertion of slots (each resonator characterized by its own resonant frequency), it is possible to significantly increase the passband of the structure if the resonant frequencies of the new obtained resonators are near to each other and the resonators are sufficiently coupled, thus achieving a new degree of freedom in the design of this kind of filters.

II. SIW-CSRR FILTERS

In this section, we describe the different structures with CSRRs in SIW technology that have been analyzed.

A. SIW periodically loaded with Symmetrical CSRRs

The first configuration was already analyzed by the authors in [11] and it will be the starting point for the design shown in the following subsection. This first SIW-CSRR filter was obtained by periodically etching symmetrical CSRRs on the top waveguide surface of a SIW, as shown in Fig. 1. The SIW is characterized by its width a_{SIW}=12.4 mm and height b=0.63 mm. The selected substrate is Taconic RF-10 (ε_r=10, tan δ = 0.0025), which yields a cutoff frequency of the initial SIW at about 4 GHz. The vias defining the lateral walls of the SIW have diameter d_v=0.8 mm and separation s_v=1.2 mm (see Fig. 1), which guarantees negligi-



(a)

(b)

Fig. 1. SIW periodically loaded with symmetrical CSRRs. (a) Unit cell. (b) Proposed filter.

ble radiation losses. A pair of identical CSRRs are adopted and periodically etched on the metal cover of the waveguide, in which the direction of the split of the outer rings are aligned face-to-face. The value of the geometrical parameters of the CSRRs in the unit cell defined in Fig. 1(a) are: l=3.92 mm, c=0.32 mm, s= 0.54 mm, t=0.26 mm, and g=0.18 mm. The center frequency, bandwidth and rejection band of the periodic microwave filter can be easily selected by analyzing the dispersion diagram of the unit cell, following the procedure already described in [11], [12]. For this case, a period of l_R=7.55 mm was selected, and a final optimization process of the parameters of the filter was performed, including the taper transitions, with the following parameters: w_t =1.9 mm, l_t=8 mm, w_m=0.6 mm, l_g=2.1 cm, l_{ext}=0.6 mm, l_T=5.3 cm (see Fig 1(b). The simulated electrical response of this filter is represented in Fig. 2 with solid line, while the measured response of a fabricated prototype of the filter is represented in the same figure with dashed line, whose photograph is shown as a figure inset. A narrow passband can be observed from 2.47 to 2.7 GHz, which has already been observed in similar sub-wavelength filter topologies reported in the technical literature that employ resonators to produce evanescent-wave transmission. Additionally, this filter shows insertion losses lower than 2.0 dB, along with a deep rejection band which extends up to 5.06 GHz, associated to the sub-wavelength nature of this topology.

B. *Proposed new SIW loaded with modified CSRRs*

The electrical response of the filter described in the previous subsection, as already mentioned, was clearly narrowband (see Fig. 2). In order to increase the passband of such structure without increasing its longitudinal size, we have divided the outer rings that constitute the CSRRs in smaller sections by introducing new slots, obtaining additional resonances in the structure. An example of it can be seen in the structure with three pairs of modified CSRRs shown in Fig. 3, where additional slots have been properly inserted in the outer rings of the CSRRs symmetrically with respect to the x-y plane at the center of the structure. Fig. 4 shows the complete structure in SIW technology, whose taper transitions have been optimized to guarantee a good matching in the passband. The electrical response obtained in this first iteration is represented in Fig. 5, resulting in a wider passband, due to the higher number of resonators, and a higher center frequency (which has been shifted upwards nearly 1 GHz with respect to the one obtained in the original filter shown in Fig. 2), which is due to the smaller size of the resulting resonators, as it is explained, for instance, in [8].

Nevertheless, a non-desired resonance appears around 5 GHz, associated to the smallest resonators. Thus, a final ite-

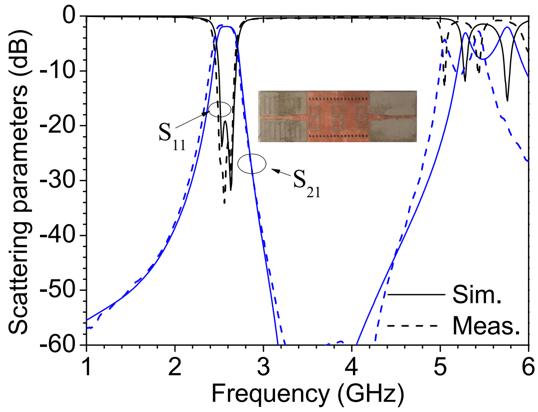


Fig. 2. Electrical response of the SIW filter periodically loaded with symmetrical CSRRs represented in Fig 1(b).

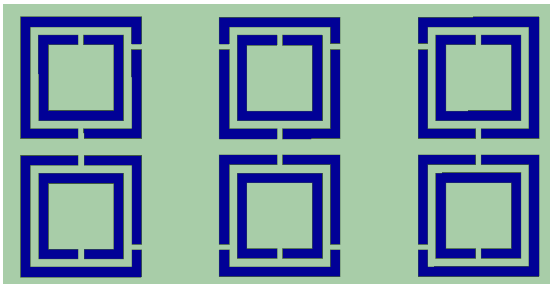


Fig. 3. SIW loaded with modified CSRRs, first iteration.

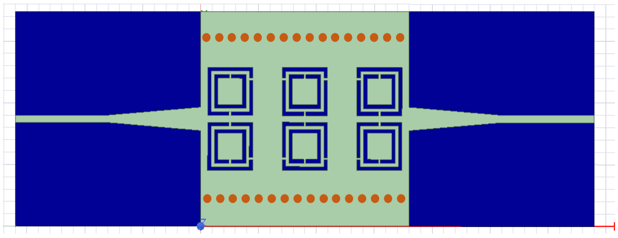


Fig. 4. Complete structure in SIW technology of the structure of Fig. 3.

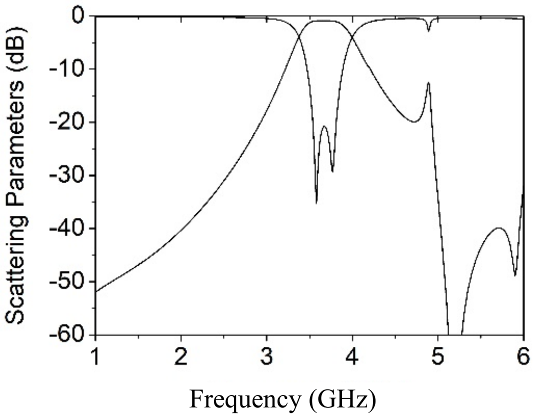


Fig. 5. Electrical response of the structure in Fig. 4 corresponding to the first iteration.

ration has been performed by progressively moving the slots of the outer rings in the central CSSRs of the previous iteration until making the undesired resonance move into the passband. The configuration obtained in this final iteration is shown in Figs. 6 and 7, respectively, where the positions of the slots defining the different resonators have been included in Fig. 6 (all units are in mm), while the parameters of the taper transitions for achieving a good matching after the optimization process are w_t =4.6 mm, l_t=5 mm, and the rest of parameters are the same as in the previous subsection.

Fig. 8 shows the frequency response of this final configuration, which has been substantially improved, with a final bandwidth of more than 1GHz, which is 5 times greater than that obtained in the original filter, along with a very good matching (return losses higher than 21 dB) and very low insertion losses (lower than 1 dB in the passband).

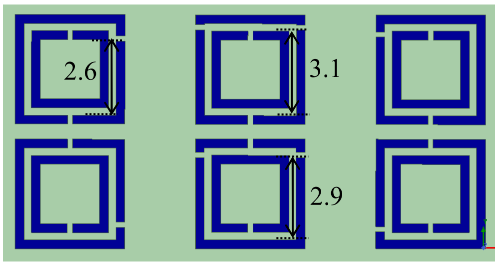


Fig. 6. SIW loaded with modified CSRRs, final iteration.

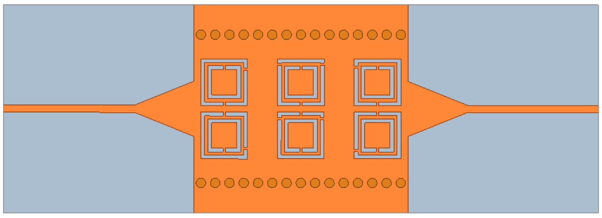


Fig. 7. Complete structure in SIW technology of the structure of Fig. 6.

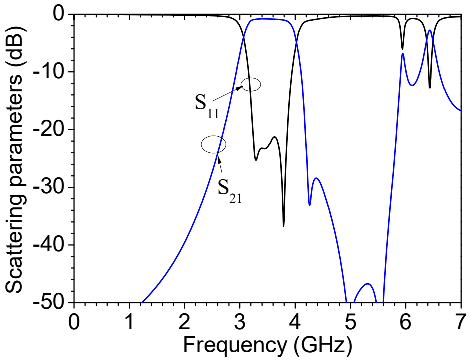


Fig. 8. Electrical response of the structure in Fig. 7 corresponding to the final iteration.

III. Experimental Results

In this section, we show the measured response of the filter prototype, which has been fabricated for validation purposes. Fig. 9 shows a photograph of the fabricated filter.

In Fig. 10, the measured electrical response of the filter has been represented along with the simulation results, showing a very good agreement.

IV. Conclusion

In this paper, a previously designed SIW-CSSRs filter has been modified and analyzed in order to improve its bandwidth. It has been shown that including new slots in the outer rings of the CSRRs for creating new resonances, and modifying appropriately their positions, it is possible to substantially increase the passband of the filter without increasing its longitudinal size. In particular, a five times improvement in bandwidth has been finally achieved, with a very good matching and very low insertion losses. A prototype of this new wideband filter has been fabricated and measured, and the simulations and measurements show a very good agreement, thus validating the proposed design.

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References

[1] X. P. Chen, and K. Wu, “Substrate integrated waveguide filter: basic design rules and fundamental structure features”. IEEE Microwave Mag., Vol. 15, pp. 108–116, 2014.

[2] X. P. Chen, and K. Wu, “Substrate integrated waveguide filters: design techniques and structure innovations”. IEEE Microwave Mag., Vol. 15, pp. 121–133, 2014.

[3] X. P. Chen, and K. Wu, “Substrate integrated waveguide filters: practical aspects and design considerations”. IEEE Microwave Mag., Vol. 15, pp. 75–83, 2014.

[4] A. Coves, G. Torregrosa-Penalva, A. A. San-Blas, M. A. Sánchez-Soriano, A. Martellosio, E. Bronchalo, and M. Bozzi, “A novel band-pass filter based on a periodically drilled SIW structure. Radio Sci., Vol. 51, pp. 328–336, 2016.

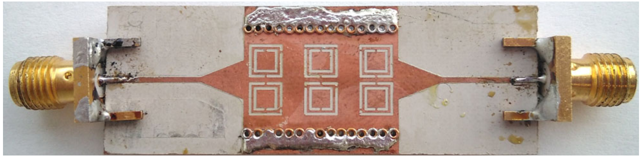

Fig. 9. Photograph of the fabricated filter corresponding to the structure represented in Fig. 7.

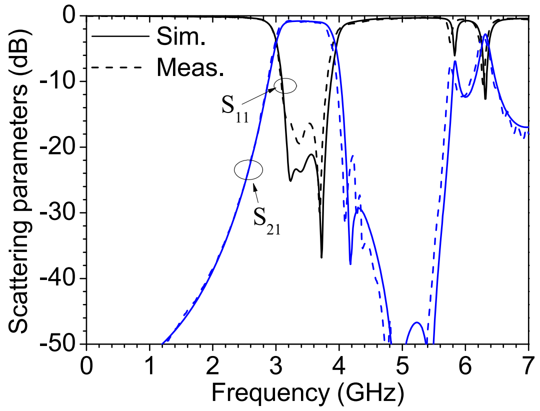

Fig. 10. Electrical response of the fabricated filter.

[5] L. Silvestri, E. Massoni, C. Tomassoni, A. Coves, M. Bozzi, and L. Perregrini, “Substrate integrated waveguide filters based on a dielectric layer with periodic perforations”, IEEE Trans. Microw. Theory Tech., Vol. 65, pp. 2687–2697, 2017.

[6] Y. Dong, C.-T. M. Wu, and T. Itoh, “Miniaturised multi-band substrate complementary split-ring resonators”, IET Microw. Antennas Propag., vol. 6, no. 6, pp. 611-620, May 2012.

[7] L. Huang, I. D. Robertson, W. Wu, and N. Yuan, “Substrate integrated waveguide filters with face-to-face broadside-coupled complementary split ring resonators," IET Microw. Antennas Propag., vol. 7, no. 10, pp. 795-801, Sep. 2013.

[8] J. D. Baena, J. Bonache, F. Martin, R. M. Sillero, F. Falcone, T. Lopetegi, M. A. G. Laso, J. Garcia-Garcia, I. Gil, M. F. Portillo, and M. Sorolla, “Equivalent-circuit models for splitring resonators and complementary split-ring resonators coupled to planar transmission lines”. IEEE Trans. Microw. Theory Techn., Vol. 53, pp. 1451–1461, 2005.

[9] Y. D. Dong, T. Yang, and T. Itoh, “Substrate integrated waveguide loaded by complementary split-ring resonators and its applications to miniaturized waveguide filters”. IEEE Trans. Microw. Theory Techn., Vol. 57, pp. 2211-2223, 2009.

[10] F. Martin, Artificial Transmission Lines for RF and Microwave Applications. John Wiley & Sons Ltd, 2015.

[11] J. Martínez, A. Coves, E. Bronchalo, A. A. San Blas, and M. Bozzi, “Band-pass filters based on periodic structures in SIW technology”. AEU Int. J. Electron. Commun., Vol. 112, p. 152942, 2019.

[12] A. Coves, A.A. San-Blas, and E. Bronchalo, “Analysis of the dispersion characteristics in periodic Substrate Integrated Waveguides”, AEU Int. J. Electron. Commun., Vol. 139, p. 153914, 2021.