Filters Modified ComplementarySplit-Ring Resonator Geometries with Face to Face Orientations in Substrate Integrated Waveguide for Applications as Band Pass

Jigyasa Sharma[1]*, Dhirendra Kumar[2], and Asok De[1]

[1]National Institute of Technology, Patna, Bihar, 800001, India;
[2] Raj Kumar Goel Institute of Technology, Ghaziabad, U.P. 201001, India.
*jigyasa.nsharma@gmail.com

Abstract. Novel face to face oriented square complementary split-ring resonators in substrate integrated waveguide (SIW) have been proposed and discussed. In the proposed structures the inner loop of the conventional CSRR is replaced by square and triangular slots. Like the conventional CSRRs, the proposed structures allow the implementation of a forward-wave passband which is propagating below the characteristic cutoff frequency of the waveguide. The proposed designs have the advantages of the better pass band and enhanced bandwidth compared to conventional CSRR for applications in miniaturized waveguide bandpass filters.

Keywords: Complementary split-ring resonators (CSRRs), electric dipoles, miniaturised planar waveguide filters, Substrate integrated waveguide (SIW).

1. Introduction

Split-ring resonators (SRR) and complementary split-ring resonators (CSRR) are the simplest metamaterial structures. The complementary split ring resonators (CSRRs) are the dual counterparts of split ring resonators (SRRs) and have been projected as effective constitutive elements for the synthesis of negative permittivity media based on resonant elements [1]. The dominant driving mechanism for CSRRs excitation is electric coupling, the condition being that the electric field must be applied in the axial direction. This is because in the complementary structure, the electric boundary conditions on the metal are replaced with magnetic ones and hence the structure becomes effectively dual. Due to this, the CSRRs electromagnetic behaviour is, in fact, an electric dipole excited by an axial electric field demonstrating propagation properties similar to an effective negative epsilon medium [2, 3]. Classical waveguide is not preferable in today's miniaturized electronic communications due to its bulk size and inability for post-tuning. When it comes to high-Q performance and low losses, even planar transmission lines are limited in performance. A solution to the aforementioned problems is a utilization of substrate integrated waveguides, which are very convenient for field transmission at high frequencies, especially, millimeter waves [4]. Furthermore, SIWs are highly applicable for mass production using well developed modern IC-technologies [5]. The field distribution in an SIW is similar to TE_{10} mode in a conventional rectangular waveguide. The electric field for TE_{10} mode within SIW is perpendicular to the surface and ground, and the direction of the magnetic field is parallel to the waveguide surface and perpendicular to the sidewalls. Hence the placement of CSRRs in an SIW is quite convenient.

As wireless communication relentlessly advances on frequency spectrum, there is a great need for designing small size active and passive circuits particularly filters at millimeter frequencies. Development of new compact, cheap components with low losses for Ka, V and W bands is strongly required from the point of satisfaction for fast increasing industrial needs. When the SIW is loaded with CSRRs, the CSRRs provide a stop band when they are resonant above the cutoff frequency [6-9] and this stop band switches to a pass band when the CSRRs are resonant below the cutoff frequency [10,11].There are derivations of CSRR orientations, such as face to face, back to back and side by side and each of these structures can be represented by equivalent circuit models [10]. In this paper, SIW loaded by novel unit cells of the modified CSRR pairs with face to face orientations are proposed and investigated. This alignment is able to provide strong coupling between the waveguide and the CSRRs since the electric field reaches maximum in the waveguide center.

In this paper, we present two novel structures which are obtained by appropriately modifying the conventional CSRR configuration in SIW with an inspection to their possible applications as pass band filters. As a validation of their working principles, the magnetic field distributions at the pass band centre frequency for the proposed structures have been presented. The transmission behavior both below and above the waveguide cutoff frequency has been considered on making this study distinctive from the previous research [6-8]. All simulations are performed using CST microwave studio [9].

2. SIW-CSRR structures and characterization

This part discusses the characteristics of CSRRs resonant below the waveguide cutoff frequency intending to their working principles and possible applications. According to the theory of evanescent-mode propagation, an additional pass band below the waveguide cutoff can be obtained for a waveguide by loading it with electric dipoles (CSRRs) [12], [13]. For the selected dielectric substrate RT/Duroid 5880 with ε_r = 2.2 and thickness of 0.787mm, the width of the waveguide, w is set to 3.5 mm (SIW1) in the design to fix the nominal cutoff frequency of the waveguide to 30 GHz and to 4mm (SIW2) for a cutoff frequency of 25.65 GHz. The metalized vias have a diameter of 0.25 mm and a center to center spacing of 0.4mm. The structure of the conventional CSRR and the layout of the unit cells are depicted in Figure 1.

Figure 2 shows the transmission response for the SIW1 and SIW2 with conventional CSRR pairs in face to face orientations as illustrated in figure 1(b), simulated with CST MWS. The values of a_1=a_2=g=d are optimized at 0.08 mm, b=0.65 mm, t= 0.43 mm and l =1.365mm. A pass band with a center frequency of 29 GHz (3dB bandwidth = 1.884GHz) is observed in SIW1 and at a centre frequency of 28 GHz for SIW2. SIW2 has been employed to obtain the resonance of face to face coupled CSRRs in the frequency band of waveguide operation, and SIW1 is used to get the resonance below the cutoff frequency of 30GHz. Hence a pass band can be obtained in both ways by using coupled CSRRs in a SIW. A microstrip feed line is used to excite the SIW, with a tapered transition. The CSRRs have not been etched on the ground to preserve its integrity as in high- frequency system design noise and radiation losses may be introduced by the ring slots.

3. Proposed structures with improved performance

This section presents the configurations of the proposed SIW-CSRR unit cells, subsequently explaining the corresponding transmission behaviour followed by the filter applications of the proposed structures.

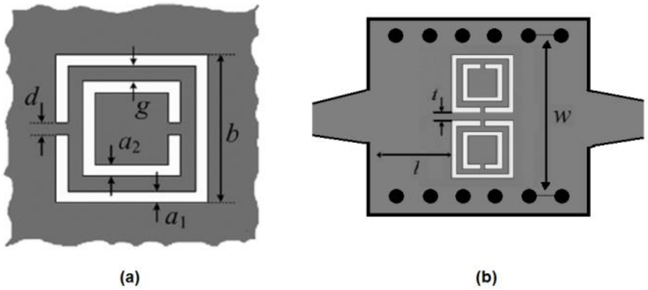

Fig.1. (a) The conventional square CSRR topology (grey zone represents metallization) (b) Face to face configuration of SIW-CSRR unit cells.

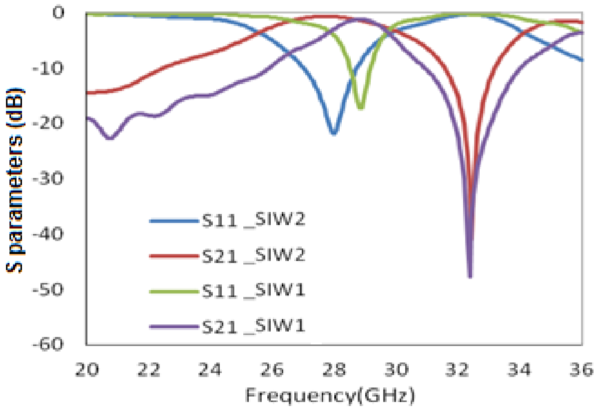

Fig.2. Transmission response for the SIW1 and SIW2 with conventional CSRR pairs.

3.1 *Configurations and Transmission Responses*

The layout of the SIW structure with a pair of modified CSRR pairs with face to face orientations is shown in Figure 3. In the structure in Figure 3(a), henceforth referred to as the structure-1, the inner loop of the conventional CSRR is replaced by a square slot of the same dimensions. In the second structure henceforth referred to as the structure-2, the square shape is replaced by an equilateral triangle with the same dimensions of the side as that of the original square. Figure 4(a) and 4(b) depicts the transmission responses of structure-1 and structure-2 respectively when incorporated in SIW1. Both the structures illustrate a better pass band with improved 3 dB bandwidths of 3.18 GHz and 7.0825 GHz for structures 1 and 2 respectively, in comparison to the conventional CSRRs in SIW1. The improved bandwidth of structure-1 is attributed to the increase in the resonant frequency of the effective capacitance between the central patch and ground for a conventional CSRR is nullified.

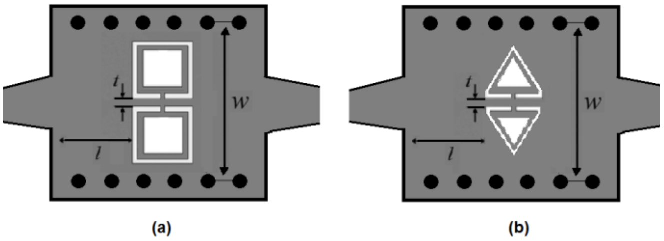

Fig.3. Configurations of the proposed SIW-CSRR unit cells: (a) Structure-1, (b) Structure-2.

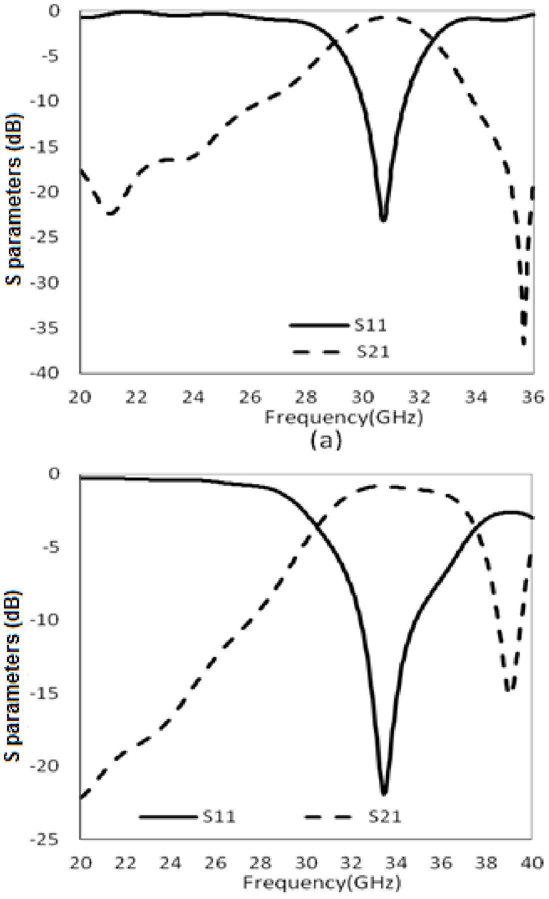

Fig.4. Transmission responses of the proposed SIW-CSRR unit cells: (a) Structure-1, (b) Structure-2.

In structure-2 the perimeter of the inner slot of CSRR is reduced compared to structure-1, as a consequence, the centre frequency of the pass band increases further giving rise to a much wider pass band which is now above the waveguide cutoff.

Figure 5 depicts the simulation results of the magnetic field distributions in the middle plane of the substrate at the center frequency of the pass band for the conventional CSRR, structure-1 and structure-2 respectively. As evident from Figure 5 the propagation of the evanescent mode is highly reliant on the middle metal region between the two CSRRs and hence on altering the configurations of the inner ring of the CSRR no harm is done to this mode.

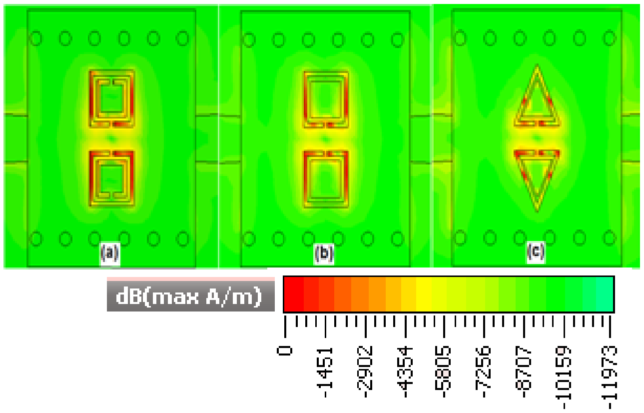

Fig.5. Magnetic field distributions of the (a) Conventional CSRR unit cell (b) Structure-1, (c) Structure-2.

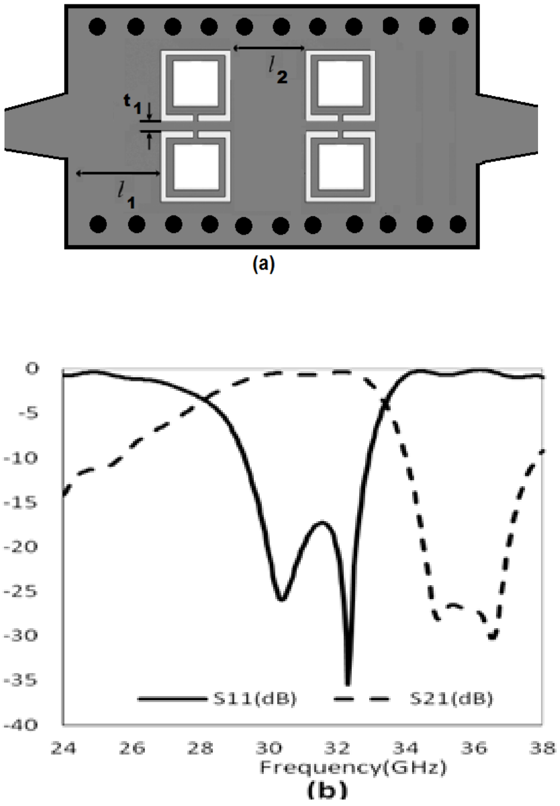

Fig. 6. (a) Two pole filter with Structure-1 unit cells (b) its transmission response.

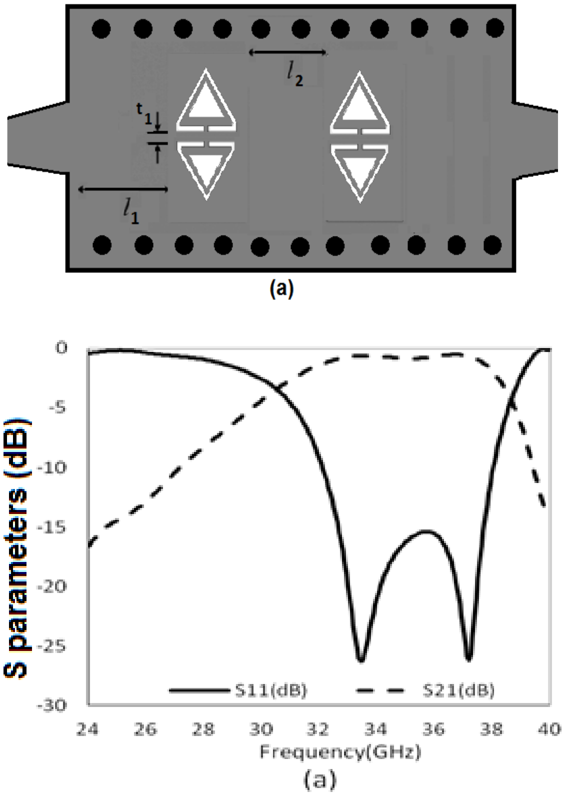

Fig. 7. (a) Two pole filter with Structure-1 unit cells (b) its transmission response.

3.2 Filter applications of the proposed structures

This section presents two types of filters based on the proposed new resonators (Structure-1 and Structure-2 unit cells respectively). The substrate, thickness, via diameter and center to center spacing of vias are same as for the above-mentioned cases. Figures 6(a) and 7(a) depict the two pole filters based on Structure-1 and Structure-2 unit cells respectively. For both the filters shown in Figure 6 and 7 l_1=l ,t_1=t and l_2=1.03mm.The transmission responses are shown in Figures 6(b) and 7(b).

4. Conclusion

Two novel structures are proposed as modifications of the conventional CSRRs in face to face configurations. Based on the theory of pass band created below the cutoff of SIW by CSRRs the proposed structures provide an enhanced bandwidth compared to the conventional CSRRs. By designing two pole filters based on the proposed structures it has been shown that the proposed structures are capable of providing suitable filtering characteristics.

References

[1] J. D. Baena, J. Bonache, F. Martin, R. Marques, F. Falcone, T. Lopetegi,M. A. G. Laso, J. Garcia, I. Gil, and M. Sorolla, Equivalent-circuit models for split-ring resonators and complementary split-ring resonators coupled to planar transmission lines, *IEEE Transactions on Microwave Theory and Techniques*, vol. 53, no. 4, pp. 1451-1461, Apr. 2005.

[2] M. Gil, J. Bonache, J. Garcia, J. Martel, F. Martin, Composite right/left-handed metamaterial transmission lines based on complementary split-rings resonators and their applications to very wideband and compact Filter design', *IEEE Transactions on Microwave Theory and Techniques*, 2007, 55, (6), pp. 1296-1303.

[3] J. Bonache, M. Gil, I. Gil, J. Garcia, and F. Martin, On the electrical characteristics of complementary metamaterial resonators," *IEEE Microwave Wireless Components Letters*, vol. 16, no. 10, pp. 543-545, Oct. 2006.

[4] Deslandes D. and K. Wu, Design considerations and performance analysis of substrate integrated waveguide components, *European Microwave Conference*, pp, 881-884, 23 - 27 sept. 2002.

[5] Wu K., D. Deslandes, and Y. Cassivi, The substrate integrated circuits-a new concept for high-frequency electronics and optoelectronics, *TELSKIS 2003, NIS, Serbia and Montenegro*, October 2003.

[6] X. Zhang, Z. Yu, and J. Xu, Novel band-pass substrate integrated waveguide filter based on complementary split ring resonators, *Progress in Electromagnetic Research.*, vol. 72, pp. 39 - 46, 2007.

[7] W. Che, C. Li, K. Deng, and L. Yang, A novel bandpass filter based on complementary split rings resonators and substrate integrated waveguide, *Microwave and Optical Technology Letters*, vol. 50, no. 3, pp. 699 - 701, Nov.2008.

[8] Jin J. D and D. H Yu, Substrate Integrated Waveguide Band-pass Filter with Coupled Complementary Split Ring Resonators, in *General Assembly and Scientific Symposium (URSI GASS)*, 2014, pp. 1 - 4.

[9] CST Microwave Studio – www.cst.com

[10] Y. D. Dong, T. Yang, T. Itoh, Substrate integrated waveguide loaded by complementary split-ring resonators and its applications to miniaturized waveguide filters, *IEEE Transactions on Microwave Theory and Techniques*, 2009, 57, (9), pp. 2211‑2223

[11] Q. L. Zhang, W. Y. Yin., S. He, and L. S. Wu, Compact Substrate Integrated Waveguide (SIW) Bandpass Filter With Complementary Split-Ring Resonators (CSRRs), *IEEE Microwave Wireless Components Letters*, vol. 20, no. 8, pp. 428 - 428, August 2010.

[12] J. Esteban, C. C. Penalosa, J. E. Page, T. M. Martin-Guerrero, and E. Marquez-Segura, Simulation of negative permittivity and negative permeability by means of evanescent waveguide modes-theory and experiment, *IEEE Transactions on Microwave Theory and Techniques*, vol. 53, no. 4, pp. 1506 - 1514, Apr. 2005.

[13] P. Belov and C. Simovski, Subwavelength metallic waveguides loaded by uniaxial resonant scatterers, Physical Review E, vol. 72, pp. 0366181 - 03661811, Sep. 2005.

Biography of the authors

Jigyasa Sharma received her MSc degree in electronics from Banasthali Vidyapeeth, Rajasthan (1999) and Ph.D. in Applied Physics (Microwaves) from Delhi College of Engineering (University of Delhi) (2012). She worked as Assistant Professor with ABES Engineering college Ghaziabad. Currently, she is a post Doctoral fellow at NIT Patna with fellowship from University Grants Commission. Her current research activities include metamaterial design, microwave and millimeter wave filter design and substrate integrated waveguides.

Dhirendra Kumar received his ME (Electronics & Communication Engineering) and Ph.D. (ECE) from Delhi College of Engineering,(University of Delhi). He is presently Professor and Head of Electronics and Communication Engineering Department at Raj Kumar Goel Institute of Technology, Ghaziabad. His area of research is Microwave Technology and Antenna Engineering.

Asok De received the Bachelor of Engineering in Electronics & Telecommunication Engineering, Master of Engineering in Electronics & Telecommunication Engineering from Jadavpur University in 1978 and 1980 respectively. He received his Doctor of Philosophy (Ph.D.) from Indian Institute of Technology Kharagpur in 1986. He is, at present, professor in Electronics and Communication Engineering, Delhi Technological University and on lien, working as the Director of NIT Patna. His fields of interest are antennas, Numerical techniques in Electromagnetic, Transmission lines etc.