A Highly Selective Band Pass Filter Using a Square Resonator

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Abstract. This work explores the development of a compact band pass filter using (CSRRs) Resonators on an FR-4 substrate. The configuration consists of two CSRRs coupled with two identical resonators and is optimized to operate in the X-band frequencies, at a 10 GHz center frequency with an insertion loss (S21) of around –1.38 dB. The filter was simulated using ADS Momentum and validated using CST Microwave Studio (CST-MW), with good agreement reported between both tools. The final design has compact dimensions of 9.42 × 6.05 mm².
Keywords: CSRR cells, band-pass, X band, simulator, filter

1 Introduction

Metamaterials, often referred to as left-handed materials, are engineered periodic structures composed of metallic and dielectric elements smaller than the operating wavelength, they exhibit unique electromagnetic properties, such as negative permittivity and permeability. In 1964, the Russian researcher Veselago presented the first idea on their electromagnetic characteristics [1]. Since then, this topic has been in hibernation until 2000, the practical development of metamaterials was achieved by D. R. Smith [2]. The capacity to regulate or alter the material's permittivity and permeability to achieve a behavior tailored to a certain application is the most significant feature of this structure. Metamaterials [3-6] are a broad field that draws researchers from globally. They enable work in a variety of applications and optimize the performance of microwave devices, particularly when it comes to circuit miniaturization and the integration of enhanced functional properties (such as high rejection, dual-band filtering, and the harmonic suppression). Through the use of left-handed materials based on complementary split-ring resonators (CSRRs) and square split-ring resonators (SRRs) [7, 8], tiny microstrip low-pass filters, band-pass filters, stop band

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filters, and others for usage with microwave frequencies. These resonators' fundamental cells are incredibly tiny concerning the guided wavelength. It is acknowledged that sizes less than λg/4 are the fixed limit of homogeneity. To achieve enhanced performance, such as size reduction, Enhanced out-of-band rejection, and the suppression of parasitic higher-order modes of harmonic responses, we will provide a novel band-pass filter in this study that uses CSRR structures.

2 CSRR cell theory

To encourage downsizing and to enhance the low-pass filter's stop-band rejection, this research uses CSRR-based metamaterials [9, 10]. Inductors (s) and capacitors (C) are arranged in parallel to produce the CSRRs, and the LC circuit is electrically coupled to the host transmission line. The techniques outlined in [11,12] may be used to compute the equivalent circuit model of the CSRR loaded transmission line and their associated with inductors and capacitors. The CSRR generates a clean rejection stop band and negative effective permittivity at resonance. The CSRR unit cell geometry with corresponding lumped-element model is displayed in Figure 1. The transmission line associated with each CSRR that has a transmission resonance frequency defined by the following expression:

$$f = \frac{1}{(2\pi\sqrt{LC([C_c+C])})} \tag{1}$$

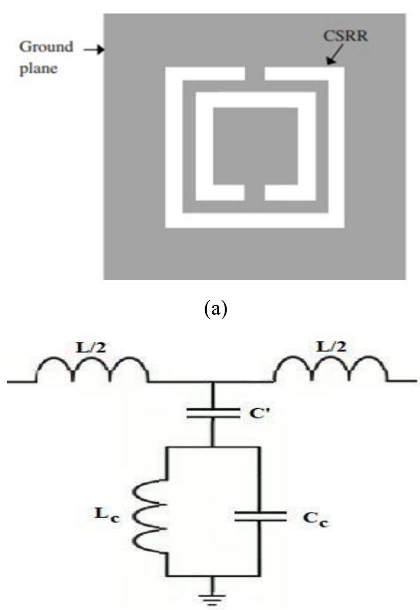

Fig. 1. (a) CSRR unit cell geometry, (b) CSRR lumped-element equivalent circuit.

Adjusting the CSRR geometry allows for the tuning of the resonant frequency, including length, gap, thickness, and the spacing between the concentric rings. According to [13-14], CSRR can significantly reduce the filter's size while preserving excellent stop band attenuation. Furthermore, compared to traditional microstrip technology, integrating these complementary split-ring resonators (CSRRs) periodically with a coplanar waveguide (CPW) provides multiple design advantages, such as the simplicity of shunt realization and the ability to mount both active and passive lumped elements [15]. We present a novel design for band-pass filter using CSRR cells are patterned into the center conductor to increase the bandwidth and rejection band.

3 Creation of a filter that passes through the base of CSRR cells

3.1 The idea of a highly selective band pass filter

This study aims to develop a band-pass filter using CSRR cells. The filter is validated for use in the X band on a type FR4 substrate. The final circuit consists of two CSRR cells coupled with two identical cells.

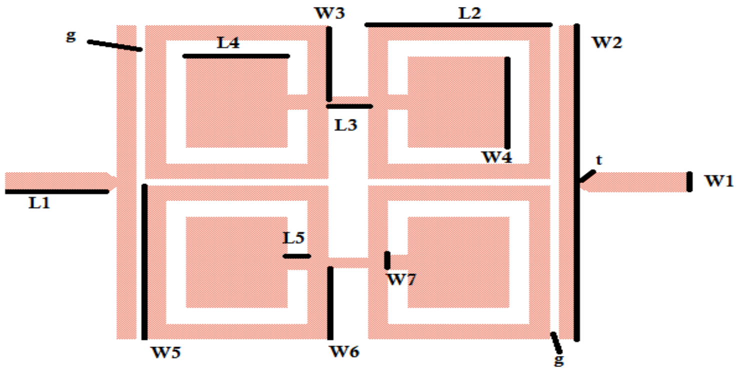

Fig.2. The suggested band pass filter layout based on CSRR resonators.

The definition of a filter structure that passes through a band centered around 10 GHz is the first step before the final filter structure is validated. The validation of a circuit that functions as a filter with a very tight band-pass filter was made possible by this initial study (Figure 2).

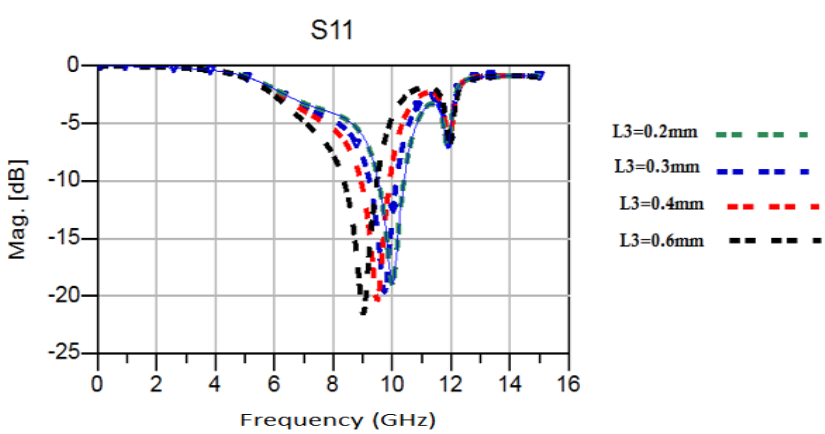

Fig. 3. The reflection coefficient S11 versus frequency for various values of the distance L3.

The following table displays the optimized dimensions:

Table 1. Optimized dimensions

Parameters	**Value in mm**
L1	1.5
L2	2.7
L3	0.2
L4	1.5
L5	0.3
W1	0.385
W2	6.08
W3	1.38
W4	1.77
W5	2.96
W6	1.38
W7	0.3
t	0.19
g	0.133

The proposed structure was developed through a systematic design optimization and a detailed parametric analysis of the cell size. The length L3 between the two cells is one of the parameters that affects the central frequency and the size of the bandwidth.

The following figure illustrates how adjusting the L3 value may change and shift the center frequency, causing the band shifted to -3 dB while maintaining a high degree of adaptability. Figure 3 shows that when the distance L3 increases, the central frequency decreases, and the bandwidth may decrease. The designed filter has an extremely narrow and selective band-pass filter.

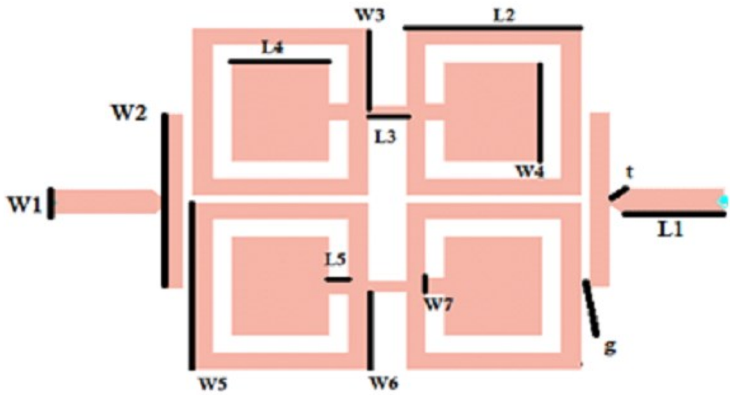

Fig.4. The suggested pass band filter

Table 2. Optimized dimensions

Parameters	Value in mm
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As seen in Figure 4, to elucidate the bandwidth, another parametric study was conducted on the size of the circuit of excitation (in T form) at the input of each port. This study was conducted on the size of W2, the gap, and the position of the circuit of excitation, which allowed for the validation of the final filtering structure shown in Figure 4.

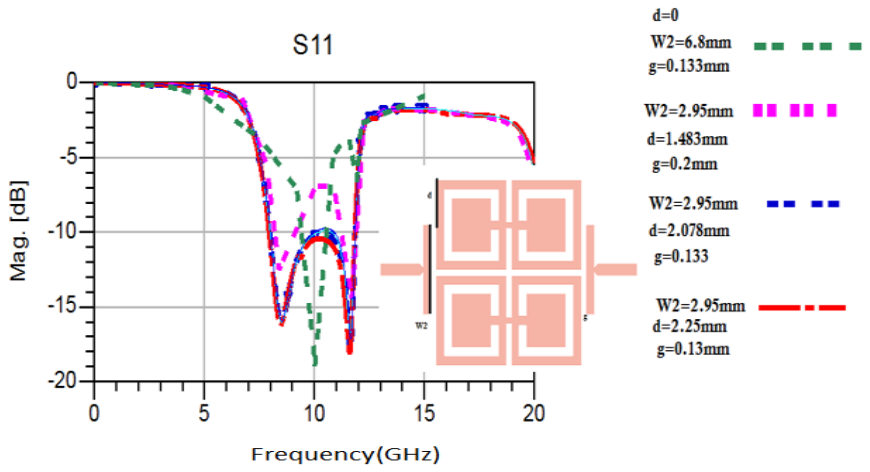

Fig.5. Parametric analysis to increase the proposed bandpass filter

The parametric study shows that as the size of W2 decreases, a larger bandwidth is created, allowing the X band application to be covered with a bandwidth of -3dB equivalent to [8 GHz, 11.75] GHz, and the loss of insertion equals -1.38dB for a central frequency of 10 GHz. The obtained results are compared using a second 3D electromagnetic simulator CST-MW in order to validate the results at the ADS simulator. A comparison of the obtained parameters S is shown in figure 6.

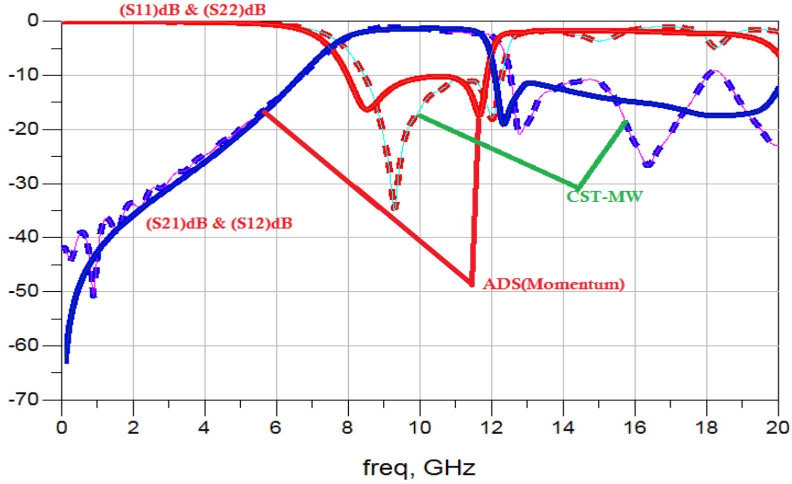

Fig.6. Comparison of ADS and CST-MW results

It can be seen that the simulation results from ADS and CST are in good agreement, with a little discrepancy caused by the various milling techniques used. Additionally, there is a finished ground plane at the CST level in contrast to an infinite ground plane on Momentum. It has been determined that the optimized structure exhibits a good rejection of the outside of the bandwidth. The band-pass filter structure is designed for applications in the X band with small and compact dimensions.

4 Conclusion

In this work, we have presented a novel band pass filter realized with periodic CSRR structures. The technique based of the use of a combination of two CSRR cells coupled to two identical cell forms. The two cells were optimized and validated to achieve the final filter design. Then, the design was validated across various EM simulation tools to confirm its performance. Simulation results from ADS and CST show good agreement, and optimized structure provides high out-of-band rejection. The final band-pass filter structure is suitable for integration into communication systems in the X band with a bandwidth of -3 dB, and the insertion loss S21 is equal to -1.38 dB at a center frequency of 10 GHz, with extremely small and compact dimensions of the validated filter are 9.42x6.05 mm^2.

References

1. Bendaoued M , Mandry R, Fouad A, Terhzaz J , In Proceedings of the 2nd International Conference on Computing and Wireless Communication Systems,(2017).
2. Bendaoued M , Es-Saleh A , Lakrit S, De A , Das S, Faize A, In Proceedings of the International Conference on Smart City Applications,(2022).
3. Su L, et al, Modeling and applications of metamaterial transmission lines loaded with pairs of coupled complementary split-ring resonators (CSRRs). IEEE Antennas Wireless Propagation Letter. 15, 15(2015)
4. Bendaoued M , Mandry R , El Abdellaoui L , Fouad A , Latrach M , Lakhssassi A, Coplanar waveguide low pass filter based on square complementary split ring resonator with wide rejection. Telkomnika (Telecommunication, Computing, Electronics and Control). 2314-2319, (2020).
5. Elmajid H , Terhzaz J , Ammor H , Chaïbi M, Mediavilla S, A new method to determine the complex permittivity and complex permeability of dielectric materials at x-band Frequencies. International Journal of Microwave and Optical Technology.34-39.(2015)
6. H. Elmajid, J. Terhzaz, H. Ammor, M. Chaïbi, A. Mediavilla, Determination of the Complex Permittivity of Each Layer for a Bi-layer Dielectric Material Using Transmission (ABCD) Matrix in Ku-Band frequency, Journal of Engineering Science and Technology Review, 61-65 (2016).
7. Nilesh K , Labade R. P, Metamaterial based ultra wide band low pass filter using new configuration of complementary split ring resonator cell. International Conference on Information, Communication, Engineering and Technology (ICICET),(2018).
8. Hanane N., et al, Novel microstrip low pass filter based on complementary split- ring resonators. International Journal of Modern Communication Technologies & Research (IJMCTR),(2014)
9. Zeng H. Y., et al, Compact microstrip low-pass filter using complementary split ring resonator with ultra-wide stopband and high selectivity. Microwave and Optical Technology Letters. (2009).
10. Hayati M., Moghadam P.,Compact microstrip lowpass filter with ultra-wide stopband using a modified circular resonator. Microwave Journal. 152-160(2015).
11. Gil M., et al.,Metamaterial filter: A review. Metamaterials. 186-197(2008).
12. Burak O, et al. , An equivalent circuit model for nested split-ring resonators. IEEE Transactions on Microwave Theory and Techniques.3733-3743(2017).
13. Kehn M. N. M., et al., Split-ring resonator loaded waveguides with multiple stopbands. Electronics Latters. 714-716(2008).
14. Lin X, Cui T, Controlling the bandwidth of split ring resonator. IEEE Microwave and Wireless Components Letters.245-247(2009).
15. Wolff I., Coplanar Microwave Integrated Circuits.New Jersey John Wiley & Sons Inc. 377-483(2006).