International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 05, May-2021

X-Band Metamaterial Bandpass Filter Design

Shikhar Chandra
School of Electronics Engineering
Vellore Institute of Technology
Vellore, India

***Abstract*— Bandpass filters have a variety of applications in fields of wireless engineering. In recent decades, metamaterial-based structures have been incorporated in design of passive microwave devices, one of them being filters. Metamaterial based bandpass filter design for operation in X-band (9.1GHz) is proposed in this paper. The proposed filter is composed of symmetrical square shaped Split Ring Resonators (SRRs) and Complementary Split Ring Resonators (CSRRs), coupled parallelly to a microstrip line on a Rogers substrate. Designs with multiple SRRs and CSRRs are also proposed and their performances are compared. The advantages of the proposed filters, namely, high in-band return loss, low passband insertion loss and compact size, have been reported. The computer-aided design (CAD) and frequency domain simulations are performed using commercial simulator, CST Microwave Studio.**

Keywords—Metamaterial; Bandpass Filter; Split Ring Resonator; Complementary Split Ring Resonator; CST Microwave Studio

I. INTRODUCTION

The fast-paced development of wireless communications presents a great demand for compact microwave devices. Couplers, power dividers, filters and antennas are being designed to achieve a miniaturized design for a better performance. Filters can be designed in various ways and by using different components. Low frequency filters can be created using lumped elements, with capacitors and inductors connected using a line printed on the printed circuit board (PCB) [3]. There exist bandpass and band-stop filters with half wavelength and quarter wavelength resonators. The size of these filters is very large at the lower end of microwave frequencies. Many microstrip filter designs have been proposed for size miniaturization and performance enhancement in the past few decades but there are still some areas for improvements.

Metamaterial based structures have been proposed theoretically as artificial materials having both electric permittivity and magnetic permeability negative. These are also known as Double Negative (DNG) materials and give rise to a negative refractive index, a property not seen in natural materials. Split Ring Resonators (SRR), which is an artificial structure of two concentric annular rings with splits on opposite sides, is an example of a DNG material [4]. Due to their low radiation losses, high-performance characteristics and small electrical length at resonance, researchers have been investigating various ways to use SRR based structures to improve microwave devices. Various metamaterial structures can be considered artificial resonators as complementary split ring resonator (CSSR) and spiral resonators, but the most popular are circular and square type split ring resonators. In order to enhance the magnetic coupling between the microstrip line and SRRs, the preferred topology for these resonators is the square type [5].

Band pass filters using metamaterial structures have been previously proposed. These include waveguide resonator filters having unit cells of SRRs and CSRRs and Substrate Integrated Waveguide (SIW) filters having Stepped Impedance CSRR unit cells. Although these filters provide a good performance and power handling capacity, the drawback of these is that they are bulky and not easy to integrate in miniaturized environments. Microstrip band-pass filters are a better alternative when it comes to size considerations and cost of manufacturing. In this paper, a square split ring resonator along with complementary split ring resonator-based design of microstrip bandpass filter is proposed.

II. PREVIOUS WORKS

A circular split ring resonator based bandpass filter was proposed by [6] to operate at a frequency of 9 GHz. The filter was developed on a microstrip structure and the effects of varying the ring gaps, ring separation and ring widths were investigated.

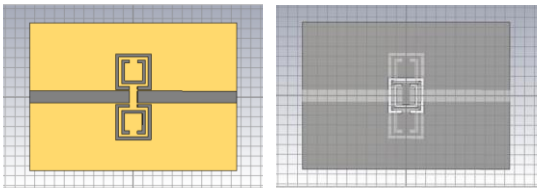
To improve the performance of filter proposed by [6], an X-band bandpass filter was proposed by [1], using only square-type, series SRRs. The design provided very narrow bandwidth and a tunable center frequency range. A similar design was proposed by [2], but the square type SRRs were coupled parallelly to the microstrip line. This filter was unique in its design as it incorporated a varactor diode to tune the capacitance of the SRRs and therefore change the resonant frequency.

Multiple double-sided SRRs were employed by [7] to achieve a band-stop response of the filter. The double-sided structure involved having SRRs on both the top and the bottom of the dielectric substrate, with the bottom layer rings having complementary orientations of the gaps. Two similar designs were earlier proposed by [8] wherein the first design had multiple square type SRRs loaded alongside a central microstrip line and the second design had multiple CSRRs just underneath the central microstrip line. The filter had a band-stop response over the frequency range of 4 – 5.8 GHz, and it was concluded that with increase in number of SRRs, better rejection levels are achieved. A narrow band pass filter was fabricated by [5], introducing metallic vias between the conducting strip and the ground plane, to make the structure have negative permittivity along with negative permeability due to SRRs.

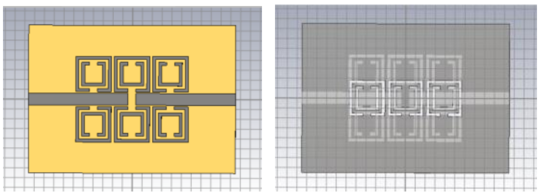
International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 05, May-2021

III. PROPOSED DESIGN

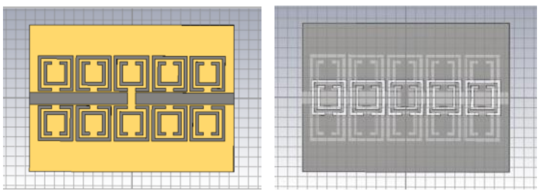
A 3-D computer aided design (CAD) model for the proposed filter was developed using the commercial design and simulation software, CST Microwave Studio. The layout of the filter was inspired by [2]. The design is composed of two double squared SRRs, coupled parallelly with a microstrip line in between, and a double squared CSRR in between the two SRRs as shown in Fig 1. The CSRR is structure is obtained by etching SRR in the ground plane. The substrate chosen was Rogers RT5880 (lossy) with relative permittivity of 2.2 and loss tangent of 0.0009. Substrate thickness was kept 1.6 mm. The ground layer and the microstrip conducting lines are of Perfect Electric Conductor (PEC) and have a thickness of 0.035 mm. The width of the conducting strip is 1.2 mm. The outer SRR ring has length of 3.6 mm and the inner SRR ring has length of 2.4 mm. All the rings are 0.3 mm wide, while the split gaps are all 0.8 mm wide. The split ring gap is appropriately chosen to achieve the desired resonant frequency. Increasing this gap would decrease the capacitance, thereby increasing the resonant frequency of the equivalent LC tank resonator, and vice-versa. The dimensions of the filter are 21 X 15 mm, providing a miniaturized design. Compared to the size of the filter proposed by [1], the length of the filter is reduced by 12.5%, owing to the parallel topology of SRRs instead of a series topology. Experimental design revealed that by increasing the number of SRRs and CSRRs, the pass band insertion loss can be improved. Placing the resonators on



(a) (b)
Fig 1. Bandpass filter with single CSRR- (a) Top view, (b) Bottom view



(a) (b)
Fig 2. Bandpass filter with 3 CSRRs- (a) Top view, (b) Bottom view



(a) (b)
Fig 3. Bandpass filter with 5 CSRRs- (a) Top view, (b) Bottom view

either side of the microstrip line, equal gap was maintained between the adjacent SRRs as shown in Fig 2. and Fig 3.

IV. SIMULATION RESULTS

Using the Frequency Domain Solver (FDS), the S-parameters for the different filter designs were simulated. S_{21} (insertion loss) and S_{11} (return loss) are plotted over the X-band frequency range of 8-10 GHz. Shown in Fig 4, Fig 5, Fig 6 and Fig 7 are the S-parameter curves for bandpass filter having no CSRR, single CSRR, 3 CSRRs and 5 CSRRs respectively. Through these curves, various metrics, namely the center frequency, 3-dB bandwidth, fractional bandwidth, minimum return loss and maximum insertion loss are calculated for each filter design. These results are tabulated as

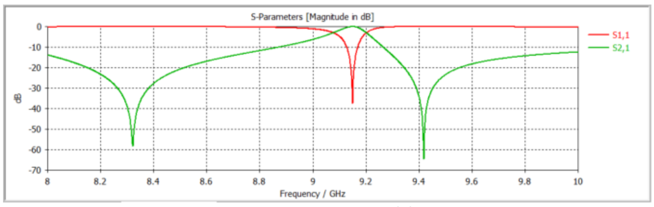


Fig 4. Return Loss and Insertion Loss of filter without CSRR

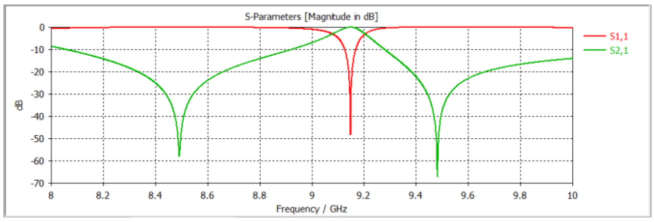


Fig 5. Return Loss and Insertion Loss of filter with single CSRR

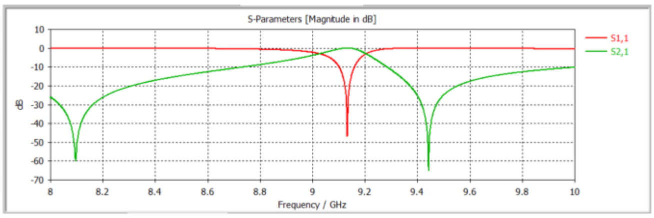


Fig 6. Return Loss and Insertion Loss of filter with 3 CSRRs

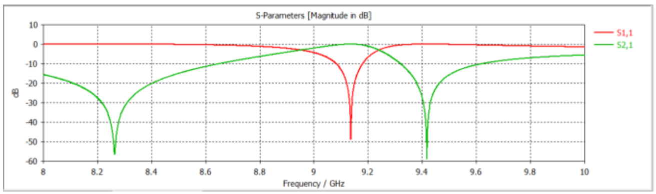


Fig 7. Return Loss and Insertion Loss of filter with 5 CSRRs

shown in Table I.

The proposed filter having only SRRs in its structure provided a minimum return loss of 37.29 dB at 9.15 GHz, which accounts for an enhancement (in return loss) of 56.6% with respect to the filter in [1]. In addition, the insertion loss was simulated to be 0.052 dB, with around 85% improvement with respect to [1]. 3 dB bandwidth was calculated as 125.4 MHz; thus, the fractional bandwidth (FBW) is around 1.37%.
Filter design having an additional CSRR etched in the ground plane gave a significant improvement in minimum return loss and slightly decreased the fractional bandwidth and maximum insertion loss. Similar results were obtained for the

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 05, May-2021

design having triple CSRRs etched, wherein, the 3 dB bandwidth had increased by 41% from the single CSRR design. A large increase in 3 dB bandwidth was observed for the filter having 5 CSRRs. From the S-parameter plots, the 3 dB bandwidth was calculated to be 284.9 MHz. The Insertion Loss and Return Loss were the best in this case.

TABLE I. RESULTS FOR DIFFERENT FILTER DESIGNS

Filter Design	*Center Frequency (GHz)*	*3 dB Band-width (MHz)*	*Fractional Bandwidth (%)*	*Minimum Return Loss (dB)*	*Maximum Insertion Loss (dB)*
No CSRR	9.15	125.4	1.37	37.29	0.052
Single CSRR	9.148	124.8	1.36	48.163	0.050612
3 SRR and CSRR	9.132	176	1.92	46.74	0.044788
5 SRR and CSRR	9.136	284.9	3.11	48.881	0.039342

V. CONCLUSION

Design and simulation of the X-band metamaterial based bandpass filter is presented in this paper. The filter was designed to have an operating frequency of 9.1 GHz. A comparative study was performed between filters having varying number of SRRs and CSSRs and the simulation results have been reported by means of S-parameter plots. It is concluded that adding multiple SRRs and CSRRs improves the return loss and insertion loss performance of the filter. The center frequency varies in the order of few megahertz which is negligible. The bandwidth of the filter, however, increases with a greater number of SRRs. All the proposed designs are well suited for radar applications as they have a narrowband with fractional bandwidth less than 5%. The length of the filter has also been reduced to give a more compact structure, hence achieving device miniaturization.

REFERENCES

[1] M. Hesham and S. O. Abdellatif, "Compact Bandpass Filter Based on Split Ring Resonators," 2019 International Conference on Innovative Trends in Computer Engineering (ITCE), 2019, pp. 301-303, doi: 10.1109/ITCE.2019.8646511.

[2] Zhao, Yj., Zhou, Bc., Zhang, Zk. et al. A compact tunable metamaterial filter based on split-ring resonators. Optoelectron. Lett. 13, 120–122 (2017).

[3] Teguh Praludi, Yaya Sulaeman, Dayat Kurniawan, and Iqbal Syamsu , "Narrow-band microwave planar filter using multiple-poled hairpin resonators", AIP Conference Proceedings 1755, 170004 (2016), doi: 10.1063/1.4958606

[4] J. B. Pendry, A. J. Holden, D. J. Robbins and W. J. Stewart, "Magnetism from conductors and enhanced nonlinear phenomena," in IEEE Transactions on Microwave Theory and Techniques, vol. 47, no. 11, pp. 2075-2084, Nov. 1999, doi: 10.1109/22.798002

[5] I. Gil, J. Bonache, J. Garcia-Garcia, F. Falcone and F. Martin, "Metamaterials in microstrip technology for filter applications," 2005 IEEE Antennas and Propagation Society International Symposium, 2005, pp. 668-671 Vol. 1A, doi: 10.1109/APS.2005.1551409.

[6] R. L. Defitri and A. Munir, "X-band microstrip narrowband BPF composed of split ring resonator," 2016 Progress in Electromagnetic Research Symposium (PIERS), 2016, pp. 3468-3471, doi: 10.1109/PIERS.2016.7735347.

[7] R. N. Mishra, A. Arora, S. Singh and S. Bhattacharyya, "A split ring resonator (SRR) based metamaterial structure for bandstop filter applications," 2017 IEEE Applied Electromagnetics Conference (AEMC), 2017, pp. 1-2, doi: 10.1109/AEMC.2017.8325685.

[8] M. K. T. Al-Nuaimi and W. G. Whittow, "Compact microstrip band stop filter using SRR and CSSR: Design, simulation and results," Fourth European Conference on Antennas and Propagation (EuCAP), Barcelona, Spain, pp. 1-5, April 2010.