Microwave Review
July 2024, Vol. 30, No. 1, pp. 75-80
DOI: 10.18485/mtts_mr.2024.30.1.10

Split Ring Resonator Loaded Conformal Loop Filter for S-Band Applications

Chandana Muniraja, Harshini Kariyanna, Dileep Kempanna, Varun Dwarakanath

Abstract – **This paper elucidates the design of an S-band conformal loop filter. A combination of loop filter loaded with split ring resonator loading is proposed for the Band Pass Filter (BPF) in the proposed design. The reduced insertion loss and improved fractional bandwidth are achieved using the symmetrical tuning stubs in the loop filter. The operating range of the proposed filter in the S-band is between 2.12 GHz to 2.24 GHz, with a fractional bandwidth of 5.5% and a reduced insertion loss of 1.1 dB. The conformal geometry has been simulated on an EM solver, and the simulation results are analyzed. The simulation results of conformal geometry show an excellent match with the planar structure. The proposed filter is further fabricated, and the S-parameters are measured. The S-parameter results of the realized filter from simulations match closely with those from measurements of prototypes but with a small shift in frequency. The measured filter operates at 2.21 GHz to 2.41 GHz with a Fractional Band-Width (FBW) of 8.6% and a minimum insertion loss of 1.4 dB.**

Keywords – **Conformal, loop filter, S-band, Split ring resonator, symmetrical tuning.**

I. INTRODUCTION

In the rapidly evolving landscape of wireless communication systems, the demand for advanced antenna and filter technologies has intensified to meet the challenges posed by ever-increasing information rates. Among all the proposed techniques, conformal filters and conformal array antennas have emerged as promising approaches in the field of wireless communication [1]. Conventional planar filters are effective in many ways but are not capable of adapting to the non-planar environment [2]. Conformal filters, on the other hand, are flexible and conform seamlessly to their surroundings. Hence, the development of conformal filters with small sizes and good bandwidth is the key point in developing wireless communication systems [3-6].

A miniaturized bandpass conformal microstrip loop filter is designed for S-band applications. The main purpose of a microstrip loop filter is to filter out the inessential frequencies from a signal while allowing the essential frequencies to pass through [7, 8]. The microstrip loop filters are generally constructed using microstrip transmission lines [9, 10], which consist of conductive traces on the dielectric substrate [11]. The loop geometry is carefully designed to achieve the desired characteristics of the filter [12].

To improve the design of the microstrip bandpass filter response, Split Ring Resonators (SRRs) are added to the design. A hexagonal SRR is an electromagnetic resonator with a hexagonal shape and a split ring structure that works on resonant electromagnetic principles [9, 13]. SRRs exhibit resonant behavior at specific frequencies and reduce transmission losses, which in turn helps in improvising the filter response. It is mainly used in filters, antennas, sensors, and metamaterials [13]. Its design and dimensions are critical for achieving the desired resonant frequency and performance characteristics in various Radio Frequency (RF) and microwave circuit applications [14].

A microstrip bandpass conformal loop filter designed for S-band applications is a specialized component used in RF and microwave circuits to select and condition signals within the 2-4 GHz frequency range [15, 16]. Its design parameters are adjusted to match the aerospace requirements, and it finds use in S-band applications, including radar, satellite communications, and wireless data links [15, 17-20].

This paper presents a compressive study on the design, analysis, and performance evaluation of a SRR-loaded conformal single-band loop filter for wireless communication systems [21].

The primary goal of this paper is to explore novel techniques, delve into the theoretical foundations of SSR-loaded microstrip loop filter design, and offer insights into the trade-offs involved in achieving optimized performance [22].

The novelty of the proposed filter is that it provides a narrowband response and can conform to a given surface. It has been found in the literature that a conformal geometry results in a change of resonant frequency. In the proposed geometry the frequency deviation is almost minimal. This is due to the Complementary Split Ring Resonator (CSRR) in the ground plane as well as symmetry in the geometry.

The rest of the paper consists of Section 2 describes the filter design, Section 3 illustrates the simulation procedure for the proposed filter also the performance metrics of conformal geometry, Section 4 compares and analyzes the simulated and measured results, Section 5 concludes the paper.

II. FILTER DESIGN

This paper focuses on developing a microstrip planar loop filter in the S-band with a conformal geometry. The design parameters are calculated using the design equations, and then the filter is designed and simulated. The same will be discussed in the upcoming sections of the paper.

Article history: Received November 30,2023; Accepted April 12, 2024.

Chandana. Muniraja, Harshini. Kariyanna, Dileep. Kempanna, Varun. Dwarakanath with the Faculty of Electronics and Communication Engineering, M S Ramaiah University of Applied Sciences, Bangalore, India (BHARAT) E-mail: chandanam0000@gmail.com ,harshinikariyanna1002@gmail.com, dileepkdileepk972@gmail.com varun.ec.et@gmail.com

A. Design Equations

Designing any filter requires the calculation of the resonant frequency, dielectric permittivity, and thickness of the substrate. The design equation for the operating frequency f, of the filter is as follows [14].

$$f = k\frac{c \times S \times n}{r \times g \times l \times \sqrt{\varepsilon_e}} \tag{1}$$

$$k = \begin{cases} 0.76, 3.27 \leq \varepsilon_r < 4.5 \\ 0.75, 4.5 \leq \varepsilon_r < 9.2 \end{cases} \tag{2}$$

Where,

s = distance between stubs
n = width of the primary loop
r = width of the stub
k = correction factor
c = speed of light
ε_e = effective permittivity

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + \frac{12 H_s}{W_f}}} \tag{3}$$

Where,

ε_r = relative permittivity
H_s = height of the substrate
W_f = width of feed line

Split rings are designed using the equations (4)

$$L_{eff} = 6L - t - 6w_l = \frac{\lambda g}{2} \tag{4}$$

Where,

L = length of SRR
L_{eff} = effective length of SRR
t = gap of the SRR
w_l = width of the SRR (0.5mm)

The dielectric permittivity ε_r considered for the FR-4 substrate is 4.6, and its loss tangent (tan δ) is 0.002.

From the results obtained using the design equations, the filter is designed on an FR-4 substrate, a double-sided Printed Circuit Board (PCB) with a thickness of 0.2 mm, a dielectric constant of 4.6, and a loss tangent of 0.02. The top surface has a closed loop along with two E-stubs. The bottom surface consists of two hexagonal, complimentary split rings. Ideally FR-4 is a rigid substrate but, in this scenario, due to lesser thickness the substrate is flexible.

The square loop has been proposed for application in a dual-mode band-pass filter [23, 24]. Because of the 4-fold symmetry property, a square loop resonator can be easily excited with feed lines at the rim of the resonator. When the mean parameters L of this square loop resonator are designed with an integral multiple of a guided wavelength λg, the resonance is found. The frequency modes are given in [25].

To reach the proposed design, a closed loop microstrip line is taken as the primary design. This design fails to perform as a resonator. So, E-shaped stubs are introduced diagonally to the closed square loop. This leads to open-ended transmission lines in the design thus providing band stop characteristics.

At high frequencies the size of the structure is getting reduced, therefore the length of the square loop has an inverse relation with frequency. The width of loop ‘W’ and the separation between E-stubs have a direct relation with frequency. With this equation (1) – (4) has been used to determine the geometry of the proposed filter.

B. Design Parameters

Using the above design equations (1), (2), and (3), the dimensions of the filter are noted in Table I.

TABLE 1
PROPOSED FILTER DIMENSION

SI.no	Parameters	Dimensions (in mm)
1	a	30
2	b	30
3	c	5
4	d	7.2
5	e	2.8
6	f	10
7	g	10
8	h	2.8
9	i	2.94
10	j	2.3
11	k	3.6
12	l	2.2
13	m	0.5
14	n	0.5
15	p	4
16	q	3

III. SIMULATION OF GEOMETRY

To design the filter, a closed-loop structure is primarily considered. The filter is designed on a FR-4 epoxy substrate. To improve the filter’s performance, the design parameters E-stubs are added to the model, which helps in resonating the frequency. These stubs are also termed tuning stubs.

The addition of SRRs to the ground plane improves the response of the SSR-loaded Conformal Loop Filter by reducing transmission loss. SRRs are electromagnetic structures that exhibit resonant behavior at specific frequencies and reduce transmission losses. By implementing SRRs and tuning stubs into the loop filter's design, it is possible to achieve improved frequency-selective filtering. The unit cell simulation of the SRR has been addressed in [22].

The proposed filter design with the SRR has been depicted in Figure 1 and Figure 2.

The filter simulation model has been developed using the dimensions in Table 1. Figure 3 shows the proposed Electromagnetic (EM) model for the filter. The Subminiature version A (SMA) connectors as input ports are also modeled to account for losses due to impedance mismatch between the feedline and the SMA. The SMA connectors are excited as waveguide ports and simulated to analyze the performance.

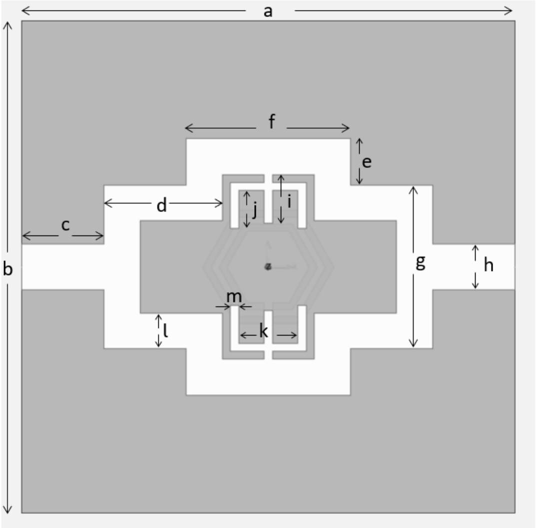


Fig. 1. Top view of the proposed filter

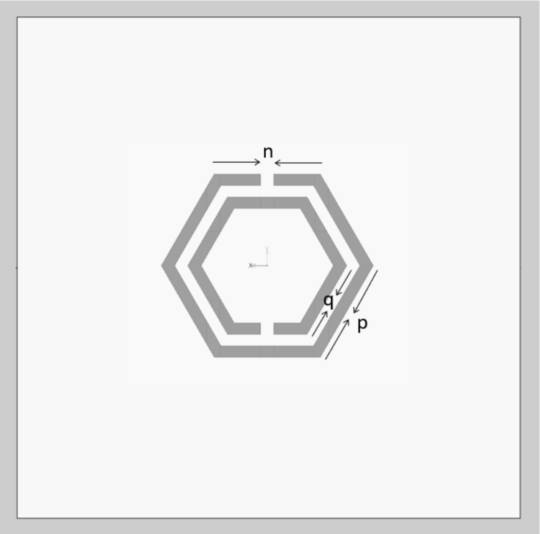


Fig. 2. Bottom view of the proposed filter

The simulation has been carried out in the EMpro EM tool. The 3D geometry consists of an FR-4 substrate with a thickness of 0.2 mm. The thickness of the substrate has been selected such that the fabricated filter can be conformed to a given surface. The conformal geometry is required as the filter needs to conform to the helmet surface (application intended). A Finite Element Method (FEM) simulation has been carried out for a frequency range of 1 GHz to 3 GHz.

Figure 4 shows the simulated S-parameters for the proposed filter. The filter shows a bandpass characteristic at 2.25 GHz and has a bandwidth of 130 MHz and an insertion loss of 1.0 dB. The proposed filter is applicable for narrowband systems where a particular band needs to be isolated for the receiver.

The simulation result in Figure 4 depicts the pass-band of the filter from 2.17 GHz to 2.30 GHz with a nominal return loss of -10 dB.

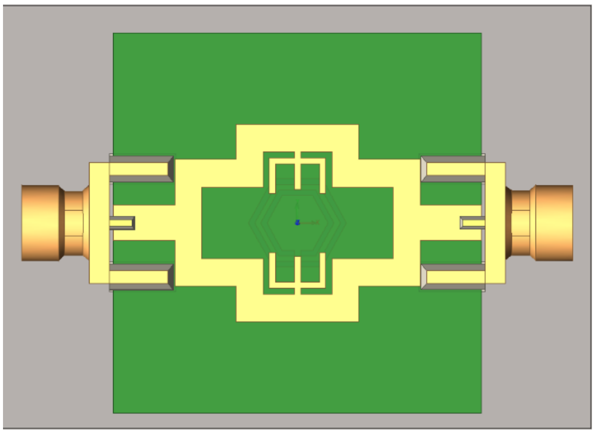


Fig. 3. Simulation model of filter with SMA connectors

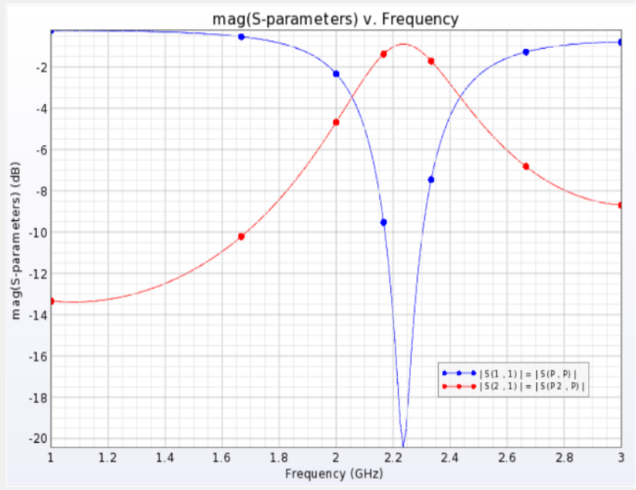


Fig. 4 Simulated S-parameter for the proposed filter

A. Conformal Filter Design

As this paper is focusing on conformal filters the designed filter is bent by 45° at the center as shown in Figure 5. Conformal geometry has been simulated and analyzed for its deviation in performance from the planar geometry. The filter response for conformal geometry is shown in Figure 6.

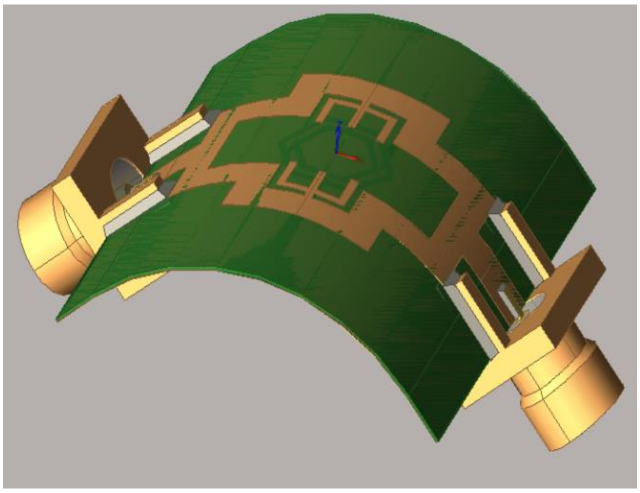


Fig. 5 Conformal filter simulation geometry

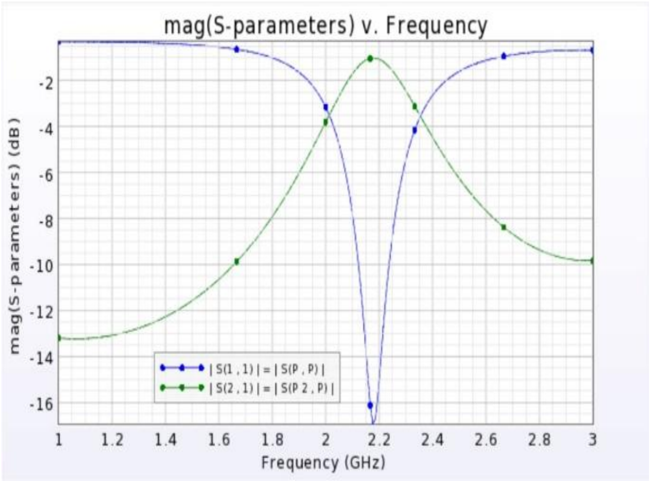


Fig. 6. Simulated S-Parameters of conformal filter geometry

The simulation result in Figure 6 depicts the pass-band of the filter from 2.12 GHz to 2.24 GHz with a nominal return loss of -10 dB. With an insertion loss of -1.0 dB. From the results shown in Fig.4. and Fig.6. It can be concluded that the filter response does not vary with conformal geometry.

B.Surface current

Current flow through the filter is in such a way that the electric field distribution through the loop is equal and opposite in strength, hence they cancel and the output at the output port is zero which provides a bandpass response at a frequency corresponding to the length of the loop.

Figure. 7 represents the current distribution on the developed filter.

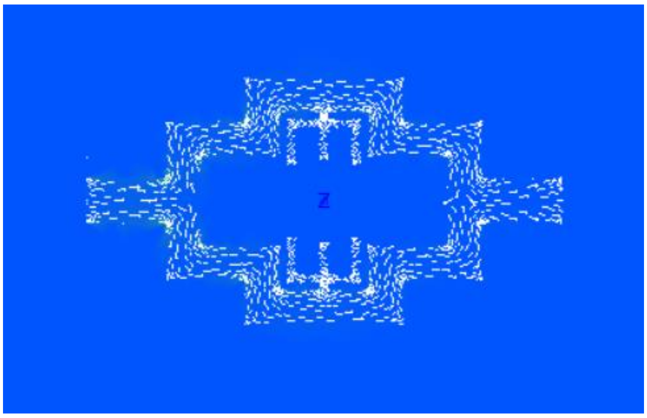
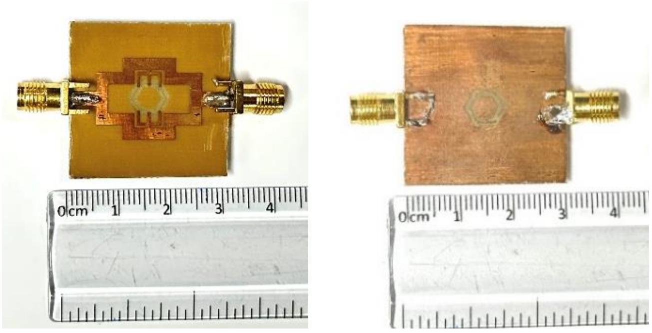


Fig. 7. Current distribution on the developed filter

IV. MEASUREMENTS AND RESULTS

The filter design is fabricated on FR-4 epoxy substrate (30mm×30mm) of thickness 0.2 and having a dielectric value of 4.6 and tangent loss of 0.02. Fig.8. shows the top as well as bottom view of the fabricated filter.

Then the fabricated filter is measured using a Vector Network Analyzer (VNA). The measured filter operates at 2.24 GHz to 2.42 GHz with a Fractional Bandwidth of 7.7% and a minimum insertion loss of 1.4 dB. The Fig.11. shows the comparison between simulated and measured S-parameter characteristics of the proposed filter.



(a) (b)

Fig. 8 Fabricated conformal filter: (a) Top view, (b) Bottom view

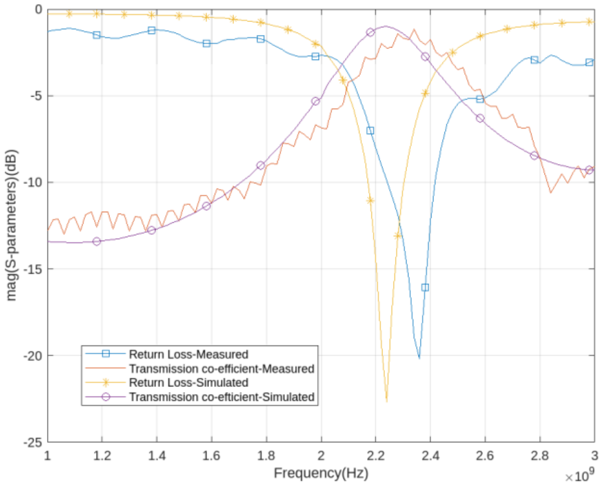


Fig. 9. Comparison of simulated and measured S-parameters of proposed planar filter

Figure 9. presents the comparison between simulated S-parameters and measured S-parameter results of the proposed filter having planar geometry. It is observed that the frequency range of operation for simulated and measured results is 2.17 GHz to 2.30 GHz and 2.24 GHz to 2.42 GHz respectively. The insertion loss is found to be 1.0 dB and 1.4 dB respectively.

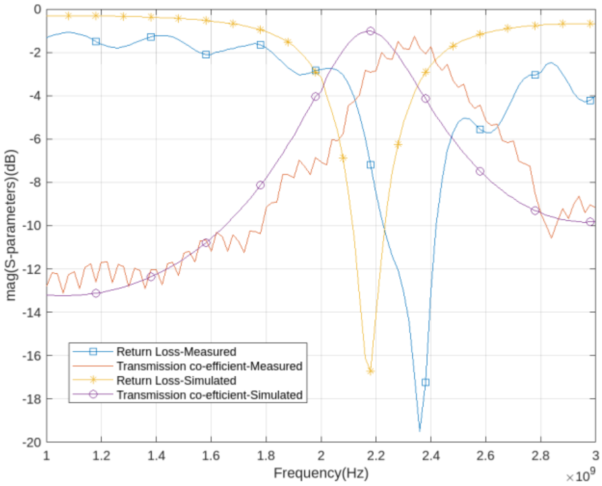


Fig. 10. Comparison of simulated and measured S-parameters of proposed conformal filter

The obtained simulated results of a proposed filter having conformal geometry are compared with the measured results of the fabricated conformal filter, the same is presented in Fig.10. The operating frequency range for simulated results is 2.12 GHz to 2.24 GHz, and for measured results, it is 2.21 GHz to 2.41 GHz. The insertion loss is 1.1 dB and 1.4 dB for simulated as well as measured results respectively.

From Fig.9. and Fig.10. it is seen that the simulated results almost match that of the fabricated results. A slight shift in the center frequency of the measured results is due to interference noise. Ripples are seen in the measured transmission coefficient.

V. CONCLUSION

In this paper, a new method of a closed-loop filter that provides a bandpass response and conforms to the given surface is proposed. Primarily a simple closed-loop structure is designed to which the E-stubs are added to tune the resonant frequency. An FEM analysis has been carried out to determine the characteristics.

The simulation results of the proposed filter show a bandpass filter response for the operating frequency range of 2.17 GHz to 2.30 GHz with an insertion loss of 1.0 dB. Also, the performance of the conformal geometry for the proposed filter is analyzed which confirms that there is no variation in the filter response. The designed filter is then fabricated on an FR-4 substrate of thickness 0.2 mm, dielectric constant of 4.6, and a loss tangent of 0.02. The simulated and measured results of the proposed filter are in good agreement. The frequency of operation can be configured to other frequencies based on the size of the stub. The length of the stub would result in a change in frequency and not essentially electronically reconfigurable.

REFERENCES

[1] M. Gupta, "Conformal Microstrip Filter Design Using Complementary Split Ring Resonator", *4th International Conference on Computing Communication and Automation (ICCCA)*, Greater Noida, India, pp. 1-4 , 2018.

[2] A. Kapoor, R. Mishra, and P. Kumar, "Frequency Selective Surfaces as Spatial Filters: Fundamentals, Analysis and Applications," *Alexandria Engineering Journal,* vol. 61, no. 6, pp. 4263-4293, 2022.

[3] B. Gohil and K. Chavda, "Design & Simulation of S Band Planar Microwave Filter for Wireless Application," in *IOP Conference Series: Materials Science and Engineering,* vol. 1187, no. 1, 2021.

[4] W. Li, Y. Lan, H. Wang, and Y. Xu, " Microwave Polarizer Based on Complementary Split Ring Resonators Frequency-Selective Surface for Conformal Application," in *IEEE Access,* vol. 9, pp. 111383-111389, 2021.

[5] Y. I. Al-Yasir, N. O. Parchin, A. M. Abdulkhaleq, M. S. Bakr, and R. A. Abd-Alhameed, "A Survey of Differential-Fed Microstrip Bandpass Filters: Recent Techniques and Challenges," *Sensors,* vol. 20, no. 8, 2020.

[6] R. K. Barik, Q. S. Cheng, N. C. Pradhan, and S. S. Karthikeyan, "Design of Miniaturized SIW Filter Loaded with Open-Loop Resonators and its Application to Diplexer," *Radioengineering,* vol. 29, no. 4, 2020.

[7] A. Ghaderi, A. Golestanifar, and F. Shama, "Microstrip Bandpass Filters using Coupled Feed Lines for Third and Fourth Generation Communications," *AEU-International Journal of Electronics and Communications,* vol. 86, pp. 195-201, 2018.

[8] N. Ab Wahab, M. N. Md Tam and M. N. Hushim, "Closed-loop ring resonator topology for bandpass filter applications," *Indonesian Journal of Electrical Engineering and Computer Science,* vol. 17, no. 3, pp. 1422-1426, 2020.

[9] G. Y. Wei, Y. X. Wang, J. Liu, and H. P. Li, "Design of a Planar Compact Dual-Band Bandpass Filter with Multiple Transmission Zeros Using a Stub-Loaded Structure," *Progress In Electromagnetics Research Letters,* vol. 109, pp. 23-30, 2023.

[10] X.-Y. Ning, H.-R. Zhu, and Z.-X. Huang, "A Compact Bandpass Filter using Novel Microstrip Dual-Mode Resonator with Hexagonal Structure," in *Photonics & Electromagnetics Research Symposium-Fall (PIERS-Fall),* pp. 1256-1259, 2019.

[11] R. A. Maulidini, M. R. Hidayat, and T. Praludi, "Band-Pass Filter Microstrip at 3 GHz Frequency using Square Open-Loop Resonator for S-Band Radar Applications," *Jurnal Elektronika Dan Telekomunikasi,* vol. 20, no. 2, pp. 53-59, 2020.

[12] S. Aiswarya, S. B. Nair, L. Meenu, and S. K. Menon, "Analysis and Design of Stub Loaded Closed Loop Microstrip Line Filter for Wi-Fi Applications," in *Sixteenth International Conference on Wireless and Optical Communication Networks (WOCN),* pp. 1-5, 2019.

[13] A. M. Tamim, M. R. I. Faruque, M. J. Alam, S. S. Islam, and M. T. Islam, "Split Ring Resonator Loaded Horizontally Inverse Double L-Shaped Metamaterial for C-, X-and Ku-Band Microwave Applications," *Results in Physics,* vol. 12, pp. 2112-2122, 2019.

[14] N. C. Babu and S. K. Menon, "Analysis of Hexagonal Split Ring Resonator," *Progress in Electromagnetic Research Symposium (PIERS),* pp. 3478-3481, 2016.

[15] B. Afzali, H. Abbasi, F. Shama, and R. Dehdasht-Heydari, "A Microstrip Bandpass Filter with Deep Rejection and Low Insertion Loss for Application at 2.4 GHz Useful Wireless Frequency," *AEU-International Journal of Electronics and Communications,* vol. 138, p. 153811, 2021.

[16] M. S. Islam, M. Samsuzzaman, G. K. Beng, N. Misran, N. Amin, and M. T. Islam, "A Gap Coupled Hexagonal Split Ring Resonator Based Metamaterial for S-band and X-Band Microwave Applications," *IEEE Access,* vol. 8, pp. 68239-68253, 2020.

[17] R. S. Sangam, S. Dash, and R. S. Kshetrimayum, "Ultra-Broadband Bandpass Filter Using Linearly Tapered Coupled-Microstrip Line and Open Loop Defected Ground Structure," *IEEE Transactions on Circuits and Systems II: Express Briefs,* vol. 68, no. 1, pp. 181-185, 2021.

[18] K. Devi, "A Compact Bandpass Microstrip Filter for Wireless Communication Applications," *Turkish Journal of Computer and Mathematics Education (TURCOMAT),* vol. 12, no. 6, pp. 161-165, 2021.

[19] A. O. Nwajana and E. R. Obi, "Application of Compact Folded-Arms Square Open-Loop Resonator to Bandpass Filter Design," *Micromachines,* vol. 14, no. 2, 2023.

[20] S. Palanisamy, B. Thangaraju, O. I. Khalaf, Y. Alotaibi, and S. Alghamdi, "Design and Synthesis of Multi-Mode Bandpass Filter for Wireless Applications," *Electronics,* vol. 10, no. 22, 2021.

[21] S. U. Afsar, M. R. I. Faruque, M. J. Hossain, M. U. Khandaker, H. Osman, and S. Alamri, "Modified Hexagonal Split Ring Resonator Based on an Epsilon-Negative Metamaterial for Triple-Band Satellite Communication," *Micromachines,* vol. 12, no. 8, 2021.

[22] N. Divya, K. Neelima, B. H. Chandana, and D. Harika, "Hexagonal Split Ring Resonator for 5G Applications," in *IEEE 12th International Conference on Communication Systems and Network Technologies (CSNT)*, pp. 66-70, 2023.

[23] J.-S. Hong and M. J. Lancaster, "Bandpass Characteristics of New Dual-Mode Microstrip Square Loop Resonator," *Electronics Letters*, vol. 31, no. 11, pp. 891-892, 1995.

[24] J.-S. Hong and M. J. Lancaster, "Microstrip Bandpass Filter Using Degenerate Modes of a Novel Meander Loop Resonator," *IEEE Microwave and guided wave letters*, vol. 5, no. 11, pp. 371-372, 1995.

[25] K. Chang and L.-H. Hsieh, *Microwave ring circuits and related structures*, John Wiley & Sons, 2004.