Design of C band Bandpass Filter using Fractal based Symmetrical Ring Resonator

Ampavathina Sowjanya[1], Damera Vakula[2]
[1]Department of Electronics and communications Engineering, NIT, Warangal, 506004, Telangana, India.
[2]Associate Professor, NIT, Warangal, Pin Code: 5060 04, Telangana, India,
Corresponding author: (e-mail: sowjanya6754@gmail.com)

ABSTRACT Symmetrical ring resonator metamaterial along with fractal boundary is proposed for Band Pass Filter (BPF) design in this paper. A combination of symmetrical ring resonators and vias is used for designing a bandpass filter. Bandpass filter with low insertion loss, better fractional bandwidth even at higher frequencies is achieved by using moore fractal applied symmetrical ring metamaterial resonators along the microstrip transmission line. The operating frequency range of the simulated filter is in the C-band between 5.47 GHz - 6 GHz having fractional bandwidth (FBW) of 9.25% and with a minimum insertion loss of 1.2 dB. Application of moore fractal to the above implementation improved the bandwidth of the filter. Fractal applied symmetrical ring resonator simulated filter operates in the C-band between 7.15 GHz - 8.15 GHz having FBW of 13.1%, with a minimum insertion loss of 1 dB. The proposed filter is simulated, fabricated and S-parameters are measured using network analyzer N5222A. S-parameters results of fractal applied symmetrical ring resonator filter realized from simulations match closely with those from measurements results performed on prototypes but with a small shift in a frequency range. The measured filter operates in 6.95 GHz - 7.8 GHz having FBW of 11.54%, with a minimum insertion loss of 0.4 dB.

INDEX TERMS Bandpass filter, Fractal, Fractional bandwidth, Insertion loss, Symmetrical ring resonator.

I. INTRODUCTION

Filters operating in the 4-8 GHz band are useful for satellite, radar, and mobile communications. In these applications, microwave bandpass filters design has challenges related to several factors which include compact size, wide bandwidth, and cost. To satisfy these requirements novel techniques are required. A customizable 3D printed insert is designed and positioned into a standard WR-90 waveguide to realize an inline waveguide filter is reported in [1], which is dimensionally large. Quarter wavelength dielectric strip resonator filter with one short circuited end is proposed in [2], which has low FBW. Fractal shaped irises are applied to waveguide bandpass filter is presented in [3] but has less FBW. As the size and mass of the device are high using waveguide and dielectric resonator structures, the filter becomes one of the massive devices in the RF payload. Reduction in size without compromising filter performance becomes a challenge and an important priority. Filters with high performance, and low insertion loss are in high demand. The performance of bandpass filters can be increased by employing metamaterials. Metamaterials alone are far being considered as a potential candidate for microwave and wireless components systems. To this end, compatibility with planar circuit technology is required. Microstrip is the best choice as it is appropriate for monolithic and hybrid integrated circuit fabrication.

The metamaterial is an artificial media consisting of parameters that are not found in nature obtained by engineering its dimensions to any specified value. The embedding of meta-material is an emerging technology in designing compact microwave devices like antennas, filters, etc., Metamaterials along with microstrip planar technology improves the performance of the filter with compact size. First time moore fractal is applied on Symmetrical ring resonators which improves bandwidth of the filter compared to fractals on stubs, Defected ground structures, Stepped impedance stubs. Symmetrical ring resonators [4] are capable of reducing their dimensions as these resonators can be designed with dimensions comparably smaller than the signal wavelength at their resonant frequency. Symmetrical ring resonator structure is essentially a single metallic ring that has been split symmetrically as in Fig.1. This structure can concentrate the electrostatic energy of the incident field into the small volume between the plates of the capacitors in the structure. This resonant structure can produce accurate response as there is less fringing effect. The coupling between electric and magnetic fields is less, so it is easy to tune permittivity and permeability individually which allows us to control electromagnetic characteristics to obtain desired response.

The difference between symmetrical ring structure and split ring structure is mainly due to implementation of their rings. By keeping the same gap, symmetrical ring structure's ring dimensions can be changed easily whereas in a split ring it is difficult to change its dimensions as it consists of one bigger ring and one smaller ring. It is required to make both bigger and smaller rings smaller to maintain a gap between them and so more parameters are involved in the split ring. Thus, the split ring is harder to tune.

Microwave circuit designers must encounter the challenges to yield components with compact size and broadband operation. To encounter these challenges, several fractal geometries become an attractive choice. The geometries of metamaterials can be modified with fractals for further improvements. The application of fractal geometry has been used in the design of broadband filters. A microstrip of the symmetrical split ring resonator, which has two gaps, is adopted for the design of the filter [4]. In one of the approaches, the microstrip line is periodically loaded with square-shaped SRRs, etched near the conductor strip, and via holes [5]. However, this will result in high insertion loss in the passband with low FBW. For three-layer frequency, selective surface minkowski fractal islands are applied to reduce the size and improve bandwidth using a novel approach in [6], which is large in dimensions. A serial resonator and a parallel resonator are connected as shunt branches and analyzed using the elliptic function to design a bandpass filter in [13], which results in low FBW. Differential structure based on analytical approach is used to design narrow bandpass microstrip filter in [14], which results in high insertion loss.

In this paper, bandpass filter design is implemented by placing moore fractal boundary applied symmetrical ring resonant structures near the conductor strip and vias are placed along the transmission line to acquire low insertion loss, broadband for C-band applications. The proposed SSRR based filter operates in C band between 5.47 GHz -6 GHz which includes the 5.4 GHz band used for IEEE 802.11a Wi-Fi wireless computer networks from 5.47-5.725, amateur radio operations are from 5.65 GHz to 5.925 GHz, amateur satellite operations are from 5.83 GHz to 5.85 GHz for down-links and 5.65 GHz - 5.67 GHz for uplinks. The frequencies are then standardized at 5.712 GHz (US) and 5.996 GHz (Europe). 5.8 GHz ISM band between 5.725 GHz - 5.875 GHz is used for many unlicensed short range communication systems. Fractal boundary applied symmetrical ring resonator-based filter operates in C band between 6.95 GHz - 7.8 GHz used for transport and mobile backhaul applications.

II. DESIGN METHODOLOGY

The microstrip transmission line acts as the basic structure for signal transmission. The microstrip transmission line is a combination of a conductor having width 'W' printed on a dielectric substrate of thickness 'h' and relative permittivity 'ε_r' and a ground plane. An effective dielectric constant ε_e is taken into account in the analysis because some of the dielectric region field lines are in the air, do not fill the air region above the strip. The effective dielectric constant 'ε_e' and line impedance is calculated using [1-3] to design an all-pass filter with proper impedance matching.

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + \frac{12h}{W}}} \tag{1}$$

$$Z_0 = \frac{60}{\sqrt{\varepsilon_e}} \ln\left(\frac{8h}{W} + \frac{W}{4h}\right) \quad for\ \frac{W}{h} \le 1 \tag{2}$$

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_e}\left[\frac{W}{h} + 1.393 + 0.667\ln\left(\frac{W}{h} + 1.444\right)\right]} \quad for\ \frac{W}{h} \ge 1 \tag{3}$$

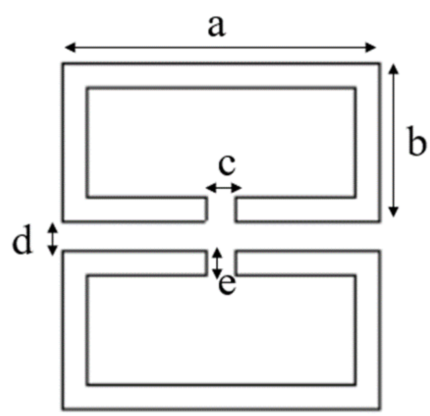

FIGURE 1. SYMMETRICAL RING RESONATOR UNIT CELL.

TABLE. I. Dimensions of Symmetrical ring resonator

Parameter	a	b	c	d	e
Value (mm)	3.12	1.56	0.3	0.295	0.24

Metamaterial structures are incorporated along the transmission line for modifying the transmission characteristics. Symmetrical rings are used as LC resonators for the proposed work to design bandpass filter. Due to its rectangular structure that the symmetric rings face opposite to each other with gaps in the ring, moore fractal best suits to apply for the symmetric rings, whereas other fractals best suits for square rings as in split ring resonators, open loop resonators etc., The symmetrical ring resonator dimensions are optimized for the desired frequency response. The unit cell of symmetrical ring resonator is shown in Fig. 1. The optimized dimensions of the symmetrical ring resonator are listed in Tab. I.

Microstrip transmission lines can generate magnetic field lines surrounding the line. Microstrip transmission line acts as All pass filter. To obtain a bandpass filter certain range of frequencies around the passband has to be inhibited. A significant portion of the magnetic field lines is expected to cut the symmetrical ring resonators when two arrays of symmetrical ring resonators are placed closely at both sides of the central line. This magnetic field portion has desired polarization that gives rise to a negative-μ effect over a band of frequencies. A significant portion of electric field lines is induced between patch and ground when vias are etched into the substrate along the transmission line. This electric field portion produces a negative-ε effect over a band of frequency. Thus, an LC resonant circuit is formed with a combination of symmetrical ring resonators and vias. At the resonant frequency, energy is absorbed by the resonant circuit which inhibits the signal transmission. Hence, signal propagation over a certain band of frequencies can be achieved.

Rogers Corporation RO 3010 material is chosen as substrate material. Substrate material has a thickness of 0.13mm, a dielectric constant of 10.2 with a 0.035 dissipation factor, copper laminates of 35μm thickness on both sides. Microstrip line has a width of 2.11 mm, for best impedance matching and has a length of 8.12 mm for single resonator bandpass filter and length of 16.2 mm for two resonators bandpass filter. Vias are 0.4 mm in diameter and with a gap of 8.08 mm are designed. The top view of proposed single resonator bandpass filter is shown in Fig.2. The top view of the proposed symmetrical ring resonators bandpass filter is shown in Fig.3.

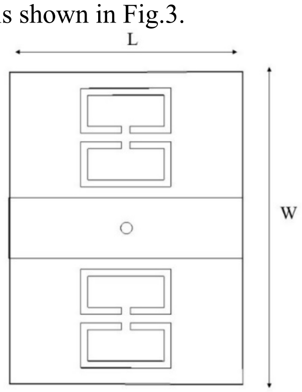

FIGURE.2. TOP VIEW OF BANDPASS FILTER USING SINGLE RESONATOR.

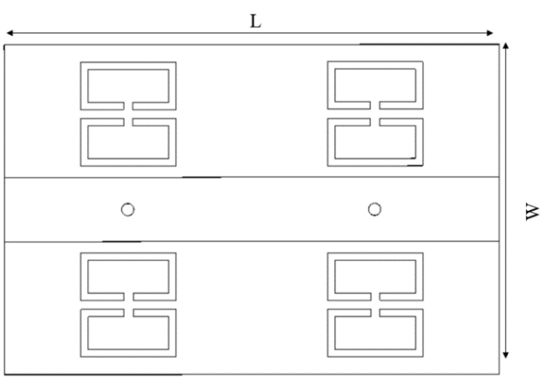

FIGURE.3. TOP VIEW OF PROPOSED SYMMETRICAL RING RESONATOR BANDPASS FILTER.

Moore fractal is applied to the symmetrical ring resonator metamaterial structure. Moore fractal is achieved by curving a single line while obeying a special recursive procedure to maintain the original length of the line when filling the space [8]. Moore has its endpoint coincides with each other and creates a spacing gap. From microstrip technology's perspective, a gap between lines creates a capacitance effect which influences the coupling characteristic. Moore curve characteristics can be conveniently fit into symmetrical ring resonant structure which improves the coupling effect and enhances the bandwidth of the filter while reducing the overall size.

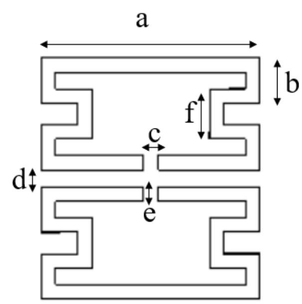

FIGURE. 4. THE UNIT CELL OF THE MOORE FRACTAL APPLIED SYMMETRICAL RING RESONATOR.

TABLE. II. Dimensions of Moore fractal applied Symmetrical ring resonator.

Parameter	a	b	c	d	e	f
Value (mm)	3.12	0.63	0.22	0.24	0.2	0.7

Moore fractal applied symmetrical ring resonator unit cell is shown in Fig.4. and dimensions are listed in Tab. II. A microstrip line having a length of 12.2mm and a width of 1.95mm is designed to provide better impedance matching. Vias are 0.4mm in diameter and with a gap of 6.08mm are designed. Gaps in between the cells are optimized. The top view of the moore fractal boundary applied symmetrical ring resonator bandpass filter is shown in Fig. 5. The size of the symmetrical ring resonator bandpass filter is 16.2 mm × 10.84mm., which is approximately 0.98 $\lambda_g \times$ 0.66 λ_g, where λ_g is guided wavelength.

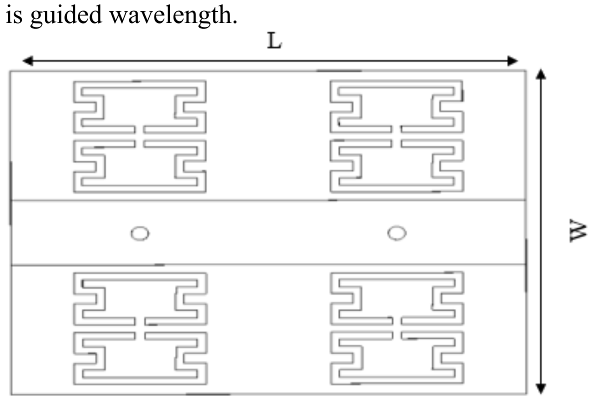

FIGURE. 5. TOP VIEW OF MOORE FRACTAL APPLIED SYMMETRICAL RING RESONATOR BANDPASS FILTER.

III. EQUIVALENT CIRCUIT

The Lumped element equivalent circuit of the proposed bandpass filter is represented using the T circuit model as shown in Fig. 6. for symmetrical ring resonator bandpass filter and in Fig. 7. for moore fractal applied symmetrical ring resonator bandpass filter. L_1 and C_1 represent line inductance and capacitance. L_2 and C_2 represent equivalent resonant structure inductance and capacitance. The lumped inductance and capacitance values of symmetrical ring resonator band pass filter are

L_1 = 30 nH, C_1=0.0257 pF, L_2=0.064 nH, C_2= 12 pF

The lumped inductance and capacitance values of moore fractal applied symmetrical ring resonator bandpass filter are

L_1 = 17.69 nH, C_1=0.024 pF, L_2=0.06 nH, C_2= 7 pF

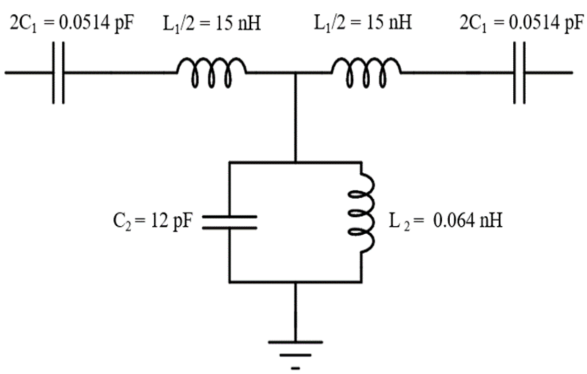

FIGURE. 6. EQUIVALENT CIRCUIT OF SYMMETRICAL RING RESONATOR BANDPASS FILTER.

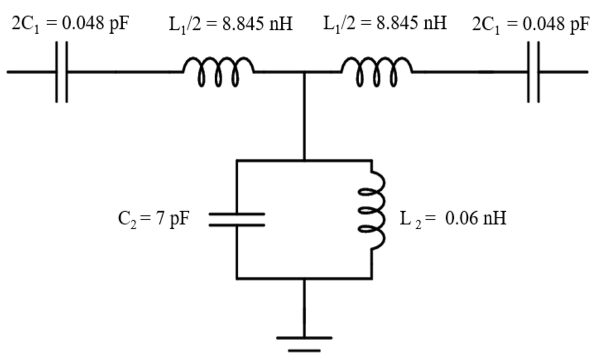

FIGURE.7. EQUIVALENT CIRCUIT OF MOORE FRACTAL APPLIED SYMMETRICAL RING RESONATOR BANDPASS FILTER.

IV. RESULTS AND ANALYSIS

Simulation of the proposed designs is done using Ansys HFSS. From Fig.8., it is observed that the improvement in the roll off rate from single resonator bandpass filter to double resonators bandpass filter.

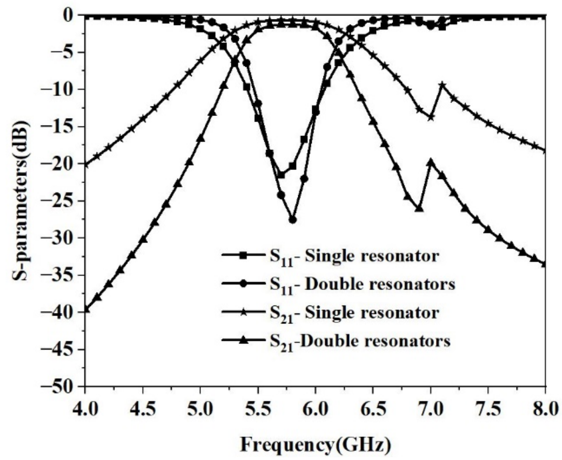

FIGURE.8. COMPARISON OF S-PARAMETERS OF BANDPASS FILTER WITHOUT FRACTAL USING SINGLE RESONATOR AND TWO RESONATORS.

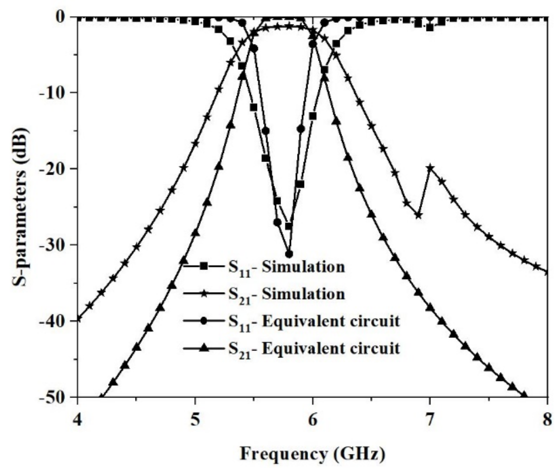

FIGURE.9. S-PARAMETERS OF SYMMETRICAL RING RESONATOR BANDPASS FILTER USING ELECTROMAGNETIC SIMULATION AND EQUIVALENT CIRCUIT SIMULATION.

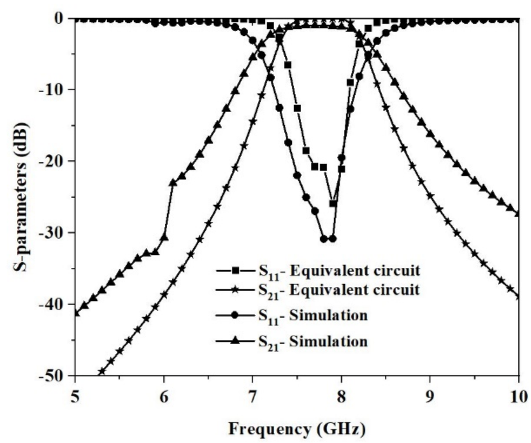

FIGURE. 10. S-PARAMETERS OF MOORE FRACTAL APPLIED SYMMETRICAL RING RESONATOR BANDPASS FILTER USING ELECTROMAGNETIC SIMULATION AND EQUIVALENT CIRCUIT SIMULATION.

An equivalent circuit is designed from the simulation results of HFSS and the circuit is simulated using an AWR design environment to determine S_{11} and S_{21} response. The electromagnetic simulation results and equivalent circuit simulation results are compared in Fig. 9. for the symmetrical ring resonator bandpass filter and in Fig.10. for moore fractal applied symmetrical ring resonator bandpass filter The frequency range of the SSRR bandpass filter designed using lumped equivalent circuit is 5.55 GHz – 5.95 GHz. The fractional bandwidth is 6.9% with a center frequency of 5.74 GHz. The return loss is 32 dB. The frequency range of the simulated bandpass filter is 5.47 GHz – 6 GHz. The fractional bandwidth is 9.25% with a center frequency of 5.73 GHz. The return loss is 29 dB. The frequency range of the moore fractal boundary applied SSRR bandpass filter designed using lumped equivalent circuit is 7.45 GHz – 8.05 GHz. The fractional bandwidth is 7.74% with a center frequency of 7.75 GHz. The return loss is 27 dB. The frequency range of the simulated moore fractal applied bandpass filter is 7.15-8.15 GHz. The fractional bandwidth is 13.1% with a center frequency of 7.63 GHz. The return loss is 32 dB. Good similarity is obtained between equivalent circuit results and electromagnetic simulation results.

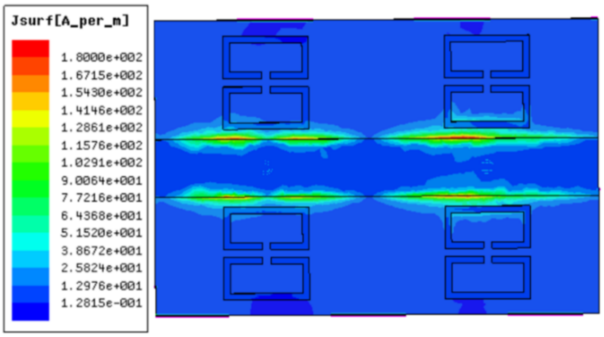

FIGURE. 11.A. THE CURRENT DISTRIBUTION OF SYMMETRICAL RING RESONATOR BANDPASS FILTER AT 5.7 GHZ FREQUENCY IN THE PASSBAND

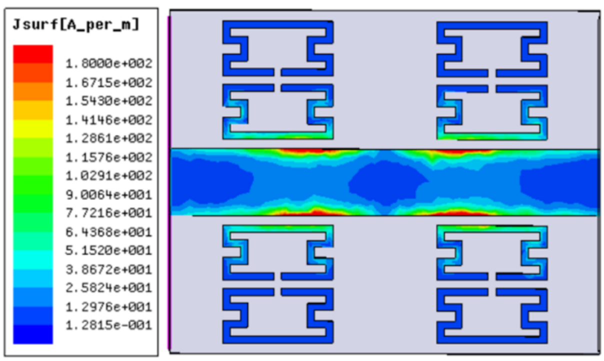

FIGURE. 11.B. THE CURRENT DISTRIBUTION OF MOORE FRACTAL APPLIED SYMMETRICAL RING RESONATOR BANDPASS FILTER AT 7.8 GHZ FREQUENCY IN THE PASSBAND.

The current distribution of the proposed bandpass filters is shown in Fig.11. A. & B. in which we can observe transmission from port1 to port 2 which represents passband.

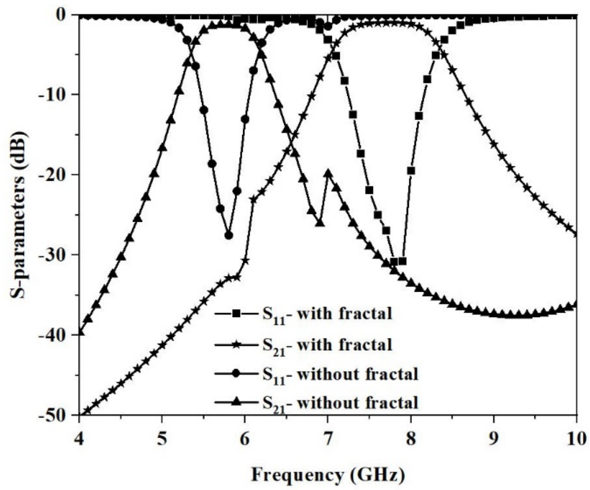

FIGURE. 12. S-PARAMETERS OF SYMMETRICAL RING RESONATOR BANDPASS FILTERS WITHOUT AND WITH MOORE FRACTAL.

The s-parameters of the proposed simulation results without and with fractal applied symmetrical ring resonator bandpass filter are represented in Fig. 12. The proposed filter is simulated using the software package ANSYS HFSS. The frequency range of the passband of the proposed symmetrical ring resonator based bandpass filter is 5.47 GHz -6 GHz . The central frequency of the symmetrical ring resonator based filter is 5.73 GHz. The fractional bandwidth of the filter is 9.25%. The minimum insertion loss of the filter is 1.2 dB. The return loss is 29 dB.The simulated Moore fractal applied symmetrical ring resonator BPF has a passband range from 7.15 GHz to -8.15 GHz. The central frequency of the moore fractal applied symmetrical ring resonator filter is 7.63 GHz. The fractional bandwidth of the filter is 13.1%. The minimum insertion loss is 1 dB. The return loss is 32 dB.

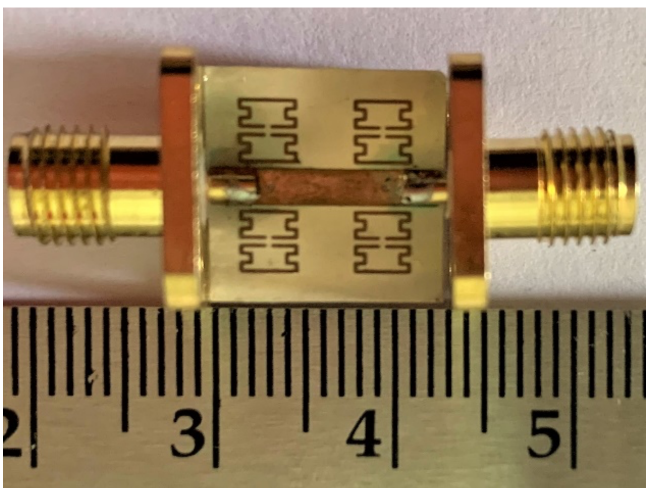

FIGURE. 13.A. TOP VIEW OF FABRICATED MOORE FRACTAL APPLIED SYMMETRICAL RING RESONATOR BANDPASS FILTER.

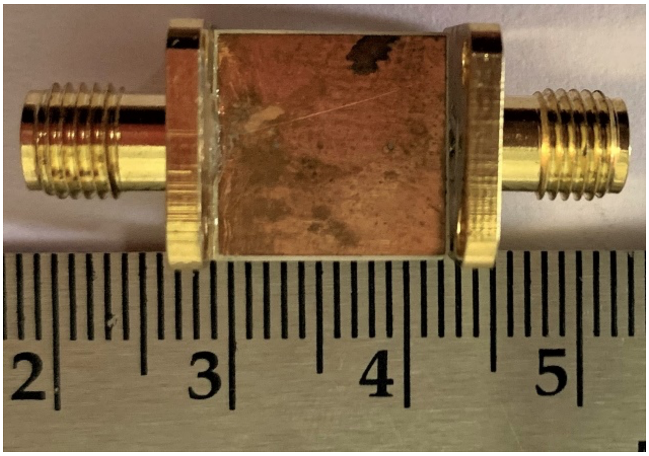

FIGURE. 13.B. BOTTOM VIEW OF FABRICATED MOORE FRACTAL APPLIED SYMMETRICAL RING RESONATOR BANDPASS FILTER.

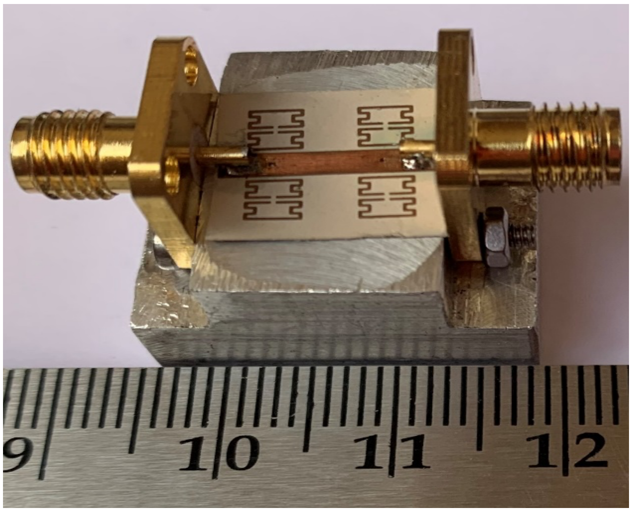

FIGURE. 13.C. TOP VIEW OF FABRICATED MOORE FRACTAL APPLIED SYMMETRICAL RING RESONATOR BANDPASS FILTER WITH MOUNTING BOX.

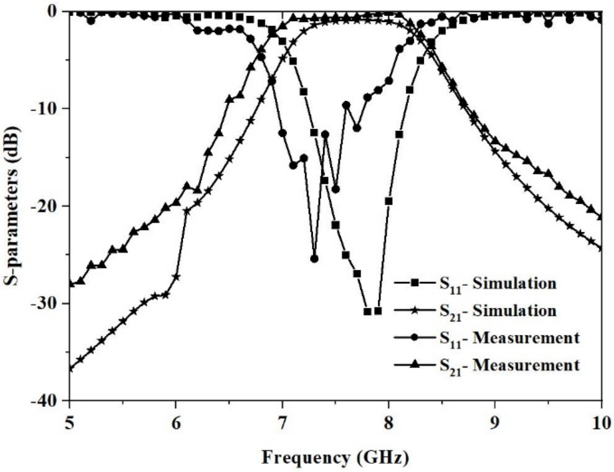

FIGURE.14. ELECTROMAGNETIC SIMULATION AND MEASUREMENT S-PARAMETERS FOR MOORE FRACTAL APPLIED BANDPASS FILTER.

The performance of the designed filter is validated by fabricating the design, and performance is measured. The S-parameters are measured using network analyzer N5222A for the fabricated prototypes shown in Fig. 13. A., Fig. 13. B. and Fig. 13. C. The size of moore fractal applied symmetrical ring resonator bandpass filter is 12.2 mm × 9.79 mm, which is approximately 0.97 $\lambda_g \times 0.78\ \lambda_g$. The measured and simulation results are compared in Fig. 14. The measured bandpass filter passband range is from 6.95 GHz - 7.8 GHz but in simulation 7.15 GHz - 8.15 GHz. The Fractional bandwidth is 11.54% at the center frequency of 7.36 GHz but is 13.1% at the center frequency of 7.63 GHz. The minimum insertion loss is 0.4 dB but is 1dB in simulation. The return loss is 28 dB but is 32 dB in simulation. A left shift in the passband frequency range is observed in the measured result which is due to dimensional tolerances during etching of the copper material of the proposed design at the time of fabrication. The left shift in frequency may be due to increment in dimensions of the design. The insertion loss is less in measured result may be due to better impedance matching in between the connectors. Bandwidth enhancement is observed by using moore fractal on symmetrical ring resonator bandpass filter. Reduction in physical size is also observed compared to the proposed basic design without moore fractal is due to reduction in interelement spacing in between moore applied resonators.

Table.III. Comparison with published bandpass filters

Published work	Center frequency (GHz)	FBW (%)	IL (dB)	Circuit size (λ_g^2)
[15]	1.75	8	4	0.3×0.14
[16]	2	8.5	1.43	0.5×0.5
[17]	5.25	9.5	<1	1.2×0.9
[18]	6	9	3.5	1.3×1
[19]	5.22	7.6	1.62	2.1×1.6
Proposed work (Without fractal)	5.75	9.25	1.2	0.98×0.66
Proposed work (With fractal)	7.36	11.5	0.4	0.97×0.78

The proposed bandpass filter parameters are compared in Table. III. with published bandpass filters. As compared to published work, the designed methodology using moore fractal presented in this paper makes it possible to attain low insertion loss and bandwidth enhancement even at higher frequencies using a simple design useful for C band applications.

V. CONCLUSION

The resonant type metamaterial structures such as symmetrical ring resonators etched close to the microstrip transmission line and vias along the transmission line are used to modify the transmission characteristics of planar microstrip line to design bandpass filter with low insertion loss and broadband for band applications in this paper. Moore's fractal boundary based symmetrical ring resonator structure enhances the bandwidth of the proposed filter. Results obtained demonstrate the potentiality of fractal and metamaterial-based filters in designing low insertion loss, broadband bandpass filters for C-band applications. The proposed symmetrical ring resonator bandpass filter is useful for Wi-Fi applications, amateur radio operations, amateur satellite operations, unlicensed short range communications, etc., Moore fractal applied symmetrical ring resonator bandpass filter is useful for transport and mobile backhaul applications.

REFERENCES

[1] R. Dahle, P. Laforge, J. Kuhling, “3-D printed customizable inserts for waveguide filter design at X-Band”, IEEE Microwave and Wireless Components Letters, vol. 27, no. 12, pp. 1080-1082, December 2017, doi: 10.1109/LMWC.2017.2754345.

[2] W. Yang, Y.Y. Zhu, J.Chen, “X band λ/4 dielectric strip resonator filter”, Electronics Letters, vol. 54 no. 19, pp. 1124-1126, September 2018, doi: 10.1049/el.2018.5497.

[3] D.Oloumi, A. Kordzadeh, A. Neyestanak, “Size reduction and bandwidth enhancement of a waveguide bandpass filter using fractal-shaped irises”, IEEE Antennas and Wireless Propagation Letters, vol. 8, pp. 1214-1217, February 2009, doi: 10.1109/LAWP.2009.2035648.

[4] B. Wu, W. Wang, J. Pacheco, et al. “A study of using metamaterials as antenna substrate to enhance gain”, Progress in Electromagnetics Research, vol. 51, pp. 295–328, 2005, doi: 10.2528/PIER04070701.

[5] I. Gil, J. Bonache, J. Garcia-Garcia, et al. “Metamaterials in microstrip technology for filter applications”, In Proceedings of IEEE Antennas and propagation society international symposium, Washington, DC, USA, vol. 1A, pp. 668-671, 2005, doi: 10.1109/APS.2005.1551409.

[6] R. Anwar, Y.Wei, L.Mao, et al., Miniaturized frequency selective surface based on fractal arrays with square slots for enhanced bandwidth”, IET Microwaves, Antennas & Propagation, vol.13. no.11, pp.1811-1819, 2019, doi: 10.1049/iet-map.2018.5224.

[7] R. Baral, P. Singhal “Recent techniques in design and implementation of microwave planar filters”, Radio Engineering, vol.17. no.4, pp.65-73, 2008, ISSN: 12102512.

[8] Y. Mezaal, J. Ali, H. Eyyuboglu, “Miniaturized microstrip bandpass filter based on moore fractal geometry”, International Journal of Electronics, vol.102. no.8, pp.1306-1319, 2015, doi: 10.1080/00207217.2014.971351.

[9] J. De Dios Ruiz, J. Hinojosa, “Double sided open split ring resonator for compact microstrip bandpass filter design,” IET Microwave Antennas&Propagation, vol. 6, no. 8, pp. 846–853, 2012, doi: 10.1049/iet-map.2011.0465.

[10] H. Shaman, “Design of a compact C-band microstrip bandpass filter for satellite communications applications”, In Proceedings of the Ninth International Conference on Wireless and Optical Communications Networks (WOCN), Indore, India, pp. 1–4, September 2012, doi: 10.1109/WOCN.2012.6335525.

[11] E. Lagunas, C. Tsinos, S. Sharma, et al. “5G cellular and fixed satellite service spectrum coexistence in C-band”, IEEE Access, vol. 8, pp. 72078–72094, 2020, doi: 10.1109/ACCESS.2020.2985012.

[12] S. Chaimool, P. Akkaraekthalin, “Miniaturized wideband bandpass filter with wide stopband using metamaterial-based resonator and defected ground structure”, Radio Engineering, vol.21. no.2, pp.611-616, 2012, ISSN: 12102512.

[13] S. Chen, L. Shi, G. Liu, et al. “An alternate circuit for narrow-bandpass elliptic microstrip filter design”, IEEE Microwave and Wireless Components Letters, vol. 27, no. 7, pp. 624-626, July 2017, doi: 10.1109/LMWC.2017.2711528.

[14] J. Xu, W. Hong, H. Zhang, et al. “Compact bandpass filter with multiple coupling Paths in limited space for Ku-band application”, IEEE Microwave and Wireless Components Letters, vol. 27, no. 3, pp. 251-253, March 2017, doi: 10.1109/LMWC.2017.2661970.

[15] M. Amirian, G. Karimi, D. Benjamin, et al. “Differential narrow bandpass microstrip filter design for material and liquid purity interrogation”, IEEE Sensors Journal, vol. 19, no. 22, pp. 10545-10553, November 15, 2019, doi: 10.1109/JSEN.2019.2932693.

[16] W. Feng, X. Ma, Y. Shi, et al. “High-selectivity narrow- and wide-band input-reflectionless bandpass filters with intercoupled dual-behavior resonators”, IEEE Transactions on Plasma Science, vol. 48, no. 2, pp. 446-454, February 2020, doi: 10.1109/TPS.2020.2968481.

[17] A. Shobit, G. Rahul Kumar, T. Raghuvir, “C-Band Microstrip Band Pass Filter Design”, International Journal of Research in Advent Technology (IJRAT), March 2018, ISSN: 2321-9637.

[18] S. Sreenath Kashyap, K. Prasad, M.D. Vipul, “Novel Microstrip Band Pass Filter for C- Band Wireless Applications”, International Journal of Engineering & Technology, vol. 7, no. 4.6, pp. 227-229, September, 2018, doi: 10.14419/ijet. v7i4.6.20481.

[19] Q. Liu, D. Zhou, S. Wang, et. al, “Highly-selective pseudo elliptic filters based on dual-mode substrate integrated waveguide resonators”, Electron. Lett., vol. 52, no. 14, pp. 1233–1235, July. 2016, doi: 10.1049/el.2016.1517.