Metamaterial Based Semi-Circular Monopole Antenna for Multiband Applications

[1]Divya Rai, [2] Dinesh Kumar Rajoriya,

[1]Ph.D Scholars, [2]Former Principal and Dean Faculty of Engineering,
[1]Department of Electronics and Communication Engineering,
[1]SORT, Peoples University, Bhopal, India

***Abstract*: In this article, a metamaterial based semi-circular monopole is presented for multiband applications. Presented antenna built of a simple semi-circular shaped monopole on the top of substrate and 3 × 2 split ring resonators are etched on its ground plane side. Antenna is intended on FR4 material with εr = 4.3 and thickness h = 1.59 mm. The antenna exhibits the multiband characteristic from 1.2 GHz to 4.5 GHz, 5.2 GHz to 11.3 GHz and 12.8 GHz to 18.2 GHz respectively. The radiation pattern of the antenna in the H-plane is virtually omni-directional, while the radiation pattern in the Eplane is directional. The maximum Gain of designed antenna 1.5 dB in the band and it also radiation efficiency is greater than 75 % within the operating band. The antenna has the potential to be beneficial for multiband current civil and military communication systems, as well as medical imaging and vehicle radar.**

***Index Terms*: Multi-band antenna, metamaterial, SRR**

I. INTRODUCTION

Nowadays, research in the field of wireless technology has exploded in recent years as a direct result of the proliferation of newly developed technologies as well as the sharp rise in the number of subscribers requests and the antenna fulfils an extremely important function in this regard, as a direct consequence of this, the design of small size, low-profile, multipurpose antennas for upcoming multifunctional wireless systems has taken place. Simultaneously, multiband smart antennas have garnered considerable interest as a result of their capacity to incorporate a number of communication protocols inside a single space-saving design [1-3]. An antenna for multi-band applications can be designed using metamaterial. The best way to explain metamaterials is to think of them as man-made structures that have been built in such a way as to provide specific electromagnetic characteristics that do not occur in nature [4-5].

In the field of optics and microwaves, metamaterials have the potential to be utilised in a wide number of applications, including the development of novel forms of antenna, beam steerers, modulators, filters and microwave couplers [6-7].

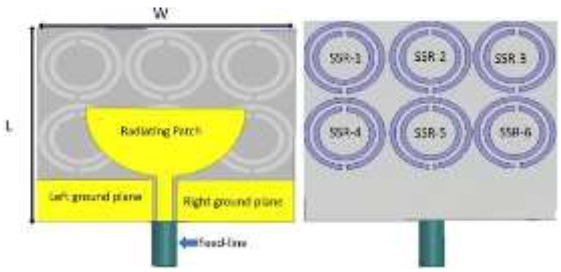
II. LITERATURE REVIEW

A dual-band patch antenna that employs metamaterial–EBG incorporated into its radiating edge is described in [8]. Low frequencies are governed by the combination of cavity and dispersive nature of EBG, whereas high frequencies are determined by the size of cavity without EBG and a highdirectivity electromagnetic bandgap design such as mushroom is proposed in [9]. In [10], double H metamaterial structures have been proposed and metamaterial is also utilised for bandwidth and efficiency enhancement. In [11] illustrates the effect that triangular complementary split ring resonators (CSRR) have on Wi-Fi patch antennas and two split-ring radiating elements based, inspired by metamaterials, are given for use in WLAN and WiMAX applications in [12]. Metamaterial-inspired antennas are described in a number of publications [13–16]. Recently, a monopole antenna has a single-cell metamaterial loaded into it, and it functions in three different bands as reported in [17]. In addition to this, the band-gap property of EBG has been put to extensive use to enhance the performance of printed antennas in terms of both efficiency and impedance matching [18].

In this article metamaterial-based antenna for multi-band applications is proposed and it contains of semi-circular shaped monopole radiator and the ground plane with metamaterial design. The presented antenna operates in multiband frequency such as from 1.2 GHz to 4.5 GHz, 5.2 GHz to 11.3 GHz and 12.8 GHz to 18.2 GHz respectively.

III. ANTENNA STRCUTURE AND DESIGN PARAMETRS

Fig. 1 illustrates the layout that will be used for the proposed multi-band metamaterial monopole antenna, in which the radiatting patch is a basic semi-circle shaped monopole, two rectangle ground plane on the top for CPW feed and back portion of the substrate, 3×2 SRR array has been designed. SRRs are used as a metamaterial structure to achieve multiband performance in this instance. The semi-circular-shaped monopole antenna is intended on FR4 material with dielectric constant 4.3 and thickness of the substrate is 1.59mm. Size of substrate is 40 mm × 45 mm.



(a) (b)

Fig. 1: Antenna layout and dimension (a) Front portion and
(a) Back portion

Both ground size of antenna is 9.1 mm × 22.0 mm, optimized feed width is 3.0 mm, optimized width of the semi- circular patch's radius is 12.3 mm and the SRR-shaped cut intothe ground plane side of the patch with radius of 8 mm and 7 mm respectively. The designed antenna's dimension and layoutis shown in Fig. 1

IV. MEMAMATERIAL ANALYSIS

Metamaterials substrate were first studied in the early 20th centuries. In 1967, a Russian physicist by the name of Victor II. described materials with a negative index of refraction and claimed that such materials could permit light to pass through it. He demonstrated the anti-parallel nature of the wave propagation and vector direction of the Poynting vector. This is the reverse of how waves travel through materials that are naturally occurring. John showed that it is possible to create metamaterials in a practical manner. A negative refractive index is one of the most distinguishing characteristics of a metamaterial, which is a type of man-made substance with electromagnetic properties that do not occur in nature and its properties as shown in Fig 2 [19].

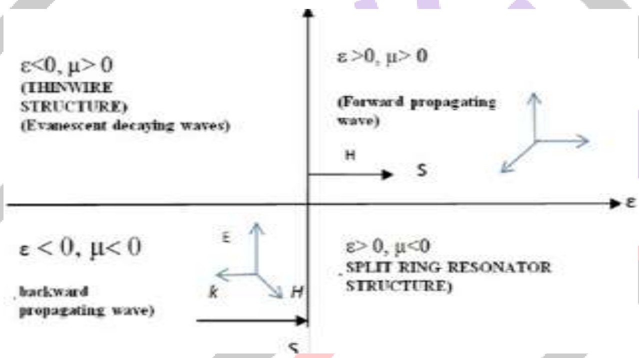


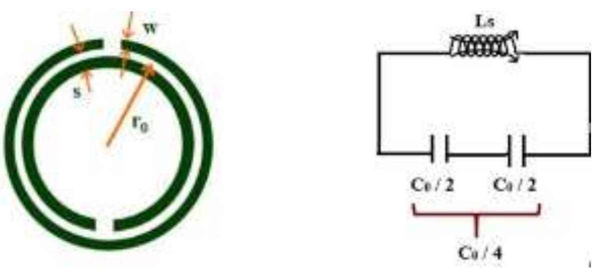
Fig. 2: Metamaterial properties for practicle applications

V. ANALYSIS OF METAMATERIAL STRCUTURE

A. SRR (Split Ring Resonator)

The term "mu-negative metamaterial" refers to a type of metamaterial that displays unusually high levels of a property known as "negative permeability". These types of materials can be produced by manufacturing two circular metallic rings, each of which has splits on the opposite side, on a dielectric material using a technique known as SRR. The rings are isolated by a gap in the central part. The magnetic resonance iscaused by splits in the rings as well as the space in betweenthe rings. If the magnetic field used to excite the rings is aligned so that it is perpendicular to the plane in which the rings are arranged, then the currents that are induced along the rings will cause the generation of magnetic dipole moments. This structure, as a result, demonstrates plasmonic negative permeability function. Fig. 3 provides a representation of the geometry of the SRR as well as its analogous circuit model.

Fig. 3: (a) Geometry of circular shape SRR and (b) equivalentcircuit model



VI. PARAMETRIC ANALYSIS

The presented metamaterial-based antenna is displayed Fig. 1 with optimal sizes and material size of 40 mm x 45 mm. The finite element method and 3D electromagnetic software An soft HFSS were used to simulate this antenna. Important design considerations include the separation between the ground plane and the patch, the width between both the feed and the ground plane, as well as the ground's breadth and length. These factors have a significant impact on the antenna's performance. Based on the current distribution over the antenna structure, the significant influence of these factors may be supported. Fig. 4 depicts the patch antenna's current distribution.

Initial resonant frequency Because of the upper half of the antenna, the frequency of the antenna should be. It has also been seen that the current distribution is on the lower side of the ground plane. This indicates that the distance between the patch and the ground has a significant impact in the antenna's overall performance. Similar to the previous point, the current distribution on the higher edges of the ground plane demonstrates that the width of the ground plane will also have an effect on the broad bandwidth of the antenna.

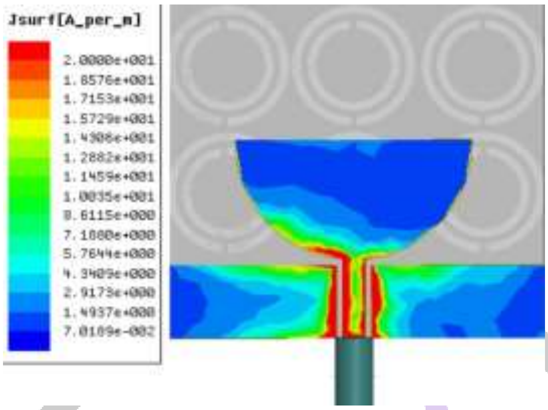


Fig. 4: Simulated current distribution of the antenna at 3.8GHz.

As shown in Fig. 5, the simulated results demonstrate theimpact of ground plane width fluctuation. The ground plane's width starts at 7.7 mm and goes up to 10.7 mm. This is an important factor to consider when determining the S11 bandwidth. When the breadth is increased or decreased, the electromagnetic interaction between the radiating element and ground plane is strengthened or weakened, respectively. Because of this, the bandwidth of proposed antenna is changed. Fig. 6 illustrates the influence of ground width on impedance bandwidth. The width of the ground plane is adjusted up to 9.7 mm. The spacing between the ground and feed was adjusted from 1 mm to 0.2 mm in increments of 0.2 mm, while holding all other parameters constant. Figure 4shows how shifting all resonant modes across the spectrumcan be achieved by varying the ground plane width. Deterioration of the reflection coefficient is caused by an unfavorable ground plane width, whether it is excessively wide or extremely narrow. The edge's current density rises as the gap widens.

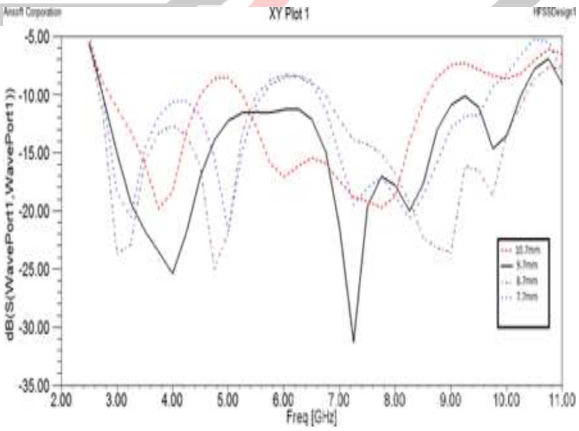


Fig. 5: Simulated results of various width of ground plane

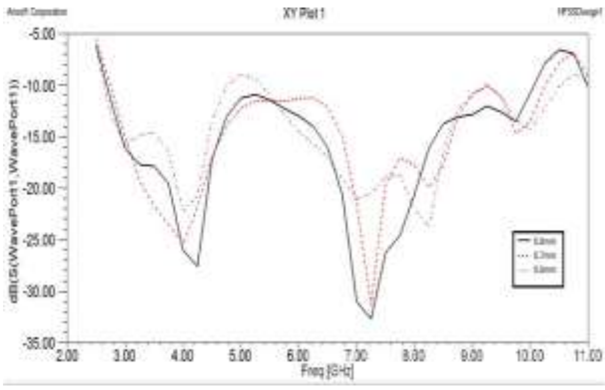


Fig. 6: Simulated result of gap between ground and feed line.

VII **SIMULATED RESULTS AND DISCUSSION**

The impedance bandwidth of proposed antenna exhibits the multiband characteristic from 1.2 GHz to 4.5 GHz, 5.2 GHz to 11.3 GHz and 12.8 GHz to 18.2 GHz respectively as shown in Fig. 7. The deeper resonance frequency can be observed in the proposed antenna at frequencies of 4.5 GHz, 10.2 GHz, and
13.8 GHz respectively. The gain of antenna is good, maximumgain is 1.5 dB as shown in Fig. 8 and radiation efficiency of antenna is approximately more than 95% within the band as shown in Fig. 9. The radiation pattern of the antenna is shown in Fig. 10 that show H-field omni diretional and E-field isdirectional at frequency 2 GHz as well as 3-D radiation patternis shown in the Fig. 11. 3-D pattern shows that radiation intensity of the presented in the plane. A multiband wireless communication system can benefit from this antenna design.

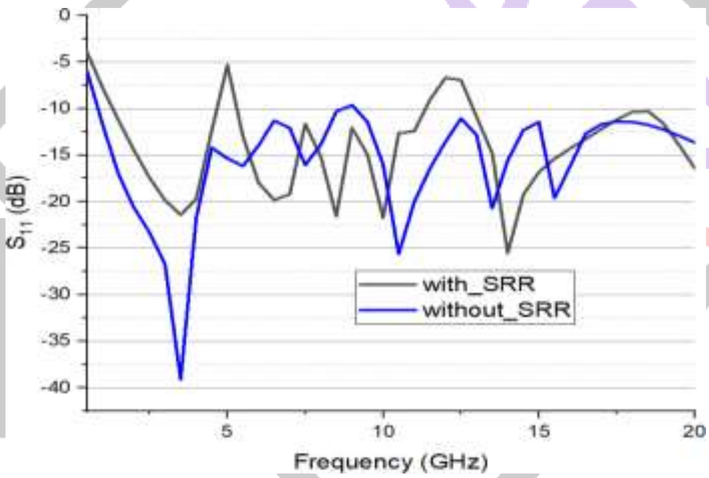


Fig. 7: Simulated results of impedance bandwidth of antenna

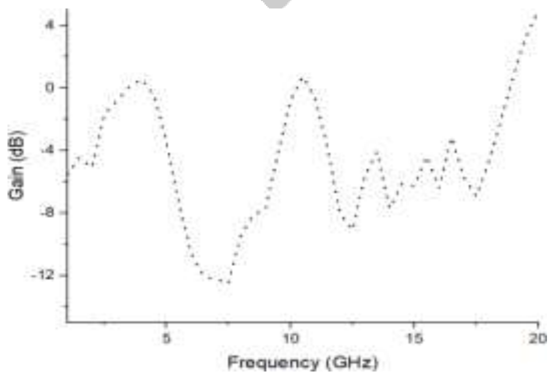


Fig. 8: simulated result of gain of antenna

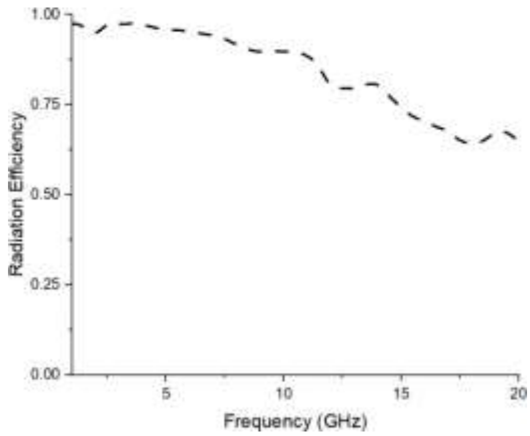


Fig. 9: Radiation efficiency of antenna

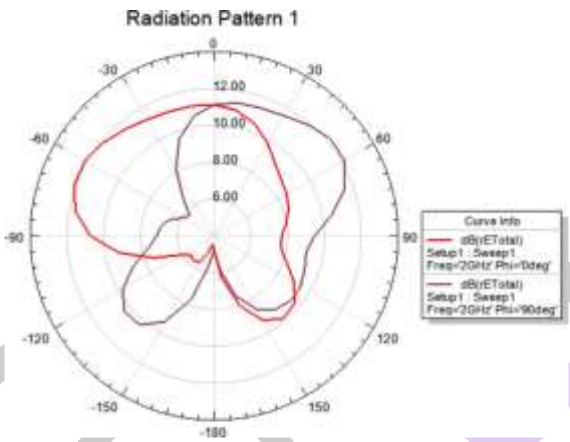


Fig. 10: E-fields and H-fields radiation pattern of antenna.

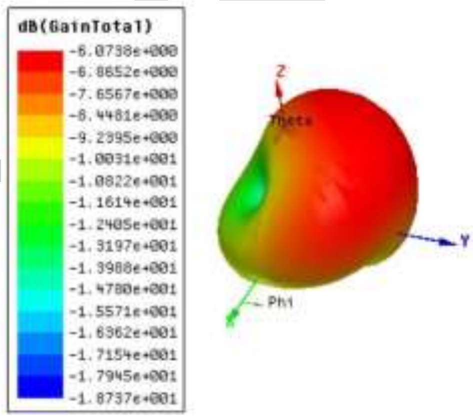


Fig. 11: 3-D radiation pattern of the proposed antenna

Table 1 shows the comparative analysis of various metamaterial based antenna and proposed structure better than other reported antenna in term of resonating frequecny, BW and simple geometry.

Table 1: Comparative analysis of various metamaterial based antenna

Ref.	Design geometry	Method Applied	Resonating.	Applications
[8]	MTM–EBG construction	MTM– EBG sections placed on the radiating edges	2.4 and 5.0 GHz	One operating frequency in each of the band gap and passband regions
[9]	Mushroom-shaped EBG design	Use of metamaterial superstrate	4.6 GHz	High gain antenna compared to conventional antenna for wireless communications
[10]	Double H-shaped metamaterial	A superstrate of double H- shaped metamaterial-embedded RMPA	5.2 GHz	Improved Efficiency and B.W. antenna for wireless applications
Proposed design	3 × 2 SRR metamaterial	semi-circular shaped monopole radiator and the ground plane with SRR shape metamaterial design	4.5 GHz and 7.2 GHz	multiband current civil and military communication systems, as well as medical imaging and vehicle radar

VIII **CONCLUSION AND FUTURE SCOPE**

A study is carried out to proposal semi-circular shaped monopole with metamaterial based for multiband applications. The performance of the antenna is strongly impacted by the width and length of the ground, in addition to the gap that exists between the ground plane and the radiating patch andthe gap that exists between the ground plane and the feed. The antenna has an operating impedance bandwidth from 1.2 GHz to 4.5 GHz, 5.2 GHz to 11.3 GHz and 12.8 GHz to 18.2 GHz respectively and S11 < - 10 dB over the operating frequency. The gain and radiation pattern this antenna is stable. Therefore, the planned antenna model is more appropriate for current wireless communications system. In the proposed design is based on SRR metamaterial geometry. In the future, other metamaterial geometry such ELC, CSRR, OCSRR metamaterial and composite metamaterial can be used to design antennas with enhanced performance parameters.

REFERENCES

[1] Basaran SC, Olgun U, Sertel K. Multiband monopole antenna with complementary split-ring resonators for WLAN and WiMAX applications. *Electron Lett*. 2013;*49*(10):636-638.

[2] Kumar, Sanjeev, Durgesh Nandan, Kunal Srivastava, Sachin Kumar, Hari Singh, Mohamed Marey, Hala Mostafa, and Binod Kumar Kanaujia. "Wideband circularly polarized textile MIMO antenna for wearable applications." *IEEE Access* 9 (2021): 108601-108613.

[3] M. D. Sindreu, J. Naqui, J. Selga, P. Vélez, J. Bonache, and F. Martín, ``Composite right-/left-handed transmission line metamaterials," in *Wiley Encyclopedia of Electrical and Electronics Engineering*. Hoboken, NJ, USA: Wiley, Apr. 2013, pp. 1_25.. *(references)*

[4] Kumar, Sanjeev, Ravi Kumar, Rajesh Kumar Vishwakarma, and Kunal Srivastava. "An improved compact MIMO antenna for wireless applications with band-notched characteristics." *AEU- International Journal of Electronics and Communications* 90 (2018): 20-29.

[5] Manohar, Kamireddy, Vijayasri Bolisetti, and Sanjeev Kumar. "An Investigation of Different Methodology Used for Achieving Compact Multiband Microstrip Antenna for Wireless Application." In *Next Generation Information Processing System*, pp. 151-160. Springer, Singapore, 2021.

[6] Alu, Andrea, Mário G. Silveirinha, Alessandro Salandrino, and Nader Engheta. "Epsilon-near-zero metamaterials and electromagnetic sources: Tailoring the radiation phase pattern." *Physical review B* 75, no. 15 (2007): 155410.

[7] Srivastava, Kunal, Ashwani Kumar, Binod K. Kanaujia, Santanu Dwari, and Sachin Kumar. "Multiband integrated wideband antenna for bluetooth/WLAN applications." *AEU-International Journal of Electronics and Communications* 89 (2018): 77-84.

[8] Smyth, Braden P., Stuart Barth, and Ashwin K. Iyer. "Dual-band microstrip patch antenna using integrated uniplanar metamaterial- based EBGs." *IEEE Transactions on Antennas and Propagation* 64, no. 12 (2016): 5046-5053.

[9] Xu, Huiliang, Zeyu Zhao, Yueguang Lv, Chunlei Du, and Xiangang Luo. "Metamaterial superstrate and electromagnetic band-gap substrate for high directive antenna." *International Journal of Infrared and Millimeter Waves* 29, no. 5 (2008): 493- 498.

[10] Kaur, Preet, Sanjay Kumar Aggarwal, and Asok De. "Performance enhancement of rectangular microstrip patch antenna using double H shaped metamaterial." *Radioelectronics and Communications Systems* 59, no. 11 (2016): 496-501.

[11] Ali, T., Khaleeq, M.M., Pathan, S. and Biradar, R.C., 2018. A multiband antenna loaded with metamaterial and slots for GPS/WLAN/WiMAX applications. *Microwave and Optical Technology Letters*, *60*(1), pp.79-85.

[12] Rosaline, S.I. and Raghavan, S., 2016. Design of split ring antennas for WLAN and WiMAX applications. *Microwave and optical technology letters*, *58*(9), pp.2117-2122.

[13] Rosaline, S.I. and Raghavan, S., 2016. Design of split ring antennas for WLAN and WiMAX applications. *Microwave*

and optical technology letters, *58*(9), pp.2117-2122.
[14] Naoui, S., Latrach, L. and Gharsallah, A., 2016. Equivalent circuit model of double split ring resonators. *Int. J. Microw. Opt. Technol*, *11*(1), pp.1-6.
[15] Gil, M., Bonache, J. and Martín, F., 2008, June. Ultra-compact band pass filters implemented through complementary spiral resonators (CSRs). In *2008 IEEE MTT-S International Microwave Symposium Digest* (pp. 1119-1122).
[16] Barbuto, M., Monti, A., Bilotti, F. and Toscano, A., 2012. Design of a non-Foster actively loaded SRR and application in metamaterial-inspired components. *IEEE Transactions on Antennas and Propagation*, *61*(3), pp.1219-1227.
[17] Zhu, J., Antoniades, M.A. and Eleftheriades, G.V., 2010. A compact tri-band monopole antenna with single-cell metamaterial loading. *IEEE Transactions on Antennas and Propagation*, *58*(4), pp.1031-1038.
[18] M.F., Azad, M.Z. and Ali, M., 2008. Wideband smaller unit-cell planar EBG structures and their application. *IEEE Transactions on Antennas and Propagation*, *56*(3), pp.903-908.
[19] https://www.slideshare.net/cocho/metamateriales