International Journal of Research and Development in Engineering Sciences
ISSN: 2582 - 4201(Online) , http://www.ijrdes.com/
Regular Issue, Vol. 7, Issue. 6 (November – December) , 2025 , Pages: 20 - 25
Received: 12 January 2025 ; *Accepted:* 17 October 2025 ; *Published:* 03 November 2025
https://doi.org/10.63328/IJRDES-V7RI6P2
Original Paper : Action Research – Experimental Research Paper

High Gain Slotted Rectangular Patch Antenna Loaded with Circular Split Ring Resonator

Jada Nageswara Rao [1 *], **R Ramana Reddy** [2]

[1,] Department of ECE, JNT University Anantapur, AP, India 516390; *jadanageswararao@gmail.com*
[2] Department of ECE, JNTUA College of Engineering Pulivendula , AP, India, 516390; *profrrreddy@yahoo.co.in*

* *Corresponding Author: Jada Nageswara Rao ; jadanageswararao@gmail.com*

Abstract: Design and analysis of a circular split-ring resonator (CSRR) loaded high-gain slotted rectangular microstrip patch antenna (RPA) exhibiting frequency notch characteristics. The primary objective of this work is to enhance the gain and bandwidth of the conventional microstrip patch antenna operating in the X-band. The CSRR structure, functioning as a metamaterial, is incorporated onto the patch to achieve the desired electromagnetic response. The proposed antenna attains dual gain peaks of 20.1 dBi and 12.0 dBi, exhibits a stable radiation pattern, and resonates at 10.76 GHz with a return loss (S11) of -18.94 dB. Owing to its high gain performance and operation within the X-band, the antenna demonstrates strong potential for satellite communication applications.
Keywords: - RPA, Metamaterial, CSRR, High gain, Slot, DGS.

1. Introduction

Wireless communication systems often use patch antennas due to their small size, inexpensive cost, straightforward construction, and simplicity of production. Metals such as copper, gold, and nickel are widely employed in the production of metallic patches. The feeding techniques of microstrip patch antennas (MPAs) may typically be categorized into two types: contacting and non-contacting ways. In non-contacting approaches, electromagnetic (EM) coupling is exploited to transmit energy between the radiating patch and the microstrip line, but in contacting methods, RF power is delivered directly into the microstrip line [2]. Although MPAs have many benefits, they also have certain drawbacks, such as a low gain, a restricted bandwidth, and poor directivity.For satellite communication, however, antennas with high gain and directivity are essential. Existing research indicates that several approaches such as employing metamaterials, artificial magnetic conductors (AMC), high-reflective surfaces (HRS), and defected ground structures (DGS) can be used to significantly enhance antenna gain.

2. Related Research

A number of ways have been used recently to disseminate microwave circuits. Defective ground structure (DGS) is one of the strategies. Patch antenna construction involves the usage of DGS with a dual layer truncated corner triangular slot. Gain is improved by using DGS. Returned loss is recorded as -24.95dBi and -21.64dBi, with gain of 6.27dBi at 3.58GHz and 6.58dBi at 5.3GHz. [1] A Pentagonal microstrip patch antenna incorporating a rhombic-slot with a gain exceeding 3.8 dBi has been reported for Global Positioning System (GPS) applications [2]. Another study presented a modified rectangular patch antenna (RPA) incorporating an inverted rectangular C-shaped slot, capable of operating across the S, C, and Ku bands. This antenna achieved a peak gain of 5.91 dBi at 6.78 GHz and provided a circularly polarized bandwidth of 260 MHz within the Ku band. An L-shaped defected ground structure (DGS) integrated with an RPA—featuring truncated cuts and slots—was also shown to enhance bandwidth and return loss, making it suitable for satellite communication applications [3].

Further improvements in gain for inset-fed microstrip patch antennas have been demonstrated through the use of H-shaped DGS structures. Such configurations suppress higher-order harmonics and thereby boost antenna gain [4]. Another study explored a single-band microstrip antenna enhanced with a metamaterial layer placed beneath the patch, with the goal of improving gain and directivity in the X-band. The metamaterial was engineered to exhibit negative electromagnetic parameters near 10 GHz. By integrating a 6×4 metamaterial array

ISSN: 2582 - 4201(Online) , http://www.ijrdes.com/ , IJRDES, Vol. 7, Issue 6, 2025 , https://doi.org/10.63328/IJRDES-V7RI6P2

underneath the patch, the antenna achieved a gain and directivity of 7.9 dBi, resonated at 11.8 GHz with a reflection coefficient of –24 dB, and demonstrated strong radiation characteristics.

The suggested antenna is suitable for Satellite applications with high gain at the X band.[5] This research introduces an ultrawideband circular monopole antenna featuring frequency notch capabilities, excited through a coplanar waveguide (CPW) with a small split ring resonator (SRR) loading. The desired notch frequency is suppressed, as confirmed by the radiation and impedance charts. Additionally, a suggested and verified theoretical method for calculating the notch frequency is provided [5].

The practise of metamaterial features in microstrip patch antennas has gained a lot of attention recently. In this work several rows-based metamaterials (CSRRs) that are related with patch resonators are discussed. In the frequency range of (1-6) GHz, Numerous designs for antennas have been developed. The effectiveness of each antenna may be evaluated by computing several characteristics such as gain, S11, and polar plot using HFSS. The findings of the simulation demonstrate that the gain increases with the metamaterial structure.[7]. The design and analysis of a broad-band patch antenna is presented in this, that utilizes split ring metamaterial. The novel and inventive insertion of SRR metamaterial structures into the patch cavity introduces subwavelength modes, resulting in patch antennas with wide bandwidths and remarkable performance characteristics. An rectangular microstrip patch antenna with a resonance frequency of 5.2 GHz and an impedance bandwidth of 70 MHz has been chosen as the reference antenna. The split ring resonator (SRR) design builds upon this reference antenna to enhance the bandwidth performance. [8]. Due to the rapid development of consumer electronics, there is a high need for tiny, highly gainy, widely-covering antennas that can accept multiple antennas at the transmitter and reception ends to boost channel capacity.

There have been a lot of presentations in the last decade on how to improve the antenna's performance. An antenna made of metamaterials (MTMs) is one way to do this. Metamaterials allow for the creation of filters, microwave devices, and high-performance antennas that would be impossible to create using traditional antenna design methods. Utilizing antennas that are modeled after MTM allows for an enhancement of both gain and bandwidth. [9]. This study introduces a 1 × 4 linear antenna array that enables switched-beam antenna array (SAA) capabilities by using metamaterial (MTM) technology linked with a Butler matrix (BM) beam forming network (BFN). The 5G communication-relevant sub-6 GHz frequency ranges are the intended focus of the design. Based on simulations run in CST Microwave Studio, the suggested SAA, which is constructed on a 1.6 mm abundant FR4 epoxy lead crystal substrate with a dielectric constant of 4.3, performs as expected. Experimental observations and modeling results both show that the MTM-BM beam forming network performs better. [10]

3. Proposed System

The presented antenna features a rectangular shaped patch design incorporating asymmetrical plus slots, DGS and metamaterial. The sizes of the presented square patch antenna are outlined in Table 1, featuring a radiating element in the form of a 26×28 mm² Rectangular patch (RP). The illustrated arrangement of the proposed antenna can be observed in Figure 1.

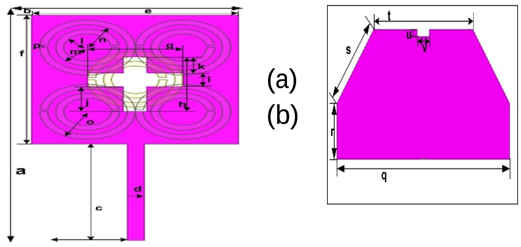


Figure.1 The geometrical design of the presented antenna (a) Top view of antenna (b) Bottom view of antenna

Table.1 Dimensions of RPA with DGS, asymmetrical plus slot and SRR

Parameter	Dimensions In mm	Parameter	Dimensions (mm)
a	70	i	3
b	70	j	5.5
c	21	k	4.5
d	2.1	l	3
e	26	m	4
f	28	n	5
g	12	o	6
h	12		

This section presents the parametric analysis and the evolution technique of the proposed antenna.

3.1. Proposed Antenna Evolution:

The arrangement of radiating patches supported by a ground plane makes up a MPA. A traditional RPA with dimensions of 26 x 28 mm is created for 10GHz on the Roger RT-Duroid 5880 substrate.

3.1.1. Conventional Rectangular Patch Antenna

The substrate has dielectric constant (εr) is 2.2 and its dielectric loss tangent (δ) is 0.0009 mm. Figure 1 shows the

ISSN: 2582 - 4201(Online) , http://www.ijrdes.com/ , IJRDES, Vol. 7, Issue 6, 2025 , https://doi.org/10.63328/IJRDES-V7RI6P2

schematic diagram for a proposed patch antenna. Applying Equations (1) and (2), patch's width (W) and length (L) can be determined. [3]

$$W = \frac{c}{2fr}\sqrt{\frac{2}{\varepsilon r+1}} \qquad [1]$$

$$L = \frac{c}{2fr\sqrt{\varepsilon_{eff}}} - 2\Delta L \qquad [2]$$

where, εreff is Effective dielectric constant, W is the width of the rectangular patch, εr is dielectric constant and c is the speed of light.

3.1.2. The Impact Of Slots On A Rectangular Patch Antenna Using Strip Feed

Rectangular slot, symmetrical plus slot and asymmetrical plus slot is created in the RPA as shown in Figure 2. Effect of the slots in the RPA is analyzed in the following section.

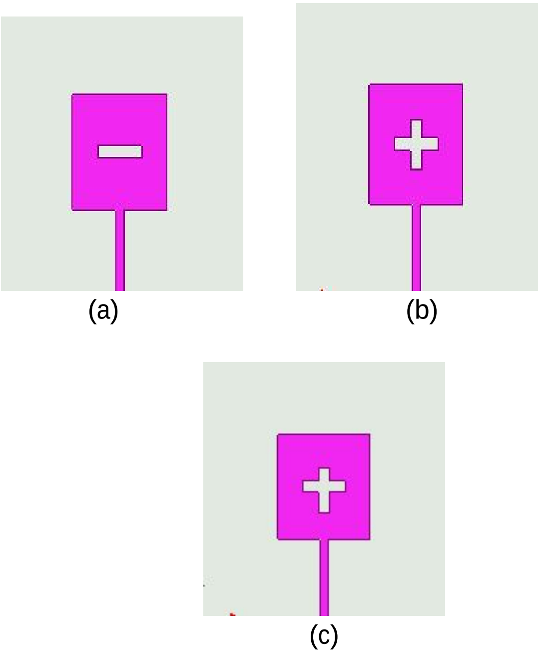


Figure.2 RPA with different slots.

The analysis of the effect of three slots is explained below. Figure 3 represents the related return loss plots.

Based on the results of the return loss investigation, the rectangular patch antenna (RPA) with the rectangular slot in the center has gain maximum of 7.8 dBi and a return loss of -12.63 dB at 6.85 GHz. The slot dimensions are g = 12 mm and i = 3 mm, and the antenna exhibits a bandwidth of 180 MHz (6.76-6.94 GHz). However, an antenna with a symmetrical plus-shaped slot may potentially work in three separate bands. Covering 180 MHz (6.75-6.93 GHz), the first band peaks at 8.5 dBi and has a reflection coefficient of -21.28 dB at 6.82 GHz. With a reflection coefficient of -13.52 dB at 7.68 GHz and a gain maximum of 7.6 dBi, the second band covers 90 MHz (7.63-7.72 GHz). There is a reflection coefficient of -25.44 dB at 9.48 GHz, gain maximum of 11.0 dBi, and a wider bandwidth of 500 MHz (9.22-9.72 GHz) in the third band.

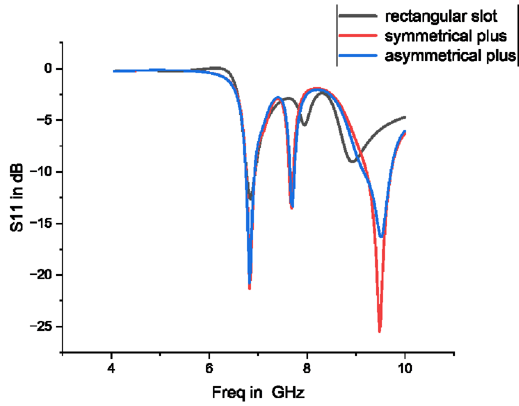


Figure.3 Return loss plots for different slots in RPA.

The triple-band properties are also shown by the antenna with the asymmetrical plus-shaped slot. With gain maximum of 8.5 dBi and a return loss of -20.84 dB at 6.82 GHz, the first band offers 180 MHz (6.75-6.93 GHz). The second band extends from 7.65 to 7.74 GHz, covering 90 MHz, and has gain maximum of 7.6 dBi and a return loss of -13.36 dB at 7.70 GHz. The third band has gain maximum of 11.7 dBi and a return loss of -16.30 dB at 9.52 GHz, with a bandwidth of 560 MHz (9.16-9.72 GHz). The asymmetrical plus slot layout was found to be the most effective after comparing it to the rectangular and symmetrical plus slots. As a result, it will be further improved.

3.1.3. Effect Of DGS

A DGS refers to a patterned discontinuity introduced in a ground plane of a microstrip antenna or other radio frequency devices.

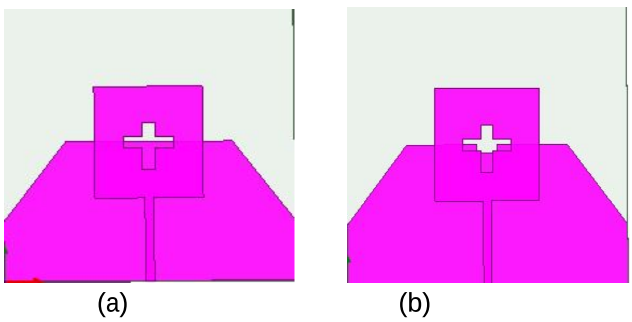


Figure.4 RPA with different DGS

It is intended to alter the ground plane's electrical characteristics., often to achieve specific antenna performance characteristics, such as improved bandwidth, enhanced radiation patterns or reduced cross-polarization. The utilize of DGS in antennas is a technique employed in RF and microwave engineering for optimizing antenna performance.

ISSN: 2582 - 4201(Online) , http://www.ijrdes.com/ , IJRDES, Vol. 7, Issue 6, 2025 , https://doi.org/10.63328/IJRDES-V7RI6P2

Raised triangular DGS with flat top in RPA is depicted in Figure 4(a), the RPA with raised triangular DGS, offers a peak gain of 4.6dBi at 10.55 GHz and a bandwidth of 1820MHz (9.05-10.87GHz). Rectangular cut is created in raised triangular DGS in RPA as shown in Figure 4(b), the presented antenna offers gain maximum of 7.76dBi at 10.38 GHz and a bandwidth of 1870 MHz (9.02-10.89GHz). After analyzing DGS results, the rectangular cut in raised triangular DGS offers better bandwidth.

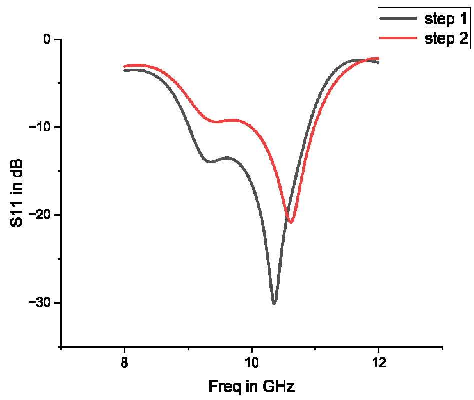


Figure.5 Return loss of RPA with slots and DGS by varying geometry.

3.1.4. Effect Of Metamaterial (Split Ring Resonator)

The circular SRR unit cell is shown in Fig. 6. Its double negative feature, as considered in metamaterial theory, is confirmed by parametric variables like refractive index (n), permeability (μ), and permittivity (ε) [8].

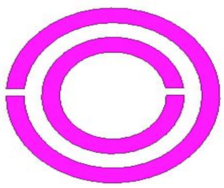


Figure.6 CSRR unit cell

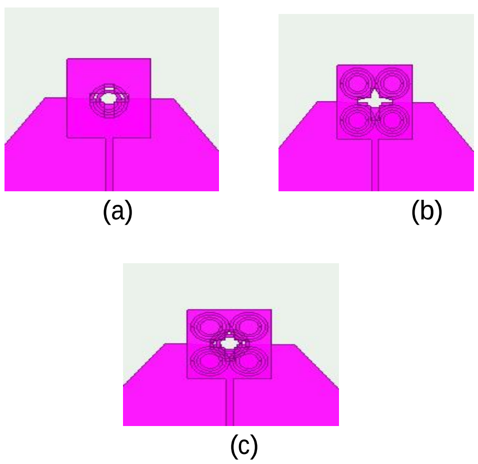


Figure.7 Iterations of CSRR on RPA with slots and DGS.

The patch exibits resonance at a frequency of 10.76 GHz, and the SRR is positioned as a crucial structural component. Covering the patch's slot is the initial prerequisite for the SRR. The quantity, layout, and direction of the rings all affect how well SRR performs. The Split Ring Resonator is designed using the unit cell SRR discussed above and has a notable increase in gain and bandwidth. Depending on their inter-element spacing, the SRR unit cells are spaced apart from one another in varying widths and lengths. The SRR designs are displayed in Figure 7(a), (b), and (c).

Figure.8 Return loss of RPA with SRR unit cell placed on patch around the slot

The reflection coefficient results of RPA with a SRR around the slot is taken. For this, two bands are exhibited. For the first band, the bandwidth is 1250 MHz with a frequency ranging from 8.95 to 10.20 GHz it provides a return loss -18.56dB at 9.29 GHz and maximum gain is 5.6 dBi. In second band, the bandwidth is 300 MHz with frequency ranging from 10.46 to 10.76 GHz with a reflection coefficient of -24.30 dB at 10.66 GHz and peak gain is 8.7 dBi.

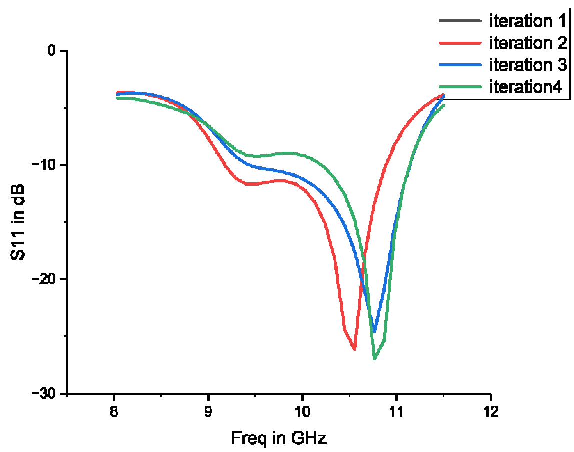


Figure.9 Return loss of RPA with iterations of SRR unit cell

The return loss results of RPA with all four iterations of SRR in a clockwise direction on the patch are taken. For the first SRR, the bandwidth is 660 MHz with a frequency ranging from 10.40 to 11.06 GHz, return loss -24.30dBi at 10.76 GHz and peak gain is 5.9 dBi. With the second SRR,

ISSN: 2582 - 4201(Online) , http://www.ijrdes.com/ , IJRDES, Vol. 7, Issue 6, 2025 , https://doi.org/10.63328/IJRDES-V7RI6P2

the bandwidth is 1710 MHz with frequency ranging from 9.18 to 10.89 GHz, return loss -26.12 dB at 10.55 GHz and peak gain is 4.6 dBi. With the third SRR, the bandwidth is 1690 MHz with frequency ranging from 9.45 to 11.14 GHz, return loss -24.57dBi at 10.76 GHz and peak gain is 7.2 dBi. With the fourth SRR, the bandwidth is 940 MHz with frequency ranging from 10.20 to 11.14 GHz, return loss -26.95 dB at 10.76 GHz and peak gain is 8.5 dBi.

Figure.10 Return loss of RPA with fifth iteration of SRR unit cell.

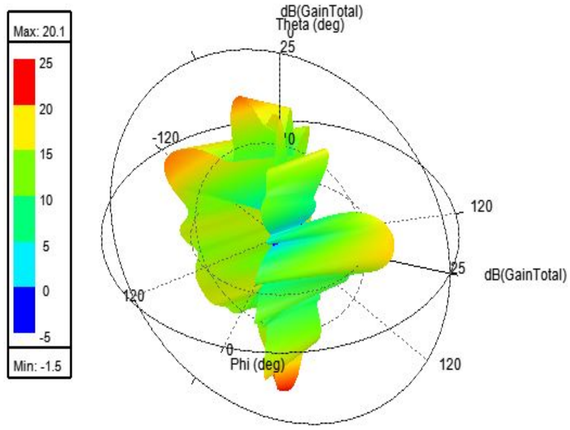
Finally, for the fifth iteration of SRR (centre of 2x2 SRR) provides two resonant peaks, the bandwidth is 1240 MHz with frequency ranging from 9.80 to 11.04 GHz, return loss -18.94 dB at 10.76 GHz and peak gain is 20.1 dBi and another peak provides return loss -17.78 dB at 10.34 GHz and peak gain is 12.0dBi. After analyzing SRR results, five SRR placed on the patch gives the better gain and bandwidth. The next part discusses the results and exploration of the antenna that was provided.

4. Results

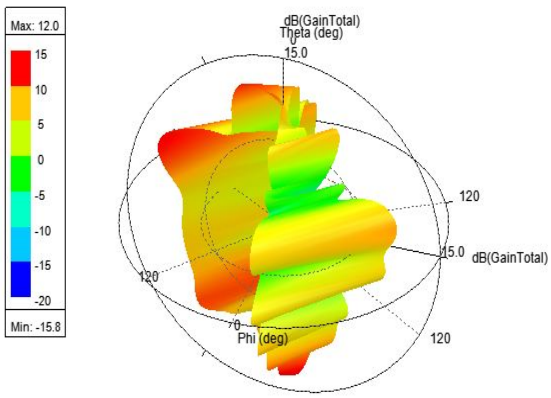
The proposed antenna's radiation pattern and peak gain are shown in Figures 11 and 12, respectively. Improving the antenna's overall performance is as simple as finding the resonance frequency and optimizing the return loss there. Figure 10 shows that after the fifth iteration of the SRR unit cells, the antenna achieves a resonance frequency of 10.76 GHz and a return loss of -18.94 dB.

By analyzing critical antenna characteristics, we can see that the suggested design offers better performance. When compared to a standard rectangular patch antenna (RPA), the SRR-loaded antenna achieves a much greater gain. The peak gain of the suggested SRR-enhanced design may reach 20.1 dBi, while the traditional single patch antenna only manages 7.8 dBi.

The plots of peak gains are shown in Figure 11.



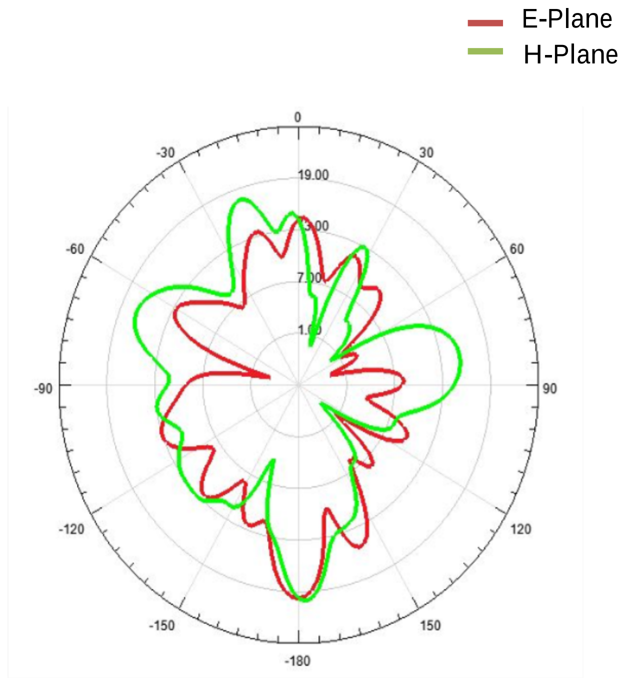
(a)



(b)

Figure.11 Peak gain plot at 10.76 GHz and at 10.34 GHz for RPA with fifth SRR

The E plane and H plane patterns of RPA with asymmetrical plus slot, DGS and SRR at 10.76 GHz and 10.34 GHz are shown in Figure 12.



ISSN: 2582 - 4201(Online) , http://www.ijrdes.com/ , IJRDES, Vol. 7, Issue 6, 2025 , https://doi.org/10.63328/IJRDES-V7RI6P2

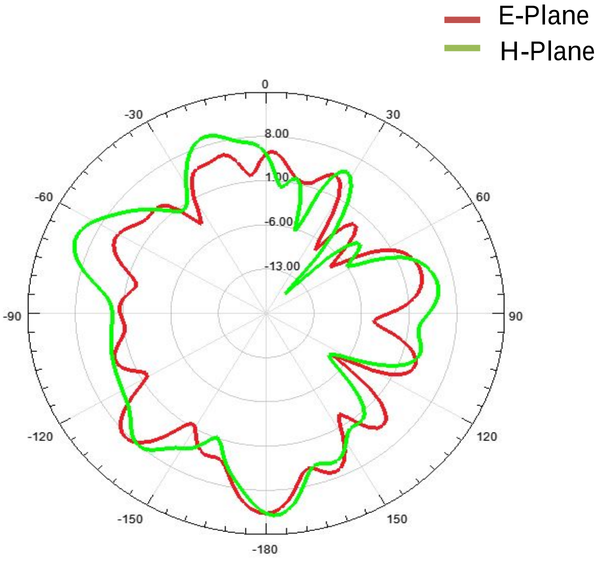


Figure.12 E- plane and H plane patterns of the proposed antenna

Table.2 Parameters of the suggested antennas.

Suggested Antenna	Resonating frequency (GHz)	Bandwidth (MHz)	Gain (dBi)
RPA with asymmetrical plus slot	9.16 to 9.72	560	11.7 at 9.52 GHz
RPA with asymmetrical plus and DGS	9.02 to 10.89	1870	7.6 at 10.38 GHz
RPA with five iterations of SRR	9.80 to 11.04	1240	20.1 at 10.76 GHz and 12.0 at 10.34 GHz

The table 2 compares the different antenna structures and their attributes, including gain and bandwidth. The table shows that by adding more unit cells (SRR) to the antenna, the peak gain is increased to 20.1 dBi. It is shown that although the improved impedance bandwidth of a DGS structure is superior, in terms of gain, an SRR structure performs better.

5. Conclusion and Future Scope

In this work, metamaterial-loaded MPA is presented and its performance parameters are evaluated. It is demonstrated that adding fifth iteration of SRR results in gain of 20.1 dBi and 12.0 dBi, respectively at two peaks. It is noted that the patch provides a broad 1.24GHz bandwidth. Therefore, the presented antenna with five SRR offers great gain and bandwidth for X-band applications. This work can be extended to obtain multi-band operation, circular polarization and the cross polarization can be reduced to improve the radiation efficiency.

References

[1]. Ambavaram Pratap Reddy and Pachiyannam Muthusamy, "Gain Enhancement of Dual Layer Truncated Corner Triangular Slot with DGS Patch Antenna for 5G/WLAN Applications", IEEE Indian Conference on Antennas and Propagation, 2021, DOI: 1109/InCAP52216.2021.9726356.

[2]. N.K. Darimireddy, R. Ramana Reddy, N. Rajasekhar and P. Srinivasa Rao "Rhombic Slotted Pentagonal Patch Antenna for GPS Applications" IEEE INCAP 2018, Hyderabad, DOI: 10.1109/INCAP.2018.8770830.

[3]. K. Sainath, P. K. Sharma, M. Basha. T.S and R. R. Reddy, "Rectangular Patch Antenna with Truncated Cuts and Slot for Satellite Communication Applications," IEEE Wireless Antenna and Microwave Symposium (WAMS), Ahmedabad,India,2023,pp.15, DOI:10.1109/WAMS57261.2023. 1024289.

[4]. Rajawat A., Singhal P.K., Gupta S.H., Jain C., Tomar P. and Kapur K. "Gain enhancement of microstrip patch antenna using H-shaped defected ground structure." Advances in Intelligent Systems and Computing, 519, pp. 517 – 526, 2018.

[5]. T. Sathiyapriya, V. Gurunathan and A. Shafeek" Design of metamaterial inspired high gain patch antenna" ICTACT journal on communication technology, march 2019, VOLUME: 10, ISSUE: 01.

[6]. Jawad Yaseen Siddiqui, Senior Member, IEEE, Chinmoy Saha, Member, IEEE, and Yahia M. M. Antar, Life Fellow, IEEE" Compact SRR Loaded UWB Circular Monopole Antenna With Frequency Notch Characteristics" IEEE transactions on antennas and propagation, vol. 62, no. 8, august 2014.

[7]. Becharef Kada, Nouri Keltouma and Abes Turkiya" Design of Patch Antennas based on Metamaterials CSRRs" 978-1-7281-2220-5/19/$31.00 ©2019 IEEE.

[8]. Sonia Bansal and Navdeep Kumar "SRR metamaterial based broadband patch antenna for wireless communications" Journal of Engineering and Applied Science (2022) 69:47 DOI:10.1186/s44147-022-00103-6.

[9]. Praveen Kumar, Tanweer Ali (Senior Member, IEEE), And M. M. Manohara Pai (Senior Member, IEEE)" Electromagnetic Metamaterials: A New Paradigm of Antenna Design" IEEE Access, DOI: 10.1109/ACCESS.2021.3053100, VOLUME 9, 2021.

[10]. Arshad Karimbu Vallappil , Mohamad Kamal A. Rahim (Senior Member, IEEE), Bilal A. Khawaja(Senior Member, IEEE), And Muhammad Naeem Iqbal" A Miniaturized Metamaterial-Loaded Switched-Beam Antenna Array System With Enhanced Bandwidth for 5G Applications" IEEE Access, DOI: 10.1109/ACCESS.2024.3351475, VOLUME 12, 2024.