# Compact High Gain Wide Band Planar Antenna Design using Metamaterial Techniques for Wireless Applications

**Potnuru Narayanarao[1] and Dr. Godi Karunakar[2]**

[1]*Asst. Professor, Department of ECE, AITAM, Tekkali, INDIA*
[2]*Assoc. Professor, Dept of ECE, GITAM (Deemed to be University), Visakhapatnam, INDIA*

**Abstract:** The paper refers to the design of metamaterial antenna configuration suitable for wideband applications in wireless communications, especially focusing on modern commercial and Defence applications. Metamaterials have emerged as a tactical solution to several electromagnetic system problems, which are highly constrained by size and volume limitations along with characteristics like multi-band, high gain and wideband requirements. In this paper, a single metamaterial radiating element has been designed for wide band in order to obtain the desired high gain. The simulation-based study uses modern EM tools and further analyzed using the reflection coefficient, current distribution and radiation patterns. The overall size of the antenna is 48 mm x 48 mm x 1.6 mm. The simulation and measurements are carried out for the performance proposed work. The simulation results are giving the bandwidth (BW) of 3.5 (2.1-5.6) GHz and a simulated gain of 4.7 dB at the centre frequency, for achieving the high bandwidth defected ground structure (DGS) technique and square ring resonator (SRR) techniques are used. The measured results are giving the bandwidth of ~10.5 (2.1-12.6) GHz and a gain of ~4.5 at the centre frequency. The simulation and measured results are achieving the similar performance and the proposed work is best suitable for wireless applications.

**Keywords:** Metamaterial, wideband, defected ground structure, square ring resonator and wireless communications

## 1. INTRODUCTION

Metamaterial antennas have garnered significant interest in antenna engineering due to their ability to manipulate electromagnetic (EM) waves in impossible ways with conventional materials. These artificially structured materials exhibit unique EM properties such as negative permeability as well as permittivity. These properties enable the design of antennas with enhanced performance characteristics, including multiband and wideband functionalities, which are critical for modern wireless communication systems. Metamaterial antennas represent a transformative approach in antenna design, offering complete control over electromagnetic wave propagation. The ability to design multiband and wideband antennas using metamaterials opens new possibilities for advanced wireless communication systems. The studies referenced in this survey highlight the innovative use of metamaterials in achieving enhanced antenna performance, paving the way for future advancements in this dynamic field. The development of metamaterial antennas continues to be a vibrant area of research, with ongoing efforts focused on optimizing their performance, reducing their size, and exploring new applications. As technology progresses, metamaterial antennas are expected to play a crucial role in the next generation of wireless communication systems, addressing the ever-growing demand for high-performance, multifunctional antennas.

Multiband antennas are essential for devices operating over multiple frequency bands, such as personal, commercial and defense wireless communication devices. Metamaterials offer a novel approach to achieving multiband operation by incorporating resonant structures tailored to resonate at specific frequencies.In [1], [2], a metamaterial-inspired multiband antenna was designed using SRR and CSRR. These resonators were strategically placed to produce multiple resonance frequencies, enabling multiband operation. The study demonstrated that by adjusting the dimensions and placements of the SRRs and CSRRs, the antenna could be tuned to operate efficiently at desired frequency bands. A compact multiband metamaterial antenna is designed in [3]–[6] using a combination of SRRs and transmission line structures. This design achieved resonance at 3 different frequency bands and is used for applications in modern communication systems that require simultaneous operation over multiple frequency channels.Wideband antennas are crucial for applications requiring a broad range of frequencies, such as radar systems, broadband wireless networks, and ultra-wideband (UWB) communication. Metamaterials can be engineered to create antennas with wideband characteristics by utilizing their ability to create artificial magnetic conductors and high-impedance surfaces.

A wideband metamaterial antenna was developed and

*E-mail address: 121960404002@gitam.in, kgodi@gitam.edu*

presented in [7]–[9] using a mushroom-like structure composed of periodic patches connected via vias to the ground plane. This configuration significantly enhanced bandwidth due to the creation of multiple resonances and impedance matching over a frequency range. [10] demonstrated a wideband planar antenna using a metamaterial-inspired structure that combined a monopole antenna with an array of metamaterial unit cells. This design provided a wide operational bandwidth with improved radiation efficiency and gain, showcasing the potential of metamaterials in wideband antenna applications.The design presented in [11]–[16] explores developing and performing a MIMO array antenna enhanced with a metamaterial for broadband wireless applications in the sub-6 GHz frequency of operation. The sub-6 GHz spectrum is crucial for modern wireless communication applications like 5G networks. The study presents a detailed design of the MIMO antenna array (AA), which incorporates a metamaterial based superstrate to achieve broadband performance. The superstrate [12] is engineered to possess unique EM properties that improves the BW, gain, and overall efficiency of the antenna. The superstrate comprises periodic structures that shows the properties not found in natural materials,referred to as metamaterial. These properties enable better control over EM wave propagation, improving antenna performance.

The antenna geometry in [13], [17], [18] features two closely spaced radiating elements integrated with metamaterial structures. Hybrid techniques, including EBG (Electriagnetic Band Gap) and DGS (Degected ground structure), mitigate mutual coupling between the antenna elements. The results demonstrate significant isolation improvement, exceeding 20 dB across the operating frequency band. This enhancement improves MIMO performance, making the antenna suitable for high-density wireless communication applications.Microstrip antenna with circular polarizatio as well as high gain is presented in [19]–[21]. The antenna geometry has a modified patch with truncated corners and a parasitic patch above the main radiating element. The technique involves optimizing the patch dimensions and introducing a parasitic element to broaden the bandwidth are discussed in [22]–[33]. The results demonstrate a significant improvement in gain and axial ratio BW, with the antenna achieving a wide impedance BW and stable circular polarization across the operating band, making it ideal for modern communication systems.

The work presented in this paper reports yet another design based on metamaterial for multiband and wideband applications in modern telecom and wireless communications. 2 deals with the literature of the previous work. Further, in this paper, the proposed geometry of the initial designs is presented in section 3. The results and discussion are provided in Section 4, fabrication techniques with measured results are discussion is in section 5 and the paper ends with a conclusions are presented in Section 6.

## 2. LITERATURE REVIEW

The work in [12], presents a compact UWB and MIMO fractal antenna inspired by metamaterial concepts. The authors focus on addressing the issue of mutual coupling of the antenna elements, a common challenge in MIMO systems. By employing a fractal design, the antenna achieves a compact form factor while maintaining wideband performance. The integration of metamaterial-inspired structures helps in reducing mutual coupling, which is critical for improving the isolation of the antenna elements in MIMO configurations. The study demonstrates significant improvements in isolation and overall antenna performance, making it suitable for UWB applications where performance is the major factors in wireless applications.

The authors Ameen and Chaudhary [13] explore the enhancement of isolation in a 2-port MIMO system using metamaterial-inspired hybrid techniques. The authors propose a novel approach that combines different isolation enhancement techniques, including the use of metamaterial-inspired elements. The focus is on reducing the electromagnetic interference (EMI) between the ports in MIMO antenna, which is crucial for improving the overall system performance in multi-antenna systems. The study presents a comprehensive analysis and demonstrates that the proposed hybrid techniques significantly enhance the isolation, leading to better MIMO system performance.

Kumar et al [19], present a high-gain, wideband circularly polarized microstrip antenna design. The study focuses on achieving wideband circular polarization, which is essential for applications such as satellite communications, where polarization mismatch can lead to signal degradation. The authors use a microstrip patch antenna design that incorporates metamaterial-inspired techniques to enhance the gain and BW The design achieves a significant improvement in both gain and circular polarization bandwidth, demonstrating its potential for high-performance wireless communication applications.

Abdalla et al [22], analyze and design a triple-band monopole antenna consists of Right/Left-Handed (CRLH) metamaterial cells. The paper focuses on achieving triple-band operation, which is beneficial for supporting multiple wireless standards within a single antenna design. The CRLH metamaterial cells are used to introduce multiple resonances, allowing the antenna to operate effectively at three distinct frequency bands. The study provides detailed analysis and design considerations, demonstrating that the CRLH-loaded monopole antenna provides a best suitable solution interms of compact and efficient design for multiband applications.

Zhu et al [23], introduces ultrasmall dual-band metamaterial antennas based on hybrid resonators. The focus is on achieving a highly compact antenna design that operates effectively at two frequency bands. The use of asymmetrical hybrid resonators, inspired by metamaterial concepts, allows the antenna to achieve dual-band operation while maintaining a minimal footprint. The study highlights the potential of metamaterial-inspired designs to create highly compact and efficient antennas suitable for modern communication devices where space is limited.

Rosaline's [24] addresses the design of a triple-band antenna using metamaterial slab aimed at enhancing a gain and reducing the SAR (specific absorption rate). SAR is a critical parameter in antenna design, particularly for mobile and wearable devices, where excessive radiation can pose health risks. The incorporation of a metamaterial slab not only improves the antenna's gain but also significantly reduces SAR, making the antenna safer for use in near spacial distance to the human body. The paper provides valuable insights into the dual benefits of metamaterial-inspired designs in enhancing performance while ensuring user safety.

Bhavani et al [25], explore design and development of a metamaterial-inspired non-uniform circular array superstrate antenna using CMA. The paper focuses on optimizing the antenna's radiation characteristics through the use of a non-uniform circular array combined with a metamaterial superstrate. Characteristic mode analysis is employed to identify the dominant radiation modes and to enhance the antenna's performance by choosing selective exciting these modes. The study demonstrates that the combination of non-uniform array design and metamaterial superstrates can lead to significant improvements in gain, bandwidth, and radiation efficiency.

Dai et al [26], present a copact equilateral triangular metamaterial antenna designed specifically for mobile applications. The study addresses the challenge of miniaturizing antennas without compromising performance, a critical requirement for modern mobile devices. By incorporating metamaterial elements into the patch design, the authors achieve a significant reduction in antenna size while maintaining efficient performance across the required frequency bands. The paper deals the potential of metamaterial-inspired designs in meeting the stringent size and electrical performance requirements of mobile communication systems.

The paper by Paul et al [27], explores design as well as performance of a MPA with a DGS structure inspired by metamaterial concepts. The authors etch four dual triangular cuts on the ground plane to manipulate the current distribution and improve the antenna's performance. The DGS technique, combined with metamaterial principles, leads to enhanced bandwidth and gain, as well as improved impedance matching. The study summarizes a detailed analysis of the antenna performance, demonstrating the effectiveness of DGS in conjunction with metamaterial-inspired designs.

Rathod and Bhakar [28] focus on improving the bandwidth and gain of a hexagonal MPA for wireless applications by employing suspended techniques. The paper investigates the effect of suspending the patch antenna above the ground plane to enhance its performance. This technique, combined with metamaterial-inspired elements, leads to significant improvements in both bandwidth and gain, making the antenna suitable for high-performance wireless communication systems. The study provides insights into the advantages of using suspended techniques in conjunction with metamaterial concepts to achieve superior antenna performance.

Rezvani and Zehforoosh [29] presents a dual-band MIMO microstrip antenna focuses on specifically for LTE and WLAN applications. The antenna incorporates a metamaterial structure to enhance its performance in terms of bandwidth, isolation, and miniaturization. The metamaterial elements are integrated into the design to introduce additional resonances, enabling the antenna to operate efficiently across the LTE and WLAN operating frequencies. The use of metamaterials also significantly improves the isolation in the MIMO antenna elements, which is critical for reducing mutual coupling and enhancing overall system performance. The authors conducted and presented a thorough analysis of their antenna performance, includes simulation and measurements, demonstrating that the proposed design meets the typical requirements for modern wireless systems. This study highlights the potential of metamaterials in creating compact, high-performance MIMO antennas that can operate effectively in multiple frequency bands, making it highly relevant for next-generation wireless applications.

Fathipour's [30] research focuses on the design and developed a metamaterial antenna using multilayer stack up intended for WiFi and WiMAX applications. The paper details the development of a high-gain antenna that utilizes multiple layers of metamaterial structures to enhance its radiation characteristics and overall performance. The multilayer design is optimized to achieve high gain as well as good radiation patterns across the targeted frequency range of operation, which are critical for efficient wireless communication. The metamaterial layers are carefully engineered to manipulate the electromagnetic waves, resulting in improved directivity and reduced side lobes. Fathipour presents both simulation and experimental results, demonstrating the effectiveness of the proposed design in achieving the desired performance metrics. The paper contributes to the field by providing a practical solution for high-gain, multilayer metamaterial antennas that can be effectively used in WiFi and WiMAX networks, where robust and efficient signal transmission is essential.

Kaur, Bansal, and Kumar [31] explore the development of a broadband patch antenna using SRR metamaterial structures for wireless communications. The paper focuses on enhancing the BW and gain of the patch antenna by integrating SRRs into the design. The SRRs are strategically placed to introduce additional resonances, thereby broadening the antenna's operational bandwidth. This enhancement is particularly beneficial for wireless communication systems that require efficient transmission over a wide range of frequencies. The authors of this publication provides a detailed analysis of the antenna's performance, including the impact of the SRR structures on bandwidth and radiation efficiency. The study demonstrates that the SRR-based metamaterial patch antenna offers significant improvements in both bandwidth and gain compared to conventional patch antennas, making it a promising candidate for modern wireless communication applications. The paper also discusses the practical implications of the design, emphasizing its potential for use in various wireless communication systems where broadband performance is critical.

In this study, the authors [34] design a circular patch antenna with SRR metamaterial structures strategically embedded into the antenna's substrate. The SRRs create localized resonances that facilitate multiband performance, making the antenna suitable for various satellite communication bands. The design focuses on achieving compactness, high gain, and enhanced bandwidth, which are critical for satellite communication where space constraints and reliable, long-distance signal transmission are paramount.The paper provide a comprehensive analysis interms of the antenna's performance, including simulations and measurements of antenna parameters like radiation pattern, VSWR, Return Loss and gain across the targeted frequency bands. The results demonstrate that the SRR-loaded circular patch antenna exhibits improved multiband performance, making it a viable option for satellite applications where versatile and efficient communication is required. This study contributes to the growing body of research on metamaterial-enhanced antennas, highlighting the potential of SRR-based designs in achieving advanced multiband capabilities for critical communication systems.

This paper [35], addresses the critical issue of mutual coupling in closely spaced MIMO antenna systems, particularly for WLAN applications. As the demand for compact and efficient wireless devices increases, antenna designers face the challenge of maintaining high isolation between MIMO antenna elements to prevent performance degradation due to mutual coupling. Suganya et al. propose a novel technique to enhance isolation by optimizing the physical distance between the antenna elements. The paper presents a detailed analysis of how adjusting the spacing impacts the overall isolation and performance of the MIMO system. The authors use simulation and experimental methods to demonstrate that their approach effectively reduces mutual coupling, leading to improved antenna performance in terms of gain, return loss, and radiation efficiency. The study provides valuable insights for designing compact MIMO antennas with enhanced isolation, making it a significant contribution to the field of wireless communications, particularly in the context of WLAN applications where space is often limited.

Satheeshkumar et al [36], presents a comprehensive study on the design and analysis of HFAA (Hexagonal Fractal Antenna Array) aimed at future wireless communication systems. The use of fractal geometries in antenna design is known for its ability to create multiband antennas with compact size and improved performance. The authors leverage the hexagonal fractal structure to develop an antenna array that not only covers multiple frequency bands but also enhances gain and directivity, which are crucial for next-generation communication technologies such as 5G and beyond. The paper details the design process, simulation results, and performance analysis of the HFAA, demonstrating significant improvements in terms of bandwidth, gain, and radiation efficiency compared to conventional antenna arrays. This work highlights the potential of fractal geometries in advancing antenna technology, making it a relevant study for researchers and engineers working on next-generation wireless communication systems.

Palanisamy et al [37], explore the design of advanced fractal antennas for wireless applications using a multi-objective hybrid metaheuristic framework. The antenna design integrates Split-Ring Resonators (SRRs) and Electromagnetic Bandgap (EBG) structures, both of which are known for their effectiveness in enhancing antenna performance. SRRs are commonly used to achieve miniaturization and multi-band operation, while EBG structures are utilized for improving radiation characteristics and reducing surface wave effects. The hybrid metaheuristic framework employed in the study combines these structures to optimize the antenna design, focusing on multiple objectives such as BW, gain, and radiation efficiency. The paper provides detailed simulations and performance evaluations, showing that the proposed hybrid antenna design offers significant improvements over traditional fractal antennas. This research is particularly relevant for wireless applications that require compact, high-performance antennas capable of operating across multiple frequency bands with enhanced efficiency.

## 3. METHODOLOGY AND ANTENNA DESIGN

To design an initial microstrip patch antenna with line feeding, we have started with a specific choice of dielectric substrate of particular thickness and relative permittivity. Further, the patch dimensions (length and width) shown in Table I, are computed using standard formulas based on the desired resonant frequency. Place the microstrip feed line at a precise location on the edge of the patch to ensure proper impedance matching, typically at the point where the input impedance is 50 ohms. This is performed by moving the line edge through the entire perimeter of the patch antenna. Adjusted the feed line width to match the characteristic impedance of the microstrip line. Following this we have optimised the design through simulation to achieve desired performance parameters of antenna, such as return loss (RL), bandwidth (BW), and the radiation pattern.

The Patch antenna presented in Fig.1 is modified regard-

TABLE I. Antenna design parameters

| S. No | Parameter | Dimensional value (mm) |
|---|---|---|
| 1 | Ws | 48 |
| 2 | Ls | 48 |
| 3 | Wp | 17.5 |
| 4 | Lp | 24.5 |
| 5 | Lf | 15 |
| 6 | Wf | 1.25 |
| 7 | a | 2 |
| 8 | b | 2 |
| 9 | S | 6.3 |
| 10 | W1 | 40 |
| 11 | L1 | 5 |
| 12 | L2 | 4.5 |
| 13 | W2 | 22 |
| 14 | Lg | 15 |
| 15 | W3 | 5 |
| 16 | g1 | 0.5 |
| 17 | g2 | 0.5 |
| 18 | LR | 3.8 |
| 19 | LR1 | 2.5 |

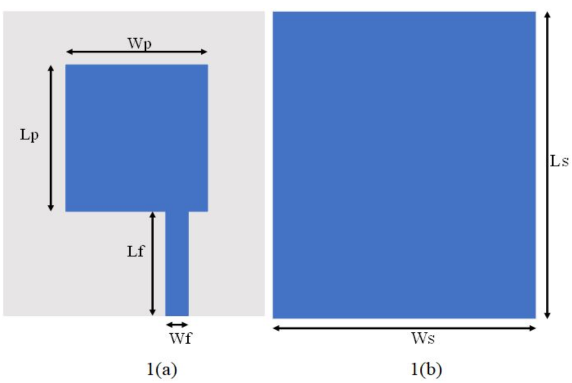



Figure 1. Geometry of initial design of MPA

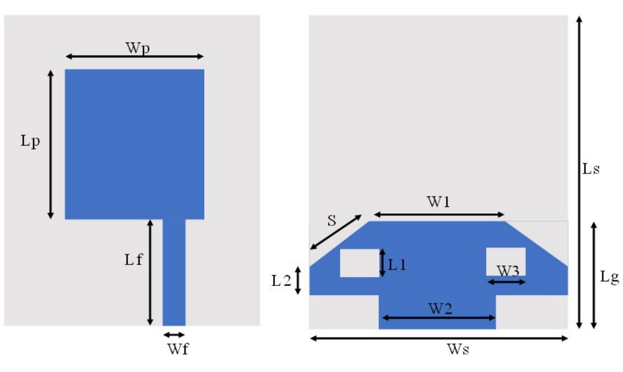



Figure 2. Geometry of MPA with DGS

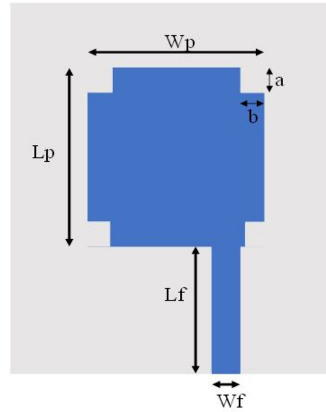



Figure 3. Tweaked edged MPA with DGS

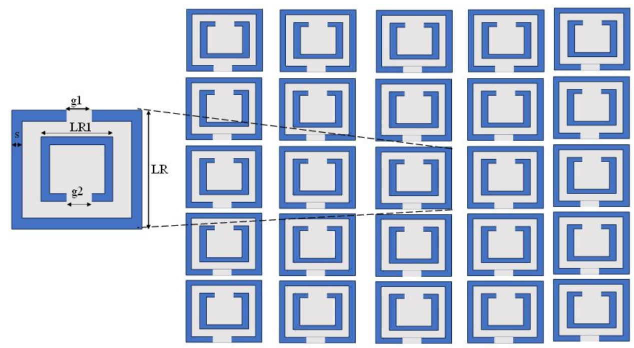



Figure 4. Metamaterial array configuration geometry

ing the ground plane (GP). The GP is modified to feature a defective ground as shown in Fig.2(b) while Fig.2(a) refers to the top plane of patch antenna. This defective GP contributes to the mitigation of the radiation and resonant characteristics of the planar antenna.A defective ground geometry in the designed has been incorporated. The defective ground structure (DGS) in a patch antenna can significantly alter the antenna's performance characteristics. Here, the DGS consists of a trapezoid and two slots on either side of it, integrated into the ground plane of the patch antenna. It has three significant regions as follows. (a) Trapezoid: Positioned centrally, the trapezoid is formed by cutting a trapezoidal shape into the ground plane. The larger base of the trapezoid is parallel to the edge of the ground plane, while the smaller base is closer to the center. (b) Slots: Two rectangular slots are placed symmetrically on either side of the trapezoid. These slots are parallel to the sides of the trapezoid, creating a symmetrical configuration. (c) Connection: The trapezoid is connected to the edge of the ground plane with a rectangular conducting plane, ensuring continuity and structural integrity.

The DGS helps achieve better impedance matching by altering the current distribution on the ground plane. The presence of the trapezoid and slots can lead to an increase in the effective inductance and capacitance, thereby

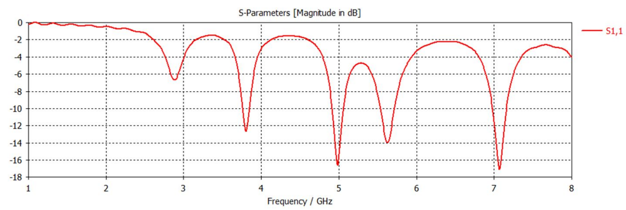



Figure 5. MPA resonant characteristics

broadening the operational bandwidth. This configuration can improve radiation pattern characteristics by suppressing unwanted modes and enhancing desired radiation patterns.

A rectangular patch antenna with tweaked edges, often called a corner-truncated patch antenna, involves modifying the edges of the rectangular patch by cutting or beveling the corners. This alteration can enhance the antenna's performance, improving impedance matching and increasing bandwidth. The tweaked edges can also help achieve circular polarization, which is beneficial for applications requiring robust signal reception regardless of orientation. This design maintains the simplicity and low-profile nature of the traditional rectangular patch antenna while offering enhanced electrical characteristics and versatility in various wireless communication systems. Such a geometry is presented in Fig.3.

Following the mitigated patch antenna design, it is further enhanced in design by placing a metamaterial configuration over the radiating patch as shown in Fig.4. This configuration strategically places a metamaterial-based array over an edge-tweaked rectangular patch antenna with a slotted DGS. As previously described, the DGS comprises a trapezoid with two slots on either side, connected to the edge of the ground plane by a rectangular conducting plane. The metamaterial array consists of periodic resonant elements like SRRs or CSRRs. These elements are designed to interact with electromagnetic waves, providing desired properties like negative permittivity and permeability. The array is placed above the patch antenna. The optimal height is determined through simulation to maximize interaction with the radiated fields, enhancing the antenna's performance.

Combining the metamaterial array with the DGS improves the antenna's effective bandwidth and gain. The metamaterials introduce additional resonances, effectively broadening the operational bandwidth. The metamaterial array influences the electromagnetic fields, leading to a more directed and stable radiation pattern. This enhancement is crucial for applications requiring high directivity and low side lobes. The interaction between the metamaterial elements and the defective ground structure provides better control over the current distribution, improving impedance matching across a wider frequency range.Integrating a metamaterial-based array over an edge-tweaked rectangular patch antenna with a slotted DGS significantly improves bandwidth, gain, and radiation pattern. This advanced configuration leverages metamaterials′ unique electromagnetic properties and the DGS's tailored current distribution, making it suitable for high-performance wireless communication applications.

## 4. SIMULATION RESULTS AND DISCUSSION

The reflection coefficient (S11) plot for the antenna indicates a bandwidth extending from 2.3 GHz to 5 GHz, with the minimum S11 value reaching approximately -25 dB, suggesting good impedance matching and minimal reflection within this range. The reference impedance plot shows a stable impedance of 49.5 ohms across the entire tested frequency spectrum, which is very close to the standard 50 ohms, indicating a well-designed matching network. Additionally, the VSWR plot remains below 2 over the same bandwidth as the S11 plot, confirming that the antenna maintains efficient power transmission with minimal reflected power across the specified frequency range is represented in Fig.6.

The E-field distribution plots for the designed antenna with a Defective Ground Structure reveal distinct patterns at different frequencies. At 3 GHz, the E-field is concentrated along one half of the patch, divided diagonally, with minimal concentration on the other side. At 3.5 GHz, the concentration shifts to the center of the patch. For frequencies of 4, 4.5, and 4.9 GHz, the E-field covers both the center and the top corners of the patch and are represented in Fig.7. Across all these frequencies, the highest current concentration consistently appears at the feed line, indicating strong coupling and efficient power transfer at the feed point.

The H-field distribution for the designed antenna exhibits different characteristics compared to the E-field. From 3 to 4 GHz, the H-field shows a minimum concentration at the central area of the radiating patch. However, at higher frequencies of 4.5 and 4.9 GHz, this low concentration area begins to shrink, indicating a more uniform H-field distribution across the patch and is represented in Fig.8. This changing distribution suggests variations in the magnetic field interactions within the antenna structure as the frequency increases.

The 2D and 3D radiation pattern plots are very similar in characteristics with no radiation in the upper hemisphere while maximum radiation in the lower hemisphere as shown in Fig.9 and 10 respectively. The S11 plot of Fig.11 is the simulated tweaked edge patch antenna with a defective ground reveals an extended bandwidth that surpasses 5 GHz by at least 0.5 GHz. This indicates an enhancement in the antenna's performance, likely due to the design modifications, which have effectively widened the operational frequency range. The additional 0.5 GHz bandwidth suggests improved impedance matching and reduced reflections, allowing the antenna to operate efficiently over a broader spectrum. This extended bandwidth makes the antenna more versatile and suitable for various applications

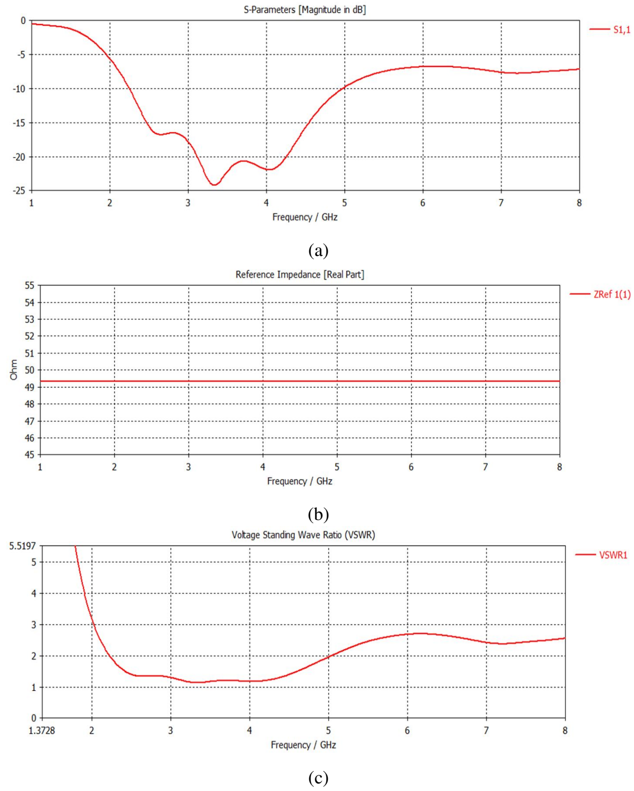



Figure 6. DGS Antenna Resonant characteristics (a) Return Loss (b) Impedance and (c) VSWR

requiring wider frequency coverage.

The incorporation of metamaterial characteristics on the tweaked patch antenna with a DGS has led to notable improvements in performance. The S11 parameter, representing the return loss or reflection coefficient of the antenna, shows a significant reduction from -25 dB to -47 dB. This indicates a much better impedance matching of the antenna with the transmission line, resulting in more of the input power being radiated rather than reflected. This improvement in the S11 values suggests an enhancement in the antenna's gain as well as efficiency, which is critical for applications requiring high-efficiency antennas such as in wireless communication systems.

Additionally, the reference impedance remains constant over the entire spectrum of operation, indicating stable and reliable performance across the antenna operational bandwidth. This stability ensures that the antenna maintains its designed impedance matching across different frequencies, leading to a predictable and uniform response. The combination of metamaterial characteristics and DGS has evidently led to improved radiation features, as seen from the better S11 values. The unique properties of metamaterials, which can manipulate EM waves in ways that conventional materials cannot, and the ability of DGS to disrupt the current distribution on the ground plane, have both contributed to better impedance matching and radiation characteristics.

The enhancements in the S11 values and the constant reference impedance plot together signify that the modifications made by incorporating metamaterial characteristics and DGS have resulted in a highly efficient antenna with improved radiation features, better gain, and stable impedance characteristics. Similar response is seen in the VSWR plots shown in Fig.12.

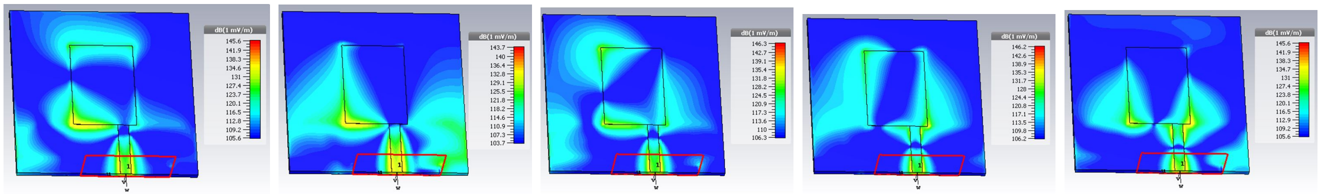
Unlike a conventional patch antenna, the incorporation of metamaterial enables a uniform distribution, which is evident from the field distribution plots at frequencies of 2.5, 3, 3.5, 4, 4.5, 5, 5.5 and 6 GHz. Examining the E-field and H-field distribution plots across these frequencies reveals a consistent and uniform pattern, highlighting the benefits of metamaterial integration. The E-field distribution plots show a more even and symmetric field distribution compared to conventional patch antennas. This uniformity is crucial for achieving better performance as it ensures that the electric field is evenly spread across the antenna surface, minimizing hotspots and enhancing overall radiation efficiency. At each of the specified frequencies, the E-field plots illustrate this uniform distribution, demonstrating the antenna's ability to maintain consistent performance over a wide bandwidth.

Similarly, the H-field distribution plots reflect a uniform magnetic field distribution across the same frequencies. The presence of a balanced H-field is indicative of effective current flow on the antenna surface, contributing to the improved impedance matching and reduced power losses. This uniform H-field distribution is a testament to the role of metamaterials in enhancing the antenna's performance by providing better control over the electromagnetic wave propagation.

The consistency observed in both E-field and H-field distributions across the different frequencies underscores the advantages of using metamaterial structures. By facilitating a more uniform distribution of the electromagnetic fields, the antenna exhibits improved radiation characteristics, better impedance matching, and higher efficiency. These enhancements are critical for applications requiring reliable and efficient antennas across a broad frequency range.

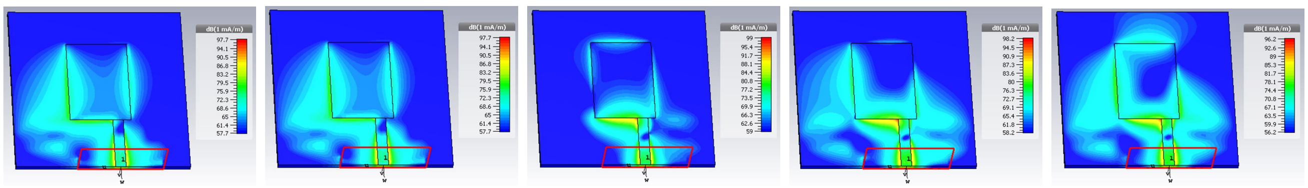
In summary, the field distribution plots for 2.5, 3, 3.5, 4, 4.5, 5, 5.5, and 6 GHz clearly illustrate the uniform distribution of E-field and H-field provided by the metamaterial-enhanced patch antenna in Fig.13 and Fig.14. This uniformity leads to superior performance compared to conventional patch antennas, highlighting the significant benefits of incorporating metamaterials in antenna design.

Further the radiation pattern plots in 2D and 3D are consistent in terms of typical patch antenna patterns are represented in Fig.15 and Fig.16 respectively. This clearly points to the resonant frequencies.



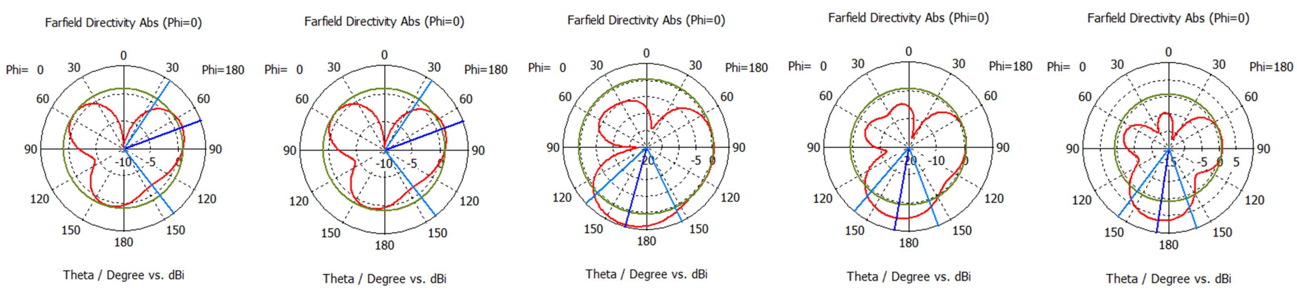
(a) (b) (c) (d) (e)

Figure 7. E-filed distribution of DGS based Antenna (a) 3 (b) 3.5 (c) 4 (d) 4.5 and (e) 4.9 GHz frequencies respectively



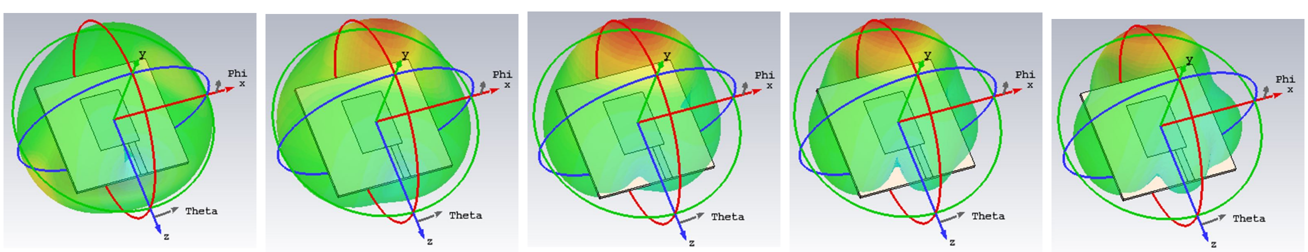
(a) (b) (c) (d) (e)

Figure 8. H-filed distribution of DGS based Antenna (a) 3 (b) 3.5 (c) 4 (d) 4.5 and (e) 4.9 GHz frequencies respectively




(a) (b) (c) (d) (e)

Figure 9. 2D Radiation pattern of DGS based antenna (a) 3 (b) 3.5 (c) 4 (d) 4.5 and (e) 4.9 GHz frequencies respectively




(a) (b) (c) (d) (e)

Figure 10. 3D Radiation pattern of DGS based antenna (a) 3 (b) 3.5 (c) 4 (d) 4.5 and (e) 4.9 GHz frequencies respectively

TABLE II. Comparison of metamaterialProposed antenna with the other MPAs

| S.No | Antenna Type | Size ($mm^3$) | Bandwidth (GHz) | Gain (dB) | Beamwidth (degrees) |
|---|---|---|---|---|---|
| 1 | Initial MPA | 48 x 48 x 1.6 | 0.13 | 6 | 80.3 |
| 2 | Modified MPA with DGS | 48 x 48 x 1.6 | 3.02 | 4.34 | 72.7 |
| 3 | Tweaked MPA with DGS | 48 x 48 x 1.6 | 3.26 | 2.87 | 192.5 |
| 4 | Proposed Antenna with Metamaterial (metamaterial size) | 48 x 48 x 1.6 (48 x 48 x 1.6) | 3.5 | 4.7 | 120 |

TABLE III. Comparison of metamaterial proposed antenna with previous literature

| Ref | Operating frequency (GHz) | BW (GHz) | Size ($mm^3$) | Gain (dB) | $\varepsilon_r$ | Type of structure used for metamaterial |
|---|---|---|---|---|---|---|
| [9] | 2.3-2.5, 3.3-3.8 & 5.3-5.9 | 0.2, 0.5, 0.6 | 35 x 32 x 1.6 | 0,1.6 & 2.7 | 4.4 | CRLH cells |
| [10] | 2.15-3.3 & 5.51-7.25 | 1.15, 1.75 | 19.8 x 10 x 3 | 2.23 , 5.72 | 2.65 | Complementary spiral resonators |
| [11] | 2.2-2.6, 3.4-3.6 & 5-6.9 | 0.4, 0.2 & 1.9 | 20 x 13 x 1.6 | 2.7 & 3 | 4.4 | SRR loaded MTM |
| [12] | 5.5-6.1 | 0.6 | 13.27 x 27.5 x 2 | 7.9 | 2.7 | CMA and Metasurface |
| [13] | 3.451-3.524 | 0.073 | 50 x 50 x 1.52 | 6.3 | 3 | Triangular MTM patch antenna |
| [14] | 10.285-10.753 | 0.468 | 39 x 30 x 1.6 | 6.2 | 3.75 | Metamaterial using DGS |
| [15] | 2.35-2.58 | 0.227 | - | 6.511 | 4.4 | Suspended Hexagonal MPA |
| [16] | 2.4-5.8 | 3.2 | 180 x 90 | 6 | 4.4 | Metamaterial MPA |
| [17] | 2.55-2.72 | 0.17 | 105 x 72.5 x 1.58 | 15.8 | 2.2 | Multilayer metamaterial |
| [18] | 1.63-4.88 | 3.25 | 70 x 70 x 1.6 | 4.5 | 4.4 | SRR Metamaterial |
| this paper | 2.1-5.6 GHz | 3.5 | 48 x 48 x 1.6 | 4.7 | 4.4 | SRR |

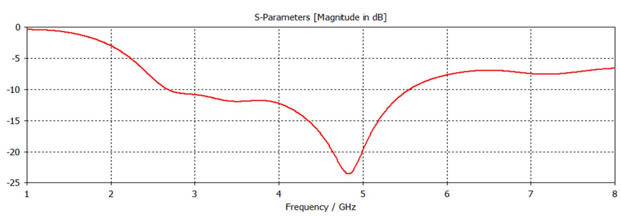



Figure 11. MPA resonant characteristics

## 5. MEASURED RESULTS AND DISCUSSION

The Fig.17 represents the fabricated prototypes of proposed tweaked MPA using standard photolithography techniques. The front and back view (DGS ground) is represented in Fig.17(a) and Fig.17(b) respectively. The antenna measurements are carried out using the Agilent Vector Network analyzer (VNA) and the measurement results is represented in Fig.17(c). The proposed antenna operating from the frequency range of 2.1-12 GHz with a bandwidth of ~10 GHz which is the good performance from the fabricated prototype.

The fabricated model of the proposed 5x5 SRR metamaterial structure is represented in the Fig.18(a). This metamaterial structure is kept 6 mm above the tweaked MPA and the measured results are represented in Fig.18(b). The bandwidth is enhanced to 12.5 GHz frequency with an operating frequency range of 2.1-12.6 GHz.

The characteristics of the all the antennas designed in this work are compared in terms of size, bandwidth, gain and beamwidth parameters are tabulated in Table II. The proposed work of metamaterial based tweaked MPA provide the best performance interns of gain and bandwidth point of view. The proposed metamaterial based tweaked MPA is compared with the existing literature interms of operating frequency, bandwidth, size of the antenna, gain, dielectric constant and type of structure used for metamaterial is tabulated in TableIII. The proposed work provides good performance in several aspects with literature and is best suitable for high bandwidth and gain for wireless IOT applications.

## 6. CONCLUSION

In this work, a combination of tweaked MPA with SRR based metamaterial antenna is designed for high gain and wide bandwidth wireless applications. The proposed antenna is designed using the low-cost laminate of FR4 with dielectric constant of 4.4 and the overall size of the antenna is 48 x 48 x 1.6 $mm^3$. The simulation and measurements are carried out for the performance proposed work. The simulation results are giving the bandwidth of 3.5 GHz (2.1-5.6 GHz) and a gain of 4.7 dB at the centre frequency. The measured results are giving the bandwidth of ~10.5 GHz (2.1-12.6 GHz) and a gain of ~4.5 at the centre frequency. The measured results are giving the almost similar performance to the simulation results.

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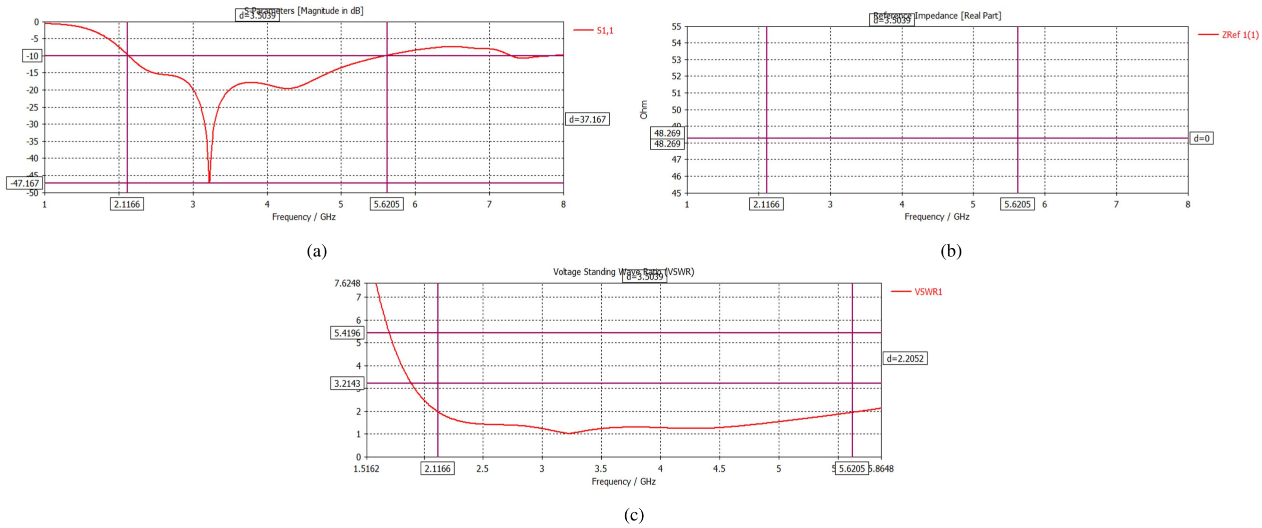
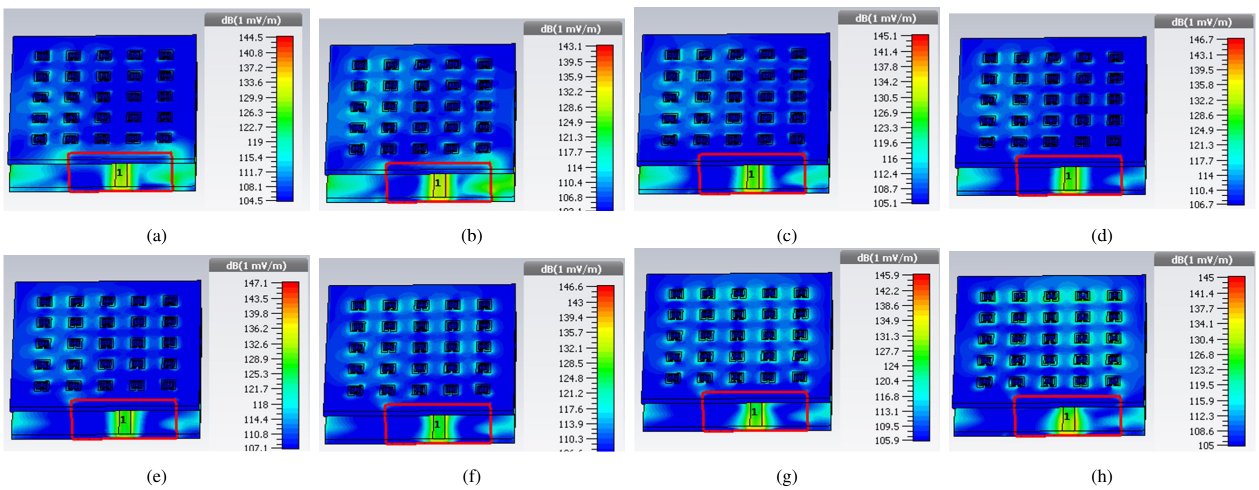


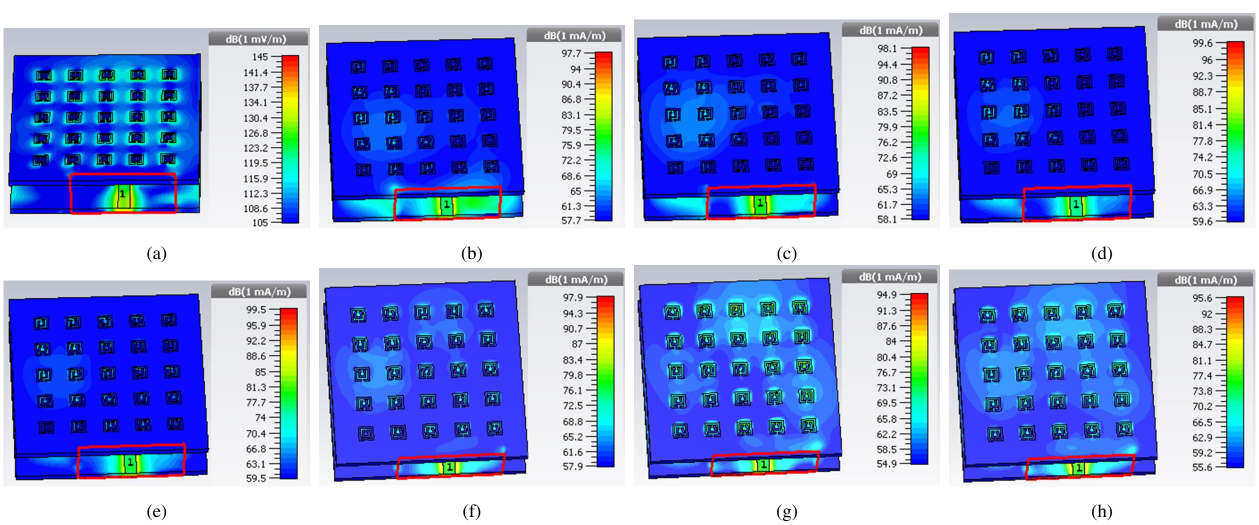

(a) (b) (c)

Figure 12. Proposed metamaterial Antenna Resonant characteristics (a) Return Loss (b) Impedance and (c) VSWR



(a) (b) (c) (d) (e) (f) (g) (h)

Figure 13. E-filed distribution of proposed metamaterial Antenna (a) 2.5 (b) 3(c) 3.5 (d) 4 (e) 4.5 (f) 5 (g) 5.5 and (h) 6 GHz frequencies respectively



(a) (b) (c) (d) (e) (f) (g) (h)

Figure 14. H-filed distribution of proposed metamaterial Antenna (a) 2.5 (b) 3(c) 3.5 (d) 4 (e) 4.5 (f) 5 (g) 5.5 and (h) 6 GHz frequencies respectively

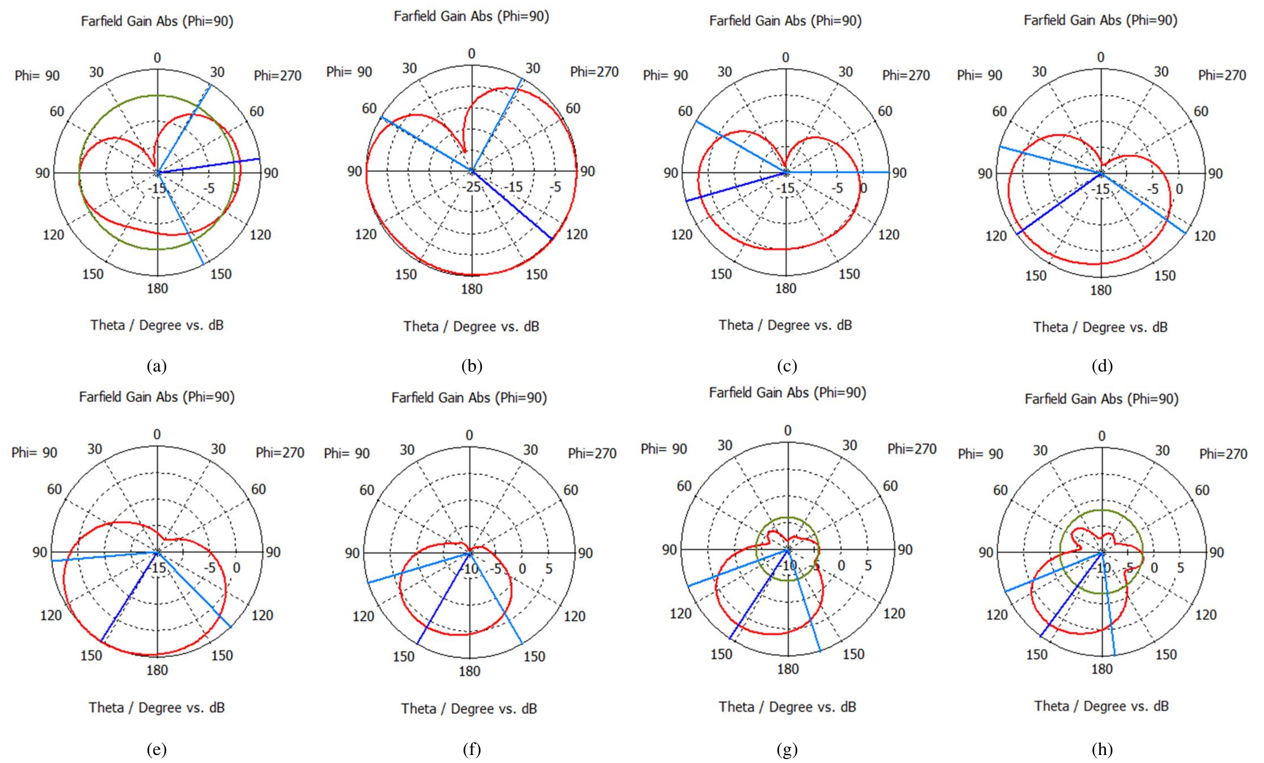



Figure 15. 2D radiation pattern of proposed metamaterial Antenna (a) 2.5 (b) 3(c) 3.5 (d) 4 (e) 4.5 (f) 5 (g) 5.5 and (h) 6 GHz frequencies respectively

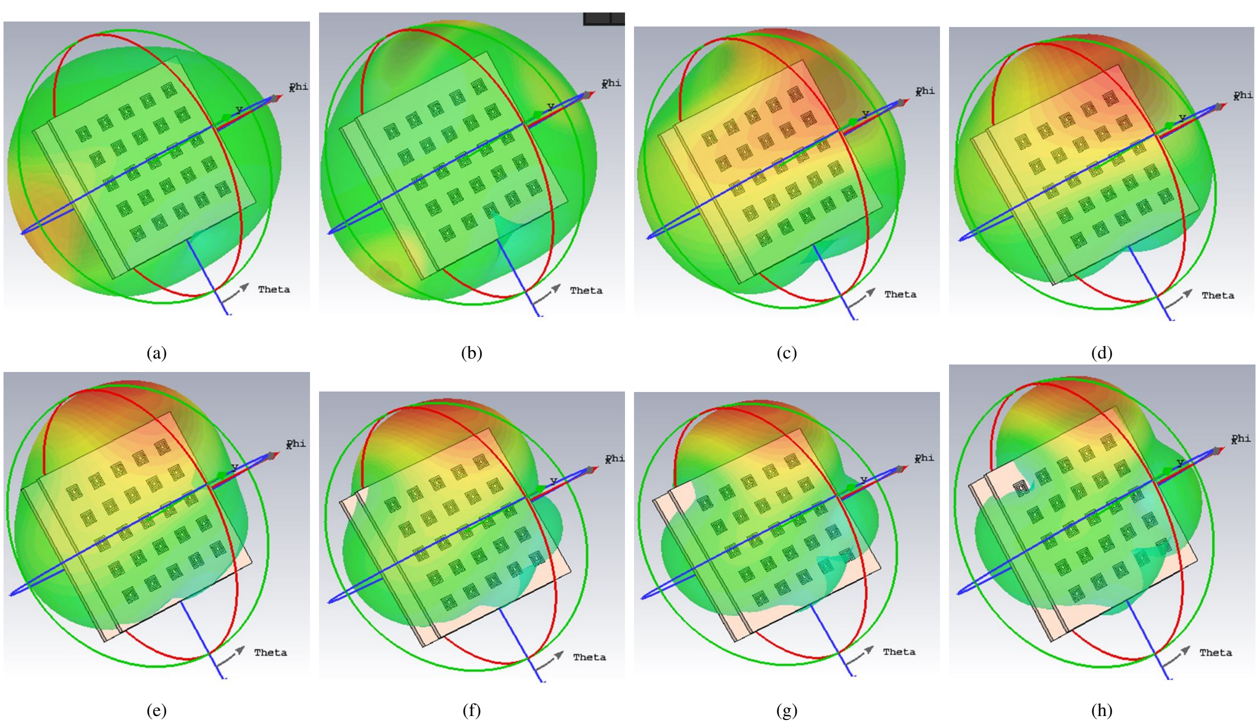
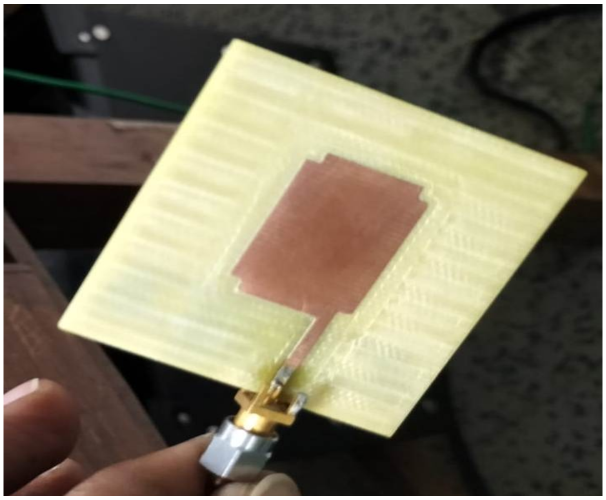
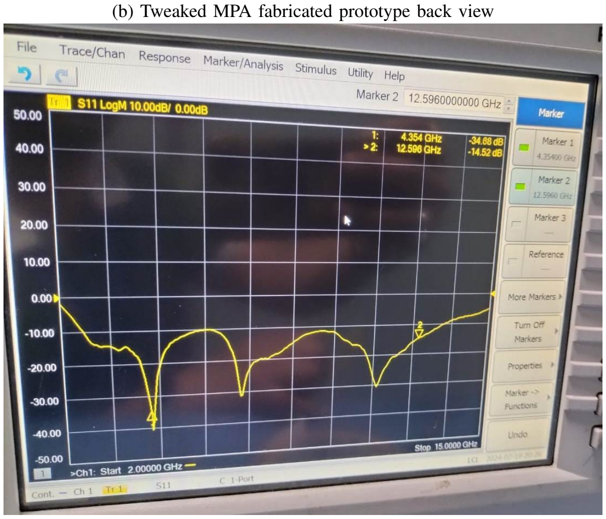



Figure 16. 3D radiation pattern of proposed metamaterial Antenna (a) 2.5 (b) 3(c) 3.5 (d) 4 (e) 4.5 (f) 5 (g) 5.5 and (h) 6 GHz frequencies respectively



(a) Tweaked MPA fabricated prototype Front view

(b) Tweaked MPA fabricated prototype back view




(c) Measured result using VNA

Figure 17. Tweaked MPA fabricated prototype

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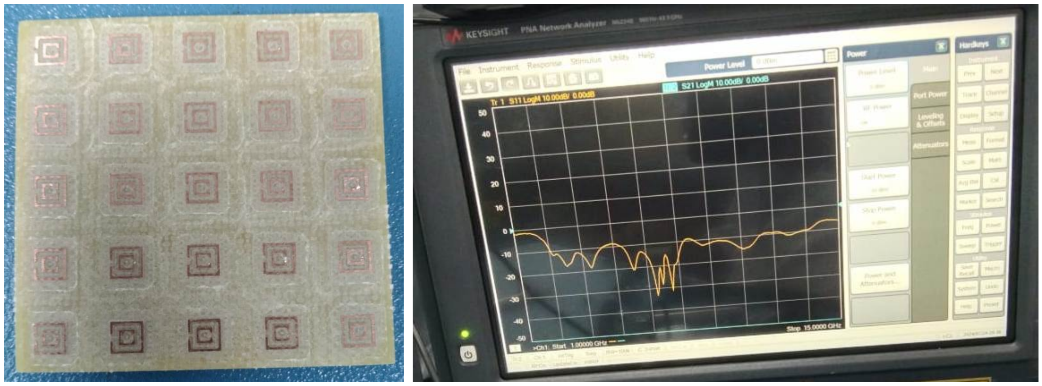

(a) (b)

Figure 18. (a) Metamaterial structure fabricated prototype (b) measured result of tweaked MPA with metamaterial structure using VNA

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**Potnuru Narayanarao** received the B.Tech degree in Electronics and Communication Engineering from Aditya Institute of Technology and Management, Tekkali, India, in 2010 and M.Tech degree in Communication Systems from Anil Neerukonda Institute of Technology and Sciences, Visakhapatnam, India, in 2014. He is currently pursuing his Ph.D in GITAM, Visakhapatnam. He is working as an Assistant Professor in Department of ECE,Aditya Institute of Technology and Management, Tekkali. He has 9 years of Teaching experiance. He published several research papers in reputed journals and conferences.

**Dr. G.Karunakar** completed his B.E. and Master of Engineering in the stream of Electronics and Communication Engineering and Radar and Microwave engineering in the year of 1996, 2003 respectively. He obtained his Ph.D from Andhra University in 2012. Now, he is working as Assoc. Professor in Department of ECE, GITAM School of Technology, GITAM (Deemed to be University), Visakhapatnam, Andhra Pradesh, India. He has more than 20 years of Teaching and Research Experience. His area of interests are Antenna and propagation, Microwave and Radars