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Design of Fractal Antenna For S-Band and X-Band Applications

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ABSTRACT- A fractal antenna that can be used for S-band and X-band applications is proposed in this paper. The antenna is able to be easily integrated into naval radar systems. The antenna is made up of fractal structures that are cross-shaped and organized in stairwell-like repetitions. It is a two-port antenna that receives its feed via coaxial cable. Meta materials are integrated into the design to achieve bidirectional gain and reduce mutual coupling. The proposed antenna is designed using ANSYS Electronic Desktop's High Frequency Structure Simulator (HFSS) with FR4 material. The antenna exhibits multiple operational bands, ranging from 2.58GHz to 3.48GHz for the S-band with gain of 3.7dB and from 8.97GHz to 11.87GHz for the X-band with gain of 5.19dB. This proposed antenna shows good performance in terms of gain, radiation pattern and return loss. It can be widely used in satellite communication and military radar systems.

General Terms: Design of Fractal Antenna, Meta material coupled Fractal Antenna.
Keywords: Fractal antenna, Gain, Radiation pattern, Return loss.

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1. INTRODUCTION

The distinctive designs of fractal antennas are defined by geometric features that go against the conventions of Euclidean geometry. They are self-similar, with recurrent patterns on different scales. The Koch, Sierpinski, Dragon, and tree structures are a few instances of these fractal formations [7]. Our goal in this work is to create a fractal antenna that can be used in both X-band and S-band applications. S-band and X-band radio frequencies are divided into channels and some of these allotments are reserved for deep space communications [8]. Because of their shorter wavelengths, these channels, which operate in the 2GHz to 12GHz range, are classified as microwaves.

The antenna is made to function well in marine radar applications [9]. Radar is a vital navigational tool that is required for a number of purposes, including adherence to COLREGs and guaranteeing safe navigation from one location to another. It is also used for the identification, tracking (with integrated ARPA), and positioning of vessels, including one's own. Marine radar is classified as operating in the x-band (10 GHz) or S-band (3 GHz) frequencies. It has multiple applications. The S-band is recommended for tracking and identification in inclement weather, such as rain or fog, while the X-band, with its increased frequency, provides crisper images and better resolution. Our suggested fractal antenna uses metamaterials to produce bidirectional gain and operates in the 2GHz–4GHz S-band and 8GHz–12GHz X-band frequency ranges. The Antenna's measurements are 56 mm by 33.6 mm, and for simulation, we used a FR-4 substrate

2. RELATED WORK

An X-band fractal monopole antenna with dual polarization reconfigurability is presented by Shankar and Upadhyay [1]. This paper describes a monopole antenna designed for X-band applications that can be adjusted between linear and circular polarizations. The antenna has a unique design that consists of a cross-shaped slot with bent arms that is situated on an inverted triangle staircase fractal patch. The antenna provides electronic switching between the two polarization states by using two piezoelectric diodes that are positioned on opposite sides of the horizontal arm of the slot. The antenna operates in the frequency range of 9.88GHz to 11.06GHz for left-hand circular polarization and 7.95GHz to 12.64GHz for linear polarization by adjusting the biasing conditions of the pin diodes. The antenna is noteworthy for achieving a 5.71dBi measured peak gain.

The study "The broadband and Low-Profile Penta-Polarization Reconfigurable Met material Antenna" by Liu, Jiang, Sun, Xi, and Gong [2] is consulted in order to construct the met material antenna. This paper describes a reconfigurable antenna with mushroom-type loading that uses penta-polarization. Operation in left-hand circular polarization, right-hand circular polarization, and x-direction linear polarization is made easier by this creative design. Through characteristic mode analysis, a complexly designed dual port dual linear polarization mushroom antenna with polarization reconfigurability is realized, excited by a crossed H-shaped slot. By varying the states of pin diodes on the reconfigurable feeding network, the dual linear polarization antenna's two ports' amplitude and phase distributions may be dynamically adjusted, enabling the attainment of five different polarization modes. Surprisingly, the antenna's measured peak gain surpasses 8.2dBi, highlighting its outstanding performance.

The study "Polarization-Reconfigurable Compact Monopole Antenna with Wide Effective Bandwidth," which explores the construction of a monopole antenna and was written by Ankit Bhattacharjee, Santanu Dwari, and Mrinal Kanti Mandal [3]. A simple micro strip line-fed antenna with broad polarization reconfigurability is shown in this work. To enable wideband circular polarization, the antenna design includes a redesigned ground plane and a circular metal ring with gaps. Exact control over polarization states is made possible by the addition of two pin diodes. The antenna may achieve linear polarization, left-hand circular polarization, and right-hand circular polarization by varying the biasing states of the diodes. This antenna is noteworthy for having a broad effective bandwidth that ranges from 3.79GHz to 7.82GHz, underscoring its usefulness and versatility.

The paper titled "Hybrid Fractal Shape Planar Monopole Antenna Covering Multiband Wireless Communications with MIMO Implementation for Handheld Devices" by Yogesh Kumar Choukiker, Satish K. Sharma, and Santanu K. Behera [4] is referred to gain knowledge about MIMO (Multiple Input Multiple Output) antennas. The goal of this research is to create a hybrid, fractal-shaped planar antenna that can be used in several wireless communication bands for multiple-input multiple-output applications on mobile devices. Improving isolation and impedance matching between antennas is the goal. The results show that the measured peak gain for band 1 ranges from 0 to -2.5dBi, with a maximum gain of 2dBi, and for band 2, it ranges from 2.5dBi to 4.85dBi, with a maximum gain of 7dBi.

The work "Compact Size MIMO Amer Fractal Slot Antenna for 3G, LTE(4G), WLAN, WiMAX, ISM, and 5G Communications" by Amer Tawfeeq Abed and Aqeel Mahmood Jawad [5] is analyzed to investigate different geometric configurations and shapes within fractals. The design of a four-port multiple input multiple output (MIMO) antenna using a FR-4 substrate is the main goal of this study. In order to control electromagnetic energy leakage and provide a high level of impedance matching between the antenna and input, the antenna is excited via a coplanar waveguide. The antenna can now function effectively in each port across two bands. This multiport antenna is specifically designed to meet the unique requirements of many wireless communication technologies. These comprise the most recent developments in 5G technology in addition to 3G.

3. PROPOSED METHODOLOGY

3.1 Design Procedure and Parameter

The physical dimensions of the antenna are 56 mm by 33.6 mm. The antenna is operated using an FR-4 substrate with a thickness of 1.6 mm as the base. Power for the antenna is provided by a coaxial feed system. A ground particle with dimensions of 25.6 mm in length and 12.8 mm in breadth is formed by the deliberate placement of ground material within the substrate. A patch that is 28.8 mm long and 22.4 mm wide is positioned on top of the substrate. At the center of the patch is a fractal slot that is finely etched and is 9.6 mm long and 8 mm wide. The design procedure involves creating a cross symbol, which is represented in *figure 1*, with the exact proportions required for the antenna to function.

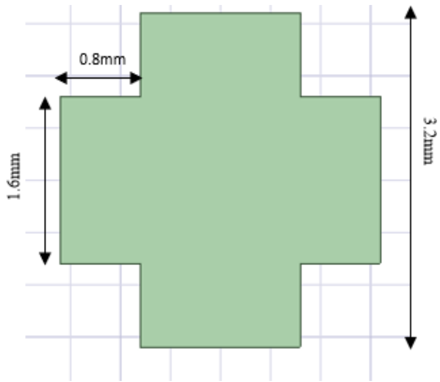

Figure 2. Single Shape Structure

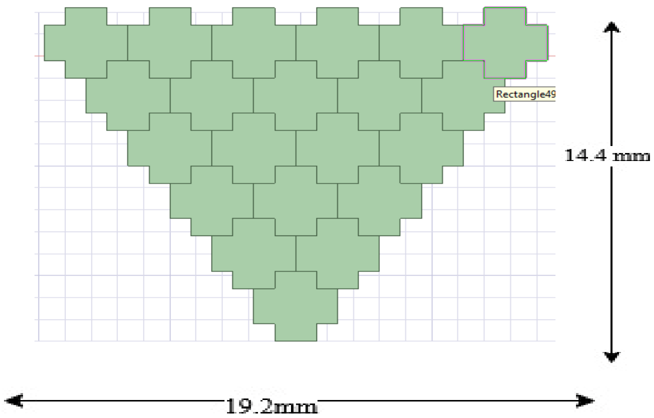

Figure 1. Alignment of the fractal shapes

The fractal structure is then methodically generated by aligning and arranging several cross symbols. The fractal structure's alignment process is graphically depicted *in figure 2*, which also shows the gradual rise of cross symbols per row. For example, the first row from bottom has one cross symbol, the second row has two, and so on. This pattern of progression is maintained in each successive row, creating a logical fractal design. The antenna's optimal performance and functioning are ensured by this careful alignment method.

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The proposed antenna top view and bottom view of the design is shown in *figure 3* and *figure 4* respectively.

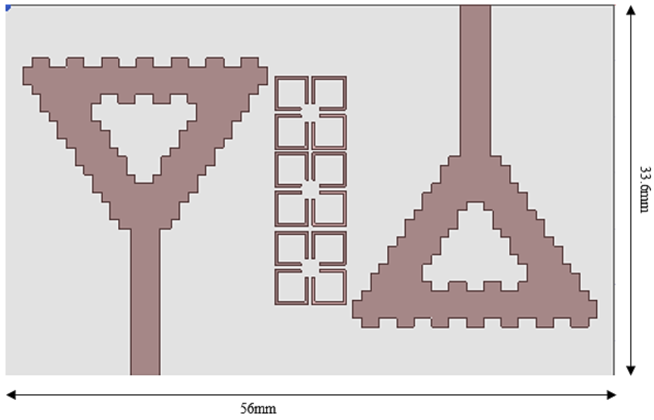

Figure 4. Top view of the proposed antenna

The feed line is connected to the lower portion of the fractal structure, which has dimensions of 2.7 mm in width and 13.6 m in length. Likewise, a fractal structure that is exactly the same is created and placed in opposition to the previous one.

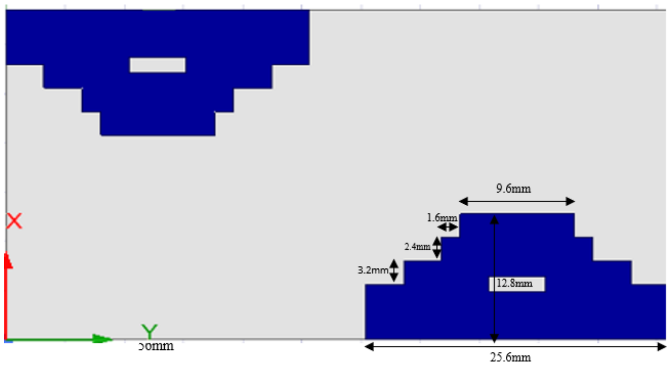

Figure 3. Bottom view of the proposed antenna

Then, between the two fractal structures, a metamaterial is created to aid in bidirectional gain and circular polarization. With a length of 6.5mm, this metamaterial design is shown in *figure 5*.

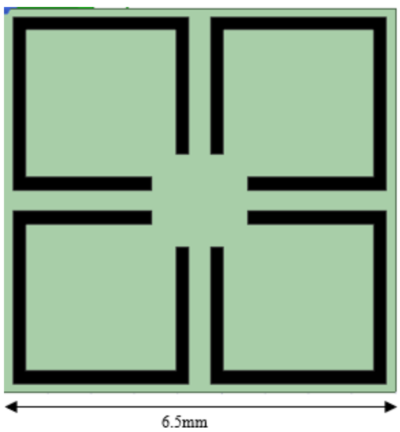

Figure 5. Structure of metamaterial

The complete design flow is illustrated in the flowchart as shown in *figure 6*.

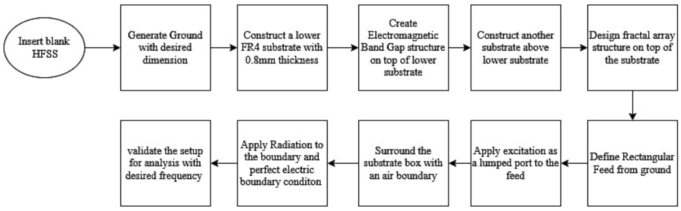

Figure 6. Proposed antenna design steps using HFSS

The patch Width is determined using *equation 1*. Here *c* represents the speed of light (c = 3x10^8 m/s) and fr is resonant frequency (fr = 2.4 GHz, 10GHz), W is the width of the antenna, ε_r is relative permittivity.

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

The effective dielectric constant is measured using *equation 2*. Here h is the height of antenna and w is width of the antenna.

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{1+\frac{12h}{w}}}\right] \tag{2}$$

The effective length is calculated using *equation 3*.

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \tag{3}$$

The length (L_s) and width (W_s) of the substrate is calculated using *equation 4* and *5* respectively. Here L and W are length and W of patch antenna.

$$L_s = 6h + L \tag{4}$$

$$W_s = 6h + W \tag{5}$$

The complete proposed antenna design parameters with feed line are listed as shown in *table 1*.

Table 1. Design Parameters

Parameter	Details
Substrate	FR-4
Substrate dimension	56mm x 33.6mm
Substrate thickness	1.6mm
Feed dimension	3.4mm x 2mm
Feed	Lumped port
Metamaterial	6.5mm
Height of cross symbol	3.2mm

4. RESULTS AND DISCUSSION

As mentioned before, this paper's goal is to examine the results of the S-band and X-band antenna simulations. Voltage Standing Wave Ratio (VSWR), Return Loss, Radiation pattern, Envelope Correlation Coefficient (ECC) and antenna gain are the characteristics that are being examined. An electrical system's relationship between input and output ports can be understood using the S-Parameter as a descriptive tool.

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The S parameters of proposed antenna are shown in *figure 7, 8, 9* and *10*. We see drops in return loss at 2.58GHz–3.466GHz, which corresponds to the S–band frequency range, and at 8.97GHz–11.87GHz, which corresponds to the X–band frequency range.

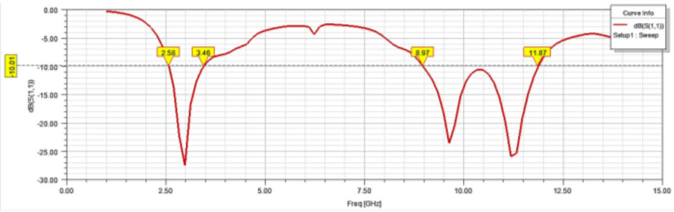


Figure 7. S11 Parameter of Proposed Antenna

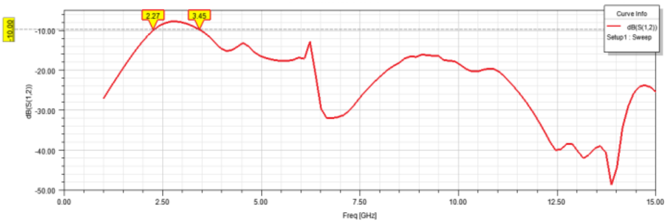


Figure 8. S12 Parameter of Proposed Antenna

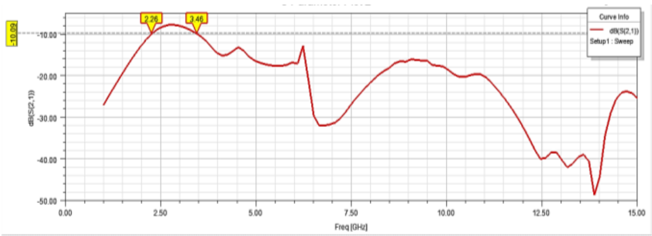


Figure 9. S21 Parameter of Proposed Antenna

One important measure of antenna performance is VSWR. An antenna with a reduced VSWR is more effective. The efficiency with which radio-frequency power is transferred from a power source into a load via a transmission line is measured by the voltage standing wave ratio, or VSWR. The VSWR of the proposed antenna is shown in *figure 10*.

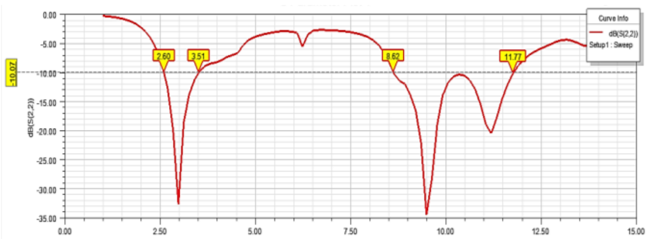


Figure 10. S22 Parameter of Proposed Antenna

It is important to remember that gain is a measurement of the antenna's ability to focus energy in a desired direction rather than its total energy generation. An antenna's gain is usually stated as the ratio of the radiation intensity in a specific direction to the radiation intensity that an isotropic radiator would produce. Frequently, this ratio is expressed in decibels (dBi) in relation to an isotropic radiator.

In a variety of applications, including satellite communication, point-to-point communications, and long-distance communication, higher gain antennas can be useful because they can focus more energy on a particular target. The gain of S band and X band of proposed antenna is shown in *figure 12* and *figure 13* respectively. An antenna's radiation pattern gives a visual depiction of the distribution and emission of energy in space in various directions. *Figure 14* shows that bidirectional gain in s-band is obtained for the proposed antenna design.

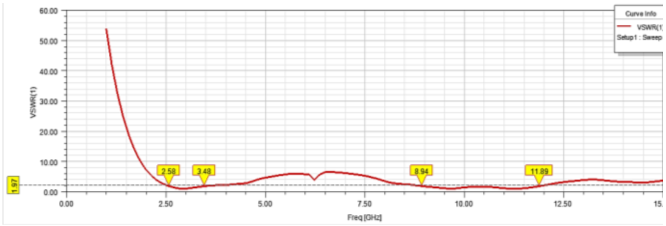


Figure 11. VSWR of Proposed antenna

The Envelope Correlation Coefficient (ECC) is a crucial metric that provides insights into the level of independence between the radiation patterns of two antennas. Figure 15 shows the ECC graph of the proposed antenna. It serves as a quantitative measure of how much the radiation patterns of the antennas differ from each other. The proposed antenna exhibits a peak directivity of 2.59, indicating its ability to focus radiation in a specific direction. With a peak gain of 2.3dB, it demonstrates its effectiveness in amplifying signals in comparison to an isotropic radiator. Radiated power is measured at 770.21 mill watts, showcasing the amount of power emitted by the antenna. Its Radiation efficiency is 83.69 and Front to back ration is 1.4691. The design analysis of different antenna structure along with its radiation pattern is shown in *table 2*.

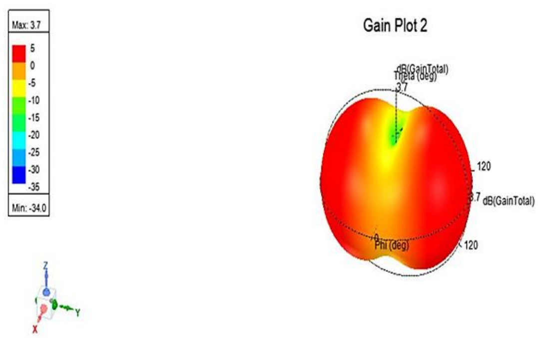


Figure 12. Gain for S-Band

The proposed antenna is fabricated and tested using anechoic chamber. Conducting S-parameter testing in an anechoic chamber ensures accurate and reliable measurements by eliminating external interference and reflections. The fabricated antenna top view and bottom view is shown in *figure 16* and *figure 17* respectively.

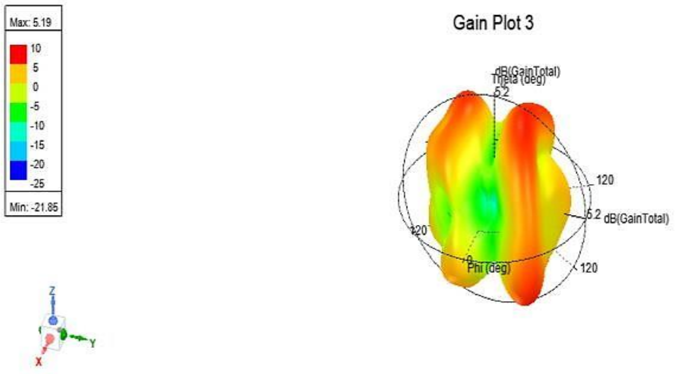


Figure 13. Gain for X-Band

Conducting S-parameter testing in an anechoic chamber ensures accurate and reliable measurements by eliminating external interference and reflections as shown in *figure 18*.

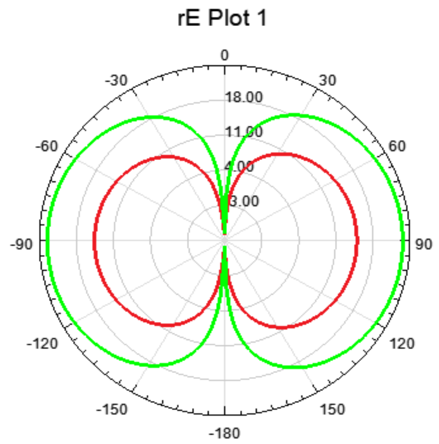


Figure 14. Radiation Pattern for S Band

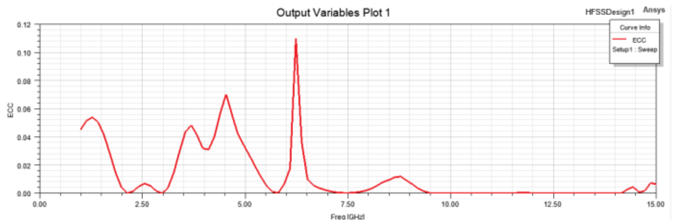
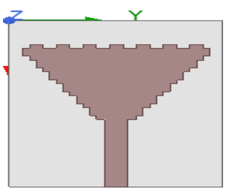
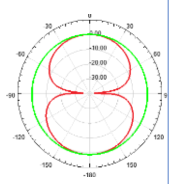
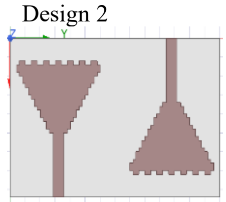
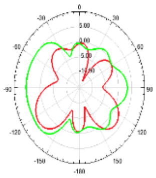
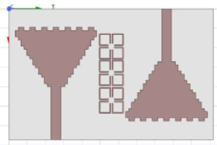
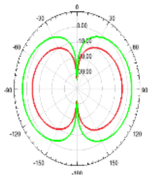
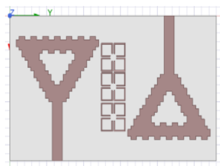
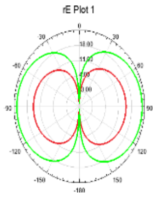


Figure 15. ECC of proposed antenna

Table 2. Design Analysis PG-Peak Gain, PD-Peak Directivity FBR-Front to Back Ratio, EFF-Efficiency, RP-Radiation Pattern

Structures	PG	PD	FBR	EFF	RP
Design 1 	2.69	2.61	1.05	96	
Design 2 	3.47	3.62	1.59	87	
Design 3 	2.45	2.96	1.43	82	
Proposed design 	2.3	2.59	1.04	88	

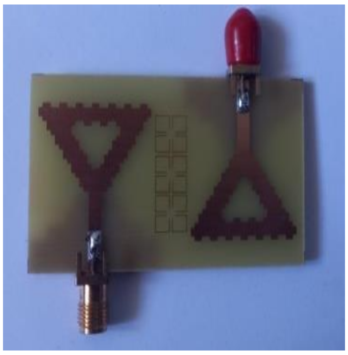


Figure 16. Top view

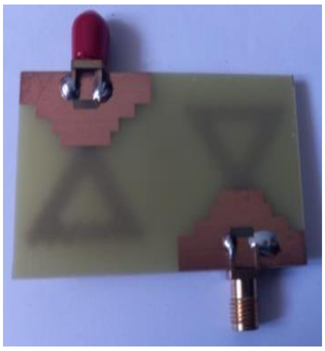


Figure 17. Bottom view

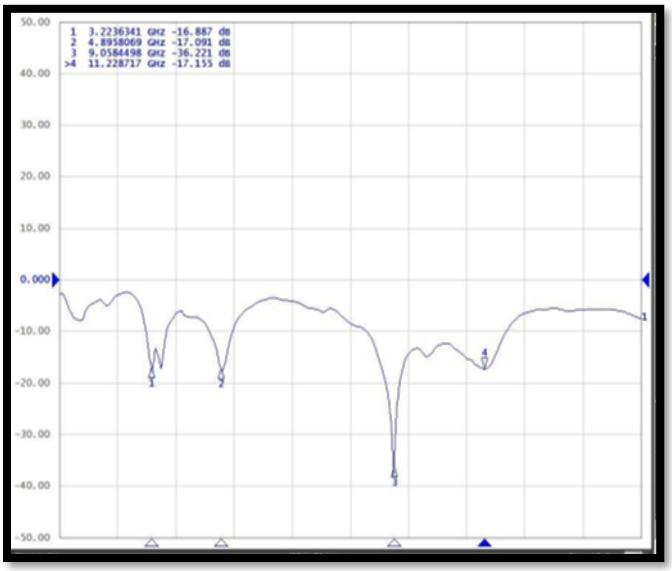


Figure 18. S parameter measurement in Anechoic chamber

Table 3. Comparative analysis

References	Peak Gain (dB)
[1]	4.97
[9]	4.41
[10]	2.5
[11]	4.8
[12]	4.4
Proposed Work	5.19

Table 3 describes the comparative analysis of proposed antenna with existing model. It shows that the proposed antenna design is suitable for *X* band and *S* band applications with peak gain.

5. CONCLUSION

As part of this research project, we have created a novel fractal antenna that can operate at both S-band and X-band frequencies. When it comes to S-band applications, the antenna performs admirably between 2.58GHz and 3.48GHz, and when it comes to X-band applications, between 8.97GHz and 11.87GHz. Our experimental evaluations show a peak gain of 5.19dB for X-band operation and 3.7dB for S-band operation. The proposed design use of Meta material not only makes it possible to achieve bidirectional gain but also to reduce mutual coupling, increasing the antenna system's overall effectiveness and adaptability. The antenna has potential for future antenna designs in a variety of applications because it is small and integrates nicely into electronic equipment. The unique contribution of this research work includes Dual-Band Operation Covering S and X-Bands, High Gain Performance Across Both Bands, Integration of Meta material for Bidirectional Gain and Reduced Mutual Coupling, Application Versatility.

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Our sincere thanks to our college management, principal and Head of the Department and my colleagues for carrying out this research work.

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