DESIGN OF MIMO FRACTAL BASED ANTENNA FOR SATELLITE COMMUNICATION

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ABSTRACT

In this letter, a modified triangular multiple input and multiple output antennas for satellite applications is presented. The Fractal enabled MIMO design enables a significant reduction in antenna size which is applicable for satellite communication. The proposed MIMO antenna is designed in ANSYS HFSS and analyzed with excellent performance in the frequency range between 12GHz to 18GHz (Ku-band). The experimental measurements demonstrate the return loss of -14.24 dB, -36.46 dB, -34.16 dB, isolation loss of -23.24 dB, -17.91 dB, -31.68 dB, and a gain of 4.6dB at the frequencies 12.76 GHz, 13.77 GHz, 16.31 GHz respectively. The compact and cost-effective nature of the proposed antenna makes it a promising solution for satellite communication systems, offering reliable and efficient wireless communication capabilities.

Keywords: *MIMO, fractal antenna, Satellite communication, Ku-band, size reduction.*

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I.INTRODUCTION

In this modern era, satellite communication has become a critical aspect of our connected world, enabling various applications such as global communication, weather forecasting, and remote sensing. Antennas play a pivotal role in satellite communication systems, facilitating the transmission and reception of signals with high efficiency and reliability. To meet the demands of satellite communication applications, extensive research and development efforts are focused on designing novel antenna solutions. Various antenna designs have been proposed to address the requirements of satellite communication systems, including MIMO and Millimeter-wave antennas. One notable study [1] presents a U-slot rectangular patch array design that achieves a good level of isolation between antenna elements, making it suitable for satellite systems. Another approach [2] involves a double-layer microstrip structure that reduces the antenna profile while maintaining excellent performance, catering to the needs of 5G satellite communication. The utilization of modified Sierpinski fractal geometry [3] in patch antenna design enables miniaturization and multiband behavior, making it well-suited for modern satellite communication systems. Similarly, a stacked triangular fractal patch structure [4] offers a compact size, low profile, and high gain, meeting the requirements of wireless communication applications. A novel MIMO antenna design specifically tailored for satellite applications. A novel MIMO antenna design specifically tailored for satellite applications leverages metamaterial-based patches [5]. This design aims to broaden bandwidth and improve overall performance. Additionally, a compact MIMO antenna design [6] capable of operating across multiple frequency bands and supporting diverse communication services is introduced. It features a compact size and incorporates innovative C- shaped elements and a hexagonal ring structure. These advancements highlight the continuous progress in MIMO antenna technologies, contributing to the development of efficient and versatile satellite communication systems. To improve antenna performance, techniques such as defected patch surfaces [7] are employed to reduce surface wave coupling and enhance cross- polarization levels. Furthermore, the design of a MIMO antenna utilizing a triangular dielectric resonator [8] enables wide bandwidth and high isolation between antenna elements, ensuring optimal performance for satellite communication applications. In [9] a compact and cost-effective ultra-broadband antenna for satellite applications at C, X, and Ku frequency bands is designed with a single-layer configuration and U-slot, the antenna achieves wide bandwidth and excellent performance. For millimeter-wave satellite communication, an antenna utilizing the substrate-integrated waveguide (SIW) technique [10] is designed to operate at a frequency of 28 GHz, commonly used in satellite and radar communication systems. In this paper, a modified triangular MIMO antenna with

Fern Fractal integration is presented which offers a compact, cost-effective, and high-performance solution for satellite communication systems. By leveraging the space-filling property of the Fern Fractal, the antenna achieves a significant reduction in size without compromising performance. The experimental measurements demonstrate excellent return loss and gain, highlighting the antenna's efficiency and reliability. With its promising attributes, the proposed antenna holds significant potential for enabling reliable and efficient wireless communication capabilities in satellite applications.

II. DESIGN OF PROPOSED ANTENNA

A novel design of a triangular MIMO antenna with fractal alignment is proposed for satellite applications. The antenna is composed of a ground plane, a dielectric substrate, and a triangular-shaped radiant metallic surface. To ensure efficient signal transmission and reception, a 50Ω microstrip feed line based on a modified rectangular patch is implemented on the top side of an FR4 substrate with $\varepsilon r=4.4$ and a height of 1.6mm utilizing an insert feed method. This design configuration and feeding technique contribute to enhanced performance characteristics and improved impedance matching. The utilization of the fractal allows for the reduction of the antenna's size while maintaining its radiating efficiency, thereby achieving a compact and lightweight design suitable for satellite applications. The design flow of the proposed antenna is illustrated in Fig 1.

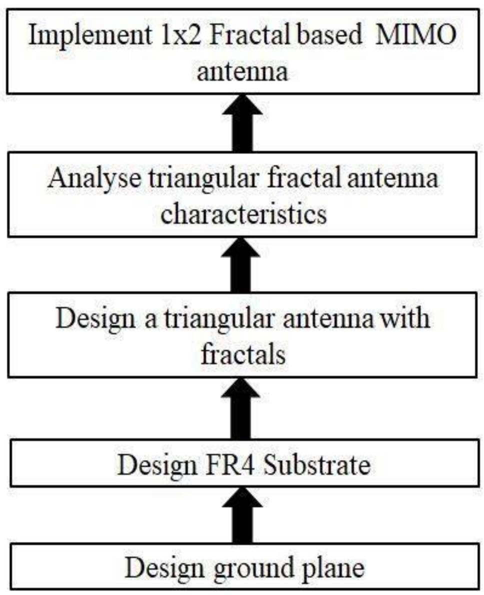

Fig.1: Design flow for the proposed antenna

The length of a ground plane (Lg) and the width of a ground plane (Wg) are calculated using the following equations:

$$Lg = 6h + L \quad (2.1)$$

$$Wg = 6h + W \quad (2.2)$$

Where L is the length of the patch, W is the width of the patch and h is the height of the substrate.

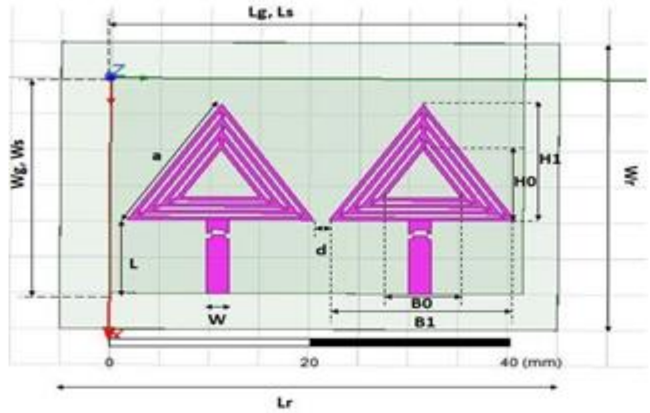

Fig 2: Proposed 1X2 MIMO antenna

The length and width of a substrate is equal to that of the ground plane. After constructing the substrate, designed the triangular-shaped patch with fractals. Then a 1x2 fractal-based MIMO is designed. The figure 2 shows the schematic of the proposed antenna design. The bottom layer has dimensions of 35 mm in length and 30 mm in breadth. The substrate was then created with a height of 1.8mm.

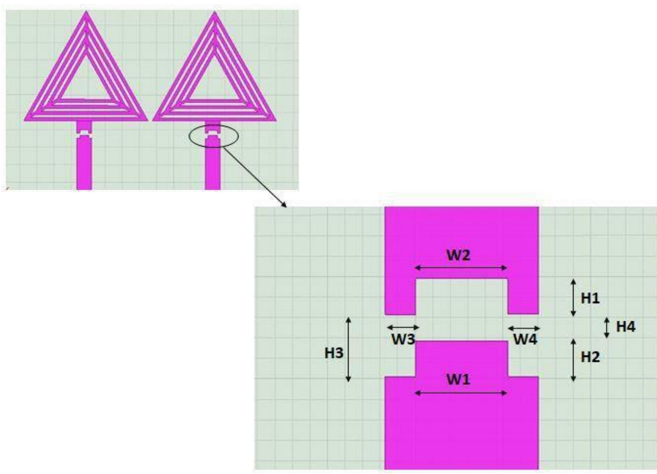

Fig 3: Inset feed line method

For feeding the proposed antenna, an inset feeding method is employed. The inset is a type of transmission line widely utilized in high- frequency applications. The inset feeding method offers several advantages in antenna design. Firstly, it allows for precise control of the impedance matching between the feeding network and the antenna, ensuring efficient power transfer. Secondly, it provides a compact and low-profile solution, making it suitable for applications where space constraints are a concern.

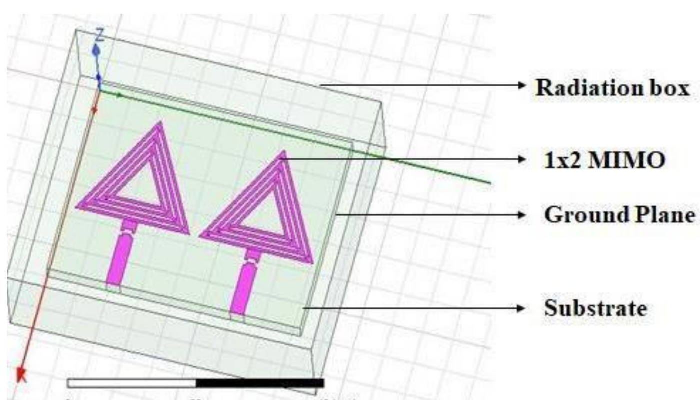

Fig 4: Side view of proposed MIMO antenna

The figure 4 illustrates the design in HFSS showing all the layers incorporated within the design.

Table 1: Structural Parameter of Proposed Antenna

Terms	Values (mm)	Description
Ls	20.92	Length of Substrate
Ws	35	Width of substrate
Hs	1.6	Height of substrate
Lg	20.92	Length of ground
Wg	35	Width of ground
Lr	50	Length of radiation box
Wr	50	Width of radiation box
Hr	35	Height of radiation box
Ho	12.65	Height of Outermost triangle
Bo	14.54	Breadth of Outermost triangle
a	14.5	Hypotenuse of Outermost triangle
Hl	5.25	Height of Innermost triangle
Bl	6	Breadth of Innermost triangle
L	7.96	Length of the insert feed line
W	1.7	Width of the insert feed line
d	0.5 mm	Distance between two triangular patch
W	1.1	Width of insert feed line cut
W2	1.1	Width of insert feed line cut
W3	0.3	Width of insert feed line cut
W4	0.3	Width of insert feed line cut
H1	0.35	Length of insert feed line cut
H2	0.35	Length of insert feed line cut
H3	0.61	Length of insert feed line cut
H4	0.26	Length of insert feed line cut

Referring table 1 design and analyze the proposed MIMO antenna.

III. RESULTS AND DISCUSSION

This section helps to analyze the effectiveness of the proposed MIMO structure for satellite applications. By evaluating the 1x2 MIMO antenna's performance such as antenna gain, radiation pattern, S-parameters, etc.

3.1 Return Loss (S_{11}) and Isolation Loss (S_{12} or S_{21}) of Proposed Antenna:

S-parameters are used to describe the behavior of linear electrical networks, such as antennas and transmission lines. They provide a convenient way to analyze and characterize the performance of these networks in terms of power transmission, reflection, and impedance matching.

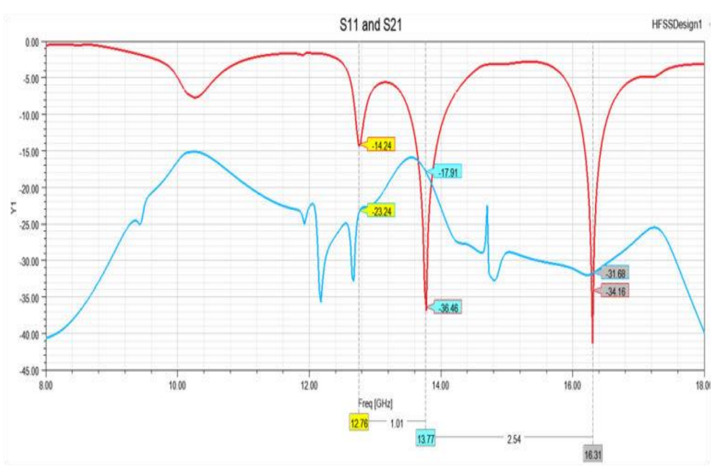

Fig. 5: Return loss and isolation loss of the proposed antenna

In fractal enabled MIMO design, the antenna operates at three distinct frequencies: 12.76 GHz, 13.77 GHz, and 16.31 GHz. Figure 5 illustrates the measured S-parameter S_{11} at these frequencies, indicating a significant return loss of -14.24 dB, -36.46 dB, and -34.16 dB, respectively. This observation offers valuable insights into the impedance matching and power reflection properties of the antenna at that specific frequency and the isolation loss or mutual coupling S_{21} is analyzed, which represents the power transmission from Port 1 to Port 2. The observed values at the corresponding frequencies are -23.24 dB, -17.91 dB, and -31.68 dB

3.2 VSWR of Proposed Antenna:

The VSWR analysis investigates the standing wave pattern and impedance matching of the antenna system. It discusses the VSWR measurement technique, the interpretation of VSWR values, and their impact on antenna performance.

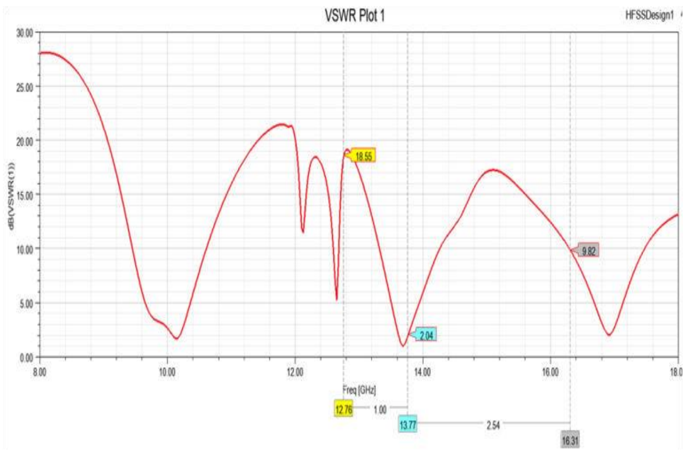

Fig .6: VSWR of the proposed antenna

The VSWR results are succinctly presented in Figure 6, specifically highlighting the operating frequencies of 12.76 GHz, 13.77 GHz, and 16.31 GHz with corresponding VSWR values of 18.55 dB, 2.04 dB, and 9.82 dB were obtained. Notably, the VSWR value must be less than 2 dB indicating good impedance matching, suggesting efficient power transfer between the antenna and the transmission line. At 13.77GHz operating frequency, with a VSWR value of 2.04 dB, has the best optimal performance.

3.3 Surface Current Distribution:

The electric field analysis focuses on the TE_{20} mode, one of the dominant modes of operation for the triangular patch antenna. It investigates the E- Field distribution and polarization characteristics in this mode.

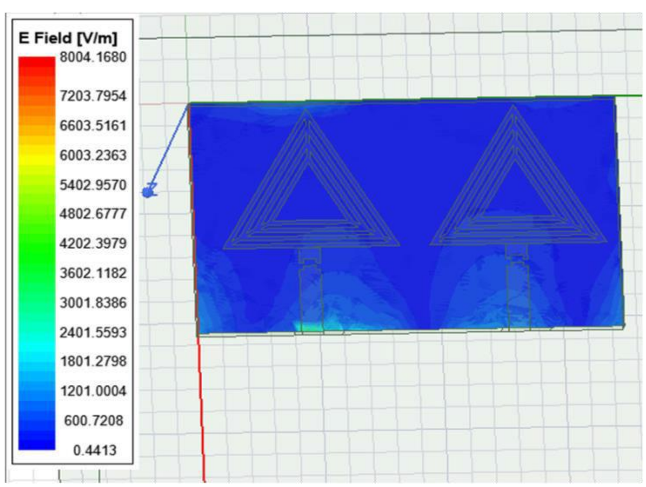

Fig. 7: Current distribution of the proposed antenna

The figure 7 presents the analysis result of the proposed antenna. The maximum electric field value recorded in the analysis is 8004.1680 V/m.

3.4 Gain of Proposed Antenna:

The gain plot analysis offers valuable insights into the antenna's directive properties and radiation pattern, showcasing its capability to concentrate radiated energy in specific directions.

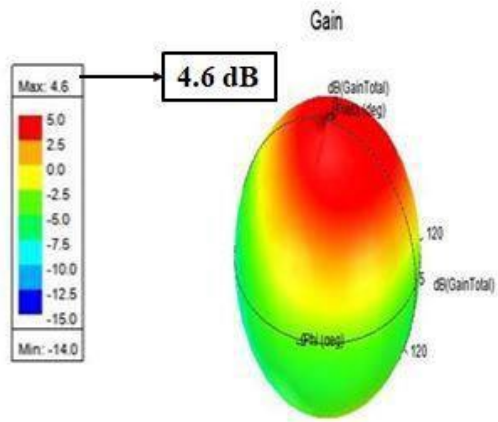

Fig. 8: Gain plot of the proposed antenna

The Figure 8 showcases the obtained gain plot results, providing emphasis on the antenna's performance characteristics. In this analysis, a gain of 4.6 dB was achieved, highlighting the antenna's ability to amplify the transmitted or received signals in comparison to an isotropic radiator.

3.5 Radiation Pattern of Proposed Antenna:

Radiation Pattern refers to the emission or reception of electromagnetic waves characterized by their strength or power. It demonstrates the antenna's ability to convert electrical energy into waves and propagate them in specific directions.

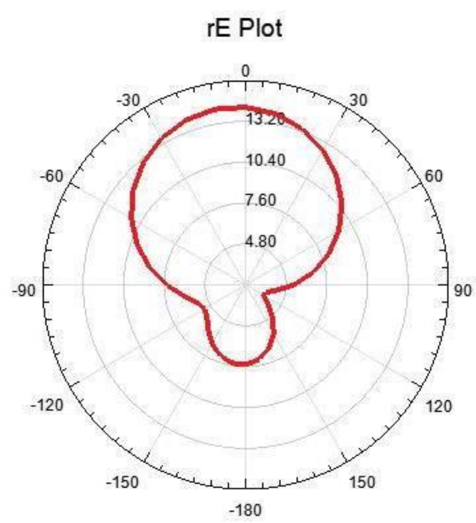

Fig 9: Radiation Pattern of the proposed antenna

The radiation pattern of an antenna describes the spatial distribution of its radiated or received power, offering insights into directivity, beam width, and polarization characteristics. In Figure 9, the radiation pattern is depicted, showing a maximum value of 13.26, indicating the direction or angle where the antenna exhibits the highest power or gain.

3.6 Envelope Correlation Coefficient (ECG) and Diversity gain (DG) of proposed antenna

The important characteristics of MIMO such as ECG and DG where the impacts of Environmental Clutter and Diversity Gain on the antenna's performance are discussed.

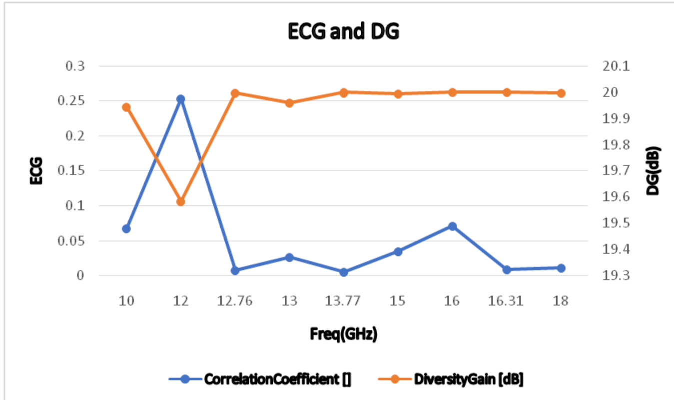

Fig 10: ECG and DG plot for the proposed antenna

ECG refers to the effects of surrounding objects on the antenna's radiation pattern and signal reception. The analysis reveals an ECG value of 0.01 at the operating frequency. Additionally, DG, which represents signal quality improvement through diversity techniques, is examined, resulting in a DG value of 19.32 db.

IV. CONCLUSION

The MIMO fractal triangular antenna for satellite applications is demonstrated. The proposed antenna design offers several advantages, including a gain of 4.6 dB and 12GHz – 18GHz as the designed frequency, and also the isolation loss is improved above 30 db. The compact size and optimized performance make it well-suited for satellite communication systems. This antenna operates within the desired frequency range, ensuring compatibility with satellite communication protocols.

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