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Analysis of Octagonal Patch K-Band MIMO Antenna with Via for Satellite Communication

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Abstract

The K-Band frequency, operating at 22.24 GHz, is widely used in satellite communication, suitable for wireless point-to-point microwave communication. The band yields an optimal small and compact antenna design for Law enforcement RADAR systems, vehicular speed detection and collision avoidance systems and satellite communication. This research focuses on the development of an octagonal patch microstrip antenna with vias and slot suitable to work for satellite communication. The proposed MIMO antenna is designed in ANSYS HFSS using RT Duroid 5880 material that has relative permittivity 2.2 and loss tangent 0.0009 and analyzed with excellent performance in the frequency range between 14GHz to 28GHz (K-band). The simulated measurements demonstrate the return loss of -43.75 dB at 19.6GHz, narrow bandwidth of 1.5 GHz and gain above 6 dBi. The antenna demonstrated an omnidirectional radiation pattern and circular polarization, which is particularly advantageous for satellite communications, ensuring stable signal reception. The results clearly explain that the proposed antenna has favorable characteristics for satellite applications.

Keywords: MIMO, K-Band, Satellite communication, vias, slot.

1. Introduction

Telecommunication services play a key role in providing fast and widespread access to information has become crucial in various sectors, particularly with the integration of broadband networks, which enable the swift and practical exchange of large volumes of data such as text, images, and videos. To ensure seamless communication, it is essential to have technologies that can transmit signals without being obstructed by geographical barriers and one of the most effective solutions is satellite technology. Satellite communication systems offer the advantage of overcoming physical obstacles, thus providing reliable and wide-reaching communication capabilities [1]. It has become a critical aspect of our modern world, enabling various applications such as global communication, weather forecasting, and remote sensing. The selection of frequency bands for satellite communications is critical, as issues like limited bandwidth and decreasing satellite separation in orbit can lead to interference from neighboring satellites [2]. Among the available frequency bands, the K-band is highly recommended due to its advantages, such as a wider bandwidth, reduced susceptibility to rain and terrestrial interference, and smaller antenna sizes [3]. Despite these advantages, satellite communication systems still face significant challenges in signal reception. Weather conditions, geographic positioning, and physical obstructions can degrade signal quality and stability, resulting in incomplete or delayed data transmission. These factors ultimately impact the reliability of satellite communication systems, emphasizing the need for robust design and optimization [4].

Antennas play a pivotal role in satellite communication systems, facilitating the transmission and reception of signals with high efficiency and reliability. One popular type of antenna is the microstrip antenna, which has become widely used due to its compact design and capability to operate at very high frequencies [5][6]

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 [7] 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 [8] 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 [9] 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 [10] 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 [11]. This design aims to broaden bandwidth and improve overall performance. Additionally, a compact MIMO antenna design [12] 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 [13] are employed to reduce surface wave coupling and enhance cross- polarization levels. Furthermore, the design of a MIMO antenna utilizing a triangular dielectric resonator [14] enables wide bandwidth and high isolation between antenna elements, ensuring optimal performance for satellite communication applications. In [15] 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 [16] is designed to operate at a frequency of 28 GHz, commonly used in satellite and radar communication systems.

In this paper, a modified octagonal MIMO antenna with slot and via integration is presented which offers a compact, high gain, narrow bandwidth and high directivity performance solution for satellite communication systems. The simulated results demonstrate an 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.

2. Design of Proposed Antenna

A novel design of a octagonal MIMO antenna with a crescent moon shaped slot on the radiating patch and a circular via is proposed for satellite applications. The antenna is composed of a ground plane, a dielectric substrate, and a octagonal-shaped radiant metallic surface. To ensure efficient signal transmission and reception, a 50Ω microstrip feed line based on a modified octagonal patch is implemented on the top side of RT-Duroid substrate with εr=2.2 and a height of 1.6mm utilizing an inset feed method. This design configuration and feeding technique contribute to enhanced performance characteristics and improved impedance matching. The utilization of the crescent slot and circular via 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 of the proposed antenna is illustrated in Fig 1.

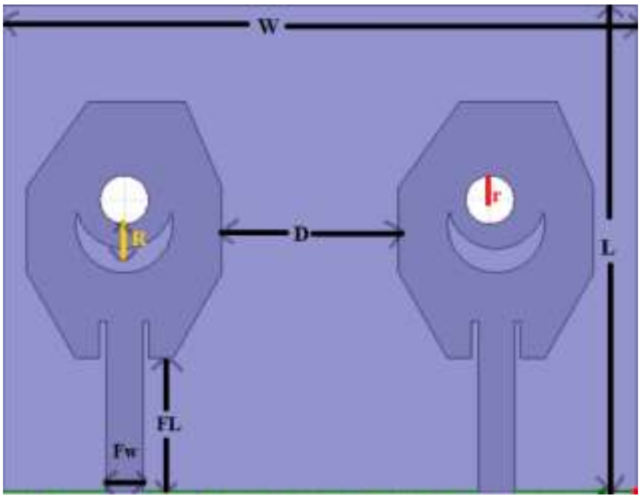
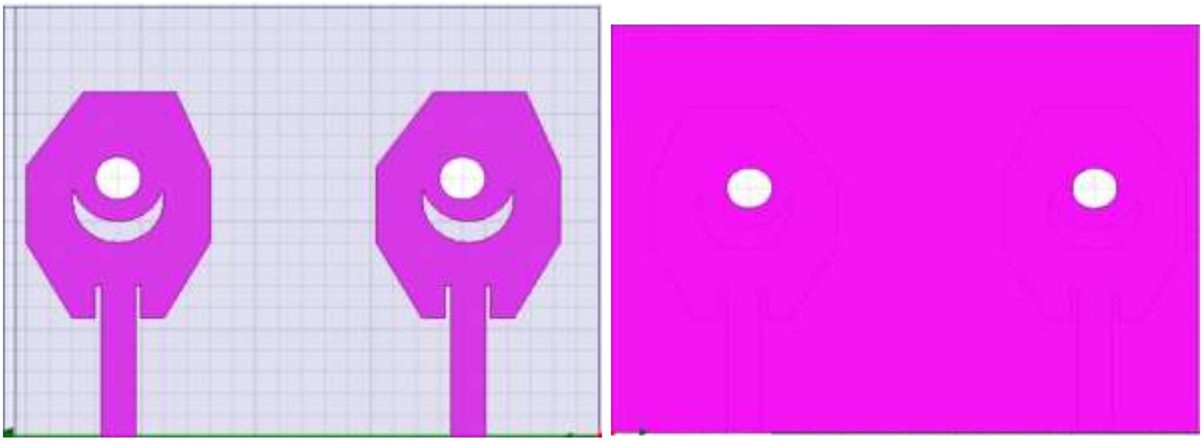


Fig.1. Design of MIMO Antenna for Satellite Communication

The length and width of a substrate is equal to that of the ground plane. After constructing the substrate, the octagonal patch is designed with a crescent moon shaped slot in the center and a circular via above it. Then a 2-port MIMO is designed by creating a mirror image of the radiating patch along the axis using HFSS software. The Fig.2 and Fig.3 shows the front patch and bottom ground layer schematic of the proposed antenna design. The bottom layer has dimensions of 52 mm in length and 40 mm in breadth. The substrate of same dimension as ground was then created with a height of 1.524 mm.



(a) **(b)**

Fig.2. Radiating octagonal Patches (a) & Ground Plane (b) of the of MIMO Antenna

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. The length of the feed is kept 11 mm and width is 3 mm. The detailed design specifications of the MIMO antenna are illustrated in Table.1.

Table.1. Structural Parameter of Proposed Antenna

Terms	Values (mm)	Description
Ls	52	Length of Substrate
Ws	40	Width of substrate
Hs	1.524	Height of substrate
Lg	52	Length of ground
Wg	40	Width of ground
R	4	Radius of crescent moon shaped slot
r	2	Radius of circular via
F_L	11	Length of the insert feed line
F_W	3	Width of the insert feed line
D	9 mm	Distance between two octagonal patches

3. Results and Discussion

This section presents the simulation outcomes of the microstrip MIMO antenna design and its performance evaluation. This section includes a detailed analysis of the antenna's key parameters, such as return loss, VSWR, gain, and radiation pattern, after optimization. Also, crucial MIMO antenna parameters such as TARC, ECC, CCL and DG are also illustrated. The discussion focuses on how the antenna's performance aligns with the specifications required for K-band satellite communication applications. Additionally, the impact of the slot and via method on antenna miniaturization, bandwidth, and impedance matching is explained. The findings are compared with the theoretical expectations, providing insights into the effectiveness of the proposed design approach.

i. Return Loss (S11) and isolation loss (S12 and S21)

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. In the proposed MIMO design, the antenna operates at three distinct frequencies: 19.6 GHz, 20.9 GHz, and 23.65 GHz. Fig. 3 illustrates the measured S-parameter S11 at these frequencies, indicating a significant return loss of -43.75 dB, -24.07 dB, and -19.77 dB, respectively. S12 and S21 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. S21 and S12 are analyzed, which represents the power transmission from Port 1 to Port 2. The observation shown in Fig.4 and Fig.5 confirms that both the parameters (S12 and S21) are exactly matched which shows the MIMO antenna has excellent isolation.

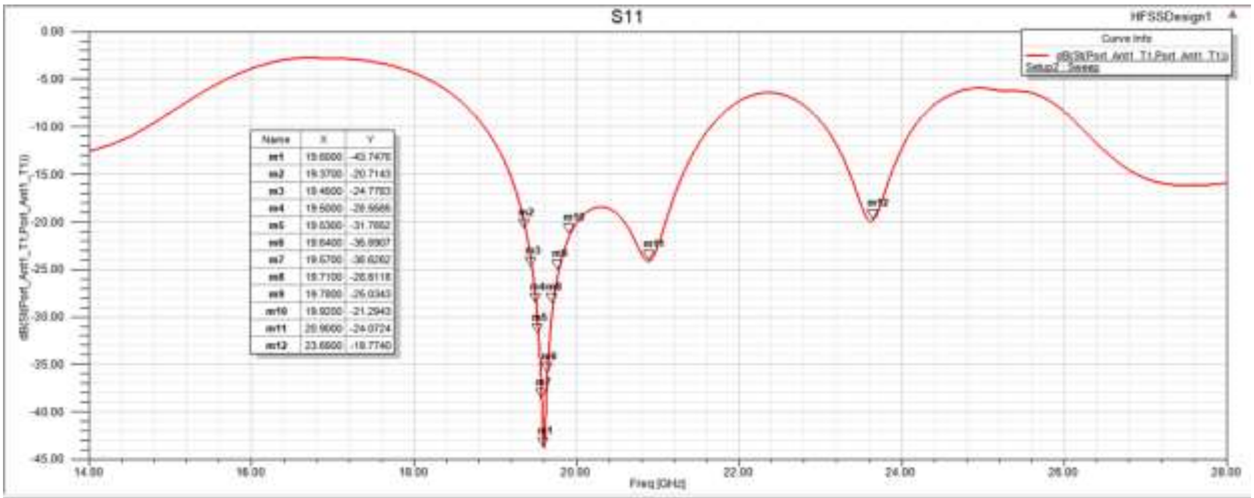


Fig.3. S11 for MIMO antenna

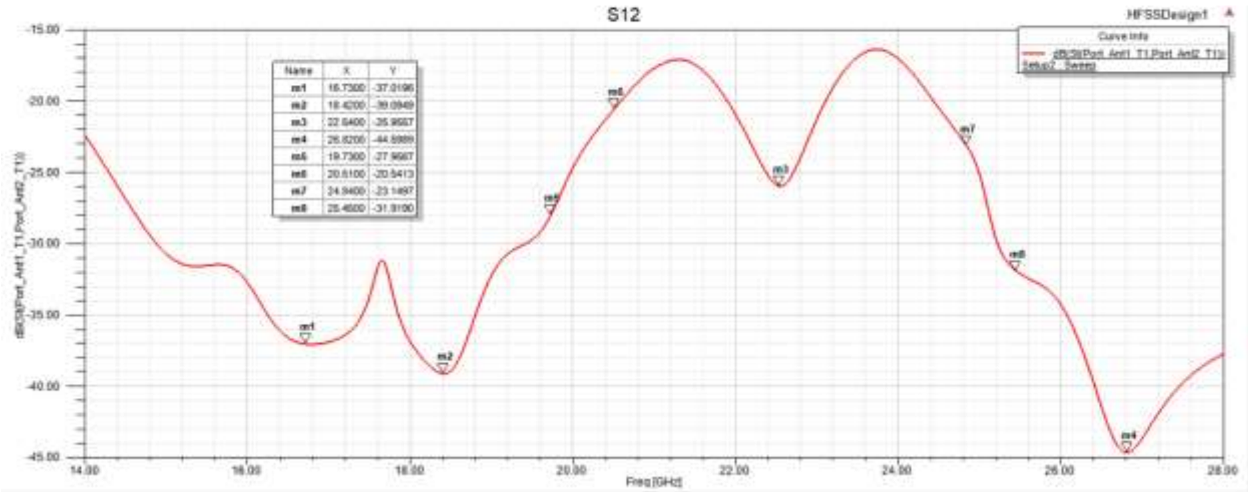


Fig.4. S12 for MIMO antenna

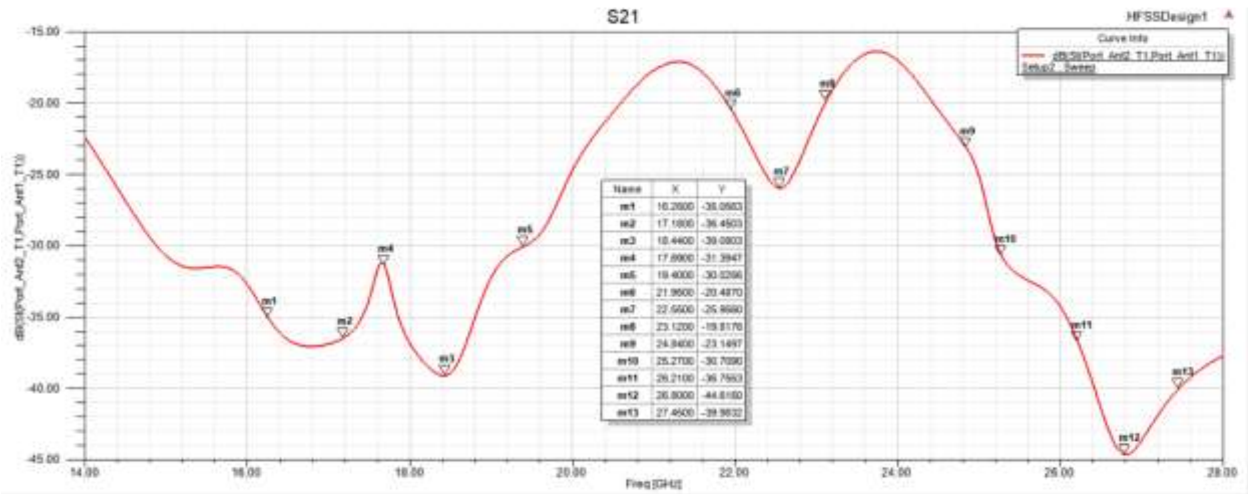


Fig.5. S21 for MIMO antenna

ii. VSWR for the proposed MIMO antenna

VSWR (Voltage Standing Wave Ratio) is an important parameter used to assess the efficiency of antenna design, as it represents the ratio between the maximum and minimum voltage on the standing wave. 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. In Figure 6, it is observed that at the target frequency of 19.6 GHz, the VSWR value is 0.11, which is lower than the ideal range of 1 to 2. For the other peak frequencies of 20.9 GHz and 23.65 GHz the VSWR value is 1.088 and 1.789 respectively. Similarly for port 2 VSWR values for the three peak frequencies does not exceed 1.5. 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.

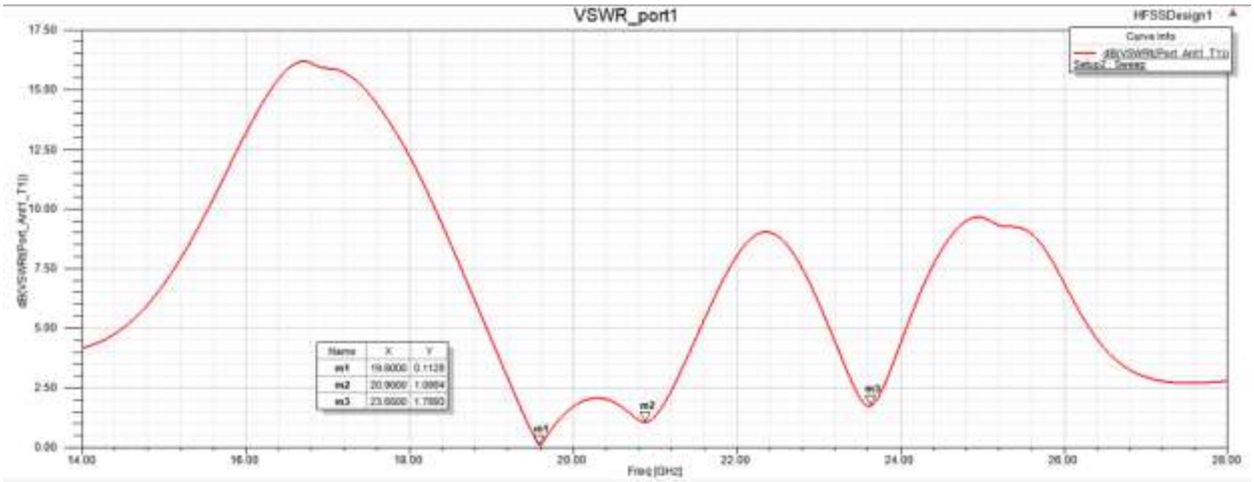


Fig.6. VSWR of Port 1 for the proposed MIMO antenna

iii. Surface Current Distribution

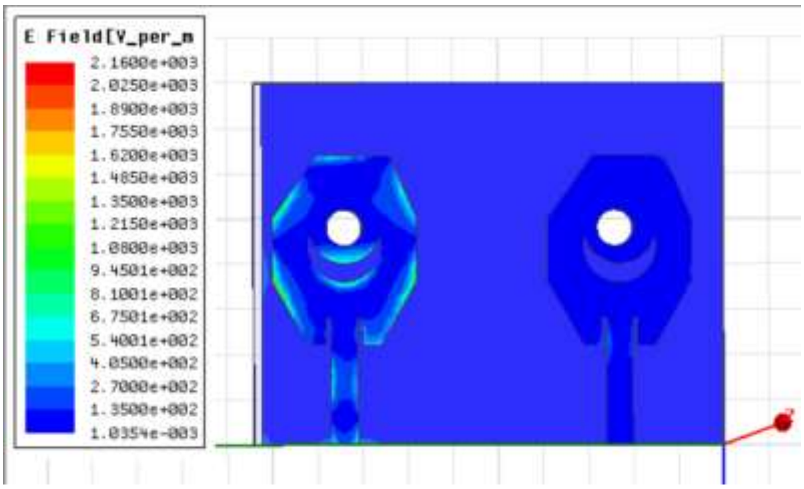


Fig.7. Surface Current Distribution for the proposed MIMO antenna

The electric field analysis focuses on the TE20 mode, one of the dominant modes of operation for the microstrip patch antenna. It investigates the E- Field distribution and polarization characteristics in this mode. The Fig.7 presents the simulated result of the surface current for the proposed antenna. The maximum electric field value recorded in the analysis is 2.600e^3 V/m.

iv. Gain of the MIMO 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.

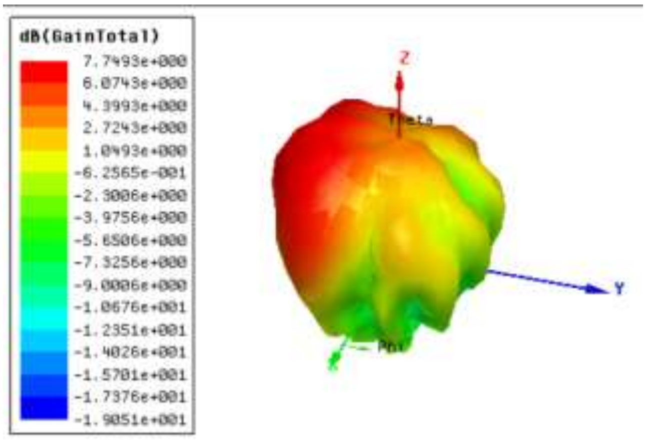


Fig.8. Gain of the proposed MIMO antenna

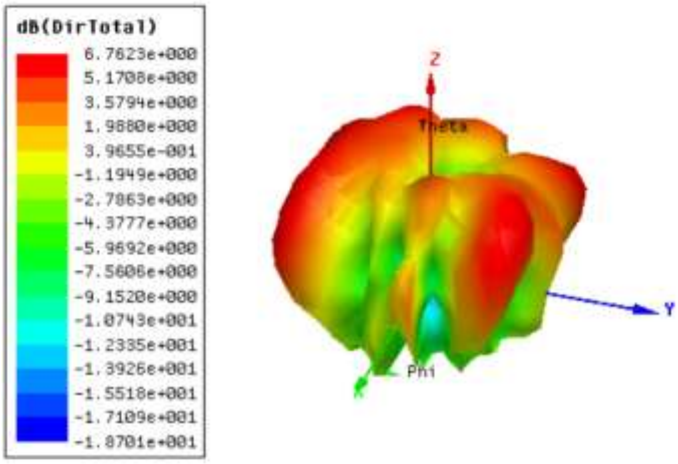


Fig.9. Directivity of the proposed MIMO antenna

The antenna design exhibits high gain and directivity, with values of 7.749 dBi and 6.762 dBi, respectively, as shown in Fig.8 and Fig.9.These high gain and directivity values indicate that antenna is capable of effectively focusing the radiated energy in a specific direction, optimizing signal reception and transmission.

v. Radiation Pattern of the MIMO 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.

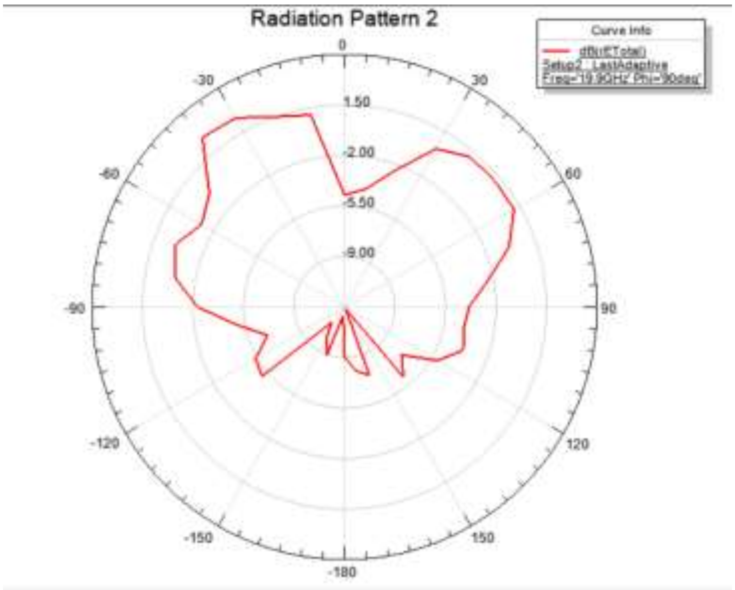


Fig.10. Radiation Pattern of the MIMO antenna at 90 degree

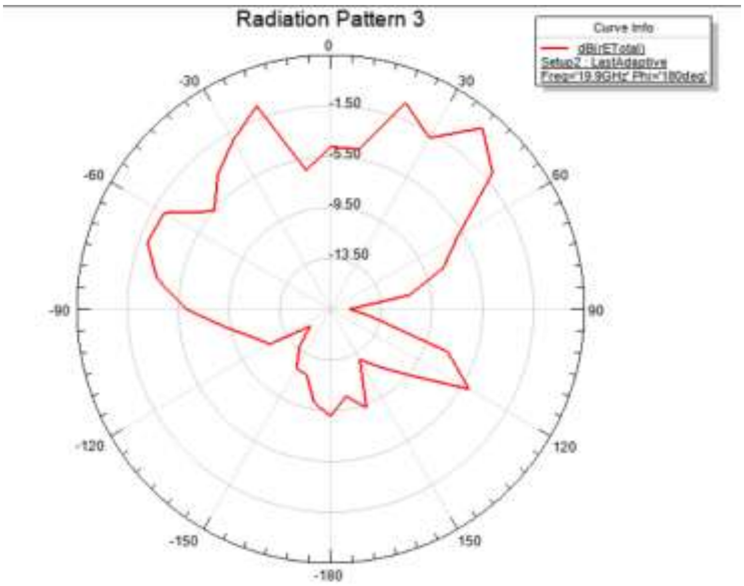


Fig.11. Radiation Pattern of the MIMO antenna at 180 degree

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 Fig.10 and Fig.11, the radiation pattern is depicted, showing a maximum value of 5.50, indicating the direction or angle where the antenna exhibits the highest power or gain. This omnidirectional characteristic is particularly useful in satellite communication, as it ensures signal reception from all directions. The combination of high gain, directivity, and appropriate radiation pattern makes this antenna suitable for efficient satellite communication systems.

vi. Envelope Correlation Coefficient (ECG), Diversity gain (DG), Channel Capacity Loss (CCL) and Total Active Reflection Coefficient (TARC) of proposed MIMO antenna

The important characteristics of MIMO such as ECG, DG, CCL and TARC which the impact the Environmental Clutter, for the proposed antenna are discussed below along with their 2-D graphs in Fig

.12, Fig.13, Fig.14 and Fig.15, respectively.

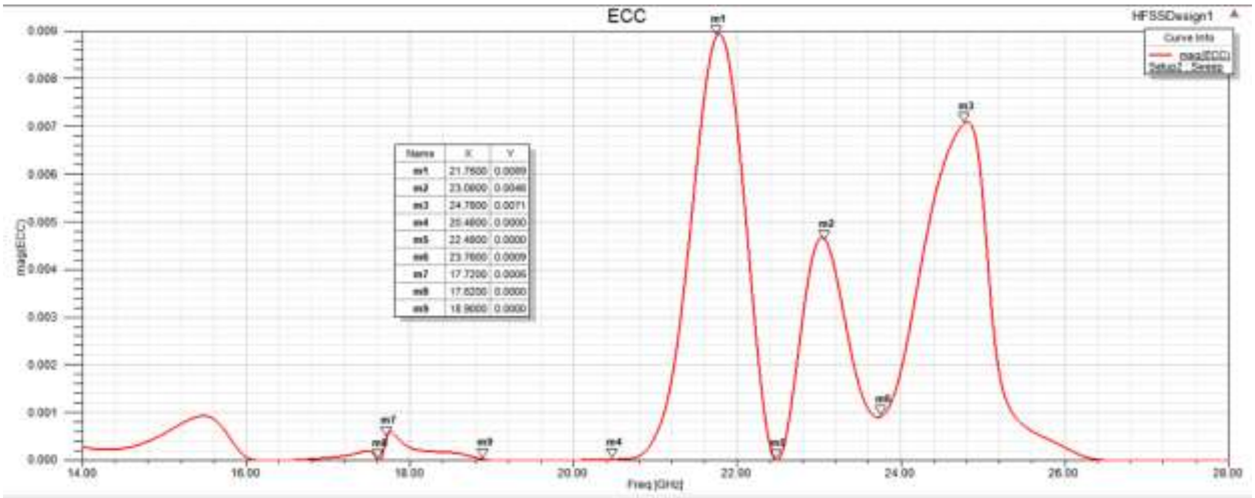


Fig.12. ECC for the proposed MIMO antenna

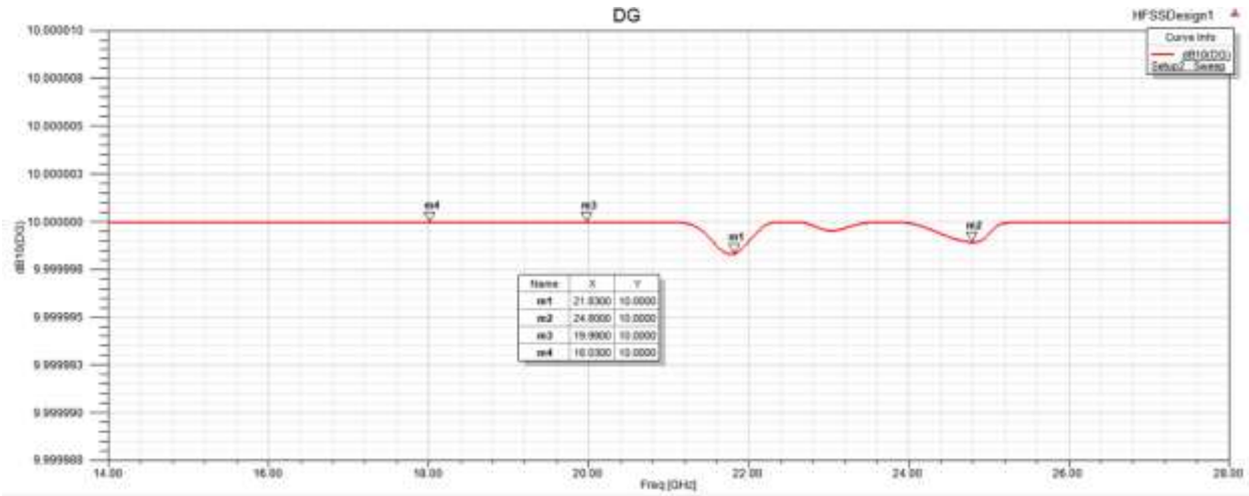


Fig.13. DG for the proposed MIMO antenna

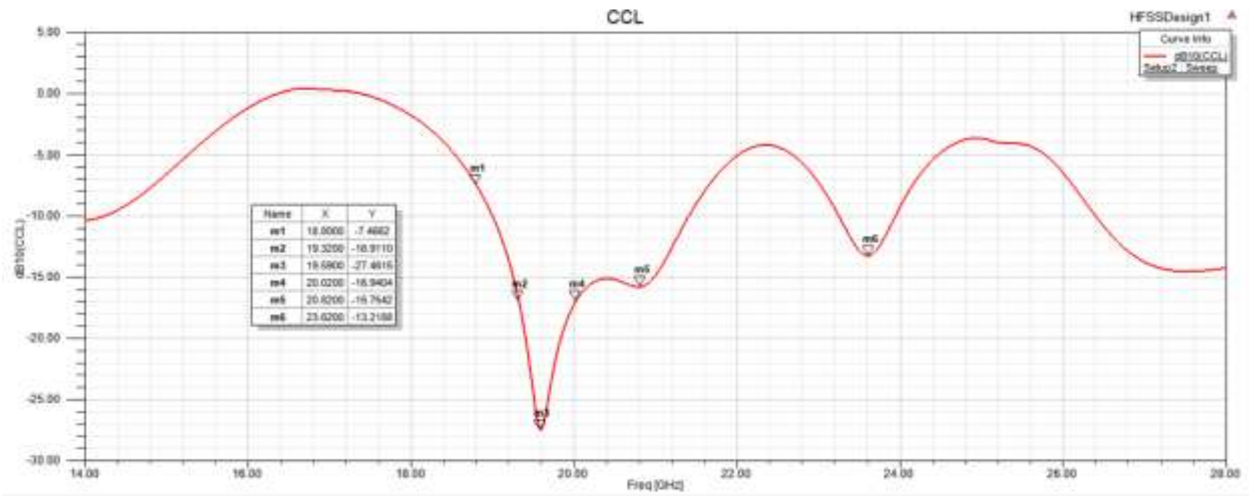


Fig.14. CCL for the proposed MIMO antenna

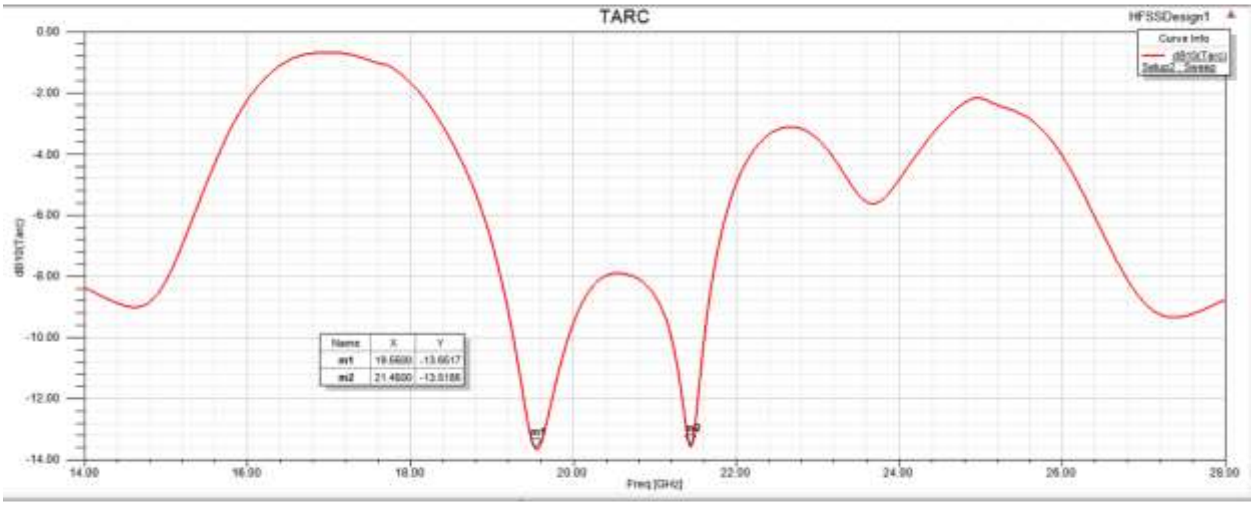


Fig.15. TARC for the proposed MIMO antenna

ECG refers to the effects of surrounding objects on the antenna's radiation pattern and signal reception. The analysis reveals an ECG value of 0.009 for the entire range of observed frequency. Additionally, DG, which represents signal quality improvement through diversity techniques, is simulated, and the resulting value of DG is 10 dB. CCL refers to Channel capacity loss which ideally should exhibit a maximum value of 0.5 dB, and for the simulated design of MIMO presented in this paper it is -16.91 for the peak frequency of 19.6 GHz. TARC is typically required to be less than 0 dB and for the proposed design the value for TARC is -13.65 and -13.61 for the two peak frequencies of 19.6 GHz and 21.5 GHz respectively.

4. Conclusion

The design of the K-band microstrip antenna with a rectangular patch for satellite communication has a targeted working frequency of 19.6 GHz. The proposed antenna design offers several advantages, including a gain of 7.74 dB at 19.37 GHz- 23.65 GHz as the designed frequency. 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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