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Design of a Bilateral Microstrip MIMO Antenna in S-Band for Satellite Communication

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Abstract: This project centers on the design and development of a bilateral microstrip MIMO antenna for S-band satellite communication, especially for mobile satellite services for high-speed communication, Earth observation data transmission, IoT networks in remote areas, military communication, and telemedicine. The microstrip MIMO antenna is designed with dimensions of 55.9 mm × 71.7 mm, operating at 2.8 GHz on low-cost FR-4 substrate with a thickness of 1.6mm is selected for its cost-effectiveness and availability. High Frequency Structural Simulator (HFSS) is used to design and simulate the antenna. Through simulation-based optimization, parameters like return loss, VSWR, radiation pattern, directivity, H-plane co-cross polarization, E-plane co-cross polarization, and gain are thoroughly analyzed to meet stringent requirements for satellite communication at 2.8 GHz.

Keywords: HFSS (high-frequency structure simulator), VSWR (Voltage Standing Wave Ratio), MSS (Mobile Satellite Service), FSS (Fixed Satellite Service), DBS (Direct Broadcast Satellites), DTH (Direct-To-Home Television), GNSS (Global Navigation Satellite Systems), MIMO (Multiple-Input Multiple-Output), AR (Axial Ratio).

1. Introduction:

Satellite communication plays a pivotal role in enabling seamless connectivity across various applications, including weather forecasting, Earth observation, Internet of Things (IoT) networks in remote areas, military communication, telemedicine, and mobile satellite services. The S-band frequency range (2–4 GHz), specifically at 2.8 GHz, stands out for its exceptional atmospheric penetration and minimal susceptibility to interference, making it a reliable choice for long-distance communication. In this paper, microstrip patch antennas are extensively utilized due to their lightweight nature, ease of fabrication, and compatibility with modern communication systems. Operating at 2.8 GHz, these antennas effectively meet the requirements of satellite communication systems while maintaining high performance. The use of FR-4 epoxy as a substrate material, known for its wide availability and cost-effectiveness, further enhances the practicality of these antennas. Achieving optimal performance involves employing an edge-feeding technique for these antennas. This feeding method offers several advantages, including simplicity of implementation, efficient impedance matching, and reduced fabrication complexity. Edge feeding ensures that the antenna structure remains compact while achieving effective power transfer, making it an ideal choice for applications operating at 2.8 GHz. To meet the demands for improved signal reliability, data throughput, and overall communication quality is possible with a Multiple Input Multiple Output (MIMO) configuration. This technique enhances key antenna parameters such as return loss, gain, directivity, and efficiency while ensuring robust performance in challenging environments. A bilateral MIMO configuration, characterized by its compact size and cost-effectiveness, becomes particularly advantageous in space-constrained environments such as satellite communication systems. Designed to operate at 2.8 GHz within the S-band, it offers an optimal balance between performance and practicality. The integration of edge feeding further enhances the efficiency of this design by ensuring effective energy transfer and minimal complexity in the feeding network, making it a suitable choice for advancing satellite communication technology.

2. Related Works

Praveen Kumar et al., [7] have designed a dual-element MIMO antenna with an elliptical shape for S-band applications, using defected ground structures (DGS) to enhance isolation between the antenna elements. The antenna achieved a return loss of -25 dB, isolation greater than 20 dB, a bandwidth of 1.1 GHz, and a gain of 7.5 dBi. This high-isolation design is particularly suitable for satellite communication systems requiring simultaneous transmission and reception with minimal interference, emphasizing its application in MIMO-based satellite communication [1].

S. Rao and Y. Wang, [2] have proposed a shared-aperture design for cellular and satellite communication antennas utilizing circular polarization in the S-band, specifically designed for metal-bezel smartphones. The integrated system demonstrated a bandwidth of 1.5 GHz for satellite communication and 1 GHz for cellular applications, with isolation levels exceeding 18 dB. The axial ratio was maintained below 3 dB, confirming the design's efficacy in minimizing polarization mismatch. These results underscore the potential of this shared-aperture design for compact and efficient integrated communication systems [2].

E. Suganya et al., [4] have analyzed an L-slotted MIMO antenna for S-band satellite applications, focusing on improving isolation using defected ground structures (DGS). The antenna achieved a return loss of -27 dB, isolation exceeding 25 dB, a bandwidth of 1.2 GHz, and a gain of 6.8 dBi. The simulation results confirmed the antenna's ability to reduce interference effectively while providing reliable performance for high-capacity communication systems in the S-band frequency range [3].

E. Suganya et al., [3] have developed and implemented a Multiple-In, Multiple-Out (MIMO) antenna system optimized for S-band satellite applications. The system features multiple antenna elements to enhance data throughput and reliability, achieving a return loss of -28 dB, isolation above 22 dB, and a gain of 7 dBi. Experimental findings also showed a 35% improvement in data rates, validating the system's ability to meet the demands of satellite communication channels with high reliability and capacity [4].

Devi et al., [4] have presented a novel expandable quad-port MIMO antenna using FR4 material, suitable for 5G networks, Wi-Fi, and satellite communication applications. The antenna achieved an isolation of 28 dB, a bandwidth of 1.8 GHz, and a gain of 8.2 dBi. The design ensures high efficiency and reliable performance, making it ideal for modern communication systems that demand compact and efficient antenna structures [5].

K. Krishna et al., [4] have proposed a dual rectangular slotted microstrip patch antenna for S-band applications, operating at 2.06 GHz. The antenna achieved a return loss of -21.6 dB, a bandwidth of 180 MHz, and a gain of 5.6 dBi. Fabricated on an FR4 substrate with a dielectric constant of 4.08 and a thickness of 1.5 mm, the design is particularly suitable for radar tracking, wireless communication, and other S-band applications such as weather monitoring and military communications [5].

3. Design of Bilateral Microstrip MIIMO Antenna at S-Band

$C = 3 \text{ x } 10^8$

$f_0 = 2.8$ GHz. $= 12 \text{ x} 10^9$Hz

$\epsilon_R = 4.4$

Design Formula

Width of the patch,

$$\text{Width} = \frac{c}{2f_0\sqrt{(\epsilon_R+1)/2}} \tag{1}$$

$$= \frac{3X10^8}{2X2.8X10^9\sqrt{(4.4+1)/2}}$$

$$w = 71.7\text{mm}$$

Effective dielectric constant,

$$\epsilon_{eff} = \frac{\epsilon_R+1}{2} + \frac{\epsilon_R-1}{2}\left[\frac{1}{\sqrt{(1+12(h/w)}}\right] \tag{2}$$

$$= \frac{4.4+1}{2} + \frac{4.4-1}{2}\left[\frac{1}{\sqrt{(1+12(1.6/71.7)}}\right]$$

$$\epsilon_{eff} = 4.25\text{mm}$$

Length of the patch,

$$\text{Length} = \frac{C}{2f_0\sqrt{\epsilon_{eff}}} - \frac{(\epsilon_{eff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\epsilon_{eff}-0.258)\left(\frac{w}{h}+0.8\right)} \quad 3$$

$$= \frac{3X10^8}{2X2.8\sqrt{4.059}} - \frac{(4.25+0.3)\left(\frac{71.7}{1.6}+0.264\right)}{(4.25-0.258)\left(\frac{71.7}{1.6}+0.8\right)}$$

$$L = 55.9\text{mm}$$

Width of the Substrate,

$$W_s = W + 6h \quad 4$$

$$= 75.9\text{mm}$$

Length of the Substrate

$$L_s = L + 6h \quad 5$$

$$= 91.7\text{mm}$$

Length of the Ground

$$L_g = L+6h \quad 6$$

$$= 75.9\text{mm}$$

Width of the Ground

$$W_g = W + 6h \quad 7$$

$$= 91.7\text{mm}$$

Where,

The parameters are as follows:

c is light velocity,

f_0 is resonant frequency,

ϵ_R is relative permittivity,

ε eff is the effective dielectric constant,

W_s is the substrate width,

W_s is the substrate length,

W_g is the ground width, and

Lg is the ground length.

Design Calculation of Proposed Antenna

From the equation [1], the width of the patch, Wp= 71.7 mm.

From the equation [2], the Effective dielectric constant, ϵ_{eff} = 4.25 mm.

From the equation [3], the length of the patch, Lp= 55.9 mm.

From the equation [4], the width of the substrate, W_s= 75.9 mm.

From the equation [5], the length of the substrate, L_s= 91.7 mm.

From the equation [6], the length of the ground, L_g= 75.9 mm.

From the equation [7], the width of the ground W_g= 91.7 mm.

Height of the substrate, H_S =1.6 mm.

Relative permittivity of the substrate (FR4), $\in_R$= 4.4.

Various Stages Of Bilateral MIMO Antenna Design At 2.8 Ghz

Stage 1 - Simple Patch

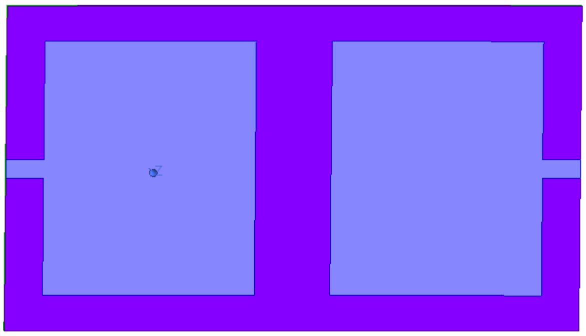

Figure-1 Design of 2 port Bilateral microstrip MIMO antenna at first stage

Stage 2 - Patch With Rectangular Slots

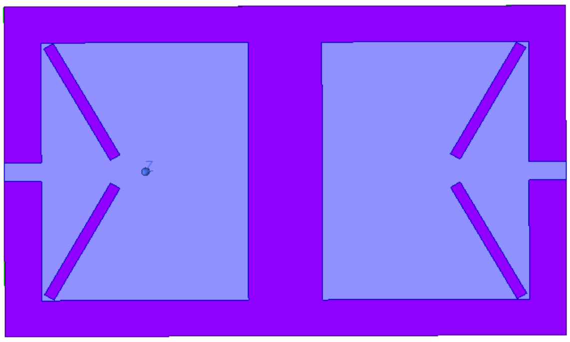

Figure-2 Design of 2 port Bilateral microstrip MIMO antenna at second stage

Stage 3 - Patch With Rectangular and Half Polygon Slots

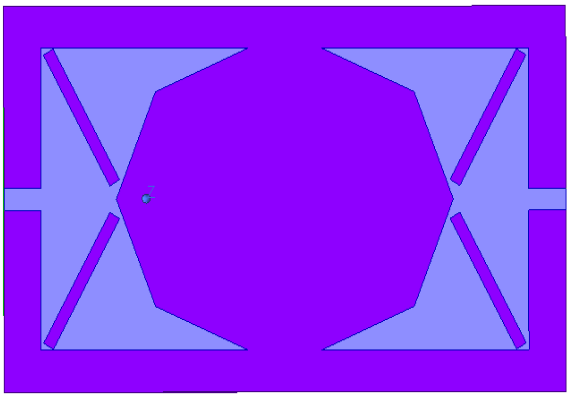

Figure-3 Design of 2 port Bilateral microstrip MIMO antenna at third stage

Stage 4 - Patch With Rectangular, Half Polygon Slots and Reflectors

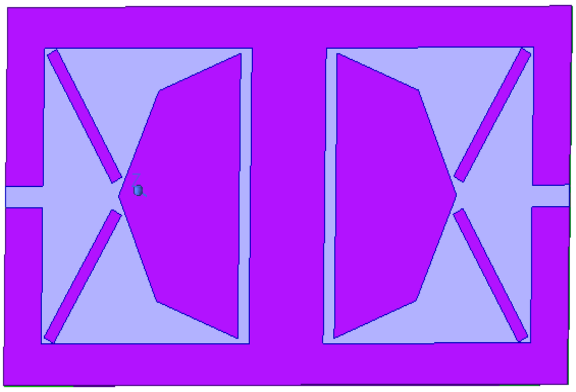

Figure-4 Design of 2 port Bilateral microstrip MIMO antenna at final stage

Table: 1 Simulation Results of Proposed MIMO Antenna

Stages	Parameters	Frequency	Port 1	Port 2
1	Return loss	2.8000GHZ	-1.9412 dB	-2.0333 dB
	VSWR		8.9862	8.6423
2	Return loss	2.8000GHZ	-24.5207 dB	-20.1286 dB
	VSWR		1.1264	1.2186
3	Return loss	2.8000GHZ	-24.4117 dB	-20.5391 dB
	VSWR		1.1281	1.2075
4	Return loss	2.8000GHZ	-27.9151 dB	-29.5140 dB
	VSWR		1.0838	1.0692

Various Stage of Return Loss

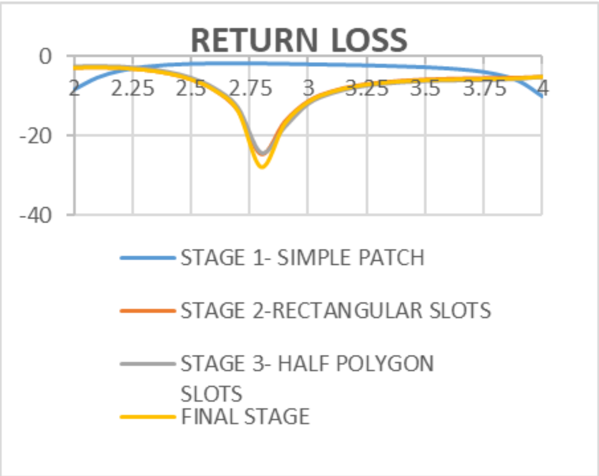

Figure-5 Return loss values at port 1

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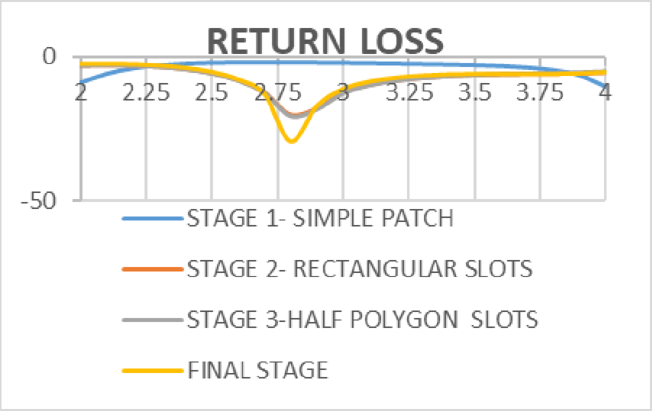
Various Stage Return Loss Values at Port 2



Various Stage VSWR Values at Port 1

Figure-6 Return loss values at port 2

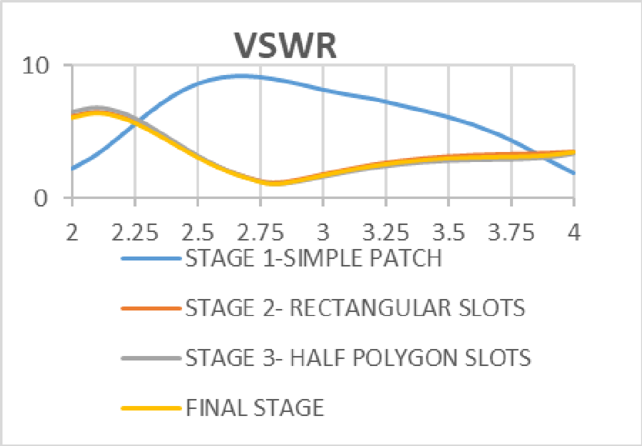


Figure-7 VSWR values at port 1

Various Stage VSWR Values At Port 2

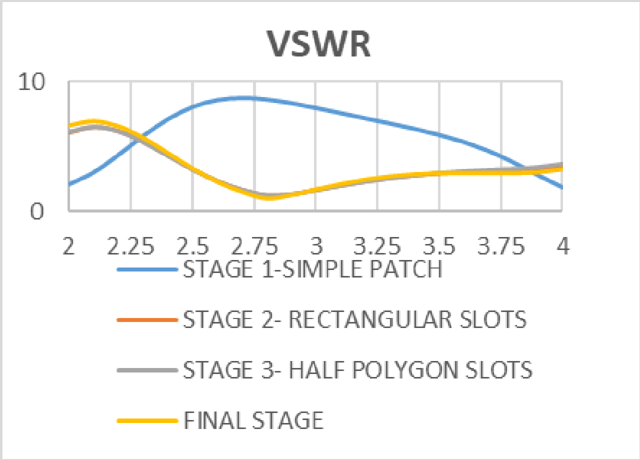


Figure-8 VSWR values at port 2

4. Antenna Design

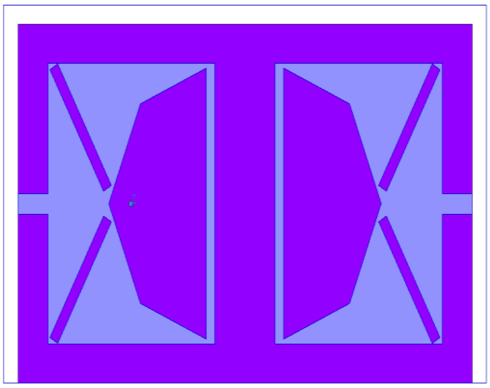


Figure-9 Overview of Bilateral 2 port microstrip MIMO antenna

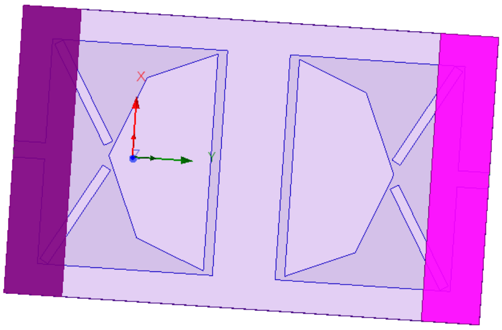


Figure-10 Ground of Bilateral 2 port microstrip MIMO antenna

5. Results

Return Loss

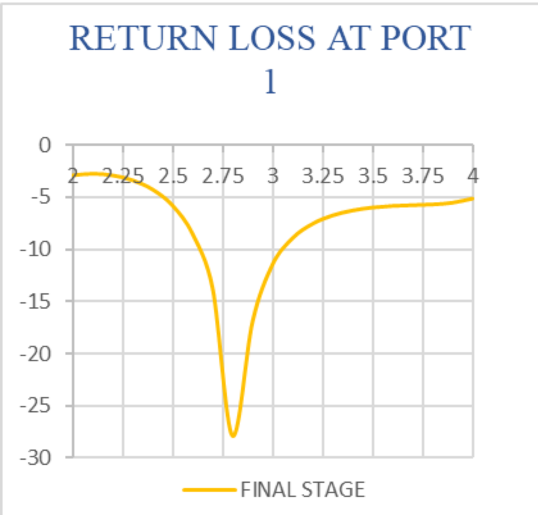


Figure-11 Return loss of Bilateral microstrip MIMO antenna at port 1

Bilateral microstrip MIMO antenna achieved a return loss of **-27.9151 dB** at port 1. that shown in Figure-11.

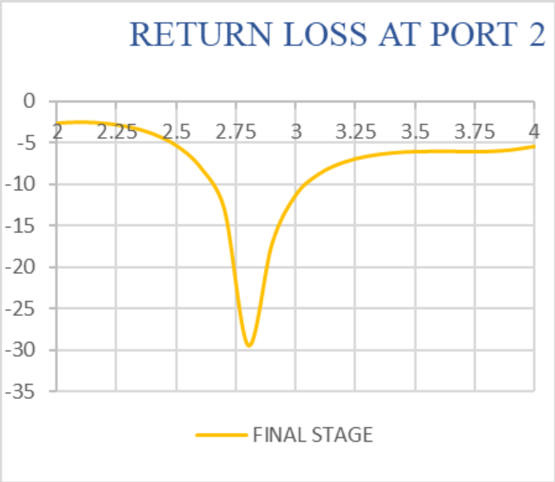


Figure-12 Return loss of Bilateral microstrip MIMO antenna at port 1

Bilateral microstrip MIMO antenna achieved a return loss of **-29.5140 dB** at port 2 that is shown in Figure-12.

Return loss is a measure of how much power is reflected back to the antenna due to an impedance mismatch. It's expressed in decibels (dB). Lower return loss indicates better impedance matching, meaning more power is being transmitted and less is being reflected.

VSWR

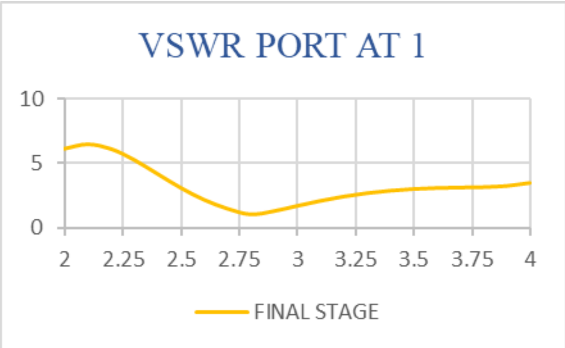


Figure-13 VSWR of Bilateral microstrip MIMO antenna at port 1

Bilateral microstrip MIMO antenna achieved VSWR of **1.0838** at port 1that shown in Figure-13.

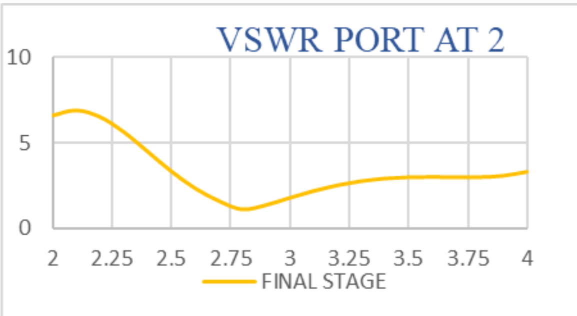


Figure-14 VSWR of Bilateral microstrip MIMO antenna at port 2

Bilateral microstrip MIMO antenna achieved VSWR of **1.0692** at port 2 shown in Figure-14.

VSWR is a measure of how well the antenna impedance matches the transmission line impedance. It represents the impedance matching quality between the antenna and the transmission line.

Mutual coupling

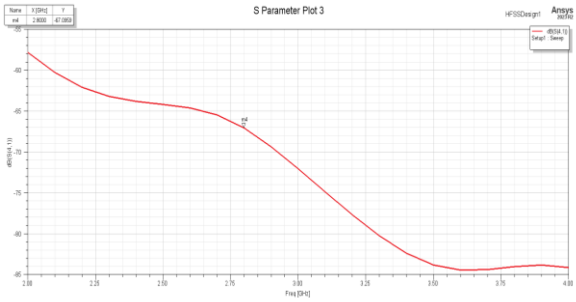


Figure-15 Mutual coupling of Bilateral microstrip MIMO antenna.

Bilateral microstrip MIMO antenna achieved Mutual coupling of **-67.0959 dB** that shown in Figure-15.

Mutual coupling in antennas refers to the interaction between two or more antenna elements that are located in close proximity to each other.

Gain

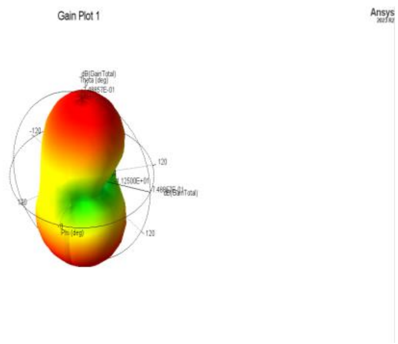


Figure-16 Gain of Bilateral microstrip MIMO antenna.

Bilateral microstrip MIMO antenna achieved Gain of **7 dBi** that shown in the Figure-16.

Gain is a measure of how much power is transmitted in a specific direction compared to an isotropic antenna, which radiates equally in all directions. Gain is usually expressed in dBi (decibels relative to an isotropic radiator). High gain in a specific direction means the antenna can transmit or receive signals more effectively in that direction.

Axial ratio

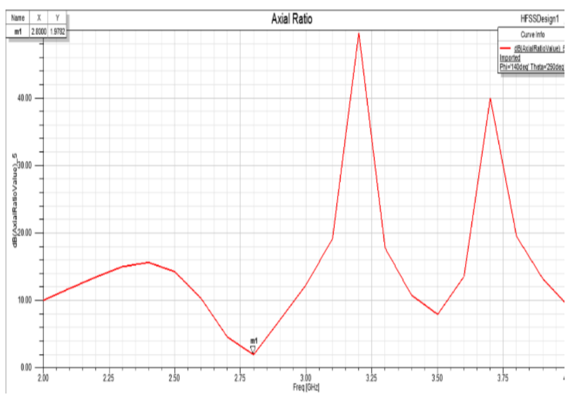


Figure-17 Axial ratio of Bilateral microstrip MIMO antenna.

Bilateral MIMO antenna achieved an axial ratio value of 1.9782 dB that shown in Figure-17.

The Axial Ratio (AR) of an antenna is defined as the minor axis to major axis ratio of an electromagnetic wave. If an antenna has perfect circular polarization, then this ratio would be (0 dB). However, if the antenna has an elliptical polarization, then this ratio would be greater than 1dB, an AR should be less than 3 dB is considered good.

H- plane co-cross polarization

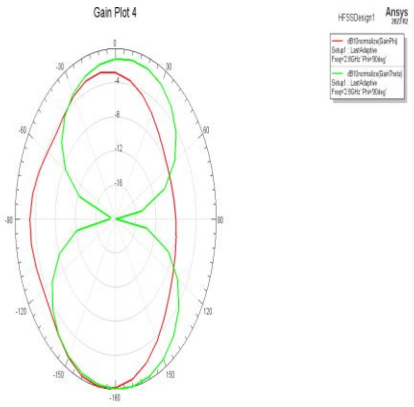


Figure-18 H- plane co-cross polarization of Bilateral microstrip MIMO antenna.

It indicates how the distribution of the magnetic field strength around the antenna. In simple words, the co-polarization is the antenna's radiation in desired directions. Whereas the cross-polarization is the antenna's radiation in the unwanted directions.

E- plane co-cross polarization

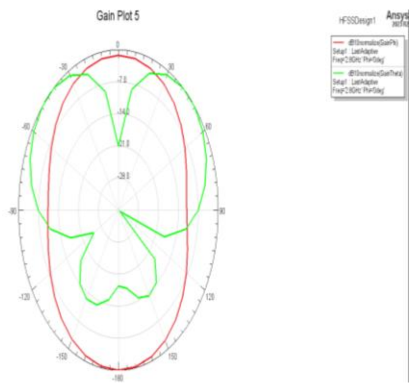


Figure-19 E- plane co-cross polarization of Bilateral microstrip MIMO antenna.

It indicates how the electric field radiates from the antenna, which is crucial for understanding the polarization and radiation characteristics. In simple words, the co-polarization is the antenna's radiation in desired directions. Whereas the cross-polarization is the antenna's radiation in the unwanted directions.

Table-2 Simulation Results Of Proposed MIMO Antenna

<table>
<tr><th>FREQUENCY</th><th>PARAMETERS</th><th>PORT 1</th><th>PORT 2</th></tr>
<tr><td rowspan="2">2.8000GHZ</td><td rowspan="2">Return loss-</td><td>< -10 dB</td><td>< -10 dB</td></tr>
<tr><td>-27.9151 dB</td><td>-29.5140 dB</td></tr>
<tr><td rowspan="2">2.8000GHZ</td><td rowspan="2">VSWR</td><td>< 2</td><td>< 2</td></tr>
<tr><td>1.0838</td><td>1.0692</td></tr>
<tr><td rowspan="2">2.8000GHZ</td><td rowspan="2">Axial ratio</td><td colspan="2">< 3 dB</td></tr>
<tr><td colspan="2">1.9782dB</td></tr>
<tr><td rowspan="2">2.8000GHZ</td><td rowspan="2">Isolation</td><td colspan="2">< -20 dB</td></tr>
<tr><td colspan="2">-67.0959 dB</td></tr>
<tr><td>2.8000GHZ</td><td>Gain</td><td colspan="2">7 dBi</td></tr>
</table>

6. Conclusion

In conclusion, the design of the S-band microstrip MIMO antenna operating at 2.8 GHz, with dimensions of 55.9 mm × 71.7 mm, is optimized for satellite communication applications. It demonstrates outstanding performance with a precise return loss of -27.9151 dB at port 1 and -27.5140 dB at port 2, a notable improvement of 9 dB over previous designs. The mutual coupling between the MIMO elements is significantly reduced, achieving -67.0959 dB, which is an 8 dB improvement over existing literature. The antenna also achieves excellent impedance matching, with a VSWR of 1.0838 dB at port 1 and 1.0692 dB at port 2, ensuring efficient power transfer. With an axial ratio of 1.9782 dB, the antenna supports circular polarization, enhancing signal reception in satellite communication environments. Furthermore, the antenna provides a gain of 7 dBi, ensuring reliable transmission and reception signal. These design achievements contribute to meeting the stringent requirements of modern S-band satellite communication systems, offering enhanced communication performance and reliability.

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