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Analysis and Design of Microstrip Antenna with Slit Method for C-Band Frequency

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Abstract

The rapid advancement of communication technology faces challenges posed by Earth's diverse topography, which necessitates the development of satellite communication systems capable of providing global coverage without being hindered by geographical variations. Traditional satellite antennas are often large and inflexible, prompting the need for more compact solutions. This research presents the design of a minimalist microstrip antenna optimized for C-band frequency, specifically operating at 6 GHz, to meet the needs of satellite communication applications. The antenna design utilizes the gap method optimization technique, which enhances its S-parameter performance and Voltage Standing Wave Ratio (VSWR) by introducing small gaps into the antenna structure. The optimization results show that the antenna achieves a return loss of -16.414 dB and a VSWR of 1.355, along with a directional radiation pattern, indicating strong performance in satellite communication systems. These characteristics demonstrate the antenna's suitability for stable signal transmission in satellite communication systems operating within the C-band frequency range. The compact size, high efficiency, and stable performance make this microstrip antenna an ideal solution for modern satellite communications, especially in scenarios requiring space-saving and flexible antenna designs.

Keyword: C-Band, Microstrip, Rectangular, Satellite, Slit

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I. INTRODUCTION

The diverse topography of the Earth plays a significant role in driving the continuous advancement of satellite communication systems. The irregularities in the Earth's surface frequently pose challenges in conventional long-distance communication methods. This issue is further amplified by the growing demand for reliable and efficient long-distance communication across the global community [1]. Consequently, the development of satellite communication systems emerges as a crucial solution to address these challenges, providing the necessary infrastructure for seamless global connectivity.

Satellite communication systems rely on antennas that function as both transmitters and receivers. Parabolic reflector antennas are widely used in such systems because of their high gain capabilities, which enhance signal reception and transmission efficiency [2]. However, the primary drawback of parabolic antennas lies in their large physical size, which reduces their versatility in certain applications. The substantial size of these antennas makes them less adaptable, especially in environments where space limitations or mobility are critical factors. As a result, there is a growing need for more compact and flexible antenna designs to address these challenges in satellite communication systems.

Microstrip antennas are known for their simple design, making them a popular choice in various communication applications. These antennas are compact, lightweight, and capable of operating at high frequencies, which makes them suitable for modern satellite communication systems. Additionally, microstrip antennas exhibit a directional radiation pattern, enhancing their efficiency in signal transmission and reception [3]. Due to their advantageous features, microstrip antennas present an innovative solution for communication systems that require small, lightweight, and efficient antennas. Consequently, further research into the application of microstrip antennas across various frequencies could lead to significant advancements in communication technologies.

C-band frequency is commonly used in satellite communications due to its reliability and performance. Compared to Ku-band frequencies, C-band frequencies offer greater resistance to adverse weather conditions, making them more suitable for regions with frequent weather disruptions [4]. This characteristic is particularly valuable in satellite communication systems, where signal stability is crucial. Although C-band frequencies are lower than those used in other satellite communication bands, their weather resilience makes them a preferable choice in light of the increasingly unpredictable global weather patterns. Therefore, C-band frequencies provide a more robust solution for satellite communication, especially in challenging environmental conditions.

Based on the background provided, an innovation is proposed in the design of a microstrip antenna operating at the C-band frequency for satellite communications. The proposed microstrip antenna offers several advantages, including a relatively small size, lightweight construction, ease of manufacturing, portability, high efficiency, and compactness, distinguishing it from conventional satellite antennas. The C-band frequency was selected for this research due to its superior stability and resistance to weather disturbances, compared to higher frequency bands. It is anticipated that the proposed antenna will maintain signal quality and reliability in receiving satellite communication signals, even under varying atmospheric conditions. Ultimately, this research aims to contribute practical solutions to enhance the efficiency and reliability of satellite communication systems operating at C-band frequencies.

II. RESEARCH METHODS

The Research Methods section outlines the strategies and procedures employed in this study to fulfill the research goals. It presents a detailed account of the methodology, encompassing the design, simulation, and analysis stages, along with other relevant aspects of the research. Additionally, it explains the materials, parameters, and optimization techniques utilized in the antenna design process. By providing this information, the section seeks to clarify the research methodology and ensure the reproducibility and comprehensibility of the results. Subsequent sections will expand on these methods, offering a deeper understanding of the findings and their analysis.

2.1 Satellite Communication System

Satellite communication systems are technologies that enable the transmission of data and information over long distances via satellites. These systems consist of three main components: satellites, ground stations, and transmitted signals, which work together to facilitate communication. Satellite communication is widely used for both civil and military purposes, providing a critical means of connectivity in remote and underserved areas. Due to their ability to cover large regions, satellite systems are particularly valuable in areas with challenging terrain, such as hills, mountains, or forests, where cable-based telecommunications or cellular networks are difficult to implement [5][17]. Satellite communication systems can be classified based on satellite orbit, including geostationary orbit (GEO), medium orbit (MEO), and low orbit (LEO), each offering distinct characteristics in terms of distance, latency, and coverage area [6].

2.2 C-Band Frequency

In satellite technology, frequency spectrum allocation is critical for ensuring efficient and reliable communication services. One of the key frequency bands in telecommunications is the C-band, which spans from 4 GHz to 8 GHz [7]. The primary advantage of C-band frequencies is their resistance to atmospheric disturbances, such as rain and humidity, which can significantly impact signal quality. This makes C-band a preferred choice for satellite communications in regions with unpredictable or harsh weather conditions, where maintaining a stable signal is essential [8]. As a result, C-band frequencies are widely utilized for reliable satellite communication, particularly in areas prone to frequent weather-related interference.

2.3 Rectangular Microtip Antenna

Rectangular microstrip antennas are commonly used in modern communication applications due to their compact design, lightweight construction, and ease of manufacturing. A typical microstrip antenna consists of a rectangular patch placed on top of a dielectric layer, which is then mounted on a ground plane. Additionally, a substrate is positioned on top, with its dielectric constant and thickness significantly influencing the antenna's operating frequency, bandwidth, and efficiency [9][10]. The patch, which forms the top layer of the antenna, is responsible for radiating electromagnetic waves and is typically made of a metal layer with a specific thickness [11]. The design of the rectangular microstrip antenna can be visualized in Figure 1.

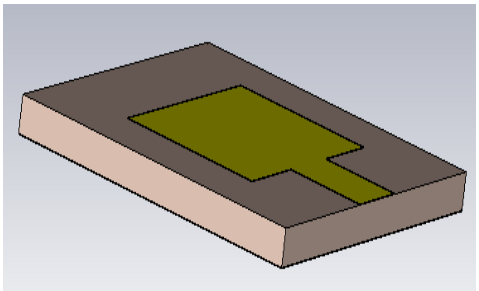

Fig. 1. Rectangular Microstrip Antenna Design

2.4 Slit Method

The slit technique used in this study introduces a small gap into the antenna structure to enhance its performance. In this approach, the width and length of the slits (ws and ls) are determined based on the optimization process and the specific design requirements. By incorporating these slits, the physical dimensions of the antenna are reduced, while simultaneously increasing its bandwidth, which refers to the operational frequency range of the antenna. This results in a more compact antenna that retains its effectiveness in supporting communication across a broader frequency spectrum. The slit technique, therefore, offers a practical solution for improving antenna performance while maintaining a small form factor [12][13].

2.5 Antenna dimension calculation

Designing a rectangular patch microstrip antenna requires a thorough understanding of the parameters and materials involved, specifically the dielectric thickness (h), and dielectric constant (εr). These values are crucial for determining the dimensions of the microstrip antenna, including the width (W) and length (L). The calculation of these dimensions is performed using specific equations derived from the properties of the materials and the desired operating frequency. Equation (1) [14][15] provides the necessary relationships to calculate the length and width of the antenna. To compute the dimensions of the patch, the following equation is applied, ensuring that the antenna meets the required performance specifications.

$$Wp = \frac{c}{2f}\sqrt{\frac{2}{\varepsilon r + 1}}\, p \tag{1}$$

$$L_{eff} = \frac{c}{2f\sqrt{\varepsilon ff}} \tag{2}$$

$$\varepsilon_{eff} = \frac{\varepsilon r + 1}{2} + \frac{\varepsilon r - 1}{2}\left[\frac{1}{\sqrt{1 + \frac{12h}{Wp}}}\right] \tag{3}$$

$$\Delta L = 0.412\, Ts \frac{(\varepsilon reff + 0.3)\left(\frac{WP}{Ts} + 0.264\right)}{(\varepsilon reff - 0.258)\left(\frac{WP}{Ts} + 0.8\right)} \quad (4)$$

$$WP = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad (5)$$

Description:

LP = Length of Patch
WP = Width of Patch
Ts = Thickness of Substrate
ΔL = Length Gain
c = Speed of Light (3 x 10^8 m/s)
L_eff = Effective length
ε_(eff) = Effective dielectric constant
ε_r = Dielectric constant of the substrate

Furthermore, to get the size of the groundplane and substrate, it is calculated using the equation below [18]:

$$Wg = 6h + Wp \quad (6)$$

$$Lg = 6h + Lp \quad (7)$$

Description:

Lg = Groundplane length and substrate length
Wg = Groundplane width and substrate width

The feedline is calculated with the equation below [16]:

$$B = \frac{60\pi^2}{Z_0\sqrt{\epsilon r}} \quad (8)$$

$$W = \frac{2h}{\pi}[B - 1 - ln(2B - 1) + \frac{\epsilon_r - 1}{2\epsilon_r}\{ln(B - 1)\} + 0.39 - \frac{0.61}{\epsilon_r}] \quad (9)$$

$$\lambda_g = \frac{\lambda_0}{\sqrt{\epsilon_{reff}}} \quad (10)$$

$$L_f = \frac{\lambda_g}{4} \quad (11)$$

Description:

1. Lf = Feedline length
2. W = Feedline width

2.6 Antenna Specifications

This research focuses on analyzing the simulated parameter values of a rectangular microstrip antenna design operating at C-band frequencies. The antenna utilizes FR-4 substrate material, which is lossy, with a dielectric constant (εr) of 4.3 and a thickness (h) of 1.6 mm. These material properties are critical in determining the antenna's performance characteristics, including its bandwidth and efficiency. The specifications of the designed antenna, including its dimensions and other relevant parameters, are detailed in Table 1. The analysis aims to assess the antenna's suitability for satellite communication systems operating at C-band frequencies, ensuring optimal performance.

Table 1. ANTENNA SPECIFICATIONS

Specifications	Description
Frequency Range	4-8 GHz
Working Frequency	6 GHz
Input Impedance	50Ω
Return loss	$\leq$ -10 dB
Radiation Pattern	Directional
Polarisation	Circular

Design Scheme

The stages of antenna design, from simulation to analysis, are carried out in a sequential manner, as illustrated in Figure 2. The process begins with the initial antenna design, where key parameters such as dimensions and substrate material are defined. This is followed by the simulation stage, where the antenna's performance is tested under virtual conditions. After simulation, the results are analyzed to evaluate the antenna's effectiveness, focusing on parameters like return loss, VSWR, and bandwidth. Finally, based on the analysis, optimization techniques are applied to refine the design, ensuring it meets the desired specifications and performance criteria.

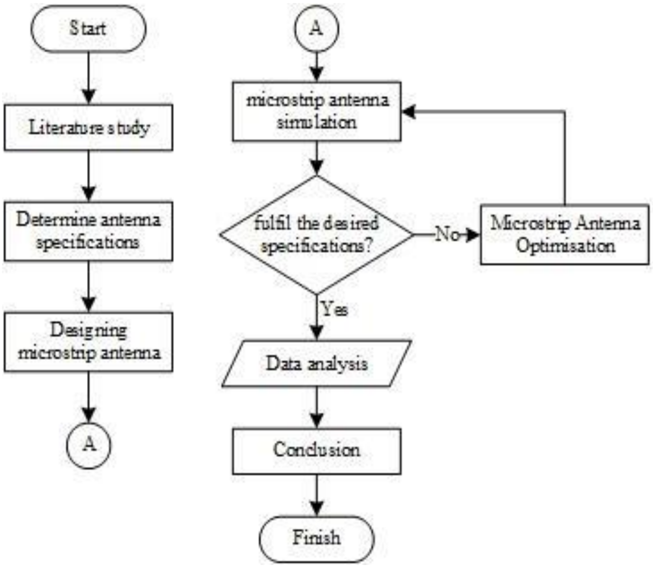

Fig. 2. Microstrip Antenna Design Flowchart

2.7 Antenna Dimensions and Design

After completing the initial antenna design, the next step is to optimize the antenna in order to enhance its performance. The previously determined dimensions serve as a reference for the design of the rectangular microstrip antenna, ensuring that the antenna meets the required specifications. These dimensions are critical for achieving the desired operational characteristics, such as bandwidth and efficiency. The detailed values for the width, length, and other relevant parameters of the microstrip antenna are provided in Table 2. Optimization of these dimensions is crucial to ensure the antenna's performance aligns with the intended communication requirements.

Table 2. RECTANGULAR ANTENNA DIMENSIONS C-BAND FREQUENCY

Parameter	Size (mm)	Description
Wg	24,957	Groundplane Width

Parameter	Size (mm)	Description
Lg	21,060	Groundplane Length
Hg	0,035	Groundplane Thickness
Hs	1,6	Substract Thickness
Wp	15.357	Patch Width
Lp	10.010	Patch Length
Hp	0,035	Patch Thickness
Wf	4.8	Feedline Width
Lf	5.525	Feedline Length

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III. RESULT AND DISCUSSION

The Results and Discussion section presents the outcomes and analysis of the research, focusing on the performance of the microstrip antenna designed for C-band frequency satellite communication systems. This section aims to elucidate how the antenna design aligns with the objectives of flexibility, portability, and high efficiency in receiving information signals. The results are carefully analyzed to assess the antenna's effectiveness in real-world applications, specifically in terms of its ability to handle C-band frequencies. In addition, the discussion will interpret the findings to highlight the success of the design and any areas for potential improvement. Ultimately, this section seeks to provide a comprehensive understanding of the antenna's capabilities and its practical implications for satellite communication systems.

3.1 Simulation

The Simulation section presents the results of the simulations conducted throughout the antenna design process, from initial calculations to optimization efforts aimed at achieving optimal performance. This section provides an overview of the simulation setup, including the key parameters and configurations used to model the antenna's behavior. The simulations were performed to evaluate the antenna's performance under different conditions and to refine the design for maximum efficiency. By adjusting the design through iterative optimization, the results were analyzed to ensure that the antenna meets the desired specifications. Ultimately, this section demonstrates how simulation plays a crucial role in optimizing the antenna design to achieve the best possible results.

3.1.1 Preliminary Antenna Design

The simulation results of the microstrip antenna, based on the calculations presented in Figure 4, indicate that the operating frequency does not align with the expected specifications. The observed frequency deviation from the target suggests that the initial design requires further optimization. This optimization process is crucial to enhance the antenna's performance, particularly in terms of achieving the desired resonant frequency. Additionally, the optimization aims to improve other key parameters, such as return loss and bandwidth, to ensure the antenna meets the performance requirements. Ultimately, the goal is to adjust the design so that the microstrip antenna is better suited for satellite communication applications within the C-Band frequency range.

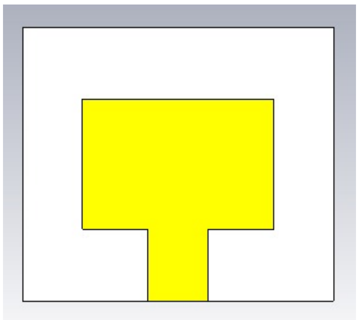

Fig. 3. Microstrip Antenna Preliminary Design

The initial design, as illustrated in Figure 3, was simulated using CST Studio Suite software. However, the simulation results, as shown in Figure 4, did not meet the desired antenna specifications. This discrepancy indicates that further optimization is necessary to achieve the best performance. The optimization process is crucial to improve key parameters such as resonant frequency, return loss, and bandwidth, ensuring that the antenna performs efficiently. Therefore, optimization is essential to refine the design and maximize the antenna's effectiveness in the researched methods.

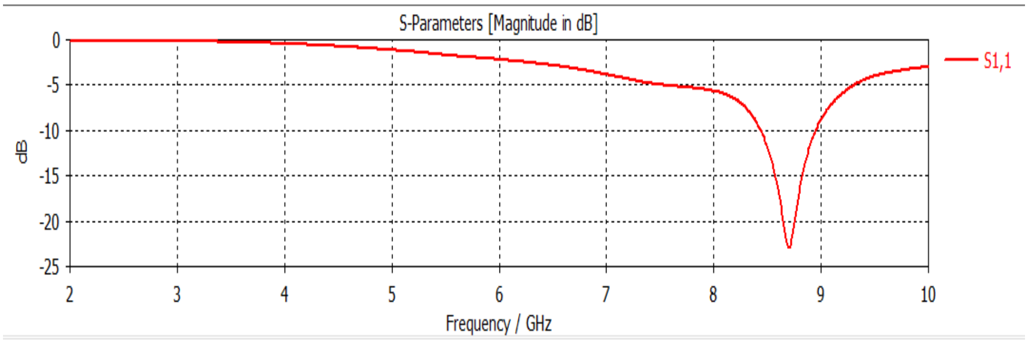

Fig. 4. Return loss of Microstrip Antenna Initial Design

3.1.2 Antenna Design After Optimisation

The antenna optimization was carried out by incorporating a slit into the antenna patch, as depicted in Figure 5. This modification was specifically designed to achieve the desired working frequency of 6 GHz and enhance the antenna's performance within the C-Band frequency range. The slit acts as a current-regulating element on the antenna surface, altering the current path and effectively extending the resonant path. By adjusting the current distribution, the slit enables fine-tuning of the antenna's operating frequency to meet the target specifications. This optimization technique significantly improves the antenna's efficiency and performance in satellite communication applications.

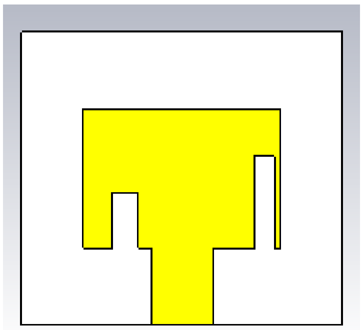

Fig. 5. Antenna optimisation with slit addition

Slit settings in the microstrip antenna design can be optimized by reducing the antenna's dimensions through the introduction of holes or gaps in the patch. These gaps alter the current distribution and extend the resonant path, allowing for a finer control over the antenna's operating frequency. The dimensions of the slits can be further adjusted by modifying the gap in the patch, with the inclusion of additional parameters in the design's parameter list. This process enables the antenna's performance to be tailored to meet specific requirements, such as enhancing bandwidth or improving resonant frequency. By carefully adjusting these slit parameters, the overall efficiency and functionality of the antenna can be significantly improved.

The slit parameter controls both the height and width of the slit, which directly influences the antenna's performance. The optimization results demonstrate that incorporating the slit successfully enhances the antenna's key performance parameters, such as reducing the return loss and achieving the desired operating frequency. This adjustment allows the microstrip antenna to operate more efficiently by improving its resonance and impedance matching.

Table 3. DIMENSIONS OF THE SLIT METHOD

Parameter	Size (mm)	Description
Xminslit	-3,4	Left side First Slit
Xmakslit	-5,4	Right Side First Slit
Yminslit	-6	Bottom Side First Slit
Ymakslit	-1	Top Side of First Slit
Xminslit2	5.7	Left side Second Slit
Xmakslit2	7.21	Right Side Second Slit
Yminslit2	7.21	Second Slit Bottom Slit
Ymakslit2	1.6	Top Side Second Slit

Consequently, the antenna's stability and effectiveness in supporting satellite communications are significantly increased. These improvements enable the antenna to function more reliably within the C-band frequency range, providing better signal reception and transmission for satellite systems.

3.2 Parameter Optimisation Results

The Parameter Optimization Results section presents the outcomes of the optimization process applied to the antenna design. This section focuses on the impact of adjusting various parameters, such as the slit dimensions, on the overall performance of the microstrip antenna. The optimization aims to achieve a more efficient antenna design by enhancing critical factors such as return loss, bandwidth, and the resonance frequency. By systematically fine-tuning these parameters, the goal is to improve the antenna's ability to meet the requirements for satellite communication systems. The following analysis discusses the effects of these adjustments on the antenna's performance and their implications for achieving optimal results.

3.2.1 Working Frequency

The working frequency of the C-band microstrip antenna, optimized through the slit method, is 6 GHz. This frequency was precisely achieved by adjusting the slit dimensions, ensuring that the antenna's operational frequency aligns with the desired target. The 6 GHz frequency is well-suited for satellite communication applications, offering efficient transmission and reception in the C-band spectrum. The slit method enables accurate tuning of the antenna's resonance frequency, thereby enhancing its performance within the specified frequency range. As a result, the antenna can operate optimally, providing reliable communication in satellite systems.

3.2.2 Return Loss

As shown in Figure 6, the return loss value of the optimized antenna design confirms that the antenna operates at the desired working frequency of 6 GHz. The low return loss of -16.414 dB at this frequency demonstrates the antenna’s ability to efficiently radiate power and achieve a good impedance match at the target frequency. This indicates that the optimization process, including the addition of the slit, has effectively enhanced the antenna's performance, ensuring compliance with the specifications necessary for satellite communication in the C-Band. The successful attainment of the 6 GHz working frequency further suggests that the antenna exhibits excellent stability and response to signals at this frequency. Overall, the optimizations have contributed to improving the antenna's performance, making it well-suited for the intended communication applications.

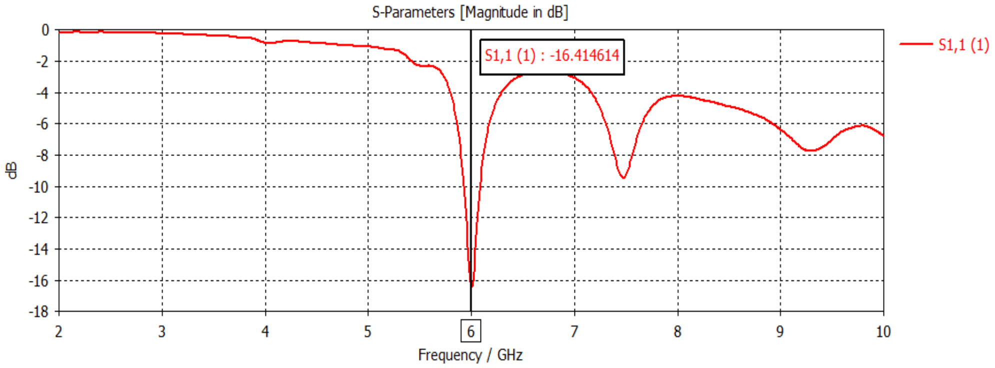

Fig. 6. Return loss of Microstrip Antenna with Slit

3.2.3 VSWR

The measurement results shown in Figure 7 indicate that the antenna design with the added slit achieves a Voltage Standing Wave Ratio (VSWR) of 1.355, which is well below the maximum threshold of 2. This low VSWR value signifies that the antenna efficiently transfers power with minimal reflection, ensuring effective energy utilization. A VSWR value below 2 is indicative of an optimal impedance match between the antenna and the transmission device, which is crucial for maximizing performance. The favorable VSWR also confirms that the antenna is operating efficiently at the target frequency, without significant power losses. Consequently, the optimized design with the slit contributes to enhancing the antenna's overall performance for its intended communication applications.

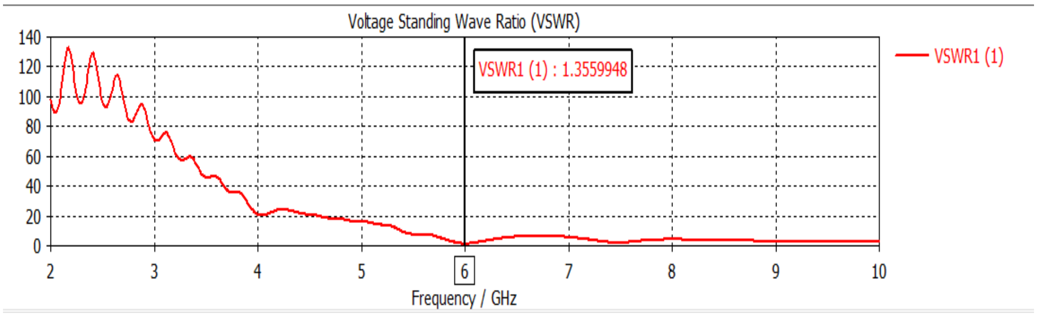

Fig. 7. Microstrip antenna VSWR results

3.2.4 Radiation Pattern

The optimization results of this rectangular microstrip antenna operating at C-Band frequencies demonstrate that the radiation pattern is directional, specifically unidirectional. As shown in Figure 8, the main lobe exhibits a relatively wide width, which contributes to a broader coverage area for the antenna. This wide coverage allows the antenna to effectively communicate with satellites over a larger spatial range.

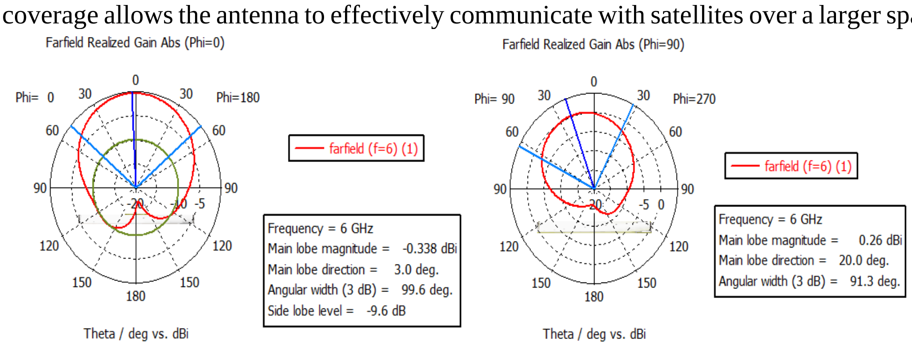

Fig. 8. The resulting of radiation pattern

The directional radiation pattern ensures that the antenna focuses its energy in a specific direction, optimizing signal strength and reducing interference from other sources. Consequently, the antenna design proves to be flexible and adaptable for various satellite configurations, making it suitable for a wide range of satellite communication applications..

IV. CONCLUSION

This research shows that a microstrip antenna can effectively operate at a C-Band frequency of 6 GHz for satellite communication. The antenna design, optimized using the slit method, successfully achieves the desired working frequency of 6 GHz, as evidenced by the return loss of -16.414 dB. Additionally, the low VSWR of 1.355 and the directional radiation pattern further validate the antenna's performance. These results indicate that the microstrip antenna is suitable for C-Band satellite communication applications. However, the antenna's gain, directivity, and bandwidth remain relatively low, suggesting potential areas for further research to enhance these performance aspects.

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