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Design of Rectangular Patch Ku Band Microstrip Antenna for Satellite Communication with Asymmetric Slit Method

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Abstract

The Ku-Band frequency, operating at 15 GHz, is widely used in satellite communication; however, previous research has not yielded an optimal small and compact antenna design for this frequency. This research focuses on the development of a rectangular patch microstrip antenna as a receiver for satellite communication, specifically tuned to a 15 GHz working frequency. Microstrip antennas are favored due to their simple design, cost-effectiveness, and capability to operate at high frequencies. In this research, the asymmetric slit method was applied by incorporating slits into the antenna's patch to enhance its performance. Before optimization, the antenna exhibited a return loss of -3.661 dB, which improved to -21.899 dB after optimization, indicating enhanced signal transmission. The Voltage Standing Wave Ratio (VSWR) also decreased from 4.813 to 1.174, indicating better impedance matching. Additionally, optimization results yielded a gain of 4.038 dBi, a bandwidth of 967 MHz, and a directivity of 5.999 dBi. The antenna demonstrated an omnidirectional radiation pattern and circular polarization, which is particularly advantageous for satellite communications, ensuring stable signal reception. These findings indicate that the designed Ku-band microstrip antenna meets the required specifications for satellite signal reception systems and is suitable for practical implementation in satellite communication applications.

Keywords: antenna, Ku-band, microstrip, return loss, satellite, slit, VSWR

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I. INTRODUCTION

The rapid advancement of information technology has significantly increased the demand for efficient and accessible information. As a result, fast and widespread access to information has become crucial in various sectors. Telecommunication services play a key role in providing this access, 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].

Satellites are communication devices deployed in outer space that act as microwave signal repeaters, enabling users to exchange information through telecommunication networks when connected to ground stations [2]. Operating on frequencies above 100 MHz, satellites utilize frequency bands categorized into very high frequency (VHF), ultrahigh frequency (UHF), and super high frequency (SHF) ranges. The SHF range is further divided into sub-bands, including the L band (1-2 GHz), S band (2-4 GHz), C band (4-8 GHz), X band (8-12 GHz), Ku band (12-18 GHz), and Ka band (26.5-40 GHz) [3]. Among these, the Ku-band frequencies are particularly important, with the lower band (12-14 GHz) primarily used for uplink signals and the upper band (14-18 GHz) designated for downlink transmissions. This segmentation facilitates efficient allocation and utilization of satellite frequencies for various telecommunication applications [3].

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 [4]. Among the available frequency bands, the Ku-band is highly recommended due to its advantages, such as a wider bandwidth, reduced susceptibility to terrestrial interference, and smaller antenna sizes [5]. 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 [6].

The process of receiving signals from satellites requires an antenna to capture and transfer radio waves, utilizing the principle of electromagnetic waves. 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 [7][8]. Microstrip antennas consist of several key components, including a groundplane, typically made of copper, which serves as a reflector [9]. Above the groundplane is a substrate with a dielectric constant (ε_r) that helps reduce the overall size of the antenna. On top of the substrate is a patch, which functions as the radiator and can take various shapes, such as rectangular, square, or circular, depending on the design [10].

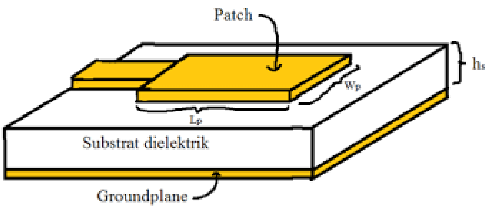

Fig. 1. Rectangular Microstrip Antenna Structure [11]

Figure 1 illustrates the structural description of the rectangular microstrip antenna used in this research. A study is essential to design a microstrip antenna with a rectangular patch shape that operates efficiently for satellite communications at Ku-band frequencies [12]. The microstrip antenna was selected due to its relatively simple design, offering the advantages of being small, lightweight, and capable of functioning at very high frequencies. Additionally, microstrip antennas are easy to manufacture, with precise control over resonant frequency, input impedance, polarization, and radiation pattern. The rectangular patch shape was chosen because it is straightforward to analyze and provides accurate performance when using thin substrates [13].

II. Research Method

This research focuses on the design of a rectangular patch microstrip antenna that operates within the Ku-Band frequency range (12-18 GHz), with a resonant frequency (working frequency) of 15 GHz. This design is intended to serve as a receiving antenna for satellite communications, as 15 GHz falls within the downlink frequency range of the Ku-Band. In satellite communication systems, circular polarization is highly recommended for antenna design, as it allows the electric and magnetic fields of the wave to rotate in a circular motion at the signal frequency, creating a spiral pattern as the wave propagates. Circular polarization helps reduce sensitivity to antenna orientation, providing a more reliable signal reception. The key advantage of circular polarization is that it causes reflected signals to change their polarization direction, preventing the typical interference caused by the combination of direct and reflected signals, thereby minimizing fading and flutter during transmission.

Prior to designing the antenna, it is essential to first define the desired specifications. These specifications are outlined in Table I.

Table I. ANTENNA PARAMETERS TO BE ACHIEVED

Parameter	Description
Working frequency	15 GHz
Input impedance	50 Ω
VSWR	1 - 2
Return loss	≤ -10 dB
Radiation pattern	Omnidirectional
Polarization	Circular

The next step involves calculating the dimensions of the antenna, including the groundplane, substrate, patch, and feedline. These calculations are crucial to ensure the antenna operates efficiently within the desired frequency range [14].

a. Patch length (Lp)

$$L_P = L_{eff} - \Delta L \tag{1}$$

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

$$\Delta L = 0.412\, h \frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W_p}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W_p}{h} + 0.8\right)} \tag{3}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\frac{1}{\sqrt{1 + \frac{12h}{W_p}}}\right] \tag{4}$$

b. Patch width (Wp)

$$W_p = \frac{c}{2f_r\sqrt{\frac{2}{\varepsilon_r + 1}}} \tag{5}$$

c. Groundplane length (Lg)

$$Lg = 6h + L_p \tag{6}$$

d. Groundplane width (Wg)

$$Wg = 6h + W_P \tag{7}$$

e. Feedline

$$L_f = W_f = \frac{6h}{2} \tag{8}$$

Description:

L_P = *Patch* length
W_P = *Patch* width
ΔL = Length difference between L_P and $Leff$
$Leff$ = Effective *patch* length
c = Speed of light ($3 \, x \, 10^8 \, m/s$)
$\varepsilon reff$ = Relative dielectric constant
ε_r = Dielectric constant of the substrate
f_r = Resonant frequency (working frequency)
h = Thickness of *substarte*
L_g = *Groundplane* length
W_g = *Groundplane* width
L_f = *Feedline* length
W_f = *Feedline* width

Based on the calculations performed using the formulas provided, the dimensions of the microstrip antenna have been determined. The obtained specifications for the antenna are as follows:

Table II. KU-BAND PATCH RECTANGULAR MICROSTRIP ANTENNA DIMENSIONS

Parameter	Value
Groundplane and patch material	Copper annealed
$L_g = L_s$	13.605 mm
$W_g = W_s$	15.743 mm
Groundplane thickness (h_g)	0.035 mm
Substrate material	FR-4 lossy
ε_r	4.3
L_P	2.636 mm
W_P	6.143 mm
Groundplane and *patch thickness* ($h_g = h_p$)	0.035 mm
L_f	5.4845 mm
W_f	4.8 mm

If the antenna parameters do not meet the desired specifications, optimization can be performed using the slit method. The slit method is a technique used to reduce the physical size of microstrip antennas, also known as miniaturization, by introducing slits on the edges of the antenna patch, either horizontally or vertically, without cutting other parts of the antenna [15]. These slits are made from the outer edge into the inner portion of the antenna patch. Besides minimizing the antenna's size, this method also helps in improving the bandwidth of the antenna. The stages of this research can be seen in figure 2.

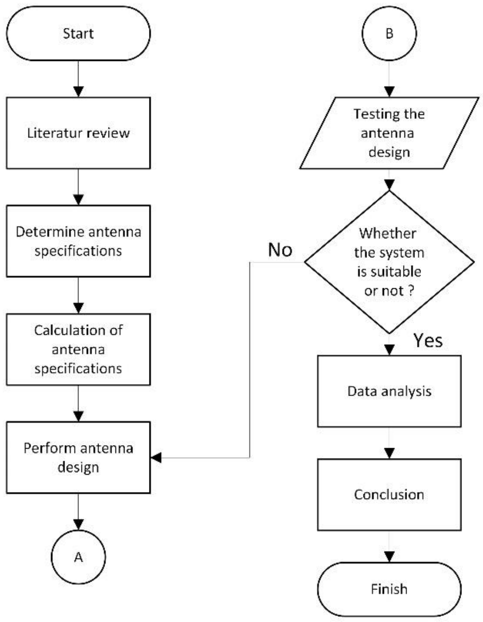

Fig 2. Rectangular Ku-Band *Patch* Microstrip Antenna Design Scheme

Figure 2 illustrates key components and structural layout of the proposed microstrip antenna. As shown in the diagram, the antenna consists of a rectangular patch positioned above a ground plane, with a dielectric substrate in between. The dimensions of the patch are carefully calculated to ensure the antenna resonates at the desired frequency within the Ku-Band range (12-18 GHz). A slit is incorporated into the patch design to optimize the antenna's performance by enhancing bandwidth and minimizing the physical size, thereby enabling efficient operation at high frequencies. The feed line connects to the patch, providing the necessary power for signal transmission and reception, while ensuring that the antenna maintains a compact and lightweight structure suitable for satellite communication applications.

III. Results and Discussion

This section presents the outcomes of the microstrip 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. The discussion focuses on how the antenna's performance aligns with the specifications required for Ku-band satellite communication applications. Additionally, the impact of the slit method on antenna miniaturization, bandwidth, and impedance matching is examined. The findings are compared with the theoretical expectations, providing insights into the effectiveness of the proposed design approach.

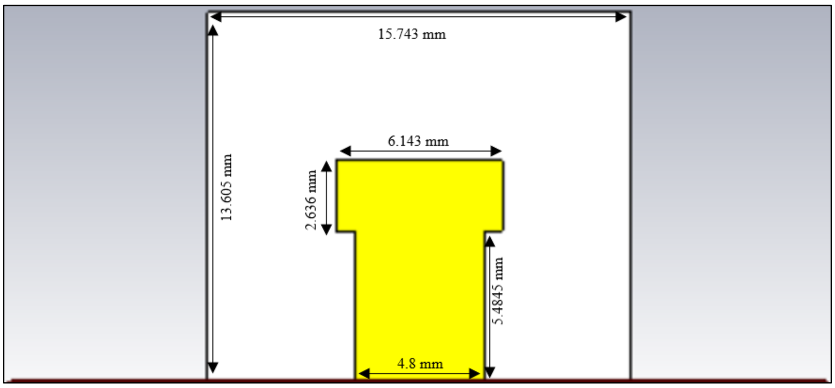

Fig. 3. Antenna Design Before Optimization

Figure 3 illustrates antenna design results without utilizing the slit method, where groundplane and substrate dimensions are 13.605 x 15.743 x 0.035 mm, patch dimensions are 2.636 x 6.143 x 0.035 mm, and feedline measures 5.4845 x 4.8 mm. The simulation results indicate that the antenna's performance parameters, including return loss and VSWR, do not meet the desired specifications. Furthermore, the expected working frequency is not achieved in this initial design. This discrepancy highlights the need for optimization to improve the antenna's performance and align it with the required operational parameters. Consequently, the slit method will be applied in the subsequent stages to refine the antenna design.

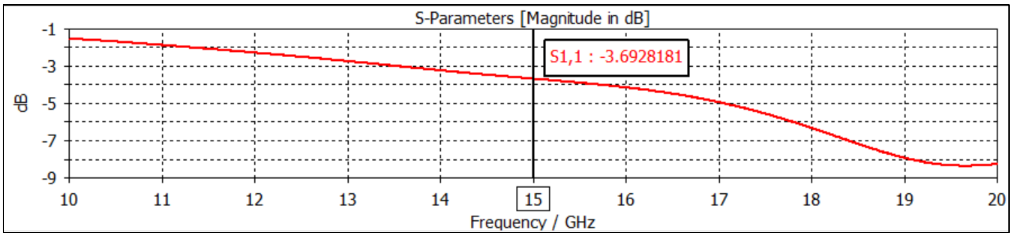

Fig. 4. *Return loss* S-Parameter (S-11) of Antenna Before Optimization

Figure 4 shows that the return loss value at expected working frequency of 15 GHz is only -3.692 dB. This value is significantly higher than desired minimum return loss value of -10 dB, indicating sub-optimal antenna performance. A higher return loss means that a considerable portion of the signal is reflected back to the source, resulting in inefficient signal transmission. Therefore, antenna's impedance matching needs to be improved to minimize signal reflection and ensure better signal reception. This emphasizes the necessity for further optimization to meet the required performance standards.

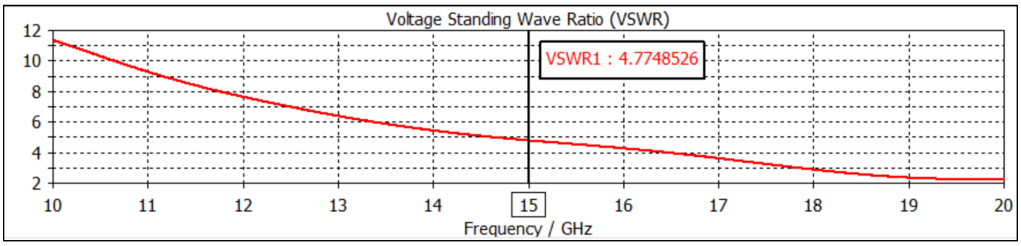

Fig. 5. VSWR S-Parameter (S-11) Antenna Before Optimization

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. In Figure 5, it is observed that at the target frequency of 15 GHz, the VSWR value is 4.774, which is significantly higher than the ideal range of 1 to 2. This elevated value indicates poor impedance matching between the antenna and the transmitter, suggesting that the antenna is not operating efficiently. As a result, it is necessary to optimize the antenna design to improve performance and reduce the power lost due to reflections. The high VSWR value also highlights the need for further adjustments to achieve the desired antenna characteristics.

To address these issues, the antenna design is optimized using the slit method. As shown in Figure 6, the slit method involves making precise cuts on the antenna patch, which helps to modify its dimensions and improve its performance. The dimensions of the patch directly affect the resonant frequency of the antenna, and any inaccuracies in these dimensions can lead to deviations from the target frequency, causing impedance mismatch. This mismatch results in higher return loss and VSWR values, as seen in the initial design. By carefully adjusting the patch dimensions through optimization, the antenna can achieve better impedance matching, leading to improved return loss and VSWR values.

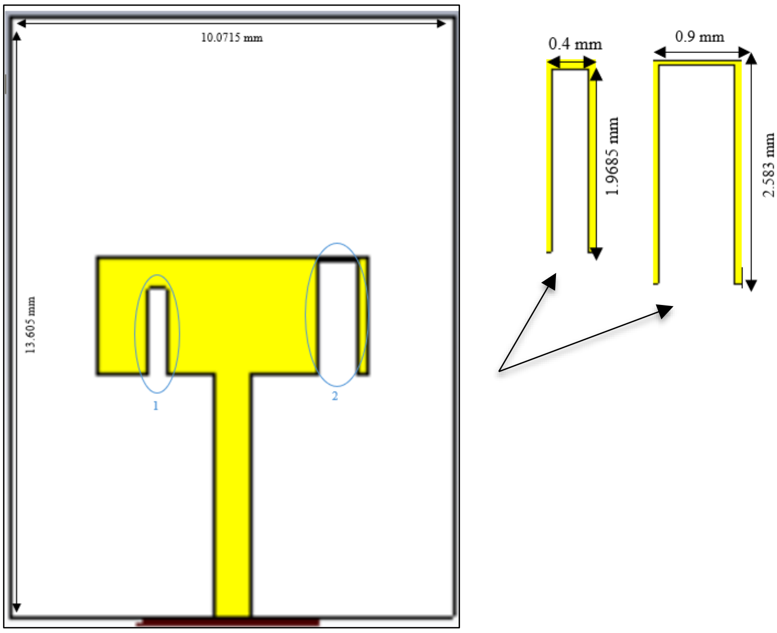

Fig. 6. Antenna Design After Optimization

Figure 6 presents the outcomes of the antenna design following the optimization process. The optimization was carried out by reducing the dimensions of the groundplane and substrate, from an initial width of 15.743 mm to a more compact 10.0715 mm. In addition, the feedline width was narrowed to 0.8 mm to further improve the antenna’s efficiency and performance. These changes were made to better align the antenna's design with the desired specifications and improve its overall functionality. The adjustments to the groundplane, substrate, and feedline contributed to a more optimized structure that allows for more effective signal transmission.

The primary factor that significantly impacted parameter results was the application of an asymmetric slit method. In this method, the patch was modified by making asymmetrical cuts on both the left and right sides of feedline, as detailed in Table 3. The dimensions of these slits are crucial in fine-tuning the antenna's characteristics. Slit 1, located on the left side, measures 0.4 x 1.9685 mm, while slit 2 on the right side is larger, with dimensions of 0.9 x 2.583 mm. These slits help improve the antenna's performance, particularly in terms of resonant frequency, impedance matching, and bandwidth.

Table III. DIMENSION OF SLIT ON PATCH

Parameter	Nilai
Xmin slit 1	-1.9 mm
Xmax slit 1	-1.5 mm
Ymin slit 1	-1.3185 mm
Ymax slit 1	1.265 mm
Zmin slit 1	1.635 mm
Zmax slit 1	1.67 mm
Xmin slit 2	1.9 mm
Xmax slit 2	2.8 mm
Ymin slit 2	-1.318 mm
Ymax slit 2	0.65 mm
Zmin slit 2	1.635 mm
Zmax slit 2	1.67 mm

Slit 1 is defined by its width, measured from Xmin slit 1 to Xmax slit 1, its length from Ymin slit 1 to Ymax slit 1, and its thickness from Zmin slit 1 to Zmax slit 1. Similarly, slit 2 follows same measurement principles for its width, length, and thickness, defined by the respective X, Y, and Z coordinates. After determining these dimensions, both slits are cut into the patch using a substrate boolean feature. This technique allows for precise control over the slit's placement and dimensions, ensuring they are aligned with the design specifications. The use of the substrate boolean feature effectively integrates the slits into the patch structure, optimizing the antenna's performance.

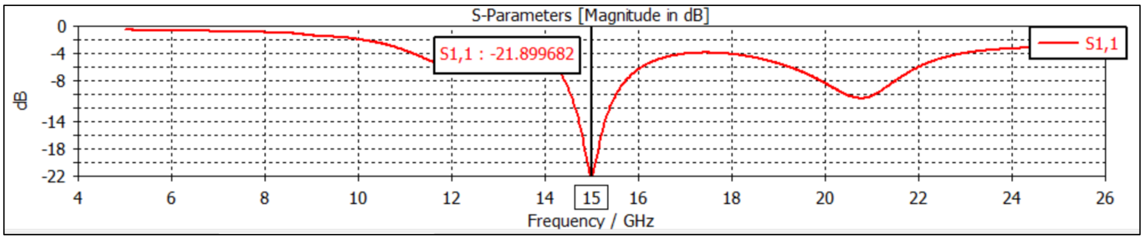

Fig. 7. *Return Loss* S-Parameter (S-11) Antenna After Optimization

Based on updated design dimensions, the simulation results fig.7 show that antenna operates at desired frequency of 15 GHz. At this frequency, the antenna achieves a return loss of -21.899 dB, which is significantly lower than the previous value, indicating a substantial improvement in signal reception. A return loss value of -21.899 dB implies that most of the transmitted signal power is effectively captured by the antenna, with minimal reflection back to the source. This indicates a well-matched impedance between the antenna and the transmission line, reducing signal losses and improving efficiency of the communication system. The optimized antenna design thus demonstrates a high level of performance at the target frequency. These results suggest that the antenna is now well-suited for satellite communication applications, ensuring stable and reliable signal reception.

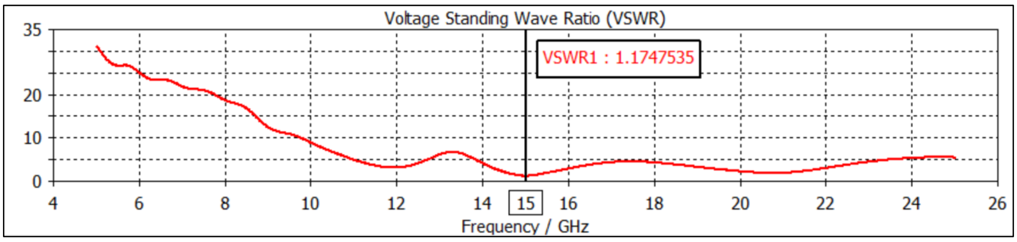

Fig. 8. VSWR S-Parameter (S-11) Antenna After Optimization

Return loss is closely related to the Voltage Standing Wave Ratio (VSWR), which indicates efficiency of signal transmission and reflection in the antenna system. In this research, Figure 8 describe optimized antenna design results in a VSWR value of 1.174, which is close to ideal value of 1.0, suggesting an excellent match between antenna and transmission line. A VSWR value near 1.0 indicates minimal signal reflection, meaning that most of transmitted power is effectively radiated by antenna. This further confirms improvement in the antenna's performance after optimization. As a result, the antenna is expected to provide stable and efficient communication at target frequency.

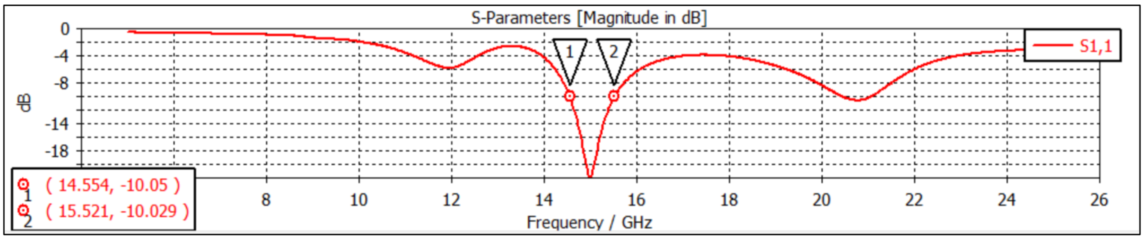

Fig. 9. Bandwidth S-Parameter (S-11) Antenna After Optimization

The bandwidth of the optimized antenna is measured to be 967 MHz, which is calculated by determining frequency range between two curve points, 14.554 GHz and 15.521 GHz, as shown in Figure 9. These points correspond to frequencies where return loss reaches approximately -10 dB, indicating effective operational range of antenna. The calculated bandwidth is significant as it demonstrates antenna's ability to operate efficiently over a wide frequency range within the Ku-band. A larger bandwidth suggests that the antenna can handle a broader spectrum of signals, making it suitable for various satellite communication applications. This enhanced bandwidth further contributes to the overall performance of the antenna in terms of signal reception and stability.

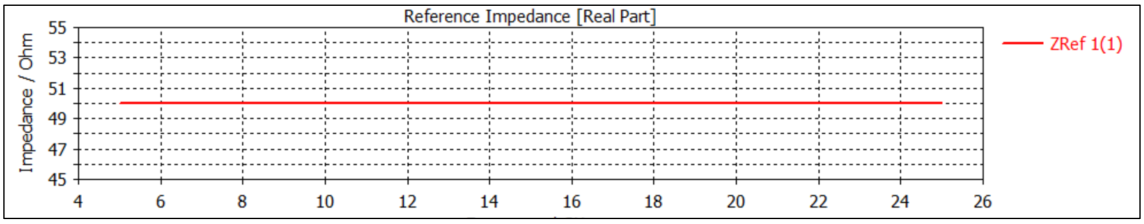

Fig. 10. Reference Impedance Antenna After Optimization

Other parameters, such as reference impedance, remain constant at 50 Ω, as depicted in Figure 10, ensuring optimal impedance matching. This matching is crucial for minimizing signal reflection and maximizing the transmitted power, allowing the antenna to operate efficiently. By maintaining a consistent 50 Ω impedance, the antenna ensures that most of power is transferred from transmitter to antenna without significant loss. Proper impedance matching also reduces the potential for signal degradation, leading to more reliable communication performance. As a result, the antenna achieves improved efficiency in satellite communication systems.

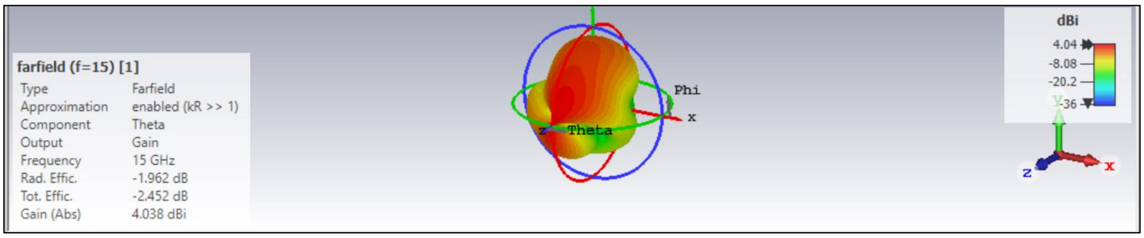

Fig. 11. Gain Antenna After Optimization

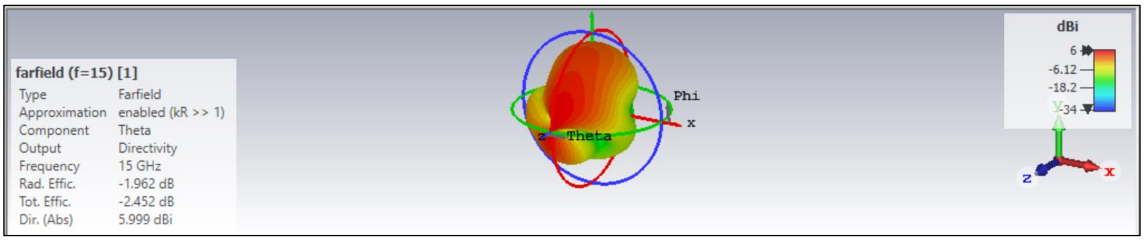

Fig. 12. Directivity Antenna After Optimization

This antenna design exhibits high gain and directivity, with values of 4.038 dBi and 5.999 dBi, respectively, as shown in Figures 11 and 12. 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. Furthermore, the antenna demonstrates desired omnidirectional radiation pattern, as depicted in Figure 13, with a main lobe of 3.33 dBi. 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.

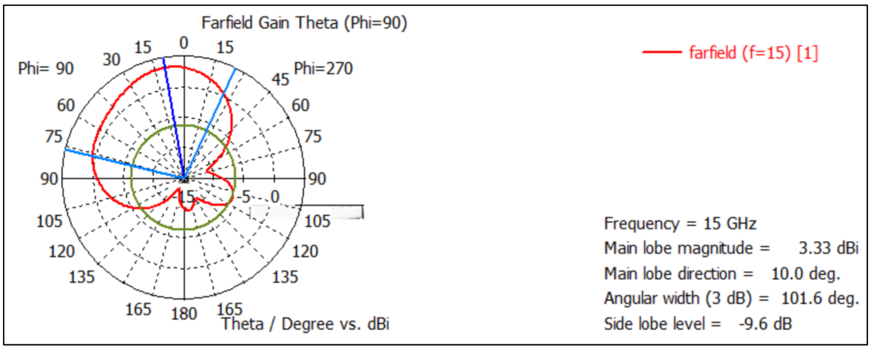

Fig. 13. Antenna Radiation Pattern After Optimization

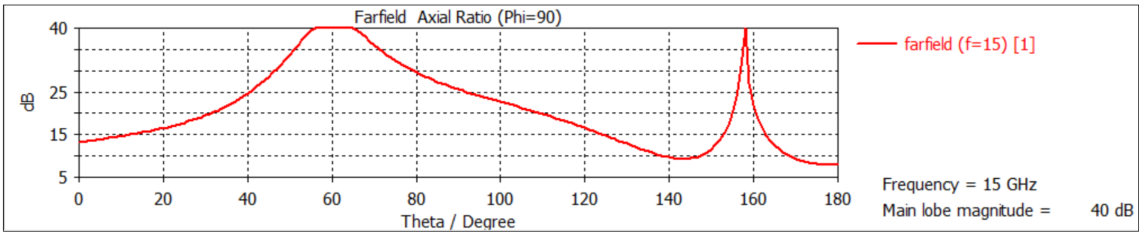

Fig. 14. Polarization After Optimization

The polarization of antenna is circular, as depicted in Figure 14, which aligns with the expected polarization type for satellite communications. Circular polarization is highly suitable for satellite communication systems because it mitigates the adverse effects of ionospheric disturbances and reduces multipath interference. This type of polarization ensures that the transmitted signal remains consistent regardless of the antenna's orientation, making it easier to maintain reliable communication. Additionally, circular polarization enables more efficient signal reception, even under challenging environmental conditions. Consequently, using of circular polarization enhances the overall performance and reliability of satellite communication systems.

Table IV. COMPARISON OF SIMULATION RESULTS OF ANTENNA WITHOUT ASYMMETRIC SLIT AND ANTENNA WITH ASYMMETRIC SLIT

Parameters	Before Optimization	After Optimization
Return loss	-3.661 dB	-21.899 dB
VSWR	4.813	1.174
Gain	-	4.038 dBi
Bandwith	-	967 MHz
Directivity	-	5.999 dBi
Radiation pattern	-	Omnidirectional
Polarization	-	Circular

The table IV presents a comparison of antenna parameters before and after optimization. After optimization, the return loss significantly improved from -3.661 dB to -21.899 dB, indicating a reduction in signal reflection and enhanced antenna performance. The VSWR also decreased from 4.813 to 1.174, aligning the antenna closer to the ideal impedance matching range, thus improving signal transmission efficiency. In addition, the optimized design achieved a gain of 4.038 dBi and directivity of 5.999 dBi, providing better signal strength and directionality. Furthermore, the antenna's bandwidth was increased to 967 MHz, and it exhibited an omnidirectional radiation pattern with circular polarization, which is well-suited for satellite communications.

IV. CONCLUSION

The design of the Ku-band microstrip antenna with a rectangular patch for satellite communication has a targeted working frequency of 15 GHz. Prior to optimization, the return loss was -3.661 dB, but after applying the asymmetric slit method, it improved to -21.899 dB. The VSWR, initially at 4.813, was reduced to 1.174 after optimization, approaching the ideal value of 1.0. Furthermore, the optimized design achieved a gain of 4.038 dBi, a bandwidth of 967 MHz, directivity of 5.999 dBi, an omnidirectional radiation pattern, and circular polarization. Although the antenna has been fabricated, direct data collection in the field was not possible due to the limitations of available tools, particularly given the antenna's small size and high operating frequency.

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