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Centre Extended Rectangular Microstrip Patch Antenna for Satellite Applications

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Abstract: The advancement of wireless communication systems has resulted in the evolution of fifth-generation (5G) communication systems, which utilize mm-wave bands to achieve high data rates. 5G communication systems require antennas with high gain, low profile, lightweight, and very simple structures to ensure reliability, ease of fabrication, low cost, and high efficiency. This paper proposes the design of a single-element rectangular microstrip patch antenna that operates in the C-band at 7.1 GHz and the X-band at 9.2 GHz. The proposed antenna is simulated using Advanced Design System (ADS) software. To meet the requirements of the proposed antenna, such as high efficiency and gain, the patch is slightly modified with a mm extension of length at the center, and the performance of the antenna is studied in terms of antenna parameters such as return loss, VSWR, gain, and radiation pattern.

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1. Introduction

In the space industry, small satellites are one of the fastest-growing sectors (<500Kg)[5]. Due to miniaturization, CubeSats are increasingly prevalent in worldwide space industries, offering advantages such as low cost, fast development, flexibility, and low mass. These CubeSats require miniature antennas with optimum performance [6], including spherical coverage, low loss, high reliability, and a compact size. Antennas with high gain must accurately point their beams to achieve high-speed ground station communication [7]. Smallsats operate at different frequency bands, including very high frequency (VHF), UHF, S, X, Ku, and Ka band. Monopoles, microstrip patches, helices, and turnstile antennas are some of the antennas used for smallsats. Microstrip patch antennas are mostly preferred for nanosats and CubeSats due to their advantages such as low profile, lightweight, low cost, robustness, shape flexibility, and ease of integration with satellite structure. A microstrip antenna consists of a radiating patch on top of the dielectric substrate and a ground plane on the bottom. Honeycomb, Duroid, Quartz, Alumina, and Epoxy/glass (FR4) are the most commonly used substrates. When comparing various substrates [15], the FR4 dielectric substrate is preferred for moderate gain and broader bandwidth, while RT Duroid is preferred for moderate bandwidth and high gain [12]. It is referred to as a planar antenna because it is usually flat. Microstrip patch antennas are well-suited for applications such as cell devices, WLAN, navigation systems, and others [8].

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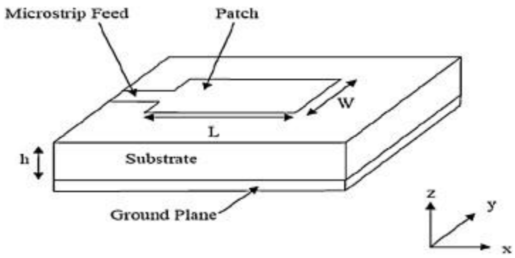


Figure-1 Microstrip Patch Antenna [Ahmed.et.al.2013]

Different feeding techniques are used to feed microstrip patch antennas, classified as contacting and non-contacting feed techniques. Contacting feed techniques include microstrip line feed and coaxial probe feed **[9, 10, 12, 15]**. Non-contacting feed techniques include aperture-coupled feed and proximity-coupled feed **[10, 11, 13]**. The selection of feeding technique and feed location influences bandwidth, return loss, VSWR, patch size, and Smith chart characteristics **[9]**. The correct selection of the feed location decreases the input impedance for the patch antenna and improves return loss, gain, efficiency, and directivity **[14]**. The center coaxial probe feeding technique is used for the proposed antenna. In this paper, an X-band antenna operating at 9 GHz is designed and simulated using Advanced Design System. The antenna parameters such as return loss, gain, VSWR, and bandwidth of the simulated and tested results are comparatively analyzed.

2. Antenna Design Procedure

The dimensions of the antennas, such as the length, width, and height of the patch, control the antenna properties. The length of the patch (L) determines the resonant frequency and affects the return loss. The width of the patch (W) influences the input impedance and radiation pattern. The relative permittivity (ϵr) of the dielectric substrate affects the fringing fields of the microstrip patch antenna. The following equations are used to determine the parameters of the microstrip patch antenna **[11]**.

- The width (W) of the patch is calculated using equation (1):

$$W = \frac{c}{2f0\sqrt{\frac{2r+1}{2}}} \quad (1)$$

where, c = velocity of light, ϵr- dielectric constant of the dielectric substrate, f0 = desired resonant frequency

- Effective Dielectric Constant (2reff) is calculated using the equation (2)

$$2reff = \left(\frac{2r+1}{2}\right) + \left(\left(\frac{2r-1}{2}\right)\left(1 + \frac{12h}{w}\right) - \frac{1}{2}\right) \quad (2)$$

where, h = height (thickness) of the dielectric substrate, ϵr = dielectric constant of the dielectric substrate, W = patch width

- Effective Length of Patch (Leff) is calculated using the equation(3)

$$Leff = \frac{c}{2f0\sqrt{\epsilon r}} \quad (3)$$

where, c = velocity of the light, f0 = desired resonant frequency, ϵreff = effective dielectric constant.

- Length Extension of Patch (ΔL) is calculated with equation (4)

$$\Delta L = \frac{0.412h\left((\epsilon reff+0.3)\left(\frac{w}{h}+0.264\right)\right)}{(\epsilon reff-0.258)(w/h+0.8)} \quad (4)$$

where, h = height (thickness) of the dielectric substrate, W = patch width, $\epsilon reff$ = effective dielectric constant.

- Real Length of Patch (L) is calculated using the equation(5)

$$L = Leff - 2\Delta L \quad (5)$$

where, Leff = effective length of patch, ΔL = length extension of patch

- Ground Dimension (Wg, Lg): The width and length dimension of ground plane is calculated by the equation (6) given below respectively.

$$Wg = 6h + W, Lg = 6h + L \quad (6)$$

where, h = height (thickness) of dielectric substrate, W = patch width, L = real length of patch.

3. Proposed Scientific Methodology

The proposed antenna is designed and simulated using Advanced Design System (ADS Version 2011). The simulated antenna operates at C and X bands. The overall size of the proposed antenna is 38 mm x 26 mm, utilizing a copper patch and FR4 substrate in the design. The structure of the proposed patch antenna is depicted in Figure-2. The length (Lg) and width (Wg) of the ground plane are 38 mm and 26 mm, respectively, while the length (L) and width (W) of the patch are 21 mm and 15 mm, respectively. A coaxial probe is used to feed the proposed patch antenna, with the feed point located at the center of the patch as shown in Figure-2.

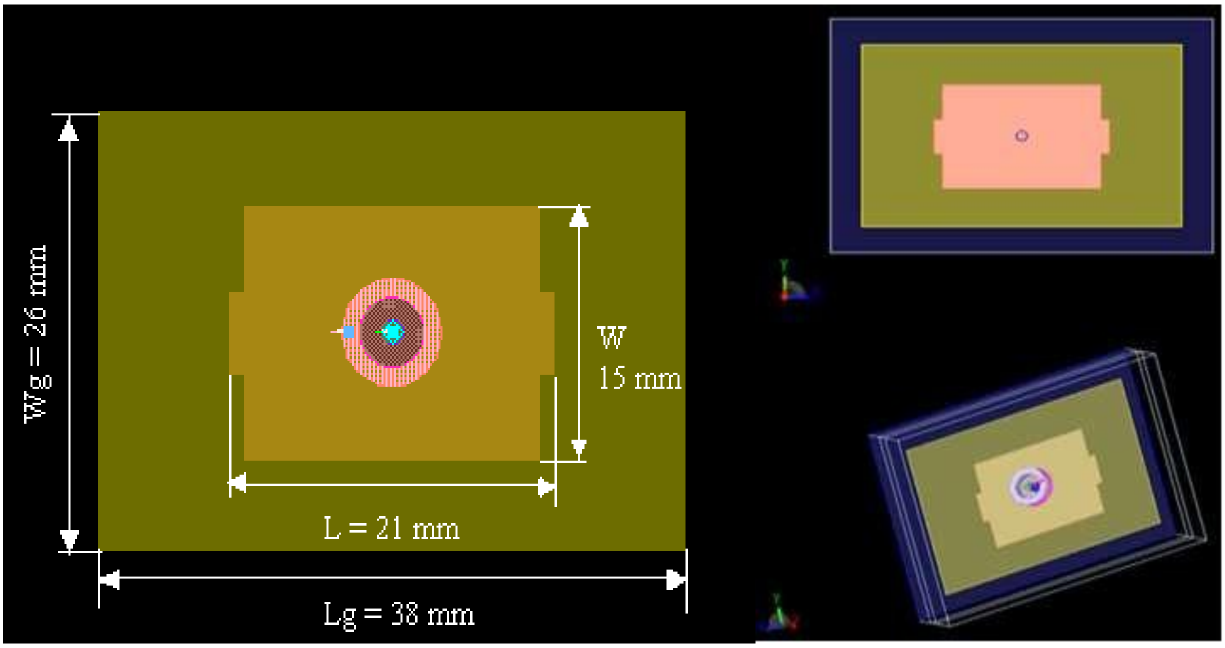


Figure-2(left) Structure and Dimensions of Proposed Patch Antenna.
Figure-3 (right) 3D Top view and Bottom view of the proposed antenna.

4. Results and Discussion

4.1. Return Loss

Return loss quantifies the amount of power reflected back to the transmitter or the power loss resulting from the discontinuity of the transmission line. A higher return loss value indicates that less power is reflected from the load, signifying better impedance matching and reduced signal loss.

$$RL = -20log|\Gamma|(dB) \quad (7)$$

where Γ = reflection coefficient.The value of the return loss is the absolute value of the reflection coefficient. Return loss of the antenna should be < -10 dB.

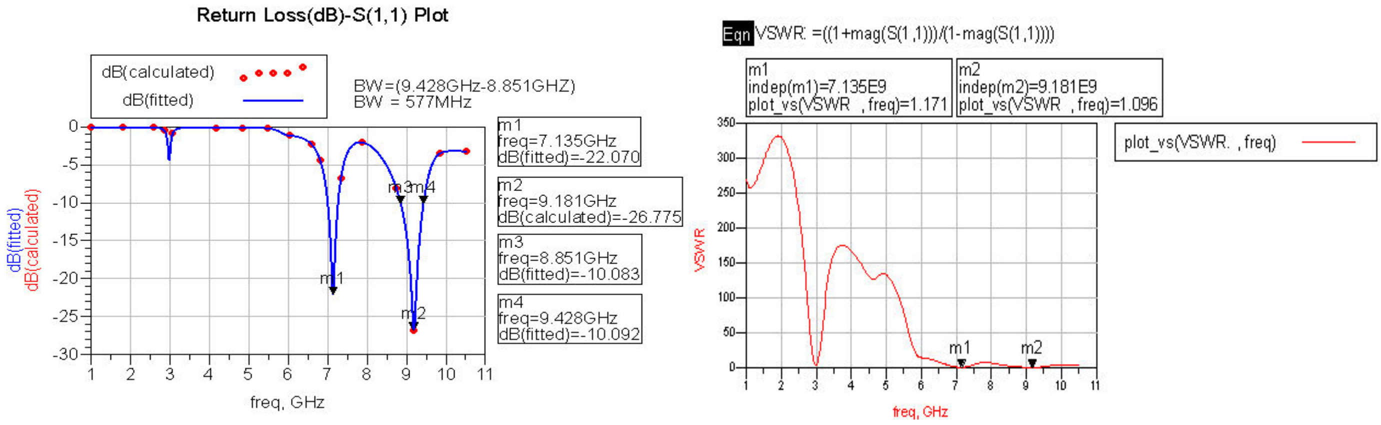


Figure-4 S11 plot (left) and VSWR plot (right) of the proposed rectangular patch antenna.

Figure-4 (left) displays the reflection coefficient of the proposed antenna. The antenna exhibits resonance at 7.1 GHz and 9.2 GHz. At 7.1 GHz, the return loss of the patch antenna is -22.070 dB, and at 9.2 GHz, it is -26.775 dB. The return loss of the proposed antenna remains below -10 dB, indicating effective impedance matching and minimal power reflection.

4.2. VSWR

The Voltage Standing Wave Ratio (VSWR) quantifies the degree of mismatch between an antenna and the feed line connecting to it. VSWR values range from 1 to infinity. A higher VSWR value indicates a greater mismatch between the antenna and the feed line, which results in increased reflections and reduced efficiency of the antenna system.

$$VSWR = (1 + |\Gamma|)/(1 - |\Gamma|) \quad (8)$$

where, Γ = reflection coefficient.

Figure-4 (right) depicts the VSWR plot of the patch antenna. At resonance frequencies of 7.1 GHz and 9.2 GHz, the VSWR values are 1.171 and 1.096, respectively. These values are below 2, indicating good impedance matching between the antenna and the feed line.

4.3. Gain

Antenna gain describes the ability of an antenna to concentrate energy in a specific direction for improved radiation performance. It is typically expressed in decibels (dB). Antenna gain is expected to be greater than 6 dBi for effective performance. The relationship between gain, directivity, and efficiency is illustrated in equation (9).

$$G = \eta D(dB) \quad (9)$$

where, η=Efficiency of the antenna, D – Directivity.

Directivity of an antenna can be defined as the ratio of radiation intensity in a given direction from the antenna to the radiation intensity averaged in all the directions.

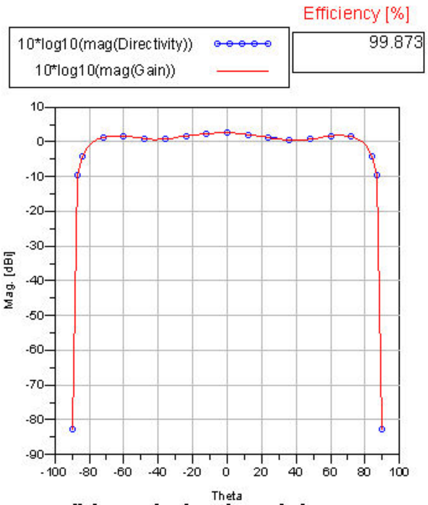


Figure-5 Plot of Directivity(dB) and Gain(dB).Vs Theta of the proposed Antenna operating at 9.2 GHz

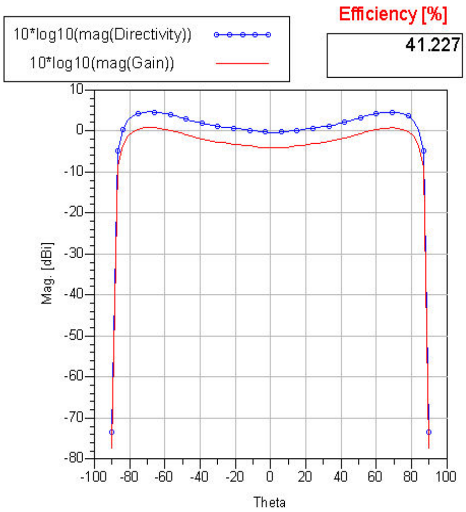


Figure-6 Plot of Directivity(dB) and Gain(dB).Vs Theta of the proposed Antenna operating at 7.1 GHz

The figures above (Fig. 5 and 6) illustrate that the proposed antenna achieves high efficiency, reaching 99.873% when operating at 9.2 GHz. However, the efficiency of the antenna is lower when operating at 7.1 GHz.

4.4. Bandwidth

The frequency range over which the VSWR is less than 2 or the return loss is less than -10 dB is defined as the bandwidth. In certain applications, the VSWR requirement is stricter, typically less than 1.5. The relationship between bandwidth and VSWR is depicted in equation (10).

$$BW = VSWR - 1/Q\sqrt{V}\ \overline{SWR}(Hz) \qquad (10)$$

where, VSWR-voltage Standing Wave Ratio. From Fig 4, the bandwidth of the proposed antenna operating at 7.1 GHz is 270MHz, 9.2 GHz is 577MHz.

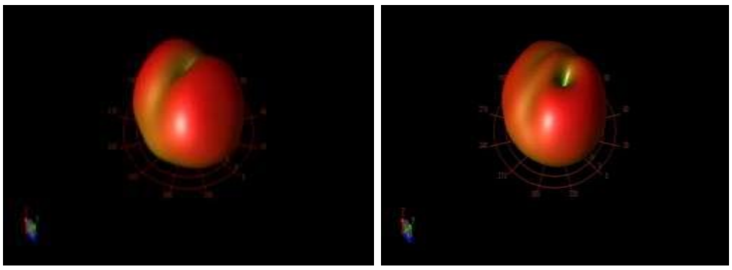
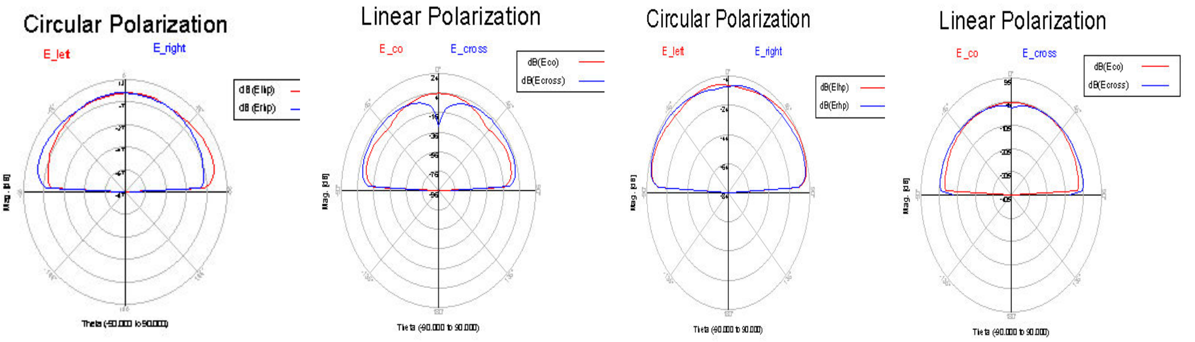


Figure-7 3D Radiation Pattern for 7.1 GHz (left), and 9.2 GHz (right)



(a) (b) (c) (d)

Figure-8 (a-b) Polar plots of circular polarization and linear polarization at (phi=90˚) of a proposed antenna operating at 7.1 GHz || (c-d) Polar plots of circular polarization and linear polarization at phi=90˚ of a proposed antenna operating at 9.2 GHz

Figure-8 (a-d) depicts linear polarization, including co-polarization (E_co) and cross-polarization (E_cross), as well as circular polarization, which comprises Left-hand circular polarization (E_left) and Right-hand Circular polarization (E_right), of the proposed antenna in the C band (7.1 GHz) and X band (9.2 GHz) at an angle of phi=90˚.

Table-1 Comparison of Antenna Parameters of the Proposed Antenna at 7.1 GHz with 9.2 GHz

Parameter	**C band**	**X band**
Resonating Frequency	7.1GHz	9.2GHz
Return Loss	-22.070dB	-26.775 dB
VSWR	1.17	1.096
Gain	2.99 dB	7.131 dB
Directivity	6.839 dB	7.136 dB
Bandwidth	270MHz	577 MHz
Efficiency	99.87%	41.22%

Table-1 presents the values of parameters for the proposed rectangular microstrip patch antenna when operated at two different frequency bands. These parameters significantly influence the application and performance of the proposed antenna.

Table-2 Comparison of the proposed antenna operating at 9.2 GHz with reference antennas operating at the same frequency.

	Gain(dB)	**Return Loss (dB)**	**VSWR**	**Bandwidth**
[1]	6.866	-31.237	1.1	-
[2]	6.13	-17.30	1.32	195MHZ
[3]	5.582	-20.65	1.2	350MHz
Proposed	7.131	-26.775	1.096	577 MHz

Table-2 illustrates that the proposed antenna exhibits higher gain, broader bandwidth, and lower VSWR (approximately 1.1) compared to other reference antennas operating at 9.2 GHz. Additionally, the return loss of the proposed antenna is lower than **[2,3]** but higher than **[1]**.

5. Conclusion

The Compact Extended Rectangular Microstrip Patch Antenna, designed using ADS2011 Software, offers excellent radiation characteristics such as bandwidth, gain, directivity, return loss, and VSWR. With a return loss of <-10 dB and a VSWR of < 2, the antenna operates effectively in dual-frequency bands (C band and X band), making it suitable for various antenna applications. Specifically, for smallsats requiring compact, high-gain, and highly efficient antennas operating in the X band for satellite-to-earth station communication, the proposed antenna provides a gain of approximately 7.131 dB and a directivity of about 7.136 dB at 9.2 GHz. Achieving a radiation efficiency of about 99.87% in the X band, the proposed antenna, with dimensions of 38 mm x 25 mm x 16 mm, proves suitable for effective satellite-to-ground station communication. Future work may involve fabricating and testing the antenna using a vector network analyzer. Additionally, further enhancements could focus on improving bandwidth, compactness, and performance optimization through the utilization of side lobe suppression techniques in the proposed antennas.

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7. Biography

Ramesh Kumar V: Ramesh Kumar V, an accomplished entrepreneur, serves as the Founder and CEO of Grahaa Space. With a background in electrical engineering and an MBA from Manipal University, he brings a wealth of expertise to his role. Over the course of his illustrious 16-year career, Ramesh has successfully established three startups, two in India and one in Singapore, amassing a combined revenue exceeding half a million dollars. Furthermore, his contributions extend beyond entrepreneurship, as evidenced by his co-authorship of five technical books utilized in distance learning programs at numerous universities.

Loganathan Muthusamy: Dr. Loganathan Muthusamy, an ex-ISRO professional, boasts a rich career spanning all phases of space missions, from ground segment applications to spacecraft mission planning, launch pad systems, space control stations, and payload processing centers. Currently serving as the Director of SRMSat at SRM University and the Director of Space Program at NMIT, Dr. Muthusamy is a seasoned leader contributing significantly to satellite technology and space exploration. His background in the Indian Space Research Organisation (ISRO) adds a valuable dimension to his expertise in advancing space-related initiatives.

8. Conflict of Interest and Funding

The author declare no competing conflict of interest..

9. Funding Information

This project was funded and supported by Akshanth Aerospace Private Limited (Grahaa Space), and completed under the guidance of Lognathan Muthusamy (Ex-ISRO).

10. About Company and Future Work

Grahaa Space is on a mission to provide on-demand, near real-time geospatial videos of any given location on earth, captured and streamed through our advanced constellation of earth observation nano satellites.Our patent-pending technology with edge computing capability enables on-board processing and transmission of the video data on-demand to public and private organizations through our secure AI powered web portal.

Our innovative technology has vast potential across various sectors, including:

1. Forest Monitoring:

Our high-resolution satellite imagery facilitates accurate analyses of land cover and changes, essential for forestry and natural resource management. Consistent monitoring of forest areas enables better decision-making and resource allocation.

2. Mining Industry:

Grahaa Space provides custom analytics to assist field workers and geologists in locating tracks, roads, fences, and populated areas within mining sites. Additionally, we offer periodic reports on geochemical, geophysical, and geological data, aiding in site assessment and exploration.

3. Industry Activity Monitoring:

With real-time satellite images and AI/ML approaches, Grahaa Space offers daily snapshots of industrial activity, allowing stakeholders to monitor operations, identify trends, and make informed decisions regarding factories, power plants, refineries, and manufacturing units.

4. Agriculture & Crop Monitoring:

Our satellite images are instrumental in monitoring agricultural fields, analyzing soil moisture conditions, crop health, vegetation water content, temperatures, and biomass information. This data helps optimize agricultural practices and increase crop yields.

5. Urban Planning & Utility Monitoring:

Grahaa Space assists smart city corporations, city planners, land managers, and government departments in monitoring urban areas and utilities using medium- or high-resolution satellite images combined with LiDAR data. This information is vital for urban planning, infrastructure management, and disaster response.

6. Military & Defense:

High-resolution satellite images provided by Grahaa Space aid military forces in managing battlefields, assessing terrain, and conducting fieldwork. This critical data supports mission planning and decision-making for defense operations.

Moving forward, Grahaa Space envisions expanding its constellation and enhancing its technology to meet the evolving needs of our customers. We are committed to pushing the boundaries of space technology to unlock new possibilities and create a positive impact on Earth. With our dedication to innovation and excellence, Grahaa Space is poised for a promising future as a leader in the space technology industry.

Future Work

We will be using this proposed antenna, as detailed in this paper, will be implemented onboard Nanosatellites to facilitate the streaming of near-real-time live videos from space. This cutting-edge antenna technology will enable us to transmit high-quality video data to our customers across various applications, as discussed earlier.

In the future, we are committed to further exploring and enhancing the capabilities of our antenna system. Our upcoming research will delve into various aspects of the antenna's performance and efficiency, culminating in another paper that will contribute to the ongoing advancement of satellite communication technology. Through continuous innovation and research, we aim to stay at the forefront of the industry and continue providing unparalleled solutions to meet the evolving needs of our customers.