

Research Article

Analysis of S-band Parabolic Antenna Performance for Microsatellite Communication Systems

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Abstract

This report constitutes of, as the title for this paper, Analysis of S-band Parabolic Antenna Performance for Microsatellite Communication Systems. The objective of the paper is to build an intelligent antenna in order to receive with less noise signal transmitted by Microsatellite. It will be a challenging project since the distance of satellite from antenna is quite far with a lot of noise can affect the transmission process. Microsatellite missions enable innovative scientific experiments using a low-cost platform but are limited by their small size and available solar power. This imposes strict power budgets on radio links. Enhancing ground station antenna systems can improve communication margins by increasing forward gain, forward-to-backward ratio, and directivity, ultimately boosting link performance with the satellite. The purpose of this paper was to analyze the performance evaluation of parabolic reflector with horn feed antenna for communication with frequency operating between 2 GHz and 3 GHz Amateur S-band. Parabolic antennas serve as effective high-gain solutions for microsatellite communication. The far-field radiation pattern produced by a parabolic reflector is influenced by the feed element's radiation pattern and the specific type and dimensions of the reflector employed. In this study, the antenna system is designed and simulated in the CST Microwave Studio to achieve specific requirements which are minimum power reflected back to the source and maximum gain with minimum front-to-back ratio, VSWR and radiation pattern for the antenna system.

Keywords

VSWR, Gain, Far-field Radiation Pattern, Return Losses, Parabolic Reflector, Horn Feed

1. Introduction

Parabolic reflector antennas are widely utilized in communication systems, radar and radio astronomy due to their high gain, directivity and ability to focus electromagnetic waves effectively. This antenna was first developed and used in the early 20th century with significant contributions from pioneers in the fields of radio and radar [2, 3]. The fundamental principle behind a parabolic reflector is its geometric shape which ensures that all incoming parallel rays

reflect and converge at the focal point. Conversely, when a source such as a feed horn is placed at the focal point, the reflected waves become collimated into a highly directional beam [5, 7]. The feed horn, typically a waveguide structure is used to illuminate the parabolic reflector uniformly and efficiently. This combination enables excellent performance in terms of gain and sidelobe suppression. The positioning and design of the feed horn are crucial as they significantly affect

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the overall radiation pattern and efficiency of the antenna system [4, 6].

The design of the parabolic antenna for microsatellite applications involving addressing unique constraint such as limited onboard power, space and weight as well as the need for resilience against the harsh condition of space.

The parabolic antenna offers the highest gain typically exceeding 30 dB focusing signals into a narrow beam. This statement describes a key feature of parabolic antennas commonly used in satellite communications due to their high efficiency and directivity. Gain represents the antenna's effectiveness in focusing radio frequency signals toward a designated direction [10, 11].

A high-gain antenna can focus more power in the desired direction (or receive more energy from a specific direction) compared to other types of antennas. A gain of 30 dB means the antenna amplifies the power by 1000 times compared to an isotropic antenna (a theoretical antenna that radiates equally in all directions) [1].

The narrow beam means the antenna focuses the signal into a tight area rather than spreading it widely. This feature reduces interference from other signals and improves the clarity and reliability of the communication link. Ideal for long-distance communication like satellite-to-ground or inter-satellite links where signal strength needs to be maintained over vast distances [8, 9]. Highly directional enabling precise targeting of communication. So, the parabolic antenna's ability to concentrate energy into a narrow beam makes it the go-to choice for high-performance communication systems requiring long-range and high-gain characteristics [12, 13].

In this study investigates the fundamental principles of parabolic antenna design its adaptation for microsatellite platforms and the challenges associated with optimizing performance within the constraints of miniaturized satellite architectures. A focus is placed on key design parameters including reflector size, feed alignment, beam width and frequency selection with an emphasis on enhancing communication reliability and signal clarity in orbital environments.

2. Antenna Design

The antenna design could be developed based on the following steps and analyses.

2.1. Mathematical Analysis

The design of the proposed antenna is shown in Figure 1. The design of the proposed parabolic antenna with focal point was modeled the classical equations.

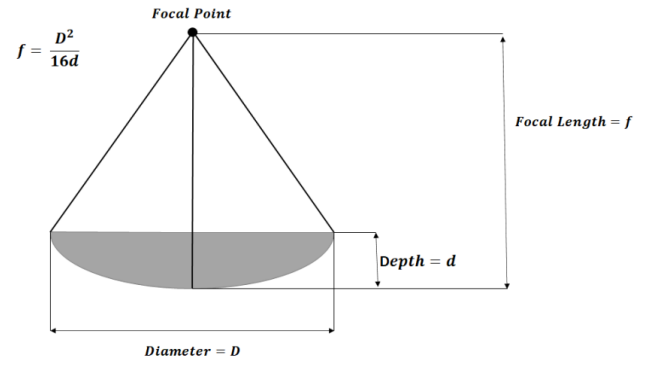


Figure 1. Mathematical Diagram of Parabolic Reflector.

Focal length,

$$f = \frac{f_r}{D} \times D \quad (1)$$

Radius of dish,

$$r = \frac{D}{2} \quad (2)$$

Depth of dish,

$$d = \frac{D^2}{f \times 16} \quad (3)$$

Angle from center to edge of dish,

$$\theta_0 = 2 \times \tan^{-1} \left(\frac{1}{4 \times \frac{f}{D}} \right) \quad (4)$$

Beamwidth,

$$\theta = 2 \times \theta_0 \quad (5)$$

Wavelength of frequency,

$$\lambda = \frac{c}{f_r} \quad (6)$$

$$c = 3 \times 10^8 \text{ m/s (speed of light)}$$

$$f_r = \text{operating frequency}$$

2.2. Proposed Antenna Architecture

Figure 2 shows the structure dimensions of a proposed S

band parabolic reflector antenna with horn feed. All of the specific dimension of the parabolic reflector antenna with horn feed was shown in Table 1. The parabolic antenna resembles with the diameter of 2.8 m and horn antenna for s band selected WR284 Rectangular Waveguide Sizes from International Electrotechnical Commission (IEC). The proposed antenna structure comprises a parabolic reflector and horn feed strategically placed at its focal point to achieve high directivity and gain. The design leverages the reflective properties of a parabolic surface which transforms spherical waveforms resulting in a highly collimated beam. The horn feed illuminates the reflector with a radiation pattern designed to minimize spillover, ensure uniform illumination of the aperture and reduce side lobes and back lobes.

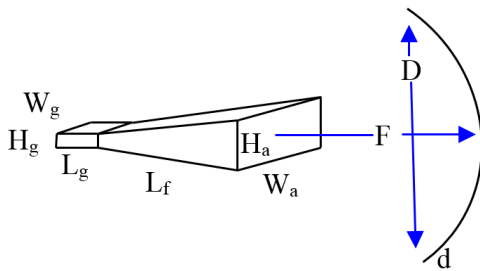


Figure 2. Geometry and Dimensions of Parabolic antenna.

Table 1. Design Parameter Specifications of Parabolic Reflector with horn feed.

Reflector (mm)	Horn (mm), WR284 for S-band
D = 2800 (2.8 m)	Lf = 700
F = 2197	Lg = 30
d = 223	Wg = 97.7
	Hg = 59.5
	Wa = 352.8
	Ha = 261.7

2.3. Rectangular Horn Feeder

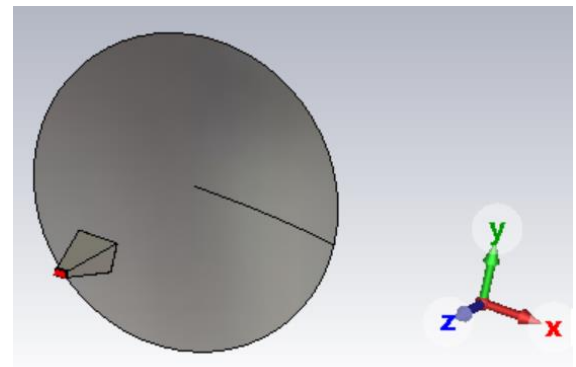
Rectangular horn feeder is particularly advantages for microsatellite applications with ground stations due to their combination of compact design, efficient waveguide coupling and compatibility with parabolic reflector.

Rectangular horn acts as gradual transitions from rectangular waveguide modes (typically TE_{10}) to free-space electromagnetic waves. This minimizes reflections and achieves low voltages standing wave ratio (VSWR) typically below 2: 1.

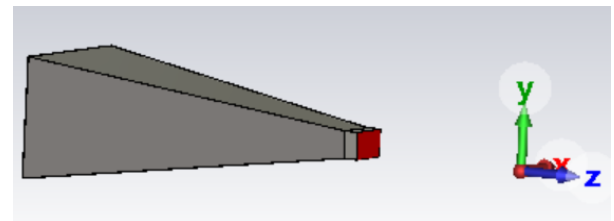
The rectangular horn's combination of wide bandwidth (10:1 ratio), stable radiation patterns and efficient waveguide matching makes it particularly suitable for feed applications

in directive antenna systems. Recent study shows optimized performance in 2.1 GHz band using multimode excitation achieving beamwidth consistency within 0.4° variation. Combined with a parabolic dish, the system achieves 30-40 dB total gain critical for overcoming free-space path loss in satellite-ground link. Rectangular horn provides low sidelobes (-20 dB typical) reducing interference in crowded frequency band. The gradual flare shape minimizes reflections and insertion losses ensuring efficient power transfer between the waveguide and free space.

Waveguide aperture is designed based on WR-284 rectangular waveguide standard, this standard is giving length of horn 730 mm and width and high of waveguide is 97.7 mm and 59.5 mm. The high and width of front-flap of horn is 216.7 mm and 352.8 mm.



a. Parabolic Reflector with horn feed.



b. Waveguide horn feed.

Designed using CST Microwave Studio

Figure 3. Proposed Parabolic Reflector antenna with horn feed.

3. Results and Discussions

The design and implementation of the parabolic antenna for microsatellite applications were evaluated through the simulation by using CST software. Key performance metrics such as gain, beam width, signal clarity, and structural integrity under space conditions were measured. The simulated return loss (S_{11}) of the designed antenna is illustrated in Figure 4. The plot indicates a peak return loss of -14.98 dB at the resonant frequency of 2.1 GHz. Additionally, the antenna achieves the voltage standing wave ratio (VSWR) of 1.4 for the proposed antenna is presented

in Figure 5. The results indicate that the VSWR remains below 2 across the entire operational band which is considered acceptable for effective antenna performance.

Figures 6 and 7 display the far-field radiation directivity and gain recorded as 33.58 dB and 33.6 dB, respectively and show a beamwidth of 4° at the 3 dB point.

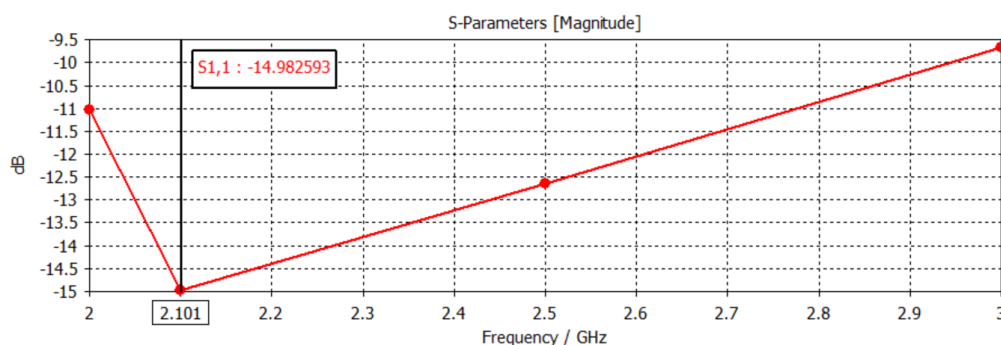


Figure 4. Return Loss at 2.1 GHz.

S1,1 parameter (also called the reflection coefficient) measures how much of the input signal is reflected back from antenna port. Figure 4 shows S1,1 value below -10 dB means

that less than 10% of power is reflected back and more than 90% is delivered to the antenna.

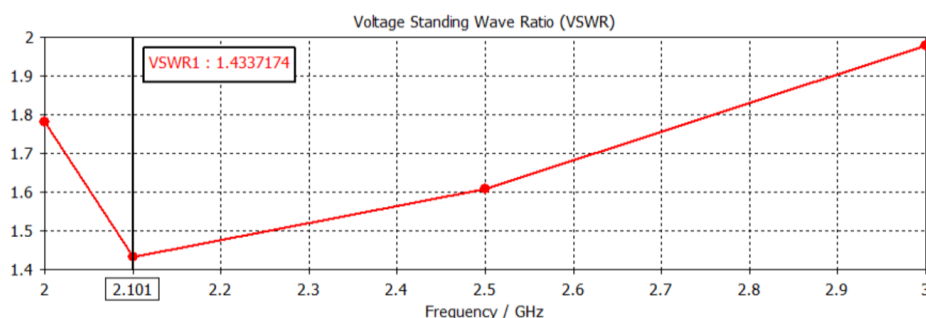


Figure 5. VSWR vs. Frequency.

VSWR is a measure of how efficiency radio-frequency power is transmitted from a power source through a transmission line into antenna. Figure 5 shows VSWR less than 2 means more efficient power transfer from the transmitter to the antenna.

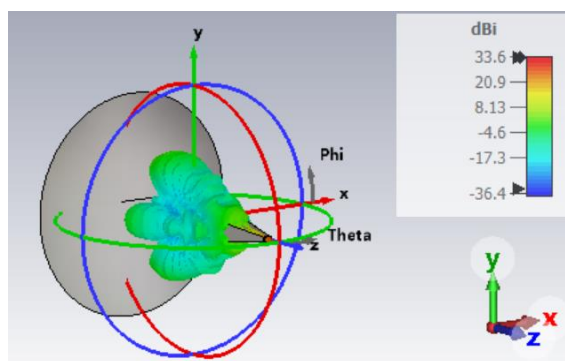


Figure 6. 3D far-field pattern at 2.1 GHz.

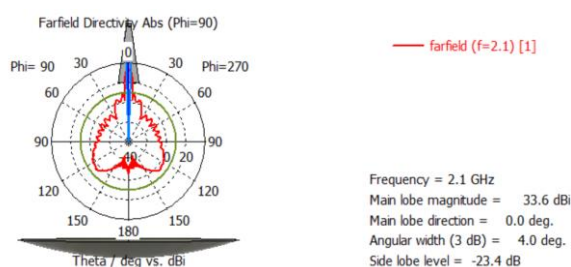
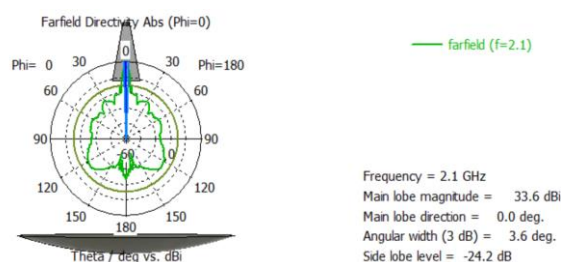
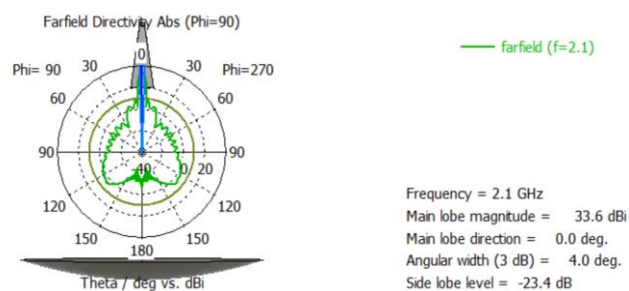


Figure 7. Gain at 2.1 GHz.



a) E-Plane.



b) H-Plane.

Figure 8. Radiation Pattern (a) $\Phi=0$ deg, (b) $\Phi=90$ deg.

Electric Field Distribution of the Parabolic Reflector

The results illustrated in Figure 9 correspond to an electromagnetic field simulation likely involving an antenna configuration such as a parabolic reflector with a waveguide horn feed. The magnetic field magnitude (in A/m) is represented at multiple points with the simulated region. This result gives a visual representation of the magnetic field distribution in and around a horn-fed parabolic reflector antenna. The magnetic field adjacent to the feed is visualized in the upper cluster with the lower disk portraying the field across the aperture plane. The color scale quantifies the field strength with most of the aperture experiencing low magnetic field values.

This detailed spatial mapping enables precise identification of regions with high and low magnetic field intensities offering crucial insight into the feed illumination pattern and its interaction with the reflector surface. Such visualization is invaluable for optimizing the antenna design as it allows for the adjustment of horn geometry and

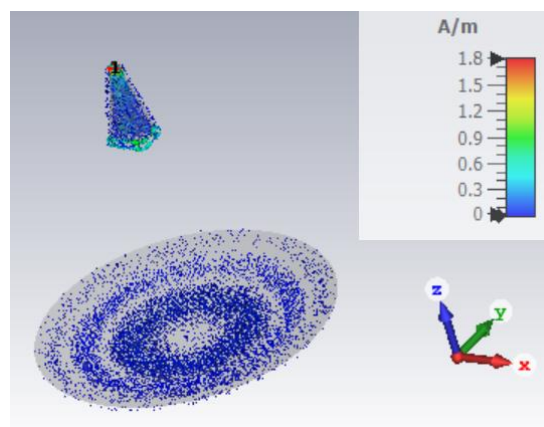
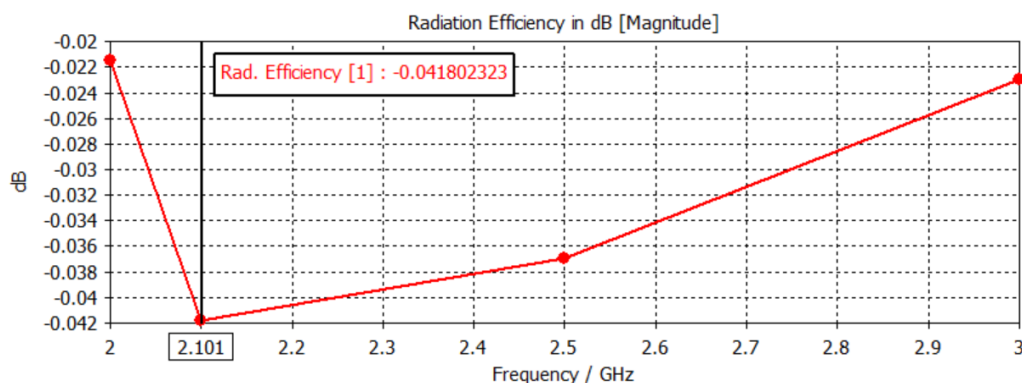
**Figure 9.** Electric field distribution of Parabolic Reflector.**Figure 10.** Radiation Efficiency.

Figure 10 shows radiation efficiency measures how effectively the antenna converts input power into radiated electromagnetic energy with losses (like heat or material absorption) subtracted.

A value closer to 0 dB means higher efficiency (less

power lost).

Negative values indicate some loss but values like -0.041 dB are very close to 0 meaning the antenna is highly efficient at operating frequency.

Table 2. Proposed Parabolic Reflector Antenna Parameters and Values.

Designed Parabolic Reflector Antenna Parameters	Simulation Results
VSWR	1.4
Return loss (in dB)	-14.98 dB
Gain (in dB)	33.6 dB
Directivity (in dB)	33.58 dB
Antenna Efficiency (%)	78.46%
Beamwidth (deg)	4°
Side lobe gain (in dB)	-23.4 dB
Radiation Efficiency (in dB)	-0.041 dB

4. Conclusions

The purposed antenna operates within the 2.1 GHz frequency band and is designed to investigate the radiation characteristics of a parabolic reflector using CST Studio Suite. The system employs a rectangular horn feed integrated with a WR-284 waveguide. At the resonant frequency of 2.1 GHz, the antenna performance was evaluated and validated through simulations in CST Microwave Studio. The observed results include a return loss of -14.98 dB, a VSWR of 1.4, directivity of 33.58 dB and a gain of 33.6 dB recorded under conditions where $|S_{11}| < -10$ dB and $VSWR < 2$. The simulated total efficiency reached 82.9% with a 3 dB beamwidth of approximately 4°. These results comprehensively demonstrate the high-performance capability of the proposed reflector antenna design.

In this paper, the simulation results validate the feasibility of the parabolic antenna for micro satellite communication, achieving peak values that highlighting their ability to provide high-gain, focused transmissions with minimal power consumption.

Acknowledgments

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Conflicts of Interest

The authors declare no conflicts of interest.

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