

CHALMERS

UNIVERSITY OF TECHNOLOGY

**Design and Optimization of a
Wideband Feed Antenna
for the Onsala 20-m Telescope**

Antenna Design and Simulation

Master's Thesis in Wireless, Photonics and Space Engineering

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Department of Space, Earth and Environment
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
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MASTER'S THESIS

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Abstract

Wideband feed antennas are an essential part of reflector antenna systems, as they affect the radiation characteristics and, in turn, the reflector performance, which is the focus of the present thesis. A wideband quad-ridge horn feed was designed and optimized for the Onsala Cassegrain reflector system.

The main objective of this work was to achieve a narrow radiation beam that satisfies the required edge taper while providing acceptable impedance matching and antenna efficiency. The antenna geometry is determined and studied by means of electromagnetic simulation. The ridge profile, horn geometry, and backshort, as well as antenna dimensions and radiation characteristics, were studied in detail.

The 3D spline-based approach was used to design the ridge profile, providing flexibility in controlling the antenna geometry. Several geometric configurations and scaling factors were investigated to study their influence on radiation beamwidth and efficiency. The scaled design of 1.8 has shown approximately a 12-degree beam width at -12 dB point at 4 GHz and has retained a narrow beam with the increase of frequency and better antenna efficiency.

The efficiency of the antenna has been assessed through simulated reflection coefficient, radiation patterns, spillover efficiency, illumination efficiency and combined aperture efficiency as measuring parameters. Although the target beamwidth could be achieved or closely approached, the overall efficiency remained below the target value of 60%.

The results indicate that modifying the geometry and scaling of a wideband quad ridge horn provides significant control over its radiation pattern. Nevertheless, further optimization and validation are required to improve the overall efficiency while maintaining the required beam characteristics.

Keywords: wideband antenna, quad-ridged horn, reflector feed, Cassegrain reflector, Onsala Space Observatory, antenna simulation, radiation pattern, beamwidth, spillover efficiency, illumination efficiency.

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Chapter 1

Introduction

1.1 Background

The study of celestial bodies using radio frequency waves and electromagnetic radiation is called radio astronomy. Radio astronomy is used to get information about objects that may be concealed by interstellar dust or be invisible through traditional observations. Radio telescopes have been developed over time and have given us knowledge on many different aspects of the universe, such as galaxies, pulsars, cosmic background radiation, and much more.

Modern radio telescopes are using techniques for their operations, such as Very Long Baseline Interferometry (VLBI). This consists of the combination of the multiple antennas that operate at various geographical locations, enabling exceptional angular resolution. The efficiencies and sensitivity of each radio telescope becomes an important elements for the overall effectiveness of the VLBI system owing to the structure and operational characteristics of its receiver.

Designing a wide-band antenna feed for these types of applications has various challenges. First of all, it must have high aperture efficiency and acceptable levels of return loss, as well as a stable radiation pattern and beam width throughout a wide frequency band. Also, this feed should satisfy all the mechanical requirements issued by the receiver cabin in order to use cryogenic low-noise amplifiers and minimize the noise generated by the antenna feed.

Different feed designs, like smooth-walled horns, corrugated horns, quad-ridged horns, and lens-assisted designs, have been developed in the past to achieve wide-band performance in radio telescopes. However, successful optimization of any feed design will depend on the particular telescope requirements, which involve beam pattern, polarization, impedance matching, and efficiency.

The aim of this research is to develop and optimize a compact, wideband antenna feed for the 20-meter radio telescope at Onsala Space Observatory, which satisfies all the

mechanical and electrical requirements of the telescope.

1.2 Motivation

Modern radio telescopes have specific needs for receiver systems that are more advanced and capable due to the growing amount of high sensitivity and broadband radio astronomy observations. So, the future of Very Long Baseline Interferometry (VLBI) and projects like the Square Kilometre Array (SKA) will need receivers that are capable of working in a wide frequency range and provide high data throughput rates.

There are many limitations with current antenna feed systems. The main limitation or challenge of the feed is to achieve wide bandwidth and feed efficiency as per requirement. The use of conventional narrowband feeds restricts the range of frequencies to be observed and requires several systems for proper wideband observation. It will increase the complexity of the system and the operational and cost constraints on the system. Developing a wideband antenna feed that can operate continuously from approximately 4 to 16 GHz enables wideband observations with a single system, increasing the capability and operational efficiency of the system.

Antenna feed design strongly influences the performance of the overall radio telescope. The antenna feed design determines the aperture efficiency, return loss, antenna pattern, and noise temperature of the whole telescope. Improvements in all these characteristics will lead to better sensitivity, which is required to detect weak astronomical signals.

The other major motivation for the system is that there is a need to comply with practical engineering requirements. There should be a way for the feed to be designed in a compact form such that it can be fitted inside the limited space available in the receiver cabin while being compatible with cryogenic cooling mechanisms for reducing noise levels.

The main aim of this study is the development of an antenna feed that is compact, energy-efficient, wideband, and satisfying the demands of modern radio astronomy and improves the observing capabilities of the Onsala 20-meter Telescope.

1.3 Onsala Space Observatory

The Onsala Space Observatory (OSO), located around 45 kilometers to the south of Gothenburg, is Sweden's national facility for radio astronomy and geodesy. OSO was established in 1949 and operated by Chalmers University of Technology under the authority of the Swedish Research Council. The observatory comes an important centre for science research and technological development to radio astronomy.

The observatory includes several radio astronomy telescopes and instruments used for different purposes, including astronomical observations and Earth sciences. The two main

facilities for astronomical observations are the 20-m and 25-m radio telescopes. These telescopes also contribute to global Very Long Baseline Interferometry (VLBI) networks, providing high-precision data for studies of distant cosmic objects.

Besides the big telescopes mentioned above, Onsala has a number of other instruments to assist in research. For example, the Low Frequency Array (LOFAR) station and the Onsala Twin Telescopes (OTT) used for next-generation geodetic VLBI (very long baseline interferometry). There are also several small educational telescopes, including SALSA. The observatory also supports international collaborations and has contributed to major projects such as the Atacama Large Millimeter/submillimeter Array (ALMA) and the Square Kilometre Array (SKA).

This thesis focuses on the 20-m telescope and is a very important part of both geodetic and astronomical observations. This telescope is designed for high-frequency measurements and has been upgraded to fulfill the current needs of radio astronomy. The need to enhance all of the receiver systems (including the use of a wideband antenna feed) will improve the existing sensitivity of the telescope, increase the operational bandwidth, and provide the means to conduct future scientific experiments.



Figure 1.1: Onsala Space Observatory.

1.4 Scope and Limitations

This thesis focuses on the design and simulation of a wideband feed antenna for the Onsala Cassegrain reflector system. The main objective of the work is to investigate how geometrical modifications of the antenna can be used to control the radiation beamwidth while maintaining acceptable impedance matching and efficiency.

The analysis covers the frequency range between 4 and 16 GHz. In this study, the

investigation of the antenna geometry is carried out, including the ridge profile, flare profile, backshort configuration, and various methods of geometrical scaling. The evaluation of antenna performance is carried out in terms of radiation patterns, reflection coefficient, radiation beamwidth (-12 dB), and spillover and illumination efficiencies.

The main aim of this thesis is to establish and optimize the feed antenna. The overall receiver system along with the detailed system-level analysis is not included in this work. The findings are mainly drawn from the electromagnetic simulations, while the physical creation of the antenna and its measurements are not carried out as part of this thesis.

Moreover, the optimization process is confined to some selected design variables and geometrical configurations. Due to an enormous number of design variables and running time to perform the electromagnetic simulations, global design optimization for all parameters was not conducted. Consequently, the final design is the best configuration that has been gained within the studied parameters.

Chapter 2

Theoretical Background

2.1 Antenna Theory

Antenna devices convert guided electromagnetic radiation into radiated electromagnetic signals (and vice versa). In transmitting, an antenna converts the electrical signal to electromagnetic radiation. When receiving, the antenna receives an electromagnetic signal and converts it to an electrical signal. Antennas have same characteristics in transverse and receive modes (for linear and passive conditions) because of the principle of reciprocity.

2.1.1 Far-Field Approximation

An antenna emits radio waves, and these waves can be divided into different regions: the near-field (reactive, radiating) and far-field. At the far-field, the angular field distribution is independent of distance.

The far-field distance is defined as:

$$R \geq \frac{2D^2}{\lambda} \quad (2.1)$$

where D is the largest dimension of the antenna and λ is the wavelength.

In this region, the electric and magnetic fields behave as plane waves and are related by:

$$\frac{E}{H} = \eta_0 \quad (2.2)$$

where $\eta_0 \approx 377 \Omega$ is the intrinsic impedance of free space.

2.1.2 Reciprocity

According to the reciprocity theorem, an antenna's transmission properties are the same in both transmitting and receiving modes. The properties like radiation pattern, impedance, and polarization, will be unchanged regardless of which direction it is being operated.

2.1.3 Radiation Pattern

In the far-field region, the electric field radiated by an antenna can be expressed as:

$$E(r, \theta, \phi) = \frac{e^{-jkr}}{r} G(\theta, \phi) \quad (2.3)$$

where r is the distance from the antenna, $k = \frac{2\pi}{\lambda}$ is the wave number, and $G(\theta, \phi)$ is the far-field function describing the angular variation of the field.

The radiation pattern of an antenna is defined by the angular dependence of $G(\theta, \phi)$ and represents the distribution of radiated energy in space.

2.1.4 Gain and Directivity

Directivity is defined as the ratio of radiation intensity in a given direction to the average radiation intensity:

$$D(\theta, \phi) = \frac{4\pi U(\theta, \phi)}{P_{rad}} \quad (2.4)$$

The maximum directivity is:

$$D_0 = \frac{4\pi U_{max}}{P_{rad}} \quad (2.5)$$

Gain accounts for antenna efficiency and is given by:

$$G = \eta D \quad (2.6)$$

where η is the radiation efficiency.

2.1.5 Polarization

Polarization is the term used to refer to the direction in which the electric field vector of the wave being emitted is pointing. The way that the electric field changes over time is what determines whether it is linear, circular, or elliptical in its orientation.

2.1.6 Bandwidth

The bandwidth of an antenna is defined as the range of frequencies over which the antenna satisfies specified performance criteria.

In general, the bandwidth is given by:

$$B = f_H - f_L \quad (2.7)$$

where f_H and f_L are the upper and lower frequency limits.

For wideband antennas, like in our case, bandwidth is defined as a ratio,

$$B = \frac{f_H}{f_L} \quad (2.8)$$

2.1.7 Effective Area and Antenna Efficiency

The effective area A_e represents the ability of an antenna to receive power and is related to the gain by:

$$A_e = \frac{\lambda^2 G}{4\pi} \quad (2.9)$$

The aperture efficiency is defined as:

$$\eta = \frac{A_e}{A_{physical}} \quad (2.10)$$

The total efficiency can be expressed as a product of several factors:

$$\eta = \eta_{rad} \cdot \eta_{spill} \cdot \eta_{taper} \quad (2.11)$$

where η_{rad} is radiation efficiency, η_{spill} is spillover efficiency, and η_{taper} is taper efficiency.

2.2 Noise and Sensitivity

In radio astronomy, the detection of weak signals is fundamentally limited by noise. Therefore, understanding and minimizing noise is essential for achieving high system performance. The overall sensitivity of a radio telescope depends on both the antenna characteristics and the noise contributions from the receiver and environment.

Noise in radio frequency systems is commonly characterized using the concept of noise temperature. The overall system performance is typically expressed by the figure of merit $\frac{A_e}{T_{sys}}$, where A_e is the effective area of the antenna and T_{sys} is the system noise temperature.

The noise power delivered to a matched load can be expressed as

$$P_n = k_B T B \quad (2.12)$$

where k_B is Boltzmann's constant, T is the noise temperature in Kelvin, and B is the bandwidth.

The received noise temperature at an antenna T_A is the accumulated noise contribution from the surroundings of the antenna. These contributors include the sky, atmosphere, ground radiation, and other sources. The overall accumulated noise contribution at an antenna depends on both its radiation pattern and the environment in which it observes.

The overall noise temperature for a system due to system components and signal sources is termed the system's noise temperature and is calculated using the following equation:

$$T_{sys} = T_A + T_{rec} + T_{loss} \quad (2.13)$$

where T_A is the antenna noise temperature, T_{rec} is the receiver noise temperature and T_{loss} represents additional noise introduced by losses in the system.

Any loss occurring before the receiver typically has resulted in an increase to the actual system noise temperature

$$T_{loss} = (L - 1)T_0 \quad (2.14)$$

where L is the loss factor and T_0 is the physical temperature typically taken as 290 K.

2.3 Reflector Antennas

Reflector antennas are commonly used in radio astronomy because they can capture electromagnetic waves over a wide aperture and direct this energy to an antenna (feed) that is positioned at the focal point of the reflector. This allows them to detect faint signals from remote celestial sources with high sensitivity.

The reflector antenna consists of one main (reflector) that is usually shaped like a parabola, which focuses incoming (plane) waves onto the focal point. A feed antenna is usually placed at or near this point to collect the energy and transmit it to the receiving system.

$$A_{eff} = \eta_A A_{geom} \quad (2.15)$$

where A_{geom} is the physical area of the reflector and η_A is the aperture efficiency

A reflector antennas performance is often measured by its aperture efficiency η_A . This parameter describes the ability of the physical aperture to effectively convert the incoming power to a usable signal. It includes a number of sub-efficiencies.

$$\eta_A = \eta_{ill} \cdot \eta_{sp} \cdot \eta_{pol} \cdot \eta_{phase} \cdot \eta_{block} \quad (2.16)$$

where:

- η_{ill} : illumination efficiency
- η_{sp} : spill-over efficiency
- η_{pol} : polarization efficiency
- η_{phase} : phase efficiency
- η_{block} : blockage efficiency

These efficiencies depend strongly on the radiation characteristics of the feed antenna

2.3.1 Cassegrain System

Many radio telescopes, including the Onsala 20 m telescope, employ a Cassegrain configuration of telescope design consisting of two main components: a primary parabolic reflector and a secondary hyperbolic (sub-reflector). In this configuration, the feed is located behind the main reflector and signals are reflected twice before they reach the feed.

This configuration offers several advantages:

- Compact feed placement
- Reduced blockage compared to prime focus designs
- Easier integration of receiver systems

2.3.2 Spill-over and Illumination

A main design trade-off in reflector antennas is between illumination efficiency and spill-over efficiency.

- **Illumination efficiency** is maximized when the reflector is uniformly illuminated.
- **Spill-over** occurs when part of the radiation from the feed misses the reflector and is lost to the ground or sky.

2.3.3 Edge Taper

The feed radiation pattern has to be carefully shaped in order to control how it illuminates the reflector. This is usually expressed with a quantity called edge taper (gain reduction at the edge of the reflector).

For the Onsala 20 m telescope, the half-subtended angle is $\theta_e = 6.09^\circ$, and the desired edge taper is approximately -12 dB.

This means that the feed radiation should drop by 12 dB at the edge of the sub-reflector to balance:

- High aperture efficiency
- Low spill-over noise

(A) The design of reflector antenna systems involves several trade-offs:

- Increasing illumination improves gain but increases spill-over noise
- Reducing spill-over decreases noise but reduces aperture efficiency
- Feed design directly controls beam shape and therefore system performance

An optimal design is achieved by balancing these factors to maximize the system figure of merit:

$$\frac{A_{eff}}{T_{sys}} \quad (2.17)$$

which represents the sensitivity of the radio telescope (A)

2.4 Feed: Horn Antennas

The feed antennas used in reflector antennas are a critical part of the performance of a complete antenna system. The feed's radiation pattern will also affect aperture efficiency, spill-over and system noise temperature.

Horn antennas are one of the most common types of antennas for use as feeds to radio telescopes, due to their simplicity, wide bandwidth and well-defined radiation pattern.

A horn antenna is made by a waveguide and a flare part that transform the guided waves into radiated waves. This gradual transition will lessen the difference of electrical resistance between the waveguide and the free space therefore allowing for the best efficient radiation.

The dominant mode in a rectangular waveguide horn is typically the TE_{10} mode, which determines the field distribution at the aperture.

2.4.1 Quad-Ridge Flared Horn

The Quad-Ridge Flared Horn (QRFH) is a wideband feed antenna utilized in many applications within the field of radio astronomy because of its ability to deliver a consistent radiating pattern, provide dual polarization and wideband operation, making it an excellent choice for use in reflector antenna systems that need to have both highly sensitive and wide-frequency coverage.



Figure 2.1: Different types of QRFH

2.4.2 Structure and Operating Principle

A QRFH is designed with four symmetrically placed metallic ridges inside a flared waveguide. The ridges gradually open outward along the flared waveguide, causing changes in the electromagnetic field distribution within the waveguide.

Each of the four metallic ridges lowers the cutoff frequency of the dominant mode and allows the QRFH to have a significantly larger bandwidth than a conventional horn antenna network. The outer wall of the flare section converts the guided wave produced into a radiated wave while controlling the beam pattern of the radiated wave.

The ridged configuration allows for the QRFH to achieve more than a 3-to-1 bandwidth which is necessary for many applications including radio telescopes that operate across several frequency bands. The wideband performance is achieved through:

- Gradual impedance transition
- Reduced waveguide cutoff frequency
- Smooth flare profile

The electromagnetic behaviour of a QRFH is complex and cannot be accurately described with simple analytical models; therefore, numerical simulation and optimization are generally needed for design.

The QRFH radiation pattern is intended to have a stable design frequency, nearly constant beamwidths, and low side-lobe levels, which allows for continuous illumination of the reflector. The far-field radiation can be expressed as

$$E(r, \theta, \phi) = \frac{e^{-jkr}}{r} G(\theta, \phi) \quad (2.18)$$

where $G(\theta, \phi)$ represents the angular field distribution.

The performance of a QRFH depends on several geometric parameters, including:

- Ridge profile and spacing
- Flare angle and horn length
- Backshort design
- Feeding structure

These parameters influence:

- Impedance matching (S_{11})
- Beamwidth and edge taper
- Cross-polarization levels
- Aperture efficiency

Chapter 3

Specifications and Requirements

3.1 System Overview

3.2 Onsala 20 m Cassegrain radio telescope

The Onsala 20-m radio telescope is a Cassegrain reflector antenna designed for radio astronomical observations. As shown in Figure 3.1, the telescope consists of a large primary parabolic reflector and a secondary hyperbolic reflector (sub-reflector). This dual-reflector configuration is widely used in radio telescopes because it provides high gain while allowing the feed system to be located near the main reflector vertex.

The electromagnetic waves from distant astronomical sources are first collected by the primary reflector and directed towards the hyperbolic sub-reflector. The sub-reflector then reflects the radiation through the central opening of the primary reflector to the feed system located at the secondary focus. This optical arrangement provides a compact antenna structure while maintaining excellent focusing performance.

The primary reflector determines the collecting area of the telescope, whereas the sub-reflector controls the final focusing of the electromagnetic waves onto the antenna feed. Therefore, the radiation characteristics of the feed, including beamwidth, phase center, and illumination pattern, have a direct influence on the overall aperture efficiency and sensitivity of the telescope.

The geometry of the Onsala 20-m Cassegrain telescope used in this work is illustrated in Figure 3.1. The proposed wideband antenna feed is designed to efficiently illuminate the hyperbolic sub-reflector while minimizing spillover and maintaining high aperture efficiency over the operating frequency range.

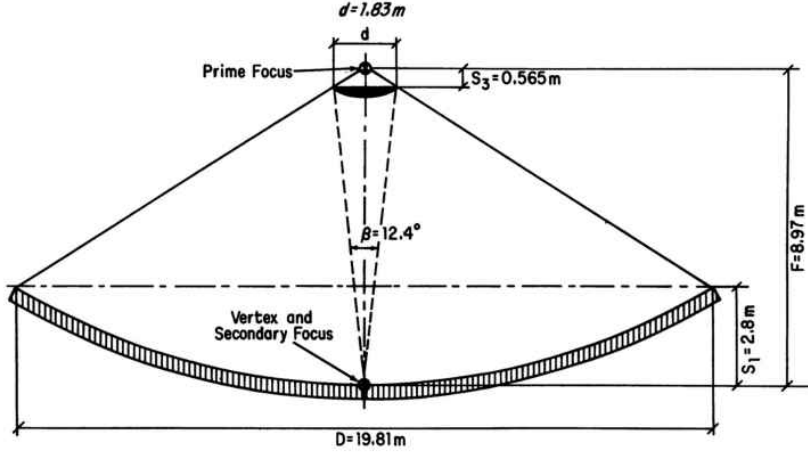


Figure 3.1: Geometry

3.3 Feed

The Quad-Ridge Flared Horn (QRFH) feed is developed specifically for the 20 m radio telescope at the Onsala Space Observatory and is used for both radio astronomy and VLBI observations and will provide the necessary support for future wideband observations in C-, X-, and Ku-bands by providing the required C-, X-, and Ku-band frequency coverage.

This feed will operate at the secondary focus of the reflector. The reflector geometry will impose very strict requirements on the characteristics of the feed's radiation pattern, edge taper and beam stability. The limited amount of space within the receiver cabin will also impose considerable mechanical limitations on the dimensions of the feed.

The QRFH feed will provide dual linear polarized radiation and will maintain stable electromagnetic performance over a very wide operational bandwidth. The overall system performance will be evaluated based on aperture efficiency, noise temperature, and sensitivity of the system.

3.4 Frequency Band (4–16 GHz)

The proposed frequency range for the feed is

$$4 \text{ GHz} \leq f \leq 16 \text{ GHz} \quad (3.1)$$

This corresponds to a 4:1 wideband antenna feed.

The receiver system was designed to operate primarily over the frequency range of 4.6–15.4 GHz. However, extending the feed bandwidth to 4–16 GHz provides additional flexibility for future radio astronomy applications.

Due to the large bandwidth and difficulty in maintaining stable beam characteristics and good impedance matching as well as low cross-polarization over such a wide potential operating range, a great deal of design considerations is required to meet these objectives.

3.5 Mechanical Constraints

The design of the feed must satisfy the physical dimensions of the receiver cabin in the Onsala 20 m telescope to ensure ease of installation. The available space dimensions are:

$$D \leq 35 \text{ cm} \quad (3.2)$$

$$L \leq 70 \text{ cm} \quad (3.3)$$

where D is the maximum feed diameter and L is the total feed length.

3.6 Electrical Requirements

Good impedance matching is required over the wide bandwidth of the design. The reflection coefficient requirement is defined as:

$$|S_{11}| \leq -10 \text{ dB} \quad (3.4)$$

with a design goal of achieving values better than -15 dB where possible.

The antenna should provide dual linear polarization with minimal cross-polarization levels in order to provide precise measurements of polarization for radio astronomical purposes.

The radiation pattern must satisfy the illumination requirements of the Onsala 20-m reflector, with a desired edge taper of approximately

$$ET \approx -12 \text{ dB} \quad (3.5)$$

at the reflector half-subtended angle:

$$\theta_e = 6.2^\circ \quad (3.6)$$

3.7 Performance Targets

The performance objectives of this research are defined according to the specifications of the Onsala Cassegrain reflector system. The feed antenna must be able to work in a wide band ranging from 4 GHz to 16 GHz. Also, it was crucial to focus on the lower band as

the creation of the necessary beamwidth is a more difficult problem in a low-frequency range.

One of the main electrical requirements is good impedance matching over the operating frequency range. The reflection coefficient target is defined as

$$|S_{11}| \leq -10 \text{ dB}.$$

Another essential criterion for the feed's functioning is the radiation characteristics of the feed antenna itself. The radiator needs to efficiently illuminate the Cassegrain reflector system while generating a narrow radiation beam. Therefore, the radiation pattern is determined in terms of the -12 dB beamwidth, which corresponds to the acceptable edge taper level of the reflector system. As a result, the -12 dB beamwidth will act as the key design parameter instead of the traditional -3 dB beamwidth.

It is also necessary to achieve appropriate spillover and illumination performance. This parameter is crucial for assessing the feed's performance with respect to the reflector system illumination parameters. The combined spillover and illumination efficiency will be applied in this work as a significant measure of the overall aperture performance, whereby a target value of 60% or more is desirable.

The main performance targets can be summarized as follows:

- Operating frequency range: 4–16 GHz.(also 4-9 GHz)
- Reflection coefficient: $|S_{11}| \leq -10 \text{ dB}$.
- Dual-polarized operation.
- Radiation pattern evaluated using the -12 dB beamwidth.
- Narrow radiation beam over the operating frequency range.
- Good spillover and illumination efficiency.
- Combined efficiency target of approximately 60% or higher.

These performance targets were used as the main criteria for evaluating the different antenna geometries and design configurations investigated in this thesis.

Chapter 4

Design Methodology

4.1 Initial Design Approach

The initial step of the design was to define all the mechanical and electrical requirements of the feed. The feed was required to operate over 4–9 GHz and 4–16 GHz while maintaining high efficiency, low cross-polarization, and good impedance matching. The mechanical dimensions of the feed were also constrained by the available space in the receiver cabin.

Many feed technologies were researched by reading textbooks and several papers, including simple horn, corrugated horn, double-ridged flare horn, and quad-ridged flare horn. From these, the quad-ridged flare horn was chosen because of the design constraints. However, good optimization is required.

Before starting the electromagnetic simulations, theoretical calculations and old feed designs were studied. These studies indicated that the initial design constraints were achievable, but the 12 dB taper at 6.2 degrees (half subtended angle) is still a problem. From this knowledge, digital design started using CST Microwave Studio.

4.2 Horn Geometry Design

After selecting the antenna type, the main geometrical parameters were determined based on the design constraints and the requirements of the antenna. The antenna was designed in a way to achieve efficiencies of more than 60 percent while maintaining radiation characteristics across the frequency band.

4.2.1 Basic Dimensions

Basic dimensions include the aperture diameter, flare length, and throat diameter.

From the project constraints, the maximum allowed diameter for the aperture is 35 cm. So, the designed diameter is 32 cm (with a little margin for the extra body), and

the maximum allowed length was 70 cm. The antenna was designed with a flare length of 66 cm plus 3.3 cm for the waveguide.

- **Lowest frequency:**

$$f_{\min} = 4 \text{ GHz}$$

A good choice is

$$f_c \approx 0.75 f_{\min}$$

Therefore,

$$f_c \approx 3.0 \text{ GHz}$$

The cutoff frequency for the dominant TE_{11} mode of a circular waveguide is given by

$$f_c = \frac{1.8412 c}{\pi d} \quad (4.1)$$

where

- $c = 3 \times 10^8 \text{ m/s}$ is the speed of light,
- d is the throat diameter of the circular waveguide.

Rearranging the equation to obtain the minimum possible diameter,

$$d = \frac{1.8412 c}{\pi f_c}$$

Substituting $c = 3 \times 10^8 \text{ m/s}$ and $f_c = 3 \times 10^9 \text{ Hz}$,

$$d = \frac{1.8412 \times 3 \times 10^8}{\pi \times 3 \times 10^9} = 0.0586 \text{ m} = 58.6 \text{ mm}$$

So, the minimum possible throat diameter was obtained from this equation.

Therefore, the throat diameter design was initially started at 56 mm. After the optimization process, the final throat diameter was fixed at 60 mm.

4.2.2 Ridge modeling

The ridge was designed using the 3D spline curve in CST. This approach was selected because it gives a smooth profile and allows control of the geometry using only a few points and parameters.

The ridge profile was defined using four control points. Initially, the first and last control points were fixed to maintain the overall length, and the other two points were

used to control the curvature. This approach is simple, gives the freedom to change the curvature, and provides the base shape of the ridge that gives the desired results.

Several other ridge profiles from the literature were tried as reference geometries. However, they did not give the desired beam characteristics and efficiency. Therefore, new spline ridge profiles were developed.

After obtaining good results with the initial design, the optimization allowed the end points to vary. This gave extra flexibility in shaping the ridge and resulted in better antenna performance.

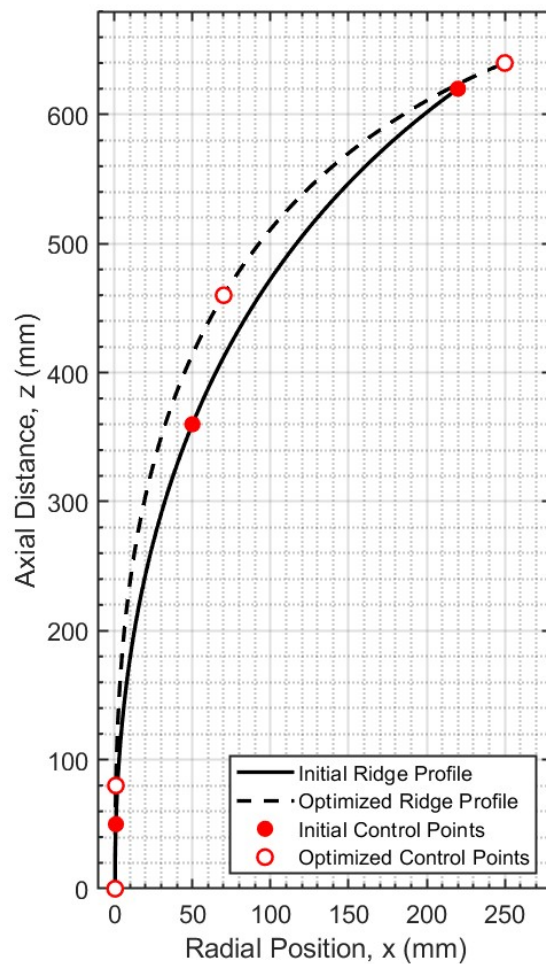


Figure 4.1: Spline-defined ridge profile.

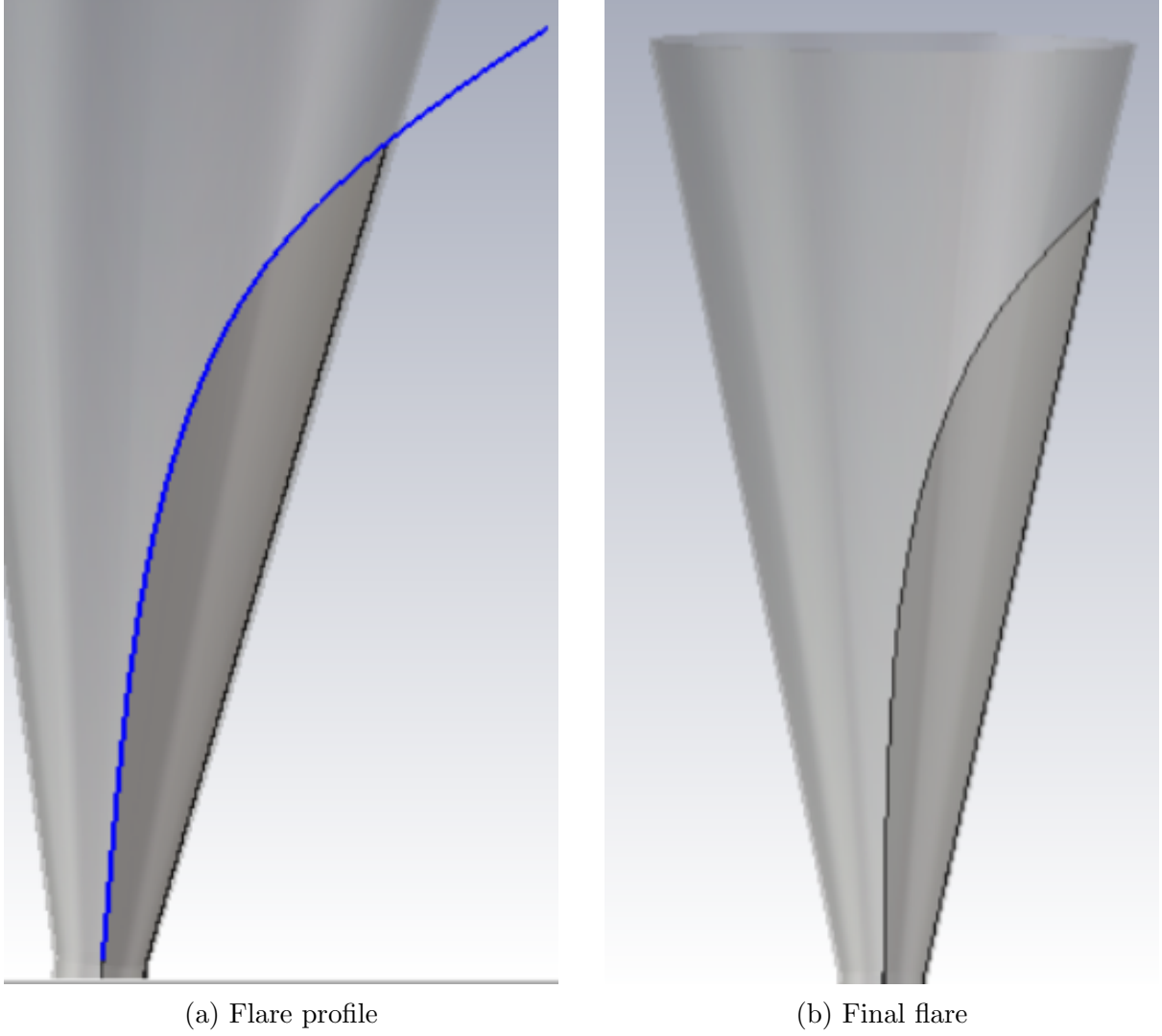


Figure 4.2: Comparison of the initial and optimized ridge profiles.

4.2.3 Flare Modeling

The outer wall was designed using an analytical curve implemented as a 3D spline with 4–5 control points. The flare profile defines the phase distribution, beamwidth, and impedance characteristics, making it one of the most important design parameters.

Every point was defined by

$$x = x_0 + (x_1 - x_0) \left(\frac{L'}{L} \right)^p \quad (4.2)$$

where x_0 is the starting point (30 mm), x_1 is a variable that changes for every point, L is the total flare length, L' is the height (or z -value) of that point, and p is the parameter used to determine the curvature.

The optimized flare profile provided improved radiation characteristics and better reflector illumination over the operating frequency range.

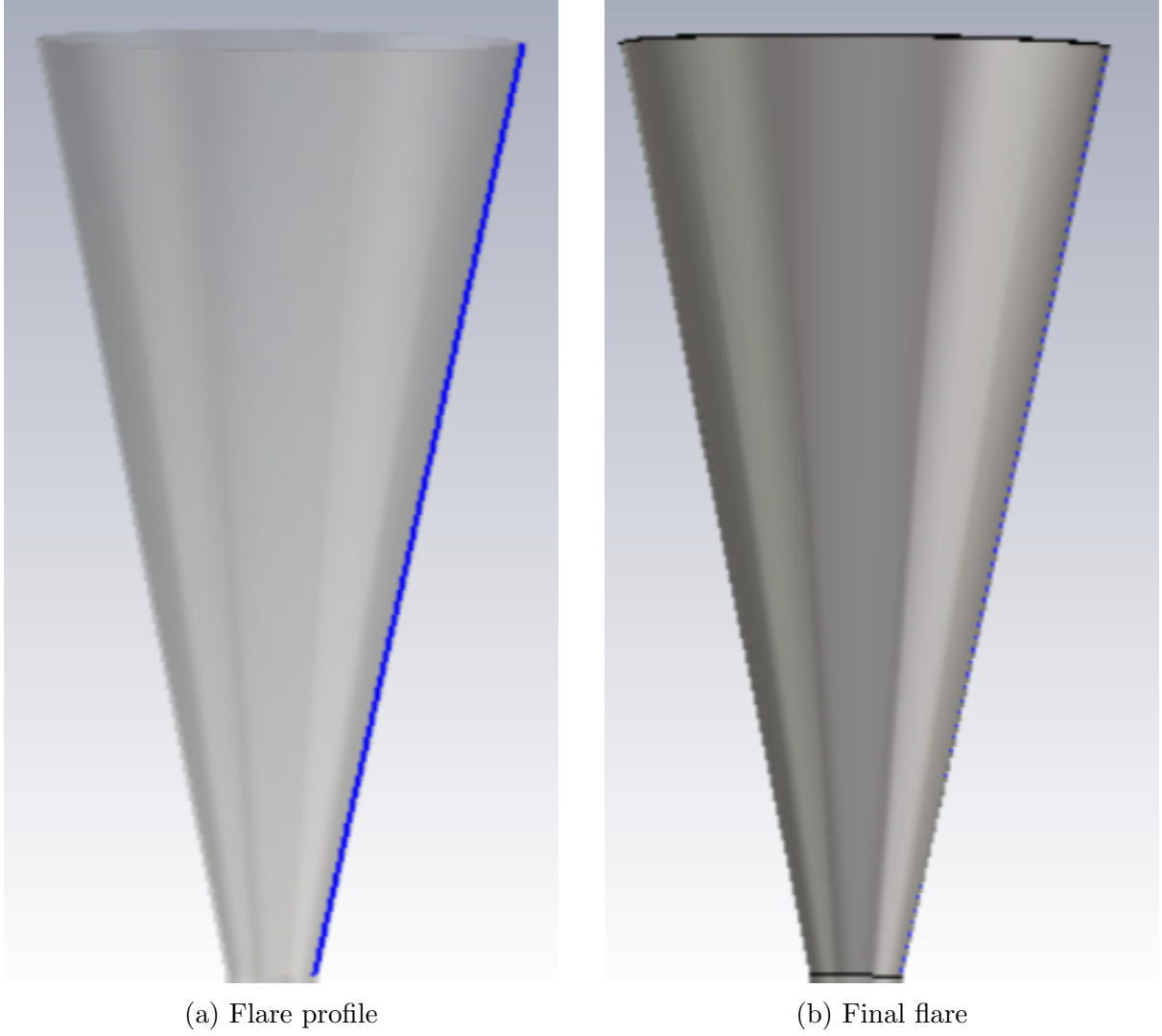


Figure 4.3: Comparison of the initial and optimized ridge profiles.

4.3 Optimization Strategy

4.3.1 Ridge Optimization

The ridge profile was optimized to improve the impedance matching (S_{11}) and radiation characteristics of the feed antenna. This was carried out using parameter sweeps in CST Studio. The optimization included the ridge width, ridge taper, ridge length, and overall ridge curvature.

Initially, the end points were fixed, and one control point was added in between to roughly study the influence of the curvature. Later, one more control point was added to provide extra control, and different positions were evaluated using parameter sweeps to find a suitable combination. This produced good far-field results, although further improvements were still required.

Therefore, the position of the last control point was also varied to improve the cur-

vature and the overall ridge length. This provided additional flexibility in controlling the overall ridge shape. For each parameter combination, the S11, radiation pattern, beamwidth, and other radiation characteristics were observed, and the final ridge geometry was selected based on the best overall performance over the required frequency range.

The optimization improved the S11 and reduced the beamwidth, which was crucial for improving the spillover efficiency, resulting in better performance than the initial ridge design.

4.3.2 Flare Optimization

Along with the ridge optimization, the horn flare was optimized to improve the radiation characteristics and reflector illumination. The flare geometry was designed using an analytical equation, which was used to define the control points, as described in the previous section.

First, a set of control points was defined using the equation 4.2 by varying the values of x_1 and L' . After defining the points, a parameter sweep was conducted by varying the parameter p , while maintaining the positions of the endpoints, which determine the throat diameter, aperture diameter, and flare length.

The performance of each flare profile was examined by observing the S11, beam width, and other radiation characteristics. It was found that a straight flare provided a better balance between beam shaping and impedance matching across the operating frequency band. The curved flare tended to produce more similar beamwidths in the two principal planes; however, it also resulted in a wider radiation beam.

4.3.3 Feed Optimization

The feed section, including the ridge gap, excitation region, and backshort geometry, was optimized along with the ridge and horn flare.

The feed part is the most important part for achieving a good reflection coefficient (S11). To optimize the feed part, parameters such as the ridge gap, ridge width, ridge cutting angle, and ridge cutting length (channel width) were first defined. These parameters helped to maintain the S11 below -10 dB.

The backshort design was adopted from the Jonas QRFH, as it provides excellent performance. Several other backshort geometries were also investigated, but they did not provide better results than the Jonas backshort. Therefore, the Jonas backshort was selected for the final design. The optimization was carried out using parameter sweeps.

The feed line was created above the backshort, and its position was also determined using parameter sweeps. The feed line was modeled using lossy PTFE as the dielectric material and copper as the conductor. To determine the optimum feed line position, a

discrete port was used, and the S11 was evaluated for each position. The position that provided the best impedance matching was selected for the final design.

Table 4.1: Design parameters of the QRFH feed structure.

Parameter	Symbol	Value (mm)
Waveguide Length	L_w	30.00
Feed Position	F_p	19.14
Ridge Gap	g_r	1.00
Ridge Width	W_r	2.00
Channel Width	W_c	0.50
Channel Cut Angle	θ_c	45°
Backshort Width	W_b	1.00
Backshort Length	L_b	6.20
Backshort Slant Length	L_s	7.07

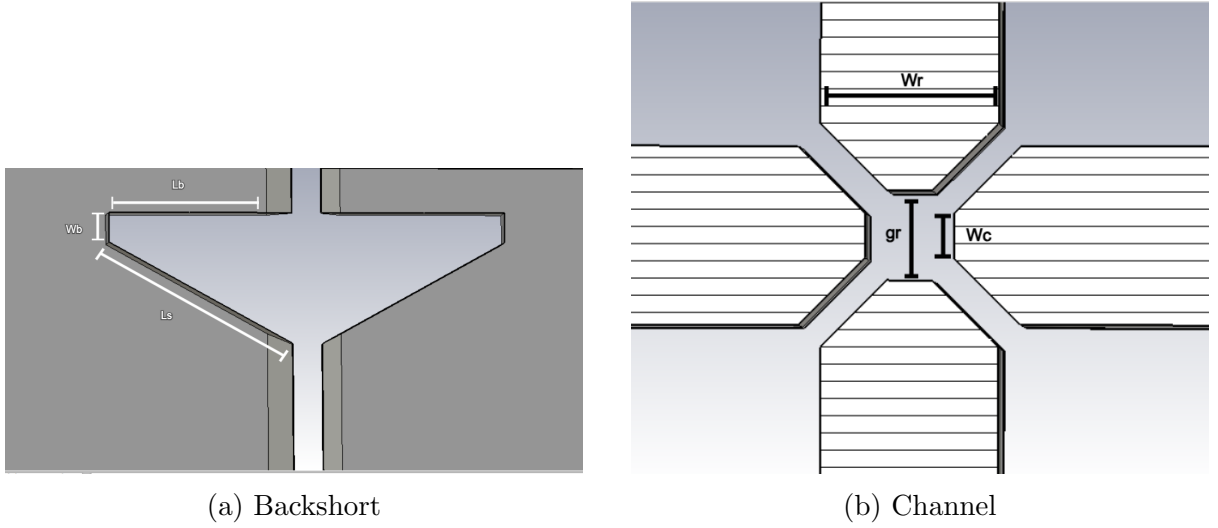


Figure 4.4: Feed part

4.3.4 Lens Optimization

After completing all the other optimizations, a dielectric lens was designed to improve the radiation pattern. The horn optimization mainly focused on achieving good impedance matching. However, to obtain higher spillover efficiency, phase correction and a reduction in beamwidth were required.

Different lens types, such as double-convex, double-concave, plano-convex, plano-concave, and Fresnel lenses, were investigated. Different positions and alignments were also evaluated. After investigating the beam characteristics of these lens types, the plano-convex lens was selected. The material used for the lens was Rexolite, with a relative permittivity of 2.53.

The final lens orientation and position were decided based on the length constraint and the overall performance. The total length of the horn is 69 cm, while the maximum

allowed length is 70 cm. Therefore, the lens was placed inside the horn, with the plane face facing outward and positioned at the aperture. The radius of the plane face was made equal to the aperture radius, and the lens thickness was determined using parameter sweeps and selected as approximately 66.2 mm.

This optimization improved the radiation characteristics and contributed to better reflector illumination across the operating frequency range.

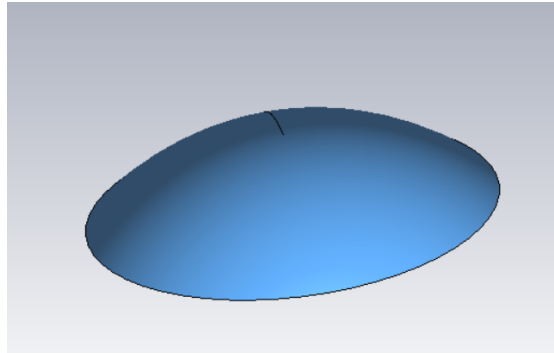


Figure 4.5: Lens

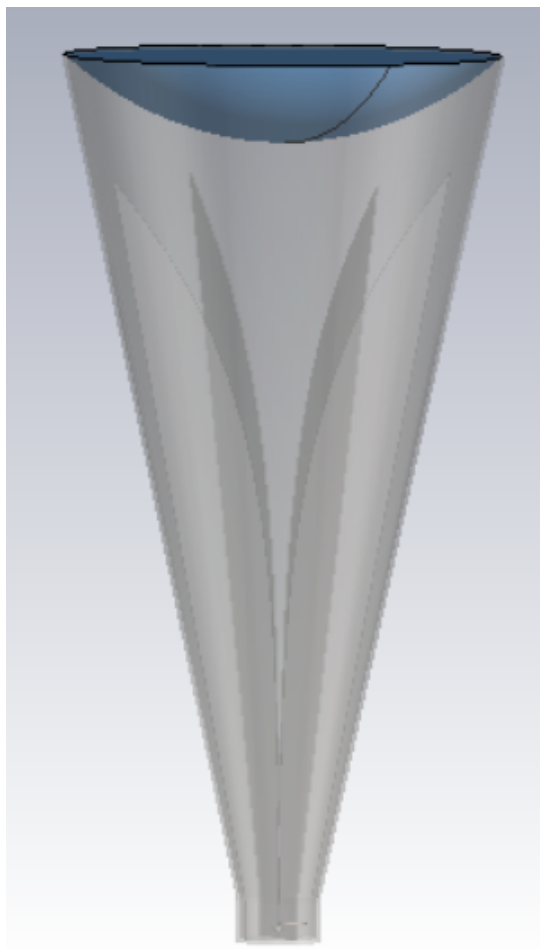


Figure 4.6: Lens

Chapter 5

Results and Analysis

This chapter presents the simulation results of the proposed wideband antenna feed. The antenna performance is evaluated using the reflection coefficient, radiation patterns, aperture efficiency, bandwidth, and noise contribution. Finally, the obtained results are compared with the design requirements presented in Chapter 3.

5.1 Reflection Coefficient (S11)

5.1.1 Wideband Performance (4–16 GHz)

The S11 performance was evaluated over two frequency bands. The first was the wideband frequency range of 4–16 GHz. The figures compare the S11 of the designed antenna with and without the dielectric lens, which was introduced to reduce the beamwidth. Both configurations show good performance throughout the wideband frequency range.

The antenna with and without the dielectric lens exhibits two different reflection coefficients. The antenna without the lens maintains an S11 below -10 dB with a good margin, which indicates excellent impedance matching. After introducing the dielectric lens, small changes in the S11 can be observed. This is an expected result because the introduction of a dielectric material changes the electromagnetic field distribution. However, the S11 throughout the frequency band still remains close to or below -10 dB, indicating good impedance matching. Therefore, although the introduction of the lens slightly changes the impedance matching, it maintains good matching while improving the radiation characteristics.

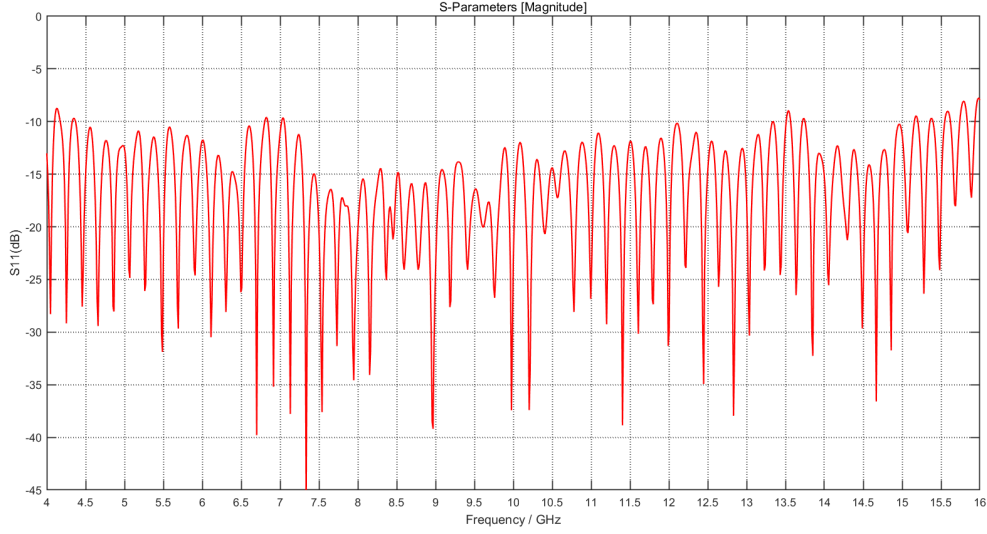


Figure 5.1: S11 4-16 GHz

5.1.2 Optimized C–X Band Performance (4–9 GHz)

The secondary application of the antenna is within the C-X band. Therefore, additional optimization was carried out to improve the S11 over the frequency range of 4–9 GHz. This optimization was achieved by making a small adjustment to the backshort position, precisely 1.5 mm lower than its initial position, which provided slightly better S11 performance within the frequency band.

The figures show the S11 before and after the dielectric lens was added. Similar to the wideband results, the antenna without the lens provides better S11 performance. Nevertheless, the simulation results with the lens are also good throughout the frequency band. The lens is one of the most important components of the horn, as it is required to maintain the desired radiation characteristics.

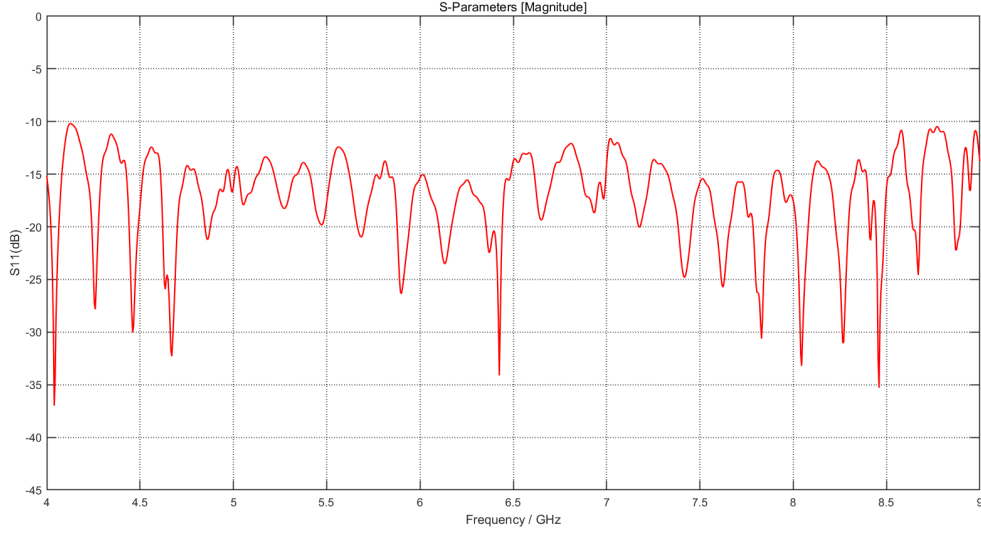


Figure 5.2: S11 4-9 GHz

5.2 Radiation Pattern Analysis

The far-field radiation characteristics of the designed antenna were analyzed with respect to the selected frequencies within the working frequency range of 4-16 GHz. The radiation patterns have been analyzed in the E-plane, D-plane, and H-plane with regard to the shape, symmetry, and polarization characteristics of the antenna.

Within the operating frequency range of 4 - 9 GHz, the radiation patterns were measured at three frequencies i.e. 4 GHz, 6.5 GHz, and 9 GHz. The extended frequency range (4-16 GHz) was checked at 4, 10, and 16 GHz. These frequencies represent the lower, mid, and upper frequency regions respectively.

The simulated radiation patterns are normalized to the maximum gain at every frequency. The E-plane and H-plane patterns are used to access the main beam features and the symmetry of the beam, while the D-plane pattern provides more understanding of the radiation behavior of the antenna in the diagonal plane. The co-polarized and the cross-polarized patterns are also presented when applicable in order to evaluate the antenna polarization.

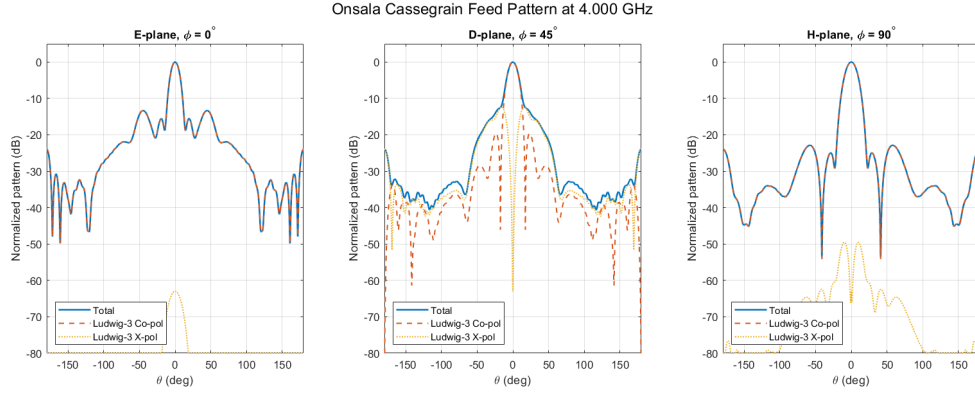
At 4 GHz, the antenna has a wider main beam because the electrical size of the aperture is smaller. The E, D, and H-plane radiation patterns show a clear main lobe and some symmetry present. The D-plane measurements show that the co-polarized and cross-polarized levels show good agreement with one another which confirms that there is a good polarization performance achieved in the lower frequency range.

With a frequency increase to 10 GHz, the main beam becomes narrower due to the enlarging electrical aperture size. The E-, D-, and H-plane radiation patterns keep being stable, however, the directivity and beamwidth measurements improve compared to the

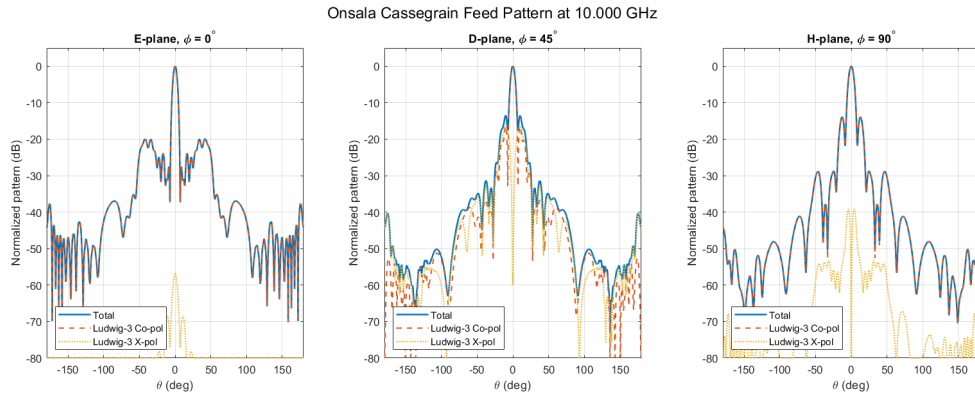
lower frequency values. The co-polarized performance dominates the radiation pattern, while the cross-polarized value stays below the main beam.

When operating at the highest frequency of 16GHz, the beamwidth of the antenna reduces further while also demonstrating a much more directional radiation pattern. The E and H plane patterns are found to have similar beam shapes, displaying that the antenna behaves symmetrically in terms of the radiation characteristics in the whole frequency region. The D plane simulation results show the co-polarized and cross-polarized levels confirming the feed polarization properties at the maximum frequency.

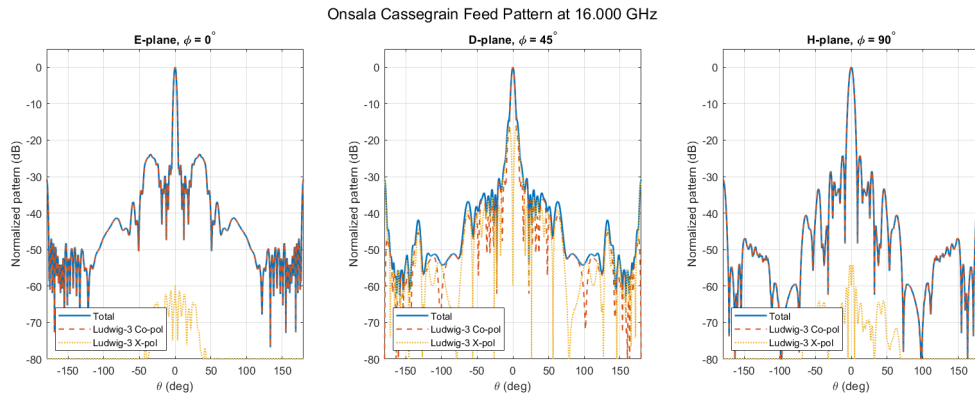
In conclusion, the pattern of the antenna radiation has stable beam parameters in a wide frequency range of 4-16 GHz. The practical effect of the narrowing of the beam with increasing frequency can be easily explained by increasing the size of the antenna aperture.



(a) 4 GHz



(b) 10 GHz



(c) 16 GHz

Figure 5.3: Radiation Pattern 4-16 GHz

5.2.1 -12 dB Beamwidth

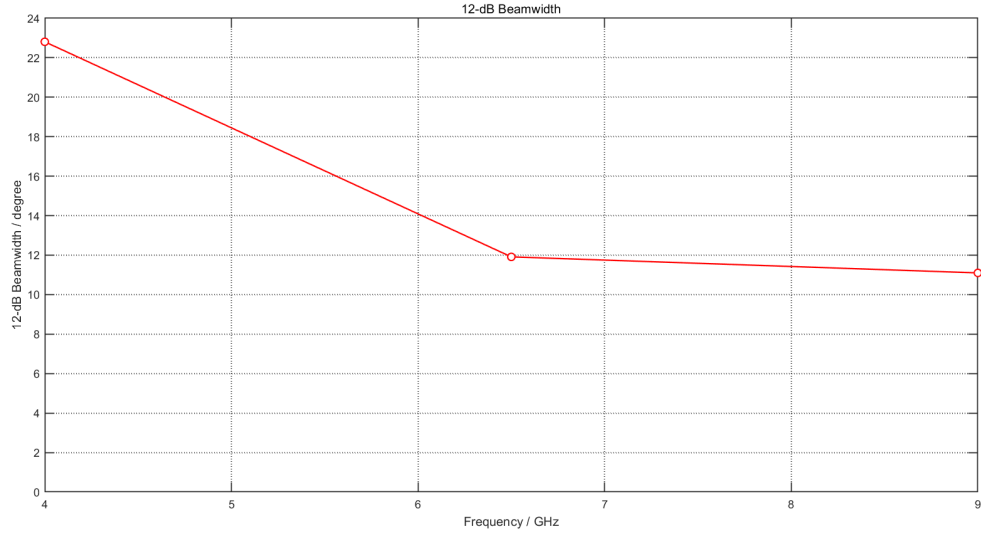
While the conventional 3dB beamwidth is a standard measure in most of the reference documents, for reflector-feed usage the beamwidth defined in terms of edge taper level is more relevant. Thus, in the specified design the target edge taper is chosen to be equal to -12 dB that allows achieving a reasonable trade-off between reflector illumination

efficiency and spillover noise.

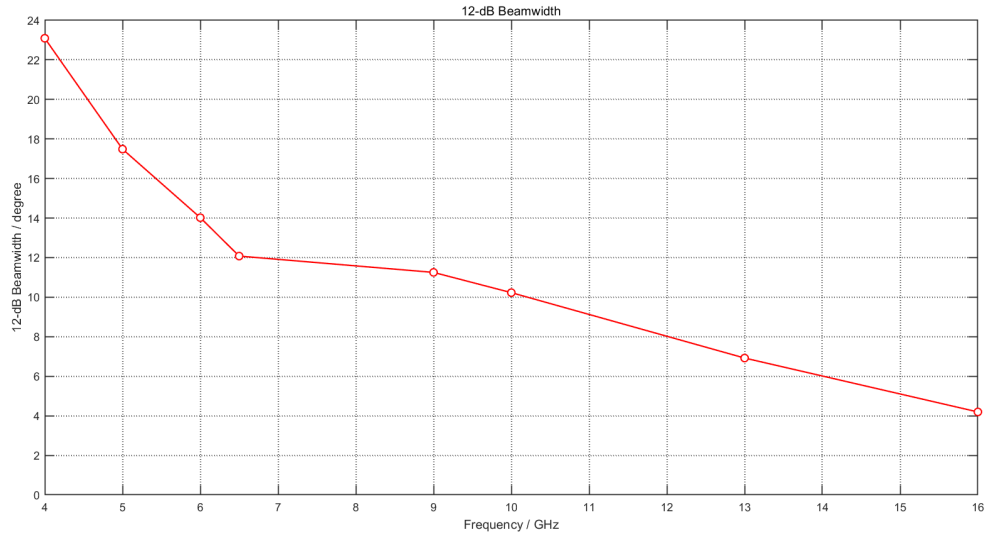
The figure presents the variations in -12 dB beamwidth measured over the operating frequency bands. The beamwidth has been calculated from the simulated radiation patterns at angular coordinates where the radiation intensity is 12 dB less than the top level of power radiated by the main beam.

The results show an overall downward trend in beamwidth with increasing frequency. This trend is expected because when the wavelength decreases, the effective electrical aperture increases.

The relatively smooth variation of the -12 dB beamwidth indicates stable radiation performance and demonstrates that the proposed feed is capable of providing the required edge taper over a wide frequency range. This contributes directly to improved aperture efficiency and reduced spillover toward the ground and surrounding structures.



(a) 4-9 GHz



(b) 4-16 GHz

Figure 5.4: 12 dB beamwidth

5.3 Antenna Efficiency

The efficiency of the presented feed antenna was determined by taking into consideration the main components of efficiency that are relevant for employing reflector antennas. The considerations consider the antenna efficiency achieved through electromagnetic simulations along with the reflector-related efficiency parameters such as spillover efficiency and illumination efficiency. GRASP used to make the copy of the reflector antenna setup.

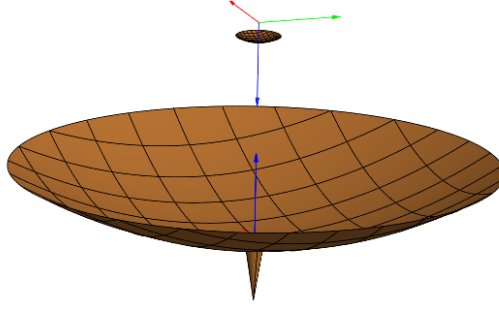


Figure 5.5: GRASP Model

5.3.1 Spillover Efficiency

The evaluation of spillover efficiency was done using the simulated radiation patterns of the feed antenna and reflector geometry. Spillover efficiency represents the fraction of the radiated power that is intercepted by the reflector compared with the total radiated power. A high spillover efficiency is always the goal, as this allows for a reduction in unwanted radiation and added noise.

Figure shows the change in the spillover efficiency with various frequencies. As seen from these results, the spillover efficiency does not exceed 60% till 10 GHz. The change of the efficiency at higher frequencies occurs due to the change of the feed radiation pattern and consequently the corresponding reflector illumination.

The obtained spillover performance is related to the frequency-dependent beamwidth of the feed antenna. As the frequency increases, the radiation beam becomes narrower, which affects the amount of power intercepted by the reflector. and increases spillover efficiency.

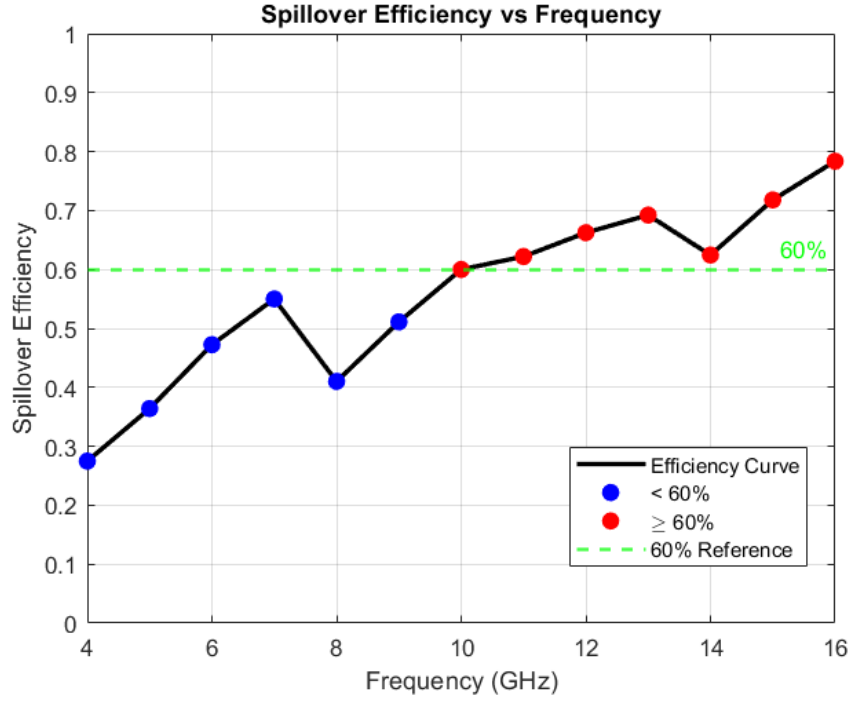


Figure 5.6: Spillover efficiency

5.3.2 Illumination Efficiency

The illumination efficiency of the reflector system was evaluated to determine how effectively the feed radiation pattern illuminates the reflector aperture. The efficiency depends on the amplitude distribution of the incident field over the reflector surface.

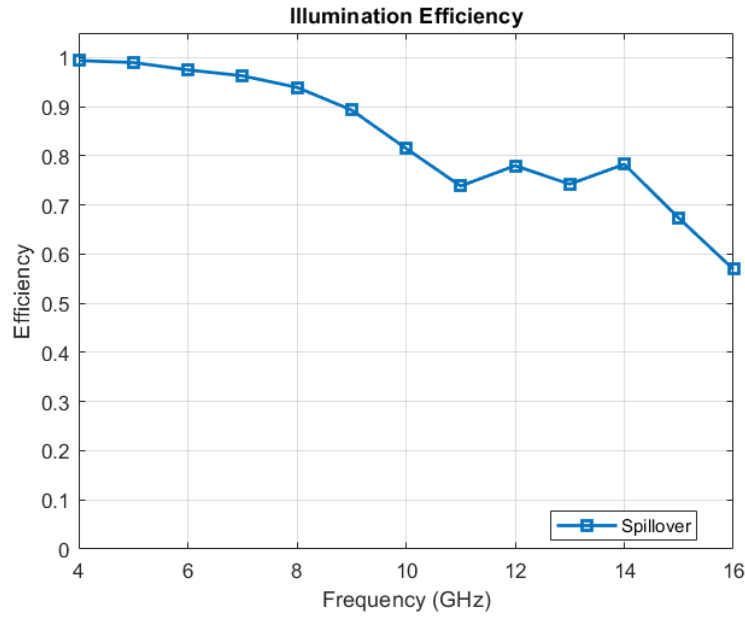


Figure 5.7: Illumination efficiency

Figure presents the illumination efficiency variation over the operating frequency

range. The figure shows a downward trend related to the frequency. Illumination efficiencies stay above 60% almost throughout the frequency range. The results are analyzed to evaluate the suitability of the proposed feed for reflector operation.

5.3.3 Aperture Efficiency

For the present reflector-feed analysis, the total efficiency is calculated from the spillover efficiency and illumination efficiency. It is expressed as

$$\eta_{\text{combined}} = \eta_{\text{spillover}} \eta_{\text{illumination}}.$$

This represents the combined effect of the power intercepted by the reflector and the distribution of the feed radiation over the reflector aperture.

This paper takes into account spillover and illumination efficiencies only as it aims to measure the performance of the feed as an illuminator for a reflector. The prefixed definition of efficiency has not included other efficiency components like phase efficiency, polarization efficiency, blockage efficiency, and surface efficiency. These efficiencies depend on other parameters of the reflector and system, which means that they are not included in the analysis of the feed design under consideration in this research work.

Therefore, the product of the spillover and illumination efficiencies is used as the combined efficiency metric for evaluating the effectiveness of the proposed feed in illuminating the reflector.

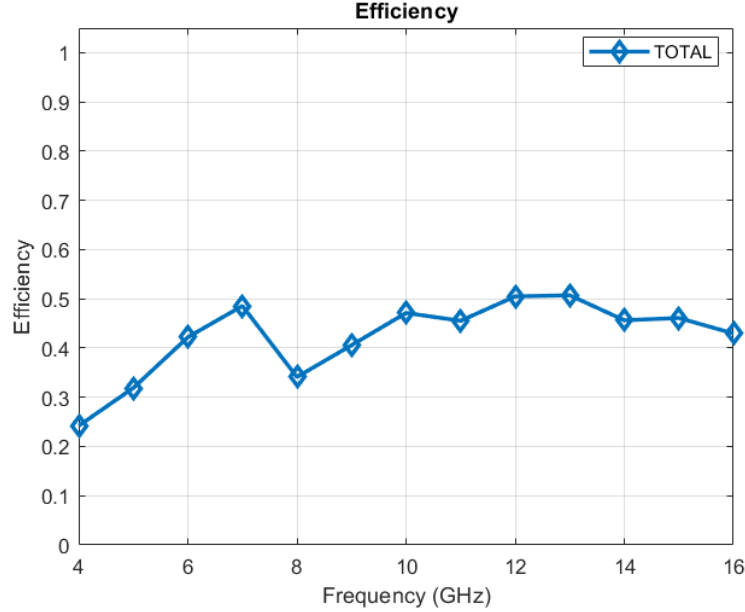


Figure 5.8: Total efficiency

5.4 Comparison with Scaled Designs

In order to understand the effect of scaling the antenna design on its performance, the scaled version of the existing design was studied. The objective of this study was to check if there is any improvement in radiation characteristics with increasing the overall dimensions of the antenna and if these can be brought closer to the reflector-feed application requirements.

5.4.1 Scaling Factor of 1.5

A scaling factor of 1.5 was applied to the original antenna geometry. With this newly scaled design, the antenna performance was then studied throughout the 4–9 GHz frequency spectrum to identify the effects of increasing the electrical size of the antenna on important characteristics such as the impedance matching, radiation pattern, and efficiency.

Based on the new dimensions of the antenna, the feeding configuration was adjusted. The first port was installed at a distance of 16.5 mm from the base position, while the second port could be found at a distance of 15.81 mm from the same base position.

The scaled design simulation reflection coefficient reflected acceptable impedance match with S_{11} nearly -10 dB throughout the selected frequency range. Also, increasing the dimensions has considerably decreased the beamwidth as compared with the original design. It can be concluded that the antenna geometric scaling improves the antenna directivity and narrows the radiation beam.

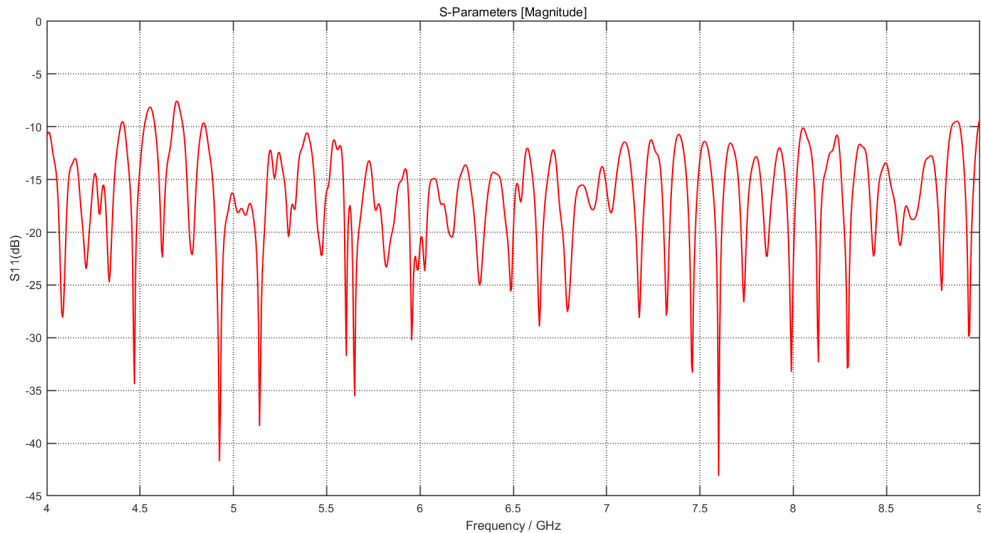


Figure 5.9: S_{11}

However, although the beamwidth was improved, the scaled design could not reach the needed beamwidth condition of -12 dB at 4 GHz. Moreover, the efficiency performance

was only below 60 percent of the required value for the whole frequency range. Hence, it is concluded that although improving in terms of geometry was realized, the performance needed cannot be reached through scaling alone.

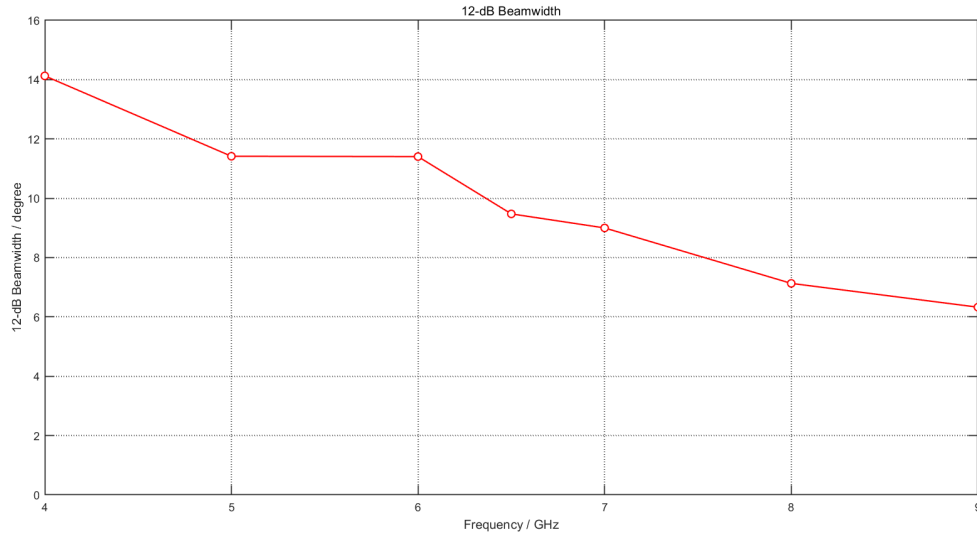


Figure 5.10: 12 dB Beamwidth

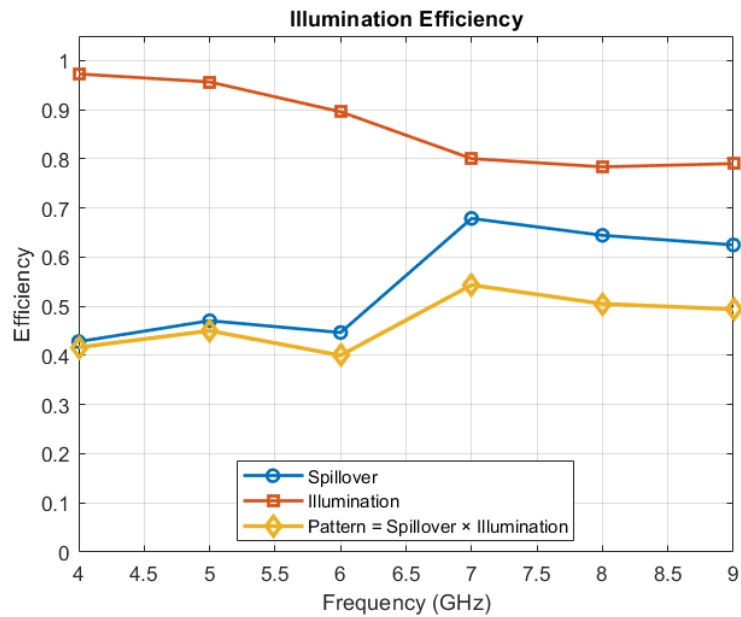


Figure 5.11: Efficiency

This scaled design study revealed the shortcomings of the sole application of geometric scaling method and revealed the need for further investigations and enhancements to the designs towards improving antenna performance.

5.4.2 Scaling Factor of 1.8

A scaling factor of 1.8 was applied to the reference antenna design so as to study the influence of antenna size increase on the radiation properties. The dimensions were tested by means of simulation in the frequency band from 4 to 9 GHz.

The position of ports was also modified to achieve appropriate impedance matching. The first port was found to be at 24.66 mm from the bottom of the antenna, which is achieved by placing it at 3.24 mm from the backshort, and similarly, the second port is adjusted at a distance of 25.66 mm from bottom which is also equal to 4.24 mm from the backshort.

According to the analyzed simulation data, it becomes clear that the reflection coefficient S_{11} reaches -10 dB within the frequency range, indicating good impedance matching between the antenna under investigation and the feed line. It should also be noted that the design enabled the significant increase in the beamwidth compared to the beamwidth associated with the smaller design.

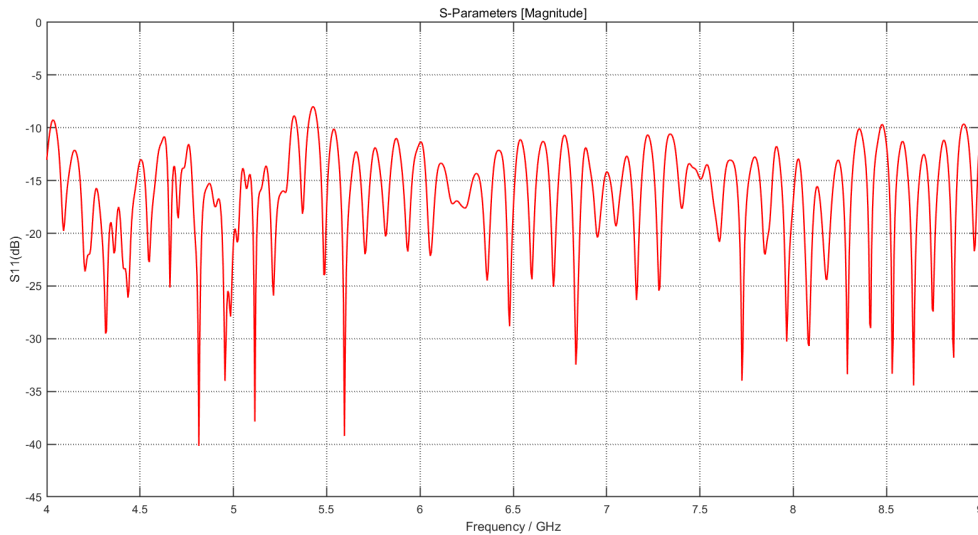


Figure 5.12: S_{11}

The beamwidth under the -12 dB radiation level was determined. This level is crucial for the reflector edge tapers which are being studied in this research. The beamwidth equal to -12 dB does not exceed 12 degrees during the frequency range, with the beamwidth reaching approximately 12 degrees at 4 GHz.

The assessment of spillover and illumination efficiencies was conducted. Despite the fact that the individual efficiencies spillover and illumination were generally greater than 60 percent, the product was still below 60 percent. Therefore, the total efficiency could not reach the target of 60 percent.

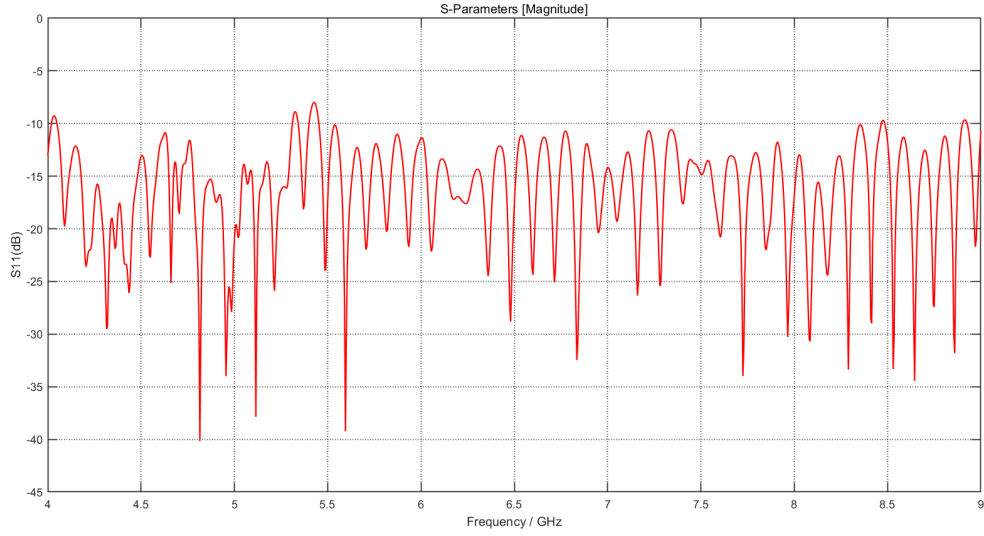


Figure 5.13: 12 dB Beamwidth

The application of the 1.8-sizing allowed for significantly better beamwidth performance and fulfilled the beamwidth requirement of -12 dB at a frequency of 4 GHz. At the same time, the total efficiency did not exceed 60 percent, which indicates that additional design changes are required.

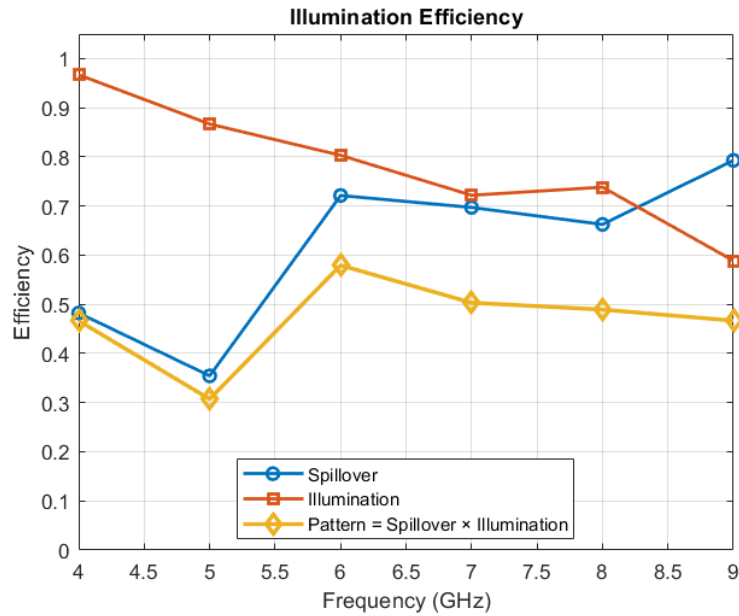


Figure 5.14: Efficiency

Chapter 6

Discussion

6.1 Design Trade-offs

The design of a wideband reflector feed requires a balance between several antenna parameters. Changing one parameter can adversely affect others. Consequently, the design is the result of consideration of the total antenna efficiency rather than optimization of a single parameter.

In the process of choosing between the beamwidth and the efficiency we faced a significant dilemma. Increasing the size of the antenna using the geometrical scale made it possible to achieve a narrower beam, which corresponded to the greater chances of obtaining the beamwidth equal to -12 dB. However, narrowing the beam does not mean that the efficiency can be increased because there are also such parameters as illumination efficiency and spillover efficiency that should be taken into account.

The geometry of the ridge performed an important role in the radiation parameters of the antenna. Changing the geometry of the ridge allowed to gain additional control over the pattern and the beamwidth. However, changing the geometry of the ridge affected the impedance matching and the field distribution in the horn.

The flare geometry provided another degree of freedom for controlling the radiation pattern. Similarly, the use of a lens helped improve the ability to shape the beam of light. It was customary to view these changes as a single entity as merely improving beamwidth would not yield the necessary reflector-feed performance results.

The position of the backshort and the ports were also influential in the impedance matching of the antenna. Their location was changed so as to achieve reasonably acceptable reflection coefficient performance while having reasonable radiation characteristics.

In general, it has been stated that the design process is characterized by a compromise between impedance matching, beamwidth, spillover efficiency, illumination efficiency, and physical characteristics of the given design.

6.2 Limitations

Despite the fact that the design presented has shown notable improvements in the area of beamforming and operation over a diverse frequency range, there are still several limitations associated with it.

The greatest limitation lies in the combined efficiency of the system. Despite the fact that both the reflectors' spillover efficiency and illumination efficiency achieved values greater than 60 percent when measured separately in the range of frequencies used, the resultant value for their combination is still below the desired level of 60 percent.

The beamwidth is another constraint as it is close to the required value at the frequency of 4 GHz. However, further progress must be made to enhance it with sufficient margin across the frequency band.

The current study is primarily focused on the analysis of feed radiation properties, spillover performance, and illumination efficiency, while other components of the total efficiency of the reflector antenna, such as phase efficiency, polarization efficiency, blockage efficiency, and reflector surface efficiency, were not studied in this work.

Moreover, the findings contained in this thesis come from electromagnetic simulations rather than any experimental data involving the manufactured antenna. Therefore, the manufacturing imperfections, diversity in materials used, and influence of connectors can alter the functioning of the real antenna.

6.3 Comparison with Existing Designs

During the antenna design process, several wideband quad-ridged horn designs documented were taken into account. These designs are characterized by a good performance over a wide frequency range but were created for different reflector systems and engineering requirements, so it would not be correct to compare them based solely on their bandwidth or efficiency.

For the present research, the main goal is to develop the antenna with narrow radiation patterns compatible with the Onsala Cassegrain reflector system while having reasonable impedance matching and efficiency. Thus, in order to select appropriate designs for the comparison purposes the existing designs are analyzed taking into consideration their radiation characteristics, design approach, difficulty of implementation and their suitability for the discussed goals.

6.3.1 Spline-Defined Quadruple-Ridge Flared Horn

The first design considered is the spline-defined quadruple-ridge flared horn reported by Dong et al. [1]. This antenna was created to serve as a broad band feed for reflector an-

tennas under operating frequency ranges of 4.6 GHz to 24 GHz. This design incorporates the use of spline-defined profiles for both horn sidewalls and ridges of the horn, and also includes a conical cavity in the backshort.

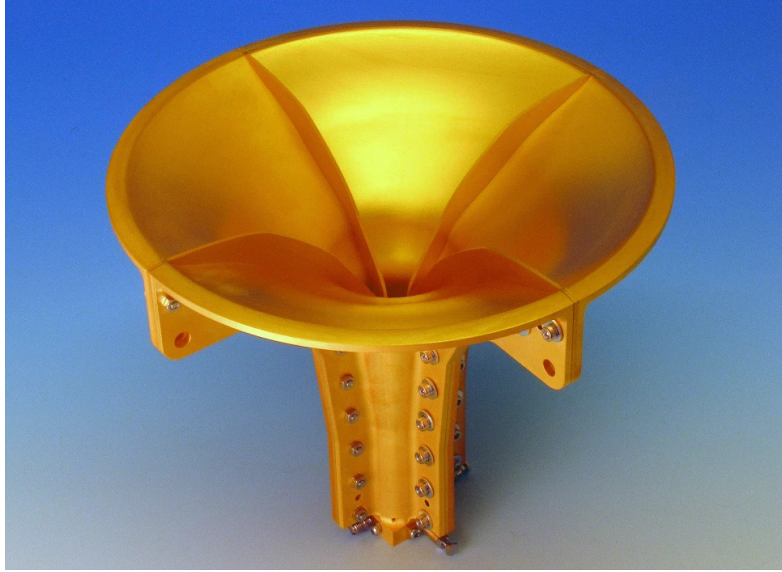


Figure 6.1: Geometry of the spline-defined quadruple-ridge flared horn

The most significant advantage of this design is that the spline-defined profiles give a great deal of freedom in controlling the design of ridges and horn during the optimization process. As reported, this design also provides a good aperture efficiency within a wide operating frequency range and preserves good matching of impedance.

This type of design is important for this thesis because of the similarity between the spline-based approach and the approach chosen for control of ridge profile. With spline-controlled points in hand, one can modify the geometry of the antenna in a way that does not restrict one to the use of simple analytical curve.

However, the antenna reported in [1] was optimized for a different reflector configuration and performance objective. Its main goal was to achieve high aperture efficiency over a very wide frequency range. The radiation beamwidth is another requirement of this work, since the proposed feed is required to provide a narrow beam in accordance with the edge-taper condition of the Onsala Cassegrain reflector.

Compared with the spline-defined reference design, the proposed antenna has been developed with a greater focus on minimization of the beamwidth, particularly at low frequencies. The present work proves that the modification of the antenna geometry can allow for the achievement of a beam that is significantly smaller than the beam obtained with the reference design. However, the overall efficiency achieved in the present work is lower than the high efficiency of the aperture provided with the reference design. Thus, the obtained comparison reveals a trade-off between low beamforming and overall efficiency.

6.3.2 Beyond-Decade Dielectric-Loaded Quad-Ridge Flared Horn

The second design considered is the beyond-decade ultrawideband quad-ridge flared horn with dielectric loading. The purpose of this design was to achieve a much wider operational bandwidth with better control of the radiation pattern.



Figure 6.2: Geometry of the beyond-decade dielectric-loaded quad-ridge flared horn

One of the key advantages of dielectric loading is that it allows for an added degree of control over the electromagnetic field configuration and the radiation pattern. Hence, it enables to achieve desired beam performances other than merely applying changes in the metallic geometry of the horn. This design also reveals very wide operational bandwidth.

When it comes to wideband reflector feeds, dielectric loading is a good way of managing beamwidth. The challenge posed by using a dielectric material, however, is that it unnecessarily complicates the design and manufacture of the reflector. Good care must be taken in developing the dielectric configuration to ensure that it does not adversely impact the efficiency and field distribution of the antenna.

In the context of this study, the main limitation is that the original design was created for a different frequency range and reflector system, which would limit its application to the Onsala Cassegrain reflector.

The described design utilizes a technique of altering geometries pertaining to both ridge as well as horn structures for purposes of directing a radiation beam. The specific goal consists of decreasing beamwidth in the particular frequency range of interest. Although the current design makes it possible to accomplish the required narrow beamwidth, especially after the process of modifying shapes and scaling, the combined efficiency still remains lower than the required value of 60%. Thus, while the current work applies a different method of shaping the beam as compared to the dielectric-loaded design, the

efficiency requires improvement.

6.3.3 Square Quad-Extended-Ridge Flared Horn

The third design that has been considered is the flared horn with a square quad extended ridge. This type of design uses extended ridges, whose width differs from one another, in a square horn structure.

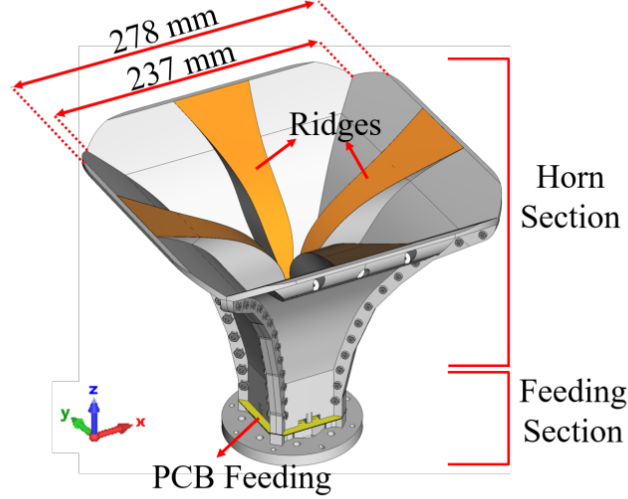


Figure 6.3: Geometry of the square quad-extended-ridge flared horn

The extended ridges have the role of allowing better control of the electromagnetic field distribution in both planes E and H. The basic quad ridge horn has very good control of electric field distribution in plane E but not as good in plane H.

Because the extended ridge method employs more geometrical features, this results in better control of the field distribution in both planes. Thus, the main advantage of this kind of design is the increased control of the radiation beam in both planes, which is very effective for wideband reflector feeds that require stable beamwidth characteristics across a relatively broad range of frequencies.

However, the nature of geometry present in the extended-ridge horn is rather complex as compared to that of the conventional quad-ridged horn. The design, however, necessitates the optimization of more design parameters. Moreover, the antenna was developed according to different operating and reflector requirements.

The goal of the proposed design is similar in the sense of providing certain control over the radiation pattern via changes in the ridge geometry. However, the main ambition of the research carried out in this paper is not about keeping the same beam width. Instead, the task is to achieve the necessary degree of beam narrowing that is attainable under the given conditions of edge tapering.

The results obtained in this work show that the beamwidth can be dramatically decreased via the procedure of changing its geometry and scaling it. In this case, the configuration processed with a 1.8 scale shows a beamwidth of 12-degree level at -12 dB at 4 GHz and maintains the same level for the greater frequencies. However, this increase of efficiency that has been achieved by changing the beamwidth is not enough, because the overall efficiency does not exceed 60%.

6.4 Effect of Dielectric Loading

The aim of this study is to analyze the influence of dielectric loading on the characteristics of radiation emitted by a quad-ridged flared horn antenna. More specifically, the role of dielectric materials in the beamwidth of radiation is analyzed. The dielectric loading affects the electromagnetic fields within the antenna and in the surrounding region, changing the radiation characteristics.

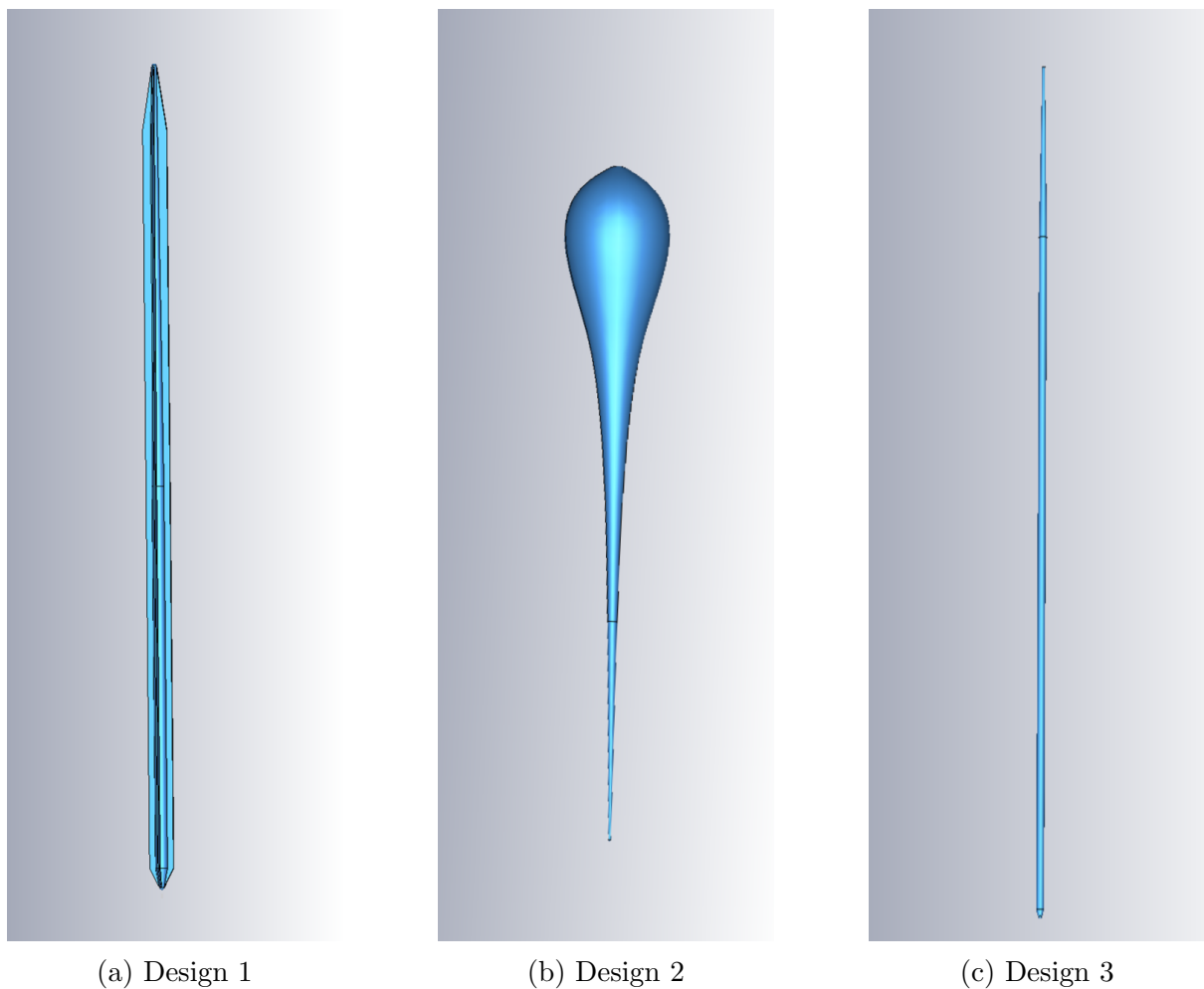
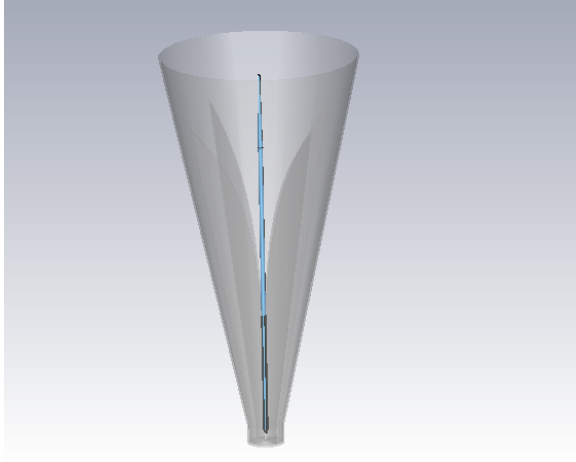
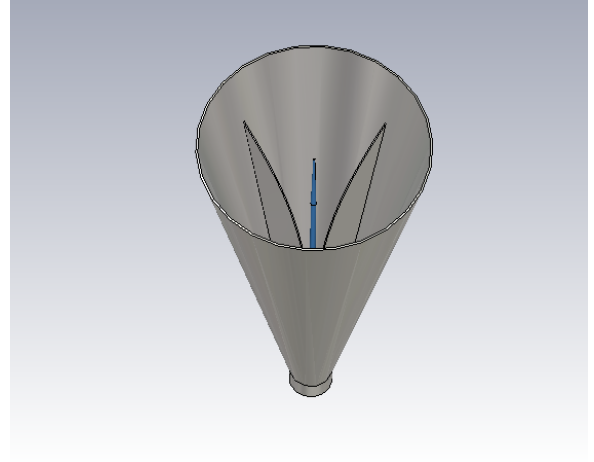


Figure 6.4: Different designs of dielectric loading



(a) Design 1



(b) Design 2

Figure 6.5: Dielectric loading (setup)

There have been various designs of dielectric-loaded quad-ridged flared horns. These designs highlight the role of dielectric loading in controlling the radiation characteristics of the antenna. Some of these designs are shown in the figure. (dielectric used 6.4 c)

Figure shows that the dielectric loading has a clear influence on the radiation beamwidth. However, the extent to which dielectric loading impacts the beamwidth is influenced by the frequency of operations and by the presence of the lens.

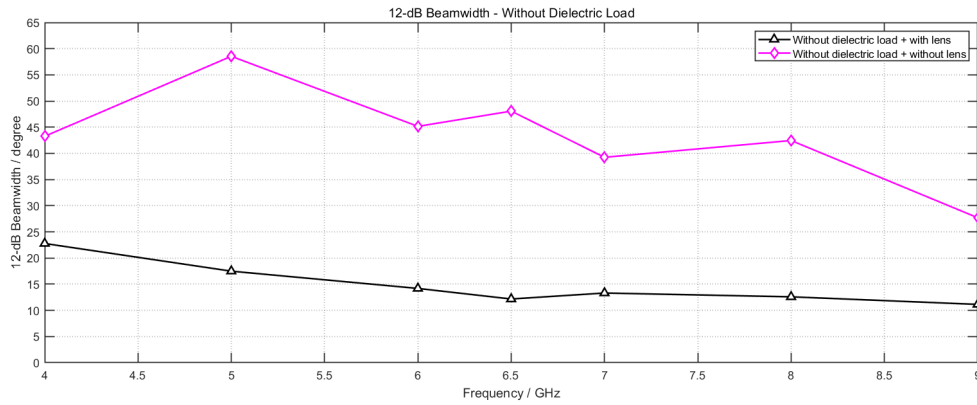


Figure 6.6: 12 dB beamwidth without load

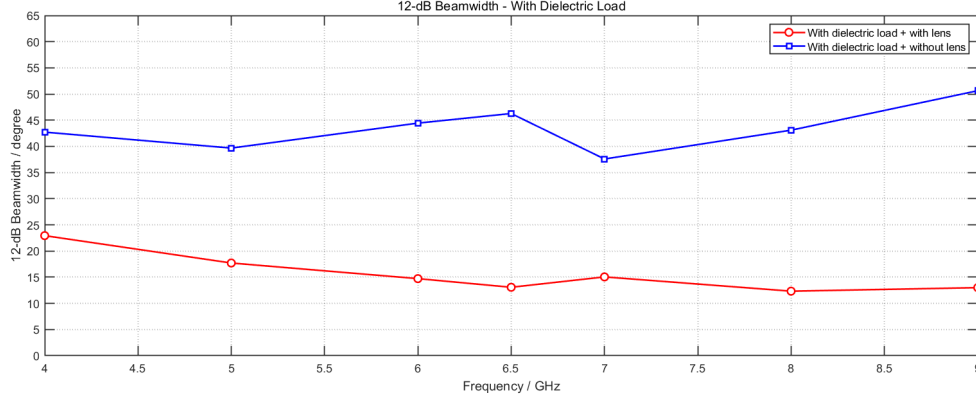


Figure 6.7: 12 dB beamwidth with load

When no lens is added to the design, the dielectric loading has a significant impact on the beamwidth at multiple frequencies considered. For instance, the -12 dB beamwidth can be reduced from around 58.5 degrees without dielectric loading to 39.5 degrees when dielectric loading is introduced at the operating frequency of 5 GHz. However, the changes are not consistent across different frequency ranges; at the frequency of 9 GHz, the beamwidth increases from approximately 28 degrees in the absence of dielectric loading to about 50.5 degrees with dielectric loading.

The presence of the lens sufficiently reduces the differences between the cases with and without dielectric loading. The beamwidth is kept at the range of approximately 11 degrees to 23 degrees for all frequencies under consideration. Thus, we can say that the lens is able to control the beamwidth to a considerable extent, while the additional influence of dielectric loading is minimized.

Thus, it is incorrect to view dielectric material as merely a method for decreasing beamwidth. The results indicate that the use of dielectric material presents additional options for modifying radiation characteristics of quad-ridged flare horns, especially at higher frequencies. The nature of its influence is dependent on frequency and dielectric material-to-lens interaction. But the load is trying to increase the higher frequency beamwidth, which will significantly improve the illumination at higher frequencies.

This result is important for further improving the feed antenna. A combined optimization of the properties and dimensions of dielectric loading, as well as of the geometry of the lens and antenna, will make it possible to achieve a greater control over beamwidth. However, such a combined optimization was not considered in this paper.

Chapter 7

Conclusion

7.1 Summary of Work

This thesis investigated the design and optimization of a wideband (4-16 GHz) feed antenna for the Onsala Cassegrain reflector system. The primary objective was to create a feed antenna with reasonable impedance matching and considerable feed-reflector efficiency in the necessary range of operating frequencies. The desired specifications included a reflection coefficient below -10 dB and an overall efficiency exceeding 60%. To meet these goals, the feed antenna radiation pattern needs to ensure proper illumination of Cassegrain reflector. Thus, the steering of radiation pattern width and -12 dB edge-taper treatment indicators play a relevant role in the antenna designing process.

The study started with a review of the theoretical concepts of antenna radiation focusing on the radiation patterns, antenna gain, directivity, polarization, bandwidth, and efficiency of antennas. Various designs of wideband feed antennas from literature were also evaluated to understand the benefits and limitations of available techniques.

The antenna designed was a quad-ridged horn configuration. The ridge profile, flare design, position of the ports, and backshort were specifically given priority. A spline-based method was utilized to create the ridge profile, enabling flexibility in improving the design of antennas in terms of radiation features and geometry. Various geometric configurations of antennas were assessed for their impact on the beamwidth, efficiency, and impedance matching of the antennas.

Geometrically scaled antennas have been studied for their capability to improve the radiation beamwidth. Types of scaled configurations show that higher antenna dimensions result in narrower beamwidth. Thus, the configuration where the antenna had a scaling factor of 1.8 exhibited improvement in beamwidth performance.

The final designs have been verified in terms of the simulated radiation patterns and reflection coefficient, spillover efficiency, illumination efficiency, and combined aperture efficiency. The radiation characteristics were analyzed within the operating frequency

ranges and compared to the requirements of the Onsala Cassegrain reflector system and other antennas used in practice.

7.2 Key Findings

The main findings of this work can be summarized as follows:

- A spline-based ridge profile provides a flexible method for controlling the quad-ridge horn shape and analyzing how it affects the radiation characteristics
- Geometric scaling greatly affects the beamwidth of radiation produced. Expanded dimensions of the antenna result in significantly narrowed beam radiation.
- In the case of the 1.8-scaled version, the beamwidth of around 12 degrees was achieved at the -12 dB level at 4 GHz frequency, while it was observed that the beamwidth stayed under this value within the studied range of frequencies.
- The optimal positions of the ports allowed achieving good impedance match with S11 around -10 dB within the frequencies considered in the work.
- Analysis of the spillover efficiency and illumination efficiency showed that in most cases their average values were above 60%. However, their joint product value remained below 60% proving that the narrow beamwidth is not necessarily followed by high overall efficiency.
- The results obtained while comparing the developed wideband feed with the existing designs showed that the majority of the reference designs yield good results in terms of bandwidth and efficiency, however, they were developed for different systems and also for other applications.

The overall results indicate that the geometry of quad-ridged horn antennas should be altered in order to improve beamwidth. The narrower beam was obtained through geometry scaling and antenna profile optimization. However, an enhancement of beamwidth also resulted in decline of efficiency. Although achievement of the desired beamwidth or close approximation was possible, the efficiency was still insufficient. Therefore, further enhancement is necessary to achieve better beamwidth-to-efficiency ratio.

Chapter 8

Future Work

8.1 Improvements

The findings of the current study illustrate considerable improvements with respect to beamwidth of the radiation via geometry modification and scaling of the antenna but the efficiency indicator did not reach the desirable level. This means that further research must focus on the optimization of the trade-off between beamwidth and efficiency parameters.

Optimizing the ridge profile, horn flare, and backshort design for field distribution may provide better gain and illumination values with required narrow beamwidth parameters. It is worth suggesting that generalized optimization of several parameters simultaneously must be considered instead of separate study of each parameter.

The placement of ports and appropriate structure can improve overall performance in terms of impedance matching for all frequencies. Furthermore, other ridge and flare shapes can be examined to determine if it is possible to get better radiation characteristics without increasing the size of the antenna significantly.

Another possible improvement is research on the positioning of the feed antenna in the Cassegrain reflector system. In the present configuration, the feed is located at the vertex of the main reflector. Moving the feed antenna up, closer to the sub-reflector may reduce the beamwidth needed to illuminate the sub-reflector. This will enable better designs of the feed, and possibly higher spillover and illumination efficiency. Thus, the influence of different positions of feed within the reflector system should be studied in the future work.

8.2 Experimental Validation

The results presented in this thesis are mainly based on electromagnetic simulations. Hence, the fabrication and experimental verification of the antenna design is an essential

follow-up step to be taken.

In order to do this, a prototype of the antenna may be manufactured and tested in order to measure the reflection coefficient and radiation patterns. The results obtained from measurements can subsequently be compared with the ones received during simulations.

Conducting experimental measurements will enable the examination of some practical factors like tolerances in manufacturing, materials, connector losses, and errors in construction that may impact the functioning of the antenna especially in the process of working at different frequencies.

Additional measurements performed while using the full reflector system will be important as well in order to understand the real spillover and illumination attributes of the antenna in practice.

8.3 Further Research Directions

There is also a possibility for further research of different techniques for enhancing both the radiation pattern and efficiency of the antenna. Different possible ridge shapes, horn forms, or dielectrics may be studied for improved control over the aperture field distribution.

Thus, an advanced line of optimization may be used in the automatic search for the best combination of ridge, flare, port, and backshort parameters. This leaves more time for the previous studies and results in better overall performance.

A different research direction involves exploring the combined system consisting of the antenna and reflector. The entire system could be optimized together instead of separately optimizing the feed antenna. Here, the pattern of the antenna radiation can be optimized directly based on the requirements and shape of the Onsala reflector.

Moreover, future studies can create an idea for improvement of the total efficiency while keeping the high gain narrow beam developed in this research. Achieving the goal of bringing high efficiency in combination with the needed beam shape over a large frequency interval still poses a challenge making it relevant for future work.

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