INVESTIGATION OF THE OPTICAL ARRANGEMENT IN RADIO TELESCOPES

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A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Engineering (Hons) Electronic Engineering

Faculty of Engineering and Green Technology
Universiti Tunku Abdul Rahman

September 2015

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"INVESTIGATION OF THE OPTICAL ARRANGEMENT IN RADIO TELESCOPES"** was prepared by YEHDISH A/L MAKHAN LAL has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons) Electronic Engineering at Universiti Tunku Abdul Rahman.

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Supervisor : Dr. Lee Sheng Chyan

Date : 15 September 2015

Specially dedicated to my beloved family
who had contributed to this point in the
success of my academic pursuit

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Thank you.

INVESTIGATION OF THE OPTICAL ARRANGEMENT IN RADIO TELESCOPES

ABSTRACT

Radio telescopes are instruments that are widely used by astronomers to study astronomical objects which emit radio waves on the Earth at different wavelengths and frequencies. A radio telescope operates by detecting and receiving the emitted radio waves from the outer space. These radio waves are converted into radio frequency (RF) signals and they are sent to the radio receiver for further processing before their information are stored into the computer and recording devices. A radio telescope basically consists of reflector system, feed system, RF transmission line and a radio receiver. Both the reflector system and feed system are the two elements that form the optical arrangement in the radio telescope. The arrangement of these optical elements has a great impact on the performance of radio telescope. Therefore, the performance of the radio telescope was analyzed by varying the size and focal length of the reflector system. This was done by inserting the desired values for the required parameters into the simulation software to design the geometry of the front-feed reflector system. The designed geometry was simulated to generate its radiation pattern for performance evaluation. Overall, the results show that the performance of single reflector feed system can be maximized either by increasing the size or decreasing the focal length of the reflector. In addition, the performance of dual reflector feed system can be improved by trading off both aperture blockage and diffraction loss. Among the 2 different reflector feed system, the single reflector feed system provides the best performance in terms of having a lowest side lobe level Unlike the dual reflector feed system, its mechanical design is much simpler and thus, only a lower construction cost needed.

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LIST OF SYMBOLS / ABBREVIATIONS

d_{ell}	aperture diameter of elliptical reflector
d_{hyp}	aperture diameter of hyperbolic reflector
D_{par}	aperture diameter of parabolic reflector
e	eccentricity of secondary reflector
f	frequency, Hz
f_c	distance between primary and secondary foci
F_{par}	focal length of parabolic reflector
L_v	distance between secondary vertex and prime focus
M	magnification
v	velocity, m/s
λ	wavelength, m
η_i	refraction index of the incident medium
η_{ref}	refraction index of the refractive medium
θ_{hell}	half-angle subtended by elliptical reflector at the feed
θ_{hyp}	half-angle subtended by hyperbolic reflector at the feed
θ_i	angle of incidence
θ_{par}	half-angle subtended by parabolic reflector at the feed
θ_r	angle of reflection
θ_{ref}	angle of refraction
EHF	extremely high frequency
HF	high frequency
LF	low frequency
LNA	low noise amplifier
MF	medium frequency
RF	radio frequency
SHF	super high frequency

UHF	ultra high frequency
VHF	very high frequency
VLF	very low frequency

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

A radio telescope is an instrument that is used in the radio astronomy. It is generally used for detecting, receiving and measuring radio waves at distinct wavelengths and frequencies received on the Earth, which are emitted from the space. These radio waves are a type of electromagnetic radiation and they are usually emitted by the stars, galaxies, pulsars and other astronomical objects. A radio telescope comprises of four basic elements, namely reflector system, feed system, transmission line and radio receiver. Each of these elements has their individual function.

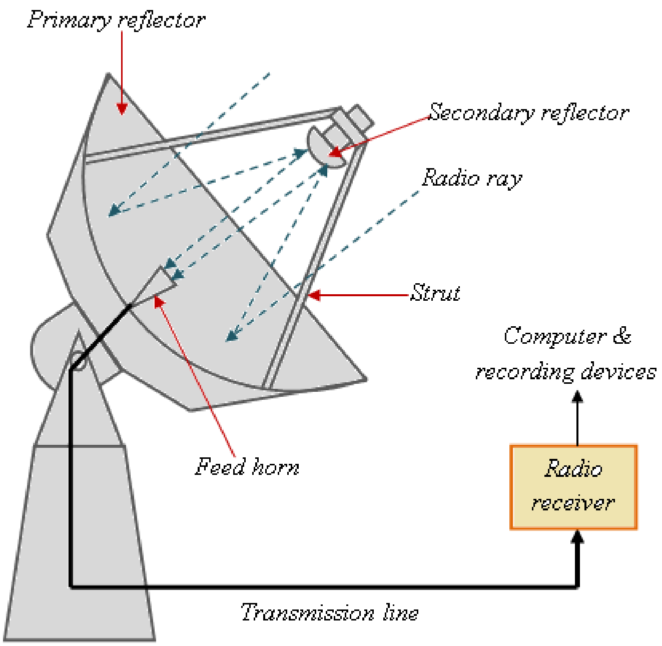


Figure 1.1: Elements of a Radio Telescope

The figure above shows the elements of a radio telescope. In radio telescope, the reflector system collects the radio waves emitted on the Earth and focuses them towards a small central antenna known as the feed horn. This feed system, which collects the reflected waves from the surface of the reflector, converts them into radio frequency (RF) signals before sending to the radio receiver. The transmission of RF signals to the receiver is then carried out by means of transmission line that is connected between the feed system and the receiver. The radio receiver, finally, receives the signal from the line and performs several operations such as amplification, heterodyning and ADC conversion before sending to the computer and recording devices.

A typical optics arrangement in a radio telescope consists of a reflector system and a feed system. The reflector system of a radio telescope can be divided into two types; single reflector system and dual reflector system. A single reflector system only has a primary reflector for collecting the incoming radio waves as well as reflecting and focusing them towards the feed that is located at the primary focal point. On the other hand, the dual reflector system consists of a secondary reflector in addition to the primary reflector. The secondary reflector collects the reflected radio waves from the primary reflector and focuses them towards the feed that is located at the secondary focal point.

A radio telescope offers several advantages compared to an optical telescope. The great advantages of this instrument is that it can operate day and night as well as it is unaffected by the clouds and dust particles in the space when detecting radio signals. However, the main limitation of this instrument is that it requires larger size of primary reflector for detecting and collecting weak radio signals.

1.2 Problem Statements

The arrangement of the optical elements such as the reflector system and the feed system greatly affects the performances of a radio telescope. In other words, the performances of the radio telescope are depending on the feed orientations as well as the sizes and focal lengths of the reflector system. Therefore, in this project we shall analyze the performance of a front-feed reflector system at distinct diameters and focal lengths of the reflector. In addition, we shall also compare the performances for various geometrical configurations of front feed-reflector system operating at different range of frequency with having fixed parameters. The performance analysis of the reflector system shall be analyzed by using GRASP simulation software.

1.3 Aim and Objective

The aim of this project is to investigate the arrangement of the optical elements in a radio telescope. The objectives of this project are shown as following:

i) To analyze the performance of a front-feed reflector system

ii) To compare the performances of various geometrical configurations of front-feed reflector system

CHAPTER 2

LITERATURE REVIEW

2.1 Radio Waves

2.1.1 Background

Radio waves are a form of electromagnetic radiation. They are emitted by astronomical objects such as the Sun, stars, quasars, pulsars and others. Like any other electromagnetic radiations such as visible light, infrared, gamma rays and others, the radio waves have three major properties, namely velocity, wavelength and frequency.

The velocity of a radio wave refers to the travelling speed of the wave and it travels at the speed of light, which is 3×10^8 meter per seconds. The wavelength of the radio wave, on the other hand, refers to the distance between two successive points of one complete cycle of waveform that having the same phase. Lastly, the frequency of a radio wave represents the number of cycles it takes to complete in a second or in other words, it is the reciprocal of the time taken by the wave to complete one full cycle.

The major differences between radio waves and other electromagnetic waves are their frequencies and wavelengths. In the electromagnetic spectrum, the radio waves have the longest wavelength and lowest frequency compared to microwaves and gamma rays *(Refer to Appendix A for Electromagnetic Spectrum).* Generally, the radio waves have frequencies ranging from 3 kHz up to 300 GHz and corresponding wavelengths ranging from 1 mm to 100 km. The relationship between the velocity, wavelength and frequency of a radio wave can be expressed in a single equation as shown below.

$$v = \frac{\lambda}{f} \tag{2.1}$$

where

v = velocity or speed of the radio wave, which is 3×10^8 m/s

λ = wavelength of the radio wave

f = frequency of the radio wave

By referring to the equation above, the wavelength of a radio wave is inversely proportional to its frequency. This indicates that a radio wave having a small wavelength has a higher frequency and vice versa. The table below shows the various frequency bands and wavelengths of radio waves.

Table 2.1: Frequency Bands and Wavelengths of Radio Waves

Band name	Abbreviation	Frequency	Wavelength
Very low frequency	VLF	3 kHz – 30 kHz	100 km – 10 km
Low frequency	LF	30 kHz – 300 kHz	10 km – 1 km
Medium frequency	MF	0.3 MHz – 3 MHz	1 km – 100 m
High frequency	HF	3 MHz – 30 MHz	100 m – 10 m
Very high frequency	VHF	30 MHz – 300 MHz	10 m – 1 m
Ultra high frequency	UHF	0.3 GHz – 3 GHz	1 m – 100 mm
Super high frequency	SHF	3 GHz – 30 GHz	1 m – 100 mm
Extremely high frequency	EHF	30 GHz – 300 GHz	10 mm – 1 mm

2.1.2 Propagation of Radio Waves

The propagation of radio waves are referred to the behaviour of radio waves when they are transmitted or propagated from one point on the Earth to another point or into various parts of the atmosphere. The radio waves are basically affected by six phenomena, namely *reflection*, *refraction*, *diffraction*, *absorption* and *scattering*.

a) *Reflection*

The *reflection* of a wave occurs when the wave hits the surface or boundary at certain angle and reflects upwards from the surface at different angle. The incoming wave which strikes the surface is known as the incident wave where else the wave that reflects from the surface of that medium is known as the reflected wave. When the wave undergoes reflection, its wavelength, frequency and speed are remain unchanged whereas its direction of propagation changes.

When the wave undergoes reflection on a smooth surface, the direction of the incident wave and the reflected wave makes the same angle with relative to the normal of the surface. Thus, the angle of incidence is equal to the angle of reflection and this type of reflection is known as specular reflection or regular reflection. This obeys the law of reflection and it can be written as,

$$\theta_i = \theta_r \tag{2.2}$$

where
θ_i = angle of incidence
θ_r = angle of reflection

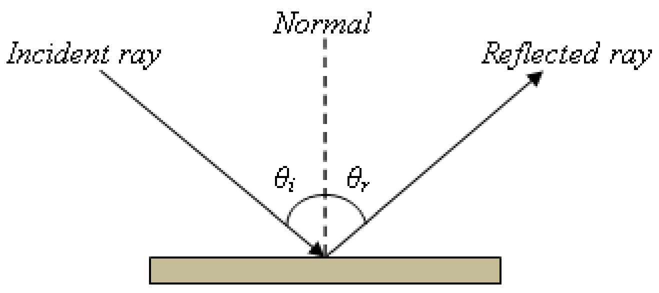


Figure 2.1: Reflection on a Smooth Surface

On the other hand, as the wave undergoes reflection on a rough surface, the direction of the incident wave and the reflected wave does not make the same angle with relative to the normal of the surface. Thus, the angle of incidence is unequal to the angle of reflection and it does not obey the law of reflection.

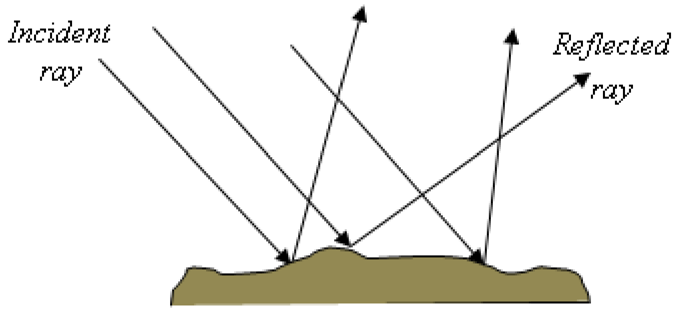


Figure 2.2: Reflection on Rough Surface

However, for the curve surface such as the parabolic shape, a series of incidents waves that move parallel to the axis of parabola are reflected from the surface and head towards to a single point. This point is known as the focal point of the parabola. After passing through the focal point, the waves tend to spread out.

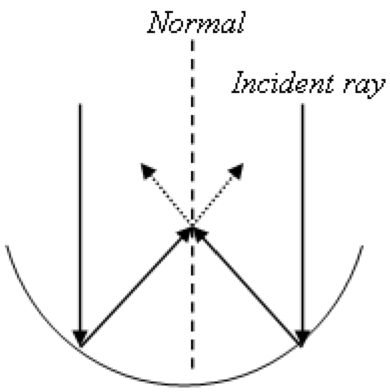


Figure 2.3: Reflection on Curve Surface

b) ***Refraction***

The *refraction* of radio wave occurs when the wave travels from one medium to another medium that are separated by a boundary and having different density levels. The incoming wave which approaches the boundary is known as the incident wave where else the wave that passes through the boundary is known as the refracted wave. The amount of refraction is dependent on the refractive index of the mediums. When the wave undergoes refraction, its frequency remains unchanged where else its wavelength, speed and direction of propagation changes.

When the radio wave propagates from one medium with low refractive index to another medium with higher refractive index, the wave tends to refract away from the normal As a result, the angle of refraction of the medium with high refractive index is smaller than the angle of incidence of the medium with low refractive index. Thus, its speed of propagation decreases which results in shorter wavelength

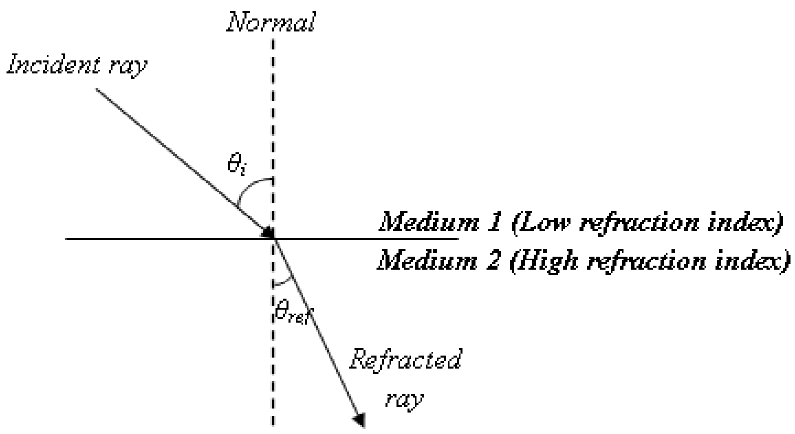


Figure 2.4: Propagation from Low to High Refractive Index Medium

However, when the radio wave propagates from one medium with high refractive index to another medium with lower refractive index, the wave tends to refract away from the normal. Consequently, the angle of refraction of the medium with low refractive index is greater than the angle of incidence of the medium with high refractive index. Thus, its speed of propagation increases which results in longer wavelength.

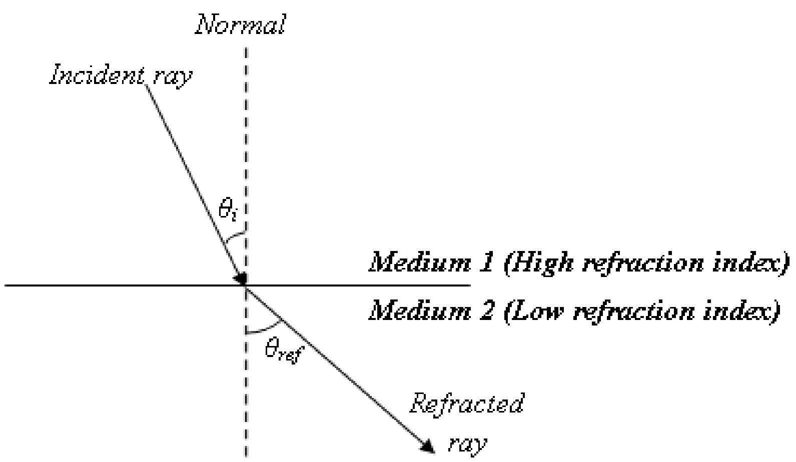


Figure 2.5: Propagation from High to Low Refractive Index Medium

The refraction of radio wave also occurs when the wave travels in a medium having gradual variation of refraction index. This effect can be seen when the wave is travelling approximately horizontally in the Earth's atmosphere because the refractive index of air is slightly greater in the denser lower atmosphere than it is at very high altitudes. This variation is only approximately linear over a restricted range of altitude which is shown in the figure below.

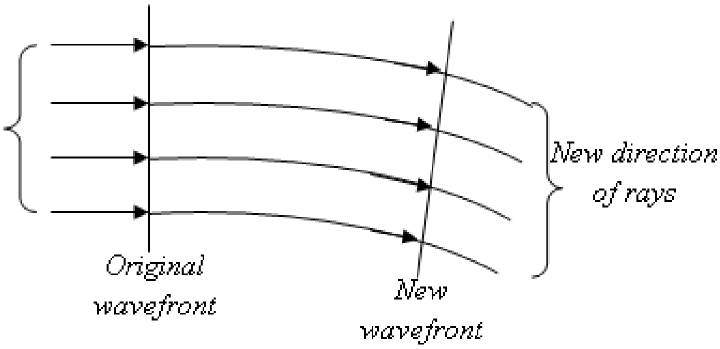


Figure 2.6: Medium Having Gradual Variation of Refractive Index

The relationship between the angles of incidence and refraction and the refraction of indices of the two media is known as the Snell's Law. This law applies to the refraction of wave regardless of what the two media are and thus it can be written as

$$\frac{n_i}{n_{ref}} = \frac{\sin(\theta_{ref})}{\sin(\theta_i)} \tag{2.3}$$

where

θ_i = angle of incidence

θ_{ref} = angle of refraction

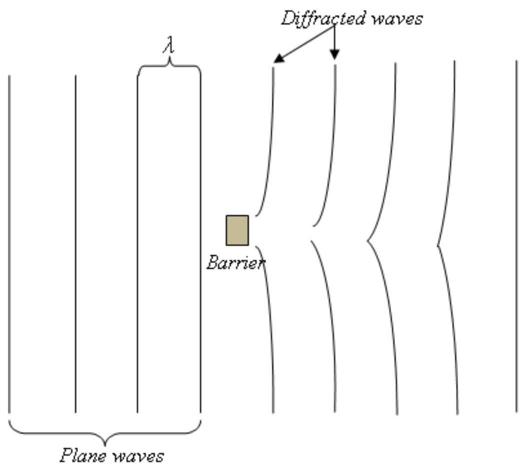
n_i = refraction index of the incident medium

n_{ref} = refraction index of the refractive medium

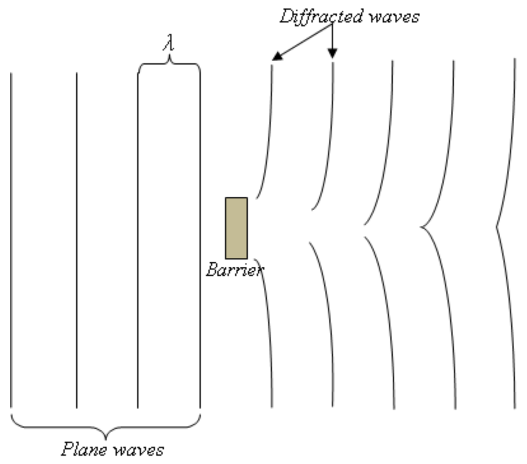
c) ***Diffraction***

The *diffraction* of a radio wave occurs when they pass through a gap or bend around an obstacle (barrier). The amount of diffraction depends on the size of the barrier or gap and the wavelength of the wave. When the wave undergoes diffraction, its direction of propagation and its pattern changes where else its frequency, wavelength and speed remains unchanged.

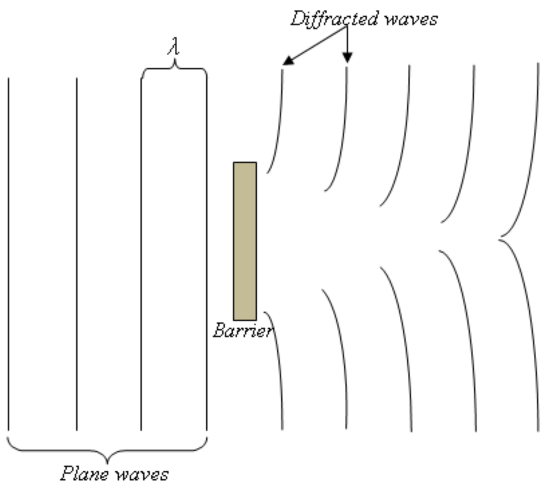
If the size of a barrier (or obstacle) is smaller than the wavelength of the wave, there is more diffraction since the wave tends to spreads out more on the other side. However, if the size of a barrier is larger than the wavelength of the wave, the wave tends to spreads out less on the other side as there is less diffraction.



(a) Size of an obstacle smaller than the wavelength



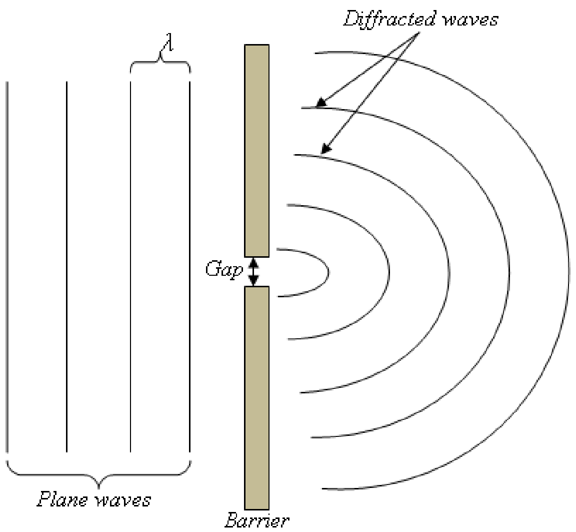
(b) An obstacle having same size as the wavelength



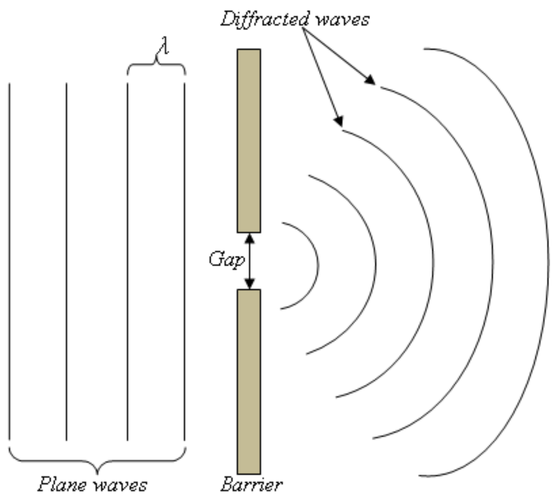
(c) Size of an obstacle larger than the wavelength

Figure 2.7: Diffraction through Different Sizes of Barrier

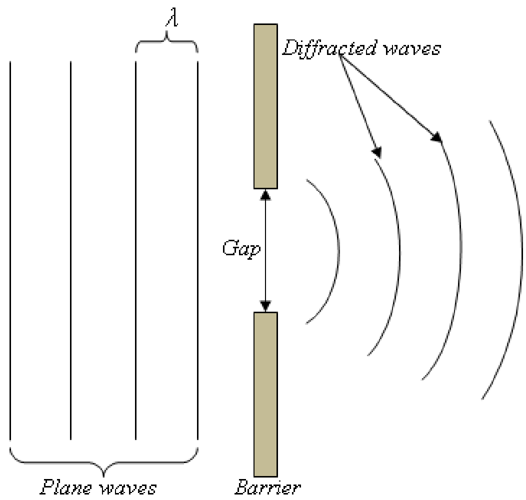
Similarly, if the size of a gap is smaller (narrower) than the wavelength of the wave, there is more diffraction since the wave tends to spreads out more on the other side. However, if the size of a gap is larger (wider) than the wavelength of the wave, the wave tends to spreads out less on the other side as there is less diffraction.



(a) Size of a gap smaller than the wavelength



(b) A gap having same size as the wavelength



(c) Size of a gap larger than the wavelength

Figure 2.8: Diffraction through Different Sizes of Gap

d) *Interference*

The *interference* of radio waves occur when the two waves from two coherent sources (that are having the same frequency and amplitude) interact with each other by overlapping and thus creating a resultant wave of higher or lower amplitude. The waves are overlapped by adding electric and magnetic fields at each point. The amount of interference depends of the phase difference at a particular point.

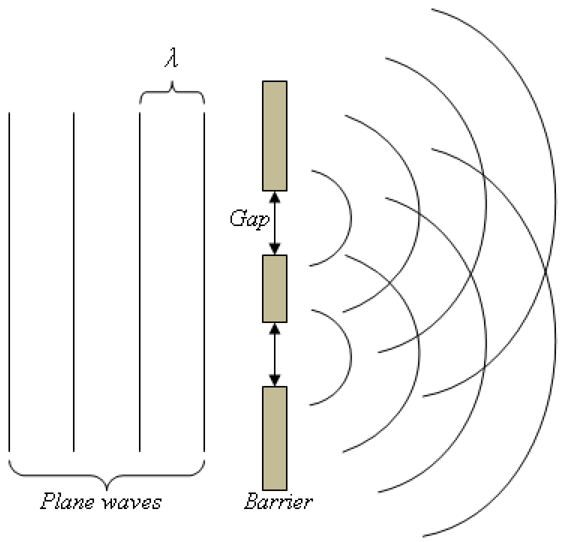
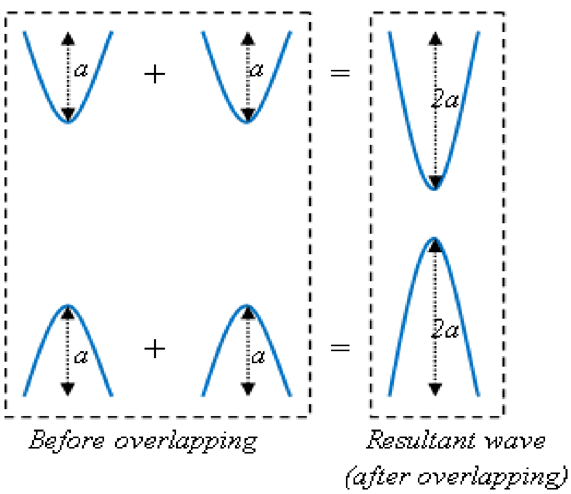
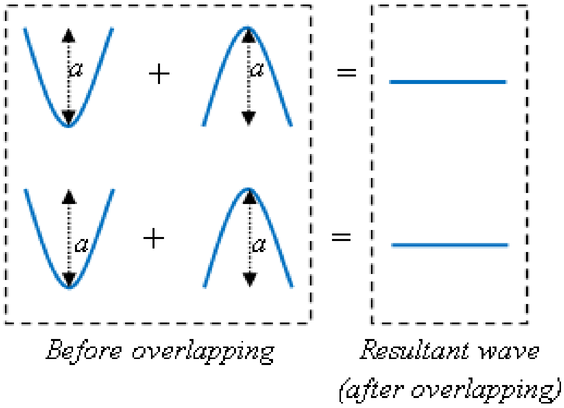


Figure 2.9: Wave Interference

The interference of radio waves can be divided into constructive interference and destructive interference. The constructive interference occurs when the crests or troughs of both waves are overlapped with each other to produce a wave with having maximum amplitude. The destructive interference, on the other hand, occurs when the crests of one wave overlapped with the trough of another wave to produce a wave with having zero amplitude. After the interference, the two waves will be separated and continue in the same direction they were travelling before the interference.



(a) Constructive interference wave



(b) Destructive interference wave

Figure 2.10: Constructive and Destructive Interference Waves

e) *Absorption*

The *absorption* of a radio wave occurs when a wave comes into contact with a medium and causing the electrons within the atoms of the medium to vibrate and move. This vibration absorbs some of the energy from the wave and less of the energy is reflected. The vibrating electrons will then create a new wave with having the same frequency as the first wave. Once the energy of the wave is reemitted by an atom, it travels through a small region of space between the atoms. Once it reaches the next atom, the wave is absorbed, transformed into electron vibrations and then reemitted as a wave. This absorption and reemission process causes the net speed of the radio wave to be less than 3×10^8 m/s.

e) *Scattering*

Scattering of radio wave is caused by the interaction of radiation with matter resulting in the reradiating of part of the energy to other directions not along the path of the incident radiation. As a result, this will remove the energy from the incident beam. However, this energy is not missing but it is redistributed to other directions unlike absorption.

2.2 Elements of Radio Telescope

2.2.1 Reflector System

In radio telescope, the reflector system collects the incoming radio waves that are emitted by cosmic sources on the Earth and reflect them towards a focal point. It is basically made of a metallic conductor sheet and operates based on the principle of reflection. The reflector system can be characterized by three main parameters, namely focal length, diameter of aperture and half-angle subtended by reflector at the focal point (θ), which are shown in the figure below.

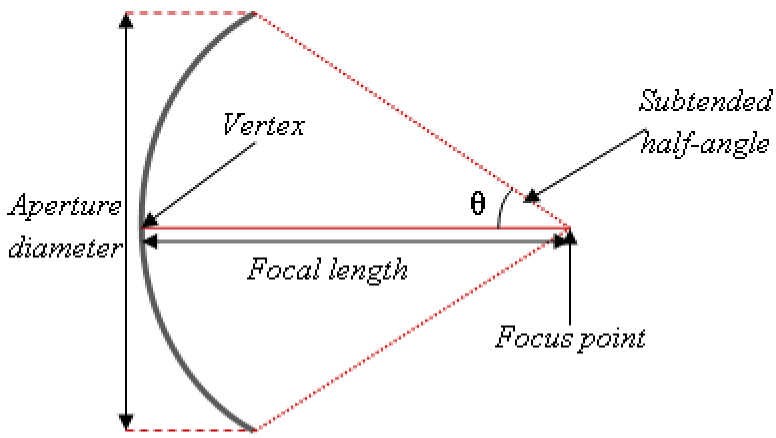


Figure 2.11: Parameters of a Reflector

The reflector system of a radio telescope can be divided into single reflector system and dual reflector system. A single reflector system comprises only a primary reflector (also known as main reflector) and is used to reflect and focus the collected radio waves towards the prime focus. The parabolic reflector is the most commonly used as a primary reflector and is designed in large size in order to have large collecting area. The main reason of having large collecting area for a parabolic primary reflector is to provide high gain level and high directivity level.

The dual reflector system, on the other hand, comprises a primary reflector and a secondary reflector (also known as subreflector). The primary reflector is used to reflect and the collected radio waves towards the secondary reflector. On the other hand, the secondary reflector is used to reflect the collected radio waves from the surface of primary reflector and focus them towards the secondary focus. The secondary reflector comes with distinct geometry such as hyperbolic and elliptical forms. The selection size of the secondary reflector is crucial in order to avoid primary aperture blockage.

2.2.2 Feed System

The feed system in a radio telescope is basically a small central antenna and it is located at the focal point of the reflector. It collects the reflected radio waves from the reflector surface and converts them into radio frequency (RF) signal before coupling to the transmission line.

In single reflector system, the feed is located at the primary focal point that is farther away from the vertex of the primary reflector. It collects the reflected rays from the surface of a primary reflector. On the other hand, in dual reflector system the feed is located at the secondary focal point, which is either nearer to or farther from the vertex of primary reflector. Unlike single reflector system, the feed collects the reflected rays from the surface of a secondary reflector.

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The orientation of the feed system can be divided into two types; *front-feed system* and *offset-feed system*. The front-feed system is where the feed, secondary reflector and/or struts (that is supporting structure) are placed in front of the primary reflector, on its axis which blocks the beam path of the incoming radio waves. As for the case of offset-feed system the feed, secondary reflector and/or struts (that is supporting structure) are placed to one side of the primary reflector for unblocking the beam path of the incoming radio waves. Hence, the orientation of the feed system is essentially important for maximizing the performance of the reflector system.

2.2.3 Transmission Line

A transmission line is a cable that carries electrical signal from one end to the other end. In radio telescope, the transmission cable is connected from the end of the feed system to the low noise amplifier (LNA) in the radio receiver for carrying radio frequency (RF) signals. There are two common types of cable used for RF path, namely twin-lead cable and coaxial cable.

The twin-lead cable is a cable is made up of two copper wires which run parallel to each other. There is spacing between these two conductors in order to keep these two wires at the same distance from each other. The disadvantage of using this cable is that it is easily affected by the presence of metal and other things that are close to the cable. However, it has much lower loss than a coaxial cable.

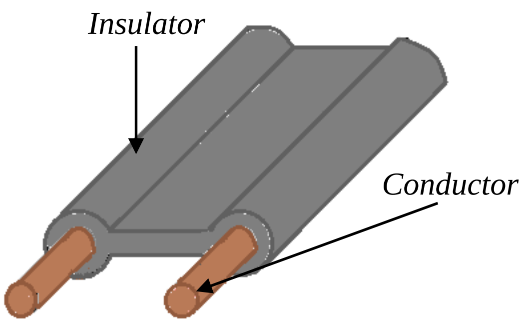


Figure 2.12: Structure of a Twin-Lead Cable

On the other hand, the coaxial cable consists of a wire inner conductor and a tubular insulating layer shielding over it. The outer tubular conductor of the coaxial conductor acts as a shield, keeping the RF signal inside the cable while keeping interference and other external influences out. The outer tubular conductor is enclosed by outer insulating sheath, or also known as outer jacket for cable protection.

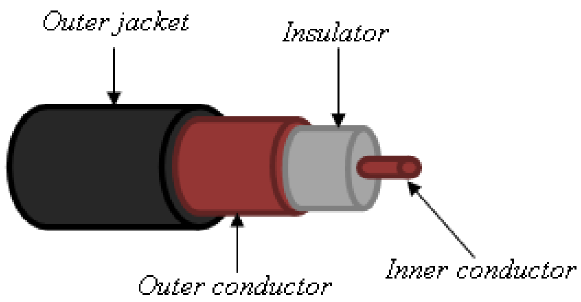


Figure 2.13: Structure of a Coaxial Cable

2.2.4 Radio Receiver

In radio telescope, a radio receiver is used to decode and extracts the necessary information from the modulated RF signals. This information will be stored in the computer and recording devices. The radio receiver basically consists of amplifier, superheterodyne receiver and A/D converter. The block diagram of a receiver circuit is shown in the figure below.

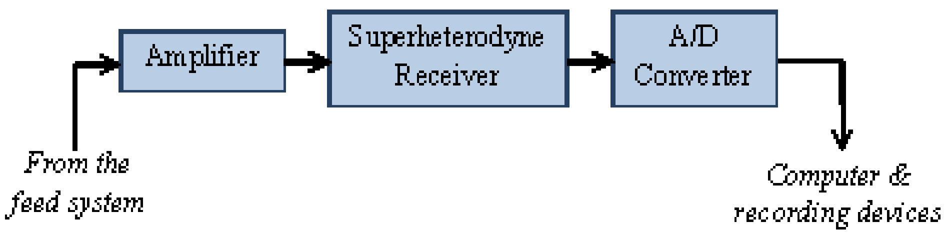


Figure 2.14: Block Diagram of a Radio Receiver Circuit

The electronic amplifier is the first stage circuit in the radio receiver. Since radio signals are basically low frequency signals thus, they are known as weak signals due to having poor strength. Hence, the amplifier is widely used to amplify weak RF signals in order to increase their strengths. The amplified RF signal is then input to the superheterodyne receiver to convert the signal into a fixed intermediate frequency (IF) signal for processing conveniently by using frequency mixing. Lastly, the output signal from the superheterodyne receiver is input to the analogue-to-digital converter (ADC) for converting into digital signal and is stored in the computer and recording devices.

2.3 Radiation Pattern

The radiation pattern describes the field strength of the radio waves. It is the most important property for analyzing the performances of the reflector system. The radiation pattern basically consists of a main lobe, vestigial lobe, side lobe and back lobe. The figure below shows sevral types of lobes in the radiation pattern.

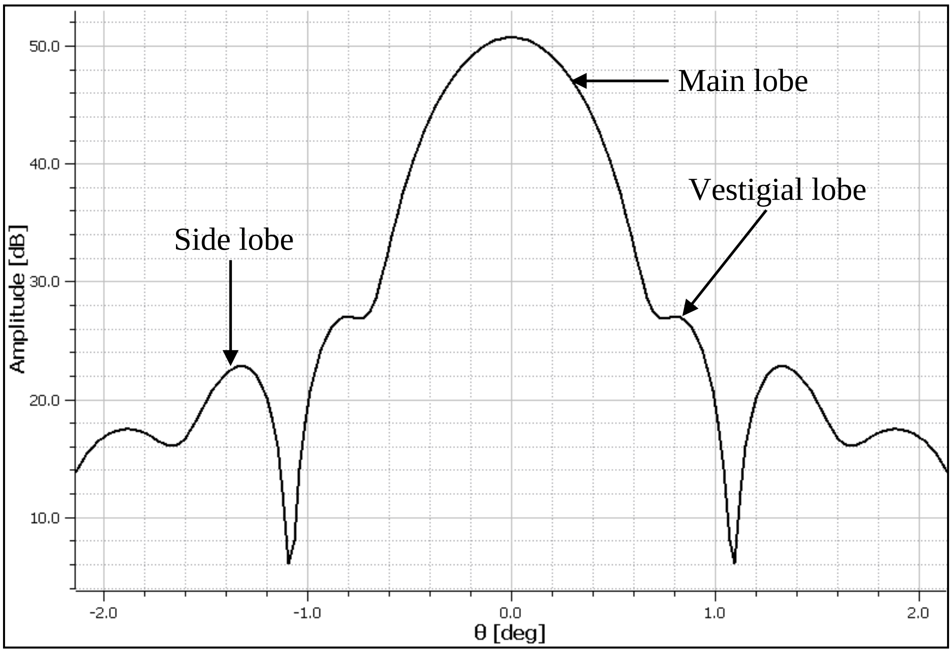


Figure 2.15: Lobes in the Radiation Pattern

The main lobe, which is also known as the major lobe or main beam represents the maximum radiation power in a desired direction and it is located at the angle of zero degree. It is the largest lobe compared to the other lobes. In reflector system, the amplitude of the main lobe determines its gain level whereas the beam width, which is the width of the main lobe, determines its directivity level.

Thus, higher main lobe level leads to higher gain level and narrower beamwidth leads to higher directivity level.

The side lobes, on the other hand, represent unwanted radiation in undesired directions and they usually surround the main lobe. Similarly, the back lobe also represents unwanted radiation in undesired directions and is surrounded by the side lobes just like the main lobe, which is not shown in the figure above. The only difference between the back lobe and the main lobe is it is located in the opposite direction (at the angle of 180°) from the main lobe and it is surrounded by side lobes. In reflector system, the side lobes occur due to having diffraction loss from the edge of reflector where else the back lobe occurs as a result of having spillover loss. Hence, increasing the side lobe and back lobe increases the diffraction and spillover losses and thus, reducing the gain and directivity levels of the reflector system.

Lastly, the vestigial lobe is formed by joining the first side lobe with a main lobe to form a shoulder and thus, the vestigial lobe is also known as the shoulder lobe. The vestigial lobe is also a part of the complex side lobes and therefore, it also represents unwanted radiation in undesired directions.

2.4 Geometrical Configuration of Front-Feed Reflector System

2.4.1 Prime Focus Feed Configuration

The prime focus feed configuration is a single reflector system that comprises only a primary reflector. Its primary reflector is basically in a parabolic form and it is designed in larger size to have larger collecting areas in order to provide high gain and high directivity levels. It is mainly used to reflect and focus the collected radio waves towards the feed system.

On the other hand, the feed system is positioned at the focal point above the reflector. It is used to detect and receive the reflected radio waves from the primary reflector and converts them into RF signals before transmitting to the radio receiver.

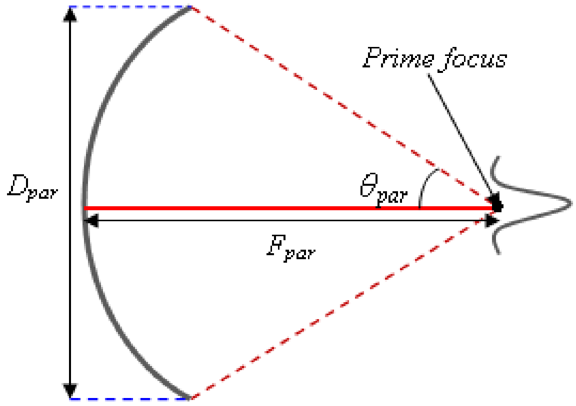


Figure 2.16: Geometry of a Prime Focus Feed System

The figure above shows the basic geometry of a prime focus feed system. By referring to its geometry, the only parameter which is the half-angle subtended by primary reflector at the feed can be computed by using the equation shown below.

$$\theta_{par} = 2\tan^{-1}\left(\frac{D_{par}}{4F_{par}}\right) \tag{2.3}$$

where

θ_{par} = half-angle subtended by parabolic reflector at the feed

D_{par} = aperture diameter of parabolic reflector

F_{par} = focal length of parabolic reflector

2.4.2 Cassegrain Feed Configuration

The Cassegrain feed configuration is a dual reflector system which comprises both primary and secondary reflectors. Like the prime focus feed configuration, its primary reflector is in a parabolic form and it is designed in larger size in order to have larger collecting areas. However, the functionality of the primary reflector is different from the prime focus configuration where it reflects the collected radio waves towards the secondary reflector.

On the other hand, the secondary reflector of a Cassegrain feed configuration is in a hyperbolic form. It is mounted above the primary reflector but below the focal point of the primary reflector and is supported by struts. It is mainly used to reflect and concentrate the radio waves collected by the primary reflector to the feed system.

Apart from that, the feed system of the Cassegrain feed configuration is positioned at the secondary focal point either nearer to or farther away from the vertex of the primary reflector. It is used to detect and receive the reflected radio waves from the secondary reflector, before converting into electrical signals in order to be transmitted to the radio receiver.

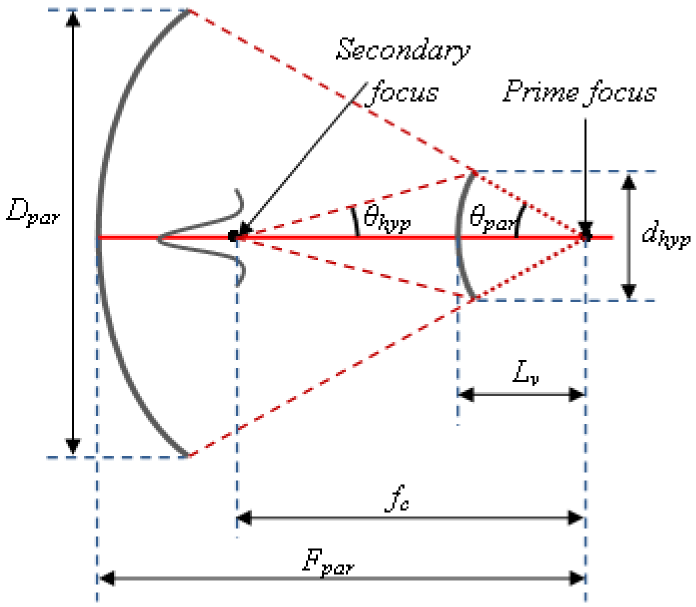


Figure 2.17: Geometry of a Cassegrain Feed System

The figure above shows the basic geometry of a Cassegrain feed system. Based on its geometry, parameters such as the half-angle subtended by primary and secondary reflectors, distance between secondary vertex and prime focus, eccentricity of secondary reflector and its magnification can be computed by using the equations shown below.

$$\theta_{par} = 2\tan^{-1}\left(\frac{D_{par}}{4F_{hyp}}\right) \tag{2.4}$$

$$\theta_{hyp} = \cot^{-1}\left(\frac{2f_c}{d_{hyp}} - \cot\theta_{par}\right) \tag{2.5}$$

$$e = \frac{\sin\left(\frac{\theta_{par}+\theta_{hyp}}{2}\right)}{\sin\left(\frac{\theta_{par}-\theta_{hyp}}{2}\right)} \tag{2.6}$$

$$L_v = f_c - \frac{f_c}{e} \tag{2.7}$$

$$M = \frac{e+1}{e-1} \tag{2.8}$$

where

θ_{par} = half-angle subtended by parabolic reflector at the feed

θ_{hyp} = half-angle subtended by hyperbolic reflector at the feed

D_{par} = aperture diameter of parabolic reflector

d_{hyp} = aperture diameter of hyperbolic reflector

F_{par} = focal length of parabolic reflector

f_c = distance between primary and secondary foci

e = eccentricity of secondary reflector

L_v = distance between secondary vertex and prime focus

M = magnification

2.4.3 Gregorian Feed Configuration

The Gregorian feed configuration is another dual reflector system, where it consists of secondary reflector in addition to the primary reflector. It has a similar functionality as the Cassegrain configuration. The differences between the Gregorian feed configuration and the Cassegrain feed configuration are its secondary reflector is in the form of ellipsoid and it is mounted above the focal point of the primary reflector.

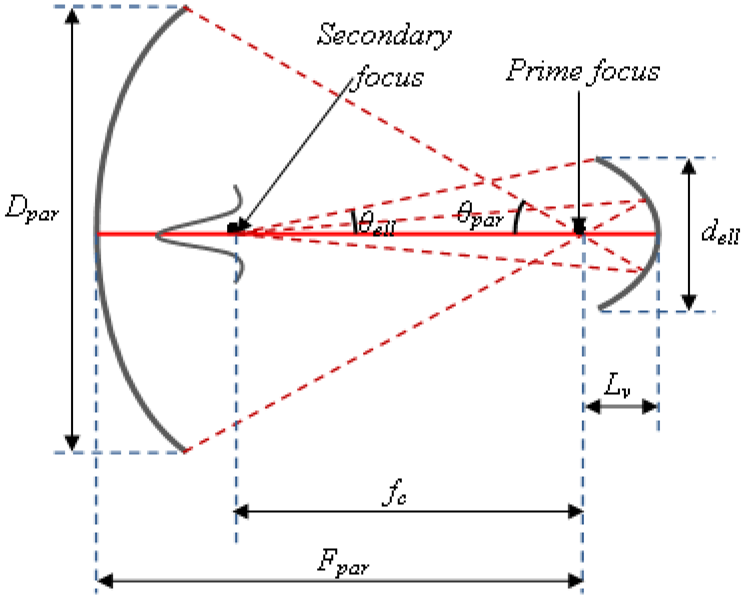


Figure 2.18: Geometry of a Gregorian Feed System

The figure above shows the basic geometry of a Gregorian feed system. Based on its geometry, parameters such as the half-angle subtended by primary and secondary reflectors, distance between secondary vertex and prime focus, eccentricity of secondary reflector and its magnification can be computed by using the equations that are shown below.

$$\theta_{par} = -2\tan^{-1}\left(\frac{D_{par}}{4F_{par}}\right) \tag{2.9}$$

$$\theta_{ell} = \cot^{-1}\left(\frac{2f_c}{d_{ell}} - \cot\theta_{par}\right) \tag{2.10}$$

$$e = \frac{\sin\left(\frac{\theta_{par}+\theta_{ell}}{2}\right)}{\sin\left(\frac{\theta_{par}-\theta_{ell}}{2}\right)} \tag{2.11}$$

$$L_v = f_c - \frac{f_c}{e} \tag{2.12}$$

$$M = \frac{e+1}{e-1} \tag{2.13}$$

where

θ_{par} = half-angle subtended by parabolic reflector at the feed

θ_{ell} = half-angle subtended by elliptical reflector at the feed

D_{par} = aperture diameter of parabolic reflector

d_{ell} = aperture diameter of elliptical reflector

F_{par} = focal length of parabolic reflector

f_c = distance between primary and secondary foci

e = eccentricity of secondary reflector

L_v = distance between secondary vertex and prime focus

M = magnification

2.5 Reflector System Performance

There are several factors that influence the performance of the reflector system in a radio telescope. These factors are referred to the *dimension of reflector, spillover loss, diffraction loss, aperture blockage* and *feed illumination*.

a) ***Dimension of reflector***

The size of the reflector is an important factor for determining its collecting areas for radio waves. This is only true for a primary parabolic reflector in both single and dual reflector system where it is constructed in a larger size in order to have larger collecting areas. The main reason for it to have a large collecting area is to provide high gain level. Based on the radiation pattern, the amplitude of the main lobe determines the gain level of the reflector system. Thus, having higher main lobe level leads to higher gain level.

Apart from that, another reason for a primary reflector to have a large collecting area is to provide a high directivity level. In radiation pattern, the beam width which is the width of the main lobe determines its directivity level. Thus, having a narrower beam width means having a higher directivity level. Since both the gain level and directivity level of the reflector system tend to increase with the increasing size of primary reflector hence, the size of primary reflector is directly proportional to the gain level and directivity level.

However, for a certain reflector its size can be a major concern for blocking the beam path of the radio waves. In front-feed dual reflector system, the secondary reflector that is mounted above the primary reflector by supporting struts is located at the beam path of the incoming radio waves. For a smaller size of secondary reflector, the beam blockage is small and this produces smaller gain level in the reflector system. As the size of secondary reflector increases, its gain level increases and then tends to drop when the size is further increased to certain extent due to having significant beam blockage. Therefore, there is a trade-off between the size of secondary reflector and the aperture blockage, and that is why its selection size is important in the front-feed dual reflector system for achieving its maximum performance.

b) ***Spillover loss***

Spillover loss is defined as the radiated energy from the feed system that misses the edge (outer part) of the reflector and it does not contribute to the main beam. This spillover energy enters into the back lobe of the radiation pattern and causing the back lobe level to increase.

The occurrence of spillover loss in the reflector system is mainly due to the distance between the feed and the center of the reflector. In other words, this distance refers to the focal length of the reflector. When the feed system is farther away from the center of the reflector than the edge of the reflector, its spillover loss increases which leads to the reduction in both gain and directivity levels. However, as the feed system is nearer to the center of reflector than the edge of reflector, its spillover loss decreases and thus leading to higher gain and higher directivity levels. Hence, in this case the spillover loss can be defined as directly proportional to the distance between feed and the center of reflector.

In addition, the spillover loss is also greatly affected by the dimension of the reflector. For a smaller size of reflector with having a fixed focal length, there is a significant increase in spillover loss since the distance between the feed and the edge of reflector is shorter. However, as the size of reflector increases with respect to the fixed focal length its spillover loss decreases due to the fact of having long distance between the feed than the edge of reflector. Therefore, in this case the spillover loss can be defined as inversely proportional to the size of reflector.

c) ***Aperture blockage***

Aperture blockage occurs when the feed and the secondary reflector that are supported by struts are located in front of the parabolic primary reflector at the primary focal point which obstructs the beam path of the incoming radio waves. This mainly happens in the front-feed reflector system.

In single feed reflector system, the blockage is not so obvious. However, in dual reflector feed system the size of secondary reflector can be a major concern for primary aperture blockage. If the size of secondary reflector is further increased to some extent, the blockage of the beam path at the primary aperture becomes significant. As a result, part of the radiations will be blocked and deflected by the secondary reflector and thus reducing the gain level of the reflector system despite of having low spillover and diffraction losses. Therefore, to avoid beam blockage both the feed and secondary reflector as well as the supporting structures are usually offset outside the beam path in order to improve the gain level of the reflector system.

d) ***Feed illumination***

In reflector system, the feed that radiates energy towards the surface of reflector will illuminate the reflector. The feed can either over-illuminate or under-illuminate the reflector’s surface depending on the distance between the feed at the focal point and the centre of reflector.

The feed over-illuminates the reflector when the feed is farther away from the center of reflector than the edge of reflector. As a result, more energy is applied to the edge of reflector rather than the center of reflector. This leads to higher spillover loss which further reduces the gain and directivity levels of the reflector system.

On the other hand, the reflector is under-illuminated by the feed when feed is nearer to the center of reflector and farther from the edge of reflector. Consequently, more energy is applied to the center of reflector rather than the edge of reflector and thus, resulting in lower spillover loss that increases the gain and directivity levels of the reflector system.

e) ***Diffraction loss***

Diffraction loss occurs when there are excessive side lobe levels radiating from the edge of reflector. In reflector system, it reduces the main beam level that leads to the reduction in the gain level. The diffraction loss is directly dependent on spillover loss because when there is a presence of high/low spillover loss, there will be also high/low diffraction loss.

The diffraction loss is greatly affected by the size and focal length of the reflector. A smaller size of reflector produces larger diffraction loss from the edge of reflector due to having higher spillover loss where else a large size of reflector produces lower diffraction loss as a result of having lower spillover loss. On the other hand, a reflector having shorter focal length produces lower diffraction loss from the edge of reflector as the reflector has weaker edge illumination whereas a longer focal length yields higher diffraction loss due to having stronger edge illumination.

2.6 Advantages and Limitations of Radio Telescope

A radio telescope offers several advantages over an optical telescope. One of the great advantages of this instrument is that it can operate both day and night unlike an optical telescope that can be used only at the night. Besides, this instrument is unaffected by the cloud cover during the reception of radio waves from the space as the radio waves are unaffected by the cloud cover. In addition, this instrument is also unaffected by the movement of cosmic dust when detecting radio waves since the radio waves are not scattered by the dust particles unlike the visible light.

However, the radio telescope also has several limitations and one of the main limitations of this instrument is that it requires larger size of parabolic main reflector for detecting radio waves. This is because the radio waves emitted from the space have long wavelengths but low frequencies. Due to this reason, the radio waves have low intensity low strength due to having low energy photons. Thus, the radio waves are known to be weak signals and that is why the size of main reflector must be greater than the wavelengths of radio waves for detecting weak radio waves. Moreover, the radio telescope has to be placed in the remote areas only since the radio waves are easily drowned by noise interference due to having weaker signal strength. Another reason why this instrument has to be placed in the remote regions is to avoid the obstruction of radio waves by large barriers such as the tall buildings, mountains and hilly areas as there is less diffraction of radio waves due to the size of barrier larger than its wavelength, which could result in poor reception for the instrument.

2.7 Very Large Array

The resolution power of a radio telescope is directly dependent on the wavelength of radio waves and the size of main reflector. Since the radio waves emitted by astronomical objects have low frequencies, they have smaller amount of energy photons resulting in low strength. Hence, this limits the resolution power of the radio telescope. In order to overcome this limitation, the collecting area of the radio telescope must be increased by increasing the size of main reflector. However, since the wavelength of radio waves is much greater than any other electromagnetic radiation therefore, the size of reflector has to be much greater than the wavelength of the radiation.

Another way of increasing the resolution power of the radio telescope is by using a number of radio telescopes together that are arranged in array. The resulting resolution from this array is determined by the telescope separation rather than using a single radio telescope.

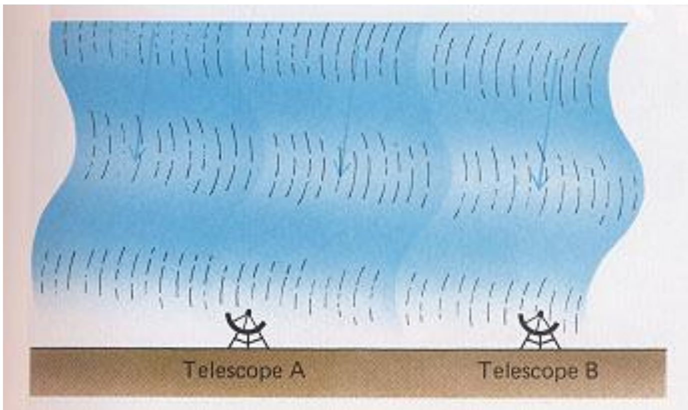


Figure 2.19: Array of Radio Telescopes

The figure above shows two separated telescopes (in general) receive radio waves from the same source at different times. Generally, the radio waves are out of phase with each other depending on the angle to the source in the sky. Thus, the direction of the radio source along the axis the two telescopes can be determined much more accurately by using more than one radio telescope.

The radio signals captured by each radio telescope in the array will be combined together. This technique of signal combining is commonly known as *interferometry*. By combining the signals from more than one radio telescope, a high resolution radiograph of astronomical objects can be created.

CHAPTER 3

METHODOLOGY

3.1 Analyzing the Performance of Front-Feed Reflector System

3.1.1 Analyzing the Performance of a Single Reflector Feed System

1. Firstly, the geometry of a prime focus feed system is designed by inserting the desired values for the required parameters in the simulation software.
2. Next, the designed geometry is simulated in order to obtain its radiation pattern.
3. As for further analysis, the above steps are repeated by varying the focal length and the diameter of reflector to the desired values one at a time whereas the other parameters are kept constant.
4. The amplitudes of both main lobe and side lobe and spillover losses are then recorded from the obtained radiation patterns and simulation output.
5. Lastly, the graphs of main lobe level, side lobe level and spillover loss are plotted separately against the diameter of reflector for having distinct focal lengths and the performance of a prime focus feed system is analyzed from the plotted graphs.

3.1.2 Analyzing the Performance of a Dual Reflector Feed System

1. Firstly, the geometry of a Cassegrain feed system is designed by inserting the desired values for the required parameters in the simulation software.

2. Next, the designed geometry is simulated in order to obtain its radiation pattern.
3. As for further analysis, the steps are repeated by varying the distance between foci and the diameter of secondary reflector to the desired values one at a time whereas the other parameters are kept constant.
4. The amplitude of the main lobes and side lobes as well as the spillover losses are then recorded from the obtained radiation patterns and simulation output.
5. Lastly, the graphs of main lobe level, side lobe level and spillover loss are plotted separately against the diameter of secondary reflector for having distinct distances between foci and the performance of a Cassegrain feed system is analyzed from the plotted graphs.

3.2 Comparing the Performances of Various Geometrical Configurations of Front-Feed Reflector System

1. Firstly, the geometry of the selected front-feed reflector system is designed by inserting the fixed values for the required parameters in the simulation software.
2. Next, the designed geometry is simulated in order to obtain its radiation pattern.
3. The operating frequency of the selected reflector system is then varied and the other parameters are kept constant throughout the simulation.
4. As for performance comparison, the above steps are repeated for different geometries of front-feed reflector system.
5. Lastly, the amplitude of the main lobes and side lobes are recorded from the obtained radiation patterns and simulation output. The graphs of main lobe level and side lobe level are plotted in separately against the operating frequency for different configurations of reflector system and their performances are compared.

CHAPTER 4

RESULTS

4.1 Analyzing the Performance of a Single Reflector Feed System

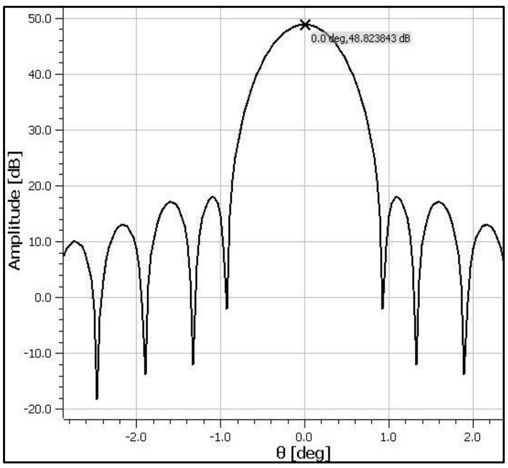
1. The table below shows the geometrical parameters for a prime focus feed system

Table 4.1: Geometrical Parameters for a Prime Focus Feed System

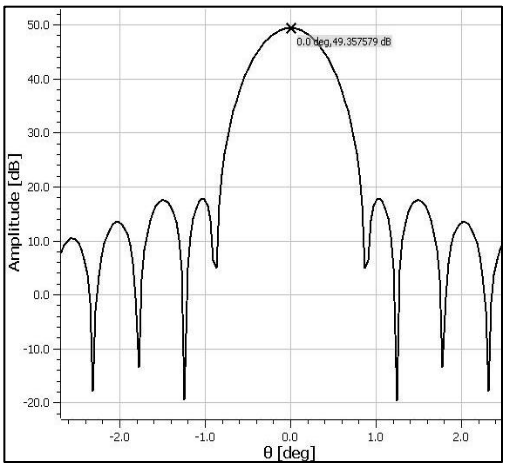
Diameter of parabolic primary reflector, D_{par}	3.0 m – 7.0 m
Focal length of parabolic primary reflector, F_{par}	1.5 m – 2.1 m
Operating frequency, f	10 GHz

2. a) The following below shows the radiation patterns of a prime focus feed system having a primary focal length of 1.5 meters with distinct diameters of reflector.

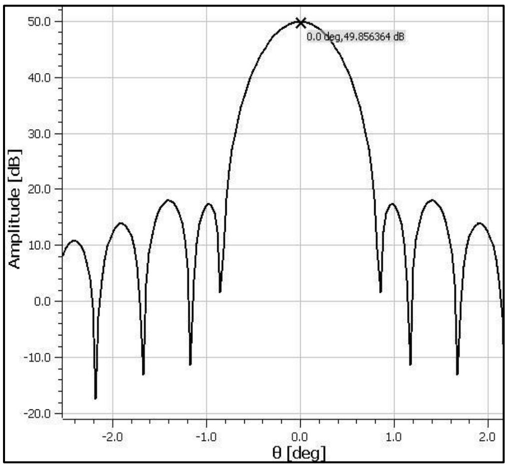
F_{par}=1.5 m, D_{par}=3.0 m



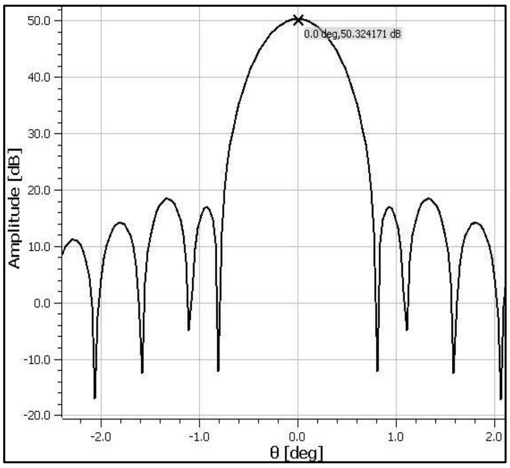
F_{par}=1.5 m, D_{par}=3.2 m



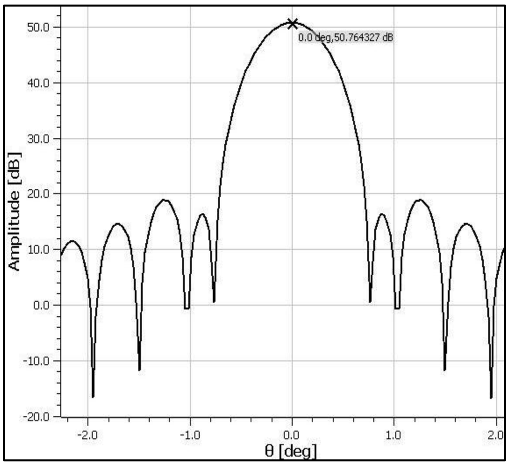
F_{par}=1.5 m, D_{par}=3.4 m



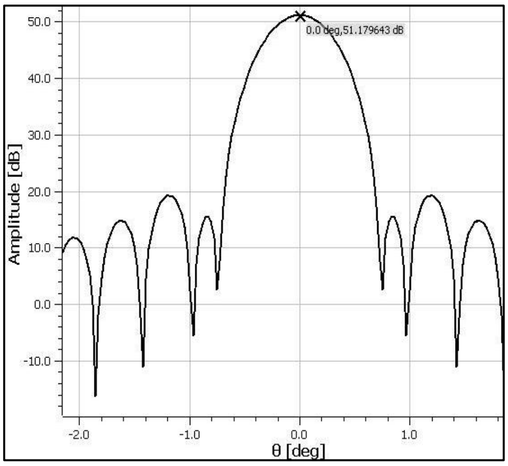
F_{par}=1.5 m, D_{par}=3.6 m



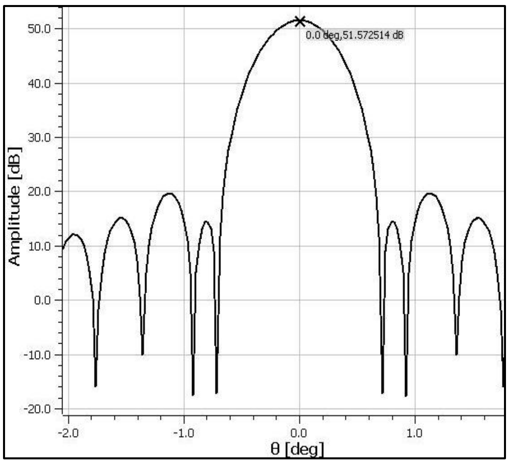
F_{par}=1.5 m, D_{par}=3.8 m



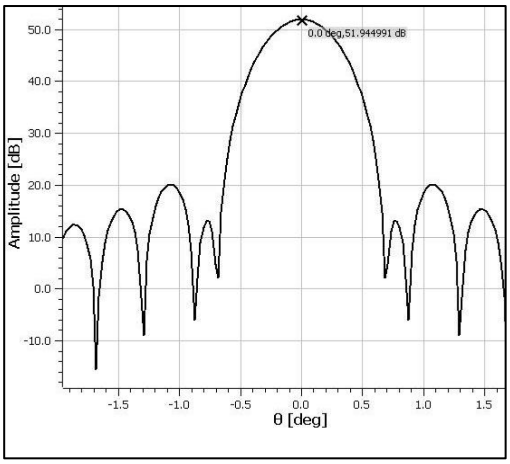
F_{par}=1.5 m, D_{par}=4.0 m



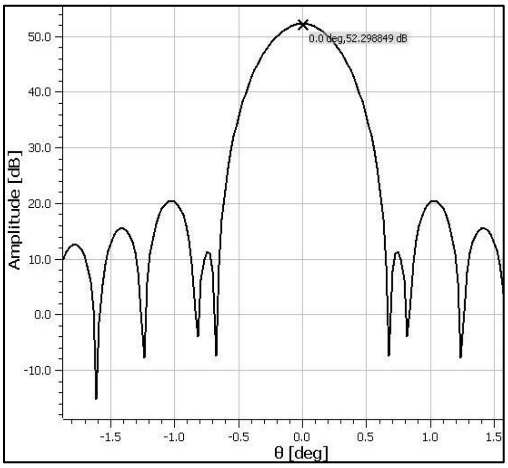
F_{par}=1.5 m, D_{par}=4.2 m



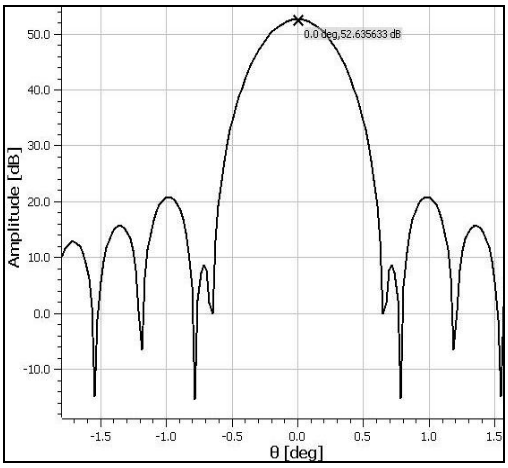
F_{par}=1.5 m, D_{par}=4.4 m



F_{par}=1.5 m, D_{par}=4.6 m



F_{par}=1.5 m, D_{par}=4.8 m



F_{par}=1.5 m, D_{par}=5.0 m

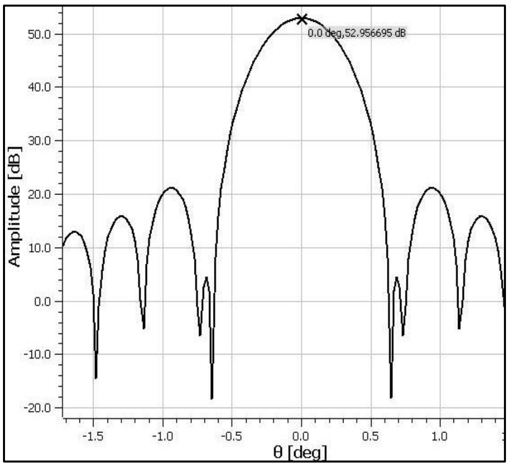


Figure 4.1: Radiation Patterns of a Prime Focus Feed System Having F_{par} = 1.5 Meters with Distinct D_{par}

b) The table below records the focal length to diameter ratio and the half-angle subtended by primary reflector at the feed for a prime focus feed system having a primary focal length of 1.5 meters with distinct diameters of primary reflector.

Table 4.2: *F/D* Ratio and θ_{par} for Prime Focus Feed System Having F_{par} = 1.5 Meters with Distinct D_{par}

Diameter of primary reflector, D_{par} (m)	Primary focal length, F_{par} (m)	Focal length to diameter ratio, *F/D*	Half-angle subtended by primary reflector, θ_{par}
3.0	1.5	0.5	53.13°
3.2	1.5	0.46875	56.14°
3.4	1.5	0.4412	59.08°
3.6	1.5	0.4167	61.93°
3.8	1.5	0.3947	64.69°
4.0	1.5	0.375	67.38°
4.2	1.5	0.3571	69.98°
4.4	1.5	0.3409	72.51°
4.6	1.5	0.3261	74.95°
4.8	1.5	0.3125	77.32°
5.0	1.5	0.3	79.61°

c) The table below records the amplitudes of the main lobe and side lobe for a prime focus feed system having a primary focal length of 1.5 meters with distinct diameters of primary reflector.

Table 4.3: Main Lobe and Side Lobe Levels for a Prime Focus Feed System Having F_{par} = 1.5 Meters with Distinct D_{par}

Diameter of primary reflector, D_{par} (m)	Primary focal length, F_{par} (m)	Main lobe level (dB)	1^{st} side lobe level (dB)
3.0	1.5	48.823843	17.961684
3.2	1.5	49.357579	17.804075
3.4	1.5	49.856364	17.501153
3.6	1.5	50.324171	17.033695
3.8	1.5	50.764327	16.422828
4.0	1.5	51.179643	15.592366
4.2	1.5	51.572514	14.443916
4.4	1.5	51.944991	13.079272
4.6	1.5	52.298849	11.291696
4.8	1.5	52.635633	8.719847
5.0	1.5	52.956695	4.528144

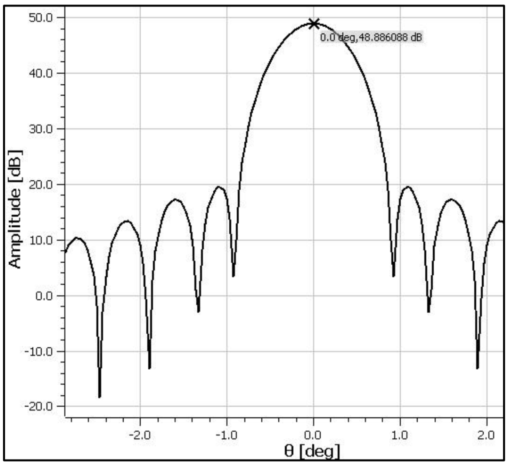
d) The table below records the spillover losses for a prime focus feed system having a primary focal length of 1.5 meters with distinct diameters of primary reflector.

Table 4.4: Spillover Losses for a Prime Focus System Having F_{par} = 1.5 Meters with Distinct D_{par}

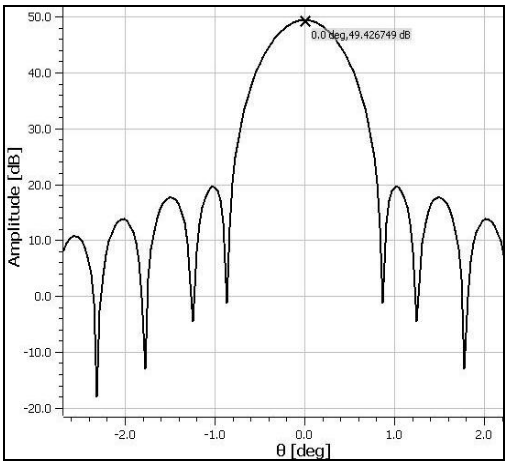
Diameter of primary reflector, D_{par} (m)	**Primary focal length, F_{par} (m)**	**Spillover loss (dB)**
3.0	1.5	0.2710
3.2	1.5	0.2677
3.4	1.5	0.2639
3.6	1.5	0.2596
3.8	1.5	0.2547
4.0	1.5	0.2494
4.2	1.5	0.2436
4.4	1.5	0.2374
4.6	1.5	0.2308
4.8	1.5	0.2240
5.0	1.5	0.2170

3. a) The following below shows the radiation patterns of a prime focus feed system having a primary focal length of 1.8 meters with distinct diameters of primary reflector.

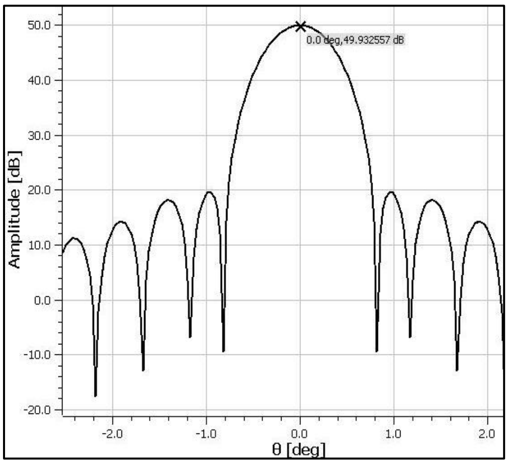
F_{par}=1.8 m, D_{par}=3.0 m



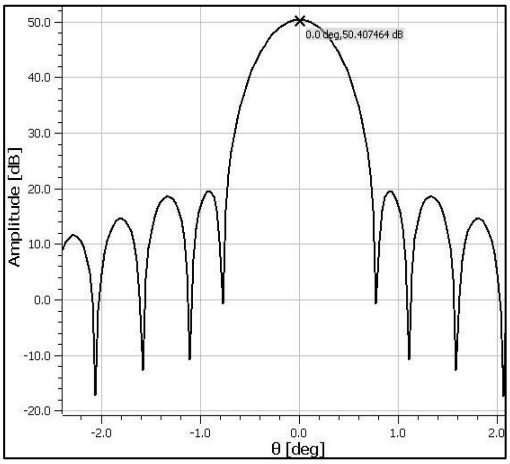
F_{par}=1.8 m, D_{par}=3.2 m



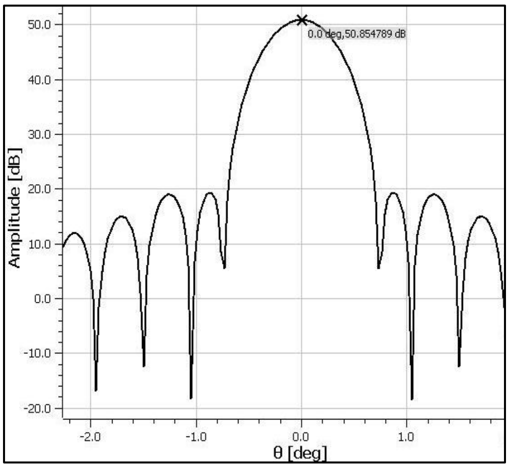
F_{par}=1.8 m, D_{par}=3.4 m



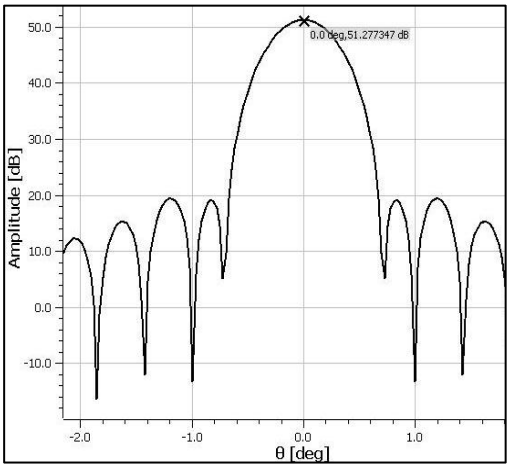
F_{par}=1.8 m, D_{par}=3.6 m



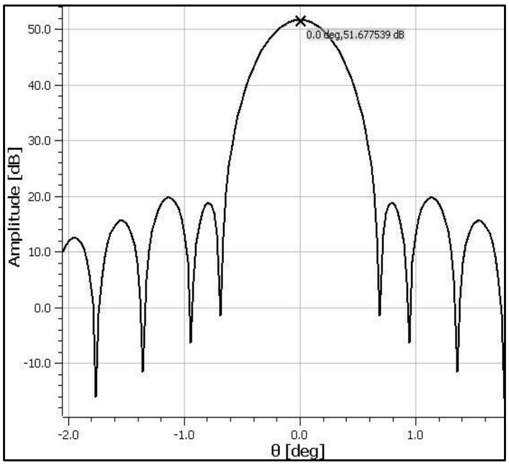
F_{par}=1.8 m, D_{par}=3.8 m



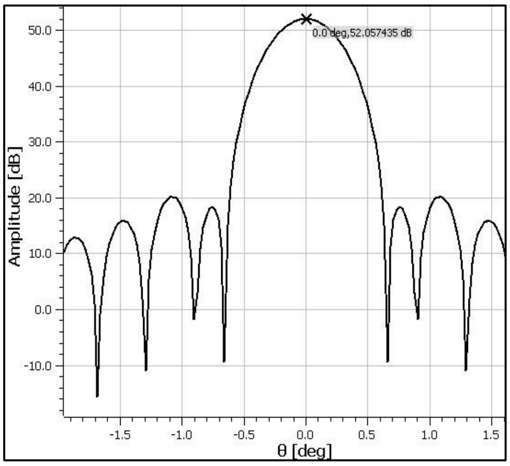
F_{par}=1.8 m, D_{par}=4.0 m



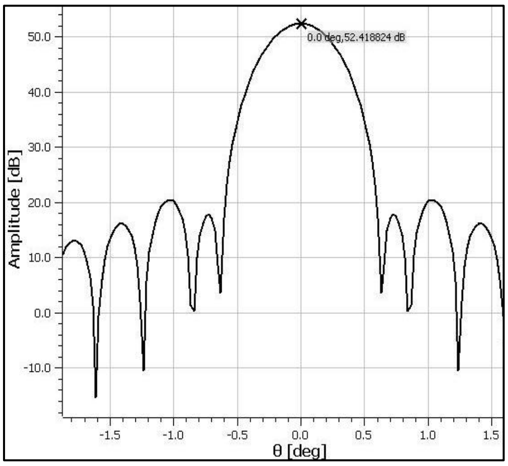
F_{par}=1.8 m, D_{par}=4.2 m



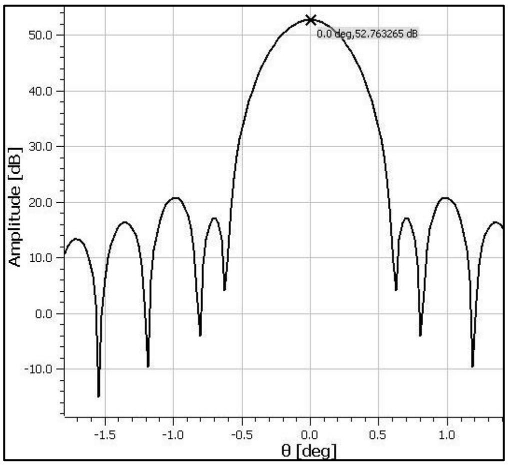
F_{par}=1.8 m, D_{par}=4.4 m



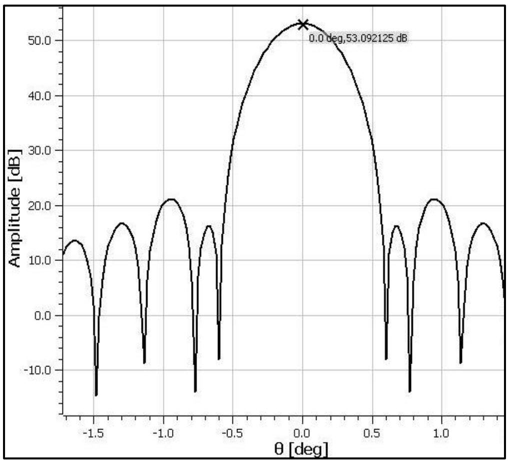
F_{par}=1.8 m, D_{par}=4.6 m



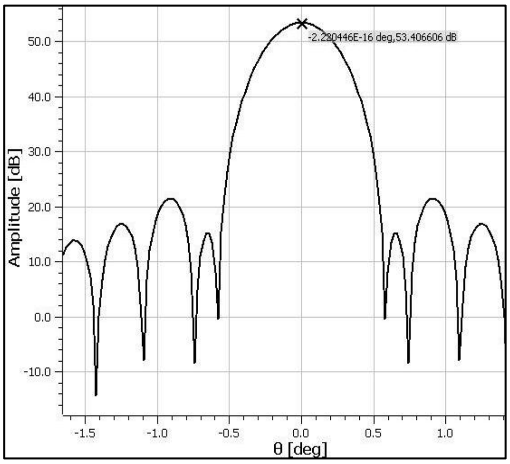
F_{par}=1.8 m, D_{par}=4.8 m



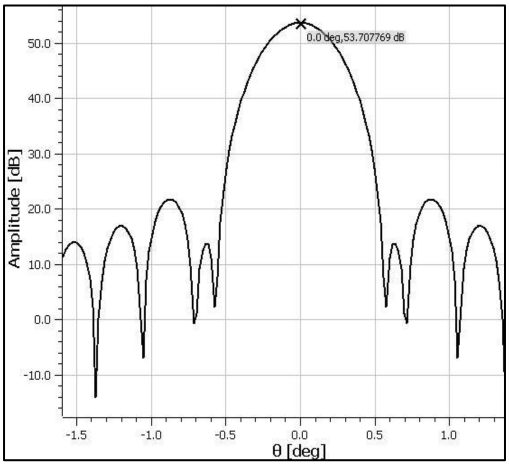
F_{par}=1.8 m, D_{par}=5.0 m



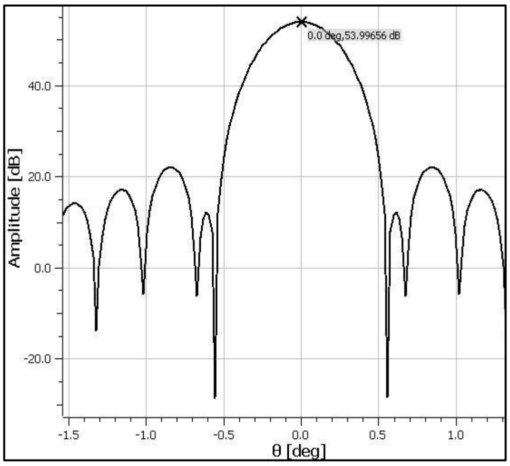
F_{par}=1.8 m, D_{par}=5.2 m



F_{par}=1.8 m, D_{par}=5.4 m



F_{par}=1.8 m, D_{par}=5.6 m



F_{par}=1.8 m, D_{par}=5.8 m *F_{par}=1.8 m, D_{par}=6.0 m*

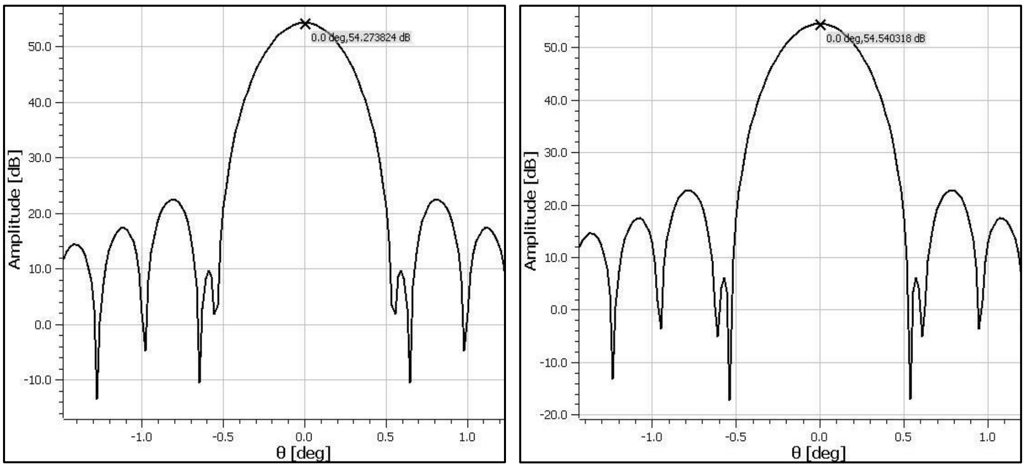


Figure 4.2: Radiation Patterns of a Prime Focus Feed System Having F_{par} = 1.8 Meters with Distinct D_{par}

b) The table below records the focal length to diameter ratio and the half-angle subtended by reflector at the feed for a prime focus feed system having a primary focal length of 1.8 meters with distinct diameters of primary reflector.

Table 4.5: *F/D* Ratio and θ_{par} for a Prime Focus Feed System Having F_{par} = 1.8 Meters with Distinct D_{par}

Diameter of primary reflector, D_{par} (m)	Primary focal length, F_{par} (m)	Focal length to diameter ratio, *F/D*	Half-angle subtended by primary reflector, θ_{par}
3	1.8	0.6	45.24°
3.2	1.8	0.5625	47.92°
3.4	1.8	0.5294	50.56°
3.6	1.8	0.5	53.13°
3.8	1.8	0.4737	55.65°
4.0	1.8	0.45	58.11°
4.2	1.8	0.4286	60.51°
4.4	1.8	0.4091	62.86°
4.6	1.8	0.3913	65.15°
4.8	1.8	0.375	67.38°
5.0	1.8	0.36	69.56°
5.2	1.8	0.3462	71.68°
5.4	1.8	0.3333	73.74°
5.6	1.8	0.3214	75.75°

5.8	1.8	0.3103	77.71°
6.0	1.8	0.3	79.61°

c) The table below records the amplitudes of the main lobe and side lobe for a prime focus feed system having a primary focal length of 1.8 meters with distinct diameters of primary reflector.

Table 4.6: Main Lobe and Side Lobe Levels for a Prime Focus Feed System Having F_{par} = 1.8 Meters with Distinct D_{par}

Diameter of primary reflector, D_{par} (m)	**Primary focal length, F_{par} (m)**	**Main lobe level (dB)**	**1st side lobe level (dB)**
3.0	1.8	48.886088	19.516027
3.2	1.8	49.426749	19.579884
3.4	1.8	49.932557	19.605199
3.6	1.8	50.407464	19.557063
3.8	1.8	50.854789	19.424528
4.0	1.8	51.277347	19.201998
4.2	1.8	51.677539	18.881039
4.4	1.8	52.057435	18.449431
4.6	1.8	52.418824	17.889626
4.8	1.8	52.763265	17.176151
5.0	1.8	53.092125	16.270980
5.2	1.8	53.406606	15.143223
5.4	1.8	53.707769	13.844824
5.6	1.8	53.996560	12.131620
5.8	1.8	54.273824	9.753609
6.0	1.8	54.540318	6.108886

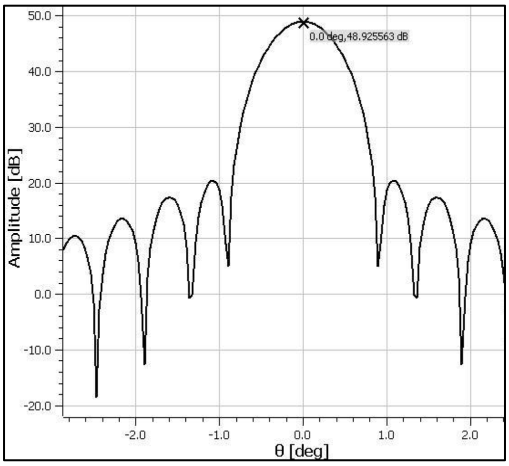
d) The table below records the spillover losses for a prime focus feed system having a primary focal length of 1.8 meters with distinct diameters of primary reflector.

Table 4.7: Spillover Losses for a Prime Focus Feed System Having F_{par} = 1.8 Meters with Distinct D_{par}

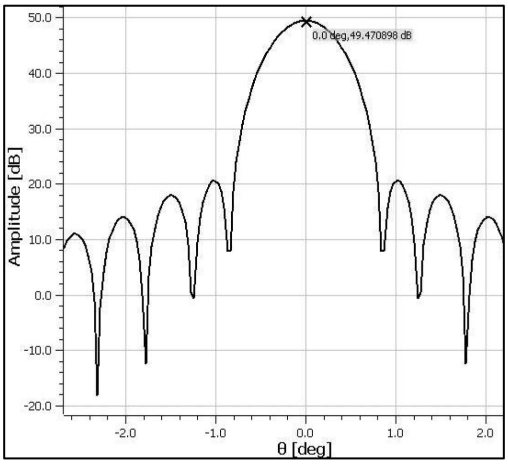
Diameter of primary reflector, D_{par} (m)	Primary focal length, F_{par} (m)	Spillover loss (dB)
3.0	1.8	0.2771
3.2	1.8	0.2754
3.4	1.8	0.2734
3.6	1.8	0.2710
3.8	1.8	0.2683
4.0	1.8	0.2653
4.2	1.8	0.2618
4.4	1.8	0.2580
4.6	1.8	0.2539
4.8	1.8	0.2494
5.0	1.8	0.2446
5.2	1.8	0.2395
5.4	1.8	0.2341
5.6	1.8	0.2286
5.8	1.8	0.2228
6.0	1.8	0.2170

4. a) The following below shows the radiation patterns of a prime focus feed system having a primary focal length of 2.1 meters with distinct diameters of primary reflector.

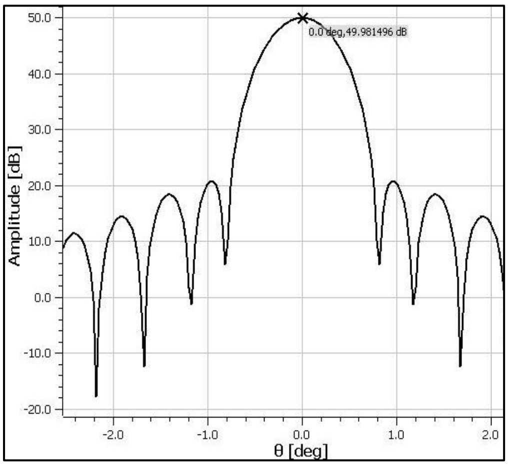
F_{par}=2.1 m, D_{par}=3.0 m



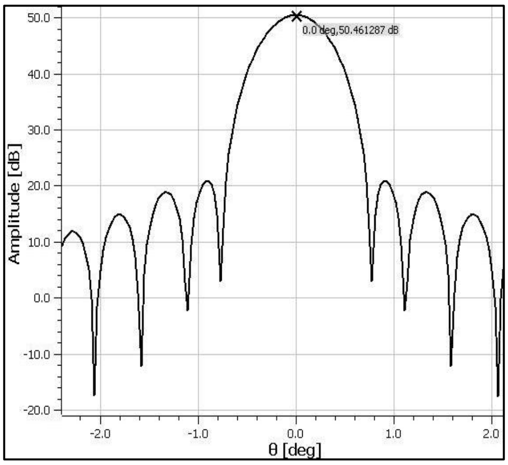
F_{par}=2.1 m, D_{par}=3.2 m



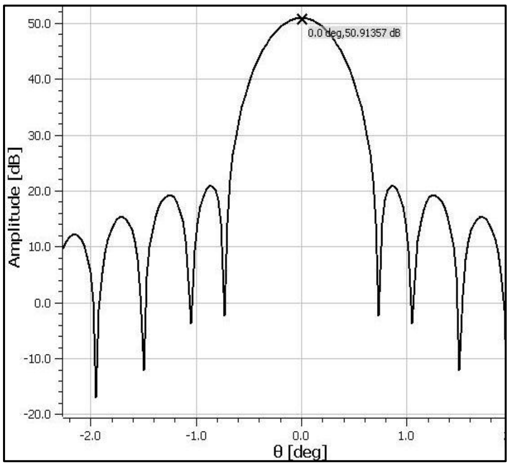
F_{par}=2.1 m, D_{par}=3.4 m



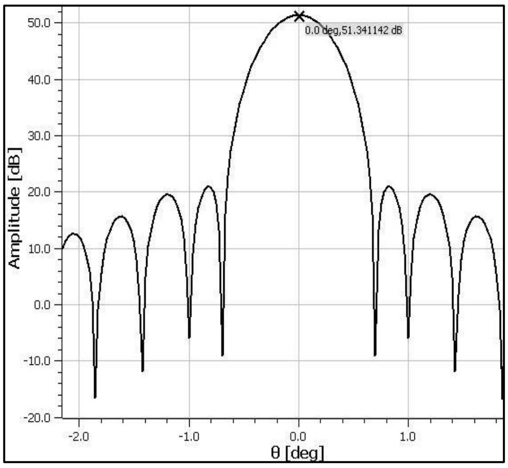
F_{par}=2.1 m, D_{par}=3.6 m



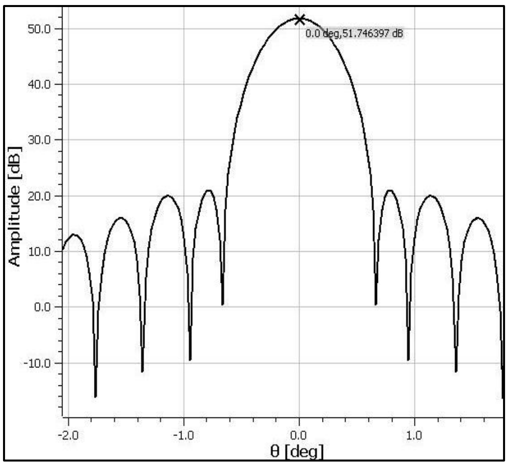
F_{par}=2.1 m, D_{par}=3.8 m



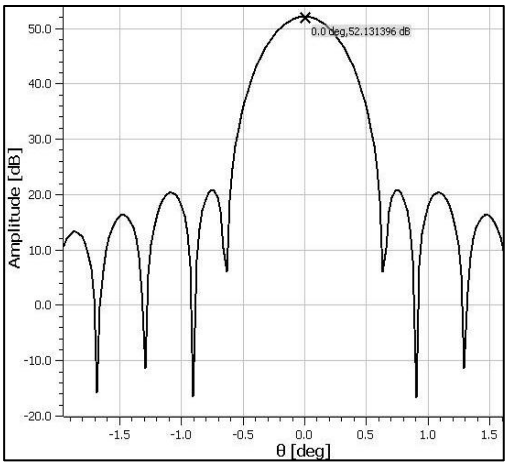
F_{par}=2.1 m, D_{par}=4.0 m



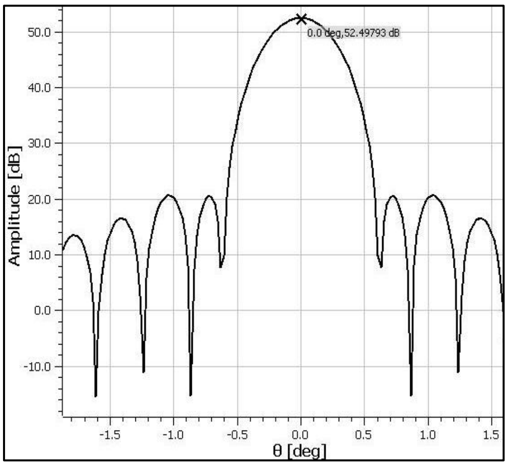
F_{par}=2.1 m, D_{par}=4.2 m



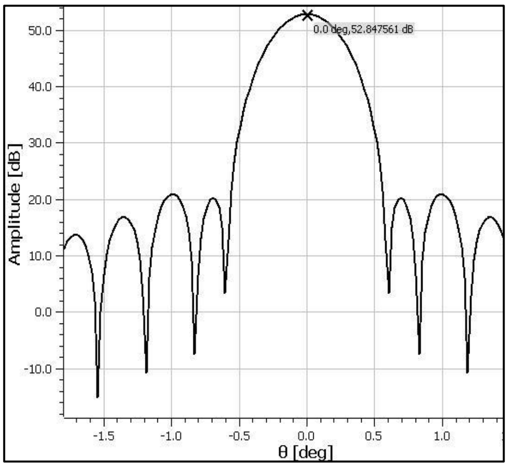
F_{par}=2.1 m, D_{par}=4.4 m



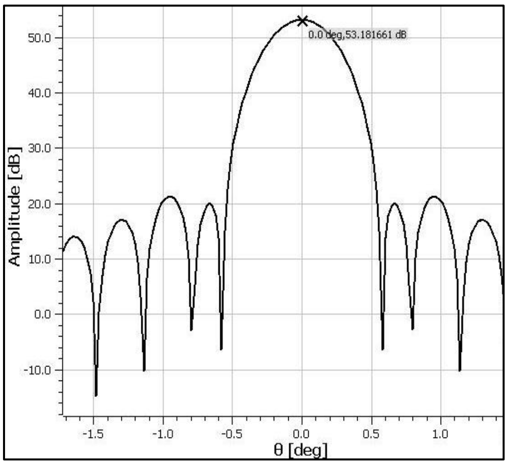
F_{par}=2.1 m, D_{par}=4.6 m



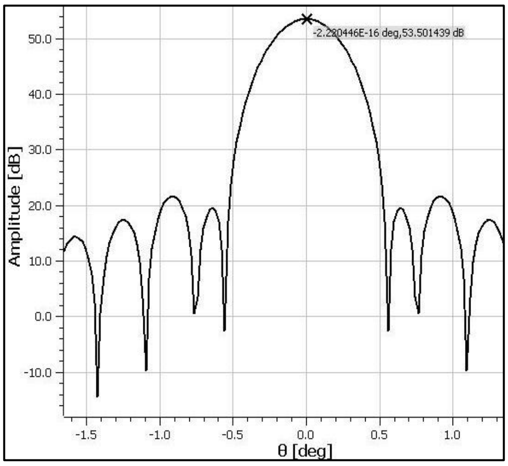
F_{par}=2.1 m, D_{par}=4.8 m



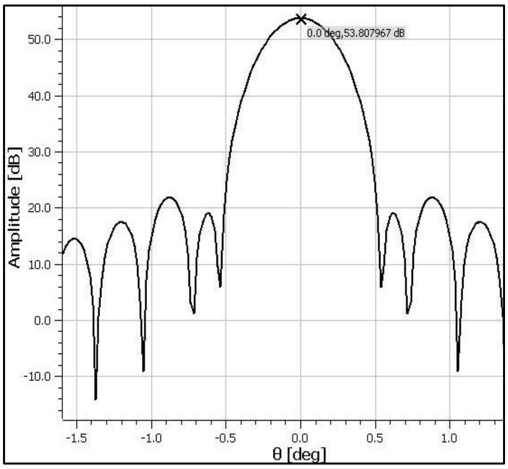
F_{par}=2.1 m, D_{par}=5.0 m



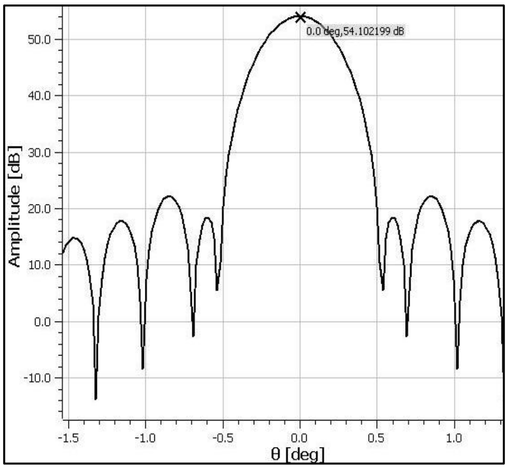
F_{par}=2.1 m, D_{par}=5.2 m



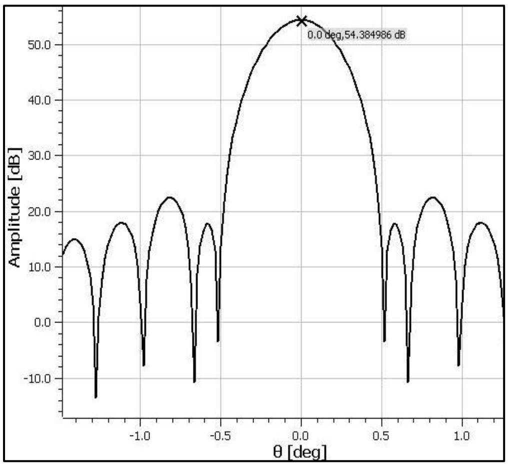
F_{par}=2.1 m, D_{par}=5.4 m



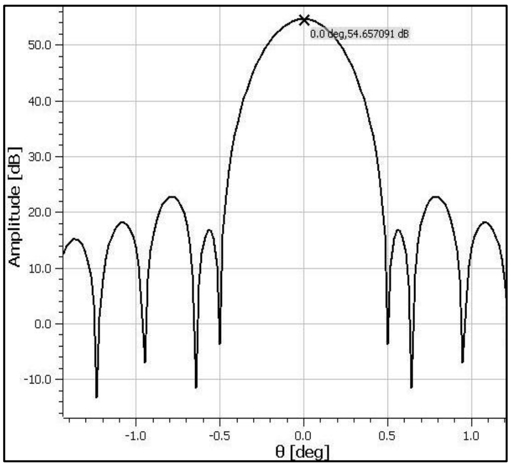
F_{par}=2.1 m, D_{par}=5.6 m



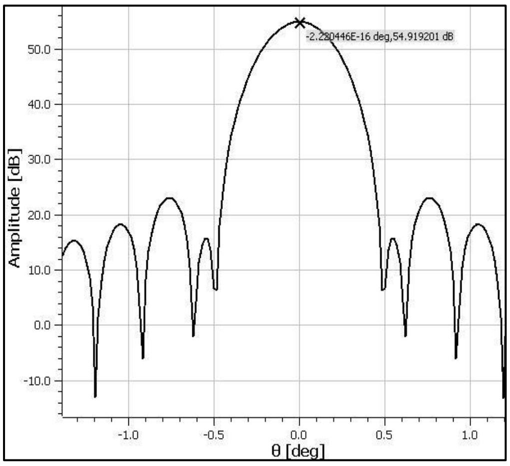
F_{par}=2.1 m, D_{par}=5.8 m



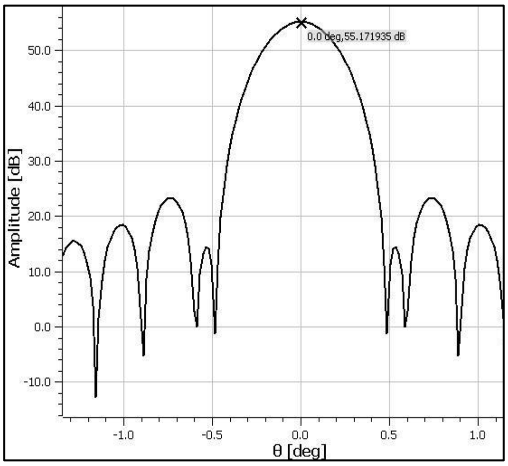
F_{par}=2.1 m, D_{par}=6.0 m



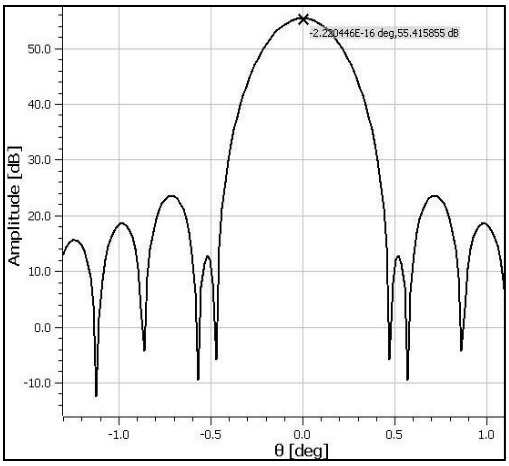
F_{par}=2.1 m, D_{par}=6.2 m



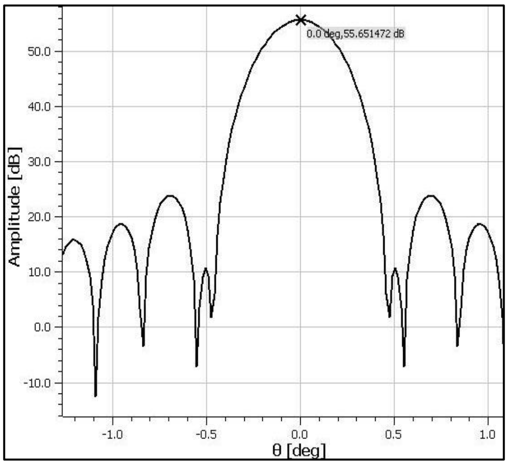
F_{par}=2.1 m, D_{par}=6.4 m



F_{par}=2.1 m, D_{par}=6.6 m



F_{par}=2.1 m, D_{par}=6.8 m



F_{par}=2.1 m, D_{par}=7.0 m

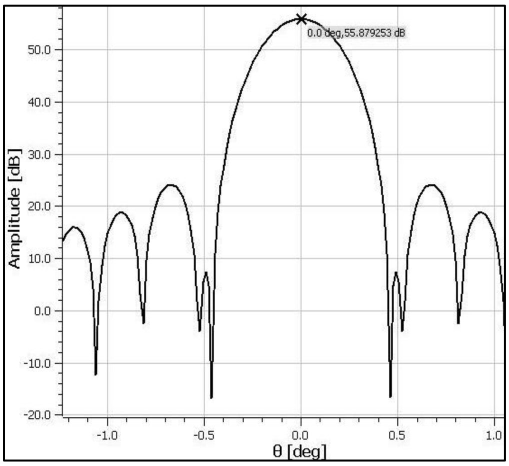


Figure 4.3: Radiation Patterns of a Prime Focus Feed System Having F_{par} = 2.1 Meters with Distinct D_{par}

b) The table below records the calculated focal length to diameter ratio and the half-angle subtended by reflector at the feed for a prime focus feed system having a primary focal length of 2.1 meters with distinct diameters of primary reflector.

Table 4.8: *F/D* Ratio and θ_{par} for a Prime Focus Feed System Having F_{par} = 2.1 Meters with Distinct D_{par}

Diameter of primary reflector, D_{par} (m)	Primary focal length, F_{par} (m)	Focal length to diameter ratio, *F/D*	Half-angle subtended by primary reflector, θ_{par}
3.0	2.1	0.7	39.31°
3.2	2.1	0.65625	41.71°
3.4	2.1	0.6176	44.07°
3.6	2.1	0.5833	46.40°
3.8	2.1	0.5526	48.68°
4.0	2.1	0.525	50.93°
4.2	2.1	0.5	53.13°
4.4	2.1	0.4773	55.29°
4.6	2.1	0.4565	57.41°
4.8	2.1	0.4375	59.49°
5.0	2.1	0.42	61.53°
5.2	2.1	0.4038	63.52°
5.4	2.1	0.3889	65.47°
5.6	2.1	0.375	67.38°

5.8	2.1	0.3621	69.25°
6.0	2.1	0.35	71.08°
6.2	2.1	0.3387	72.86°
6.4	2.1	0.328125	74.61°
6.6	2.1	0.3182	76.31°
6.8	2.1	0.3088	77.98°
7.0	2.1	0.3	79.61°

c) The table below records the amplitudes of the main lobe and side lobe for a prime focus feed system having a primary focal length of 2.1 meters with distinct diameters of primary reflector.

Table 4.9: Main Lobe and Side Lobe Levels for a Prime Focus Feed System Having F_{par} = 2.1 Meters with Distinct D_{par}

Diameter of primary reflector, D_{par} (m)	Primary focal length, F_{par} (m)	Main lobe level (dB)	1st side lobe level (dB)
3.0	2.1	48.925563	20.424156
3.2	2.1	49.470898	20.644631
3.4	2.1	49.981496	20.800200
3.6	2.1	50.461287	20.892116
3.8	2.1	50.913570	20.928075
4.0	2.1	51.341142	20.941713
4.2	2.1	51.746397	20.895536
4.4	2.1	52.131396	20.787371
4.6	2.1	52.497930	20.613820
4.8	2.1	52.847561	20.370016
5.0	2.1	53.181661	20.049230
5.2	2.1	53.501439	19.642287
5.4	2.1	53.807967	19.136654
5.6	2.1	54.102199	18.515003
5.8	2.1	54.384986	17.752839
6.0	2.1	54.657091	16.814357
6.2	2.1	54.919201	15.781398
6.4	2.1	55.171935	14.510231
6.6	2.1	55.415855	12.874224
6.8	2.1	55.651472	10.666374
7.0	2.1	55.879253	7.435521

d) The table below records the spillover losses for a prime focus feed system having a primary focal length of 2.1 meters with distinct diameters of primary reflector.

Table 4.10: Spillover Losses for a Prime Focus Feed System Having F_{par} = 2.1 Meters with Distinct D_{par}

Diameter of primary reflector, D_{par} (m)	Primary focal length, F_{par} (m)	Spillover loss (dB)
3.0	2.1	0.2798
3.2	2.1	0.2789
3.4	2.1	0.2777
3.6	2.1	0.2764
3.8	2.1	0.2748
4.0	2.1	0.2730
4.2	2.1	0.2710
4.4	2.1	0.2687
4.6	2.1	0.2662
4.8	2.1	0.2633
5.0	2.1	0.2602
5.2	2.1	0.2569
5.4	2.1	0.2533
5.6	2.1	0.2494
5.8	2.1	0.2453
6.0	2.1	0.2410
6.2	2.1	0.2365
6.4	2.1	0.2318
6.6	2.1	0.2270
6.8	2.1	0.2220
7.0	2.1	0.2170

5. a) The figure below shows the graph of main lobe level against the diameter of primary reflector for a prime focus feed system with distinct primary focal lengths.

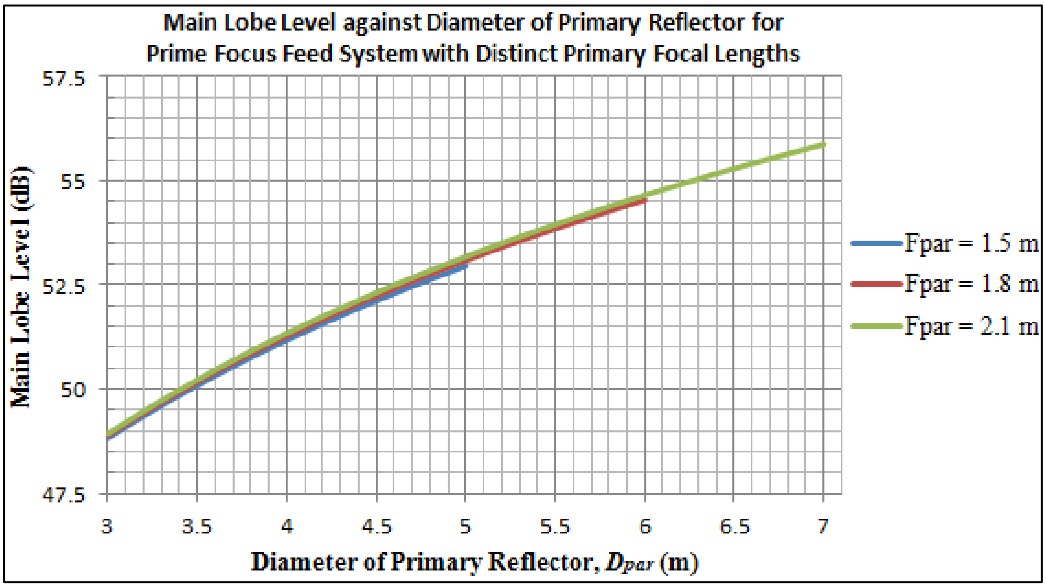


Figure 4.4: Graph of Main Lobe Level against D_{par} for a Prime Focus Feed System with Distinct F_{par}

b) The figure below shows the graph of first side lobe level against the diameter of primary reflector for a prime focus feed system with distinct primary focal lengths.

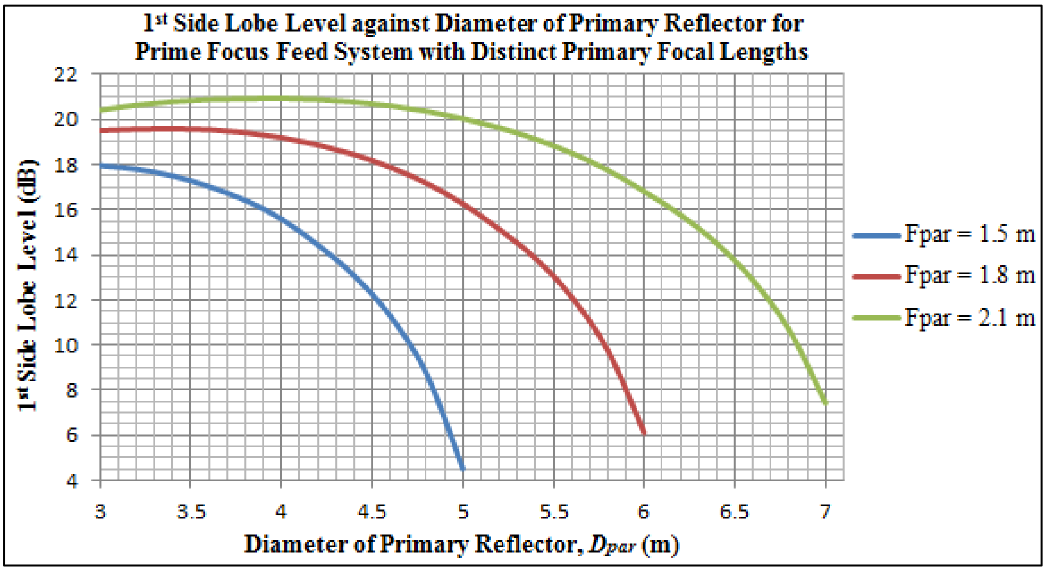


Figure 4.5: Graph of 1st Side Lobe Level against D_{par} for a Prime Focus Feed System with Distinct F_{par}

c) The figure below shows the graph of spillover loss against the diameter of primary reflector for a prime focus feed system with distinct primary focal lengths.

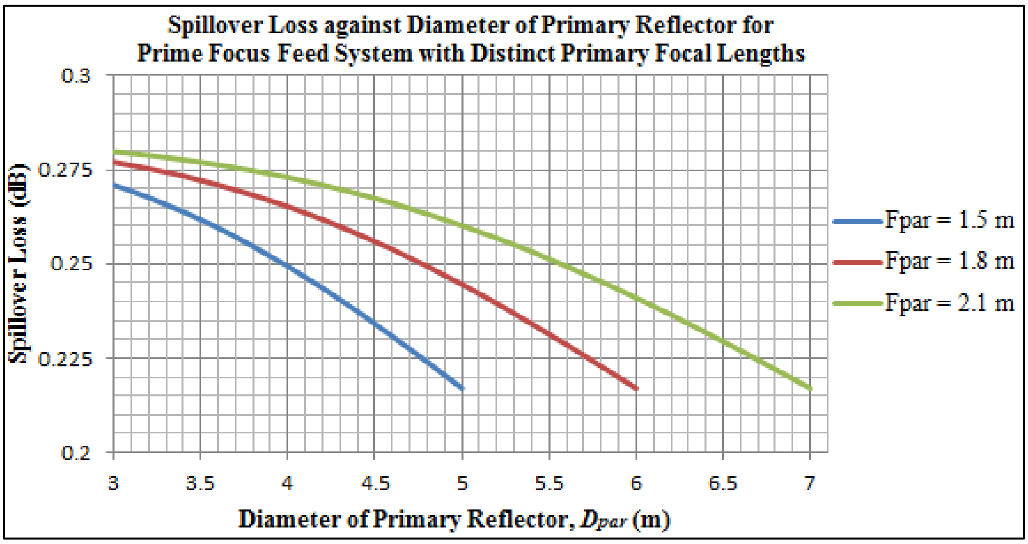


Figure 4.6: Graph of Spillover Loss against D_{par} for a Prime Focus Feed System with Distinct F_{par}

4.2 Analyzing the Performance of a Dual Reflector Feed System

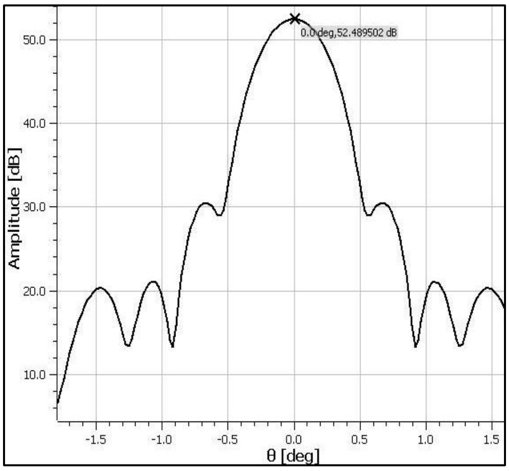
1. a) The table below shows the selected geometrical parameters for a Cassegrain feed system.

Table 2: Geometrical Parameters for a Cassegrain Feed System

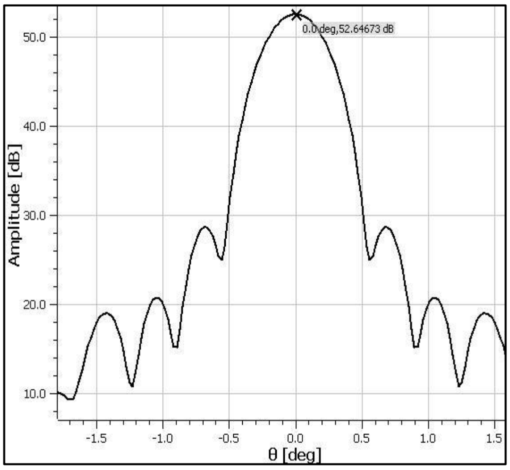
Diameter of parabolic primary reflector, D_{par}	4.8 m
Primary focal length, F_{par}	1.5 m
Diameter of hyperbolic secondary reflector, d_{hyp}	0.3 m – 1.4 m
Distance between primary and secondary foci, f_c	0.6 m – 1.2 m
Operating frequency, f	10 GHz

2. a) The following below shows the radiation patterns of a Cassegrain feed system having distance between foci of 0.6 meters with distinct diameters of secondary reflector.

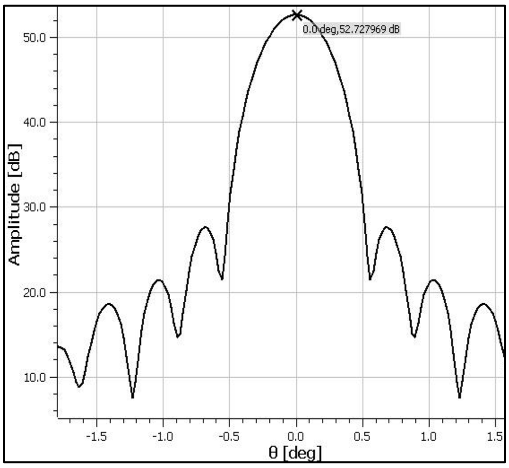
f_c=0.6 m, d_{hyp}=0.3 m



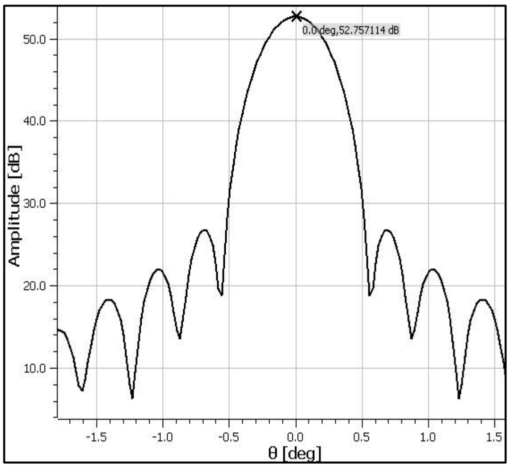
f_c=0.6 m, d_{hyp}=0.4 m



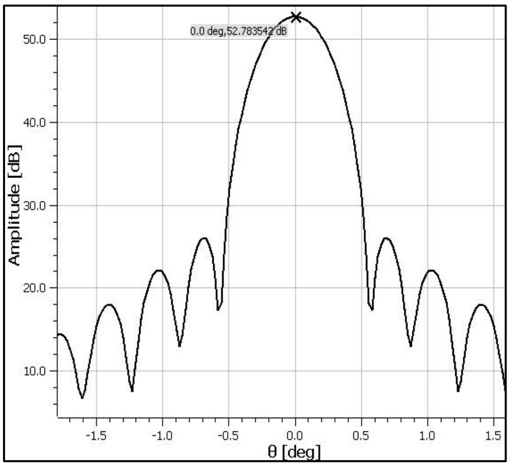
f_c=0.6 m, d_{hyp}=0.5 m



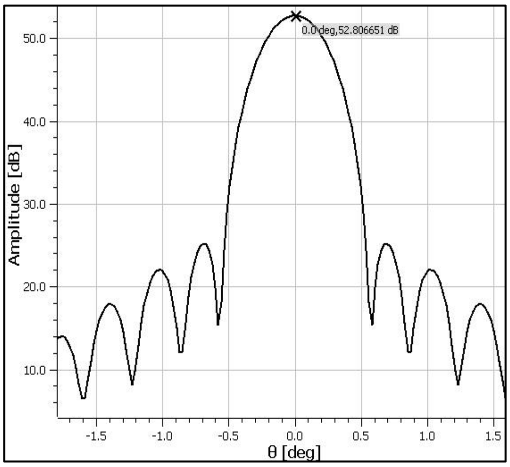
f_c=0.6 m, d_{hyp}=0.6 m



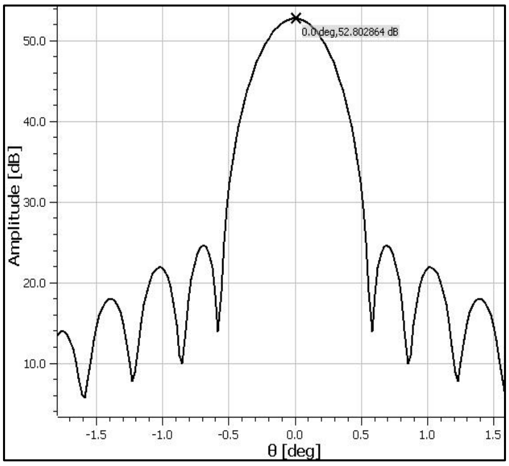
f_c=0.6 m, d_{hyp}=0.7 m



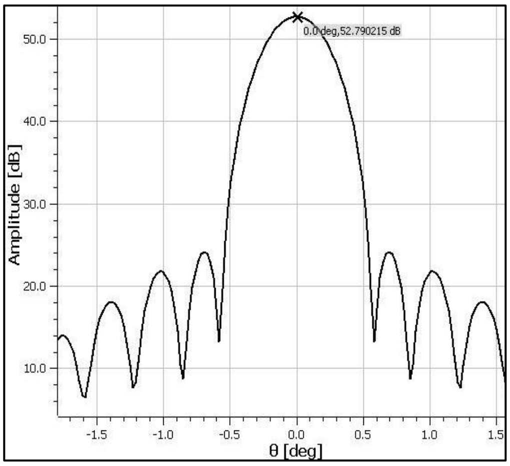
f_c=0.6 m, d_{hyp}=0.8 m



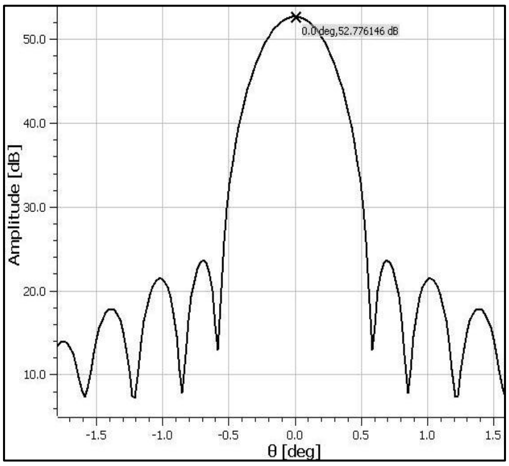
f_c=0.6 m, d_{hyp}=0.9 m



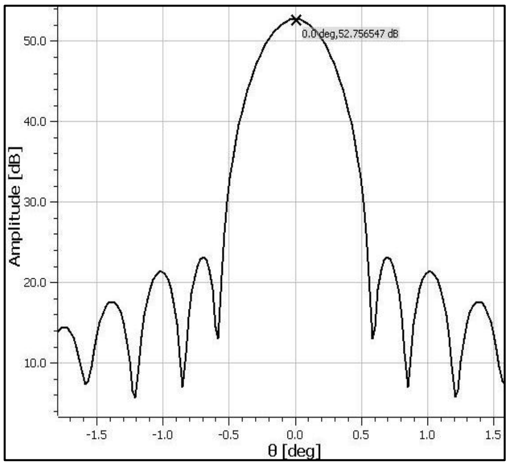
f_c=0.6 m, d_{hyp}=1.0 m



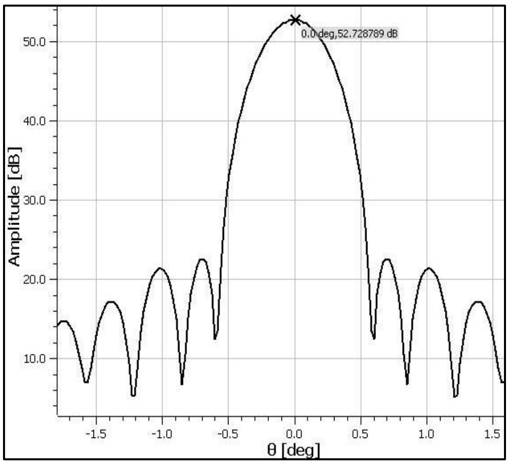
f_c=0.6 m, d_{hyp}=1.1 m



f_c=0.6 m, d_{hyp}=1.2 m



f_c=0.6 m, d_{hyp}=1.3 m



f_c=0.6 m, d_{hyp}=1.4 m

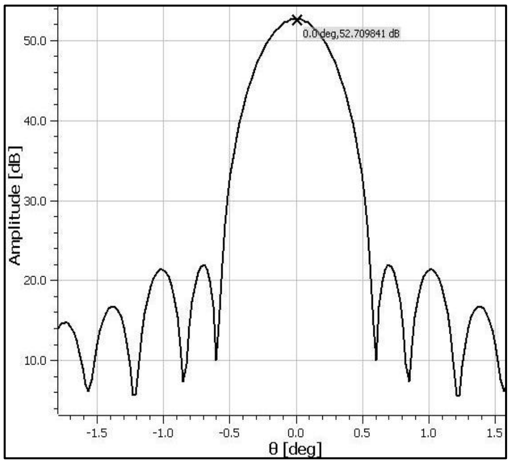


Figure 4.7: Radiation Patterns of a Cassegrain Feed System Having f_c = 0.6 Meters with Distinct d_{hyp}

b) The table below records the calculated half-angle subtended by secondary reflector at the feed and the eccentricity of secondary reflector for a Cassegrain feed system having distance between foci of 0.6 meters with distinct diameters of secondary reflector.

Table 4.12: Secondary Eccentricity and θ_{hyp} for a Cassegrain Feed System having f_c = 0.6 Meters with Distinct d_{hyp}

Diameter of secondary reflector, d_{hyp} (m)	Distance between foci, f_c (m)	Half-angle subtended by secondary reflector, θ_{hyp}	Eccentricity, e_{hyp}
0.3	0.6	14.84°	1.3888
0.4	0.6	19.82°	1.5587
0.5	0.6	24.69°	1.7533
0.6	0.6	29.40°	1.9757
0.7	0.6	33.88°	2.2296
0.8	0.6	38.11°	2.5194
0.9	0.6	42.06°	2.8503
1.0	0.6	45.73°	3.2289
1.1	0.6	49.11°	3.6632
1.2	0.6	52.22°	4.1639
1.3	0.6	55.08°	4.7446
1.4	0.6	57.70°	5.4233

c) The table below records the amplitudes of the main lobe and side lobe for a Cassegrain feed system having distance between foci of 0.6 meters with distinct diameters of secondary reflector.

Table 4.13: Main Lobe and Side Lobe Levels for a Cassegrain Feed System Having f_c = 0.6 Meters with Distinct d_{hyp}

Diameter of secondary reflector, d_{hyp} (m)	Distance between foci, f_c (m)	Main lobe level (dB)	1st side lobe level (dB)
0.3	0.6	52.489502	30.524669
0.4	0.6	52.646730	28.690523
0.5	0.6	52.727969	27.567922
0.6	0.6	52.757114	26.797285
0.7	0.6	52.783542	26.039850
0.8	0.6	52.806651	25.246639
0.9	0.6	52.802864	24.651145
1.0	0.6	52.790215	24.187957
1.1	0.6	52.776146	23.634482
1.2	0.6	52.756547	23.116260
1.3	0.6	52.728789	22.623988
1.4	0.6	52.709841	21.933044

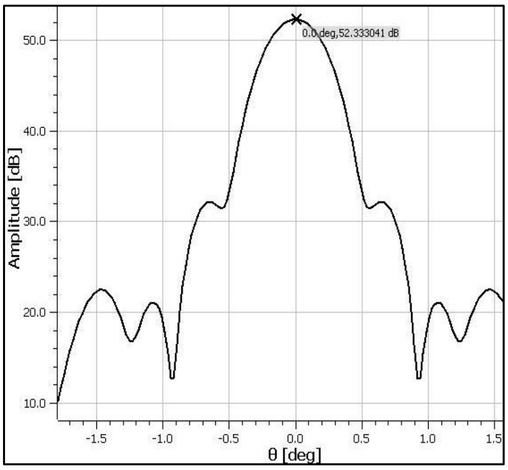
d) The table below records the spillover losses for a Cassegrain feed system having distance between foci of 0.6 meters with distinct diameters of secondary reflector.

Table 4.14: Spillover Losses for a Cassegrain Feed System Having f_c = 0.6 Meters with Distinct d_{hyp}

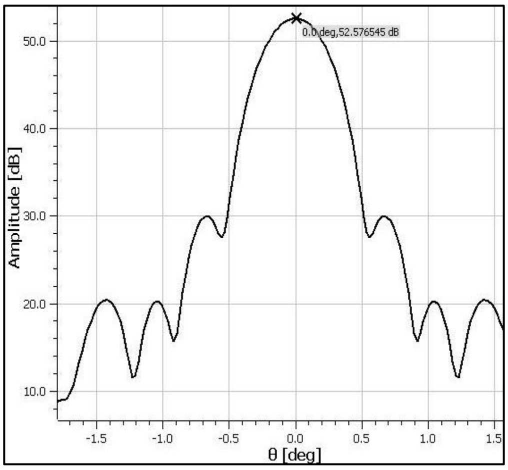
Diameter of secondary reflector, d_{hyp} (m)	Distance between foci, f_c (m)	Rear spillover loss (dB)	Forward spillover loss (dB)
0.3	0.6	0.4742	0.3776
0.4	0.6	0.3839	0.3109
0.5	0.6	0.3539	0.2936
0.6	0.6	0.3442	0.2872
0.7	0.6	0.3342	0.2840
0.8	0.6	0.3239	0.2817
0.9	0.6	0.3189	0.2796
1.0	0.6	0.3129	0.2774
1.1	0.6	0.3072	0.2749
1.2	0.6	0.3008	0.2722
1.3	0.6	0.2964	0.2692
1.4	0.6	0.2905	0.2659

3. a) The following below shows the radiation patterns of a Cassegrain feed system having distance between foci of 0.9 meters with distinct diameters of secondary reflector.

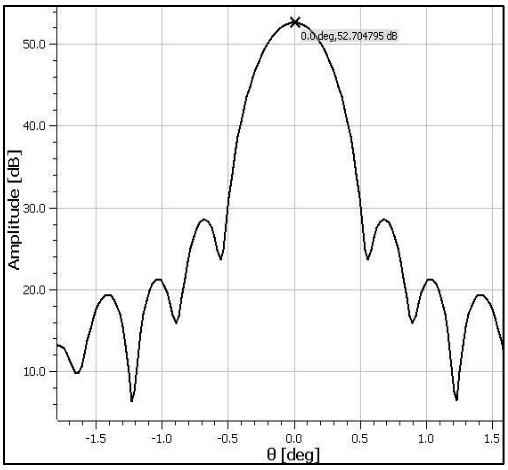
f_c=0.9 m, d_{hyp}=0.3 m



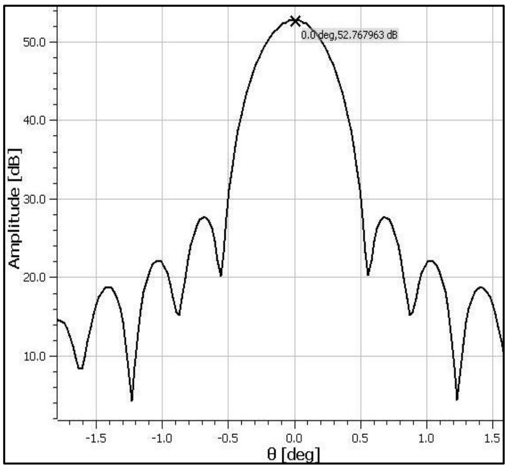
f_c=0.9 m, d_{hyp}=0.4 m



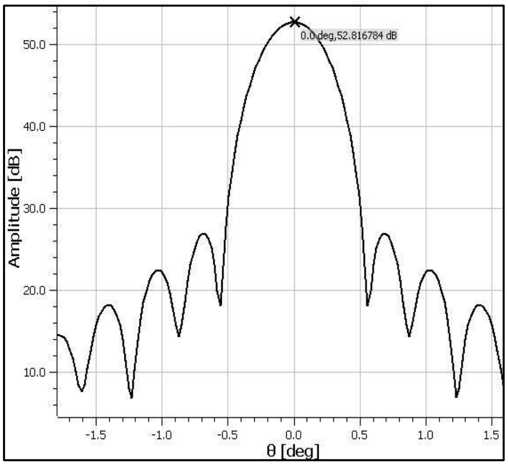
f_c=0.9 m, d_{hyp}=0.5 m



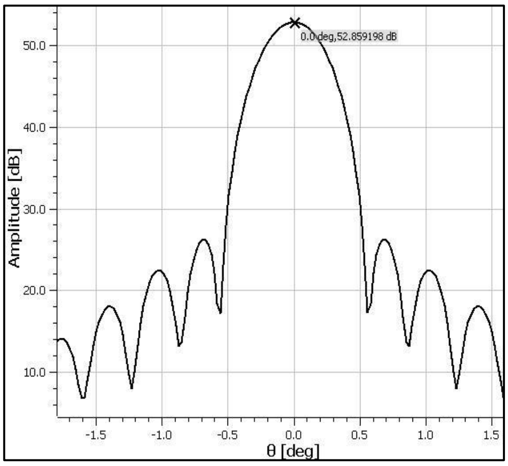
f_c=0.9 m, d_{hyp}=0.6 m



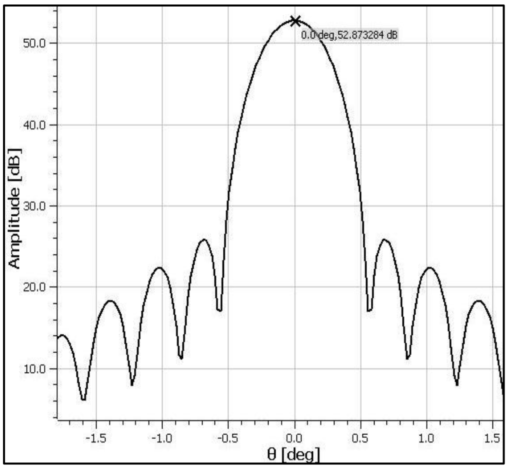
f_c=0.9 m, d_{hyp}=0.7m



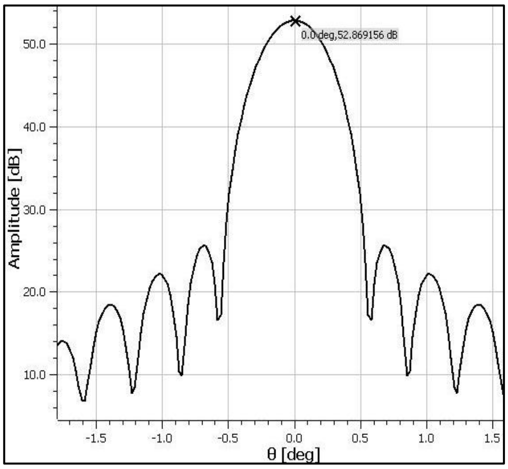
f_c=0.9 m, d_{hyp}=0.8 m



f_c=0.9 m, d_{hyp}=0.9 m



f_c=0.9 m, d_{hyp}=1.0 m



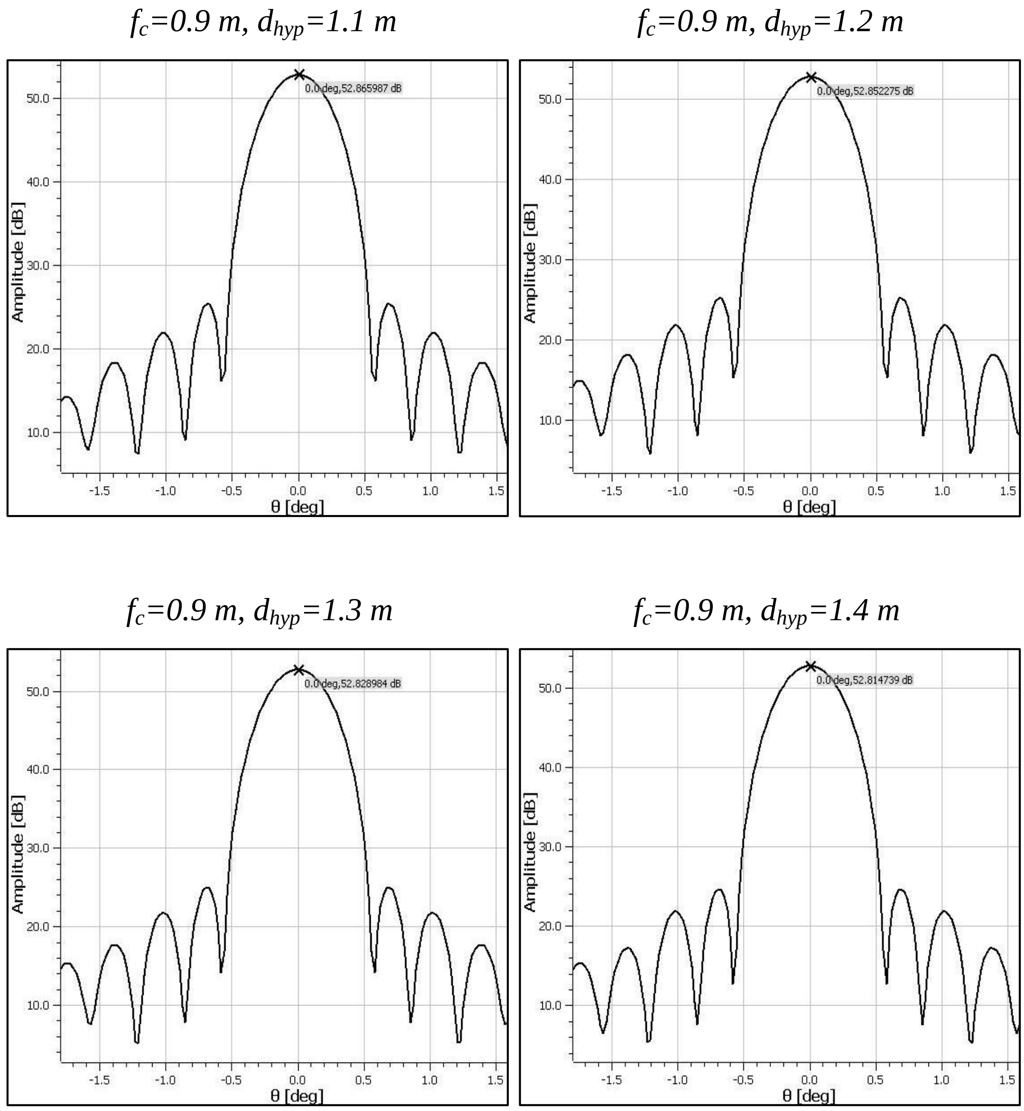


Figure 4.8: Radiation Patterns of a Cassegrain Feed System Having f_c = 0.9 Meters with Distinct d_{hyp}

b) The table below records the half-angle subtended by secondary reflector at the feed and the eccentricity of secondary reflector for a Cassegrain feed system having distance between foci of 0.9 meters with distinct diameters of secondary reflector.

Table 4.15: Secondary Eccentricity and θ_{hyp} for a Cassegrain Feed System Having f_c = 0.9 Meters with Distinct d_{hyp}

Diameter of secondary reflector, d_{hyp} (m)	Distance between foci, f_c (m)	Half-angle subtended by secondary reflector, θ_{hyp}	Eccentricity, e_{hyp}
0.3	0.9	9.82°	1.2407
0.4	0.9	13.17°	1.3371
0.5	0.9	16.50°	1.4429
0.6	0.9	19.82°	1.5587
0.7	0.9	23.08°	1.6855
0.8	0.9	26.28°	1.8241
0.9	0.9	29.40°	1.9757
1.0	0.9	32.41°	2.1412
1.1	0.9	35.32°	2.3220
1.2	0.9	38.11°	2.5194
1.3	0.9	40.77°	2.7351
1.4	0.9	43.31°	2.9708

c) The table below records the amplitudes of the main lobe and side lobe for a Cassegrain feed system having distance between foci of 0.9 meters with distinct diameters of secondary reflector.

Table 4.16: Main Lobe and Side Lobe Levels for a Cassegrain Feed System Having f_c = 0.9 Meters with Distinct d_{hyp}

Diameter of secondary reflector, d_{hyp} (m)	Distance between foci, f_c (m)	Main lobe level (dB)	1st side lobe level (dB)
0.3	0.9	52.333041	32.195203
0.4	0.9	52.576545	29.969417
0.5	0.9	52.704795	28.578919
0.6	0.9	52.767963	27.662758
0.7	0.9	52.816784	26.901682
0.8	0.9	52.859198	26.227711
0.9	0.9	52.873284	25.812528
1.0	0.9	52.869156	25.616727
1.1	0.9	52.865987	25.397649
1.2	0.9	52.852275	25.193164
1.3	0.9	52.828984	24.985891
1.4	0.9	52.814739	24.641425

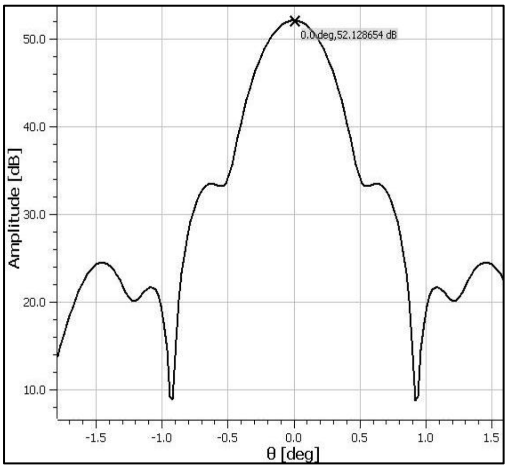
d) The table below records the spillover losses for a Cassegrain feed system having distance between foci of 0.9 meters with distinct diameters of secondary reflector.

Table 4.17: Spillover Losses for a Cassegrain Feed System Having f_c = 0.9 Meters with Distinct d_{hyp}

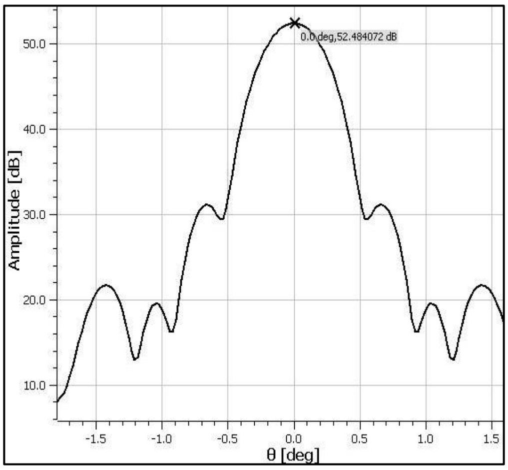
Diameter of secondary reflector, d_{hyp} (m)	Distance between foci, f_c (m)	Rear spillover loss (dB)	Forward spillover loss (dB)
0.3	0.9	0.6313	0.5140
0.4	0.9	0.4320	0.3502
0.5	0.9	0.3727	0.3093
0.6	0.9	0.3524	0.2952
0.7	0.9	0.3413	0.2892
0.8	0.9	0.3315	0.2862
0.9	0.9	0.3264	0.2843
1.0	0.9	0.3232	0.2830
1.1	0.9	0.3174	0.2819
1.2	0.9	0.3132	0.2808
1.3	0.9	0.3109	0.2797
1.4	0.9	0.3067	0.2784

4. a) The following below shows the radiation patterns of a Cassegrain feed system having distance between foci of 1.2 meters with distinct diameters of secondary reflector.

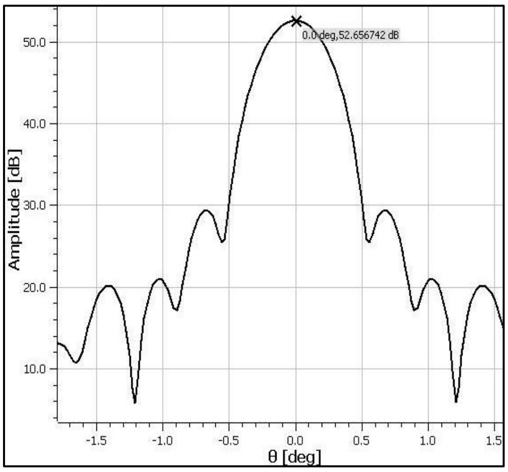
f_c=1.2 m, d_{hyp}=0.3 m



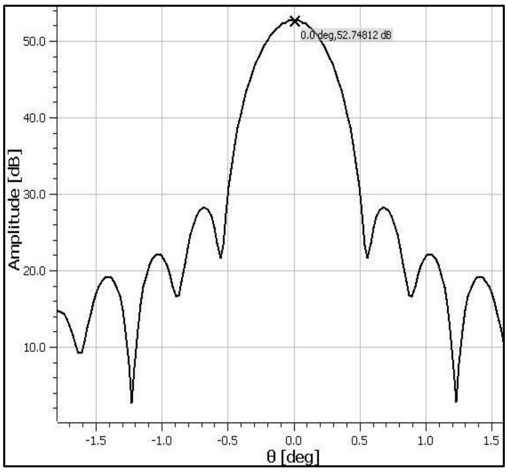
f_c=1.2 m, d_{hyp}=0.4 m



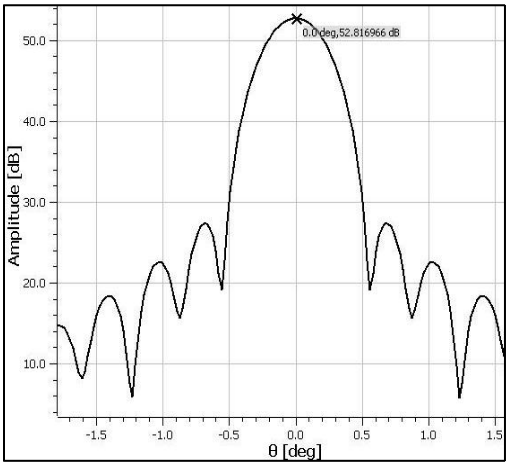
f_c=1.2 m, d_{hyp}=0.5 m



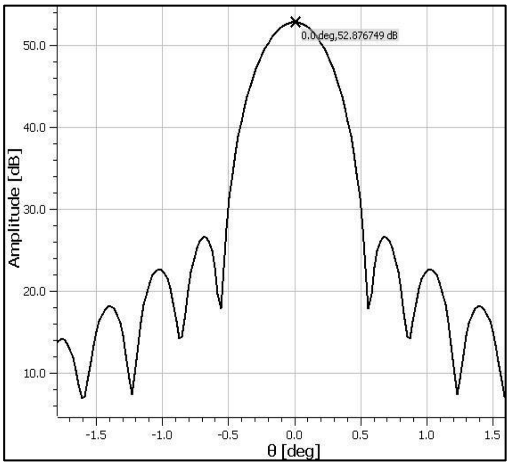
f_c=1.2 m, d_{hyp}=0.6 m



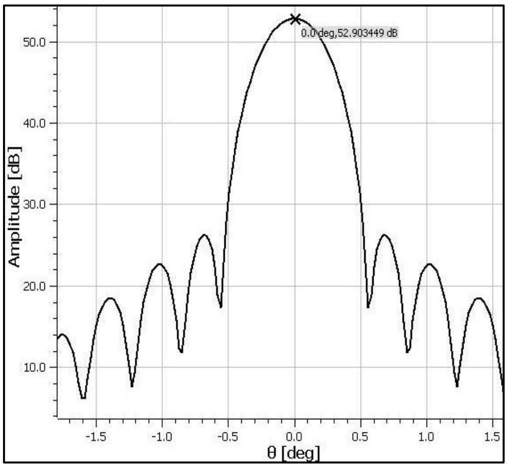
f_c=1.2 m, d_{hyp}=0.7 m



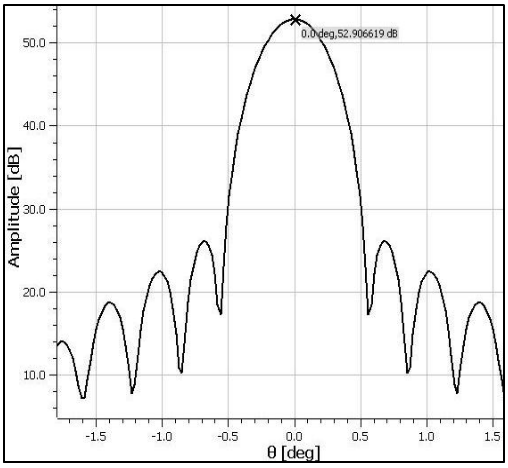
f_c=1.2 m, d_{hyp}=0.8 m



f_c=1.2 m, d_{hyp}=0.9 m



f_c=1.2 m, d_{hyp}=1.0 m



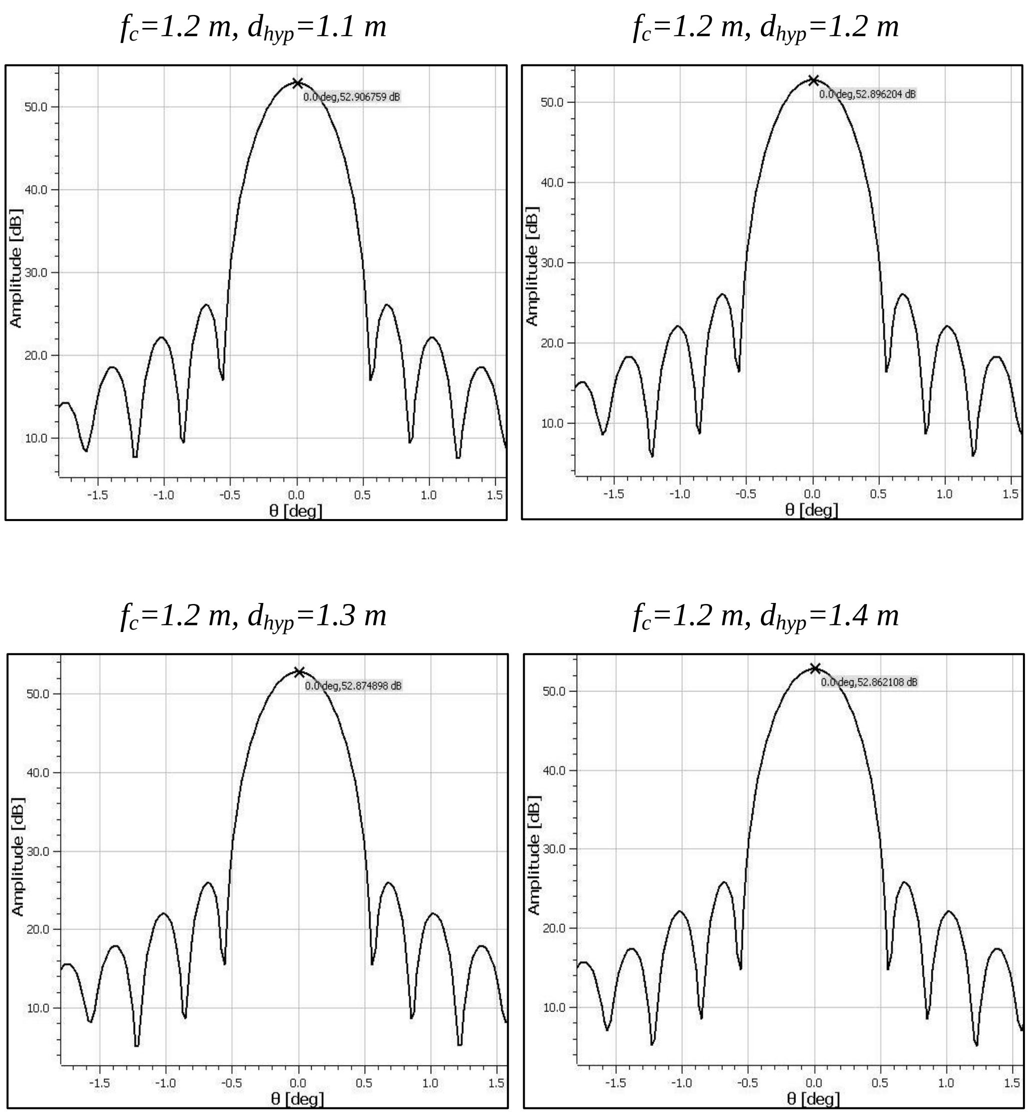


Figure 4.9: Radiation Patterns of a Cassegrain Feed System Having f_c = 1.2 Meters with Distinct d_{hyp}

b) The table below records the half-angle subtended by secondary reflector at the feed and the eccentricity of secondary reflector for a Cassegrain feed system having distance between foci of 1.2 meters with distinct diameters of secondary reflector.

Table 4.18: Secondary Eccentricity and θ_{hyp} for a Cassegrain Feed System Having f_c = 1.2 Meters with Distinct d_{hyp}

Diameter of secondary reflector, d_{hyp} (m)	Distance between foci, f_c (m)	Half-angle subtended by secondary reflector, θ_{hyp}	Eccentricity, e_{hyp}
0.3	1.2	7.33°	1.1740
0.4	1.2	9.82°	1.2407
0.5	1.2	12.33°	1.3122
0.6	1.2	14.84°	1.3888
0.7	1.2	17.34°	1.4708
0.8	1.2	19.82°	1.5587
0.9	1.2	22.27°	1.6527
1.0	1.2	24.69°	1.7533
1.1	1.2	27.07°	1.8608
1.2	1.2	29.40°	1.9757
1.3	1.2	31.67°	2.0985
1.4	1.2	33.88°	2.2296

c) The table below records the amplitudes of the main lobe and side lobe from the radiation patterns of a Cassegrain feed system having distance between foci of 1.2 meters with distinct diameters of secondary reflector.

Table 4.19: Main Lobe and Side Lobe Levels for a Cassegrain Feed System Having f_c = 1.2 Meters with Distinct d_{hyp}

Diameter of secondary reflector, d_{hyp} (m)	Distance between foci, f_c (m)	Main lobe level (dB)	1st side lobe level (dB)
0.3	1.2	52.128654	33.484300
0.4	1.2	52.484072	31.106404
0.5	1.2	52.656742	29.381945
0.6	1.2	52.748120	28.220852
0.7	1.2	52.816966	27.298127
0.8	1.2	52.876749	26.558504
0.9	1.2	52.903449	26.213504
1.0	1.2	52.906619	26.110792
1.1	1.2	52.906759	26.034912
1.2	1.2	52.896204	25.986400
1.3	1.2	52.874898	25.932447
1.4	1.2	52.862000	25.731948

d) The table below records the spillover losses for a Cassegrain system having distance between foci of 1.2 meters with distinct diameters of secondary reflector.

Table 4.20: Spillover Losses for a Cassegrain Feed System Having f_c = 1.2 Meters with Distinct d_{hyp}

Diameter of secondary reflector, d_{hyp} (m)	Distance between foci, f_c (m)	Rear spillover loss (dB)	Forward spillover loss (dB)
0.3	1.2	0.8616	0.7201
0.4	1.2	0.4985	0.4082
0.5	1.2	0.3993	0.3317
0.6	1.2	0.3663	0.3057
0.7	1.2	0.3504	0.2949
0.8	1.2	0.3378	0.2898
0.9	1.2	0.3306	0.2870
1.0	1.2	0.3267	0.2853
1.1	1.2	0.3214	0.2842
1.2	1.2	0.3171	0.2833
1.3	1.2	0.3155	0.2826
1.4	1.2	0.3128	0.2820

5. a) The figure below shows the graph of main lobe level against diameter of secondary reflector for a Cassegrain system with distinct distances between foci.

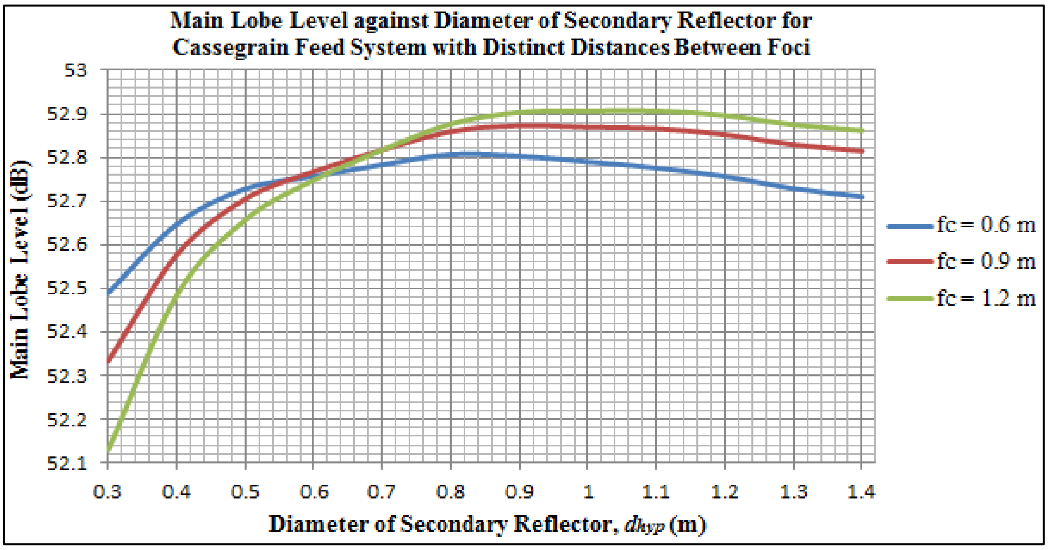


Figure 4.10: Graph of Main Lobe Level against d_{hyp} for a Cassegrain Feed System with Distinct f_c

b) The figure below shows the graph of first side lobe level against diameter of secondary reflector for a Cassegrain system with distinct distances between foci.

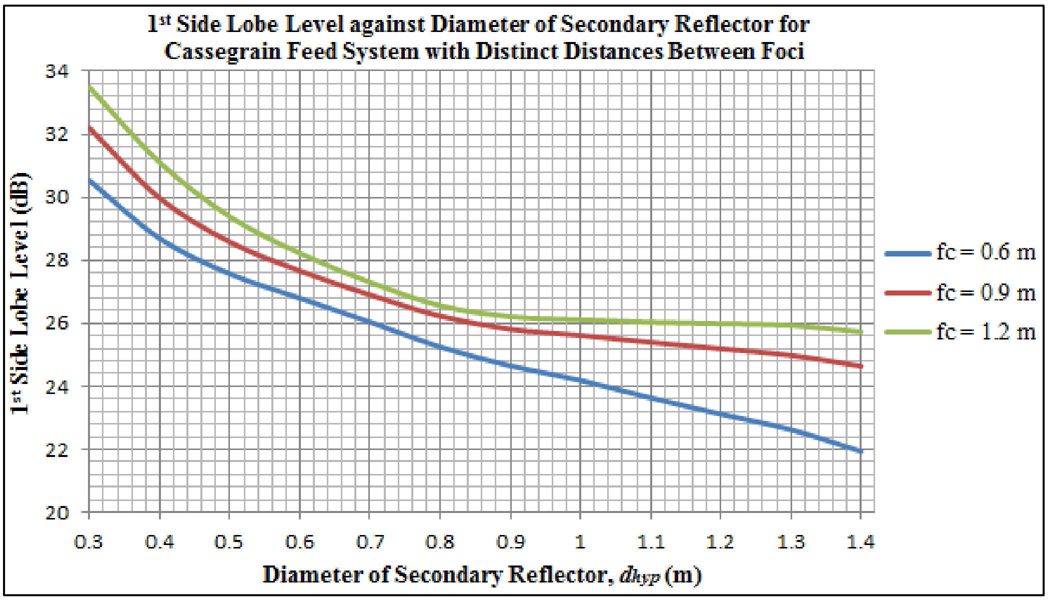


Figure 4.11: Graph of 1st Side Lobe Level against d_{hyp} for a Cassegrain Feed System with Distinct f_c

c) The figure below shows the graph of forward spillover loss against diameter of secondary reflector for a Cassegrain system with distinct distances between foci.

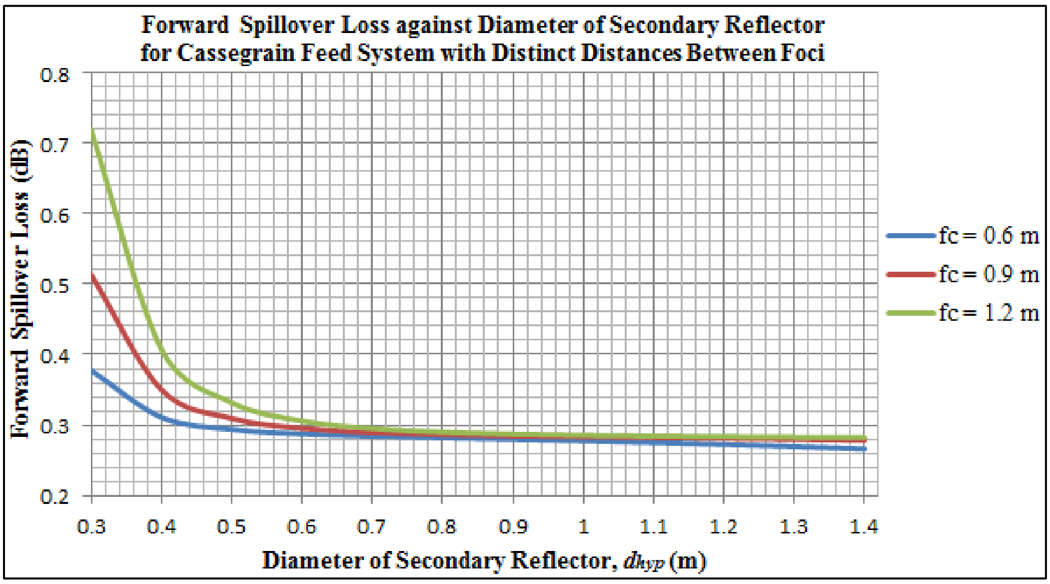


Figure 4.12: Graph of Forward Spillover Loss against d_{hyp} for a Cassegrain Feed System with Distinct f_c.

d) The figure below shows the graph of rear spillover loss against the diameter of secondary reflector for a Cassegrain system with distinct distances between foci.

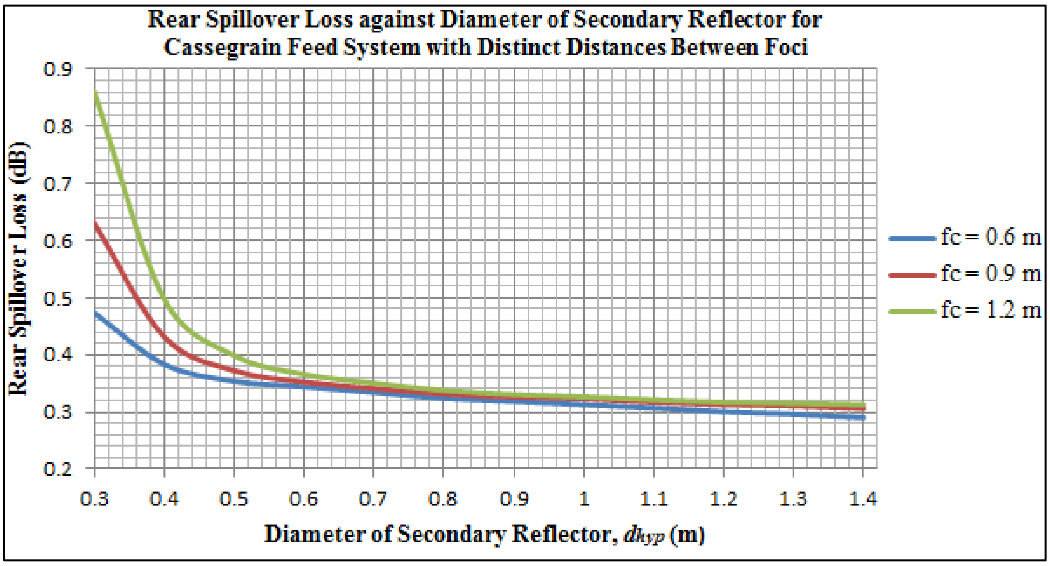


Figure 4.13: Graph of Rear Spillover Loss against d_{hyp} for a Cassegrain Feed System with Distinct f_c.

4.1.3 Comparing the Performances of Various Geometrical Configurations of Front-Feed Reflector System at Various Operating Frequencies

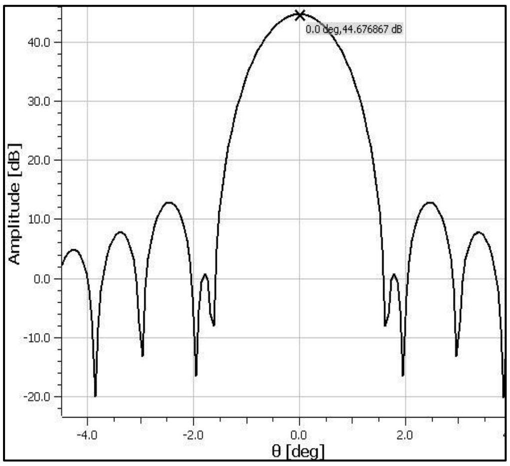
1. a) The table below shows the selected geometrical parameters for a prime focus feed system.

Table 4.21: Geometrical Parameters for a Prime Focus Feed System

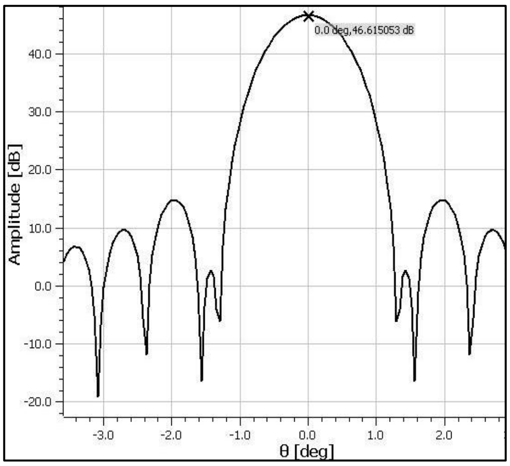
Diameter of parabolic primary reflector, D_{par}	4.8 m
Focal length of parabolic primary reflector, F_{par}	1.5 m
Focal length to diameter ratio, *F/D*	0.3125
Half-angle subtended by parabolic primary reflector, θ_{par}	77.32°
Operating frequency range, *f*	4 GHz – 18 GHz

b) The following below shows the radiation patterns of a prime focus feed system operating at different frequency.

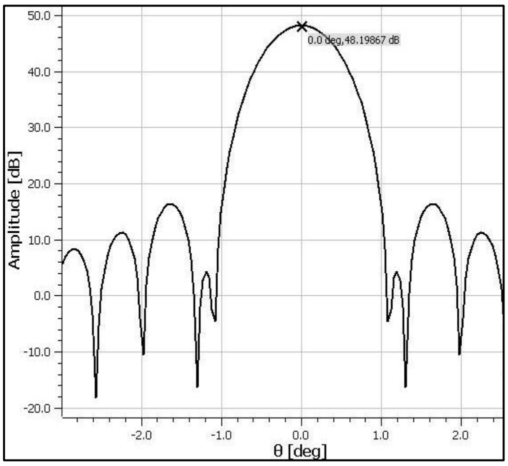
f = 4 GHz



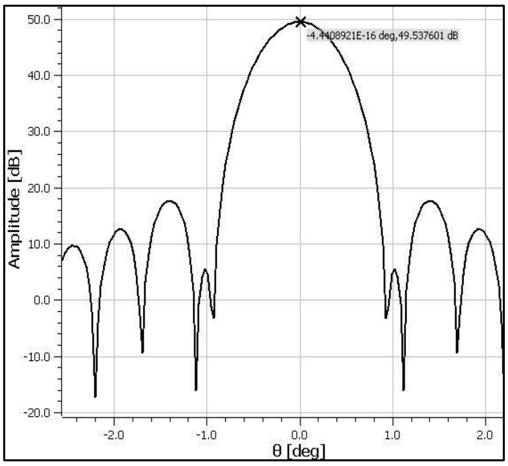
f = 5 GHz



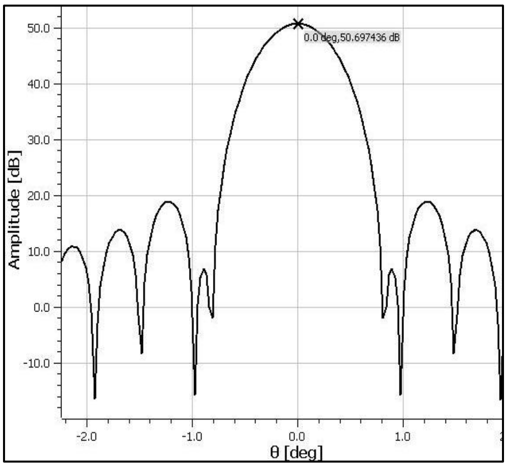
f = 6 GHz



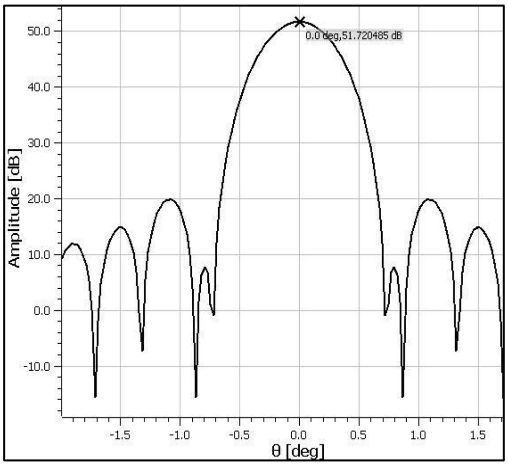
f = 7 GHz



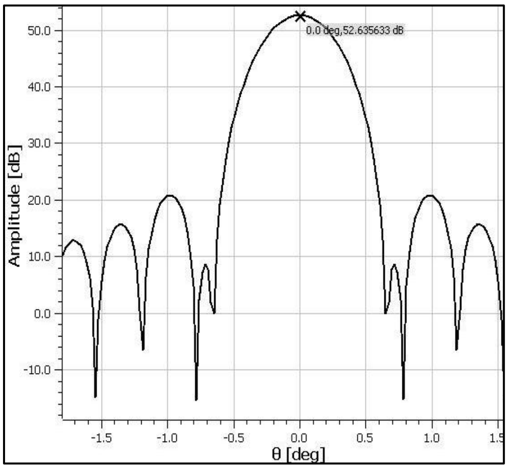
f = 8 GHz



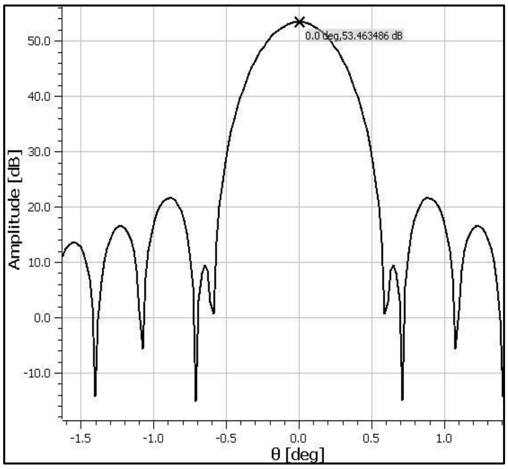
f = 9 GHz



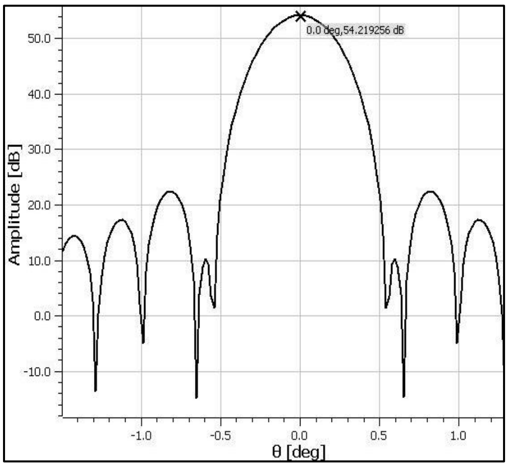
f = 10 GHz



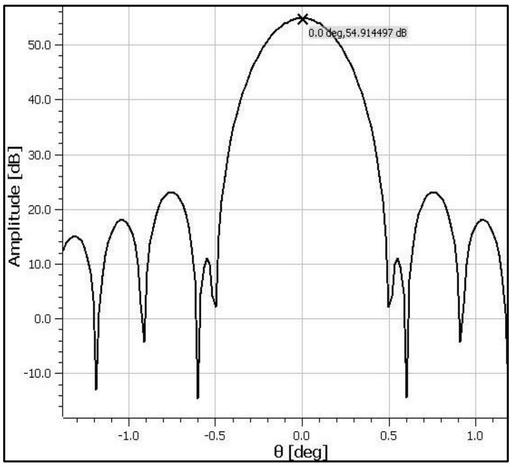
f = 11 GHz



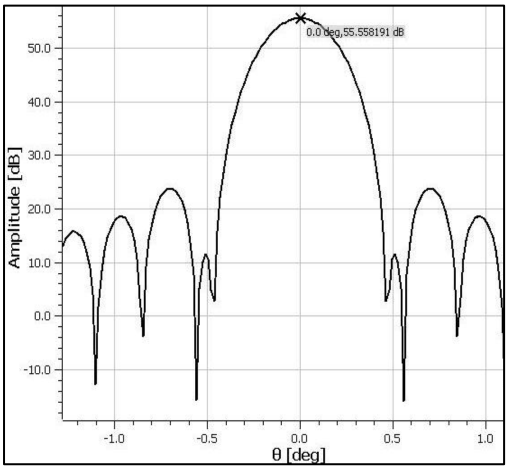
f = 12 GHz



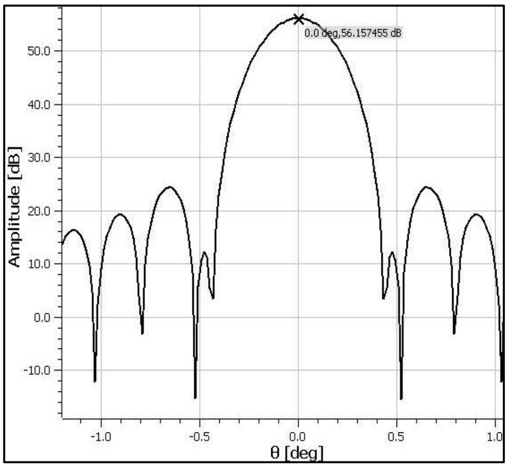
f = 13 GHz



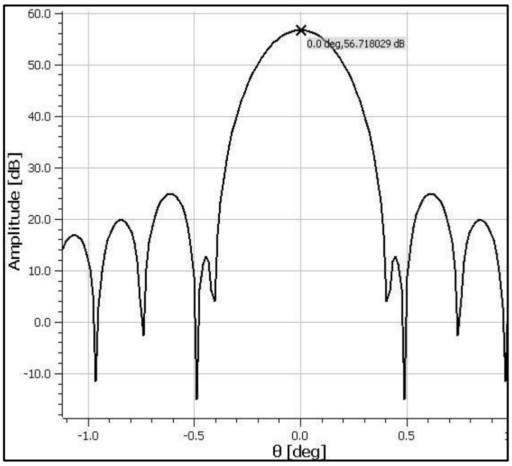
f = 14 GHz



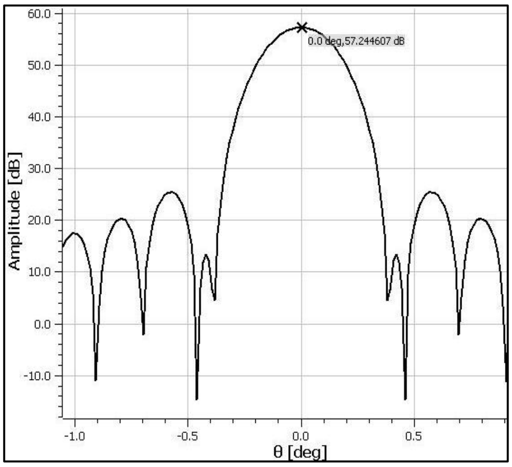
f = 15 GHz



f = 16 GHz



f = 17 GHz



f = 4 GHz

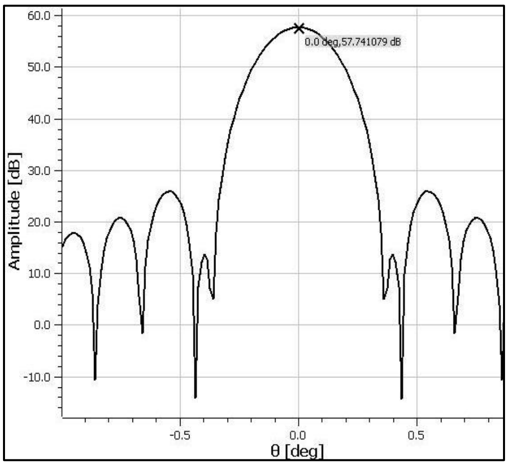


Figure 4.14: Radiation Patterns of a Prime Focus Feed System Operating at Different

c) The table below records the amplitudes of the main lobe and side lobe for a prime focus feed system operating at different frequency.

Table 4.22: Main Lobe and Side Lobe Levels for a Prime Focus Feed System Operating at Different Frequency

Operating frequency, *f* (GHz)	**Main lobe level (dB)**	**1st side lobe level (dB)**
4	44.676867	0.800440
5	46.615053	2.711521
6	48.198670	4.296933
7	49.537601	5.630351
8	50.697436	6.787002
9	51.720485	7.807643
10	52.635633	8.690709
11	53.563486	9.547645
12	54.219256	10.302445
13	54.914497	10.996930
14	55.558191	11.637012
15	56.157455	12.205891
16	56.718029	12.796678
17	57.244607	13.323189
18	57.741079	13.819606

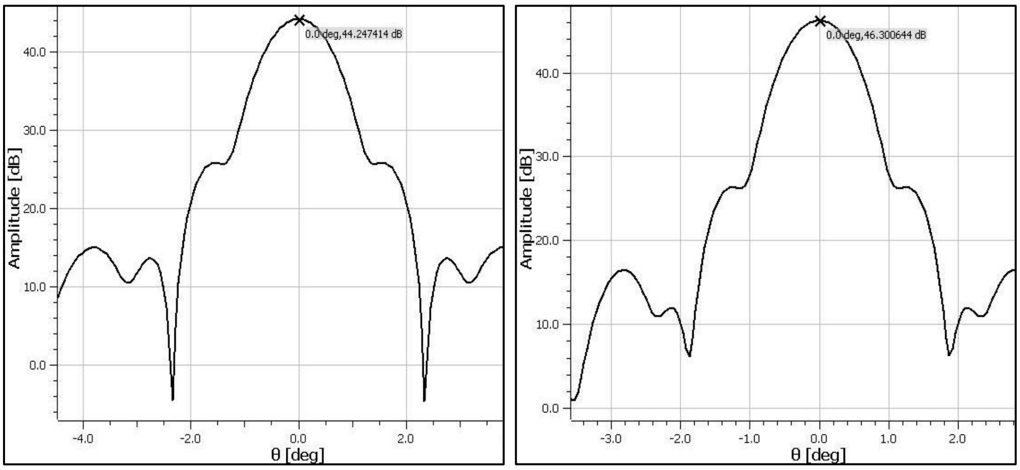
2. a) The table below shows the selected geometrical parameters for a Cassegrain feed system.

Table 4.23: Geometrical Parameters for a Cassegrain Feed System

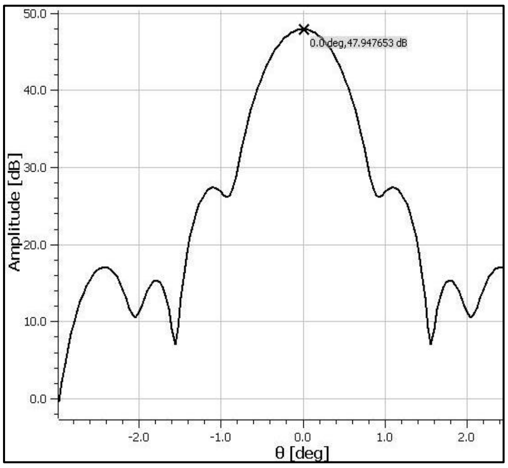
Diameter of parabolic primary reflector, D_{par}	4.8 m
Focal length of parabolic primary reflector, F_{par}	1.5 m
Focal length to diameter ratio, *F/D*	0.3125
Half-angle subtended by parabolic primary reflector, θ_{par}	77.32°
Diameter of hyperbolic secondary reflector, d_{hyp}	0.5 m
Distance between primary and secondary foci, f_c	1.2 m
Half-angle subtended by hyperbolic secondary reflector, θ_{hyp}	12.33°
Eccentricity of hyperbolic reflector, e_{hyp}	1.31219
Operating frequency, *f*	4 GHz – 18 GHz

b) The following below shows the radiation patterns of a Cassegrain feed system operating at different frequency.

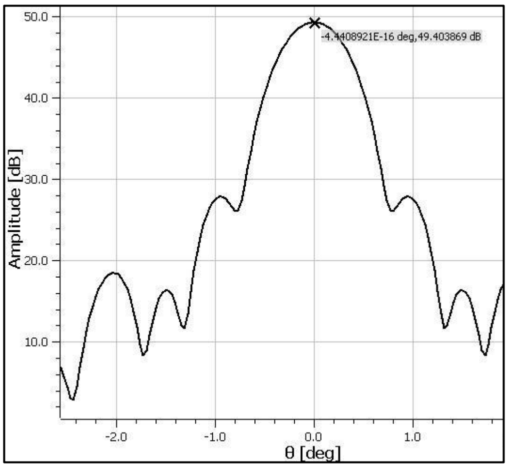
f = 4 GHz f = 5 GHz



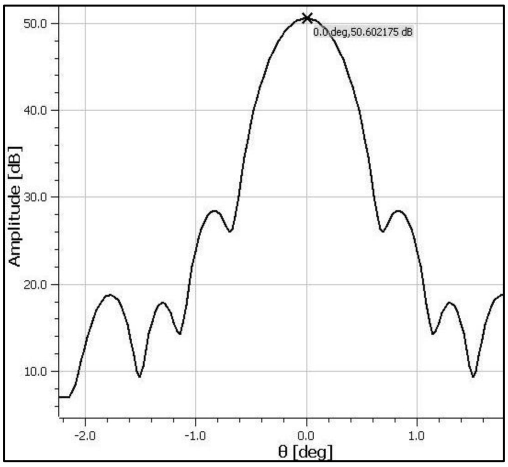
f = 6 GHz



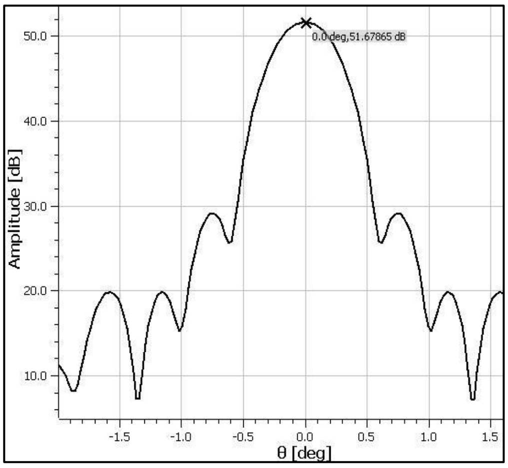
f = 7 GHz



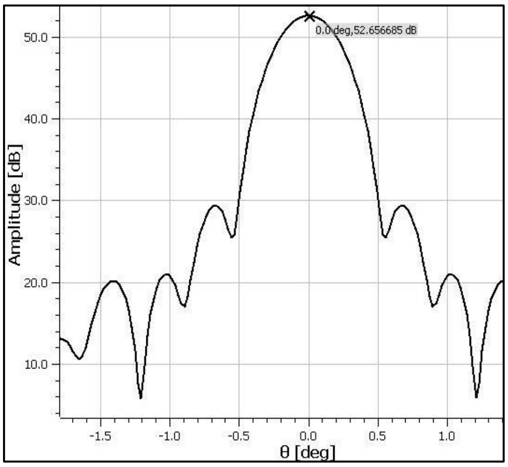
f = 8 GHz



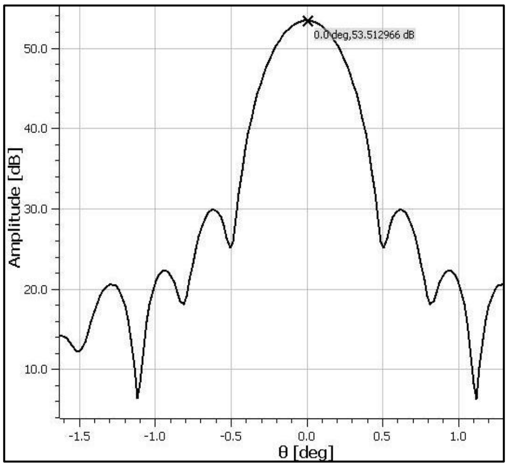
f = 9 GHz



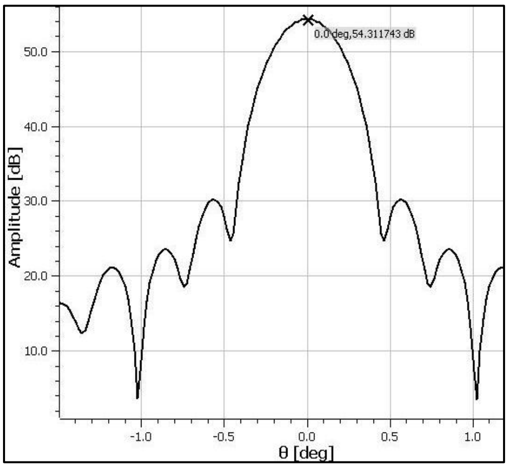
f = 10 GHz



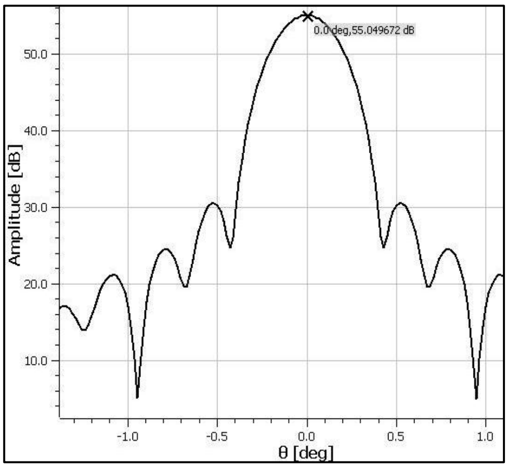
f = 11 GHz



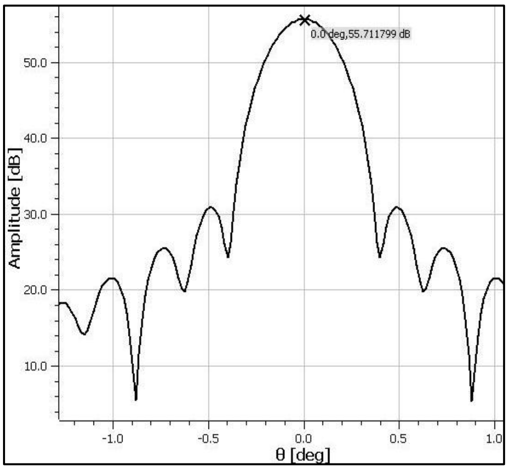
f = 12 GHz



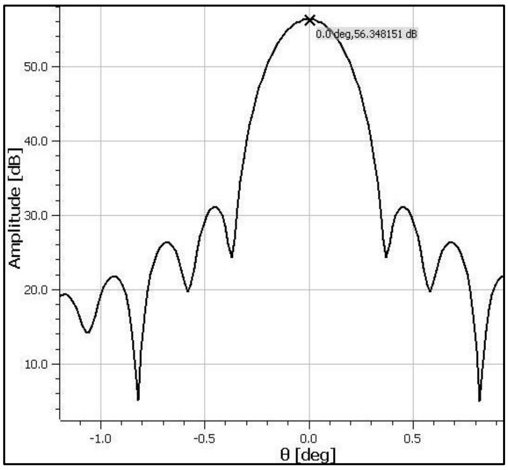
f = 13 GHz



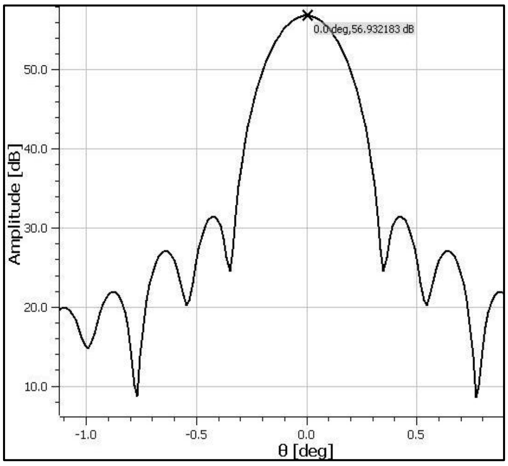
f = 14 GHz



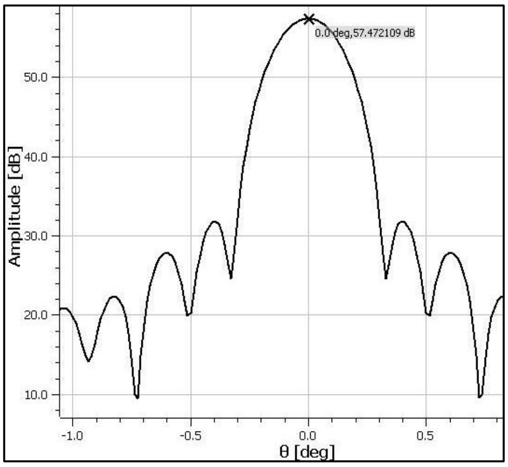
f = 15 GHz



f = 16 GHz



f = 17 GHz



f = 18 GHz

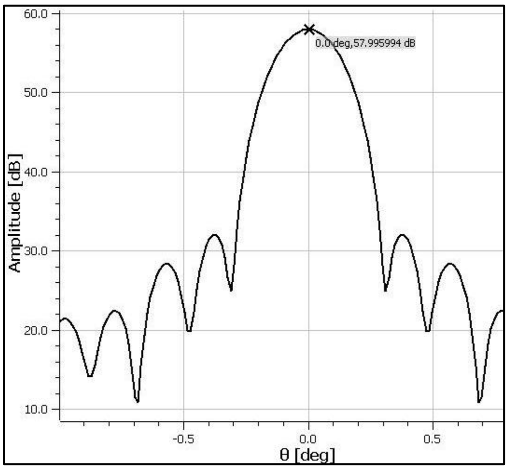


Figure 4.15: Radiation Patterns of a Cassegrain Feed System Operating at Different Frequency

c) The table below records the amplitudes of the main lobe and side lobe for a Cassegrain feed system operating at different frequency

Table 4.24: Main Lobe and Side Lobe Levels for a Cassegrain Feed System Operating at Different Frequency

Operating frequency, *f* (GHz)	Main lobe level (dB)	1st side lobe level (dB)
4	44.247414	25.867611
5	46.300644	26.379537
6	47.947653	27.359089
7	49.403869	27.911642
8	50.602175	28.458070
9	51.678650	29.126970
10	52.656685	29.386572
11	53.512966	29.922596
12	54.311743	30.252255
13	55.049672	30.534128
14	55.711799	30.920816
15	56.348151	31.157361
16	56.932183	31.466992
17	57.472109	31.808120
18	57.995994	32.088607

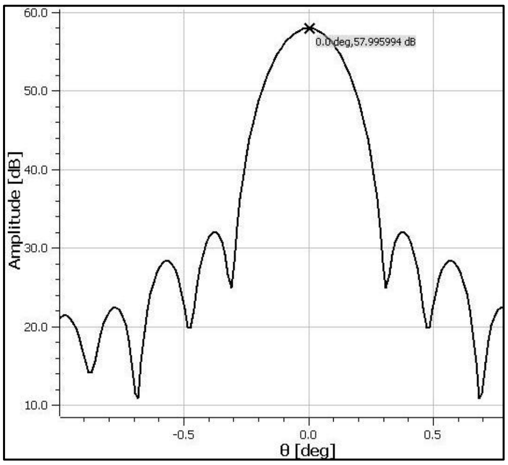
3. a) The table below shows the selected geometrical parameters for a Gregorian feed system.

Table 5: Geometrical Parameters for a Gregorian Feed System

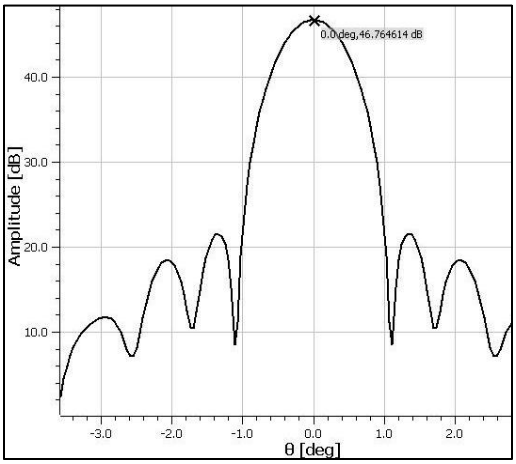
Diameter of parabolic primary reflector, D_{par}	4.8 m
Focal length of parabolic primary reflector, F_{par}	1.5 m
Focal length to diameter ratio, F/D	0.3125
Half-angle subtended by parabolic primary reflector, θ_{par}	-77.32°
Diameter of elliptic secondary reflector, d_{ell}	0.5517 m
Distance between primary and secondary foci, f_c	1.2 m
Half-angle subtended by elliptic secondary reflector, θ_{ell}	12.33°
Eccentricity of elliptic reflector, e_{ell}	0.76208
Operating frequency, f	4 GHz – 18 GHz

b) The following below shows the radiation patterns of a Gregorian feed system operating at different frequency.

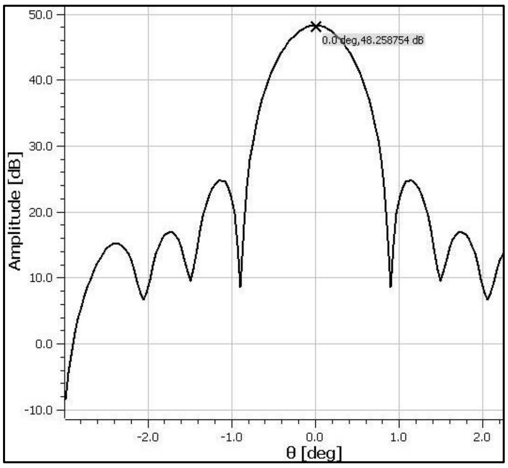
f = 4 GHz



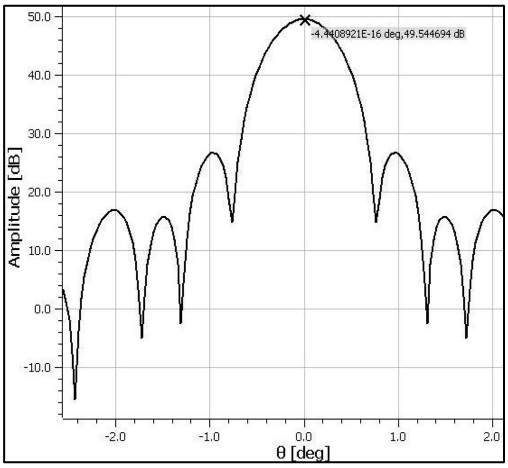
f = 5 GHz



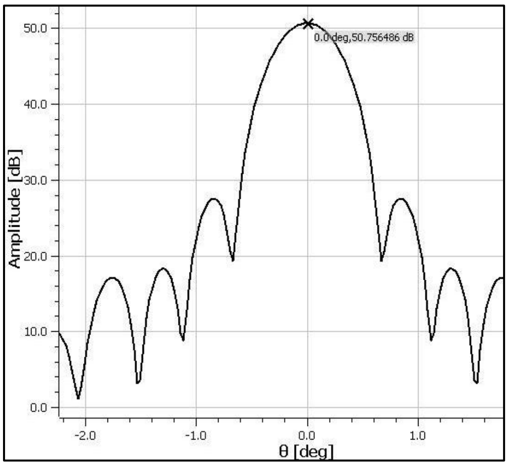
f = 6 GHz



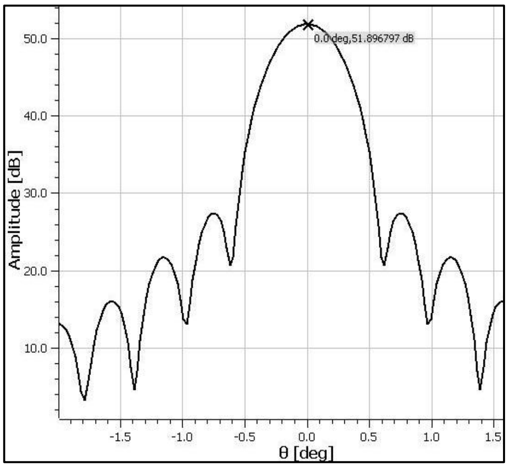
f = 7 GHz



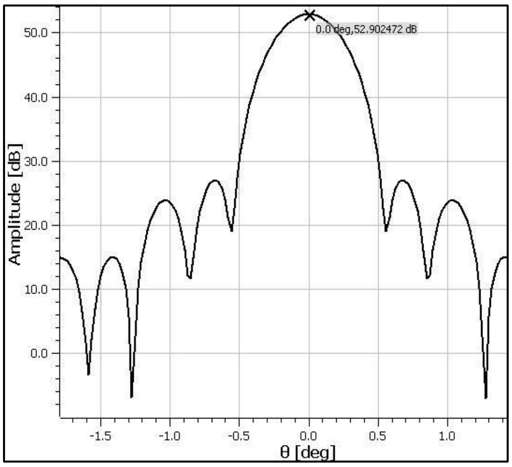
f = 8 GHz



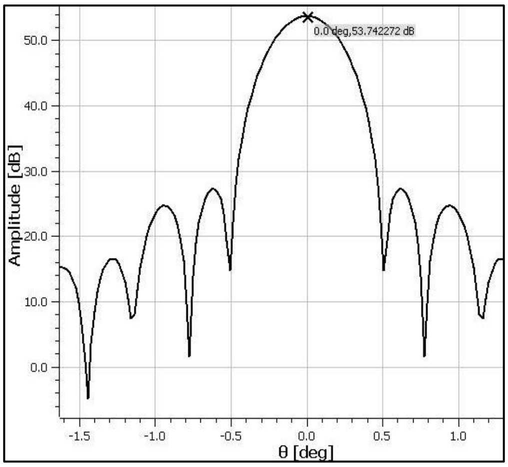
f = 9 GHz



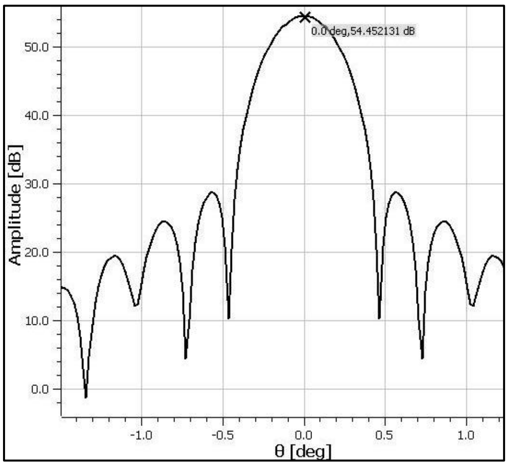
f = 10 GHz



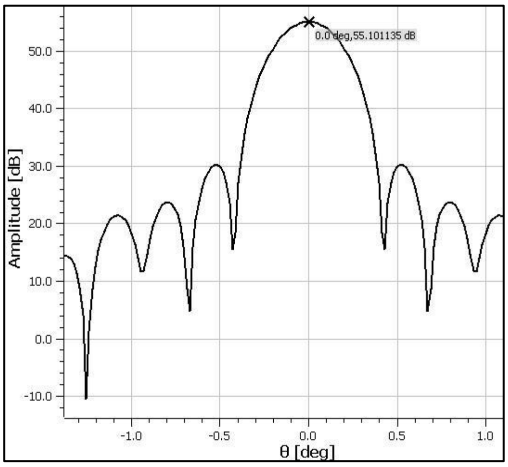
f = 11 GHz



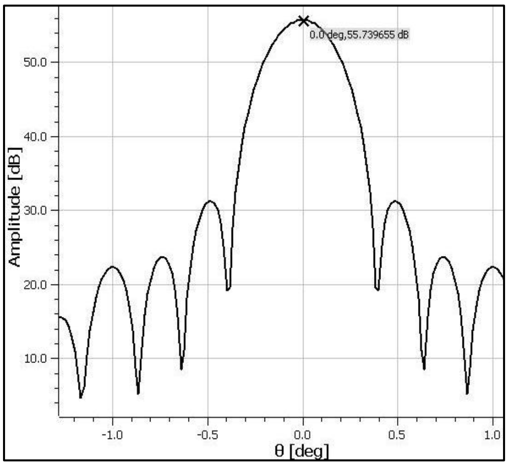
f = 12 GHz



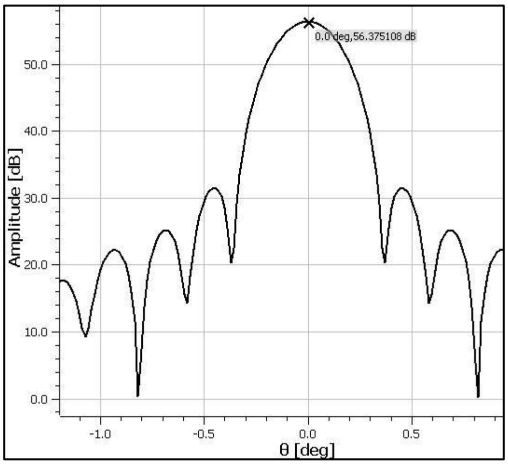
f = 13 GHz



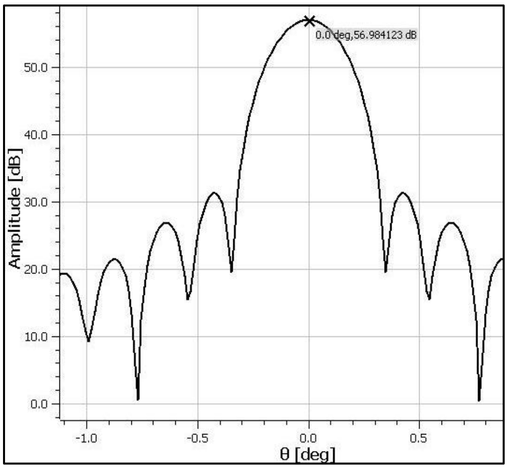
f = 14 GHz



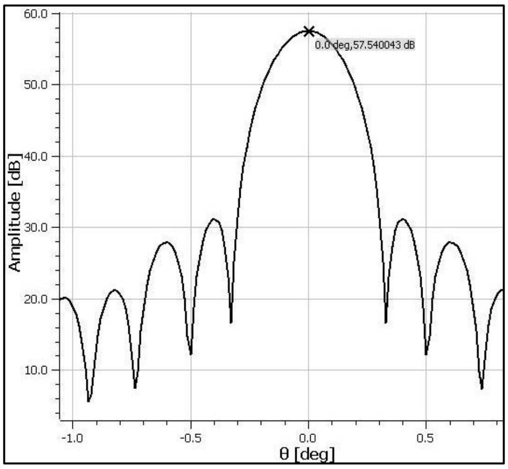
f = 15 GHz



f = 16 GHz



f = 17 GHz



f = 18 GHz

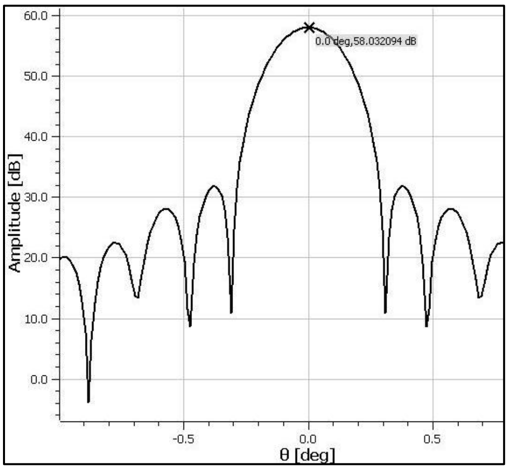


Figure 4.16: Radiation Patterns of a Gregorian Feed System Operating at Different Frequency

c) The table below records the amplitudes of the main lobe and side lobe of a Gregorian feed system operating at different frequency.

Table 4.26: Main Lobe and Side Lobe Levels for a Gregorian Feed System Operating at Different Frequency

Operating frequency, *f* (GHz)	Main lobe level (dB)	1st side lobe level (dB)
4	44.827309	17.278496
5	46.764614	21.489719
6	48.258754	24.829234
7	49.544694	26.737858
8	50.756486	27.540748
9	51.896797	27.466451
10	52.902472	26.966536
11	53.742272	27.296458
12	54.452131	28.706684
13	55.101135	30.279818
14	55.739655	31.270808
15	56.375108	31.511298
16	56.984123	31.276446
17	57.540043	31.172922
18	58.032094	31.799907

4. a) The following below shows the graph of main lobe level against operating frequency for different geometry of front-feed reflector system.

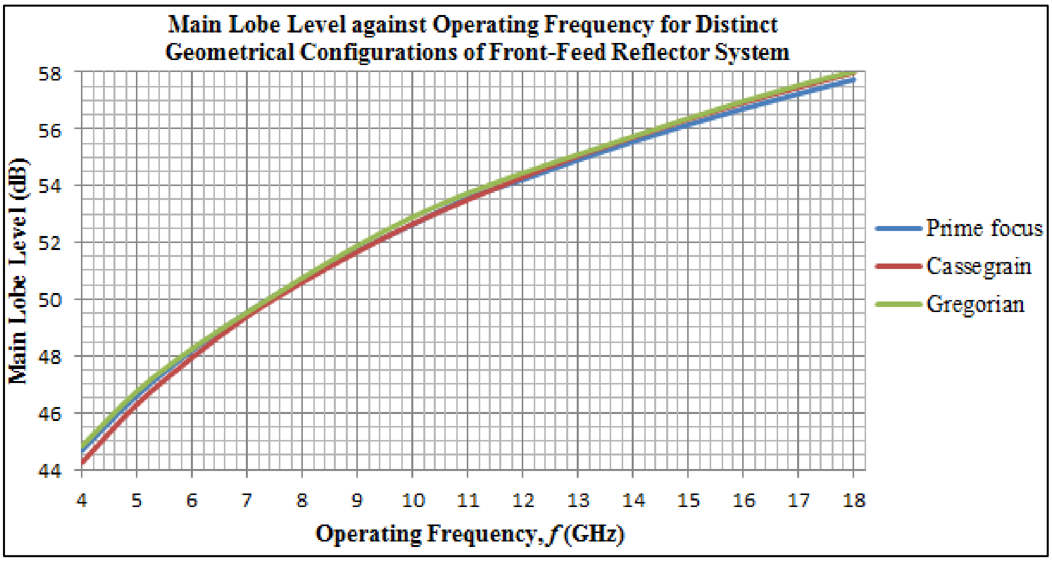


Figure 4.17: Graph of Main Lobe Level against Operating Frequency for Distinct Geometrical Configurations of Front-Feed Reflector System

b) The following below shows the graph of first side lobe level against operating frequency for different geometrical configurations of reflector feed system.

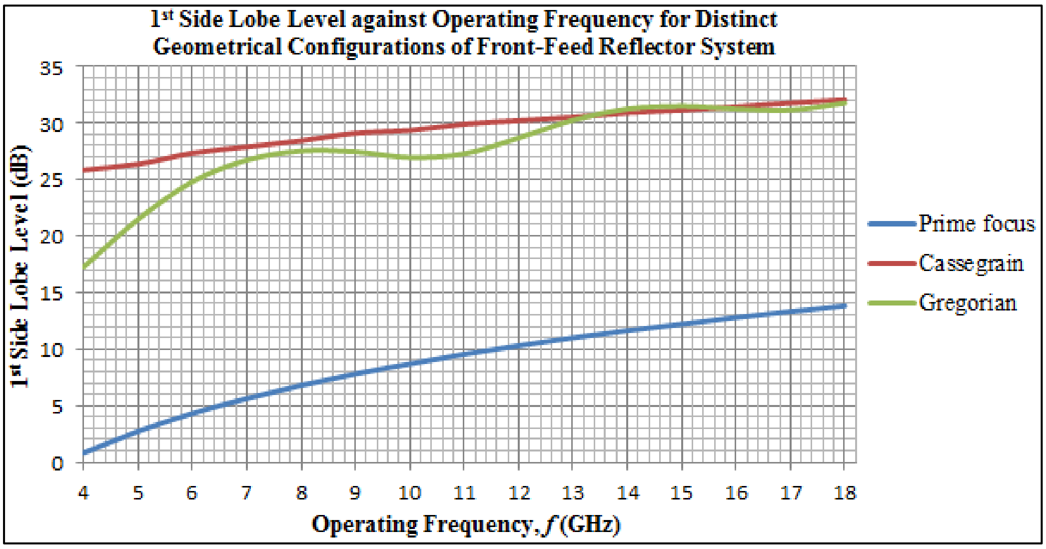


Figure 4.18: Graph of 1st Side Lobe Level against Operating Frequency for Distinct Geometrical Configurations of Front-Feed Reflector System

CHAPTER 5

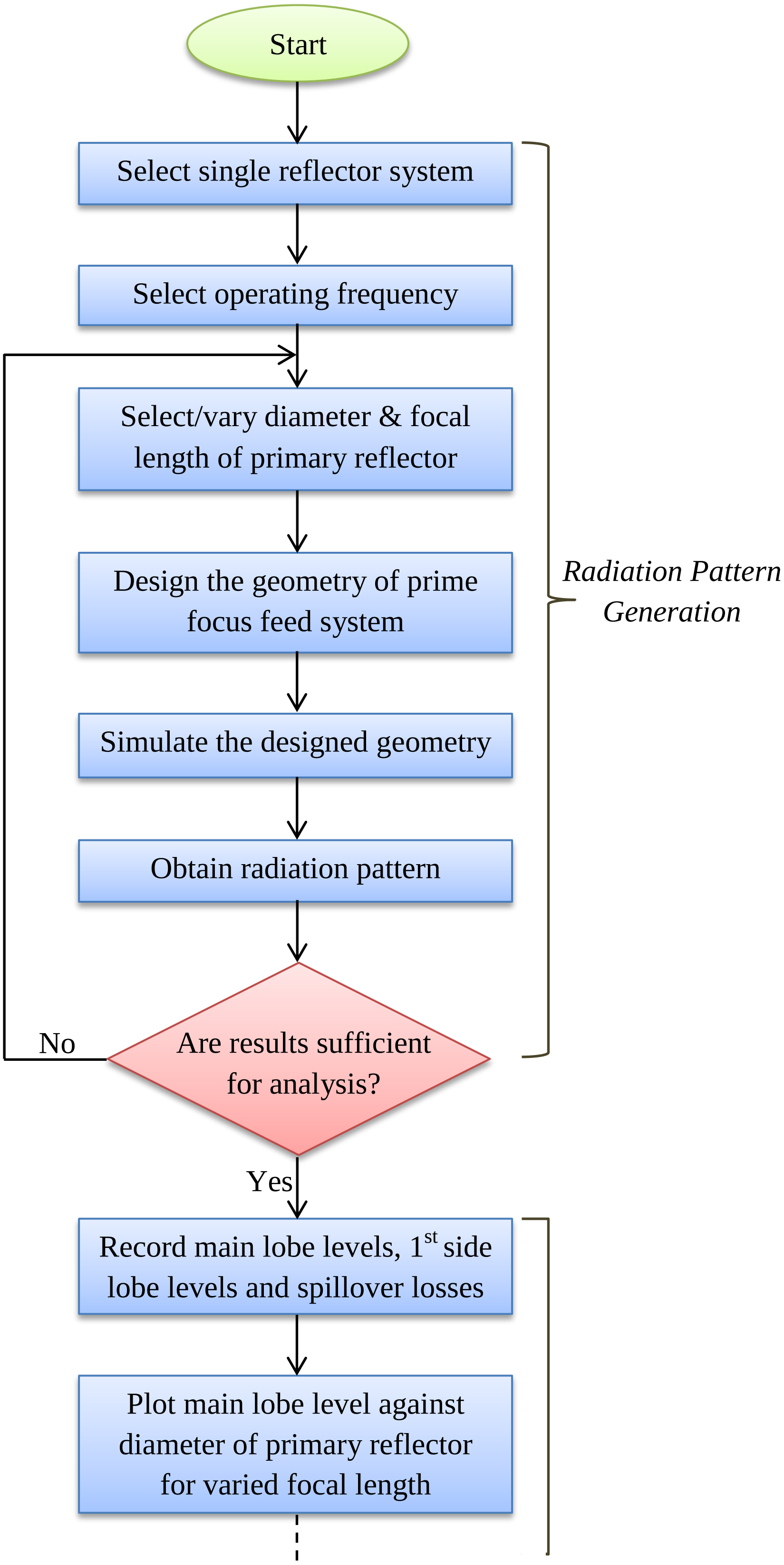
DISCUSSION

5.1 Performance Analysis of a Single Reflector Feed System

The performance analysis of a prime focus feed system was begun by generating its radiation pattern. This was done by getting into the GRASP simulation software and selecting single reflector system. Next, the parameters such as the operating frequency and the diameter and focal length of parabolic primary reflector were selected for modelling its geometry. The designed geometry was then simulated to obtain its radiation pattern.

For further analysis, the steps were repeated by varying the diameter and focal length of the primary reflector one at a time. In other words, either varying the diameter of primary reflector while keeping the primary focal length fixed or vice versa. On the other hand, the selected operating frequency was kept fixed throughout the simulation. The generation of radiation patterns would be discontinued only when the output results were sufficient for analysis.

Lastly, the performance analysis of the prime focus feed system was carried out by extracting and tabulating the necessary information such as the amplitude of main lobes and first side lobes as well as spillover losses from the radiation patterns and simulation output. In addition, parameters such as the focal length to diameter (F/D) ratio and the half-angle subtended by primary reflector were also calculated and tabulated. The graphs of main lobe level, first side lobe level and spillover loss were plotted separately against the diameter of primary reflector for having distinct primary focal lengths and the performance of the prime focus feed system was analyzed based on the plotted graphs. The figure below shows the flowchart for analyzing the performance of a prime focus feed system.



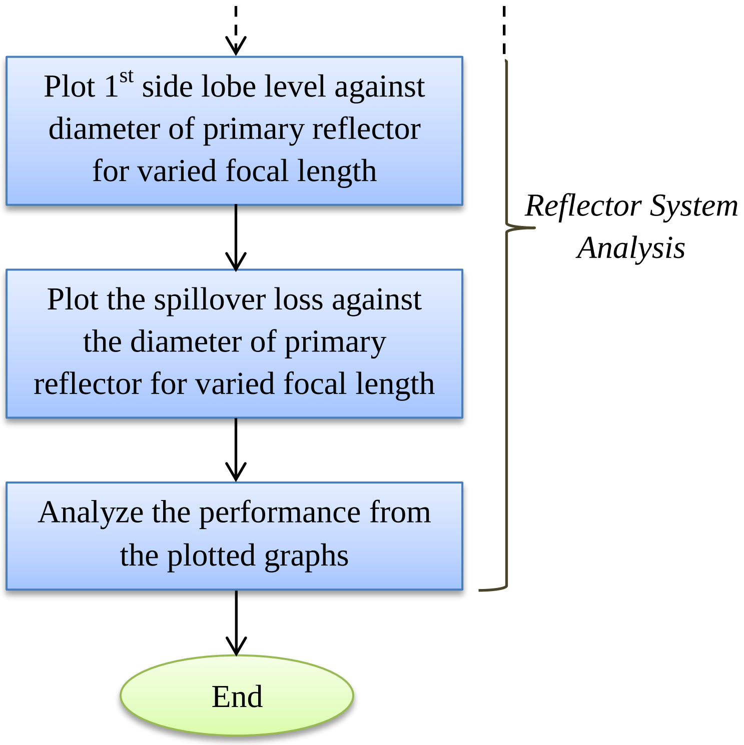


Figure 5.1: Flowchart for Performance Analysis of a Prime Focus Feed System

In this project, the diameter of parabolic primary reflector was varied from 3.0 meters to 7.0 meters with the increase in step size of 0.2 meters. The primary focal length, on the other hand, was varied from 1.5 meters to 2.1 meters with the increase in step size of 0.3 meters. The diameter of primary reflector was varied differently under different primary focal lengths. For the focal length of 1.5 meters, the diameter of reflector was varied from 3.0 meters to 5.0 meters. However, as for the focal lengths of 1.8 meters and 2.1 meters, the diameter of the reflector was varied from 3.0 meters to 6.0 meters and from 3.0 meters to 7.0 meters. The main reason of varying the diameter of primary reflector differently under different primary focal lengths was to design the parabolic primary reflector with having a maximum half-angle subtended at the feed of 79.61°. For analysis, the prime focus feed system was operated in the X band frequency of 10 GHz.

We shall analyze the performance of a prime focus feed system by varying the size of the primary reflector while keeping its primary focal length fixed. Supposing that the diameter of the primary reflector is 3.0 meters and its focal length is 1.5 meters. By referring to the plotted graphs, the reflector system will have a spillover loss of 0.2710 dB for that given diameter and focal length of reflector. The value of spillover loss is significantly high since much of the energy radiated by the feed misses the edge of the reflector and enters into the back lobe, causing the back lobe level to increase. Thus, this yields a lower main lobe level of approximately 48.82 dB as the spill over energy does not contribute to the main beam. As a result, the reflector system will have a lower gain level as well as lower directivity level (due to having wider beamwidth) which can be seen from the radiation pattern. With the implication of having high spillover loss, the diffraction loss from the edge of reflector also increases due to having high side lobe level of approximately 17.96 dB.

However, if the diameter of the primary reflector increases to 5.0 meters for a fixed focal length, the spillover loss of the reflector system will be reduced by approximately 0.054 dB as there is less radiated energy spills over the edge of the reflector. Consequently, the amplitude of the main beam will be increased by approximately 4.14 dB and the beamwidth tends to be narrower, leading to higher gain and directivity levels for the reflector system. The side lobe level, on the other hand, will be significantly reduced by approximately 13.43 dB and this produces smaller diffraction loss from the edge of reflector as a result of having low spillover loss. Since a large size of reflector has larger collecting areas, it is capable of capturing more radio waves compared to smaller one. This also contributes to higher gain level and directivity level as both the gain and directivity levels are directly proportional to the size of reflector. Hence, based on the analysis we can say that the spillover loss of the prime focus feed system can be reduced by increasing the size of the reflector or in other words, with having smaller F/D ratio.

What happens to the performance of a prime focus feed system if its focal length increases for a fixed size of reflector? Let us assume that the diameter of the primary reflector is 4.8 meters and its focal length is 1.5 meters. By referring to the graphs, the reflector system will have a spillover loss of 0.224 dB for the given diameter and focal length of primary reflector. The reason of having low spillover loss is because the feed is positioned nearer to the center of reflector and farther from the edge of reflector. As a result, the feed under-illuminates the reflector and more radiated energy arrived at the center of the reflector than the edge of it that leads to low spillover loss. Moreover, the reflector system will also have low diffraction loss from the edge of reflector due to having low side lobe level of approximately 8.72 dB.

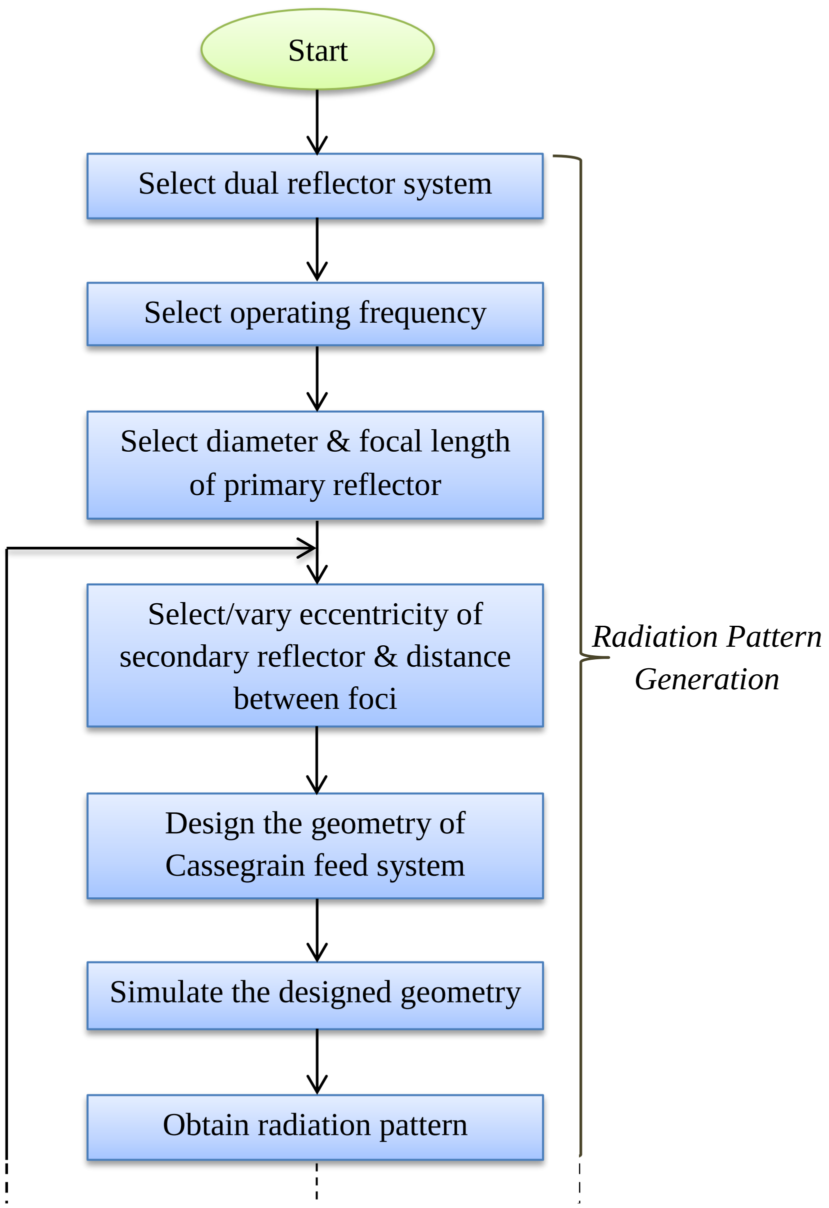
As the focal length increases to 2.1 meters for a fixed size of reflector, the feed will be positioned farther away from the center of reflector but nearer to the edge of reflector. As a result, the spillover loss of the reflector will be increased by approximately 0.0393 dB since the feed over-illuminates the reflector and causing more radiated energy to arrive at the edge of the reflector than the center of it. Due to having high spillover loss, the diffraction loss from the edge of reflector also increases as the side lobe level is increased by approximately 11.65 dB. Overall, we can conclude that both the spillover and diffraction losses of the prime focus feed system can be reduced either by decreasing the focal length or increasing the size of the reflector.

5.2 Performance Analysis of a Dual Reflector Feed System

The performance analysis of a Cassegrain feed system was begun by generating its radiation patterns. This was done by getting into the GRASP simulation software and selecting dual reflector system. Next, the parameters such as the operating frequency, diameter and focal length of parabolic primary reflector, eccentricity of hyperbolic secondary reflector and the distance between primary and secondary foci were selected for modelling its geometry. The designed geometry was then simulated to obtain its radiation pattern.

For further analysis, the steps were repeated by varying the eccentricity of secondary reflector and the distance between primary and secondary foci one at a time. In other words, either varying the eccentricity of secondary reflector while keeping the distance between foci fixed or vice versa. On the other hand, the selected operating frequency and the diameter and focal length of the primary reflector were kept fixed throughout the simulation. The generation of radiation patterns would be discontinued only when the output results were sufficient for analysis.

Lastly, the performance analysis of the Cassegrain feed system was carried out by extracting and tabulating the necessary information such as the amplitude of the main lobes and first side lobes as well as spillover losses from the generated radiation patterns and simulation output. In addition, parameters such as the half-angle subtended by secondary reflector and the secondary eccentricity were also calculated and tabulated. The graphs of main lobe level, first side lobe level, forward spillover loss and rear spillover loss were plotted separately against the diameter of secondary reflector for having distinct distances between foci and the performance of the Cassegrain feed system was analyzed based on the plotted graphs. The figure below shows the flowchart for analyzing the performance of a Cassegrain feed system.



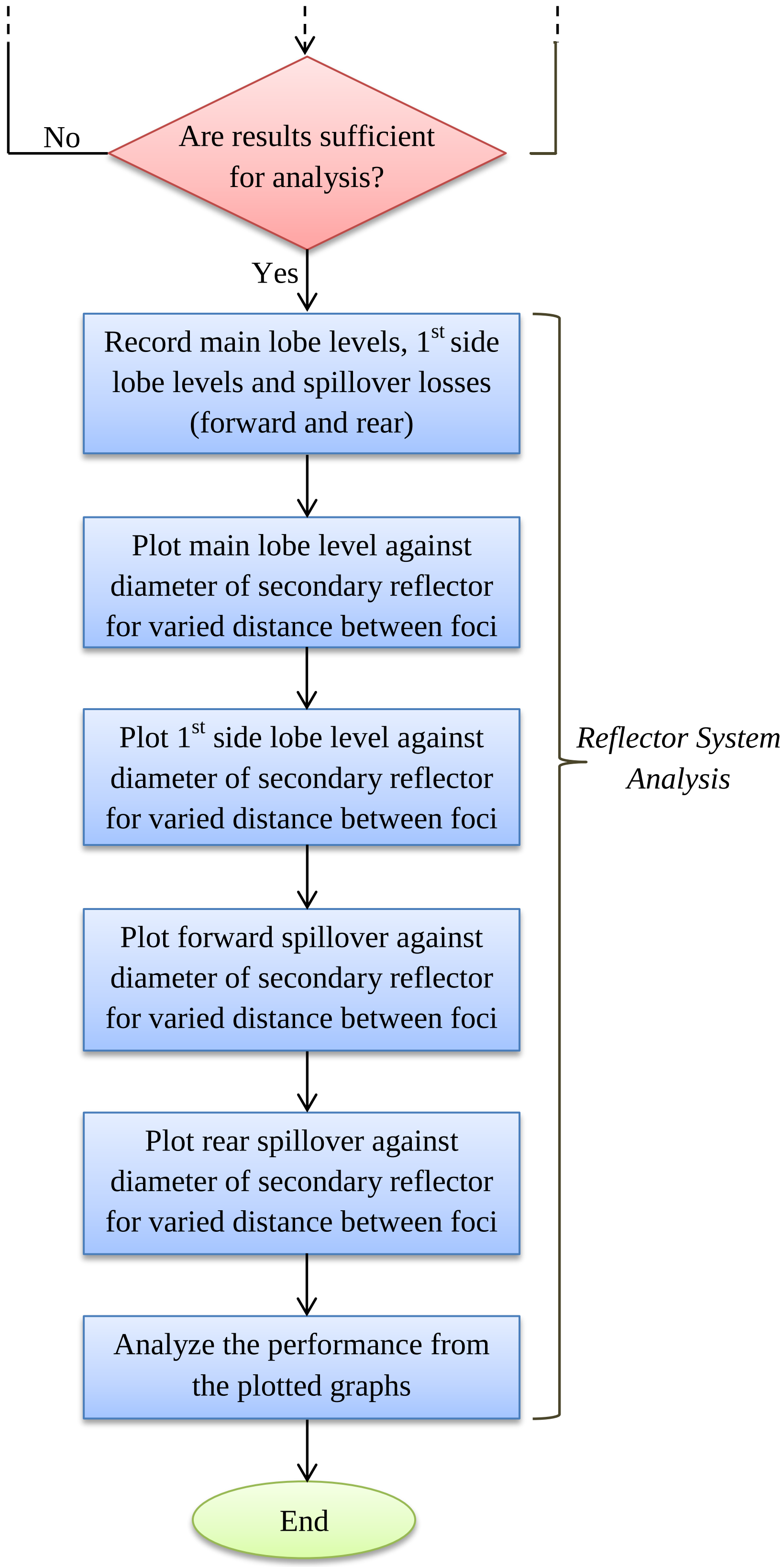


Figure 5.2: Flowchart for Performance Analysis of a Cassegrain Feed System

In this project, the diameter of secondary reflector was varied from 0.3 meters to 1.4 meters with the increase in step size of 0.1 meters. On the other hand, the distance between primary and secondary foci was varied from 0.6 meters to 1.2 meters with the increase in step size of 0.3 meters. The eccentricity of hyperbolic secondary reflector was computed using the equation (2.6) before its value was inserted into the simulation software. Both the diameter and focal length of the primary reflector were kept fixed to 4.8 meters and 1.5 meters throughout the simulation. For analysis, the Cassegrain feed system was operated in the X band frequency of 10 GHz.

We shall analyze the performance of a Cassegrain feed system by varying the size of secondary reflector while keeping the distance between primary and secondary foci fixed. Supposing that the diameter of secondary reflector is 0.3 meters and the distance between foci is 0.6 meters. By referring to the plotted graphs, the reflector system will have a high forward spillover loss of 0.3776 dB because there is a short distance between the edge of reflector and the feed that causes much of the energy radiated by the feed fall outside the edge of secondary reflector. Due to having high forward spillover loss, the reflector system will also have high rear spillover loss of 0.4742 dB as there is much energy being scattered by the secondary reflector fall outside of the primary reflector. As a result, this produces lower main lobe level of approximately 52.49 dB since the radiated energy that spill over the edge of primary reflector does not contribute to the main beam and thus, resulting in lower gain level for the reflector system. With the implication of having high spillover losses, the diffraction loss from the edge of secondary reflector also increases as a result of having high side lobe level of approximately 30.52 dB.

However, if the diameter of secondary reflector increases to 0.8 meters for a fixed distance between foci, the forward spillover loss is reduced by 0.0959 dB because there is less radiated energy spills outside the edge of secondary reflector due to having longer distance between the edge of reflector and the feed. The rear spillover loss is also reduced significantly by 0.1503 dB due to the reduction in the forward spillover loss as there is less radiated energy being scattered by the secondary reflector falls outside of the primary reflector. Consequently, the amplitude of the main beam will be increased by approximately 0.32 dB, resulting in higher gain level. The side lobe level, on the other hand, will also be reduced by approximately 5.27 dB and this yields smaller diffraction loss from the edge of secondary reflector.

If the diameter of secondary reflector is increased beyond 0.8 meters for a fixed distance between foci, the amplitude of the main beam tends to decrease although the spillover losses and the side lobe level continue to decrease. This is because the beam blockage on the primary aperture becomes too significant and thus, causing some part of the radiations to be blocked and deflected by the secondary reflector. Consequently, the gain level of the reflector system tends to decrease. Hence, based on the analysis we can say that a trade-off must be made between the primary aperture blockage and the size of secondary reflector in order to maximize the performance of the Cassegrain feed system.

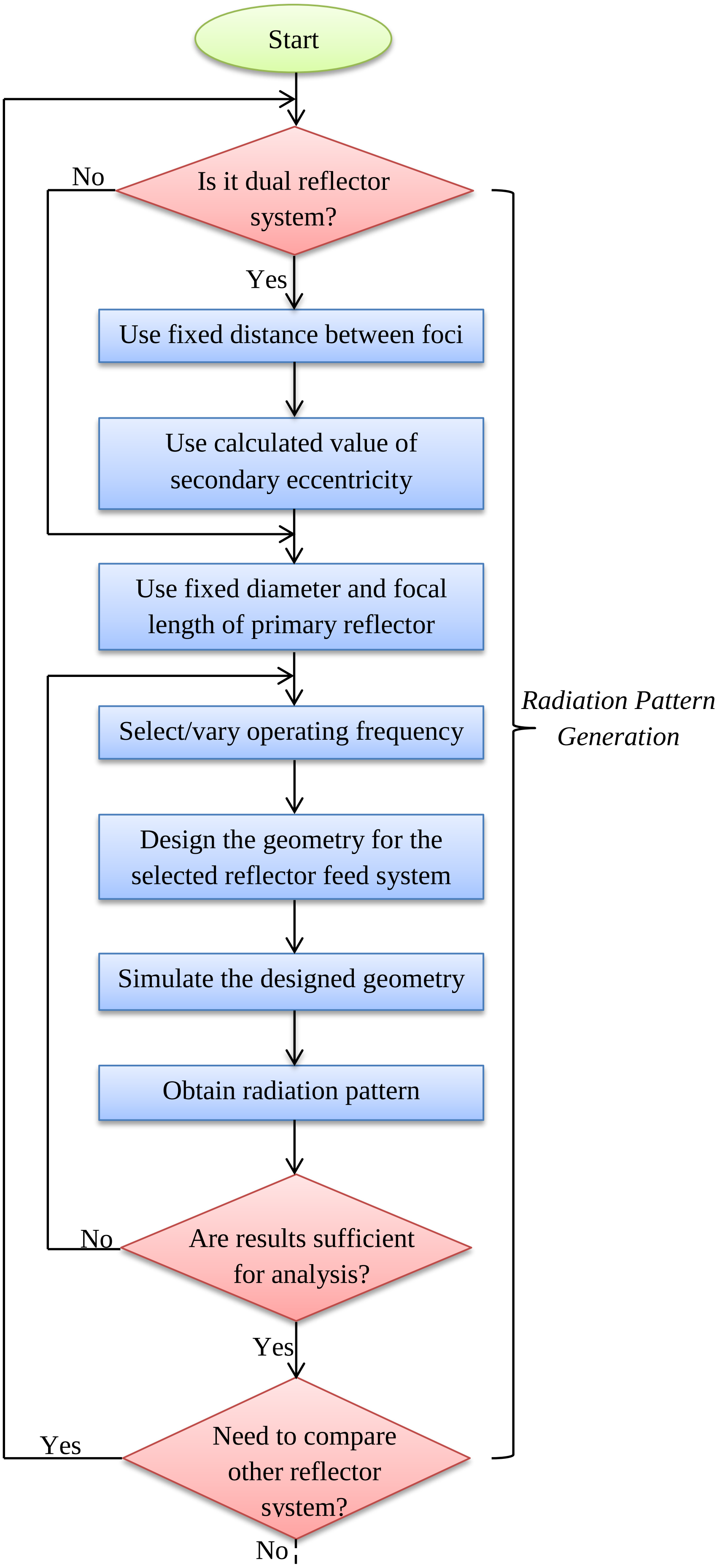
What happens to the performance of a Cassegrain feed system if the distance between foci increases for a fixed size of secondary reflector? Let us assume that the diameter of secondary reflector is 0.9 meters and the distance between foci is 0.6 meters. By referring to the plotted graphs, the Cassegrain system will have low forward spillover loss of 0.2796 dB since the feed is positioned nearer to the center and farther from the edge of secondary reflector. This causes the feed to under-illuminate the secondary reflector, causing more radiated energy to arrive at the center than the edge of secondary reflector. Due to having low forward spillover loss, the primary reflector will also have a weaker edge illumination as there is less radiated energy being scattered by the secondary reflector fall outside of the primary reflector and thus resulting in low rear spillover loss of 0.3186 dB. With having a shorter distance between foci, the reflector system will have lower main beam level of approximately 52.79 dB due to large beam blockage and lower side lobe level of approximately 24.19 dB. As a result, the reflector system will have low gain level but with having much lower diffraction loss from the edge of secondary reflector.

As the distance between foci is increased to 1.2 meters for a fixed size of secondary reflector, the feed will be positioned farther away from the center of secondary reflector. Consequently, both the forward spillover and rear spillover losses will be increased slightly by 0.0074 dB and 0.0117 dB. With the increased distance between foci, the main beam level tends to increase by approximately 0.1 dB but the diffraction loss also increases slightly as a result of having slight increment in the side lobe level by approximately 1.56 dB. Overall, we can conclude that we must trade-off both aperture blockage and diffraction loss in order to maximize the performance of the Cassegrain feed system.

5.3 Performance Comparison of Various Geometrical Configurations of Front-Feed Reflector System

The performance comparison for different geometrical configurations of front-feed reflector system was begun by generating the radiation pattern for the selected reflector feed system. This was done by getting into the GRASP simulation software and selecting the type of reflector system. Next, the parameters such as the operating frequency, diameter and focal length of primary reflector, eccentricity of secondary reflector and the distance between primary and secondary foci were selected for modelling the selected geometry. The design was then simulated in order to generate its radiation patterns. The steps were repeated by varying the operating frequency where else the other parameters were kept constant throughout the simulation. The generation of radiation patterns would be discontinued only when the output results were sufficient for analysis. On the other hand, as for performance comparison the entire steps were repeated for different geometrical configurations of reflector feed system.

Lastly, the performance comparison for different geometrical configurations of front-feed reflector system was carried out by extracting and tabulating the necessary information such as the amplitude of the main lobes and first side lobes from their radiation patterns. The graphs of main lobe level, first side lobe level and spillover loss were plotted separately against the diameter of the secondary reflector for distinct geometrical configurations of reflector feed systems and their performances were compared among each other from the plotted graphs. The figure below shows the flowchart for comparing the performances of different configurations of front-feed reflector system.



Start
Is it dual reflector system?
No
Yes
Use fixed distance between foci
Use calculated value of secondary eccentricity
Use fixed diameter and focal length of primary reflector
Select/vary operating frequency
Design the geometry for the selected reflector feed system
Simulate the designed geometry
Obtain radiation pattern
Are results sufficient for analysis?
No
Yes
Need to compare other reflector system?
Yes
No
Radiation Pattern Generation

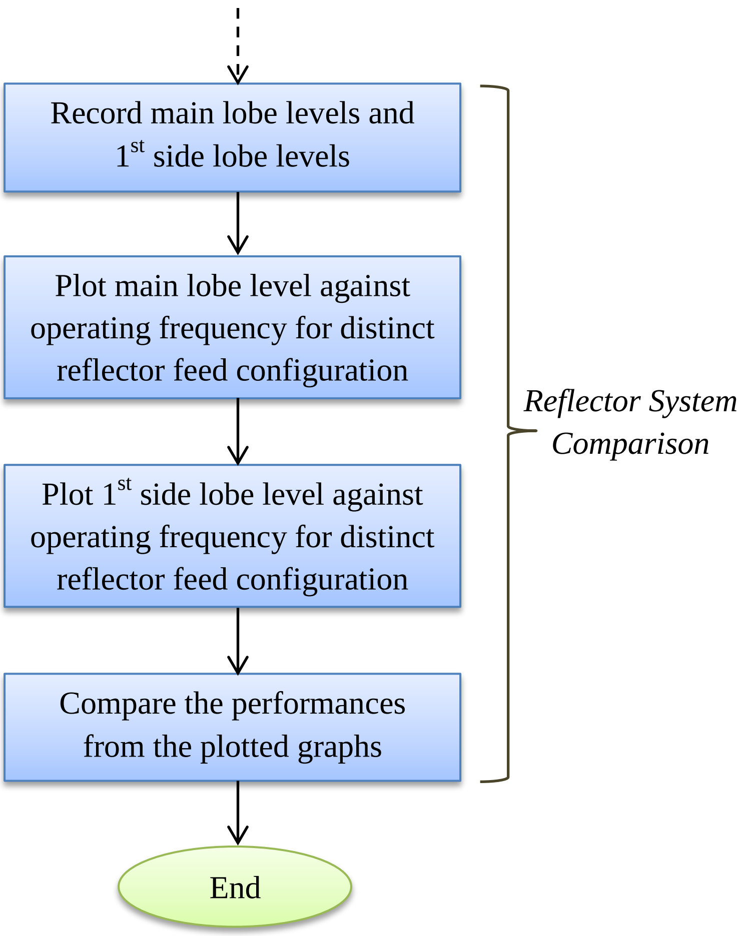


Figure 5.3: Flowchart for Performance Comparison of Different Configurations of Front-Feed Reflector System

In this project, the prime focus, Cassegrain and Gregorian feed systems were the 3 reflector systems selected for performance comparison. The diameter and focal length of the parabolic primary reflector for the 3 reflector systems were kept fixed to 4.8 meters and 1.5 meters throughout the simulation. On the other hand, the distance between primary and secondary foci and the half-angle subtended by secondary reflector for the dual reflector feed configuration was kept fixed to 1.2 meters and 12.33°. The eccentricity of a hyperbolic reflector for Cassegrain configuration was computed from the equations (2.4) and (2.5), and followed by the equation (2.6). Similarly, the eccentricity of an elliptic reflector for Gregorian configuration was computed from the equations (2.9) and (2.10), and followed by the equation (2.11). The only difference between these 2 configurations is that the Cassegrain configuration takes the positive sign of the half-angle subtended by parabolic reflector where else the Gregorian configuration takes the negative sign of it. Due to this reason, the eccentricity of hyperbolic reflector is greater than 1 while the eccentricity of elliptic reflector is less than 1. The 3 reflector systems were operated between the C band and Ku band frequencies, which is from 4 GHz up to 18 GHz.

By referring to the plotted graphs, the curves of the main lobe level for the three reflector systems are linear and overlapping with each other, which indicate that their main lobe levels are very close with each other. However, the curves of the first side lobe level are distinct among each other. We can see that both the Cassegrain and Gregorian feed systems provide higher side lobe levels where else the prime focus feed system provides lower side lobe level which gives a great advantage over the dual reflector feed system.

The main disadvantage of a prime focus feed is it requires excessive length of RF transmission line for connecting the low noise amplifier (LNA) to the feed since the feed is positioned above the parabolic primary reflector, resulting in noise and power loss. Besides, any radiated energy from the feed that is not obstructed by the reflector will fall outside of it towards the noisy ground. Thus, this will contribute to high noise temperature.

On the other hand, the dual reflector system such as the Cassegrain and Gregorian feed systems offer several advantages over the single reflector feed system. One of the main advantage is it requires shorter length of transmission line for connecting the LNA to the feed since the feed is placed nearer to the vertex of the parabolic primary reflector. Furthermore, any radiated energy from the feed that is not obstructed by the secondary reflector will fall outside of it towards the low noise sky region. This reduces the spill over energy towards the noisy ground and thus contributing to low noise temperature.

The only drawback of a dual reflector feed system is the size of secondary reflector tends to block the primary aperture, causing some part of the radiations to be deflected. In addition, the supporting structure for the secondary reflector such as struts does not only scatter the plane wave from the primary reflector but also the spherical wave from the secondary reflector. Consequently, these lead to high side lobe levels due to having high diffraction loss from the edge of secondary reflector. In order to eliminate the aperture blockage and excessive diffraction loss, the feed, secondary reflector and its supporting structure must offset outside of the beam area. The gain level of the offset dual reflector system can be maximized by increasing the size of secondary reflector but care must be taken not to block the beam path of the incoming radio waves.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

For single reflector feed system such as the prime focus feed system, its performance in terms of gain level and directivity level can be maximized either by increasing the size of parabolic primary reflector or decreasing its focal length. As for dual reflector feed system such as the Cassegrain feed system, its performance in terms of gain level can be maximized by trading-off the aperture blockage and diffraction loss.

Among the 2 different reflector feed systems, the single reflector feed system provides the best performance in terms of having lowest side lobe levels compared to dual reflector feed system. Although it contributes to high noise temperature, its aperture blockage is much smaller compared to dual reflector feed system since only the feed is located at the beam path of the incoming radio waves. Its noise temperature can be reduced by offsetting the feed so that the radiated energy from the feed is reflected by the main reflector and misses the feed on its way to the sky instead of falling towards the noisy ground. Moreover, unlike the dual reflector feed system, the mechanical design of a single reflector feed system is much simpler as it only requires a single reflector which leads to lower construction cost.

5.2 Recommendation

The main limitation of this research project is that the performance of the Gregorian feed system was not analyzed like any other reflector feed system such as the prime focus and Cassegrain feed systems due to time constraint. However, its performance as a dual reflector feed system was compared with the single reflector feed system in terms of the main beam level and the side lobe level. Hence, the performance of the Gregorian feed system shall be analyzed and compared with the Cassegrain feed system for future research.

In addition, regarding the discussion on the performance comparison of different front-feed reflector configurations, we have seen that the main lobe levels for the single reflector and dual reflector feed configurations are very close with each other but their side lobe levels are much comparable. This can be seen where the dual reflector feed system has much higher side lobe levels compared to single reflector feed system but it has advantages over a single reflector system in terms of requiring shorter RF path as well as having low noise temperature. The excessive side lobe levels can be reduced by increasing the size of secondary reflector but this will only leads to aperture blockage. The only way to reduce both the side lobe levels and aperture blockage is by offsetting the feed, secondary reflector and its supporting structure outside the beam path of the incoming radio waves. Therefore, in future research the performance of the offset-feed reflector system (such as the offset prime focus system, offset Cassegrain system and offset Gregorian system) shall be analyzed and compared with the front-feed reflector system.

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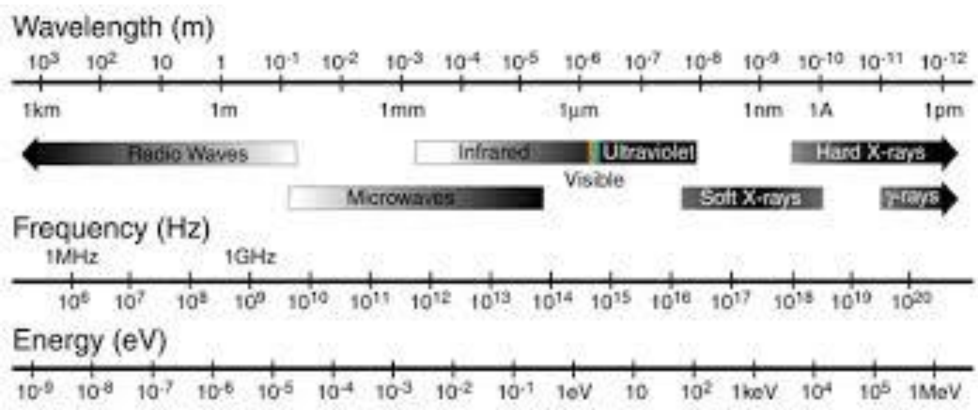
APPENDICES

APPENDIX A: Electromagnetic Spectrum



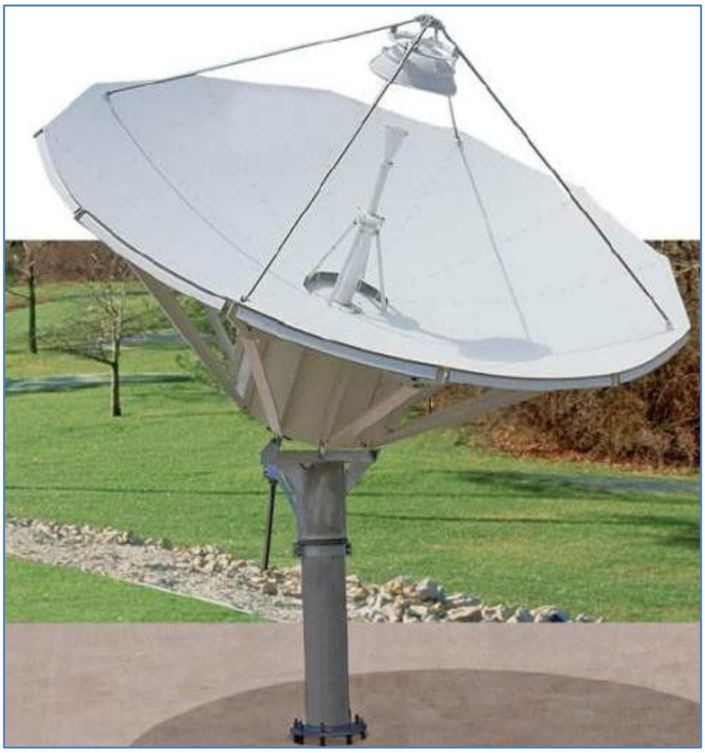
APPENDIX B: IEEE Standard Letter Designations for Radar-Frequency Bands

Band Designator	Frequency (GHz)	Wavelength in Free Space (cm)
L band	1 to 2	30.0 to 15.0
S band	2 to 4	15 to 7.5
C band	4 to 8	7.5 to 3.8
X band	8 to 12	3.8 to 2.5
Ku band	12 to 18	2.5 to 1.7
K band	18 to 27	1.7 to 1.1
Ka band	27 to 40	1.1 to 0.75
V band	40 to 75	0.75 to 0.40
W band	75 to 110	0.40 to 0.27

APPENDIX C: Types of Front-Feed Reflector Systems

Front-Feed Prime Focus Reflector System

Front-Feed Cassegrain Reflector System



Front-Feed Gregorian Reflector System

APPENDIX D: Very Large Array