CHAPTER 4

POINTING ACCURACY OF CASSEGRAIN ANTENNA IN SATCOM

The major drawback in the hybrid beam steering method which is implemented in this work is Pointing error (beam squint). Due to antenna pointing errors, the gain of the antenna is reduced and also increases the interference with the adjacent satellites. For high frequency applications like SATCOM we prefer antennas producing narrow beam width. Due to restricted beam width for those applications precise pointing is required. To achieve pointing accuracy in 1.5m cassegrain antenna, the structural displacements (shifting the actual position) for vertex, Feed and secondary reflector is implemented. The change in the displacement effects peak gain, phase error and side lobe level and can be evaluated. The pointing error may rise up to 1.6 degrees for 1-inch displacement of structures. Compensation technique along with these is also developed to optimize the cassegrain (ground antenna) pointing accuracy. By using this compensation technique loss of peak gain and increased side lobes is compensated by 75% by using feed and sub reflector displacement.

4.1 BASICS OF POINTING MECHANISM

Elevation angle, range and azimuth angle of satellites can be found by the tracking system located on the ground station. Orbital change in the satellite can be computed with the help of these three data. These data also helps for antenna beam pointing. Beam Pointing refers to the orientation of antenna beam exactly in the reference direction. If satellite position vector and antenna pointing vector are not in the line of sight, it is called pointing error. Also, pointing error can be defined as the inability of the antenna to point the desired satellite exactly. Pointing error causes the decrement of the link margin to the targeted satellites. Pointing loss can be categorized into two terms static, at the time of installation and dynamic, which varies with time.
As in above figure, the pointing error decreases the gain for desired satellite as well as acts as a source of interference to the neighboring satellite. The pointing methods can be classified into following ways [40]:

- Fixed Pointing
- Pre-programmed Pointing
- Step Pointing and
- Fully Automatic Pointing

For antennas having wide beam-width, pointing issue may not be a big deal as like narrow beam antenna. So, wide beam antennas used fixed pointing method. In pre-programmed pointing, first satellite position is calculated with the help of ephemeris data. Then, the output of encoders and ephemeris data is compared. Moving antenna in a certain direction and measuring the received signal strength, this method of pointing is called step pointing. Here, by displacing the antenna in a specific direction, the received signal is measured. If the measured signal level is higher than previous one, it is moved again in that direction. On the other hand, if the signal level decreases, the antenna is returned to its previous position. Fully automatic pointing uses mono pulse or simultaneous lobing techniques. By comparing the strength of two beams, error signals are generated. The difference in two beams indicates the tracking error. When the error signal becomes null, the antenna points satellite accurately. Required antenna beam is
produced depending upon the application. For broadcasting, the antenna having global beam is used and for point to point communication spot beam is used. Burst transmission requires scanning beams. The antenna can be mounted in the ground station in various ways depending upon the coverage and tracking requirements of the system. Some of them are listed as follows:

- Azimuth-Elevation Mount
- X-Y Mount and
- Polar Mount

Azimuth-Elevation is two axes mounting technique where rotating and supporting structures are perpendicular to each other. The rotation of vertical structure leads to change in azimuthal angle whereas to change elevation angle, the horizontal structure should be rotated. This type of mount covers an entire area except for the point which is directly overhead of azimuth axis. This uncovered area is called the cone of silence. The condition where the horizontal and vertical axis is not in 90 degrees to each other is called non-orthogonal Azimuth-Elevation mount. This non-orthogonal mount is normally used in Cassegrain system. The overhead problem of Azimuth – Elevation mount can be eliminated by using X-Y mount. The X-Y mount maintains primary axis as horizontal
and secondary axis vertically, opposite of Azimuth-Elevation mount. The horizontal axis of the X-Y mount is fixed and the secondary axis is rotated about a primary axis. Here, the earth axis and primary axis are in parallel. Secondary axis maintains 90 degrees with primary axis. This mounting technique is useful for LEO satellites rather than geostationary. It behaves as an X-Y mount in equator and Azimuth-Elevation mount at poise. In deep space communication, the usually polar mount is used.

![X-Y Mount](image)

**Figure 4.3: X-Y Mount [40]**

### 4.2 ANTENNAS IN SATELLITE COMMUNICATION

The main antennas used in Satellite Communication applications are Wire Antennas, Horn Antennas, Reflector Antennas and Phased Array Antennas. The performance of any antenna can be decided by high Gain, low Noise Temperature, steer ability, narrow beam width, Low Side lobe and low Cross-Polarization.

Reflector antenna has major role in this project. This antenna is used to reflect the incident electro magnetic energy to the desired direction. Reflector antennas consists of one or more reflectors with a feed system to illuminate reflector surface. As this has a high gain value it is used widely in satellite communication, radio astronomy and radar systems. Also because of low weight, low power consumption and grating lobe free radiation, reflector antenna remain in forefront comparing to lens and phased array antennas. Out of various geometrical shapes, Parabolic, Cassegrain and Georgian are
mostly used. Due to low power consumption, low weight and grating lobe free radiation, it has vast applications compared to lens and phased array antennas. Reflector antenna has many geometrical shapes, among all the shapes Parabolic and Cassegrain structures are widely used.

Figure 4.4: Various Types of Reflector Antennas [41]

From the figure 4.4, the plane reflector is the simplest geometry. Corner Reflectors prevent the electromagnetic energy to radiate in the undesired direction. The parabolic surface creates a highly directional beam in the desired direction. The cassegrain system uses two reflectors along with the feed, and this arrangement reduce the feed blocking and shortens the transmission line.
4.3 GEOMETRY OF ANTENNA SYSTEM

Cassegrain antenna consists paraboloid main Reflector and hyperbola as a Subreflector. First, we will discuss the geometry of parabola and hyperbola respectively.

4.3.1 Geometry of Parabola

Parabola is the locus of points which maintains equal distance to the directrix and focus. Mathematically,

\[ PQ = PF \]  \hspace{1cm} (4.1)

Also,

\[ FP + PQ = 2f \]  \hspace{1cm} (4.2)

The equation of the parabola in Cartesian coordinate can be represented by:

\[ x^2 = 4fz \]  \hspace{1cm} (4.3)

In spherical coordinates,

\[ FP + PQ = \delta + \delta \cos(\theta) = 2f \]  \hspace{1cm} (4.4)

Figure 4.5: Parabola
Which results,

\[
\delta = \frac{2f}{1 + \cos(\theta)} \quad (4.5)
\]

From the above geometrical configuration, it can be concluded that all rays emitted from z-axis upon reflection from reflector surface (point P) travel towards directrix and also makes an equal path length.

4.3.2 Geometry of Hyperbola

The locus of points which maintains a constant distance between two points is called hyperbola.

Mathematically,

\[
PF' - PF = \text{constant} \quad (4.6)
\]

For any point P on the reflector surface,

\[
\sqrt{(z + c)^2 + x^2} - \sqrt{(z - c)^2 + x^2} = 2a \quad (4.7)
\]
Finally, the equation of hyperbola can be written as,

\[
\frac{z^2}{a^2} - \frac{x^2}{c^2-a^2} = 1 \tag{4.8}
\]

Parabola, hyperbola, and ellipse can be categorized in terms of eccentricity also. Eccentricity gives information about the deviation of geometry from being circular. The eccentricity of the parabola is one and for hyperbola it is greater than one. The eccentricity of hyperbola can be written as:

\[
e = \frac{\sqrt{a^2+b^2}}{a} \tag{4.9}
\]

### 4.3.3 Geometry of Dual Reflector Antenna

The figure shows the three-dimensional view of the paraboloid. In above figure \( F_p \) indicates the focal point along the z-axis. \( \psi_0 \) is the opening half angle of reflector. By referencing above figure the following is derived for parabola and hyperbola.

![Figure 4.7: Cassegrain System [60]](image)
The equation of parabola in spherical coordinate is:

\[
\delta = \frac{2f}{1 + \cos(\psi)} \quad (4.10)
\]

In Cartesian coordinate,

\[
r_p = \sqrt{x^2 + y^2} = 4fz \quad (4.11)
\]

Similarly, the equation of hyperboloid is given by:

\[
r_s = \frac{c^2 - a^2}{a + c \cos(\psi)} \quad (4.12)
\]

\(r_s\) represents the radius of Subreflector (i.e. hyperbola)

Also,

\[
\sin(\psi) = \frac{r}{\delta} \quad (4.13)
\]

By combining the equation (4.10) and (4.13), the equation of parabola also can be represented as:

\[
\frac{\psi}{2} = \arctan\left(\frac{r_p}{2f}\right) \quad (4.14)
\]

\[
\frac{\psi_0}{2} = \arctan\left(\frac{D_1}{4f}\right) \quad (4.15)
\]

The parabola can be defined by only two parameters diameter \((D_1)\) and focal length \((f)\). But, in above figure, the additional parameter \(h\) represents the depth of reflector which is given by,

\[
h = \frac{D_1^2}{16f} = f \tan\left(\frac{\psi_0}{2}\right)^2 \quad (4.16)
\]

The important aspect of Cassegrain antenna is magnification factor. With the help of magnification factor, Cassegrain antenna can be modeled as a single parabolic reflector for analysis purpose. Modeling of Cassegrain system into equivalent paraboloid increases the effective focal length of the system. The increase in effective focal length leads to
decrease in cross polarization as well as an increase in aperture efficiency. The diameter of reflector remains same.

Mathematically,

\[ D_{eff} = D_1 \]  \hspace{1cm} (4.17)

And,

\[ f_{eff} = Mf \]  \hspace{1cm} (4.18)

M is the magnification factor of Cassegrain antenna which is related with an eccentricity of hyperbola by the following relation:

\[ M = \frac{e+1}{e-1} \]  \hspace{1cm} (4.19)

To represent the equivalent paraboloid of Cassegrain antenna, equation (4.14) can be modified as,

\[ \frac{\theta}{2} = \arctan \left( \frac{r_p}{2Mf} \right) \]  \hspace{1cm} (4.20)
And,

\[
\frac{\theta_0}{2} = \arctan \left( \frac{D_1}{4MF} \right) \quad (4.21)
\]

\( \theta_0 \) is the opening half angle of hyperbolic Reflector. When the secondary focus of hyperbola lies on the vertex of the main reflector, the magnification factor is simply the ratio between main Reflector diameter to Subreflector diameter.

\[
M = \frac{D_{\text{main Reflector}}}{D_{\text{subreflector}}} = \frac{D_1}{D_2} \quad (4.22)
\]

### 4.4 TAPER LEVEL AND BEAM DEVIATION FACTOR

Horn antennas are used to illuminate the reflector surface in reflector type antenna for high-frequency applications. The ability of horn to illuminate the reflector surface uniformly determines the illumination efficiency of feed.

The illumination efficiency also can be defined in terms of tapered value. Tapered value gives the information about illumination in the edge of the reflector with respect to the centre of the reflector. Normally, 10 dB tapered value is used while designing single parabolic reflector.

The tapered value is a function frequency to diameter ratio of an antenna and is given by:

\[
T(dB) = 20 \times \log \left( 1 + \left( \frac{D_1}{Af} \right)^2 \right) \quad (4.23)
\]

The above equation is applicable to calculate the value of edge tapered for the single parabolic reflector.

For Cassegrain magnification factor also should be included. Thus, edge tapered value for Cassegrain antenna is,

\[
T_1(dB) = 20 \times \log \left( 1 + \left( \frac{D_1}{4MF} \right)^2 \right) \quad (4.24)
\]
The above figure shows the edge taper value for single reflector and Cassegrain antenna as a function of frequency to diameter ratio. This shows that taper value for double reflector antenna is negligible.

Another factor which needs to be considered while designing reflector antenna is Beam Deviation Factor (BDF). The ratio of beam maximum to offset angle is called beam deviation factor and it is denoted by K. The value of beam deviation factor (BDF) depends upon the F/D value of antenna [REF]. The value of BDF varies according to the shape of the reflector. For a concave reflector, BDF varies from less than one whereas for convex it varies from greater than one. The BDF is approximately one for the flat reflector. The relation between frequency to diameter ratio and beam deviation factor can be expressed by:

\[
BDF = \frac{(\frac{\lambda f}{D_1})^2 + 0.36}{(\frac{\lambda f}{D_1})^2 + 1}
\]  

(4.25)
When the frequency to diameter ratio approaches infinity (flat reflector), the value of beam deviation factor becomes one. The value of BDF for various values of $f/D$ is listed in table below.

**Table 4.1: Beam Deviation Factor**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Frequency to Diameter Ratio($f/D_1$)</th>
<th>Beam Deviation Factor(K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.30</td>
<td>0.724</td>
</tr>
<tr>
<td>2</td>
<td>0.40</td>
<td>0.818</td>
</tr>
<tr>
<td>3</td>
<td>0.50</td>
<td>0.874</td>
</tr>
<tr>
<td>4</td>
<td>0.60</td>
<td>0.908</td>
</tr>
<tr>
<td>5</td>
<td>0.70</td>
<td>0.930</td>
</tr>
<tr>
<td>6</td>
<td>0.80</td>
<td>0.945</td>
</tr>
<tr>
<td>7</td>
<td>0.90</td>
<td>0.957</td>
</tr>
<tr>
<td>8</td>
<td>1.0</td>
<td>0.965</td>
</tr>
<tr>
<td>9</td>
<td>1.6</td>
<td>0.986</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>0.991</td>
</tr>
</tbody>
</table>

### 4.5 FEED ILLUMINATION FUNCTION

The illumination on reflector depends upon the edge tapered value. Mathematically, the illumination efficiency of feed is given by:

$$
\eta = \frac{\int F(r)dr}{\int F^2(r)dr}
$$

(4.26)

Feed illumination follows $F(r)$ either Gaussian distribution or quadratic distribution. These two methods are most widely used illumination function. The Gaussian illumination function can be expressed as,

$$
F(r) = e^{-\beta r^2}
$$

(4.27)
$r$ is the normalized radii and $\beta$ is related with tapered value by:

$$\beta = \left( \frac{T}{20} \right) \ln 10 \tag{4.28}$$

With the help of above stated three equations, illumination efficiency is derived and given by:

$$\eta = \frac{2(1-e^{-\beta})^2}{\beta(1-e^{-2\beta})} \tag{4.29}$$

On the other hand, the quadratic illumination is expressed using following equation:

$$F(r) = 1 - (1-t)r^2 \tag{4.30}$$

Where $\log(t) = \frac{T}{20}$

Figure 4.10: Taper Vs illumination efficiency
With the help of above equation, the figure is plotted in MATLAB which shows the relation between tapered value and illumination efficiency. For a low value of taper, both functions have the same performance. On the other hand, Quadratic illumination function shows superior performance than Gaussian for high tapered value. For a taper value -12 dB, Quadratic illumination provides 89% illumination efficiency whereas 86% in Gaussian illumination.

### 4.6 APERTURE INTEGRATION TECHNIQUE

Maxwell equations always remain at the heart of any electromagnetic analysis. The figure below represents the coordinate system and geometry of reflector antenna which acts as a basis for electromagnetic computation. Q and P are the observation point where the radiation intensity is to be found.

The radiation energy at point Q near the aperture field is given by:

$$H_Q(\rho, \psi, \chi, \lambda) = -\frac{i}{2\lambda} \left(\exp\left(i\frac{kr}{\lambda}\right)\right) F(\psi, \chi) \left(1 + \cos\psi\right) \left(i\psi \cos\chi + i\chi \sin\chi\right)$$  \hspace{1cm} (4.31)

$F(\psi, \chi)$ in equation (4.27) represents the feed illumination function.

Generally, two methods are used to compute radiation pattern of the reflector antenna. The first one is surface current distribution method which is based on physical optics. Current distribution method assumes the incident energy on the reflector surface is
known. Another technique used in radiation pattern analysis is aperture integration technique which is based on geometrical physics.

![Diagram of aperture integration method](image)

Figure 4.12: Aperture Integration Method [60]

The radiation pattern at point P can be calculated by integrating the incident current on the reflector surface. The surface current in reflector surface which is perfect conductor is given by:

$$ J = n \times H $$  \hspace{1cm} (4.32)  

$H$ represents the magnetic field and $n$ is the normal vector. Total magnetic field is the sum of incident and reflected magnetic field.

$$ H = H_i + H_r $$  \hspace{1cm} (4.33)  

And

$$ n \times H_i = n \times H_r $$  \hspace{1cm} (4.34)  

The above three equation can be combined to form a new equation,

$$ J = 2 (n \times H_i) $$  \hspace{1cm} (4.35)
Surface current at point Q is given by:

\[ J_Q = -2H_Q(i_y \cos \left( \frac{\psi}{2} \right) + i_z \sin \left( \frac{\psi}{2} \right) \sin \chi) \]  
(4.36)

And the magnetic field at point Q is:

\[ H_Q = -\frac{i}{2\lambda} \left( \frac{\exp(ik\rho)}{\rho} \right) F(\psi, \chi) (1 + \cos \psi) \]  
(4.37)

The relation between surface current and electric field at aperture A can be expressed by the following equation.

\[ E_A = -0.5 \left[ \frac{\mu}{\sqrt{\varepsilon}} \right] \sec \left( \frac{\psi}{2} \right) J_Q(y) \]  
(4.38)

The distance between aperture field and observation point P is given by the relation:

\[ r = R - b \sin \theta \cos(\theta - \chi) + \frac{b^2}{2R} \]  
(4.39)

Where \( b = \frac{da}{2} \), is the radial coordinate.

Equation (4.31) gives the information about current density on the reflector surface. With the help of this radiated field by the reflector can be found at point P which is given as,

\[ E_p(\theta, \phi) = \frac{d^2}{4} * \frac{\varepsilon^{ikR}}{R} \int_0^1 \int_0^{2\pi} F(a, \chi) \exp \left[ ik \left\{ -\frac{da}{2} \sin \theta \cos(\chi - \phi) + \frac{(da)^2}{2R} \right\} \right] a \ da \ d\chi \]  
(4.40)

Equation (4.34) shows that \( r \) and \( R \) follows non linear relationship. While considering point P as a far field distance, the two vectors \( R_1 \) and \( r_1 \) becomes parallel. Thus, the same equation can be rewritten as in linear form by excluding non linear part.

\[ r = R - b \sin \theta \cos(\theta - \chi) \]  
(4.41)
The radiation equation becomes,

\[
    f(\theta, \varphi) = \frac{a^2}{4} e^{ikR} \int_0^1 \int_0^{2\pi} F(a, \chi) \exp \left[ ik \left\{ -\frac{da}{2} \sin \theta \cos (\chi - \varphi) \right\} \right] a \, da \, d\chi \quad (4.42)
\]

\(F(a, \chi)\) in above equation represents the feed illumination function which have amplitude and phase function which can be written as,

\[
    F(a, \chi) = A(a, \chi) \exp (\phi(a, \chi)) \quad (4.43)
\]

The first and second term of equation (4.37) represents amplitude function and phase function respectively. The assumption of constant phase function and symmetric amplitude function leads the radiation pattern to become,

\[
    f(\nu) = \int_0^1 F(r)J_0(\nu r) \, rdr \quad (4.44)
\]

\(J_0\) is the first order Bessel function and \(\nu\) is angular coordinate which equals to \( \frac{\pi d}{\lambda} \sin \theta \). The feed illumination function \(F(r)\) can be written in terms of taper value as follows:

\[
    F(r) = 1 - (1 - t)r^2 \quad (4.45)
\]

Where \(t\) follows the relation, \(\log(t) = T/20\)

### 4.7 FEED DEFOCUS

The main function of feed is to illuminate the reflector surface with electromagnetic energy. It converts the input radio frequency signal into electromagnetic energy. If the antenna is acting as a receiver, feed collects energy incident on the reflector. In this case, feed transforms electromagnetic energy into radio frequency signal. The performance of feed is measured in terms of its illumination and spillover efficiency. Ideally, the feed should have a uniform illumination over the whole reflector surface. This implies amplitude and phase of the every incident signal should be same. Also, the directivity of feed should be high. The energy radiated by the feed should not spill over the edge of the
reflector. But in reality, feed suffers from many factors like gravitational loading, wind effect or manufacturing imperfections. These factors force feed to deviate from its original position which results in phase error over the aperture. The decrease in performance of feed due to manufacturing imperfections comes under random error. These errors can be modeled by using the normal distribution. On the other hand, the deviation of feed due to wind force, thermal distortions or gravitational loading falls into systematic error. In this part, we focus more on systematic error than random error.

The shift of feed due to above-stated factors is decomposed into two parts axial displacement and lateral displacement of feed. The shift of feed from its true position along the axis is called axial displacement whereas in lateral displacement feed follows the direction perpendicular to the axis. The displaced position of feed changes the path length which results in phase error. With the help of phase information, the characteristic of radiation pattern can be analyzed.

4.7.1 Axial Displacement

The initial and true position of feed is located at point $F$. The feed is axially displaced by length $dL$. The new position of feed is at point $F'$. The path length to reflector changes from $L$ to $L'$. $\theta_0$ is the opening half angle of reflector.
Applying cosine law in triangle AFF’, we get

\[ L'^2 = L^2 + dL^2 - 2L \, dL \cos(\pi - \phi) \]
\[ = L^2 + dL^2 + 2L \, dL \cos(\phi) \]  
(4.46)

The path length difference (\( \Delta L \)) due to axial shift of feed by \( dL \) is given by:

\[ \Delta L = dL - (L' - L) \]
\[ = dL - \frac{dt^2 + 2L \, dL \cos(\theta)}{L' + L} \]  
(4.47)

For very small displacement with respect to wavelength and assuming \( L' = L \), the path length difference approximately becomes,

\[ \Delta L = dL \,(1 - \cos\phi) \]  
(4.48)

The difference in path length leads to phase error over the aperture. The relation between phase error (\( \Delta \phi_a \)) is given as:

\[ \Delta \phi_a = \frac{2\pi}{\lambda} dL(1 - \cos \phi_a) r^2 \]  
(4.49)
This phase error causes deviation of the energy radiated by the reflector. The effect of phase error on the radiation pattern can be presented by modifying equation (3.43) with the help phase error. So, the radiation equation in the case of axial displacement is given by:

\[
f(\nu) = \int_0^1 F(r) J_0(\nu r) \exp(-j\Delta \phi_a) \, r \, dr \quad (4.50)
\]

Equation (4.52) is modified form of equation (4.44) with phase error which is expressed in exponential form. \( f(\nu) \) is the antenna field pattern and squaring of field pattern gives power pattern.

\[
Power \ Pattern, \ G(\nu) = f^2(\nu) \quad (4.51)
\]

### 4.7.2 Lateral Displacement

As stated earlier, lateral displacement of feed follows perpendicular direction from the axis. \( OF \) in the figure represents the antenna axis. The feed shifts from initial position \( F \) to new position \( F' \) with displacement \( dL \) along the perpendicular direction.

![Figure 4.14: Lateral Defocusing of Feed](image-url)
In previous section path length error due to axial defocusing of feed was independent with azimuthal coordinate $\chi$. But, in the case of lateral defocusing, path length error also depends upon azimuthal coordinate which complicates the analysis. Using cosine rule on triangle AFF’, we get

$$L'^2 = L^2 + dL^2 - 2L \ dL \sin \phi \cos \chi \quad (4.52)$$

The Taylor Series expansion of equation (4.54) gives,

$$L' = L \sqrt{1 + \left( \frac{dL^2}{L^2} - \frac{2dL}{L} \sin \phi \right)}$$

$$= L + \frac{L}{2} \left( \frac{dL^2}{L^2} - \frac{2dL}{L} \sin \phi \right) + O(dL^2)$$

$$= L - dL \sin \phi + \frac{dL^2}{2L} + O(dL^2) \quad (4.53)$$

$O(dL^2)$ is the higher order terms which includes $dL^2$. Since, we are considering the small defocus with respect to focal length of the system, these higher order terms can be neglected. Equation (4.53) becomes,

$$L' = L - dL \sin \phi \quad (4.54)$$

The path length difference is given by

$$\Delta L = L - L' = dL \sin \phi \quad (4.55)$$

The corresponding phase error over the aperture due to above path length difference ($\Delta L$) is,

$$\Delta \phi_l = \frac{2\pi}{\lambda} \Delta L = \frac{2\pi}{\lambda} \ dL \sin \phi \quad (4.56)$$

In this case, antenna radiation pattern can be computed by using following equations,
Pointing Accuracy of an Antenna

Chapter 4

\[ f(v) = \int_0^1 f(r) J_0 \left( r \left[ v - 2 * k * \frac{delt}{x} * \frac{1}{1+b^2} \right] \right) r dr \]  

(4.57)

Where, \( x = \frac{4Mf}{D_1} \), \( b = \frac{r}{x} \) and \( delt \) represents lateral displacement.

As like in axial displacement case, power pattern can be computed by squaring field pattern. The above-stated equation helps to analyze the beam squint and side lobe levels of antenna power pattern. The axial displacement of feed causes the phase error over the aperture which reduces the gain. On the other hand, lateral displacement is responsible for pointing error. The direct computation of pointing error caused by the lateral displacement of feed can be performed by using following equation,

\[ \theta_f = \frac{K*dL}{Mf} \]  

(4.58)

\( \theta_f \) and \( K \) represents pointing error due to feed displacement and beam deviation factor respectively.

4.8 SUBREFLECTOR DISPLACEMENT

The function of Subreflector is to reflect the incoming radio signal from feed and direct towards the main reflector. The position of Subreflector plays an important role for the optimum performance of an antenna. As like feed defocusing, Subreflector displacement also can be categorized into two terms axial and lateral. The same concept and methodology of feed defocusing can be implemented in the case of Subreflector displacement too. The only one difference is that focal length should be multiplied by magnification factor while analyzing feed defocusing effect. But, in the case of Subreflector displacement focal length remains same as the system focal length. Axial displacement of feed and Subreflector does not induce pointing error since it does not distorts the antenna symmetry. But lateral displacement causes the antenna to become asymmetrical about the antenna axis. The phase error in reflector surface due to axial displacement of Subreflector with \( dL_s \) is given by:

\[ \Delta \phi_s = \left( \frac{2\pi}{\lambda} \right) \left( 2 - \cos\theta - \cos\psi \right) dL_s \]  

(4.59)
\( \theta \) and \( \psi \) are the opening half angle of opening half angle of Subreflector and main reflector respectively. The beam deviation characteristic due to Sub reflector shift can be performed by using same equation as (4.57) with small modification.

\[
f(v) = \int_0^1 f(r) \left( r \left[ v - 2 * k * \frac{dL_s}{x} * \frac{1}{1+b^2} \right] \right) r dr \quad (4.60)
\]

Where \( x = \frac{4f}{D_1}, b = \frac{r}{x} \) and \( dL_s \) is the Subreflector displacement (lateral).

From above geometry, the direct computation of pointing error is possible by taking the location of the virtual focal point. The equal amount shift of feed and Subreflector makes displaced feed and focus coincident. In this case beam deviation becomes,

\[
\theta = \frac{-dL_sK}{f} \quad (4.61)
\]
But some correction should be provided to translate the displaced feed to the original position (i.e. focal axis). Thus,

\[ y = \frac{dL_s}{M} \quad (4.62) \]

The virtual focal point \( x \) in the above geometry can be expressed as,

\[ x = -dL_s + y \quad (4.63) \]

From equation (4.62), substituting the value of \( y \), we get

\[ x = -dL_s + \frac{dL_s}{M} = \frac{M-1}{M}(-dL_s) \quad (4.64) \]

The beam deviation due to lateral displacement of focal point by an amount \( x \) is;

\[ \theta_h = xK/f \quad (4.65) \]

Substituting the value of \( x \) from equation (4.64), equation becomes

\[ \theta_h = \frac{M-1}{M} \frac{K}{f} (-dL_s) \]

\[ = \frac{(-dL_s)(M-1)K}{Mf} \quad (4.66) \]

For upward shift i.e. along the positive y-axis, \( dL_s \) becomes positive. Finally, the pointing error due to Subreflector displacement is,

\[ \theta_h = \frac{(dL_s)(M-1)K}{Mf} \quad (4.67) \]

### 4.9 PRIMARY REFLECTOR DEFLECTION

As like Subreflector displacement and feed shift, the deflection of the main reflector from its original position vertex also impacts on the pointing performance of an antenna. It also distorts the symmetry of an antenna. The reflector deflection leads to vertex shift as well as a change in focal point of the system. The total pointing error due to reflector
deflection becomes the algebraic sum of individual error (i.e. vertex shift and focal point translation). In figure thin line shows the designed parabola and the thick bold line represents deflected reflector from its initial position. The amount of vertex shift due to deflection is represented by \( dL_v \) and \( dF \) shows the amount of focal point translation. \( f \) is the system focal length.

![Diagram of Main Reflector Deflection](image)

Figure 4.16: Main Reflector Deflection

Not only gravitational loading, wind effects, and thermal distortions, reflector deflection arises from the manufacturing imperfection and tolerance value mismatch also. To compute the pointing error first we calculate the contribution of each factor (vertex shift and focal point shift) in pointing error. Then, the algebraic sum of two gives total pointing error due to reflector deflection. The pointing error due to rotation of reflector is,
Pointing Accuracy of an Antenna

To relate the designed focal point and displaced focal point, the focal point should be translated by an amount \( -dF \) which gives point error,

\[
\theta_2 = \frac{-K \, dF}{f} \quad (4.69)
\]

The total point error becomes,

\[
\theta_T = \theta_1 + \theta_2 \quad (4.70)
\]

Substituting the value of \( \theta_1 \) and \( \theta_2 \) in equation (4.70), we get

\[
\theta_T = \frac{dL_v - dF}{f} + \frac{-K \, dF}{f}
\]

\[
= \frac{[dL_v - dF (1+K)]}{f} \quad (4.71)
\]

The pointing error due to reflector vertex shift only is given by:

\[
\theta_v = \frac{KdL_v}{f} \quad (4.72)
\]

The given table summarizes the pointing error due to structural deflections.

**Table 4.2: Beam Deviation**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Structural Deflection</th>
<th>Symbol</th>
<th>Pointing Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Feed Defocusing</td>
<td>( dL )</td>
<td>( \frac{K , dL}{Mf} )</td>
</tr>
<tr>
<td>2</td>
<td>Subreflector Translation</td>
<td>( dL_s )</td>
<td>( \frac{(dL_s)(M - 1)K}{Mf} )</td>
</tr>
<tr>
<td>3</td>
<td>Vertex Shift</td>
<td>( dL_v )</td>
<td>( \frac{KdL_v}{f} )</td>
</tr>
</tbody>
</table>
4.10 POINTING LOSS

The loss due to misalignment of an antenna is regarded as pointing loss. All gains and losses associated with equipment as well as environment should be included while designing satellite link budget. So, both transmitting and receiving antenna pointing loss should be included in satellite link budget. General expression for link budget equation is,

\[ Rx \text{ Power}(dB) = Tx \text{ Power}(dB) + Gains(dB) - Losses(dB) \]

Effective isotropic radiated power (EIRP) is associated with transmitting link of satellite and it gives maximum radiated power in a specific direction.

\[ EIRP = P_T G_T \]  \hspace{1cm} (4.73)

This radiated power suffers from various losses while directing toward the receiving antenna. \( L \) in above figure represents various path losses. \( \theta_T \) and \( \theta_R \) is the transmitting antenna and receiving antenna pointing loss respectively. Transmitting equipment is connected to antenna with the help of feeder which also contributes some losses (\( L_{FTX} \)). On the receiving side, the antenna having gain \( G_R \) is connected to receiver through feeder. The performance of receiving subsystem is measured by the ratio \( \frac{G}{T} \). This ratio is called figure of merit (FOM) of the receiver. \( G \), represents overall gain of receiving equipment and \( T \) is the system noise temperature. The radiation pattern of an antenna shows distribution of energy (gain) over a space. The gain is calculated by taking reference of isotropic antenna. The gain of an antenna is the ratio of power radiated by an antenna in specific direction to the power radiated by isotropic antenna. Isotropic
Antenna is a hypothetical antenna which transmits energy equally in all directions (Omni directional).

The gain of a reflector antenna is given by,

$$\text{Gain}(G) = \frac{4\pi}{\lambda^2} A_e$$  \hspace{1cm} (4.74)

$A_e$ is the effective area of an antenna. For antenna having circular aperture, the area is $\frac{\pi D_1^2}{4}$ and its effective area becomes $\eta A$. Here, $\eta$ is the efficiency of the antenna and $D_1$ is the main reflector diameter. Putting all these values, the maximum gain of an antenna becomes,

$$G_{\text{max}} = \frac{4\pi}{\lambda^2} \left( \frac{\pi D_1^2}{4} \eta \right)$$  \hspace{1cm} (4.75)

While discussing gain and radiation pattern of the antenna, half power beam width always comes into the picture. It is the angular width between two points in radiation pattern where the power becomes half. The Half Power Beam Width (HPBW) $\theta_{3dB}$ of a reflector antenna is,

$$\theta_{3dB} = \frac{70\lambda}{D_1} = \frac{70c}{fD_1}$$  \hspace{1cm} (4.76)

For a specific direction $\theta$ with respect to its maximum radiating direction, the value of gain becomes,

$$G(\theta) = G_{\text{max}} - 12 \left( \frac{\theta}{\theta_{3dB}} \right)^2$$  \hspace{1cm} (4.77)

The equation (4.77) is restricted to small values of off-axis angle ($\theta$) in the range, $0 < \theta \leq \frac{\theta_{3dB}}{2}$. 
Figure 4.18: Antenna Gain vs Half Power Beam Width

The above figure shows the general relation between maximum gain and half power beam width. The green solid line shows the gain for an antenna having efficiency 80% and red dashed line is for the antenna of efficiency 60%. Extending equation (4.77), the difference in gain in specific direction and maximum direction ($\Delta G$) is,

$$\Delta G = 12 \left( \frac{\theta_p}{\theta_{3dB}} \right)^2 \quad (4.78)$$

Where, $\theta_p$ is pointing error. This gives the pointing loss in dB when there is pointing error. The pointing loss of transmitting antenna is given as,

$$L_T(\theta) = 12 \left( \frac{\theta_p}{\theta_{3dB}} \right)^2 \quad (4.79)$$
4.10.1 Design parameters of Cassegrain Antenna

The table below shows the taken parameters to design Cassegrain antenna and analyze its pointing performance in 20GHz frequency. The above table shows the design parameters of Cassegrain antenna in this paper. The focal length to main reflector (F/D) ratio plays an important role while designing antenna. Normal design principle follows F/D ratio between 0.25 to 0.6. Parabolic reflector antennas having low F/D ratio suffers from polarization distortion and poor beam axis performance. On the other hand, the increase in F/D ratio causes a decrement in edge angle making the system to require more directive and large feed for uniform aperture illumination. Also, mechanical supporting structures create a blockage which reduces gain and increases side lobe levels. To avoid this problem we can use dual reflector antenna system. For generating apertures, dual reflector antenna gives more degree of freedom.

*Table 4.3: Design Parameters of Cassegrain Antenna*

<table>
<thead>
<tr>
<th>Seq. No.</th>
<th>Specifications</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Main Reflector Diameter(D1)</td>
<td>1.5 meter</td>
</tr>
<tr>
<td>2</td>
<td>Sub reflector Diameter(D2)</td>
<td>0.1725 meter</td>
</tr>
<tr>
<td>3</td>
<td>Primary Focal Ratio</td>
<td>0.6</td>
</tr>
<tr>
<td>4</td>
<td>Cassegrain Focal Ratio</td>
<td>5.75</td>
</tr>
<tr>
<td>5</td>
<td>Beam Deviation Factor(K)</td>
<td>0.991</td>
</tr>
<tr>
<td>6</td>
<td>Magnification Factor(M)</td>
<td>8.7</td>
</tr>
<tr>
<td>7</td>
<td>Frequency(f)</td>
<td>20 GHz</td>
</tr>
</tbody>
</table>

While analyzing the double reflector using equivalent parabola technique, we need magnification factor. In the case when feed is placed at the vertex of the main reflector, the magnification factor is simply the ratio between main Reflector Diameter to Sub reflector Diameter.
The primary reflector diameter is chosen 100λ and 11.5λ for Sub reflector. Beam deviation factor is calculated using equation (4.25) with the help of primary focal ration. The focal length of the system is taken 60λ. For magnification factor of 8.7, the eccentricity of hyperbola becomes 1.25. Since the tapered value for Cassegrain antenna is negligible, simply it is ignored assuming feed have a uniform illumination.

GRASP and MATLAB are used here to design and analyze the performance of proposed Cassegrain antenna.

### 4.11 GRASP SIMULATION

![Image of GRASP window for reflector design]

Figure 4.19: GRASP Window for Reflector Design

GRASP, a product of TICRA is reflector antenna modeling and analysis software. It uses PO/PTD method to analyze the radiation performance of an antenna. The above
figure shows the GRASP software window where all design parameters are entered to create the object (i.e. Cassegrain antenna). Since, feed is placed at the vertex of main reflector distance between foci relative to main reflector focal length becomes 0.9 m, that is system focal length only. Figure 4.19 shows the designed Cassegrain antenna according to the above-entered parameters. A Gaussian illuminating feed is used which is linearly polarized.

Figure 4.20: 3D View of Designed Antenna
Figure 4.21: E-Field for $\varphi = 0$

Figure 4.22: E-Field for $\varphi = 90$
The above three figures represent co-polarized and cross polarized electric field pattern of designed antenna for three different values of $\varnothing = 0$, 45 and 90 degrees. The radiation pattern is measured in the surface like a planar, cylindrical or spherical plane rather than in single point. Mostly, planar and cylindrical surface measurements are used in the near-field measurement of an antenna whereas spherical measurement can be used in near-field as well as far-field measurement. The above three figures (Fig 36, 37 and 38) represents the far-field measurement taking spherical surface. The spherical surface is represented by its coordinates $r, \theta, \text{and } \varnothing$. For far field, $r$ tends to infinity and electric filed distribution with respect to angle $\theta$ presented by taking $\varnothing$ as a constant. Linear polarized feed is chosen and antenna also follows same. But antenna cannot be designed for 100% polarized in single a direction. Thus, Cross-polarization comes into picture which is orthogonal to referenced polarization. Fig 37 shows that at $\varnothing = 45$ degree, the impact of cross-polarization is significant. The 25 dB of gain is obtained for $\varnothing = 0$ degree and it slightly reduced for $\varnothing = 45$ and 90.
4.12 Radiation pattern of Cassegrain Antenna

MATLAB is used to simulate the influence of structural shift in the gain and side lobe level of designed antenna. Theory derived from aperture integration technique in section 3.6 is implemented in MATLAB to analyze the performance of an antenna. First, the normalized radiation pattern of an antenna is presented in Figure 39 which shows the main lobe and various side lobes. The radiation pattern is plotted by assuming constant phase and amplitude distribution over the reflector surface.

![Normalised Radiation Pattern](image)

Figure 4.24: Normalised Radiation Pattern

In the above radiation pattern, the x-axis shows the variation in angle, $\theta$ and power level (in dB) which can be obtained by squaring the gain pattern is shown in y-axis.

4.13 Structural Displacements in Cassegrain Antenna

A Cassegrain antenna is a dual reflector antenna which consists of paraboloid main reflector, hyperboloid sub-reflector, and feed. The focal point of the paraboloid and virtual focal point of hyperboloid converges on the same point. Phase center of feed lies
on the real focal point of sub-reflector. Usually, a horn antenna is the good choice as a feed for high-frequency applications whereas dipole antenna is the low-frequency counterpart. The energy from the feed illuminates the sub-reflector which reflects the signal energy to the main reflector. The reflected energy is again get reflected the by the main reflector to form a desired beam. Cassegrain antenna offers low noise temperature, better pointing accuracy and flexibility in feed design than parabolic reflectors. Cassegrain configuration allows the receiver/transmitter to be placed near the feed which greatly reduces the transmission loss of the system. Amplitude and phase variation in the primary reflector of Cassegrain system can be controlled by shaping the Sub reflector. This will reasonably balance the spillover and illumination efficiency. The figure below shows the basic structure of double reflector system used in transmitting case. The same antenna also can be used as a receiving antenna.

![Figure 4.25: Basic Geometry of Cassegrain Antenna](image_url)

Due to the thermal deformation, gravitation loading or wind effect, the Cassegrain antenna suffers from structural distortions. The main structural distortions can be categorized into three ways as stated below [9]:

- Feed Displacement
- Sub reflector(Hyperbola) Translation and
- Vertex Shift

These structures shift follows either along the axis of an antenna which is Axial Displacement or perpendicular to the axis which is regarded as Lateral Displacement.
4.14 Feed Displacement

Shifting the feed in the axial direction of reflector axis causes under-illumination of the main reflector whereas Sub reflector translation is responsible for the under-illumination of both Sub reflector and main reflector. Loss in gain is the result of phase error over the aperture and slipover losses. The impact feed shift and Sub reflector translation in gain profile of the antenna is shown in figure below. This is the situation where Feed or Sub reflector is shifted along the axis of an antenna (axial shift). The on-axis gain (i.e. for \(v=0\)) profile of the antenna with feed and Sub reflector displacement is shown in Fig 40.

Feed and Sub reflector has been shifted up to one inch (i.e. 0.025 meter). The 0 inch displacement represents there is no any defocusing (antenna in normal condition). For the equal displacement, Sub reflector translation is more vulnerable to gain loss than feed displacement. For one inch of feed shift gain gets reduced by 0.009 dB whereas for same displacement of Sub reflector in axial direction, 4.5 dB of gain decrease is observed. Here, the result is obtained by displacing feed and Subreflector individually in positive x-axis direction.

![Normalized Power vs Feed Displacement](image1)

![Normalized Power vs Subreflector Displacement](image2)

Figure 4.26: Axial Defocusing of Feed and Sub reflector
Not only uniform illumination over an aperture is a performance measure of feed but it also should have uniform phase distribution of the aperture. Incident energy which is out of phase leads to subtraction of out of phase energy from total radiated energy which eventually reduces the gain of the antenna. Polarization performance of the system also can be predicted by the type of feed used. In the case of the parabolic reflector, the phase center of feed should be the focus of the reflector. Ideally, the energy radiated by feed should originate from a single point source. But, it is not possible in practical aspects. In the case of the dual reflector (Cassegrain), hyperbola comes into the picture as a Sub reflector which contains two foci. The energy radiated by feed which is nearby the vertex appears as they are coming from the virtual focus of the system. It is strictly required to be the phase center at an accurate position. Axial displacement of structure distorts the phase center of an antenna. For a reflector antenna in high-frequency application, a horn antenna is used as a feed. The addition of energy occurs when incident signals are in phase and reverse is true for out of phase signal. Those signal which is partially out of phase, partial cancellation of energy occurs. But axial displacement of feed and Sub reflector cause phase error over the aperture which is presented in Table 4.4.

Table 4.4: Phase Error Due to Axial Defocusing

<table>
<thead>
<tr>
<th>S.No</th>
<th>Displacement (inch)</th>
<th>Phase Error Due to Feed Displacement(deg)</th>
<th>Phase Error Due to Subreflector displacement(deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.2</td>
<td>0.0097</td>
<td>0.6393</td>
</tr>
<tr>
<td>3</td>
<td>0.4</td>
<td>0.0195</td>
<td>1.2786</td>
</tr>
<tr>
<td>4</td>
<td>0.6</td>
<td>0.0292</td>
<td>1.9179</td>
</tr>
<tr>
<td>5</td>
<td>0.8</td>
<td>0.0390</td>
<td>2.5572</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>0.0487</td>
<td>3.1965</td>
</tr>
</tbody>
</table>
Unlike axial defocusing, shifting the Sub reflector or Feed perpendicular to the antenna axis (Lateral Defocus) causes beam deviation from the original position. It doesn’t have impact on the gain performance of an antenna. The red dashed line in Figure 4.27 shows the antenna beam pattern without any displacement of feed. Then, the corresponding beam pattern is obtained by translating feed one inch in the direction perpendicular to antenna axis which is shown by a green dotted line. Same principle as like lateral feed displacement is applied in the case of Sub reflector and obtained result is presented in Figure 4.28. One inch lateral displacement of feed shifts the antenna beam by 0.18 degree whereas for the same amount of Sub reflector displacement beam is squinted by 1.4 degrees. In addition to beam deviation, lateral defocusing produces asymmetric side lobes called coma lobes which are the source of interference for other satellites. Shifting the structures in the positive y-axis, the beam is shifted to the right side. In a similar way, displacement in opposite direction (negative y-axis) causes the beam to shift in the left side. 0 inch in Figure 4.27 and Figure 4.28 represents the antenna pattern without any displacement.

Figure 4.27: Lateral Defocusing of Feed
Lateral defocus increases the side lobe in the shifted direction and the reverse is true for opposite direction. The measured value of side lobe level in original (true) position and shifted position is listed in Table 4.5.

**Table 4.5: Measurement of Side lobe Level**

<table>
<thead>
<tr>
<th>Displacement (Inch)</th>
<th>Feed Shift</th>
<th>Sub reflector Shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-20.44 dB</td>
<td>-20.44 dB</td>
</tr>
<tr>
<td>1</td>
<td>-20.29 dB</td>
<td>-15.83 dB</td>
</tr>
</tbody>
</table>

Figure 4.29 shows the pointing error caused by lateral displacements of feed, Sub reflector, and vertex of the main reflector. These figures show the pointing error for various displacements ranging from 0 to 1 inch. The effect of feed displacement has a negligible effect on pointing errors while hyperbola translation and vertex shift shows significant impact on it. One inch shift of vertex causes about 1.6-degree pointing error.
On the other hand, the same displacement of feed produces only 0.18-degree pointing error which is about $1/10^{th}$ of pointing error due to vertex shift.

![Figure 4.29: Pointing Error Vs Displacements](image)

Table 4.6 represents the same information in tabular form. The misalignment of an antenna beam from the true direction leads to loss of gain which is considered as antenna pointing loss in satellite link design. The gain of an antenna falls from maximum gain. Both transmitting and receiving antenna may suffer from this situation. In this case, the loss is transmitting antenna pointing loss.
Equation (4.79) gives the general relation between the amount of misalignment and pointing loss in dB scale. But, this is valid only for the misalignment up to \( \frac{\theta_{\text{dB}}}{2} \). Since, the half power Beam width of designed antenna is 0.70 degree, corresponding pointing loss is calculated up to 0.35 degree only which is shown in Figure 4.29.

The x-axis in the figure shows the antenna beam deviation and y-axis shows the fall of gain from its maximum value. The point loss due to vertex shift and hyperbola translation varies linearly with displacement for small value of small misalignment angle while feed displacements have negligible effect on pointing loss. For the beam squint of 0.35 degree, 3 dB loss of gain is observed in the case of vertex shift whereas 2.2 dB loss for hyperbola displacement. For the large value of pointing error, the relation tends to follow exponential relation.
Reflector surface errors can be categorized into two terms random surface errors and systematic errors. Up to now, all analysis performed above are based on systematic errors. This implies the displacement of feed, Subreflector, and vertex due to the external factors like wind effect and gravitational loading. On the other hand, reflector surface may suffer from manufacturing error which is called random error. In this section, we will analyze the gain performance of an antenna considering random surface error over the reflector. These errors are also called Ruze errors since he performed the fundamental analysis of such errors and initially predicted more or less these errors follow a random distribution. Calculation of gain loss due to random errors requires the value of rms surface error ($\varepsilon$) over the aperture. Here, we will assume the value of rms errors and corresponding gain loss is calculated. Not only gain loss, random errors affects on side lobe as well as in beam efficiency. Loss of gain with respect to $\varepsilon/\lambda$ is shown in Figure 4.30. The value of $\varepsilon/\lambda$ is varied from 0 to 0.1 and corresponding gain loss is calculated.
The exponential decrease of gain is observed while increasing rms surface error value. The rms errors for reflector surface can be calculated by dividing the surface into multiple grid points and measuring surface distortions on each point. After implementing some numerical techniques on the value of individual error one can get total rms error.

![Figure 4.31: Effect of Random Surface Error on Gain Profile](image)

The above figure is the implementation of Ruze equation which is valid for small rms errors with respect to wavelength. The sole reason for the random surface error is fabrication error. While assembling large reflector multiple small reflectors needs to be combined, this introduces some tolerance value for reflector antenna which is a source of random surface error. The tolerance value of reflector impacts on both incident and reflected energy from the reflector.

In the following section compensation technique for Sub reflector translation and feed shift is presented to optimize the antenna performance. By considering the provision of movable Feed and Sub reflector, gain compensation technique for each is performed. The
gain loss due to the axial shift of Sub reflector can be compensated by moving the feed in the opposite direction of Sub-reflector shift. The result of compensation technique shifting the feed by half of that displacement of sub-reflector is shown in Figure 4.32. The red dashed line shows the gain profile of an antenna with Sub reflector translation along positive x-axis and green dashed line shows the compensated gain value. For compensation, the feed shift should follow opposite direction of Sub reflector translation.

![Figure 4.32: Compensation for Subreflector Translation (Axial)](image)

The table below summarizes the improved gain after implementing compensation technique for Sub reflector shift.
Table 4.7: Compensation Effect on Gain

<table>
<thead>
<tr>
<th>Displacement (m)</th>
<th>Before (dB)</th>
<th>After (dB)</th>
<th>Compensation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Not Required</td>
</tr>
<tr>
<td>0.01</td>
<td>-0.54</td>
<td>-0.14</td>
<td>74.07</td>
</tr>
<tr>
<td>0.02</td>
<td>-3.10</td>
<td>-0.76</td>
<td>75.54</td>
</tr>
</tbody>
</table>

In the same way, axial feed shift also can be compensated by moving Subreflector in opposite direction of Feed shift. Note that the amount of Subreflector shift required is only half of the Feed shift.

![Figure 4.33: Compensation for Feed Defocus (Axial)](image)

The amount of beam deviation and asymmetric side lobe due to lateral displacement is a function of F/D ratio and displacement. The lateral defocused effect can be reduced by increasing the focal length of the Cassegrain system. The figure below represents the
compensation for 1-inch displacement of Sub reflector by increasing focal length of the system by one and half times.

Figure 4.34: Compensation of Sub reflector Translation (Lateral)

It is required that the side lobe level of antenna radiation pattern should be minimum in order to avoid the interference. The increment in F/D ratio decreases pointing error as well as minimizes the side lobe levels. The improvement in side lobe level after increasing the frequency to diameter ratio is listed in table below.

<table>
<thead>
<tr>
<th>Side lobes</th>
<th>F/D=0.6</th>
<th>F/D=0.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Side lobe</td>
<td>-15.83 dB</td>
<td>-18.71 dB</td>
</tr>
<tr>
<td>2nd Side lobe</td>
<td>-23.73 dB</td>
<td>-26.31 dB</td>
</tr>
<tr>
<td>3rd Side lobe</td>
<td>-29.25 dB</td>
<td>-35.35 dB</td>
</tr>
</tbody>
</table>
SUMMARY

Beam squint due to the structural deflection is calculated for 1.5m Cassegrain antenna for 20.2 GHz. Axial displacement is responsible for the loss of gain whereas lateral displacement is accountable for the pointing error. The effect of lateral defocus on the gain profile is negligible. Vertex shift and sub-reflector displacement have the significant role in distorting the pointing precision. For one inch displacement of vertex and Sub reflector, the beam deviates by 1.6 and 1.4 degrees respectively. These beam deviation forces the antenna to miss the target resulting in pointing loss. Also, an inch lateral displacement of Sub reflector results increment of the side lobe level by 4.61 dB whereas for the same displacement of feed, the side lobe level rises by 0.15dB. Pointing loss of antenna varies exponentially with structural displacement. The feed displacement has a low impact on Cassegrain antenna performance. But in prime reflector case, it may have the significant impact.

For the optimum performance of Cassegrain antenna, sub-reflector should be placed exactly in the prime focus of the main reflector. The gain of the antenna can be increased from -4.14 dB to -0.99 dB by moving the feed in the opposite direction of Sub reflector shift. The required feed shift is smaller than Sub reflector shift. The pointing error can be reduced about 0.8 degrees by increasing the focal length of the system by 1.5 times. Also, the side lobe level can be decreased by 2.52 dB for a one-inch Sub reflector displacement (lateral) case.