Telescope Beam Width

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1 Introduction

One of the main aim of a telescope is to increase the signal intensity received from space. Telescope used in Radio astronomy could be of different types. These include (i) parabolic reflector which focuses the electromagnetic signal from far away objects at its focus, and (ii) combination of conductor wires called antennas, which increases the signal strength due to resonance of incoming radio waves on the antenna.
The primary instrument used in this experiment is the 4-meter Single Dish Radio Telescope (SRT) located at the NCRA. The telescope is designed to perform various radio astronomy experiments, including the detection of Galactic HI lines. The system comprises several key subsystems: a 4-meter parabolic dish mounted on an Alt-Azimuth mount, a 21-cm horn feed, a drive box for motion control, and a receiver system.
The 4-m antenna can be employed to perform a variety of radio astronomy experiments, including the determination of telescope coordinate offsets, measurement of the telescope beam-width, and detection of the Galactic HI line. In this experiment, we aim to characterize the performance and alignment of the 4-m telescope.

The main objectives of this experiment are as follows:

- To execute the standard procedure for initializing the telescope drive system, encoders, and receiver prior to observations.
- To measure the azimuth and altitude offsets by performing scans across a strong radio source (the Sun) and comparing the electronically recorded telescope position with the source's calculated astronomical position.
- To determine the beam width (Full Width at Half Maximum, FWHM) of the telescope by analyzing the intensity profiles obtained from azimuth and elevation scans and fitting them with a Gaussian model.

The primary instrument used in this experiment is the 4-meter Single Dish Radio Telescope (SRT) located at the National Centre for Radio Astrophysics (NCRA). The telescope is designed to carry out a wide range of radio astronomy observations, including the detection of Galactic HI emission.
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2 Theory

Beam Width

If light from a point source passes through a circular aperture, the light rays are diffracted to form an Airy disk [**?**] as shown in the image below:

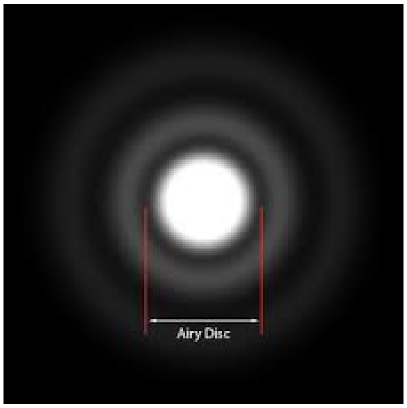

Figure 1: Airy Disk

If the smearing of the image of the point source due to the Airy Disk is larger than that produced by the aberrations of the radio antenna system, the imaging process is said to be diffraction-limited, and that is the best that can be done with that aperture size. The cross section of the Airy Disc reveals the following nature which involves a Bessel Function.

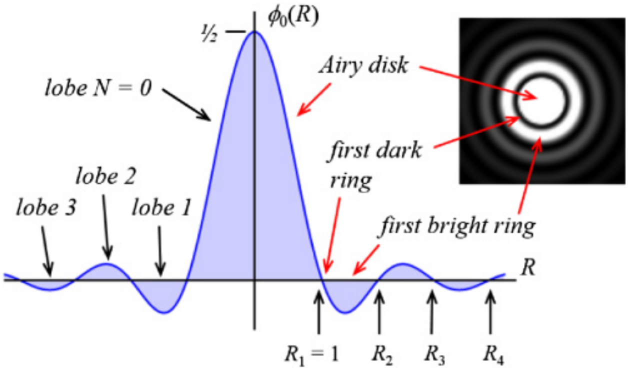

Figure 2: Cross section of the Airy Disk

The reflectivity at the edges of a parabolic radio reflector is often tapered so the *beam* or the diffraction pattern can be modeled as a Gaussian curve, the full width at half maxima is taken as the *beam width*. In this experiment we use the Sun as the source and calculate the Beam Width of the telescope.

Beam Offset

Beam Offset is the difference between the observed altitude and azimuth (local coordinates) of the source and its true local coordinates. The beam offset is essentially a systematic determinate error in the position of any source being observed in the sky.

The maxima power inside the beam when the source is observed (the peak of the Airy Disk modeled by a Gaussian) is taken to be the observed altitude and azimuth of the source. The "true" local coordinates are taken using an ephimeris and the difference between the two sets of coordinate is calculated to get the beam offset.

3 Observations & Calculations

The azimuth scan of the Sun was performed by slewing the telescope across the source while maintaining a fixed elevation. During the scan, the azimuth encoder angle and the corresponding received power in dBm were recorded at uniform angular intervals. The scan covered the Sun symmetrically on both sides of the expected position to capture the full beam profile.

The recorded power values were converted to a linear scale and plotted as a function of azimuth angle. The resulting beam profile was fitted with a Gaussian function. From the Gaussian fit, the azimuth corresponding to the peak power was obtained as the observed beam centerθ_0.

The standard deviation obtained from the fit was $\sigma = 25.26066°$. The beam width was calculated using FWHM$= 2.35\sigma$

The expected azimuth position of the Sun at the time of observation was obtained from ephemeris data. The azimuth beam offset (z) was calculated as

$$z = \theta - \theta_0$$

Table 1: Results from Azimuth Scan

Scan	No. of Data Points	Gaussian Peak at (deg)	FWHM (deg)	Expected Az (deg)	Offset (deg)
AZ	120	25.1586	9.4359	12.3167	12.8420

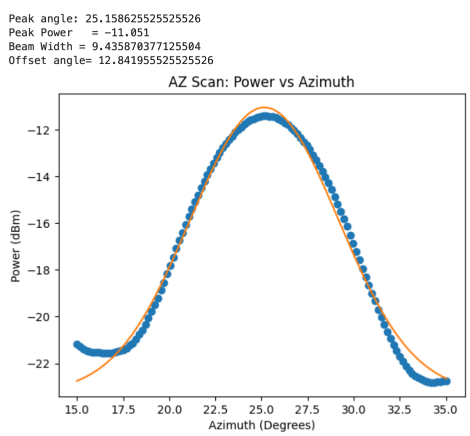

Figure 3: Azimuth scan of the Sun.

3.1 Elevation Scan

The elevation scan was analysed in the same manner as the azimuth scan. The recorded elevation encoder values and received power measurements were fitted with a Gaussian function. The peak of the Gaussian fit yielded the observed elevation position of the Sun, ϕ_0.

The elevation beam offset was calculated using

$$\Delta \mathrm{El} = \phi_0 - \phi_{\mathrm{expected}}$$

where ϕ_{expected} is the ephemeris elevation of the Sun at the time of observation. From the fit values obtained, the elevation beam offset was found to be

$$\Delta \mathrm{El} = 31.98°$$

Table 2: Results from Elevation Scan

Scan	No. of Data Points	Gaussian Peak at (deg)	FWHM (deg)	Expected Alt (deg)	Offset (deg)
ELE	68	47.3301	5.1563	46.5166	0.8135

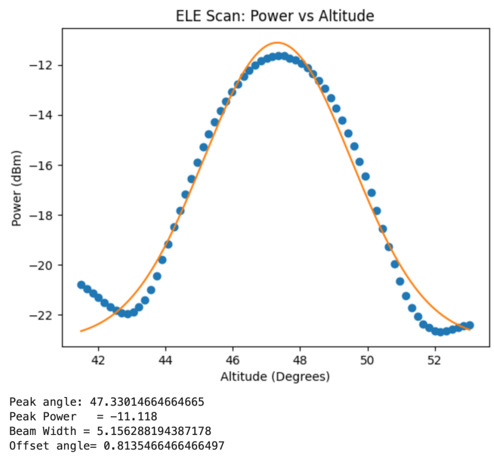

Figure 4: Altitude scan of the Sun.

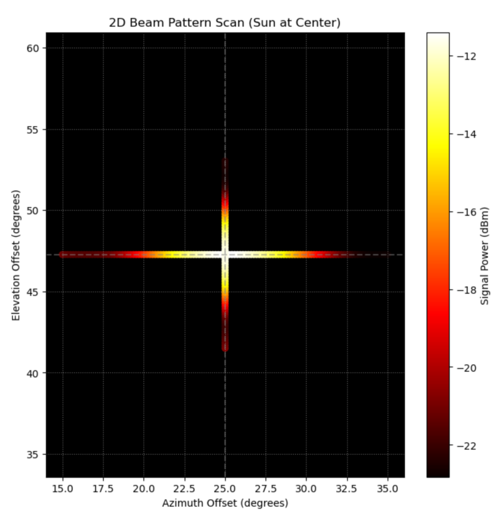

Figure 5: Reconstructed two-dimensional beam pattern of the Sun obtained by combining orthogonal azimuth and elevation scans. The color scale represents the received signal intensity, and the intersection of the scans corresponds to the nominal beam center.

4 Results

1. Azimuth Offset: 12.8420 Deg
2. Altitude Offset: 0.8135 Deg
3. The Beam-Width of the 4-m telescope (FWHM) obtained from the Azimuth scan is: 9.4359 Deg.
4. The Beam-Width of the 4-m telescope (FWHM) obtained from the Altitude scan is: 5.1563 Deg.

5 Interpretation

- This experiment characterizes the pointing accuracy and angular resolution of the 4-m single-dish radio telescope using the Sun as a strong and well-known radio source. By performing orthogonal azimuth and elevation scans and fitting the resulting beam profiles with Gaussian functions, both the beam-width and systematic pointing offsets of the telescope were quantified.

- The measured beam profiles closely follow a Gaussian shape, validating the assumption that the telescope operates in a diffraction-dominated regime, with edge tapering effects smoothing the ideal Airy pattern. The Full Width at Half Maximum (FWHM), derived using
- FWHM $= 2.35\sigma$, provides a direct measure of the telescope's angular resolution. The obtained beam-widths of $9.44°$ in azimuth and $5.16°$ in elevation indicate an asymmetric beam. Such asymmetry may arise due to structural deformation, feed misalignment, or differing illumination efficiencies along the two axes.

- The non-zero beam offsets observed in both azimuth ($12.84°$) and elevation ($0.81°$) reveal systematic pointing errors in the telescope. These offsets can originate from encoder zero-point errors, mechanical misalignment of the dish or feed, or inaccuracies in the telescope's pointing model. Identifying and correcting these offsets is crucial, as uncorrected pointing errors directly impact source localization and flux density measurements in astronomical observations.

- The reconstructed two-dimensional beam pattern confirms consistency between the azimuth and elevation scans and provides a visual validation of the beam center and overall shape. This demonstrates that cross-scans across a strong source serve as an effective and reliable method for telescope characterization.

- The sun moves faster in the azimuthal plane than the elevation. That can be a source of error too.
- Overall, the experiment verifies the operational performance of the 4-m radio telescope and highlights the importance of beam-width estimation and pointing calibration prior to scientific observations such as Galactic HI line studies. Accurate knowledge of the beam properties ensures reliable intensity measurements, improved source localization, and reduced systematic uncertainties in radio astronomical data.

6 Brain Teaser

(i) From the terrace, sky directions were identified using the Sun as a reference. At NCRA (latitude $\sim 19°$N), the Sun lies in the southern sky around local noon, with north opposite to the Sun's direction. The telescope's Alt–Az position can be estimated by the Sun's height above the horizon (altitude) and its compass direction (azimuth).

(ii) At NCRA, the Sun rises in the east, reaches maximum altitude toward the south at noon, and sets in the west. The azimuth changes continuously east to west, while altitude increases until noon and then decreases. At $+50°$ latitude, the Sun reaches a lower maximum altitude and follows a shorter arc. At $-50°$ latitude, the Sun culminates toward the north, with a mirrored daily path.

(iii) The Sun has well-defined RA and Dec and always lies on the ecliptic within a zodiac constellation. Right Ascension increases eastward along the celestial equator, while Declination increases northward. The point RA$=0$, Dec$=0$ is located at the vernal equinox on the celestial equator.

(iv) The angular diameter of the Sun is $\sim 0.5°$. The diffraction-limited resolution is

$$\theta \approx 1.22\frac{\lambda}{D}.$$

For an optical telescope with $D = 10\,\mathrm{cm}$ and $\lambda \approx 500\,\mathrm{nm}$, $\theta \sim 1''$. To achieve the same resolution at $\lambda = 21\,\mathrm{cm}$, a telescope diameter of $\sim 40\,\mathrm{km}$ is required, demonstrating the need for radio interferometry.

7 Acknowledgements

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8 Contributions

Introduction - Saanvi Pande[6]
Theory - Pranjal Sengupta[5]
Observations - Ambika S[1] and Dhairya Kotecha[4]
Data Analysis, Plotting - Saanvi Pande[6] and Pranjal Sengupta[5]
Results - Bhargava Ganesh Bhat[3]
Interpretation - Anaya Atul Dixit[2]

9 References

airy disk, Beam offset, Initialization, Chatgpt