ATA GRASP Simulation Memo 1.0

J. R. Hill-Valler

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Abstract

This memo details the GRASP optical model of the ATA off-axis Gregorian antennas. The parameters for the secondary reflector have been derived from design curves in the original ATA design memo, using an iterative process to match the sub-reflector eccentricity and focal length to the design feed half angle, $\theta_H = 42.0°$, and the sub-reflector diameter, $D_{sub} = 2.4$m. The optics have been designed for a frequency of 11.0 GHz. A hybrid mode conical feed pattern of aperture size 2.6λ and semi-flare angle 12.0° has been used to generate the beam patterns of the ATA optical model. A feed of this aperture size achieves a primary illumination of edge taper -40dB.

1 Optical Model

The design parameters specified by the memo for the ATA antennas are given in Table 1. The feed half angle and the f-number of the optics can be described by the variable ξ given by [1]

$$\xi = 2\frac{f}{D}\tan\frac{\theta_H}{2}. \tag{1}$$

The eccentricity e is related to this variable by

$$e = \frac{\cos\beta \pm \sqrt{\cos^2\beta + 4\xi^2 - 1}}{1 + 2\xi}, \tag{2}$$

where the angle β defines the angle between the primary and secondary axes.

$D(f_p)$	f/D	y_c/D	θ_H	D_{sub}
6.08982526 m	0.4	0.45	42.0°	2.4m

Table 1: Design parameters from ATA Optical Design Memo [1].

Using the design curves in the ATA Offset Gregorian Antenna memo, an estimate of the values for β and e were used as a starting point. When using these values in the GRASP wizard, it possible to fine tune them to match the feed half angle of $\theta_H = 42.0°$. This was found to be $\beta = 33.0°$ to give a value of $e = 0.34369695$.

The distance between the two foci can also be fine tuned iteratively to match the sub-reflector diameter of 2.4m. The absolute value in the GRASP wizard represents the sub-reflector parameter $2c$. The value of $2c = 1.1638198$m gives an x rim radius and y rim radius of 1.2356364m and 1.1643636m respectively. The sum of these half axes gives 2.4m exactly. Figure 1 shows a screen grab of the final GRASP dual reflector wizard. The corresponding design parameters are listed in Table 2. Note that the equivalent focal length of the optical system is f_e is given by [3]

$$f_e = fM_0 \frac{1 + \tan^2(\frac{\alpha}{2})}{1 + M_0^2 \tan^2(\frac{\alpha}{2})}, \tag{3}$$

where M_0 is the magnification due to the secondary mirror, given by $M_0 = \frac{e+1}{e-1}$, and α is the angle that is given by the Mizuguchi condition [3], such that

$$\tan(\frac{\theta_H}{2}) = M_0 \tan(\frac{\alpha}{2}). \tag{4}$$

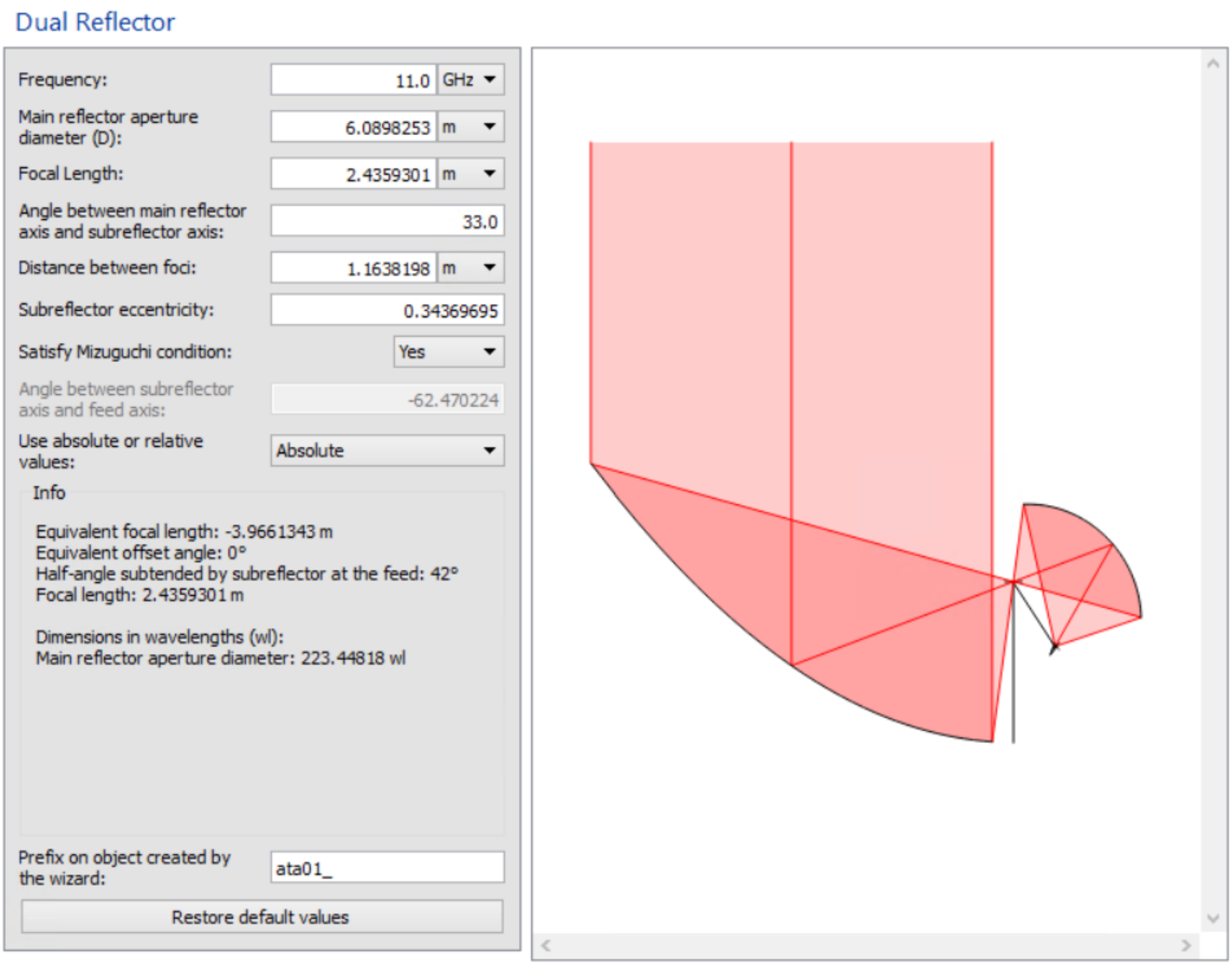

Figure 1: ATA Offset Gregorian GRASP Model

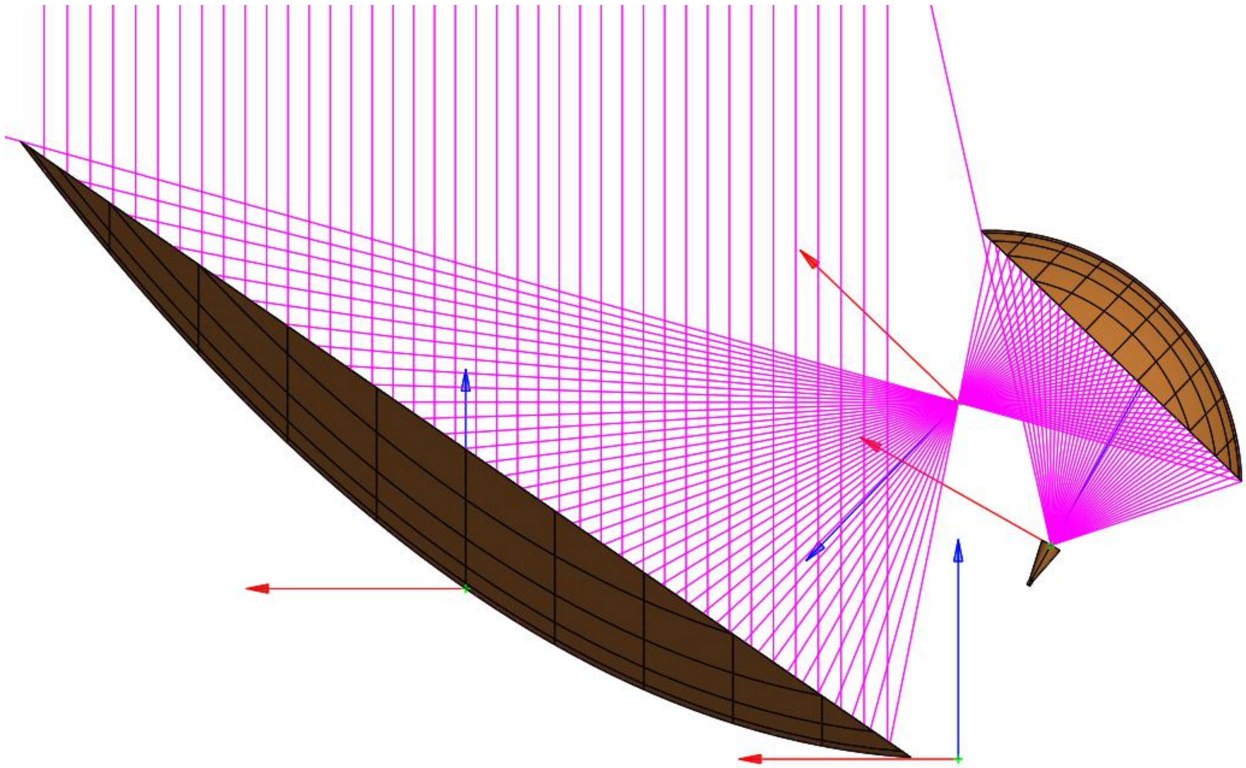

Figure 2: The ray diagram of the optical model of the ATA off-axis Gregorian antenna.

Parameter	Value
f_e	4.49955647 m
f_p	2.4359301 m
$D(f_p)$	6.0898253 m
f_s	1.1638198 m
D_s	2.4 m
$x(f_s)$	1.2356364 m
$y(f_s)$	1.1643636 m
α	21.23831852°
β	33°
e	0.34369695

Table 2: The optical parameters used in the GRASP simulation of the ATA optics.

2 Hybrid Mode Horn

To generate the beam pattern of the optics, a hybrid mode conical horn has been generated in GRASP and placed at the focal position of the antenna. This will give an indication of the illumination pattern that would behave similarly to a corrugated feed horn of a similar aperture size. The input waveguide radius of such a horn can be calculated as [2]

$$a_i = \frac{3\lambda_c}{2\pi} \tag{5}$$

For a frequency of 11.0 GHz, the input waveguide radius is 13.0218 mm. Setting the aperture radius to be 2.6λ, a hybrid mode horn has been built into GRASP and placed at the focal position of the optics. In Table 3, I list the parameters used for the hybrid mode feed in this optical model. The semi-flare angle has been set to an arbitrary 12.0° as this maintains a narrow flare angle however does not under-illuminate the optics.

Parameter	Value
λ	27.2727 mm
a_i	13.0218 mm
a_o	70.9091 mm
l	333.6010 mm
θ_{flare}	12°

Table 3: Parameters used to design a hybrid mode feed in GRASP. Where a_i is the waveguide radius, a_o is the aperture radius (2.6λ), l is the length of the horn and θ_{flare} is the semi-flare angle of the feed horn.

3 Beam Pattern

The overall beam properties of the optical system boast low cross-polarization and low-sidelobes, however some loss of symmetry due to the nature of an off-axis Gregorian.

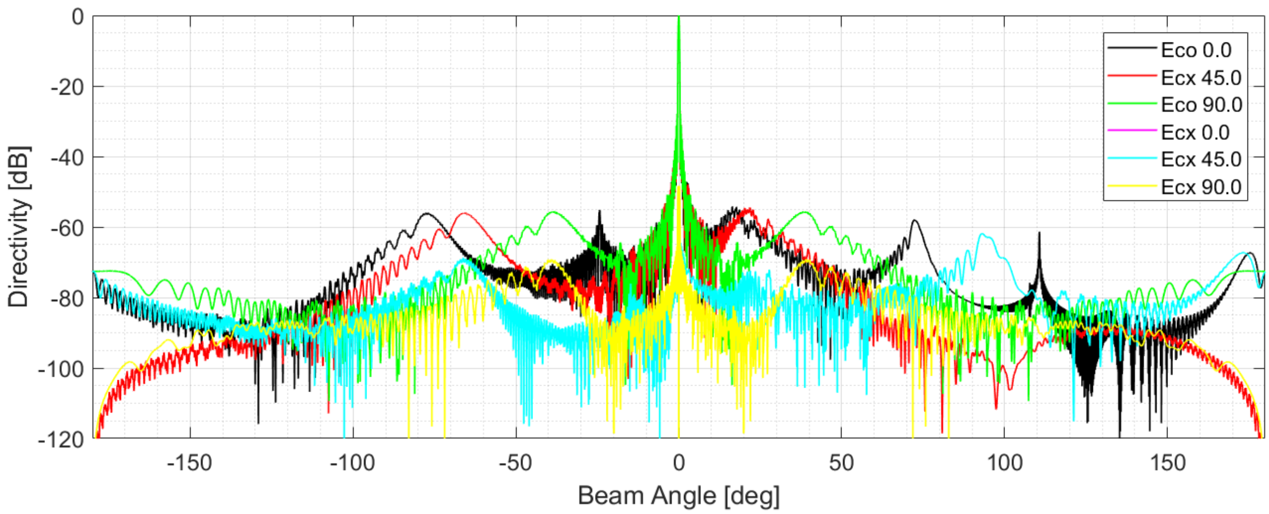

Figure 3: The full beam of the ATA offset Gregorian Antenna at cuts $\phi = 0.0°, 45.0°$ and 90.0°. Offset Gregorian antennas have asymmetric sidelobes due to the lack of symmetry in the optical system. The sidelobes are below -60dB due to the small sub-reflector size relative to the main-reflector.

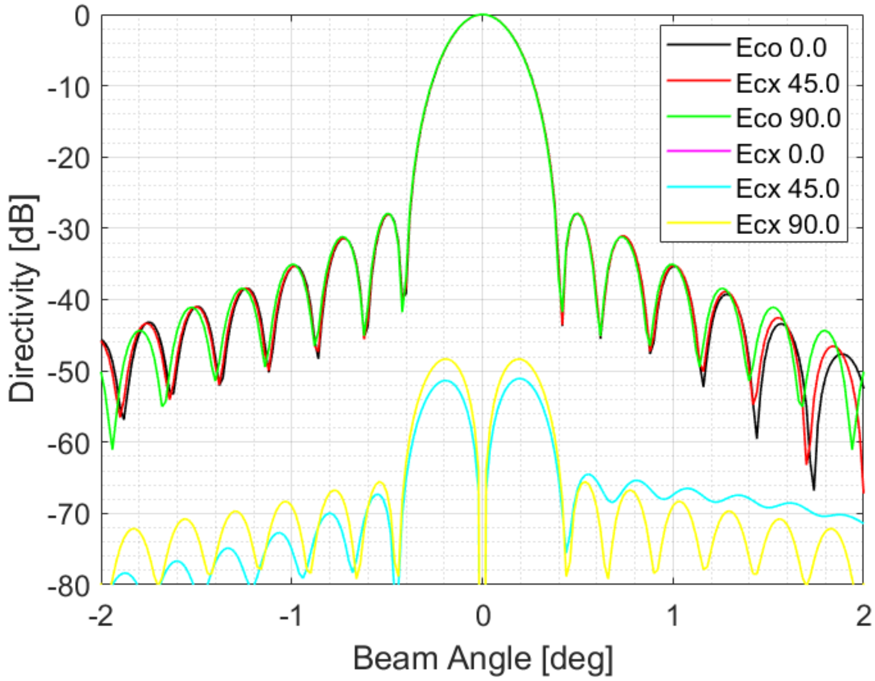

Figure 4: The main beam of the ATA optics with the 2.6λ hybrid mode conical horn. The full width half maximum of this beam is $\sim 0.8°$. The main beam cross-polarization is $\sim$ 48dB when generated with an ideal hybrid mode feed.

4 Edge Taper on Primary

For the 2.6λ aperture feed horn, the edge taper on the primary and secondary mirror will indicate whether the optics has been either over or under illuminated. This should help in establishing the appropriate aperture size of a feed horn to be used in conjunction with the optics. Figures 5 and 6 give the sub-reflector and main-reflector edge tapers respectively. The main-reflector edge taper can be decreased by making the aperture size of the horn smaller. For the 2.6λ horn, the primary edge taper is -40dB. Note the discrepancy in the left-hand and right-hand edge tapers due to the asymmetry of the off-axis Gregorian optics.

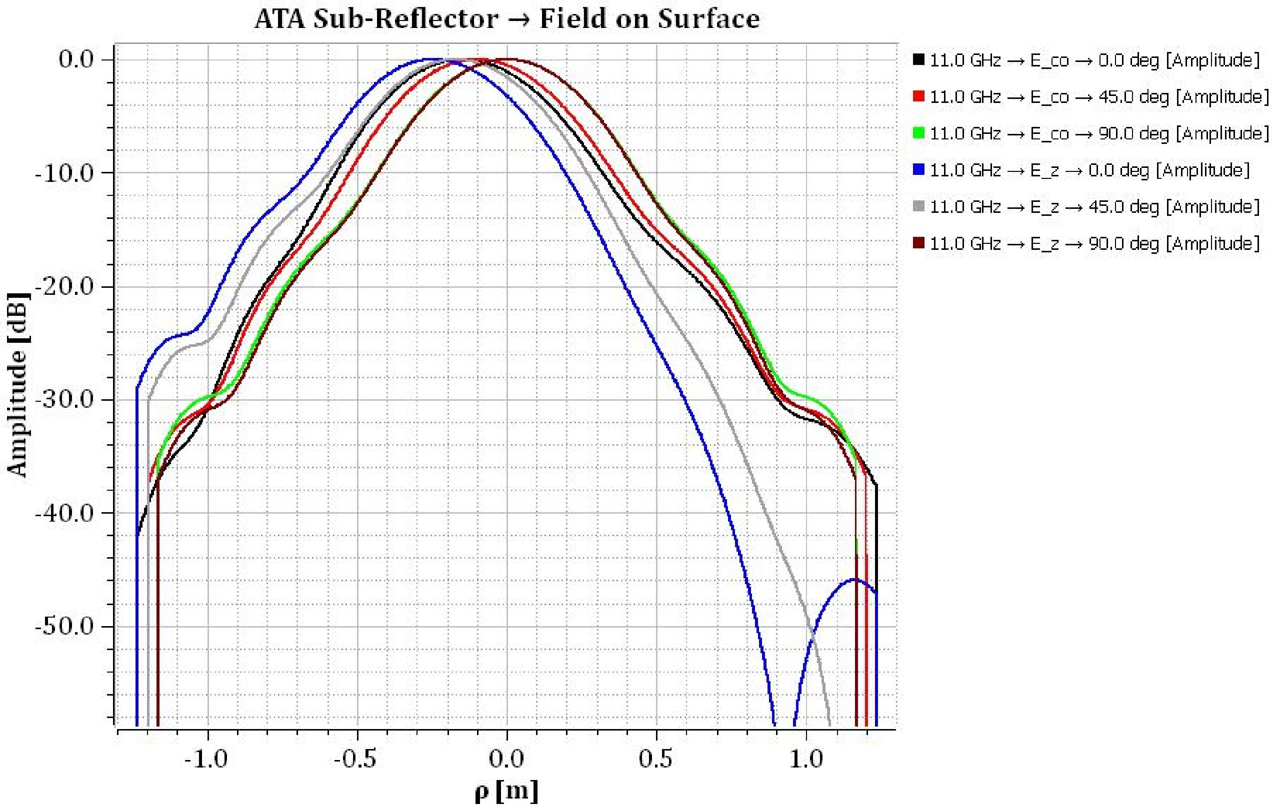

Figure 5: The edge taper produced on the sub-reflector of the ATA antenna using a 2.6λ hybrid mode feed. The edge illumination is ≈ -40dB. The Figure shows both the far-field co-polar (E_{co}) and near-field (E_z) surface cuts.

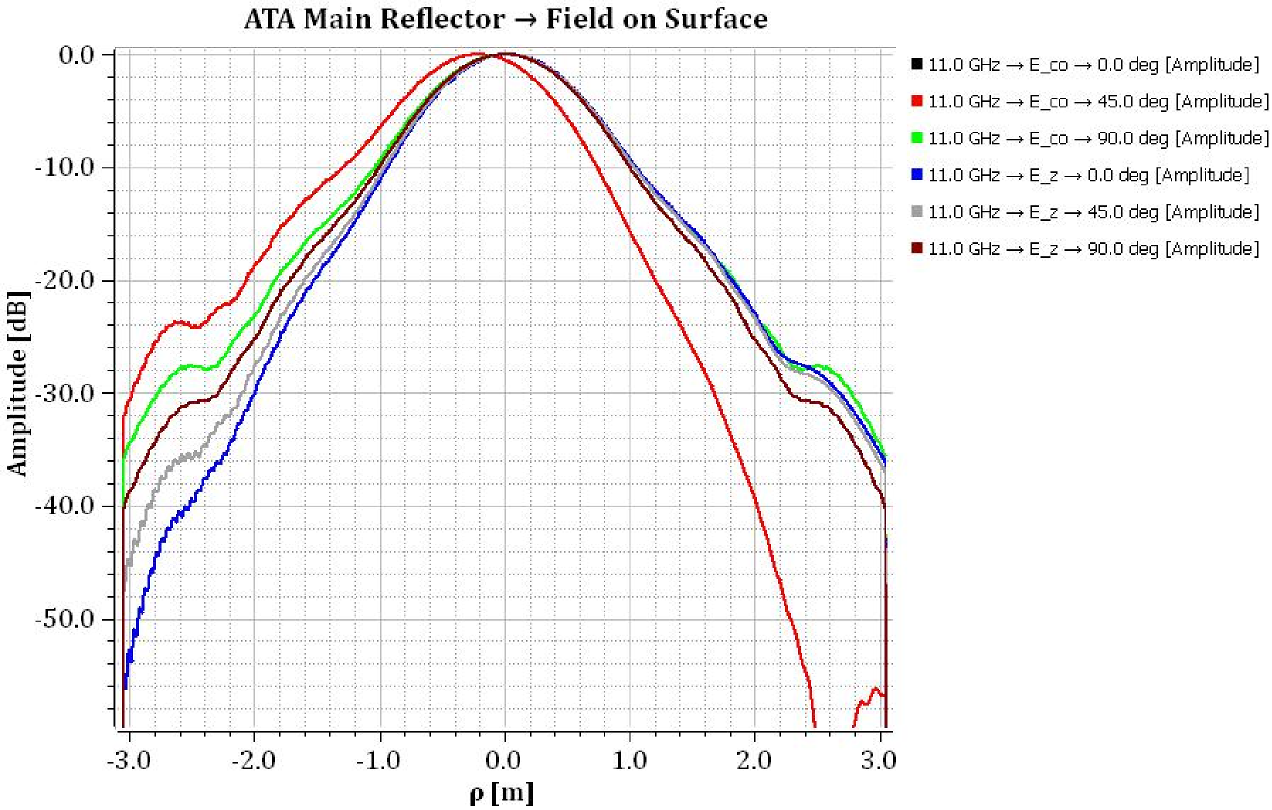

Figure 6: The edge taper produced on the main-reflector of the ATA antenna using a 2.6λ hybrid mode feed. The edge illumination is ≈ -40dB. This can be made to illuminate more of the dish by decreasing the aperture size of the feed horn. The Figure shows both the far-field co-polar (E_{co}) and near-field (E_z) surface cuts.

References

[1] D. DeBoer. The ATA Offset Gregorian Antenna. *ATA Memo 16*, 2001.

[2] C. Granet and J. Graeme, L. Design of Corrugated Horns: A Primer. *Antenna Designer's Notebook*, 2005.

[3] TICRA. *Useful Geometric Equations for Reflector Antennas*, 2015.