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# Shaping the sub-reflector of a ring focus antenna for tailored beamwidth applications

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**Abstract**—This paper introduces a comprehensive investigation on the possibility to tailor the ring focus antenna’s beamwidth by manipulating the shape of the sub-reflector, and more specifically its eccentricity, determining the location of the focal points of the dual reflector system. Eccentricity variation affects the sub-reflector’s reflected field and thus the main reflector’s illumination. The examined antenna configuration includes a main reflector with a diameter of 13.5 m, a sub-reflector with a diameter of 1.35 m, and employs a linearly polarized Gaussian beam as feed. Changing the sub-reflector’s eccentricity from the original value of 0.6 to 0.66 reduces the directivity from 70 dB to 55 dB, widening the beamwidth from 0.05° to 0.45° at 26 GHz. This feature is of great interest for applications needing adjustable beamwidth, such as satellite location acquisition. The beamwidth switching may be implemented using a reconfigurable transmitarray providing two states equivalent to the two sub-reflector shapes.

**Index Terms**—reflector antennas, space communications, ring-focus, ray tracing, tailored beam.

## I. INTRODUCTION

Ground station antennas for satellite communications at Ka-band generally use large reflectors. A typical main reflector has a diameter of approximately 500 to 1000 free-space wavelengths. This large reflector aperture provides high gain, which is required for high speed data transmission, and consequently a very narrow beam. The automatic tracking system implemented in such an antenna permits to follow the satellite trajectory with a very high accuracy (tracking error in the order of few millidegrees). However, because of the narrow beam, the tracking range is also limited. This range is typically sufficient for nominal operations, when the antenna tracks already low orbit satellites in a stable and well defined orbit. In this scenario, the orbital predictions are accurate enough to point the antenna to the target [1]. However, during the acquisition phase at very low elevation angles, the orbital predictions cannot be so accurate due to the high uncertainty about the spacecraft position. In this scenario, tracking accuracy is limited because it is challenging to keep the satellite within the relatively narrow beam of the large reflector antenna. Therefore, in the case where the satellite does not have the capability to operate at a lower frequency

such as S or X band, it is essential to find new solutions to widen the ground station beam for a quick and reliable acquisition. A practical and commonly chosen method consists in defocusing the sub-reflector. This approach is more practical than moving the feed. By displacing the sub-reflector away from the feed, a smaller fraction of the feed power will be intercepted by the sub-reflector. Therefore, an additional loss of gain is expected due to the spillover, which leads to the beam broadening [2], [3]. The shaping of the sub-reflector can potentially introduce path length errors due to surface deformation [4].

The conventional approach to address this issue involves the use of mechanical or electrical actuators to deliberately deform the surface as demonstrated in [5]. The shaping of the sub-reflector causes the phenomenon of phase aberration that leads to a wide beam as shown for a Gregorian dual reflector antenna in [6].

This paper aims to tune the collimating properties of an axially displaced Gregorian configuration, in hereinafter referred as ring-focus antenna, by shaping its sub-reflector. Modifying the eccentricity of the sub-reflector presents a viable method to achieve a wide beam. The beam’s characteristics can then be analyzed to devise an innovative solution, involving the utilization of a reconfigurable transmitarray [7], to replicate, with a specific phase mask enabled by active diodes, the same beam properties achieved through sub-reflector shaping.

The paper is organized as follows. First, Section II provides the fundamental theory regarding the ring focus sub-reflector, highlighting its focal points and geometric configuration. The design of the system is described in Section III and the numerical results are presented in Section IV. Finally, Section V draws conclusions and presents future perspectives.

## II. THEORY

The ring focus concept builds on the Gregorian or Cassegrain dual-reflector antennas. The main reflector is created by rotating a displaced section of a parabola around the antenna’s symmetry axis. Consequently, it exhibits a ring caustic rather than a singular focal point.

The ring focus sub-reflector is derived from the cross-sectional

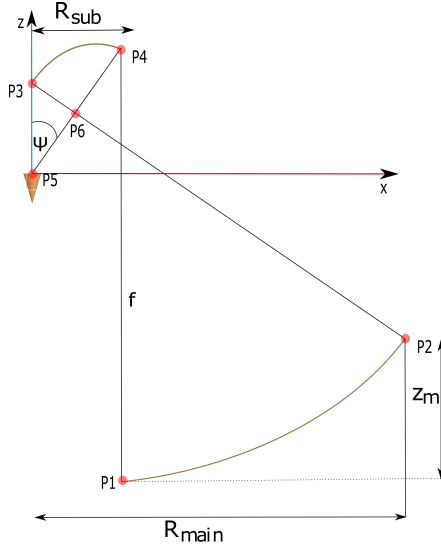


Figure 1. Section of ring focus antenna

shape of either the Gregorian (elliptical sub-reflector) or Cassegrain (hyperbolic sub-reflector) type. In this case, to construct the sub-reflector, a tilted-axis ellipse is utilized. The sub-reflector is oriented such that one of its foci aligns with the antenna's symmetry axis, while the other one coincides with the ring caustic of the parabola. This tilted-axis ellipse is then rotated around the symmetry axis to complete the sub-reflector assembly. Such a configuration presents the benefits of a non-offset systems: the mitigation of the back-scattering to the feed and thus the direct coupling [8]. The cross-section of the ring focus antenna is depicted in Fig. 1. The main reflector end points are denoted as P1 and P2, while those of the sub-reflector are identified as P3 and P4. The sub-reflector is generated by an ellipse with focal points at P5 and P6. P5 represents the location of the feed, and P6 the focal point of the main reflector. The numerical coordinates of these points are depending on the input parameters of the system, like the main reflector diameter  $D_{main}$ , the sub-reflector diameter  $d_{sub}$ , the taper angle of the feed towards the sub-reflector  $\psi$  and the focal length of the system  $f$ . Defining  $z_m = (R_{main} - R_{sub})^2/4f$ , we can precisely formulate the equation required to assess the coordinates of the six points:

$$x1 = R_{sub}, \quad z1 = \frac{R_{sub}}{\tan(\psi/2)} - \frac{2fR_{sub}}{R_{main} - R_{sub}} - f \quad (1)$$

$$x2 = R_{main}, \quad z2 = z1 + z_m \quad (2)$$

$$x3 = 0, \quad z3 = z1 + f + \frac{f - z_m R_{sub}}{R_{main} - R_{sub}} \quad (3)$$

$$x4 = R_{sub}, \quad z4 = \frac{R_{sub}}{\tan(\psi)} \quad (4)$$

$$x5 = 0, \quad z5 = 0 \quad (5)$$

$$x6 = R_{sub}, \quad z6 = z1 + f \quad (6)$$

The principal points responsible for modifying the eccentricity of the sub-reflector are the points between P3 and P4. This will

Table I  
INPUT SYSTEM PARAMETERS

Parameter	Dimension
$D_{main}$	13.5 m
$d_{sub}$	1.35 m
$f$	4,05 m
$e$	0.60
$t_{angle}$	40°
Edge-illumination taper	-12 dB

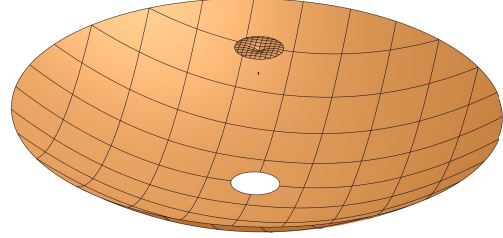


Figure 2. Geometry in GRASP of a ring focus antenna

lead to a shift of the point P6. In our scenario, it is important to note that P5 should remain unchanged, as the feed will retain its current position. Considering an ellipse forming the ring focus sub-reflector, the eccentricity  $e$  for a single profile of the ellipse, is expressed as:

$$e = \frac{\text{focidistance}}{\text{vertexdistance}}, \quad 0 < e < 1 \quad (7)$$

The foci distance is the separation between P6 and P5, the two foci of the single profile of the ellipse. The vertex distance corresponds to the geometrical distance between P3 and P4.

### III. DESIGN

The initial configuration under consideration in this study is a ring focus dual-reflector antenna, designed in GRASP [9]. The system is depicted in Fig. 2 and its parameters are presented in Table I: the main reflector has a diameter of 13.5 m and consists in a parabolic dish formed by rotating a parabolic curve along a 360° axis, featuring a hole to account for the blockage from the sub-reflector that has a diameter of 1.35 m. The feed, operating at 26 GHz, features a linearly polarized Gaussian beam. It is implemented in GRASP using a point source emitting a tapered beam, which results in a Gaussian beam pattern with a taper angle of 40° and a taper edge-illumination taper of -12 dB, defined as input parameters. The sub-reflector is constructed from two profiles of displaced ellipses with tilted axes. As depicted in Fig. 3, the single profile of ellipse, has two focal points. The coordinate systems has its origin between the feed and the sub-reflector. This arrangement enables us to observe the displacement of point P6 from the x-axis as we vary the eccentricity of the sub-reflector. Modifying the eccentricity will naturally induce alterations in the ray tracing, both in terms of reception and transmission perspectives, as we will elaborate in the next section.

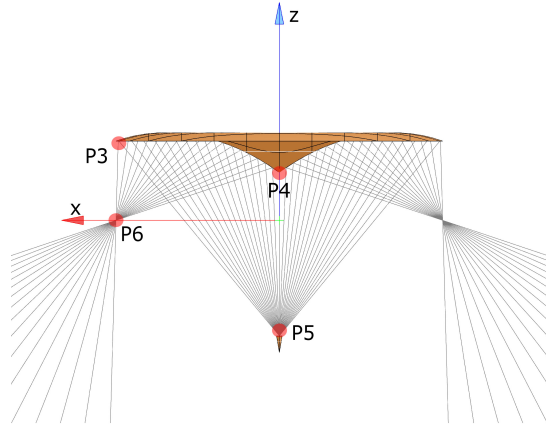


Figure 3. Zoom on the feed and on the foci of the sub-reflector in GRASP

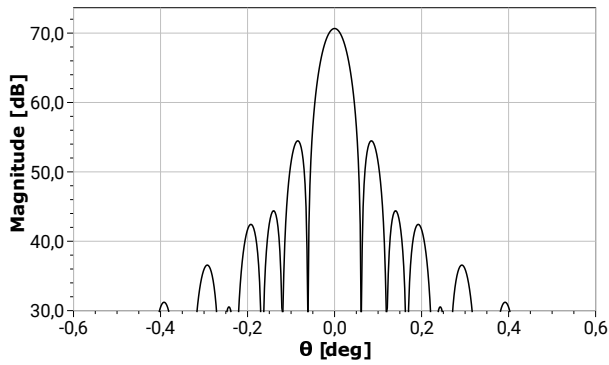


Figure 4. Far field co-polarization component of the ring focus antenna at 26 GHz - Original configuration,  $e=0.6$

#### IV. VALIDATION OF THE CONCEPT

Starting our analysis with the original configuration presented in Table I, the ring focus achieves a peak directivity of 70.6 dB at the frequency of 26 GHz, as depicted in Fig. 4. This corresponds to an aperture efficiency of 86% and a  $0.05^\circ$  half-power beamwidth. The coordinates of the original configuration, in mm, taking into account the points in Fig. 3 and its coordinates systems, are:

$$\begin{aligned} x_3 &= 0 & z_3 &= 0.19 \\ x_4 &= 0.675 & z_4 &= 0.33 \\ x_5 &= 0 & z_5 &= -0.48 \\ x_6 &= 0.675 & z_6 &= 0 \end{aligned}$$

These specific points result in an eccentricity of 0.6.

By modifying the points between the two extremities of the sub-reflector, thus the points between P3 and P4 considering the single profile of the ellipse, its concavity and eccentricity will change. As a consequence, the far-field pattern will be modified.

Fig. 5 illustrates the radiation pattern for a configuration with a reduced eccentricity of 0.57. This change leads to increased sidelobe levels, a decrease in directivity to 55.5 dB, and a

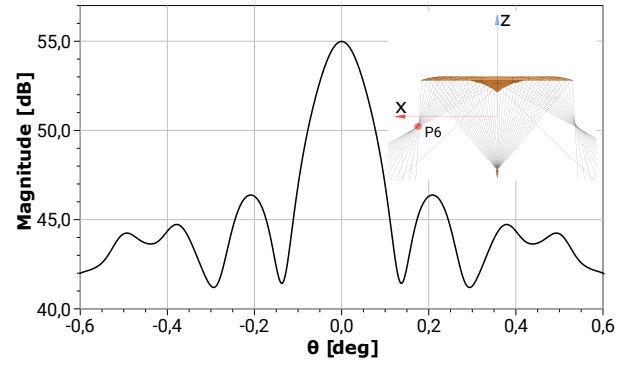


Figure 5. Far field co-polarization component of the ring focus antenna at 26 GHz -  $e=0.57$

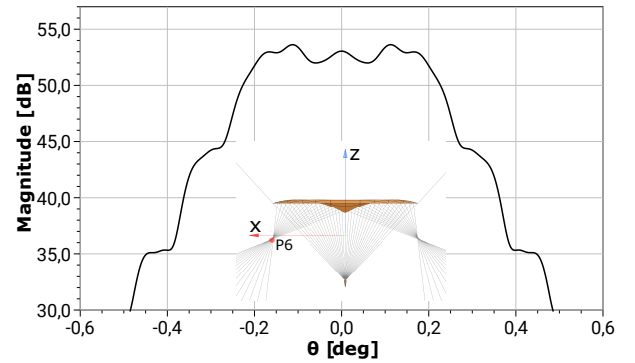


Figure 6. Far field co-polarization component of the ring focus antenna at 26 GHz -  $e=0.66$

widening of the beamwidth to  $0.2^\circ$ . Upon examination of the reference point, P6, one can notice that it has shifted downwards relative to the origin of the coordinate system. This results in P6 being at  $z_6 = -0.05$  mm.

The exercise above demonstrates that modifying the beam shape by adjusting the eccentricity is feasible. Next, we illustrate that it is possible to broaden the beam by nearly a factor of 10 compared to the original beam by adopting an eccentricity of 0.66.

Fig. 6 clearly shows that the beam has significantly widened. This broadening comes with a reduction in directivity of about 23 dB compared to the original configuration, but also yields a larger beamwidth. Indeed, we go from  $0.05^\circ$  in the original configuration to  $0.45^\circ$  in the configuration with a sub-reflector with an eccentricity of 0.66. Once again, the change in the focal points positions is noticeable and the z-shift value now is  $z_6 = -0.02$  mm.

Reducing the directivity is essential to expand the scanning range for potential satellite acquisition. Figure 7 provides a comparison of the beams corresponding to the three different eccentricities. The characteristics of the beams are given in Table II. An analysis of the ray tracing in transmission mode also provides valuable insights. By comparing the rays impinging on the main reflector from the original configuration with a sub-reflector with  $e = 0.66$  and the modified configuration

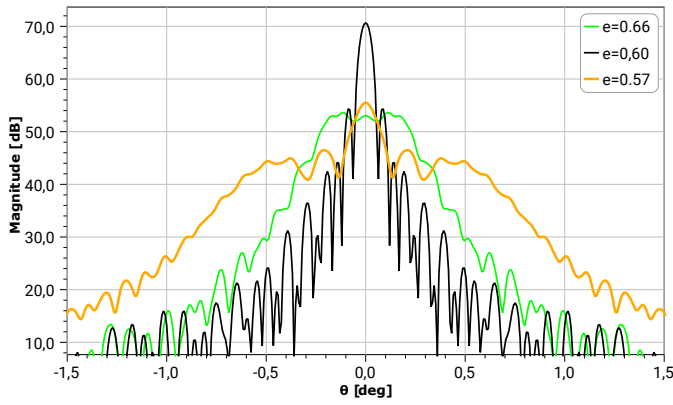


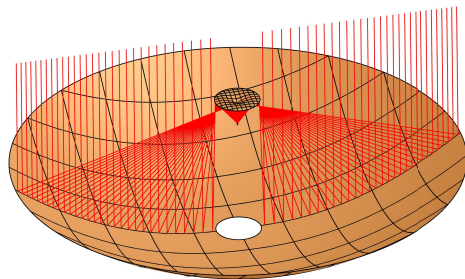
Figure 7. A comparative illustration of the far field beam patterns

Table II  
PATTERN DIFFERENCES BY SHAPING THE SUB-REFLECTOR

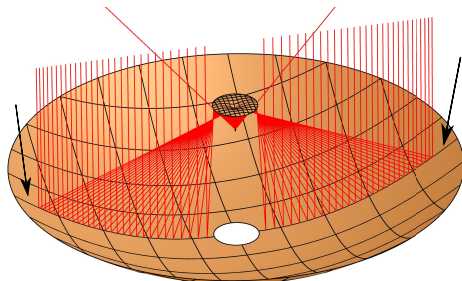
Eccentricity	Directivity[dB]	Beamwidth[°]
0.57	55.5	0.2
0.60	70.6	0.05
0.66	53.6	0.45

$e = 0.60$ , the one that enlarge more the beamwidth, we can observe variations in the illumination of the main reflector. Fig. 8 displays the illuminated areas on the main reflector for the two configurations.

The circular area illuminated by the original sub-reflector on the main reflector has a diameter of 13.24 m, out of the total main reflector diameter of 13.5 m. However, with the change of eccentricity, the illuminated area on the main reflector reduces

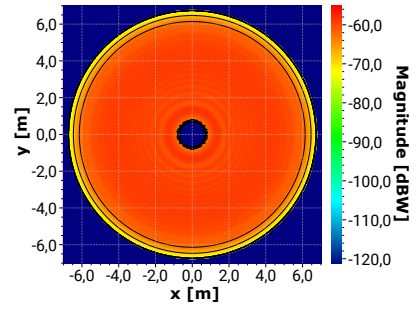


(a) Original configuration,  $e=0.6$

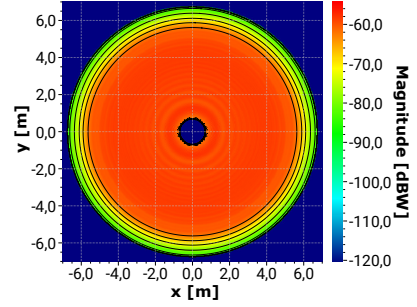


(b) Shaped sub-reflector,  $e=0.66$

Figure 8. Ray tracing difference



(a) Currents - Eccentricity: 0.6



(b) Currents - Eccentricity: 0.66

Figure 9. Current on the main reflector

to a diameter of 11.4m. This signifies a loss of approximately 2 meters in the diameter of the illuminated area.

Fig. 9(a) and (b) show the current distribution on the main reflector for  $e = 0.6$  and  $e = 0.66$ , respectively. In the original configuration, a substantial current level persists at the edge of the main reflector. However for the modified configuration with  $e = 0.66$  the current level diminishes at the edge, following the rays tracing illustration in Fig. 8.

## V. CONCLUSION

A ring focus antenna with a sub-reflector characterized by three different sub-reflector's eccentricity values has been studied. By employing an eccentricity of 0.66, a significantly broader beam was attained, almost increasing the beamwidth of the original configuration by a factor 10. This beam broadening resulted in a reduction of directivity by about 25 dB.

The change in eccentricity, while widening the beam, also led to under-illumination of the main reflector. Nevertheless, this trade-off was necessary to achieve a broader beam. It is worth noting that the sub-reflector's shape serves as a key element for tailoring the beamwidth. The implementation of this configuration can be realized through a range of technologies, including mechanically actuated sub-reflectors, as well as reconfigurable transmit/reflectarray sub-reflector emulating the change of eccentricity with a specific phase mask.

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