Experimental validation of a compact 3D-printed subreflector subsystem for Cassegrain antenna in X-band

Alejandro Rebollo, Álvaro F. Vaquero, Manuel Arrebola, Marcos R. Pino
Universidad de Oviedo, Department of Electrical Engineering, Group of Signal Theory and Communications (TSC-UNIOVI)
Gijon, Spain, {UO250424, fernandezvalvaro, arrebola, mpino}@uniovi.es

***Abstract*— In this work, a dual-reflector antenna based on a Cassegrain optics with a compact self-supported subreflector is presented to operate at X-band. The feeding subsystem is composed of a subreflector surface, the primary feed and a supporting structure in a single dielectric piece, providing a smart solution. The antenna is fed by a metallic rectangular waveguide with a H-plane transition to a Dielectric Rectangular Waveguide (DRW) finished on a hyperboloid. The designing process presented is based on optical geometrics and it is validated through the manufacture of the Cassegrain antenna. The prototype is fabricated using a 3-D printed technique and the subreflector and main parabolic reflector are metalized by a coating technique. The antenna is simulated and measured obtaining a high agreement on both. The prototype shows good performances in the whole band, validating both the designing technique and the proposed subreflector.**

Index Terms— *Dual-reflector antenna, 3-D printed Cassegrain, X-band reflectors.*

I. Introduction

High gain antennas are extensively used in applications such as satellite communications [1], DBS missions [2] or radars [3]. A common approach is a reflector antenna due to its geometry enables to collimate the field provided by a conventional antenna in a certain direction wherein a plain wave is obtained. Reflectors are a high-gain, high-efficiency, and low cross-polarization solution. However, one of its major disadvantages regards on the feed location. When dealing with centered configurations, the feed is placed on the middle of the antenna aperture, therefore a decrease of the efficiency is obtained due to the feed blockage. Offset configurations reduce this issue, nonetheless a bulkier antenna is obtained since an auxiliar structure is needed.

On the other hand, dual-reflector antennas are used when the sidelobe level and the noise figures are thigh requirements. In this case, the blockage is not due to the feed but the reflector and its structure. An approach to minimize these effects is the use of self-supported subreflectors such as hat-feeds [4]-[6]. This solution has demonstrated good performances improved by the use of corrugations. However, these corrugations lead to a very complex manufacturing process. Recent approaches take advantage from 3-D printing techniques to reduce the cost of the manufacturing process and produce complex pieces easier than other milling techniques. In the literature few works have applied 3-D printing techniques to reflector antennas [7]-[8], but only concerning to the reflector and using conventional antennas as primary feeds. The 3-D printed reflectors are later metallized with different techniques as vacuum metallization, electroplating or conductive coating.

In this work, a dual-reflector antenna with a novel self-supported subreflector is proposed to operate at X-band. The primary feed is composed of a dielectric waveguide, a subreflector surface and a supporting structure integrating both in a single dielectric piece. The proposed antenna is designed through a novel designing technique based on optical geometrics for Cassegrain configurations. This process is validated with full-wave simulations and a prototype manufactured with a 3-D printing technique. The reflector surfaces are coated with a conductive spray. The antenna is measured in a compact antenna range, showing a very good agreement with simulations. The measurements exhibit very good performances at the whole band. This solution provides a very compact, light, and inexpensive antenna designed through a simple method.

II. Description of the Antenna

A. Cassegrain Antenna

Dual-reflector antennas are composed of a primary feed, a parabolic main reflector, and a secondary subreflector. One type of dual-reflector is the Cassegrain antenna, where the subreflector is a hyperboloid. Since in a centered-optics configuration the reflective surfaces have axial symmetry, both the main reflector and the subreflector are represented in the design process as a parabola and a hyperbola, respectively, as shown in Fig. 1. This shows the side view of the structure.

Parabola is a conic section composed of one focus, whereas the hyperbola has two foci, and the proper performance of a Cassegrain antenna is based on the correct location of them. Specifically, the phase center of the feed is placed on one of the foci of the hyperbola (F_1 in Fig. 1), whereas the other focus (F_2) and the focus of the parabola (F in Fig. 1) are coincident. Due to geometric properties, the main reflector is illuminated by the radiation of the feed in form of a spherical wave front as if its origin were F, achieving an equal-phase front at the aperture of the antenna in an ideal case. This leads to

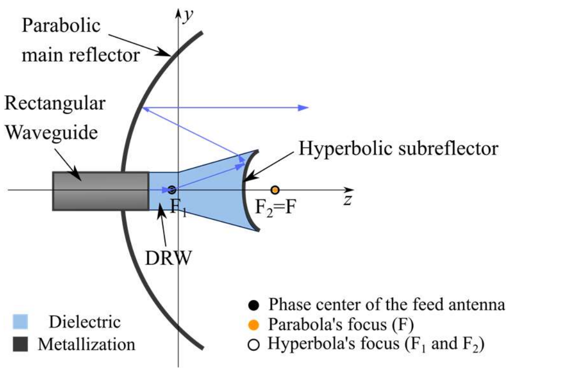


Fig. 1. Cassegrain antenna using the proposed self-supported subreflector, showing its side view. Also, it is represented the path though the structure of one example ray (in blue).

accomplish high directivity values [9], although the subreflector needs a structure to sustain it which blockages some of the radiation from the main reflector.

B. *A one-piece self-supported subreflector and feeding system.*

A single-piece self-supported subreflector is proposed to replace the feed and the subreflector of a conventional Cassegrain antenna. The feeding system is made up of a metallic standard waveguide connected to a Dielectric Rectangular Waveguide (DRW). The transition between both waveguides is made by a H-plane linear taper to minimize the reflection losses and to ensure that only the fundamental mode is propagated through the DRW. As Fig. 1 depicts, a dielectric cone with a hyperbolic base is joined at the end of the DRW in order to obtain the subreflector. The hyperbolic base is metallized and the incoming rays are reflected to the main reflector, acting as a Cassegrain subreflector. This solution provides a single only-dielectric piece that includes the feeding and subreflector, and can be easily integrated with a conventional standard waveguide, a rectangular one in this case.

The feeding system depicted in Fig. 2 is defined by the next hyperbola equations

$$\frac{(z-z_0)^2}{a^2} - \frac{(y-y_0)^2}{b^2} = 1 \tag{1}$$

$$c^2 = a^2 + b^2 \tag{2}$$

where a and b are the transverse and conjugate semi-axes and $2c$ is the focal length of the hyperbola.

Then, r_s is the radius of the subreflector which is placed along the hyperbola and sets the maximum value of z (L_2). The cone length is $L_1 + L_2$, and it is defined by the diagonal of the section of the DRW (h) and the end of the hyperbola. L_1 is the depth that the cone is embedded into the DRW and it is computed as:

$$L_1 = L_2 \frac{h/2}{r_s - h/2} \tag{3}$$

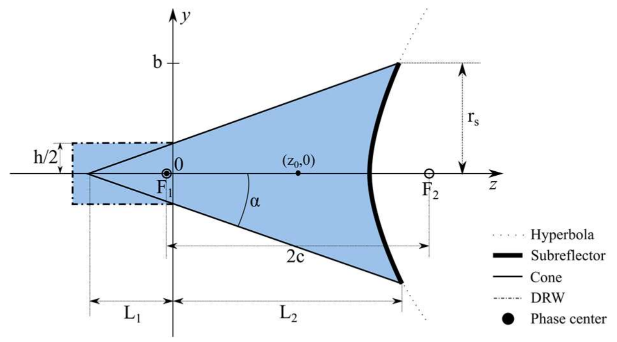


Fig. 2. Side view of the self-supported subreflector and feeding system, showing its geometric characterization.

The angle α is the angle of the generatrix and the axis of the cone, defining the opening of the DRW respects to the z-axis. Note that, α is especially important to design the cone since the reflected rays on the hyperboloid propagates through two media, dielectric and air, therefore α has a deep impact on the reflection/transmission of the rays.

III. Experimental Validation

A. *Antenna optics*

The proposed technique is validated through a design at 10 GHz. A waveguide WR-90 is connected to the DRW to feed the antenna using a linear H-plane taper that minimize the reflection losses. The DRW has a rectangular section of 12×24 mm^2 and a total length of 39 mm. The dielectric cone is designed to minimize the refraction on the dielectric-air interface; therefore, the surface of the cone may be as perpendicular as possible to the rays. Table I outlines the proposed antenna dimensions according to Fig. 3. The diameter of the main reflector is set to 300 mm or $10\lambda_0$, and the focal length of the paraboloid is such that $\mathrm{F} = \mathrm{F}_2$ and equal to 115.5 mm.

Fig. 3. Manufactured dual-reflector antenna using the novel subreflector in the measurement setup.

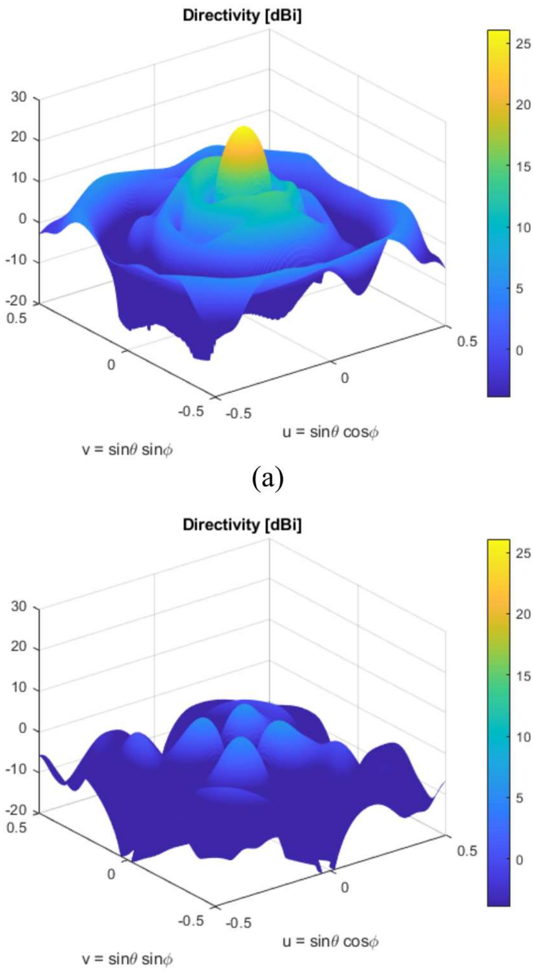
TABLE I. DIMENSION OF THE PROPOSED SUBREFLECTOR GEOMETRY

b (mm)	c (mm)	r_s (mm)	L_1 (mm)	L_2 (mm)	α (°)
30.0	36.0	45.0	29.3	68.9	24.6

B. Manufacturing process

The proposed geometry is manufactured using Fused Deposition Modeling (FDM), a 3-D printing technique based on the melting of a thermoplastic polymer, and its deposition layer by layer through a mobile nozzle tip. The dielectric used is a polylactic acid called PLA with a dielectric constant $\epsilon_r = 2.85$ and $\tan\delta = 0.015$ at 60 GHz [10]. The antenna is printed in an Ultimaker 3, where the feeding subsystem is manufactured in a single PLA piece, whereas the main reflector is divided into 6 pieces due to the printing area is shorter than the reflector diameter.

After the printing process, the reflector surfaces, both reflector parabolic and subreflector hyperbolic, are metallized applying a coating of a conductive metal spray.



(a)

(b)

Fig. 4. 3-D representation of the measured radiation pattern at 10 GHz at (a) Co-polar component and (b) Cross-polar component.

C. Measurements

The prototype is evaluated in a compact spherical range at the University of Oviedo. The measurements are carried out with a vector network analyzer R&S©ZVK of Rohde&Schwarz, where the probe, a standard gain horn antenna of 20 dBi gain, is connected to one port and the antenna under test (AUT) to a second port. The distance between the probe and the AUT is 5.5 meters, and the far-field region starts at 6.0 meters. Therefore, a near-field acquisition is carried out. Then, the radiation pattern is obtained using the spherical wave expansion and near- to far-field (NF-FF) transformation software from TICRA [11]. The prototype is evaluated in the whole X-band, from 8 to 12 GHz.

The radiation pattern at the design frequency, 10 GHz, shows a maximum directivity on the pointing direction of 26.1 dBi, as shown in Fig. 4, and a CP/XP of 20 dB, considering that the maximum value of the XP is in the plane $\phi = 45°$. The SLL is close to 12 dB lower than the maximum and the measured gain is 24 dBi with an efficiency of 61.60%. The measured E- and H-plane ($\phi = 90°$ and $\phi = 0°$, respectively) of the CP and the plane $\phi = 45°$ of the XP are compared with simulations in Fig. 5. An excellent agreement between both is obtained, validating the proposed designing technique and showing really good performances of the proposed self-supporting subreflector.

The in-band response of the antenna is shown in Fig. 6. The variation of the directivity in the whole band is less than 1.5 dB. This variation is due to the electrical size of the reflector changes with frequency, nonetheless the prototype operates in a fractional bandwidth larger than 40%. The in-band response of the antenna is limited by the bandwidth of the WR-90 waveguide used to feed the antenna.

IV. CONCLUSIONS

An alternative to conventional Cassegrain antennas based on a novel only-dielectric self-supported subreflector is proposed as a low-cost and easy-manufactured solution. The structure is based on a dielectric waveguide attached to a cone ended in a hyperbolic shape, both fully made of dielectric,

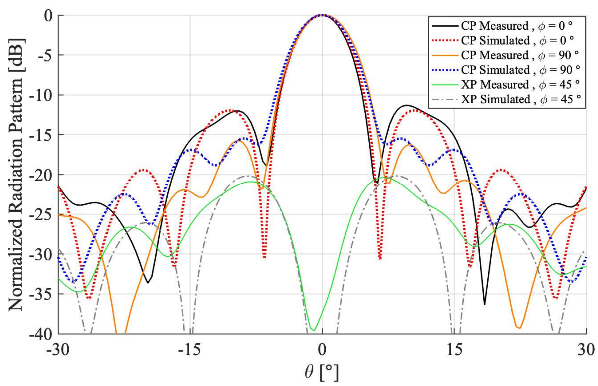


Fig. 5. Representation of the main planes of the measured and simulated radiation patterns, where $\boldsymbol{\phi} = \mathbf{0°}$ (H-Plane) and $\boldsymbol{\phi} = \mathbf{90°}$ (E-Plane).

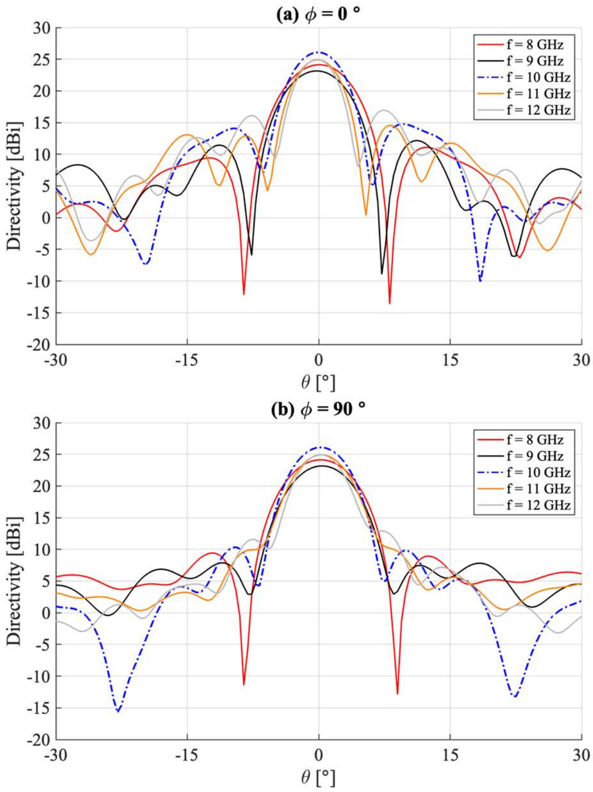


Fig. 6. Variation of measured directivity (co-polar component) trough the X-band in the main planes. a) $\boldsymbol{\phi} = \mathbf{0}°$ (H-Plane) and (b) $\boldsymbol{\phi} = \mathbf{90}°$ (E-Plane).

offering a very compact and light solution. The subreflector is evaluated in a Cassegrain configuration which is manufactured with a 3-D printing technique using PLA as dielectric material at 10 GHz. The main reflector and the subreflector surfaces are metallized using a coating solution applying a conductive spray. The manufactured prototype is measured in a compact spherical range and the agreement between simulations and measurements is quite good. The antenna gain is 24 dBi, the CP/XP ratio is 20 dB and low-level sidelobes. These features are kept through the whole X-band, obtaining a fractional bandwidth larger than a 40%. These results demonstrate the good performances of the proposed subreflector, providing an attractive solution to self-supported Cassegrain reflectors.

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