Compact, Lightweight and Low-Cost Reflectarray Antenna for SmallSats

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***Abstract*—This paper describes the design of a reflectarray antenna to be mounted on a small satellite that is part of a mega-constellation. The generalized intersection approach is employed in two stages to design an antenna to provide a constant flux power over a given area of the Earth surface. The performance of the antenna is assessed in a 2 GHz frequency range, corresponding to a commercial bandwidth. A good trade-off is obtained between the reflectarray performance and the compact, lightweight and low-cost characteristics of the antenna.**

Keywords—SmallSat; reflectarray antenna; phase only synthesis; mega-constellation satellites;

I. Introduction.

One of the main drivers of technological development in telecommunications is the space sector, where there are numerous applications such as satellite mega-constellation comprised hundreds or thousands of small satellites (SmallSat) working together to provide global coverage. In this application, parabolic reflectors and phased array antennas are commonly used as communication antennas. However, reflectarrays [1] are an interesting candidate for these applications because compared to the previous ones, they are compact, low losses, have greater integrability with the satellite and allow beam forming although have a lower bandwidth [2]. This type of antenna has already been used in real space missions such as NASA's MarCO mission [3].

In this paper, we propose a compact, lightweight and low-cost reflectarray antenna for using on a mega-constellation. The designed antenna radiates a shaped-beam isoflux pattern that illuminates a certain area of the Earth surface. The design is based on the use of the generalized Intersection Approach (gIA) in two stages: first, applying this algorithm for a Phase Only Synthesis (POS) at center frequency and then using it for a bandwidth optimization starting from the previous design. Good results are obtained taking into account the characteristics of the antenna.

II. Reflectarray Design

A. Requirements.

The isoflux radiation pattern is defined by the angular margin, the allowed ripple in the illuminated area and the side lobe level (SLL). The antenna will be mounted on a satellite in

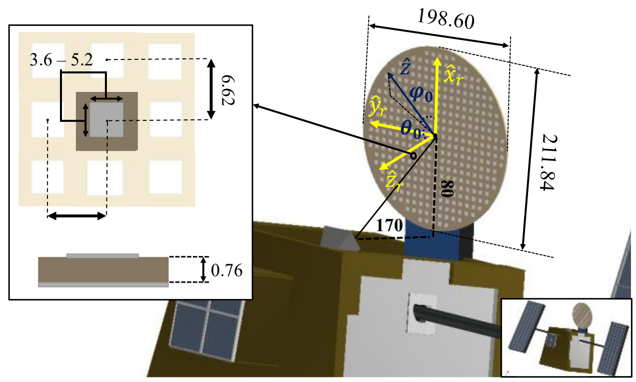

Fig. 1. Sketch of the reflectarray mounted on a SmallSat, with the geometry and cell characteristics. Consider $\hat{x}_r, \hat{y}_r, \hat{z}_r$ as the axis of the reflector and $\hat{z}$ the pointing direction. All dimensions in mm.

LEO orbit at 1200 km from the Earth surface, considering a circular coverage of 400 km radius, which translates to an angular margin of 36.5º. The ripple and SLL values as set to 2 dB and 15 dB respectively. A working frequency of 17 GHz is chosen with a bandwidth of 2 GHz (16-18 GHz).

B. Reflectarray Geometry.

Fig. 1 shows a sketch of the proposed reflectarray structure, integrated on a SmallSat example. The reflectarray panel is comprised of 668-unit cells, distributed in an elliptical grid of 30 x 28 elements, with a periodicity of 6.62 mm in both dimensions, which at the working frequency is $3\lambda_0/8$. Narda 639 horn, with a gain of 17.5 dB, is used as a feed, and its placed at coordinates (-80, 0, 170) mm, which corresponds to a value $F/D = 1$. The pointing direction (see Fig. 1) is defined by $(\theta, \varphi) = (22,0)°$. At the edges of the reflector a space of 6.62 mm is considered as dielectric frame to screw the reflectarray to the supporting structure.

The reflectarray element is a single rectangular patch backed by a ground plane. The substrate is the Rogers 3003 ($\epsilon_r = 3, \tan\delta = 0.001$) with a thickness of 0.762 mm. This cell topology provides a phase-shift of only 260º.

C. Shaped-beam Synthesis Procedure.

The reflectarray design is done in two stages, both using the (gIA) [4] an iterative algorithm that performs two operations in each iteration on the field radiated by the antenna.

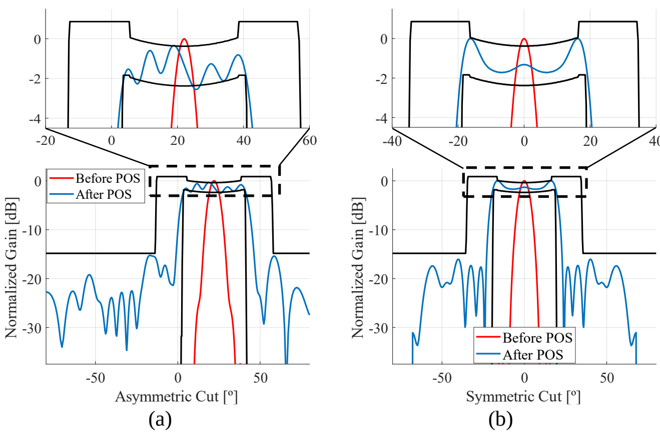

Fig. 2. Normalized diagram patter before and after POS synthesis in polarization X: (a) Asymmetric Cut; (b) Symmetric Cut.

$$\vec{E}_{i+1} = \mathcal{B}[\mathcal{F}(\vec{E}_i)] \quad (1)$$

In each iteration i, the forward projector $\mathcal{F}$ projects the radiated field by the antenna onto the set of fields which comply with the specifications, imposed by masks of minima and maxima in far field. Then, the backward projector $\mathcal{B}$ projects the field which complies with the specifications onto the set of fields which can be radiated by the antenna. The goal is to find a field which belongs to both sets, or if that is not possible, to find a field whose distance to the set of fields was minimum.

First, the algorithm is applied for a POS, where the phase of the reflexion coefficients are considered as an optimization variable and assuming the patches as an ideal phase shifter, that is

$$\rho_{xx} = \exp(j\phi_{xx}) \; ; \rho_{yy} = \exp(j\phi_{yy}) \quad (2)$$

Where ρ_{xx}, ρ_{yy} are the reflexion coefficients of X and Y polarizations, and ϕ_{xx}, ϕ_{yy} the phases of those coefficients. The phases are optimized independently for each polarization, taking into account the 260º restriction. Using a Method of Moments based on Local Periodicity (MoM-LP) [5], a layout is obtained that meet the specifications at center frequency.

The second stage performs a direct optimization of the layout in a bandwidth of 2 GHz using MoM-LP directly in the process loop. The goal of this stage is to try to improve the bandwidth performance of the antenna.

III. Results

Fig. 2 shows the normalized gain of the reflectarray radiation pattern before and after the first stage. It is observed that at the center frequency, the design almost meets the requirements set by the masks. The high ripple observed is produced due to the restriction in the phase-shift imposed in the optimization high ripple due to the phase restriction considered. The results for Y-polarization are similar. Due to the narrow band of reflectarrays, a bandwidth optimization will be performed.

The results after this optimization are shown in Fig. 3. The reflectarray does not comply with the specifications mainly because of its ripple. This is due to the use of a single unit cell with very few degrees of freedom and reduced phase shift. However, there is a good trade-off between performance and physical characteristics of the reflectarray. It is possible to improve the results of this design by using two layers of stacked patches which would provide more degrees of freedom for the bandwidth optimization.

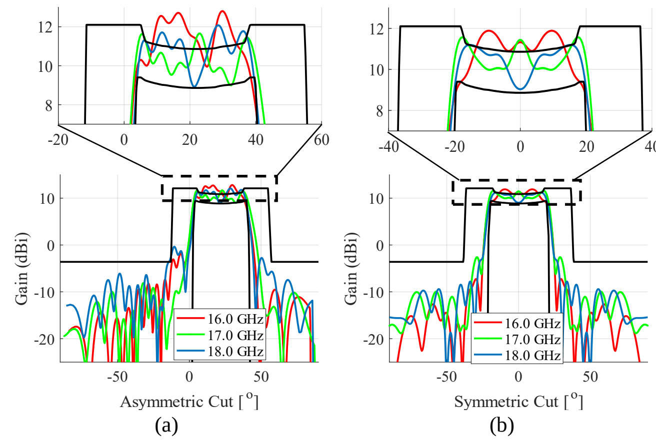

Fig. 3. Gain of the reflectarray optimized in a 2 GHz bandwidth for polarization X: (a) Asymmetric Cut; (b) Symmetric Cut.

IV. Conclusions

A compact, lightweight and low-cost reflectarray antenna has been designed, which can be fully integrated on a SmallSat as part of a mega-constellation. This antenna generates an isoflux radiation pattern that provides a constant flux power in the surface of the Earth. It was designed in Ku-band at 17 GHz, covering an operation range of 2 GHz with a slight degradation at extreme frequencies. This work demonstrates the capabilities of this type of antenna to provide a low-cost, low-profile solution for the mega-constellations with a good trade-off between antenna characteristics and achieved performance.

V. Acknowledgment

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