Satellite SAR Antenna based on Multi-faceted Reflectarray with tilted panels

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***Abstract*- In this contribution, a multi-faceted reflectarray for SAR applications onboard a satellite is evaluated and designed. The reflectarray antenna consists of 9-panels distributed in a parabola along the axis with the largest size. Working in Ka-band, the antenna generates a beam on each polarization to illuminate different areas of the Earth's surface. The multi-faceted structure achieves a good in-band stability in terms of gain, sidelobes and beamwidth of the pattern, which suppose an improvement in the antenna performance with regard to a conventional printed reflectarray.**

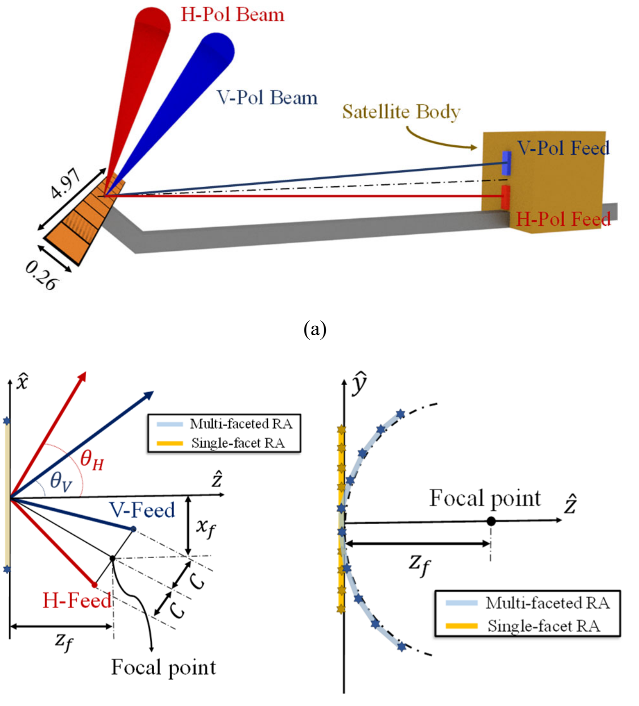
I. INTRODUCTION

Interferometric Synthetic Aperture Radar (InSAR) has become a popular technique in many remote sensing applications. The use of these systems onboard a spacecraft is hereby extended in the research community for Earth observation and imaging due to their reliability and immunity against several circumstances and weather [1].

In some of these applications, it is required high-resolution and highly sensitive instruments, which conditions the requirements of the radar, such as the bandwidth of the chirp pulse or the signal-to-noise ratio (SNR) among others [2]. In addition, the use of small satellites in SAR applications has been proposed due to the scalability and low-cost of these spacecraft, although they pose a challenge for the systems onboard them in terms of stowage.

Based on this, the antenna subsystem onboard a SAR satellite must provide high-gain and good performance in-band as well as high integrability with the spacecraft. Several antenna solutions onboard satellites have been proposed in the literature in a SAR context, such as rectangular patches [3], reflectors [4], or waveguide slot arrays [5]. Another potential candidate is printed reflectarray antennas [6]. This low-profile antenna can generate one or multiple high-gain beams with low sidelobe levels and good cross-polarization. Printed reflectarrays have successfully been implemented in interferometric SAR satellite missions such as the SWOT mission [7]. In this case, the reflectarray structure consists of several panels aligned with each other to conform a single-facet electrically large aperture.

However, printed reflectarray antennas have a narrow bandwidth [8] because of the in-band performance of the radiant element and the spatial phase delay effect. There are several broadband techniques in the literature which mitigate these issues. Some of them, focused on the element cell such as the use of multi-resonant [9] or true-time delay cells [10]. Other ones focused on the antenna structure to reduce the spatial phase delay effect. An increase in the f/D ratio could be a solution to reduce this effect although this can lead to a bulky antenna solution [6]. Alternatively, parabolic [11] and multi-faceted [12] reflectarrays mitigate the spatial phase delay effect maintaining an antenna compact structure. In fact, the use of multi-faceted reflectarrays can improve the reflectarray performance without reducing the integrability with the satellite.



(a)

(b) (c)

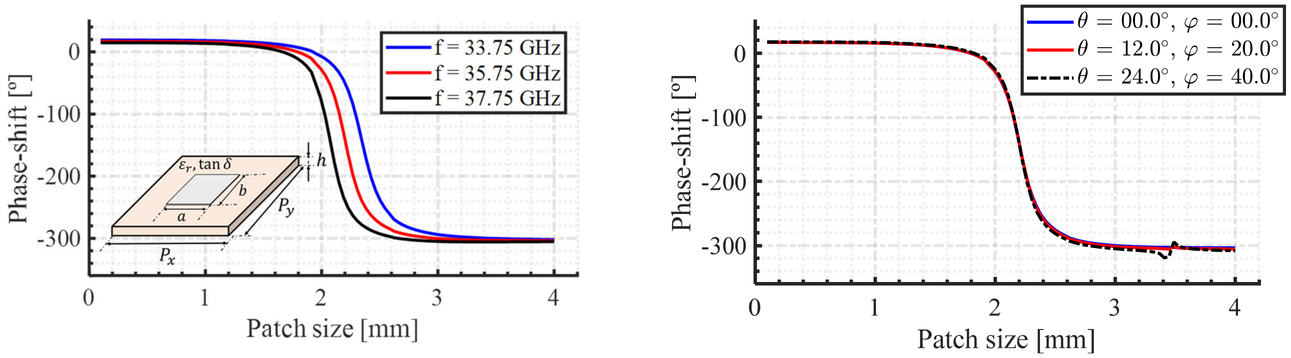
Fig. 1. Structure of the reflectarrays proposed: (a) 3D view of the reflectarray structure; (b) 2D view of each reflectarray in XZ plane; (c) 2D view of each reflectarray in YZ plane. All dimensions in meters.

In this contribution, it assessed the use of multi-faceted reflectarray structures for InSAR satellite missions to improve the performance of a conventional reflectarray. For this purpose, a multi-faceted reflectarray is designed based on the electrical requirements of a real InSAR system [7]. The antenna facets are tilted in order to follow a cylindrical parabola defined on the y-axis of the structure. The proposed antenna is compared to its equivalent single-facet reflectarray.

II. MULTI-FACETED REFLECTARRAY DESIGN

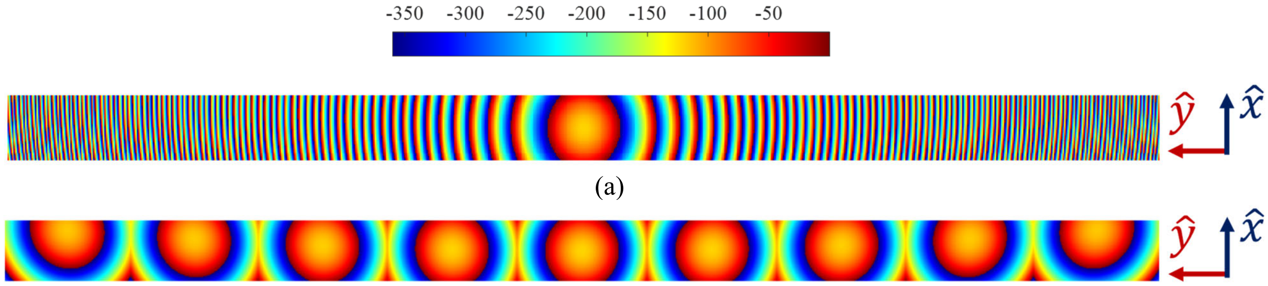
A. Antenna Specifications

According to the specifications of the SWOT mission [7] (see Fig. 1(a)), the reflectarray antenna is part of a radiometer which operates in Ka-band at 35.75 GHz and simultaneously measure two coverage areas or swaths.



(a) (b)

Fig. 2. Electromagnetic response of the unit cell as a function of the patch size: (a) Sketch and phase at different frequencies under normal incidence; (b) Phase at different angles of incidence at 35.75 GHz.



(a)

(b)

Fig. 3. Phase-shift in degrees [°] required on each cell in V-polarization: (a) Single-facet reflectarray; (b) Multi-faceted reflectarray.

Based on this, the reflectarray must generate two high-gain beams, one for each linear polarization (V- and H-polarization). These beams have a narrow beamwidth in azimuth and tilted in elevation to cover each one of the swaths.

B. Antenna Optics & Unit Cell.

The optics of the reflectarray designs is depicted in Fig. 1 (b),(c). The structure follows a single offset configuration, where the focal point is located at coordinates $(x_f, y_f, z_f) = (-1.5, 0.0, 4.1)$ m with regard to the central panel coordinate system. Both reflectarrays are composed by 9 panels of 8184 elements each one. These elements are distributed in a rectangular lattice of 62 x 132 elements. Thus, the total size of the reflectarray is 0.26 x 4.97 m^2. In the single-facet design, the panels are all aligned in both planes of the coordinate system. In the multi-faceted reflectarray, the panels rest on chordal planes of a parabola defined along the y-axis (Fig. 1(c)). The focal distance of this parabola is $z_f = 4.1$ m.

Each polarization is generated by an independent feed located perpendicular to the direction joining the focal point with the center of the reflectarray (see Fig. 1 (b)) and separated $\pm C = 0.2$ m from the focal point. The pattern of the feeds is modeled as a $\cos^q \theta$ with a different q for each main cut, so the beamwidth in both planes is similar to the feed used in [7]. At design frequency, the q is 3000 and 8 in the E- and H-plane respectively and it varies linearly in-band. The F/D relation in both reflectarray designs is approximately 0.9 m.

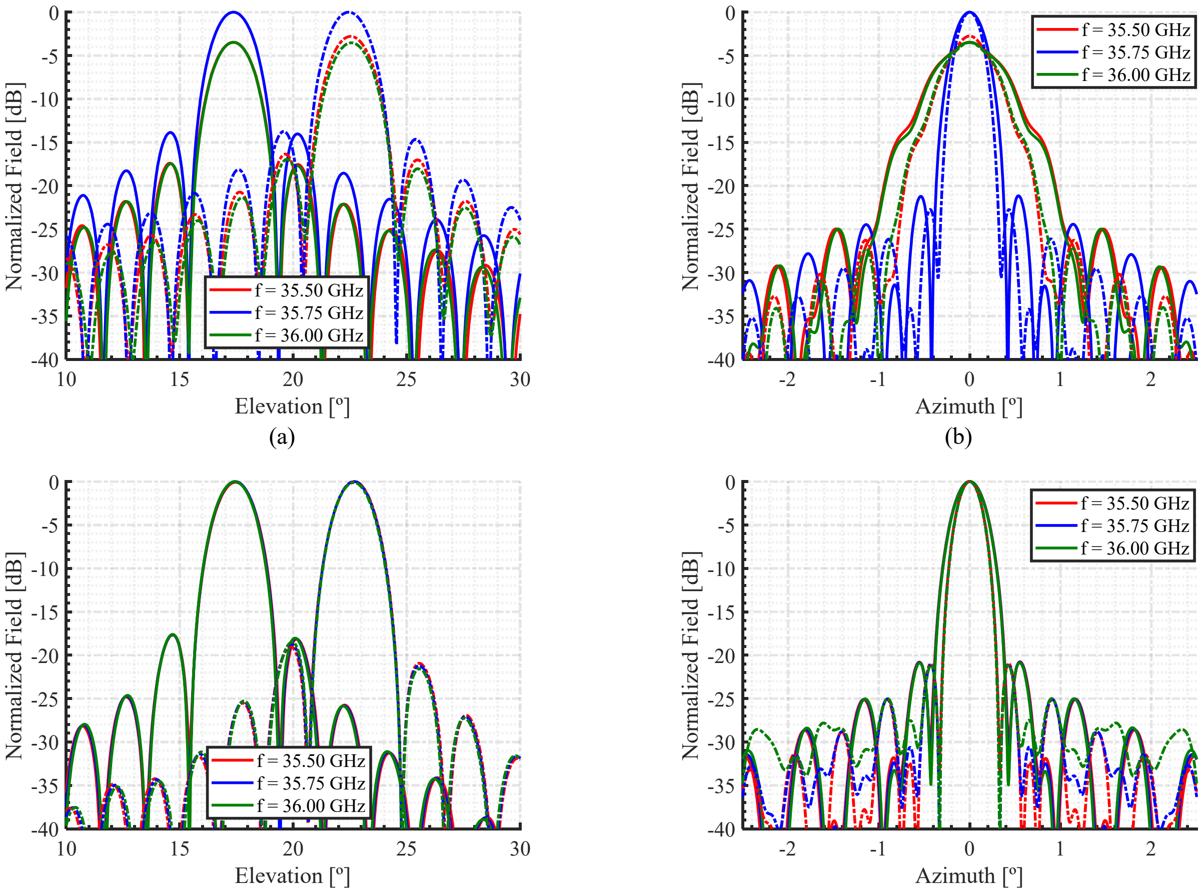
The radiant element chosen (see. Fig. 2(a)) is a variable-size rectangular patch backed by a ground plane. The substrate is Rogers 6002 ($\varepsilon_r = 2.94; \tan\delta = 0.0012$) with a thickness $h = 0.381$ mm. The periodicity in both axes is 4.91 mm ($0.4\lambda_0$). The behavior of this cell topology is analyzed in-band and under oblique incidence, using a Method of Moments based on Local Periodicity (MoM-LP) [13]. The results of this study are shown in Fig. 2. Between 1.8 and 2.6 mm, the phase introduces by the cell has a quasi-linear dependence on the size of the patch. In this range, the cell response has a good angular and band stability but its maximum phase-shift range provided is 280º.

C. Reflectarray Aperture Design.

The phase-shift that each reflectarray element must introduce on the incident field to produce a pencil beam in a generic direction (θ_0, φ_0) is given by,

$$\phi(x_i, y_i, z_i) = k_0[d_i - (x_i \sin\theta_0 \cos\varphi_0 + y_i \sin\theta_0 \sin\varphi_0 + z_i \cos\,\theta_0] \qquad (1)$$

where (x_i, y_i, z_i) are the coordinates of the i-th reflectarray element, k_0 is the propagation constant in vacuum and d_i is the distance between the element and the phase center of the feed. Considering the coordinate system depicted in Fig. 1, both reflectarrays are designed to generate a pencil beam in V-polarization pointing at $(\theta_V, \varphi_V) = (17.3, 0.0)°$ and another pencil beam in H-polarization pointing at $(\theta_H, \varphi_H) = (22.7, 0.0)°$. The phase distribution in V-polarization for each design is shown in Fig. 3. Along the y-axis, the single-facet design requires rapid phase variations with several phase jumps, especially in the panels on the edges of the aperture. Due to the use of a cell whose phase range is lower than a full cycle, such phase jumps generate phase wraps in the layout (the size of the patch jumps abruptly from the smallest to the largest size). For its part, the phase distribution of the multi-faceted reflectarray is much smoother on the y-axis, which reduces considerably the number of phase wraps in the layout. On the other axis, each panel of the multi-faceted structure has similar behavior to



(a) (b)

(c) (d)

Fig.4. Field pattern of reflectarray designs normalized to the gain at design frequency (35.75 GHz) in 0.5 GHz of bandwidth. Elevation (a) and Azimuth (b) cuts of single-facet reflectarray: Elevation (c) and Azimuth (d) cuts of the multi-faceted reflectarray. Solid lines correspond to the pattern in V-polarization and dotted ones with the pattern in H-polarization.

that observed in the central panel of the single-facet reflectarray. Similar behavior is achieved for H-polarization.

The phase distribution of each polarization is translated into patch sizes by applying the phase curves shown in Fig. 2 at 35.75 GHz considering the real incidence angle in each cell. To evaluate the performance of both designs, it is followed the methodology explained in [14] and the MoM-LP [13] to evaluate the layout of each panel. The results achieved after this process are shown detailed in the next section.

III. REFLECTARRAY PERFORMANCE

Fig.4 shows the farfield of the reflectarrays in both polarizations in-band, normalized to the gain at 35.75 GHz. At the design frequency, both designs generate two pencil beams in the pointing directions designed, with a narrow beamwidth in azimuth (HPBW ~ 0.3º). In terms of side lobe levels, the multi-faceted structure achieved a lower level compared to the single-facet version. Outside the design frequency, the beams of the single-facet design suffer strong degradations in azimuth (see Fig.4 (b)), which rapidly increases the HPBW, and the gain is reduced. Since it is used a cell with a phase range restricted, the areas of the layout with several phase wraps introduce significant phase errors, which degrades considerably the pattern of the antenna. In the case of the multi-faceted design, the sectorization applied to the azimuth cut makes the design more robust, maintaining the beamwidth and the gain achieved at 35.75 GHz. In the elevation cut, the shape of the beam in both designs remains stable in-band, although in the single-facet reflectarray the gain is reduced because of the degradation in the azimuth cut.

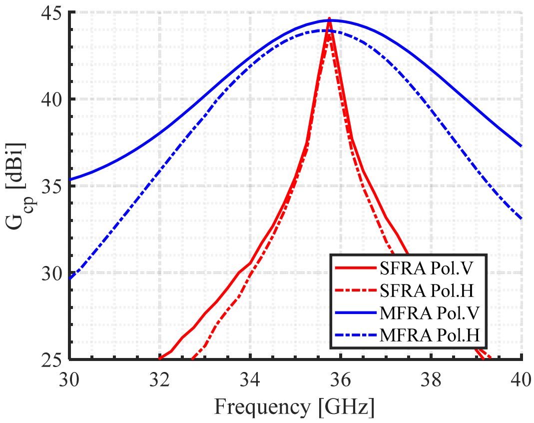


Fig.5. Copolar gain from 30 to 40 GHz for multi-faceted reflectarray (MFRA) and single-facet reflectarray (SFRA) in both polarizations.

Fig.5 shows the copolar gain for both designs in a wider range (30 – 40 GHz) for each polarization and design. The gain achieved at 35.75 GHz is almost the same for both designs. However, the in-band pattern degradation suffered by the single-faceted reflectarray has a direct impact on the maximum gain of the antenna, decreasing rapidly outside the design frequency. On the other hand, the multi-faceted design maintains high gain levels over a wider frequency band.

TABLE I. BANDWIDTH PERFORMANCE.

Design	**Range in GHz [Bandwidth (GHz/%f_0)]**	
	V- Polarization	**H- Polarization**
Multi-faceted RA	34.5 - 37.0 [2.5/7.0]	34.5 – 37.0 [2.5/7.0]
Single-facet RA	35.7 – 35.8 [0.1/0.3]	35.7 – 35.8 [0.1/0.3]

To quantify the bandwidth enhancement achieved in the multi-faceted, Table-I lists the operating frequency range of both antennas taking the 1 dB drop of gain as a reference. The multi-faceted design improves the bandwidth of about 2.4 GHz, which is about an enhancement of 7% with regard to the working frequency.

IV. CONCLUSIONS.

In this paper, a multi-faceted reflectarray structure is designed and proposed as an antenna candidate for SAR applications onboard a satellite. The antenna, designed according to the specifications of a real SAR mission, consists in several panels disposed on chordal planes of a parabola along the largest axis of the antenna. The antenna generates two beams in dual-linear polarization to illuminate different swaths in the Earth surface. The multi-faceted antenna is compared with a single-facet version identical in optics and dimensions.

The sectorization applied in the multi-faceted structure drastically reduces the number of phase jumps on the sectorization axis. As it is used a cell that provides a phase range less than 360º, less phase jumps in the distribution required means less error between the phase required and the one introduced by the cell.

The relaxation in the phase distribution has a direct impact on the radiation pattern of the antenna. In the sectorization cut, the multi-faceted reflectarray generates a narrow beam more stable in-band than the single-facet version with a reduce level in the side lobes. The improvement in the performance of the pattern is also translated into the gain achieved, significantly increasing the bandwidth of the antenna with regard to the single-facet version.

This contribution shows that the use of multi-faceted structures improves the antenna performance in electrically large reflectarrays for SAR applications. This makes multi-faceted reflectarrays an interesting candidate for future SAR missions.

ACKNOWLEDGEMENTS

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