Effect of Mechanical Tolerances in Deployable Multi-Faceted Reflectarrays

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***Abstract*—In this paper, an analysis of the performance degradation in a multi-faceted reflectarray antenna because of the assembling tolerances is presented. In different scenarios of misalignment between panels, two multi-faceted reflectarrays which work in linear polarization at Ka-band are evaluated. They are designed to generate a pencil beam pattern in a certain direction of space. The results of this study show that the errors in the relative placement and tilting between panels in the sectored cut cause an increase in the side lobe levels. When these errors are significant, this means a degradation of the main beam, leading to an increase in the beamwidth and a significant loss of gain.**

***Index Terms*— satellite communications; reflectarray antennas; multi-faceted structures;**

I. Introduction

Printed reflectarrays [1] have emerged as a potential candidate in many wireless applications which require high-gain antennas. In particular, the use of these spatial-fed antennas is interesting in the space sector, especially for those systems onboard a satellite. They exhibit advantages in comparison to the traditional antennas used such as phased arrays and parabolic reflectors. Printed reflectarrays are low-loss compared with the first ones because they do not require a feeding network. Besides, they are compact, lightweight, and have a low profile, which allows them to have good integrability with the satellite. According to this, the use of reflectarrays has been considered for their use in large and medium satellites [2],[3]. But also, they have been proposed and successfully implemented in space missions that involve SmallSats [4] - [6].

As a counterpart, printed reflectarrays have narrow bandwidth [7] mainly due to the bandwidth of the radiant element and the spatial phase delay effect. In the literature, several strategies are proposed to mitigate these issues [8] – [13]. One of them is the use of multi-faceted structures [11] – [13]. They achieved a performance improvement of a conventional reflectarray thanks to their optics, more similar to a parabola. In a satellite, the multi-faceted reflectarrays can exploit efficiently the unit cell and the optics without increasing the complexity of the accommodation onboard it [13].

In all the above-mentioned missions, reflectarray antennas are implemented in the same way as other types of Large Spaceborne Deployable Antennas (LSDAs) [14]: the antenna is divided into several panels which are integrated with the spacecraft body. Once the satellite is in orbit, they are deployed to composite a single facet. Based on this, the alignment of the panels after deployment is important for the correct working of the antenna. In case of misalignments due to imperfect deployments, the impact on the performance of the antenna must be known. In this sense, there are some studies about the misalignment in deployable antennas ([6],[7], and [15]), and more specifically in conventional reflectarrays [5],[6].

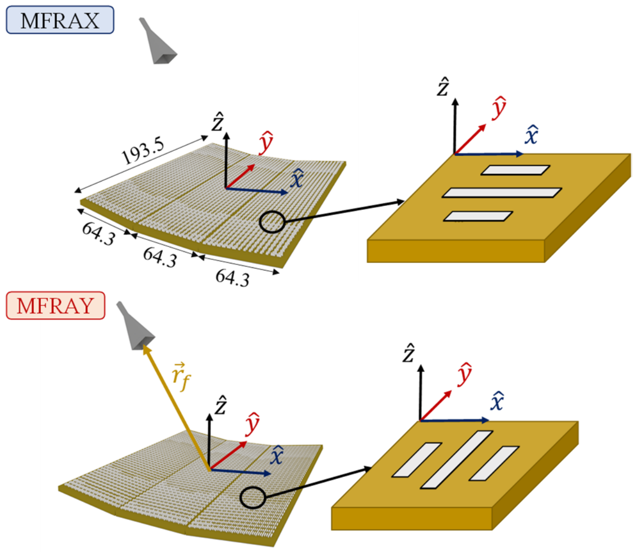


Fig. 1. Sketch of the reflectarrays considered in this study: multi-faceted reflectarray in X polarization (MFRAX) and Y polarization (MFRAY). All dimensions are in mm.

In this contribution, a further study about the effects of misalignments in a multi-faceted reflectarrays is carried out. Taking as reference two single-offset multi-faceted reflectarrays composed by three facets, the effect of errors in the relative position and orientation of the side panels regarding the central one is evaluated. For this purpose, a Method of Moments based on Local Periodicity (MoM-LP) [16] and the formulation depicted in [13] is used to assess the pattern and main parameter of the antenna (gain, side lobe

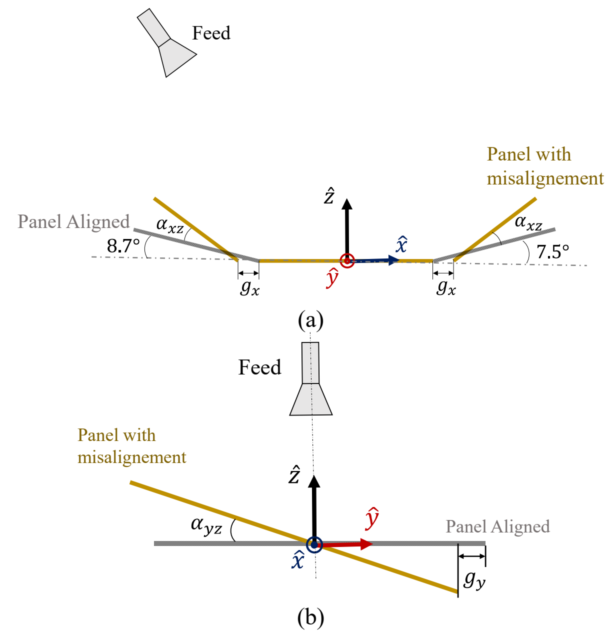


Fig. 2. Antenna optics of both multi-faceted reflectarrays and misalignments considered in the study: (a) XZ plane; (b) YZ plane. In **grey**, the location of the panels considered in the design, in **yellow** the location of the side panels with different misalignments.

levels, beamwidth) under different misalignments conditions in the main planes of the antenna optics: offset and symmetric.

II. Case of Study.

Fig. 1 shows the multi-faceted designs reported in [13] and considered in this study. They are two antennas linearly polarized, one works in X polarization (MFRAX) and the other in Y polarization (MFRAY). They are designed to generate a pencil beam at 28 GHz pointing at $(\theta,\varphi) = (19.16°, 0.0)$ regarding the coordinate system of the central panel. These antennas are composed of three panels of identical size which are placed following a parabola in a single-offset configuration of $f/D \approx 1$. Each panel has 675 radiating elements, distributed in a 15 x 45 rectangular grid, and spaced 4.29 mm in both axes. Therefore, the equivalent aperture in the designs is 191.80 x 193.05 mm^2.

The multi-faceted reflectarrays are illuminated by a Narda 665-20 pyramidal horn located at $\vec{r}_f = (-68{,}0{,}189)$ mm. According to this, the feed generates an average taper at the edges of the reflectarrays of about 15 dB.

The radiant element that composes the reflectarray surfaces consists of three metallic dipoles on a single-layer substrate backed by a ground plane. In the MFRAX the dipoles are aligned with the x-axis of each panel and in the MFRAY they are aligned with the y-axis.

III. Effect of Misalignaments in Multi-Faceted Reflectarrays

In this work, a set of antenna misalignments because of assembly tolerances that can have a deployable multi-faceted reflectarray are presented. These misalignments consist of errors in the position and orientation of the side panels regarding the central one as shown in Fig. 2.

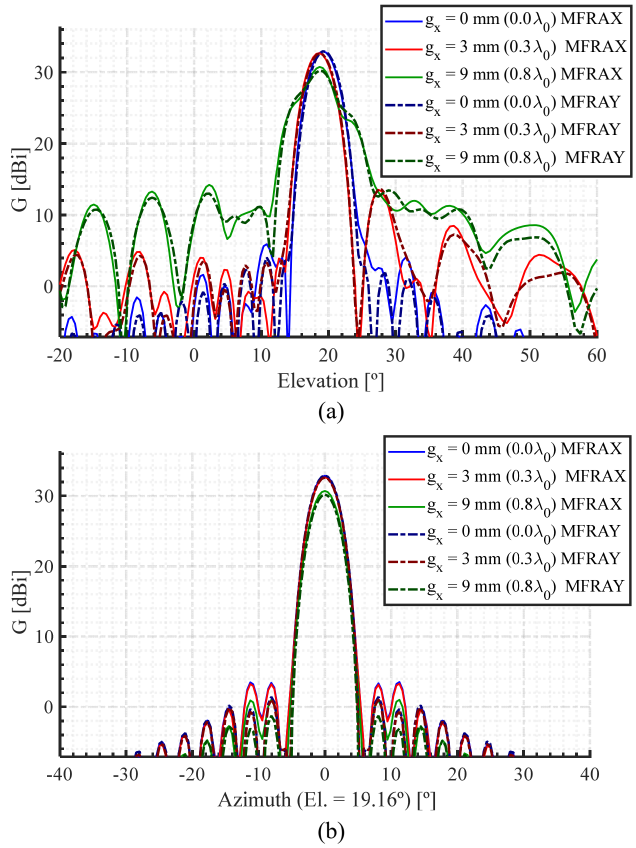


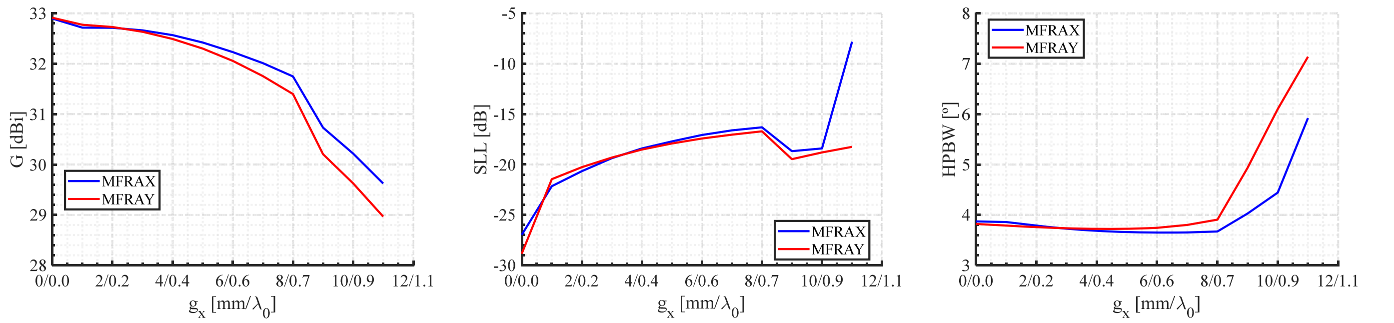
Fig. 3. Gain pattern of the multi-faceted reflectarrays (MFRAX, MFRAY) at 28 GHz, for different gaps in the side panels (g_x). (a) Elevation cut; (b) Azimuth cut.

The performance of the multi-faceted reflectarrays has been evaluated considering these different misalignment conditions. For this purpose, an analysis based on the methodology depicted in [13] has been carried out, where CST-MW [17] has been used to calculate the incident field in each panel and the MoM-LP [16] to assess the response of each radiating element, considering the layouts of each reflectarray design, shown in Fig. 1.

A. Gap between panels.

Along the antenna deployment plane (see Fig. 2(a)), the hinges that joints the different panels commonly create some gaps (g_x) between them [5],[6]. Such gaps produce an error in the relative position of the side panels regarding the central one.

Fig. 3 shows the radiation pattern of the multi-faceted designs considering different gaps g_x expressed in mm and in terms of the wavelength at design frequency (λ_0). In elevation (offset plane), the main beam in both multi-faceted reflectarrays is stable for small gap sizes although a significant increase in the side lobe levels appears. For higher gaps, both



(a) (b) (c)

Fig. 4. Main parameters of the pattern in the elevation cut of the multi-faceted reflectarrays at 28 GHz as a function of the gap (g_x) between the side and the central panels: (a) Gain; (b) Side Lobe Levels (SLL); (c) Half Power Beam Width (HPBW). The gap is expressed both in mm and in terms of the wavelength (λ_0) at design frequency (28 GHz).

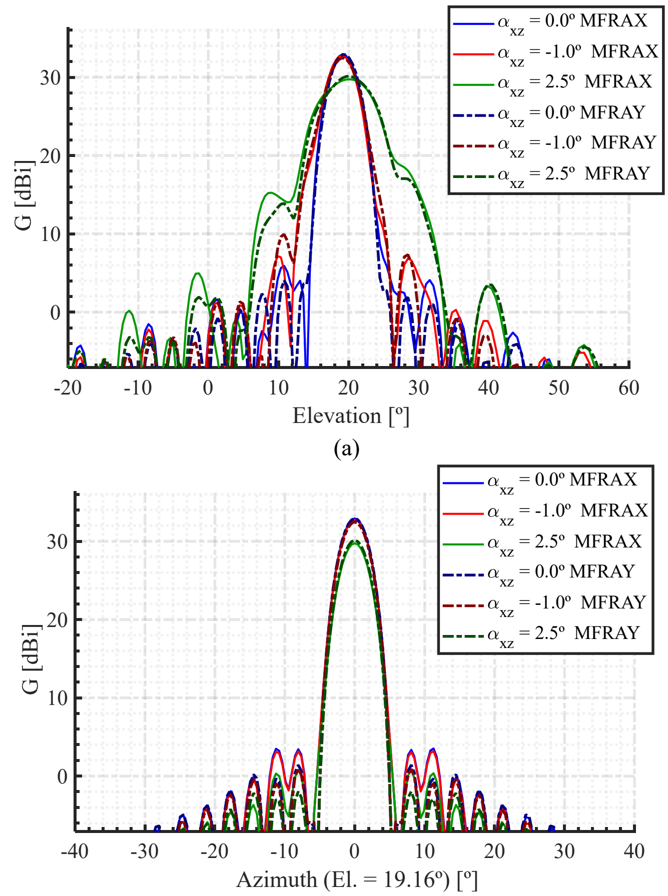
antennas show significant degradation of the radiation pattern, especially in the main beam. This beam also suffers a slight deviation (~ 0.5º) regarding the pointing direction designed. In the azimuth cut, small variations of the diagram pattern appear.

The effect of the gaps can also be seen in Fig. 4 in which the main parameters in the elevation cut are expressed as a function of g_x. For gaps lower than 5 mm ($0.5\lambda_0$), little variations in the gain and the beamwidth are observed. But for gaps higher than $0.5\lambda_0$, the loss of gain is higher than 1dB and the Half Power Beam Width (HPBW) rapidly increases in both designs. The Side Lobe Level (SLL) is the most sensitive parameter, since it increases rapidly in the presence of gaps, especially in the MFRAX.

B. Errors in the tilt of the side panels.

To follow the cylindrical-parabolic structure, the side panels of the multi-faceted structures have a certain tilt regarding the central one. Fig. 2(a) shows the angles required in the lateral panels considering the vertex which joints the panels as the axis of rotation. An error made in these tilts α_{xz} because of a malfunction in the deployment [15] means a misalignment not only in the orientation of the panels but also in the position of their center.

Without considering gaps between panels ($g_x = 0$ mm), Fig. 5 and Fig. 6 show the radiation pattern and main parameters for both multi-faceted designs when the side panels have angles of tilting greater (positive α_{xz}) or lower (negative α_{xz}) than those considered during the design. With small tilt errors ($\alpha_{xz} = \pm 1°$), the main beam has a slight defocusing at 10 dB below the maximum, and the SLL increase in the elevation cut. However, these effects have a minimal impact in the gain. For tilt errors of $\pm 2.5°$ (equivalent to an arc length of $0.3\lambda_0$), both reflectarrays suffer a strong degradation of the pattern in the same cut, with a significant increase in the side lobes, and in the beamwidth of the main beam. The beam also has some deviation regarding the pointing direction designed of about 1º. According to Fig. 6, the multi-faceted reflectarrays suffer a gain loss of almost 3 dB for the highest tilt errors evaluated, due to the rapid SLL



(a) (b)

Fig. 5. Gain pattern of the multi-faceted reflectarrays (MFRAX, MFRAY) at 28 GHz, for different errors in the tilt of the side panels (α_{xz}): (a) Elevation cut; (b) Azimuth cut.

increase and the beamwidth of the antenna. Both designs are more robust in terms of gain, SLL and HPBW when $\alpha_{xz} < 0$, especially in the MFRAX case. As the errors in the optics only affects the offset cut, the behavior of the pattern in the azimuth cut remains stable.

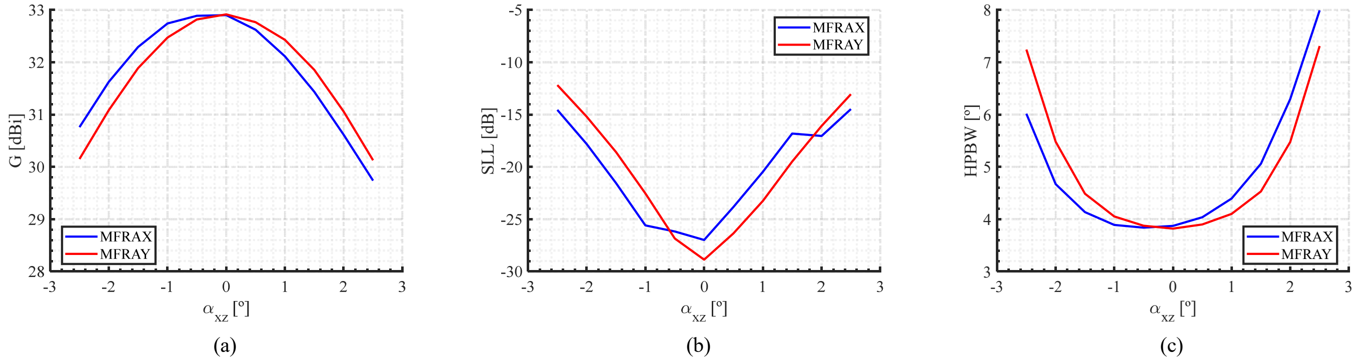


Fig. 6. Main parameters of the pattern in the elevation cut of the multi-faceted reflectarrays (MFRAX, MFRAY) at 28 GHz as a function of the error in the tilt of the side panels (α_{xz}): (a) Gain; (b) Side Lobe Levels (SLL); (c) Half Power Beam Width (HPBW).

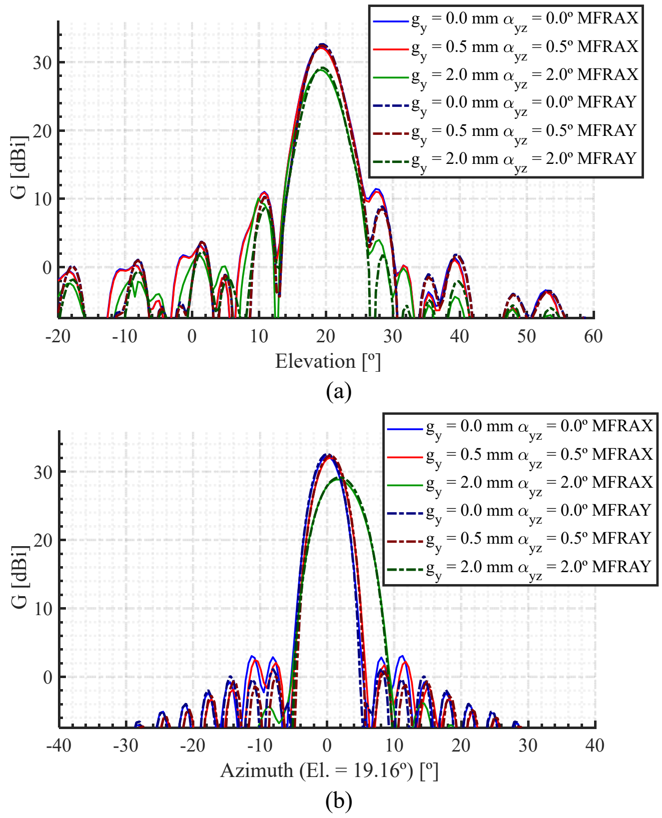


Fig. 7. Gain pattern of the multi-faceted reflectarrays (MFRAX, MFRAY) at 28 GHz, under different conditions of misalignement along y-axis: (a) Elevation cut; (b) Azimuth cut.

C. Orientation and location along the symmetric axis.

Other misalignments in the antenna optics resulting from a malfunction of the reflectarray deployment are those which may occur on the non-sectored axis (see Fig. 2(b)).

Considering a misalignment in the offset plane of $g_x = 1$ mm and $\alpha_{xz} = 1$º, Fig. 7 shows the radiation pattern of the reflectarray designs when both side panels suffer some errors in the location g_y and orientation α_{yz} regarding the coordinate system of the central panel. In this case, the pattern in both designs is almost insensitive in elevation, with slight variations in the levels of the side lobes. In azimuth, the misalignments on the y-axis do not significantly affect the shape of the pattern. Neither they introduce an increase in the level of the side lobes. However, it appears a deviation and defocusing of the main beam which reduces the gain of the antenna. In the worst case ($g_y = 2$ mm; $\alpha_{yz} = 2°$), the main beam suffers a deviation in the beam pointing of about 2° and a gain loss of 3 dB.

IV. Conclusions

In this work, a parametric study on how errors in the antenna optics can affect the performance of a multi-faceted reflectarray is carried out. This analysis proposes different cases of misalignments in the optics of the antenna structure, evaluating their impact on the performance of two linearly polarized multi-faceted reflectarray examples, designed to generate a high gain pencil beam pattern.

In both polarizations, the existence of gaps or errors in the relative tilt between panels leads to a degradation of the pattern and a significant increase in the side lobe levels along the sectorization axis. For gap sizes close to the wavelength at the design frequency, there is a defocusing of the main beam which implies a loss of gain. Similar behavior is obtained for greater angular misalignments of the side panels, in which a higher gain loss and a slight deviation of the main beam appear. Errors in antenna optics along the non-sectorized cut have less impact on the radiation pattern. However, when they are high, they can produce a significant deviation and defocusing of the main beam.

This work serves as a starting point to understand the consequences of errors in the antenna optics of multi-faceted reflectarrays, to establish alignment requirements for the proper operation of the antenna.

During the presentation of this work, the effect of the misalignments described will be compared with the experimental validation of the proposed reflectarray prototypes, identifying the errors made during the assembly and the manufacturing tolerances of the structure.

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