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Modeling and Design of a Folded Transmitarray Antenna on Quartz for Radiometric Applications

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Abstract—This paper presents an effective modeling strategy applied to the design of a folded transmitarray (TA) antenna at 183 GHz. The structure at hand is amenable for fabrication by photolithography on low-loss quartz substrates. The proposed method, based on ray-tracing, provides a good agreement with full-wave simulations for the folded TA. A peak gain of 28.2 dBi and 52% aperture efficiency is achieved for a folded F/D of 0.33, which translates into a total TA thickness of 6 mm.

I. INTRODUCTION

Transmitarray (TA) antennas are well established in the telecommunication application domain. They are an attractive choice at sub-millimeter wave frequencies due to their lossless spatial feeding, beam-shaping capability, and potential to achieve very high gains. In addition, given the wide variety of available unit cells (UC), high radiation efficiencies and low quantization losses can be achieved. Furthermore, the vertical profile of these antennas can be reduced by folding the TA [1]. Based on these characteristics, folded TAs can be an interesting candidate for radiometric applications in small-satellite platforms with compact front-ends as well.

Radiometric instruments play an important role in the atmospheric remote sensing for quantifying the composition of atmospheres, wind speed measurements or temperature sensing [2]. Such instruments can be conveniently integrated as payload on small-satellite platforms to reduce the development time and cost of the mission. Due to the limited space in such platforms, low-profile antennas easy to integrate with receiving front-ends are preferred. However, one typically finds reflector antennas in radiometric instruments. Although these antennas exhibit high radiation and beam efficiencies, they occupy a volume that may be too large for a small satellite. Recently, flat antennas for compact platforms based on lenses or metasurfaces have been introduced [3],[4]. In this communication, we describe an efficient modeling approach based on geometrical optics (ray-tracing) [5] for folded TA antennas and apply it for a design at 183 GHz (water vapor absorption line).

The paper is organized as follows. Section II describes folded TA's principle of operation. Section III presents the antenna geometry and its basic building blocks. Section IV. The analytically-modelled and simulated gains and far-field patterns of the final antenna are provided in Section IV.

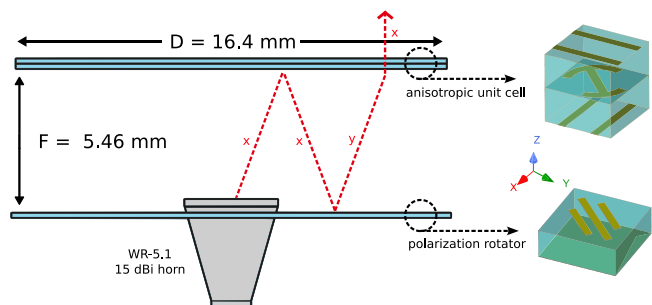


Figure 1. Geometry of the proposed structure, the insets show the TA anisotropic UC (top) and the polarization rotator UC (bottom)

II. PRINCIPLE OF OPERATION

TA antennas consist of a focal source placed at a focal distance from the TA aperture, which is made of periodically distributed UC. The profile of the TA corresponds to its focal distance; it can be reduced by a factor of 3 by adopting a folded architecture. The latter includes an additional aperture of polarization rotators in the plane of the focal source, as depicted in Figure 1. The operation principle is as follows. The rays leaving the focal source are x -polarized and fully reflected by the bottom polarizing grid in the TA UC. After reflection at the polarization rotator, the signal is y -polarized and enters the anisotropic UC, which rotates the signal to x -polarization and introduces the desired phase shift. By creating these multiple reflections inside the structure, the optical path of the rays emanating from the horn are prolonged as if they originated from a focal source placed three times farther in a standard non-folded TA.

The proposed folded TA consists of a 15-dBi pyramidal horn as a source, a polarization rotator approximately aligned with the horn's aperture and based on a three-dipole topology, and a surface placed at the focal distance and made of anisotropic UC for focusing the beam. The dimensions of the polarization rotating UC and TA UC are $0.3\lambda \times 0.3\lambda$ and $0.2\lambda \times 0.2\lambda$ at the center frequency (183 GHz), respectively. For the analytical design, we are using an in-house developed code based on the ray-tracing principle [5]. The structure of the array is shown in Figure 1. The total size surface of the array is $16.4 \text{ mm} \times 16.4 \text{ mm}$, which corresponds to the electrical size of $10\lambda \times 10\lambda$ at 183 GHz.

III. TA GEOMETRY AND UNIT CELLS

A. F/D ratio

For the above-mentioned configuration, we sweep the F/D to get the optimum folded F/D of 0.33 that maximizes the aperture efficiency. The horn aperture is slightly higher than the polarization rotator to place the phase center of the horn at the level of the polarization rotating surface (Figure 1).

B. Polarization rotator unit-cell

The purpose of the polarization rotator is to rotate the polarization of the incident signal by 90° and reflect it back with minimum loss. The rotator topology employed in this design is based on a three-dipole structure on a grounded dielectric slab, which is usually used as reflectarray UC [6]. In this case, the dipoles are rotated 45° to split the incident field into two orthogonal components and perform the polarization rotation. A quartz dielectric substrate is adopted due to its low-loss (expected loss tangent of 0.0002) and its compatibility with photolithography. It is important to note that the method in [5] has been modified to account for the effect of the rotator.

C. Transmitarray unit-cell

The UC used for the TA aperture follows the commonly used anisotropic structure due to its low insertion loss and large operating bandwidth [7]. The outer two metallic layers are orthogonal polarizing grids, and the middle layer contains an element that controls a desired phase shift and rotates the polarization. The used dielectric substrate is also quartz. The phase mask of the antenna is synthesized with a 3-bit resolution. This approach provides a good compromise between synthesis complexity and gain penalization, which is only 0.2 dB in case of a 3-bit quantization [5].

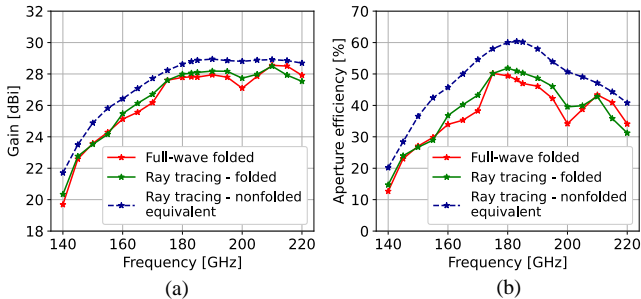


Figure 2. Gain (a) and aperture efficiency (b) versus frequency for the proposed folded TA obtained with a full-wave solver (red) with the ray tracing (green) and for the equivalent conventional TA (blue).

IV. SIMULATION RESULTS

Figure 2 shows the achieved gain and aperture efficiency versus frequency for the proposed antenna. A peak gain of 28.2 dBi with a 52% aperture efficiency was obtained at 183 GHz. The ray-tracing model provides a good agreement with the full-wave simulation (CST Microwave Studio), which validates the analysis approach even for folded architectures. Furthermore, the simulation time is reduced by a factor of 21, without considering the simulation of the UC database synthesis.

The gain versus frequency response was also calculated using ray-tracing for an equivalent non-folded antenna of same aperture dimensions. This structure has three times longer focal length and the same phase mask as its folded counterpart. The analysis reveals that folding the antenna leads to a gain drop of around 1.5 dB across the full bandwidth.

Figure 3 shows the normalized E- and H-plane directivity patterns at 183 GHz simulated with a full-wave solver and the ray-tracing approach. The calculated patterns are obtained by computing the array factor using FFT as the last step of the ray-tracing procedure [5].

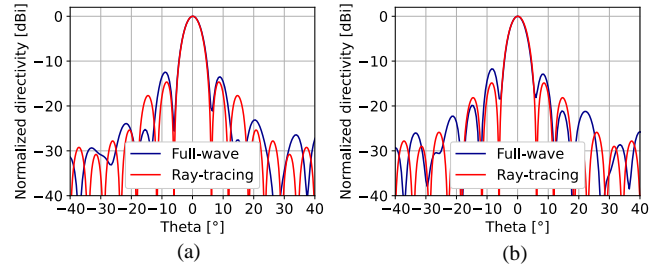


Figure 3. Normalized co-polarization radiation patterns of the folded TA at 183 GHz computed with a full-wave solver and with the ray tracing approach. (a) E-Plane. (b) H-Plane.

V. CONCLUSIONS

A folded TA on quartz with $F = 3.33\lambda$ and a $10\lambda \times 10\lambda$ aperture, and operating at a center frequency of 183 GHz was analyzed using a ray-tracing algorithm and simulated. A peak gain of 28.2 dBi and a 52% aperture efficiency at 183 GHz have been achieved. The proposed analysis method provides a good agreement between full wave simulations and the analytical model.

REFERENCES

- [1] A. Boriskin and R. Sauleau, Aperture Antennas for Millimeter and Sub-Millimeter Wave Applications. 2017. doi: 10.1007/978-3-319-62773-1.
- [2] F. Ulaby, Microwave Radar and Radiometric Remote Sensing. Ann Arbor: University of Michigan Press, 2013.
- [3] G. Chattopadhyay et al., "Terahertz Antenna Technologies for Space Science Applications," *Int. Symp. Antennas Propag. (ISAP)*, Oct. 2018, pp. 1–2.
- [4] D. González Ovejero, O. Yurduseven, G. Chattopadhyay, and N. Chahat, "Metasurface Antennas: Flat Antennas for Small Satellites," in *CubeSat Antenna Design*, IEEE, 2021, pp.255-313.
- [5] A. Clemente, Design of transmitarrays with beamforming/beamtilting capability. PhD thesis, University of Rennes 1, 2012.
- [6] R. Florencio, R. R. Boix, V. Losada, J. A. Encinar, E. Carrasco, and M. Arrebola, "Comparative study of reflectarrays based on cells with three coplanar dipoles and reflectarrays based on cells with three stacked patches," *6th Eur. Conf. Antennas Propag. (EUCAP)*, Mar. 2012, pp. 3707–3710.
- [7] O. Koutsos, F. Foglia Manzillo, A. Clemente, and R. Sauleau, "High-Resolution Quartz Transmitarray Antenna for Sub-THz Applications," *IEEE Int. Symp. Antennas Propag. USNC-URSI Radio Sci. Meet. (AP-S/URSI)*, Jul. 2022, pp. 1600–1601.