REFLECTARRAY ANTENNA DEVELOPMENTS AT ANYWAVES

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***Abstract*—This paper discusses the outcome of recent activities at Anywaves aiming at the development of a reflectarray antenna product for space missions using NanoSat platforms. These missions are particularly well suited for this product, when high antenna gain is required and limited volume is available for stowage. In an effort to industrialize the concept, a generic product definition is retained, which is suitable for operating frequencies ranging from X-band up to K_a-band, and possibly even higher. A patent pending panel design has been developed, providing stable RF and mechanical properties over typical low Earth orbit environmental conditions. The results of a K_a-band demonstrator, developed with the support of CNES, are reported here. A similar design was successfully validated in orbit recently, constituting the first commercial deployment of a reflectarray antenna product in space. These achievements confirm the potential of the defined solution to address the needs of future science and exploration missions using NanoSats.**

I. INTRODUCTION

Reflectarray antennas have emerged as a promising candidate for NewSpace missions using CubeSats and NanoSats [1]. While the technology has been investigated for decades [2]-[4], the specific constraints of CubeSats and their dispensers have opened recent opportunities for this antenna solution, benefiting from its low-stowage volume and well-suited form factor, thus enabling high gain RF links on very small platforms. NASA/JPL was the first institution to validate the technology in low Earth orbit (LEO) with the ISARA mission, a 3U CubeSat providing a technology demonstration, combining a solar array with the reflectarray panels, successfully launched in 2017 [5]. A larger reflectarray solution was later embarked on the MarCO exploration mission onboard a 6U CubeSat orbiter, relaying the data collected on Mars [6]. The antenna was designed to operate over the portion of the X-band allocated to data relay services.

With the support of CNES, Anywaves is developing a generic reflectarray sub-system for LEO missions, adding a high-gain antenna product to its portfolio of innovative NewSpace solutions [7]. The technology is meant for commercial missions and thus, careful considerations on materials and processes have led to a patent pending metallic panel design [8]. The selected stack-up provides stable performance over temperature and is more robust over the satellite's lifetime, typically of 5 years or more for most LEO missions. A first demonstrator was developed in the frame of an R&T activity supported by CNES, targeting the portion of the K_a-band allocated for data downlink. The development of a qualification model is currently on-going in the frame of a follow-up demonstrator activity, co-funded by CNES. A critical aspect of this antenna technology is the deployment in-orbit and accurate positioning of the panels to achieve the desired gain. Anywaves benefited from a recent in-flight demonstration opportunity to be the first commercial provider deploying the technology in orbit. This fast-track development confirmed the potential of this antenna product for future LEO missions, which may be tuned to operate at different frequencies ranging from X-band to K_a-band and above. In parallel, Anywaves is also running R&D activities exploring alternative manufacturing techniques [9] as well as wide-band and dual-band designs [10].

This paper provides a description of the generic reflectarray product under development at Anywaves. It also reports the results of the first experimental validation in K_a-band and discusses perspectives for future developments, building on the recent successful in-orbit deployment.

II. REFLECTARRAY ANTENNA PRODUCT

The baseline antenna geometry corresponding to the generic product envisioned is schematically illustrated in Fig. 1, also describing the main parameters and relevant coordinate systems. The RF axis, corresponding to the pointing direction of the main lobe, is set in the specular direction of the signal coming from the feed, co-located with the focal point **F** of the reference parabola, and impinging the radiating aperture at the center of the panel **C**, as this is known to maximise the aperture efficiency.

The selected configuration with 3 panels requires a sequential deployment, as represented in Fig. 2. The

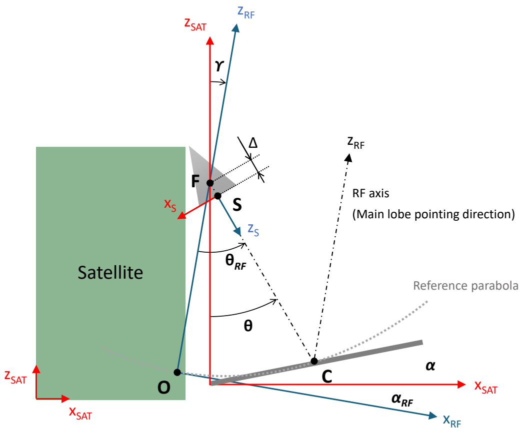
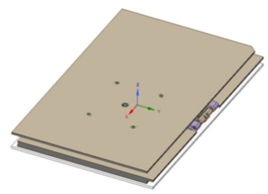


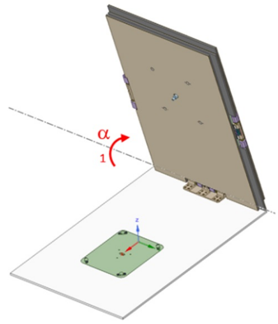
Fig. 1. Schematic representation of the antenna geometry on the platform and associated coordinate systems.

first deployment phase is controlled by the central self-motorized hinge connecting the panel assembly to the platform, with associated deployment angle α as defined in Fig. 2(b). The second deployment phase is controlled by the lateral inter-panel hinges, which define the relative angle β between the panels. This relative angle is meant to reduce the phase dispersion across the panels by approximating the curvature of the ideal reference parabola. A hold down and release mechanism (HDRM) is keeping all 3 panels together during launch and releases them simultaneously once in orbit. Its location is schematically represented by the green area in Fig. 2(b) and Fig. 2(c). Its central position is necessary to optimize the mechanical response of the stack-up to vibrations during launch while in stowed configuration. This design requires the implementation of 5 holes in all 3 panels, but these were found to have limited impact on the RF response. The sequential deployment of this 3-panel assembly is guaranteed by the central hinge that releases the lateral panels following the primary deployment stage. The proposed baseline configuration may be adapted in the future to enable the assembly of more panels for missions requiring higher antenna gain [11].

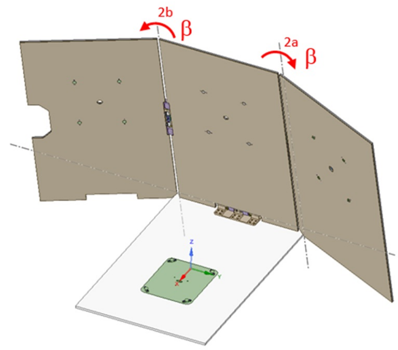
The panels are made primarily of aluminum. The unit cell, shown in Fig. 3, is a cavity backed patch element in a hexagonal lattice. The diameter of the patch is the main design parameter, providing close to 360° relative phase range in reflection. The results reported in Fig. 4 were obtained at 30 GHz for normal incidence. The response of the unit cell remains stable over frequency and for oblique incidence as well, with some discrepancy between transverse electric (TE) and transverse magnetic (TM) incidence response appearing at larger angles and impacting mainly the cross-polarization discrimination (XPD). The printed elements are etched on copper deposited on a kapton layer. An adhesive layer is added to the stack-up to attach the kapton layers to the aluminum panel. A key advantage of this solution



(a)



(b)



(c)

Fig. 2. Schematic representation of the deployment sequence of a 3-panel reflectarray antenna system. (a) Stowed configuration, (b) primary deployment and (c) secondary (i.e., lateral panel) deployment.

is that the kaption layers have a coefficient of thermal expansion (CTE) close to that of the aluminum, thus providing a very stable panel design with temperature. The printed layer provides design flexibility, enabling more complex patterns, including slots, and fine tuning to a given operating frequency, while the aluminum panel is intended to be more generic and contribute mostly to the mechanical stability of the stack-up.

The feed system is a conical horn antenna, with its phase center located at the focal point **F** of the synthesized parabola, as schematically represented in Fig. 1. The circularly-polarized signal is generated with a stepped septum polarizer, enabling broadband and dual-circular polarization operation. The fractional bandwidth of the antenna system is primarily driven by the reflectarray geometry and unit cell performance, compatible with typical needs in X-band and K_a-band [12].

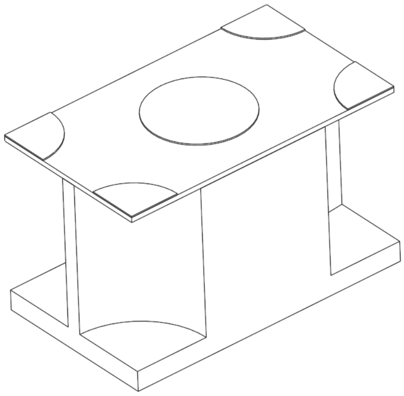


Fig. 3. Isometric view of the cavity-backed reflectarray unit-cell in a hexagonal lattice.

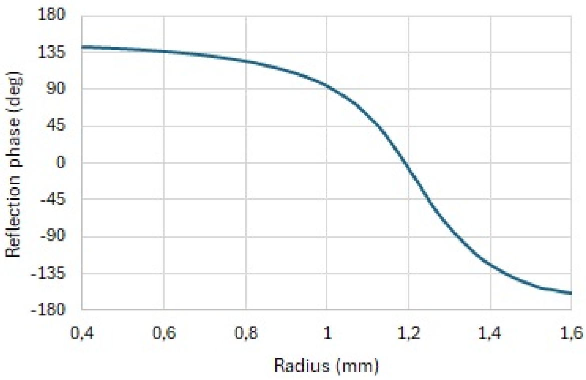


Fig. 4. Reflection phase versus the radius of the etched patch element at 30 GHz and for normal incidence (the cylindrical cavity has a diameter of 3 mm and a depth of 3 mm).

III. K_a-BAND REFLECTARRAY DEMONSTRATOR

A first reflectarray demonstrator was developed for operation in K_a-band with a gain in the order of 40 dBi. The operating bandwidth was set to 31.8 – 34.7 GHz, covering prospective future mission needs formulated by CNES. The antenna system is capable of operating in dual-circular polarization. Its focal length is set to $f = 270$ mm. The central panel has in-plane dimensions of 190 mm $\times$ 335 mm, while the lateral panels have dimensions of 199 mm $\times$ 335 mm. The metallic panel design achieves a flatness of 200 μm and the self-motorized hinges have an angular precision in deployed configuration of $\pm 0.1°$. The angles as defined in Fig. 2 were set to $\alpha = 74.2°$ and $\beta = 202.5°$. The pointing angle of the feed is set to $\theta = 35.7°$. A photograph of the demonstrator under test in the compact range available at CNES, Toulouse, France, is provided in Fig. 5. This demonstrator comprises a fixed supporting frame meant to be assembled directly on the platform. The HDRM is to be integrated on that supporting frame, but it was not included in the demonstrator since deployment tests were not foreseen as part of this development. The feed horn is visible in the foreground.

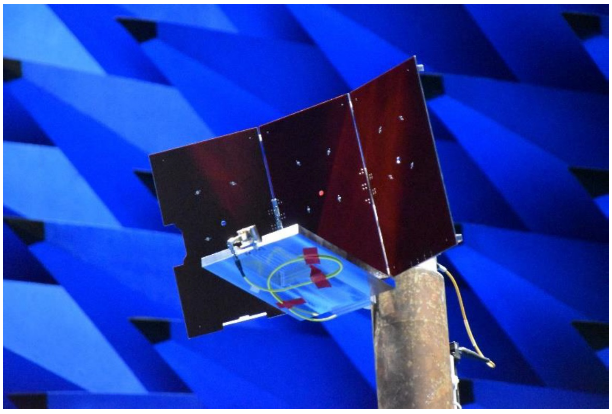


Fig. 5. K_a-band reflectarray antenna demonstrator under test in the compact range at CNES, Toulouse, France.

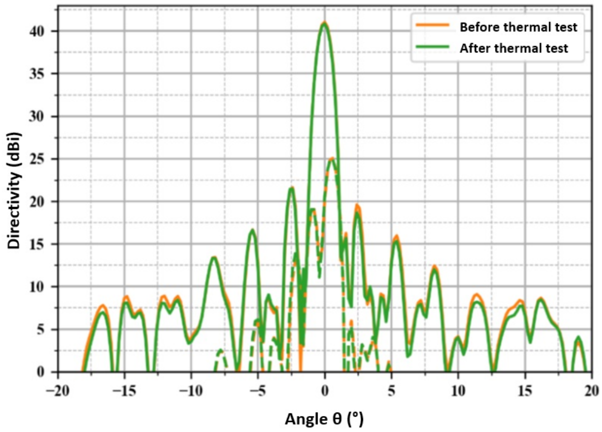


Fig. 6. Measured co-polarized (*solid lines*) and cross-polarized (*dashed lines*) radiation patterns at 32 GHz of the K_a-band reflectarray antenna demonstrator.

The measured radiation patterns at 32 GHz are shown in Fig. 6, including co-polarized and cross-polarized signals. The figure compares the measurements before and after thermal cycling, confirming the robustness of the mechanical design. The measured boresight directivity versus frequency is reported in Fig. 7, confirming that a minimum of 40 dBi is achieved over the desired operating range. The loss budget is evaluated to be in the order of 1 dB worst case, indicating a realized gain better than 39 dBi is achievable over the operating frequency band. The loss budget includes RF losses due to materials as well as peak gain degradation resulting from panel flatness and deployment uncertainties. Finally, the pointing deviation versus frequency is reported in Fig. 8, indicating the synthesis of the reference parabola is fairly stable across the considered operating frequency band. The residual deviation is due to the dispersive nature of the unit cell, which is considered acceptable for this antenna design. Overall, this demonstrator displays encouraging performance suitable for applications requiring very high gain antennas on CubeSats.

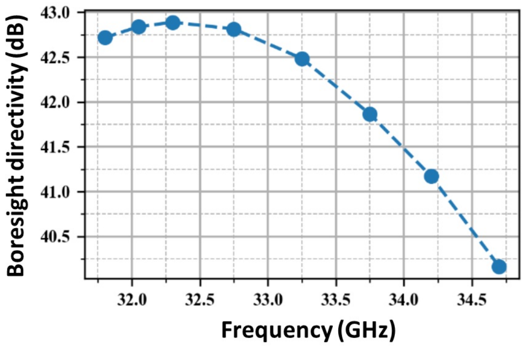


Fig. 7. Measured boresight directivity versus frequency of the K_a-band reflectarray antenna demonstrator.

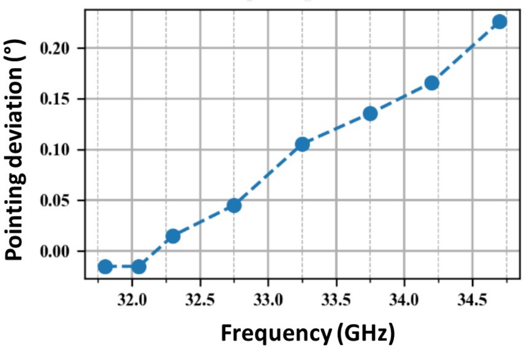


Fig. 8. Measured pointing deviation versus frequency of the K_a-band reflectarray antenna demonstrator.

IV. Conclusions

This paper reviewed the results of recent activities led by Anywaves and aiming at the development of a reflectarray antenna product for space missions onboard NanoSat platforms. In an effort to industrialize the concept, a generic configuration is proposed using a 6U form factor for the panels. The concept was validated in K_a-band with a fully representative engineering model. A similar design was successfully validated in orbit as part of a fast-track development, constituting the first commercial deployment of a reflectarray antenna in low Earth orbit. Activities are on-going to complete the qualification of the product and make it available to institutional customers as well.

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