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Ultra-wide beam scanning using a Conformal Transmit-array for Ka-band

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Abstract— **A conformal cylindrical transmit-array (TA) for ultra-wide mechanical beam steering is presented. The curved design allows to overcome the effective aperture size reduction caused by the beam tilt - intrinsic to all types of planar arrays. This design must also deal with the aberrations caused by feed displacement relative to the TA focus. Instead of using the usual unifocal approach, the TA phase correction was designed to have two pseudo-foci. In this way, the intrinsic phase error caused by feed displacement can be smeared among all beams improving the overall scanning performance of the antenna. The TA is composed of a collection of curved 5-layer stacked patches designed for the Ka-band uplink (30 GHz). The aperture has 215x143 mm in plane dimensions. The presented solution provides a 28.9 dBi maximum gain and scanning range up to 80º within 3.9 dB scan loss, which far exceeds the scanning performance of conventional planar TA.**

Index Terms—**Conformal antenna, transmit-array, beam steering, high gain, Ka-band satellite communications.**

I. INTRODUCTION

The continuous increase in the demand for broadband access with high mobility, fomented by the advent of the new generations of communication systems (5G, SoTM) is pushing the technology forward. Wireless millimeter wave communications (such as in Ka, V – bands) can potentially boost the current available throughputs. Cost-effective beam-steering, multibeam and beam-forming antennas assume a central role for these systems.

This work focuses on the design of a beam steering transmit-array (TA) antenna. We adopted a mechanical steering approach to minimize the antenna cost and avoid complex feeding networks (as in phase arrays) or active elements that greatly limits the radiation efficiency of the antenna [1]. It was shown in [2] that an offset TA design can achieve high gain (28 dBi) and wide-beam scanning: [-50,50º]. However, more extreme scanning ranges are often required. For example, in SoTM applications 75º azimuth scanning is a typical requirement for GEO satellites. The approach used in [2] is mainly limit by two factors: i) the aberrations caused by the feed displacement relative to the lens focus; ii) the intrinsic scan loss caused by the tilt angle relative to the boresight direction, α, of the planar aperture (given by the factor $\cos\alpha$). In [3] a different design approach, designated as the bifocal TA, was proposed to minimize effect i). Instead of having only a well-defined focus, the TA has two pseudo-foci. In this way, the intrinsic phase error caused by feed displacement can be smeared among all beams rendering a more uniform TA performance within the scanning range. However, even if aberrations caused by the feed displacement are neglected, beam tilts higher than 60º have intrinsically more than 3dB of scan loss relative to boresight collimation. This is true for general planar arrays. Herein, we propose a cylindrical TA design to overcome this physical limitation of planar apertures. We show that the TA design is not bounded to planar surfaces. Indeed, conformal designs may even be more suitable for the integration of the antenna in non-planar terminals, as is in airborne applications [4]. Conformal solutions for reflect arrays and phase arrays can be found in the literature [4]-[6]. However, as far as the authors are aware, there is still lacking the study of conformal TA for mechanical beam steering. The performance of the antenna is demonstrated using full-wave simulation in ® CST Microwave Studio [7]. The unit cells of the TA are of the same type as in [2] and the TA is illuminated by a 14.5 dBi horn antenna at 30 GHz, place at 105 mm from the aperture. The antenna provides a gain between 25 and 28.9 dBi for a scanning range between [-4,78º] at 30 GHz. This document is organized as follows: In section II we present the design principle of the TA. In Section III, we assess the performance of the TA using full-wave simulation. Finally, the main conclusions are outlined in Section IV.

II. DESIGN OF CONFORMAL TA

Let us consider a spherical wave source placed at $(x_{fi}, -F)$ as depicted in Fig. 1 . The collimation is achieved by compensating the free-space path between the source and the plane wave front, i.e.

$$\Phi_{lens}^{i} = k_0(R+L) \tag{1}$$

According to Fig. 1, the lengths R and L are obtained from the coordinates

$$\begin{cases} z_a = R_0 - \sqrt{{R_0}^2 + x_a^2} \\ x_{wf} = \sin(2\alpha_{0i})\frac{R_0 - z_a + \tan\alpha_{0i} x_a}{2} \\ z_{wf} = R_0 - \cos^2\alpha_{0i}(R_0 - z_a + \tan\alpha_{0i}\, x_a) \end{cases} \quad (2)$$

Instead of defining the phase correction of the TA based on the collimation of a single focal position (as usually done), we use the bifocal approach introduced in [3]. The bifocal phase correction is given by a weighted sum of two unifocal corrections

$$\Phi_{bifocal} = \frac{A_1\Phi^1_{lens} + A_2\Phi^2_{lens}}{A_1 + A_2} \quad (3)$$

The Gaussian weight functions have expected values aligned with the pseudo-focus positions and standard deviations adjusted according to the intensity of the TA illumination

$$A_i = e^{-\frac{x - x_{fi}}{\sigma_i}} \quad (4)$$

For the proposed design we used $x_{f1} = -58\,mm$, $\alpha_{01} = 57°$, $x_{f2} = -23\,mm$, $\alpha_{01} = 32°$. In the y-direction the cylindrical shape has 143 mm of depth to ensure a proper illumination taper by a 14.5 dBi horn antenna placed at 105 mm of the TA. The TA is composed of a collection of curved versions of the 5-layer stacked patches designed in [2] for the Ka-band uplink (30 GHz) (see Fig. 2). One should stress that to avoid misalignments each layer must have slightly different curvature ratios. In Fig. 2 we present the first layer profile of the curved TA.

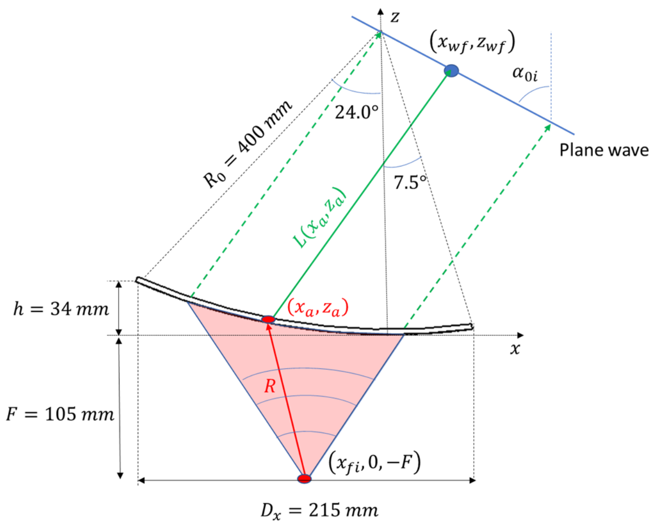

Fig. 1 - Curved Transmit array design

The mechanical scanning is analogous to the one proposed in [2]: the elevation scanning is obtained by displacing the feed along a line (x-axis) at constant height *F*, while rotating around an offset vertical axis (coaxial with the feed) provide the 360◦ azimuth scan.

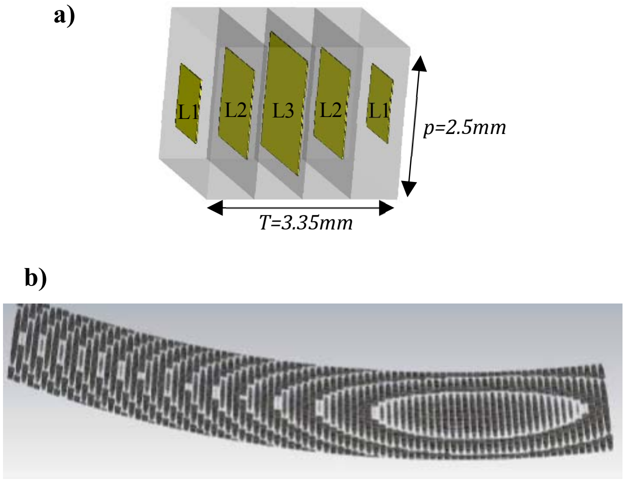

Fig. 2 – a) TA unit cell [2]; b) first layer of the TA

III. NUMERICAL EVALUATION

A displacement of 120 mm along the x-direction at $z = -105\,mm$ was considered. The corresponding radiation patterns are represented in Fig. 3. The 3dB scan loss is obtained for a scanning interval of 75º. The TA can still scan with low distortions up to 82 degrees, as show in Fig. 3. The side lobe level is always above 8 dB for all beams. Further optimizations can be conducted to reduce this level of aberration, which is also an important figure of merit. Nevertheless, the provide results show that the curved configuration can far extend the scanning performance of a planar TA.

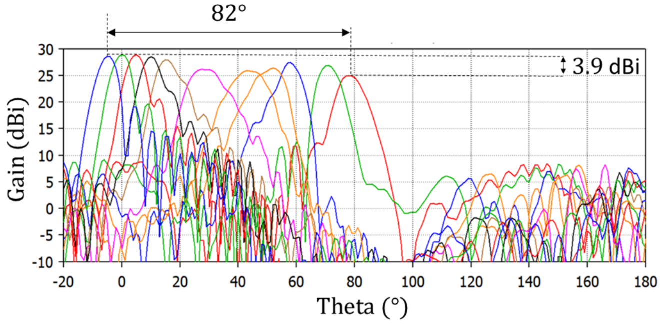

Fig. 3 – Radiation patterns of curved transmit array for a feed displacement of 130 mm for the focal distance $F = -105\,mm$.

IV. CONCLUSION

We have successfully demonstrated that a curved bifocal TA design can be used to provide ultra-wide beam scanning, compatible of SoTM applications. The developed antenna has an elevation scanning from [-75º, 75º] with 3 dB scan loss and maximum gain of 28.6 dBi. Experimental validation of this concept is being conducted.

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REFERENCES

[1] A. Clemente, L. Dussopt, R. Sauleau, P. Potier and P. Pouliguen, "1-Bit Reconfigurable Unit Cell Based on PIN Diodes for Transmit-Array Applications in X-Band," *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 5, pp. 2260-2269, May 2012.

[2] E. B. Lima, S. A. Matos, J. R. Costa, C. A. Fernandes and N. Fonsenca, “Circular Polarization Wide-angle Beam Steering at Ka-band by In-plane Translation of a Plate Lens Antenna,” IEEE Trans. Antennas and Propag., Vol. 63, No. 12, pp. 5443-5455, Dec. 2015.

[3] S. A. Matos, E. B. Lima, J. R. Costa, C. A. Fernandes and N. J. G. Fonseca, "Design of a 40 dBi planar bifocal lens for mechanical beam steering at Ka-band," *2016 10th European Conference on Antennas and Propagation (EuCAP)*, Davos, 2016, pp. 1-4.

[4] H. Schippers et al., "Conformal phased array with beam forming for airborne satellite communication," *2008 International ITG Workshop on Smart Antennas*, Vienna, 2008, pp. 343-350.

[5] P. Nayeri, F. Yang and A. Z. Elsherbeni, "Radiation characteristics of conformal reflectarray antennas," 2011 IEEE International Symposium on Antennas and Propagation (APSURSI), Spokane, WA, 2011, pp. 365-368.

[6] E. Vourch, G. Caille, M. J. Martin, J. R. Mosig, A. Martin and P. O. Iversen, "Conformal array antenna for LEO observation platforms," *IEEE Antennas and Propagation Society International Symposium*. 1998 Digest. Antennas: Gateways to the Global Network. Held in conjunction with: USNC/URSI National Radio Science Meeting (Cat. No.98CH36, Atlanta, GA, 1998, pp. 20-23 vol.1.

[7] CST Microwave Studio. [2018, Oct.]. Computer Simulation Technology [Online]. Available: http://www.cst.com.