Wide-angle mechanical scanning Transmit-arrays for satellite Ka-band user terminals

Sérgio A. Matos, Jorge R. Costa
Instituto de Telecomunicações, IST,
Instituto Universitário de Lisboa, (ISCTE-IUL)
Lisbon, Portugal
sergio.matos@lx.it.pt

Eduardo B. Lima, Parinaz Naseri, Carlos A. Fernandes
Instituto de Telecomunicações, IST
Universidade de Lisboa
Lisbon, Portugal,

Nelson J. G. Fonseca
ESA Antenna and Sub-Millimeter Wave Section
Noordwijk, The Netherlands

***Abstract*—The antenna design for broadband satellite communications is particularly challenging, new cost-effective solutions are still needed. An overview of recent contributions from the authors on planar transmit-arrays (TAs) for satellite Ka-band user terminals is presented. We tackle several design problems: how to improve the scanning coverage using low cost mechanical beam steering, how to choose the type of unit cells that compose the TA, how to devise a single aperture with high gain that operates simultaneous at two widely separate frequency bands. Different prototypes are used to conduct these studies. All these TAs provide wide beam zenith scanning, [-50º,50º] with less that 3dB of scan loss, good circular polarization performance and low beam distortions. The prototypes have the same aperture size, 195 × 145 mm², that provide gains up to 29 dBi for 30 GHz.**

Keywords—Transmit-arrays, high-gain antennas, wide-beam steering, mechanical scanning, dual band, circular polarization, satellite-on-the-move (SOTM), Ka-band.

I. INTRODUCTION

Transmit-arrays (TAs) and reflectarrays are being widely investigated for integrating the ground terminal antennas of the next generation of satellite communications that operates at Ka-band. TA based antennas, although requiring an additional design effort to achieve high transmissivity, do not suffer from the inherent feed blockage of reflect-arrays. The requirements for the ground terminal in satellite-on-the-move (SOTM) applications are particular challenging, which includes: high gain, wide-beam scanning coverage, multiband operation, pure circular polarization operation, low profile and weight. Furthermore, the antenna cost is another important factor to be considered, which makes mechanical beam steering an attractive technology. In [1] we proposed a simple mechanical beam steering antenna concept, where the wide-angle elevation beam steering is achieved using only in-plane displacements (Fig. 2). The elevation beam steering results from the in-plane translation of a thin offset flat lens in front of a stationary primary feed, while full azimuth coverage is obtained by simple 360◦ rotation of the lens. In this way, the mechanical movements do not impact on the antenna height.

Work partly funded by the European Space Agency under contract no. 4000109111/13/NL/AD, by the Fundação para a Ciência e Tecnologia under Projects mm-SatCom PTDC/EEI-TEL/0805/2012, PEst-OE/EEI/LA/0008/2013 and UID/EEA/50008/2013.

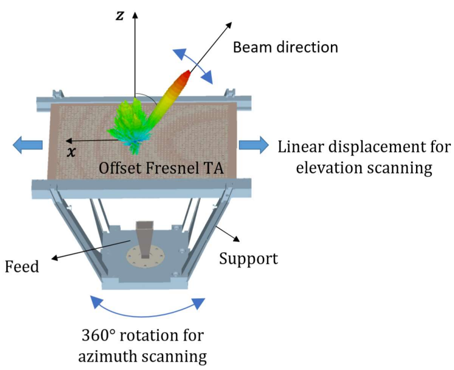


Fig. 1 -Working principle of the mechanical steering concept based on an offset Fresnel TA [1].

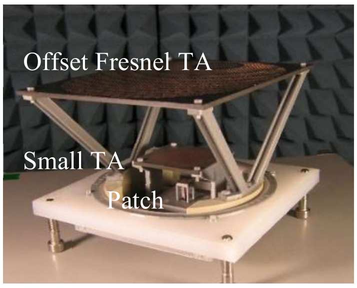
II. DEVELOPED PROTOTYPES

A. Single band TA at 30 GHz for wide beam scanning

We experimentally demonstrated a zenith scanning range between [-50º,50º] with a 3dB scan loss and 29 dBi maximum gain at 30 GHz for an aperture size of $14.5\,\lambda_0$ x$19.5\,\lambda_0$. Furthermore, in [1], we developed a new strategy to reduce the effective F/D of the focusing system and consequently the total antenna height without increasing beam distortion: a second small TA was added on top of the primary feed (a patch antenna) to create a virtual focus located well below the patch phase center (see Fig. 2b). This process allowed to reduce the focal distance to $F = 8\lambda_0$, using a transmit-array designed for $F = 10\lambda_0$, corresponding to an effective $F/D = 0.55$.

B. Phase rotation implementation of the single band TA

There are generally two approaches to generate different phase shifts for passive unit-cells. In the designated phase delay (PD) approach, the required phase span is provided by a discrete number unit cells with slightly different geometries. In the second method – phase rotation (PR) – a continuous phase shift, up to 360°, is obtained by different rotation angles of the same unit-cell. The latter operates only for circular polarization, whereas PD cells can be polarization insensitive. On the other hand, PR-TA acts as a polarization filter, providing a much pure circular polarization than the PD counterpart. A thorough comparison between these two types of transmit-arrays was conducted in [2]. In Fig. 3, we show the two developed prototypes that were compared, being the PD-TA the same as in [1].



Feed (small TA + Patch) for virtual focus

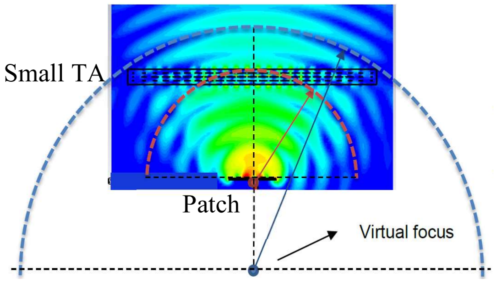


Fig. 2 – (a) Fabricated prototype for single band TA at 30 GHz, that implements the steering and virtual focus concepts proposed in [1]. (b) Simulation of the electrical field radiated by the feed and the change on the phase center positions as the field passes the small TA.

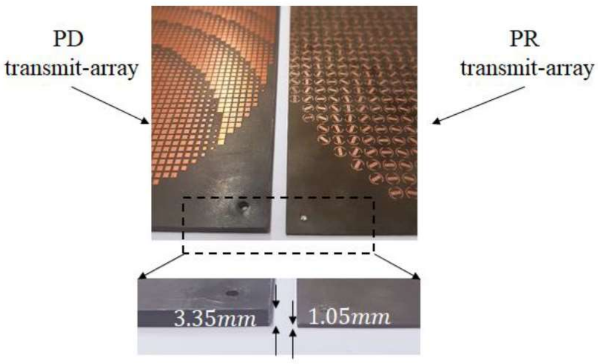


Fig. 3 – Comparison the PR and PD design approaches for transmit-arrays using the configuration represented in Fig. 2a [2]. The height of the TA was reduced by 1/3, the axial ratio was also reduced from 2.7 dB to 0.9 dB. Similar gains were obtained (29 dBi with 3 dB scan loss) and beam scanning up to 50º.

C. *Dual band Transmit-array for Rx and Tx Ka-bands*

Transmit array design is more challenging for dual band operation than for single band, due to the independent 360° phase wrapping jumps needed at each band when large electrical length compensation is involved. This happens when aiming at large gains. In [3] we presented a general method to reduce the complexity of dual-band transmit-array design, valid for arbitrarily large phase error compensation and any band ratio, using a finite number of different PD unit cells. Based on the same scanning working principle and aperture size of [1], a dual band prototype was evaluated [4]. A 27.4 dBi gain was obtained for 30 GHz and 24.4 dBi for 20 GHz (which is according to the expect effective area dependence with frequency). The 50º scanning results in a 2dB scan loss, where each feed position produces the same beam tilt for both frequency bands.

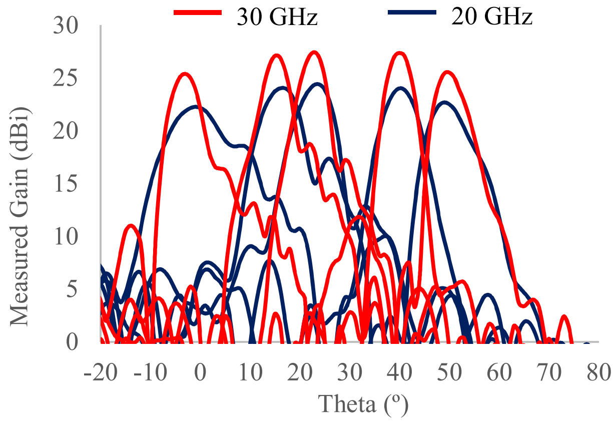


Fig. 4 - Circular polarization radiation patterns for 20 GHz and 30 GHz .

III. Conclusions

In this communication, we present an overview of our recent research in transmit-arrays. This integrated perspective allows to point out several challenges that this technology faces for SOTM terminals and highlight effective solutions. We demonstrate experimentally that high gain and wide-angle mechanical scanning can be accommodated in a single aperture with low profile, good circular polarization and dual band operation at Ka-band.

Acknowledgment

The authors would like to thank the collaboration from C. Brito, J. Farinha, and J. Felício for prototype construction and A. Almeida for prototype construction and measurements.

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