Reducing Beam Aberrations of Mechanical Scanning Transmit-array Antennas

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***Abstract*—There is a new demand for high gain antennas capable of achieving wide-angle beam steering in the microwave and millimeter wave (mmW) regimes. This work focuses on transmit-array (TA) antennas that steer the beam using only in-plane displacement of the TA or feed. We showed in previous works that, for some applications, this solution can be a viable alternative to the more costly electronic beam steering of phased arrays. However, it is necessary to balance the trade-offs between several factors such as gain, beam aberrations, antenna size, maximum scanning angle and the complexity of the mechanical steering system. This communication surveys different techniques that we developed to improve the overall scanning performance of these antennas.**

Keywords— Wide-angle scanning, Mechanical Beam Steering, Transmit-arrays, High gain, KA band, Satellite on-the-move

I. Introduction

Mobile communications, terrestrial or satellite based, are evolving to provide wireless broadband access everywhere, anytime, for everyone. To deal with the unprecedented data demand that follows, the operation frequencies of these systems are continuously increasing, trending to the mm waves. High gain is required to compensate for the path loss, but this calls for wide-angle beam steering to support user mobility. Antennas must be as compact and low-cost as possible. Electronic beam steering [1], although matching better beam agility and compactness requirements, is too costly and usually implies complex feeding networks with significant losses, especially at mm-waves. Mechanical beam steering is a more affordable alternative, although bulkier. These systems usually involve reflector antennas [2], 3-D lenses [3] or flat zone-plate lenses [4]. Planar geometries are usually simpler to fabricate and integrate. Lens-based systems do not suffer from feed blockage simplifying the deployment of the antenna system. In [4] we show that wide-beam steering can be obtained with a TA using only in-plane movements, favouring mechanical simplicity. By combining an offset Fresnel phase correction with the translation and rotation of the structure (see Fig. 1) it is possible to roughly double the scanning range relative to the typical configuration that uses TA for boresight collimation. We showed that this concept can be applied for different types of TAs [5] and generalized for dual band operation [6]. Beam scanning aberrations depend on the size of the aperture and focal distance. For elevation beam steering, the phase errors build up along the aperture as the feed is displaced away from the nominal focal point. This effect worsens as F/D decreases to favour low profile. We introduce a few new strategies to mitigate the effect, while keeping a reasonably low antenna profile. These involve the design of the TA aperture, of the feed or the co-design of both.

II. Strategies to Mitigate Scanning Aberrations

A. Virtual focus

This approach can be used to reduce the overall height of the antenna, maintaining the same scan loss of a larger focal length design. It involves the association of the primary feed with an intermediate lens or TA as in [4] (see Fig. 1). While increasing the primary feed (PF) directivity to ensure proper illumination of the main TA, the small auxiliary TA also shifts down the PF phase centre. Therefore, instead of being located near the PF aperture as usual, the phase centre of the feed assembly is located significantly behind the PF aperture. This technique was applied in [4], reducing the antenna height by 20% without affecting the overall scanning performance of the antenna.

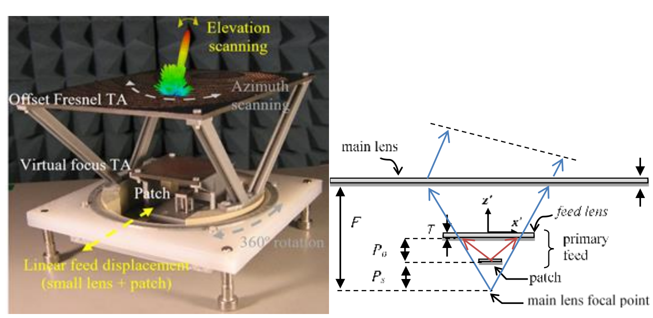

Fig. 1- Developed mechanical steering concept combined with the virtual focus approach [4]

B. *Multi-pseudo focal phase correction*

TAs are usually designed based on a Fresnel correction assuming a well-defined single focal position. However, we can optimize the TA phase correction to distribute aberrations evenly among all beams. In Fig. 2a) we show an example where the scanning performance of a conventional unifocal TA is severely affected because of the low $F/D = 0.33$. By designing the TA with the multi-pseudo focal phase correction, a very significant improvement of the overall performance of the TA can be achieved, as shown in Fig. 2b).

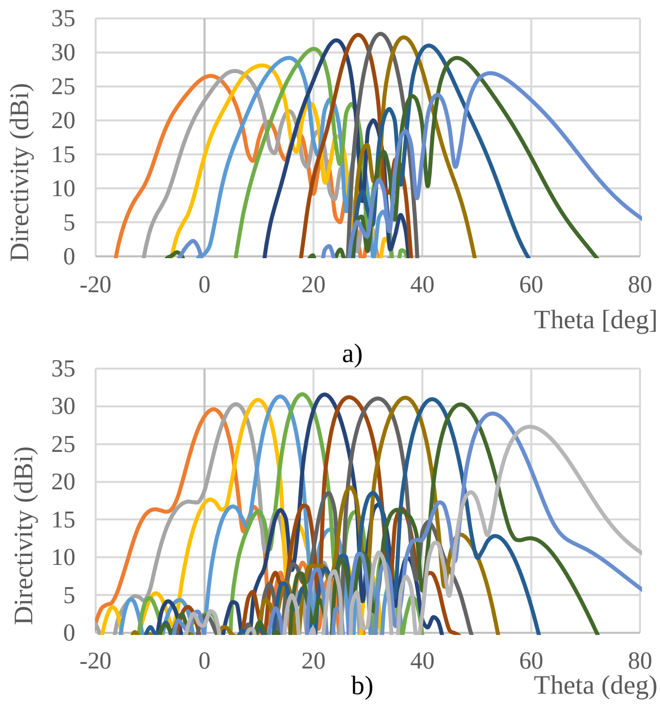

Fig. 2- GO/PO analysis of the radiation patterns of a TA with $F/D = 0.33$ and in-plane aperture size of $195 \times 145\ mm^2$ considering: (a) conventional unifocal phase correction; (b) multi-pseudo focal phase correction.

C. *Co-design of feed illumination and TA phase correction*

In all previous cases the TA is designed for a spherical illumination. However, by having a proper co-design between the incoming phase of the feed and the TA phase correction it is possible to avoid the intrinsic aberrations caused by the linear displacement of the feed. Using a GO/PO analysis we prove this concept for a high-gain TA antenna system with $F/D = 0.67$ and aperture size of $600 \times 450\ mm^2$. Because we are considering such a large aperture, aberrations rapidly dominate as the feed is displaced relative to the TA focal position, even for this conservative value of $F/D = 0.67$ (see dashed curved in Fig. 3). However, with the proposed technique almost perfect collimation is achieved for all feed positions (see blue solid curve in Fig. 3).

Due to the lack of available space, the details of the proposed methods as well as their range of applicability will be further explained on the presentation of this communication.

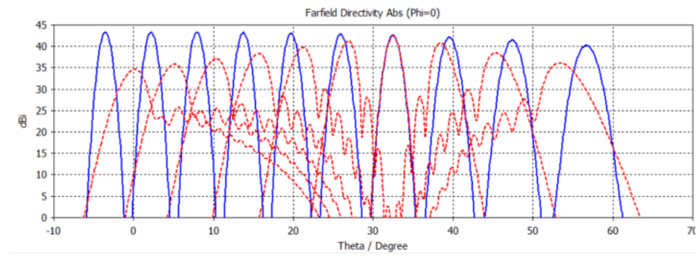

Fig. 3- Directivity of a TA with $F/D = 0.67$ and in-plane aperture size of $600 \times 450\ mm^2$ considering a conventional unifocal phase correction for spherical illumination (red dashed curve) and a co-design of the TA phase correction and the feed illumination (blue solid line).

ACKNOWLEDGMENT

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