Beam-Steering Ka-Band Phase Rotation Cells-Based Transmit-Array for Circular-Polarization

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***Abstract*— Planar transmit-arrays (TAs) have been an attractive solution as gain-enhancers for various applications, e.g. satellite communications. For the first time, a TA composed of sequentially rotated cells is employed as beam-steering circular polarization Ka-band satellite ground terminal. Moreover, it is shown that the intrinsic filtering effect of phase rotation (PR) cells for this kind of TA enables improvement in the axial ratio bandwidth. The performance of the TA is evaluated through simulation. The TA presents only 2.7dB loss over zenith scan between 15º and 50º while its structure rotation provides 360º azimuth scan. The TA offers 2GHz (28.7–30.7GHz) combined 3dB axial ratio and 3dB gain bandwidth.**

***Index Terms*—transmit-array, circular polarization, wideband antenna, satellite communication.**

I. Introduction

Passive printed transmit-arrays (TAs) have been an attractive solution to realize high-gain, low-cost, low-profile, and efficient antennas in point-to-point and satellite communications [1]. Particularly for Ka-band satellite communication, additional traits such as circular polarization, wide combined 3dB axial ratio and 3dB gain bandwidths, and beam steering are required.

In order to achieve the combination of the mentioned requirements, there have been an extensive research on proposing different types of unit-cells to populate a transmit-array [2]-[8]. In those works, the unit-cells outperform each other in one or another parameter like: better transmission coefficient, lower profile, etc. However, all those unit-cells types have the same working principle: each cell within the same type applies a discrete amount of phase shifts through slightly different dimensions of the objects that constitute the unit-cell. Those types of unit-cells are usually called phase delay (PD) cells.

Here, for the first time, we employ phase rotation (PR) cells to populate a TA for beam-steering. Although phase rotation cells have been employed for transmit-arrays before [10]-[11], none of these works have designed a beam-steering TA and studied its scanning loss. Moreover, here we present results that show that a phase rotation TA (PR-TA) can improve the axial ratio (AR) bandwidth of a circularly-polarized feed. This particular effect of a PR-TA stems from the fact that it filters the cross-polarization component of the feed. Moreover, the improved AR of the PR-TA leads to a wider combined 3dB axial ratio and 3dB gain bandwidth for the TA.

II. Beam Steering Phase Rotation Transmit-Array

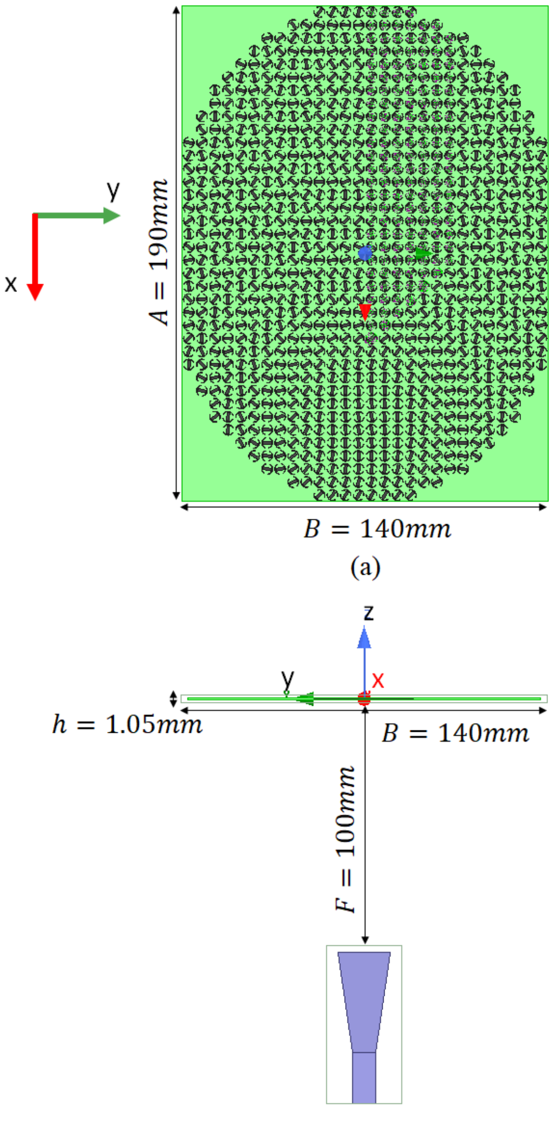
The proposed TA is composed of phase rotation unit-cells rotated by various continuous angles. This unit-cell is a modified version of the cells introduced in [11]-[12] so that it operates at Ka-band. As explained in [11], by rotating each cell up to 180º, it is possible to achieve any phase shift between 0º and 360º in the circular transmission coefficient of the cell. The metallic layers of the cells are separated by 0.508mm-thick Duroid 5880 ($\varepsilon_r = 2.2$ and $tan\delta$=0.0009). Therefore, the thickness of the TA is only 1.05mm taking into account the glue thickness to bond the two Duroid layers.

The designed TA is 190 mm×140 mm and composed of 38×28 PR cells. The rectangular shape of this TA is chosen to maximize the aperture efficiency when the feed is mechanically moved for beam steering [2] along the feed movement axis (x-axis) shown in Fig. 1(a). The phase shift function of the TA is calculated based on

$$\varphi_{lens}(x, y) = k_0\left(x \sin\alpha_0 - \sqrt{x^2 + y^2 + F^2}\right) \quad (1)$$

where focal distance F is 100mm and the collimated beam direction is α_0=32.5º when the feed is at the focal position [2]. The configuration of the designed TA is shown in Fig. 1 (a). The TA is fed by standard 14.5dBi gain Ka-band rectangular horn positioned at F=100mm from the surface of the TA, see Fig. 1 (b).

The horn antenna is then shifted along x-axis in Fig. 1(a) to steer the beam. Here, we shifted the horn from x=+30mm to x=–27mm which corresponds to steering the beam from 15º to 50º in zenith angle, respectively. Fig. 2 shows the LHCP and RHCP patterns of the PR-TA at 30GHz for different positions of the feed antenna. Fig. 2 confirms that the scanning loss of the PR-TA over this range is only 2.7dB and the cross-polarization level is more than -25dB in the beam widths of all the shown beams.



(b)

Fig. 1 (a) Top view of the PR-TA and (b) configuration of the PR-TA and the horn antenna used for full-wave simulations in ANSYS HFSS [13].

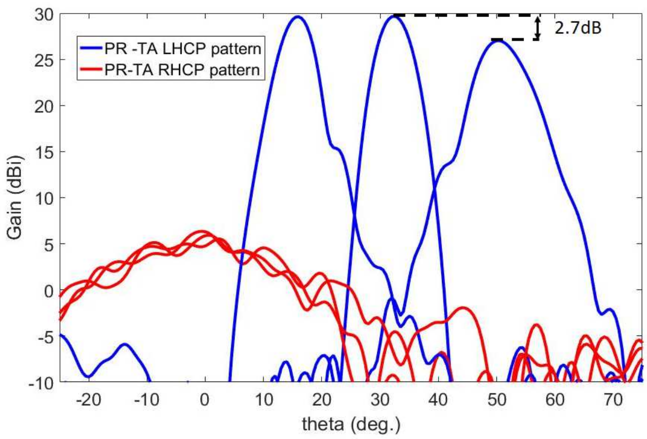


Fig. 2 LHCP and RHCP patterns of the PR-TA scanning from 15º to 50º at 30GHz when the feed is moved from +30mm to -27mm along the axis shown in Fig 1(a).

The performance of the TA for different frequencies is evaluated when the feed is at the focal position and the beam is directed to α_0=32.5º. To do so, the response of the TA to a circularly-polarized feed is synthesized by simulating the TA in front of the horn and its 90º-rotated one for both orthogonal linear polarizations. Each linear polarization configuration is simulated in ANSYS HFSS [13] using the hybrid finite element-boundary integral (FE-BI) method. Then, we intentionally post-processed the patterns of the horn antenna and the TA for the two linear polarization with phase difference ($\Delta\varphi$) based on (2) to first generate a circularly-polarized feed antenna with the axial ratio versus frequency presented in Fig. 3 and then find the response of the TA to such feed.

$$\Delta\varphi \;=\; 5\pi\frac{f}{f_0} - 4.5\pi \qquad (2)$$

where f_0 is the design frequency 30GHz.

As shown in Fig. 3, this post-processed feed has a $\sqrt{2}$ ($\approx$ 3dB) axial ratio bandwidth of 1.4GHz (29.3GHz–30.7GHz). However, it can be seen that despite the high axial ratio of the feed in some frequencies, the PR-TA always presents a good axial ratio and its axial ratio is below 1.2 in the whole 28GHz–32GHz bandwidth. The wideband axial ratio of a PR-TA stems from the filtering effect of its composing unit-cells toward the CP cross polarization component of the primary feed. The LHCP and RHCP gains of the PR-TA fed by the same post-processed feed in α_0=32.5º direction when the feed is at the focal position are shown in Fig. 4. This figure confirms that the PR-TA offers maximum gain of 30dB in LHCP pattern at 29.8GHz and it has a 3dB gain bandwidth of 2GHz (28.7–30.7GHz). Therefore, the PR-TA offers a combined 3dB gain and 3dB axial ratio bandwidth bounded only by the 3dB gain bandwidth of 2GHz.

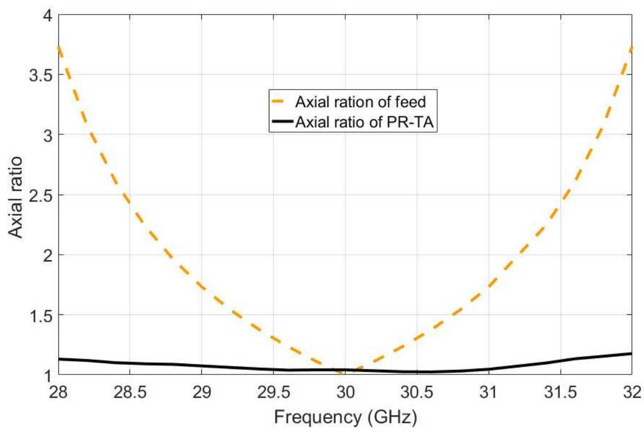


Fig. 3 Axial ratio of the post processed feed at broadside and the PR-TA at α_0=32.5º direction when feed is at focal position for different frequencies.

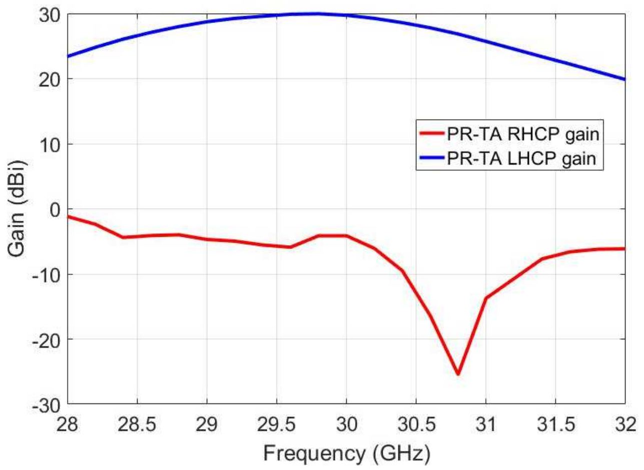


Fig. 4 LHCP and RHCP gains of the PR-TA at α_0=32.5º direction when feed is at focal position for different frequencies.

III. Conclusion

A transmit-array composed of sequentially rotated cells is proposed for steering circularly polarized beam at satellite communication Ka-band. The performance of the TA was evaluated by full-wave simulation, where it was shown that the TA can improve the axial ratio bandwidth of the primary feed. This leads to an improved combined 3dB gain and 3dB axial ratio bandwidth of 2GHz (28.7GHz–30.7GHz). Moreover, for the first time, this kind of TA is employed for beam-steering that presents only 2.7dB scanning loss over the zenith scanning range of 15º–50º.

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