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KA-BAND METAL-ONLY TRANSMITARRAYS FOR LOW-COST SATCOM TERMINALS

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ABSTRACT

A novel C-shaped unit-cell is introduced to design metal-only transmitarrays for low-cost solutions in Ka-band Satcom applications. The unit-cell is linearly-polarized and includes three layers with periodicity of 5 mm. It provides 360 degrees of phase-shift with a 3-dB fractional bandwidth of 2.8 GHz. Several transmitarrays have been designed with an F/D ratio equal to 1.1. They have been fabricated by ablation process using laser machining with high precision on 200- μ m-thick copper foil. The experimental results obtained for various main beam directions validate successfully the concepts proposed here.

1. INTRODUCTION

Satellite communications (Satcom) are an important feature in the fifth generation network (5G) to deliver services demanding high data rate and spot beam plan over extended geographical areas.

Transmitarray antennas (TAs) are promising antenna solutions for high-gain and beam forming applications, as demonstrated by numerous experiments. Thanks to their spatially-fed architecture and operation in transmission, TAs exhibit many advantages over traditional antennas in terms of feed blockage and feeding network losses. Many properties and characteristics of TAs have been investigated and accomplished using mature printed-circuit-board (PCB) technologies which require dielectric substrates as a support of metal layers and as a propagation medium. Low-loss dielectric substrates may lead to expensive implementations of TAs in practice and instability in harsh and/or outdoor environments. In recent years, metal-only transmitarray antennas (MOTAs) have been introduced to overcome this limitation [1],[2].

MOTAs have been reported at X- and Ku-bands with good bandwidth and high efficiency [3],[4]. Nevertheless, in order to provide a 360° transmission phase variation, four layers are required with an air-separation between layers equal to a quarter-wavelength at center frequency. Misalignment and fabrication tolerances are the main contributors to degradation of the radiation performance in addition to insertion loss, phase quantization and spillover radiation.

The objective of this paper is to present a novel design of metal-only unit-cell and experimental results of MOTAs, with a reduced number of metal layers. The proposed unit-cell is linearly-polarized and includes three layers (receiving, intermediate, and transmitting layers) separated by air gaps, with a square lattice size of 5 mm (i.e. half-wavelength in the free space at 30 GHz). The C-slots in the intermediate and transmitting layers are rotated each by 45°-consecutively to radiate in orthogonal polarization (for instance, a horizontally-polarized incident wave can be collimated in a given direction into a vertically-polarized transmitted wave). A 360°-phase-shift has been achieved by varying the inner radius of the C-slot while the outer one is fixed to keep the rigidity of the layer.

Several MOTA prototypes with different radiation properties have been fabricated by laser ablation using 200- μ m thick copper foils. The prototypes are made of 125 unit-cells arranged in 25-by-25 square matrices and illuminated by a 15-dBi standard gain horn with an F/D ratio equal to 1.1 to maximize the gain at 29.5 GHz. The layers are assembled with 3-mm separation and fixture holes are placed around edges. The beam radiated by these prototypes point in different directions, particularly at 30° in H-plane for prototype #1 and at 50° in E-plane for prototype #2.

2. METAL-ONLY UNIT-CELL

The proposed unit-cell model is illustrated in Fig. 1(a) and Fig.1(b). Each metal layer is made of a 200- μ m thick brass plate whose conductivity equals 1.5×10^7 S/m. The transmission band of this structure, thus its transmission phase, is tuned by varying the inner radius (R_i , Fig. 1c) of the C-shaped slot between 1 mm and 1.8 mm, while its outer radius (R_o) is kept constant (2.3 mm). A 0.8-mm-width bridge (G) keeps the inner disc in direct contact with the entire metal sheet. The spacer between layers is 3 mm-thick (convenient value to ease prototyping). The detail parameters are depicted in Fig. 1(c).

The unit-cell exhibits promising polarization properties, which is a key technique in this architecture. Particularly, to change polarization orthogonally with

metal-only structures (i.e. without any metallized via hole), we propose to rotate one layer with respect to the other, as represented in Fig. 1(a). In this study, the incident wave E_i is polarized along x-direction, while the transmitted one E_t lies along y-direction. The solution to obtain a 90° polarization rotation is to change gradually the polarization of the transmitted wave inside the unit-cell until it reaches the top layer. Fig. 1(a) and Fig. 1(b) illustrate this principle with a rotation step of 45° in clockwise (CW) and counter-clockwise orientation (CCW) respectively, the rotation direction being typically defined by the direction of the slot in the intermediate layers.

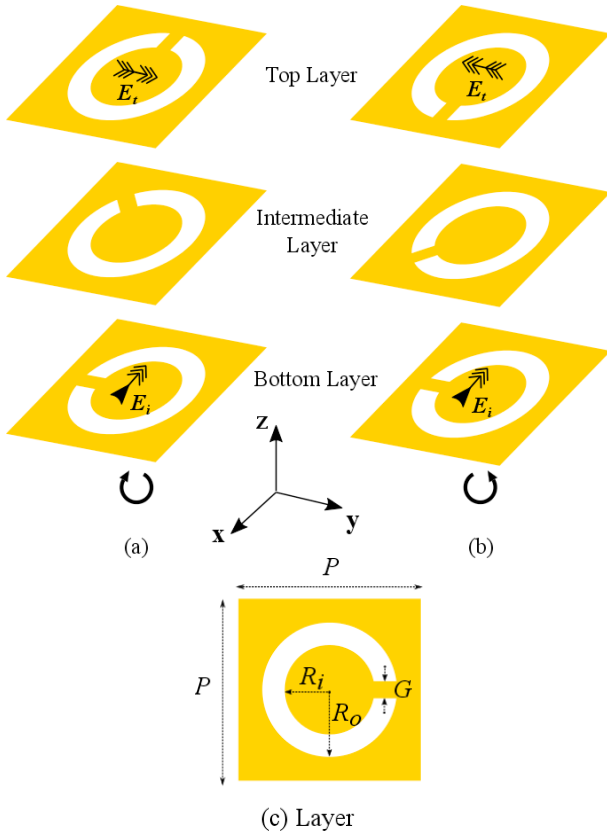


Figure 1. Ka-band metal-only unit-cell (a) Clockwise structure, and (b) Counter-clockwise structure.

The variation of the transmission magnitude and phase are depicted in Fig. 2 at 29.5 GHz as a function of the inner radius of the C-slot. More than 260° of phase shift is obtained for either CW or CCW structure (Fig. 2(b)). Due to the rotation in two opposite directions, the electric current flows on the radiating layer are opposite between CW and CCW structures. As a results, a 180° phase difference is obtained over a wideband and for the whole range of variables (Fig. 2(b)). Therefore, combination of two structure allows reaching a 360° phase shift while the loss remains below 1 dB (Fig. 2(a) for R_i from 1.3 mm to 1.7 mm).

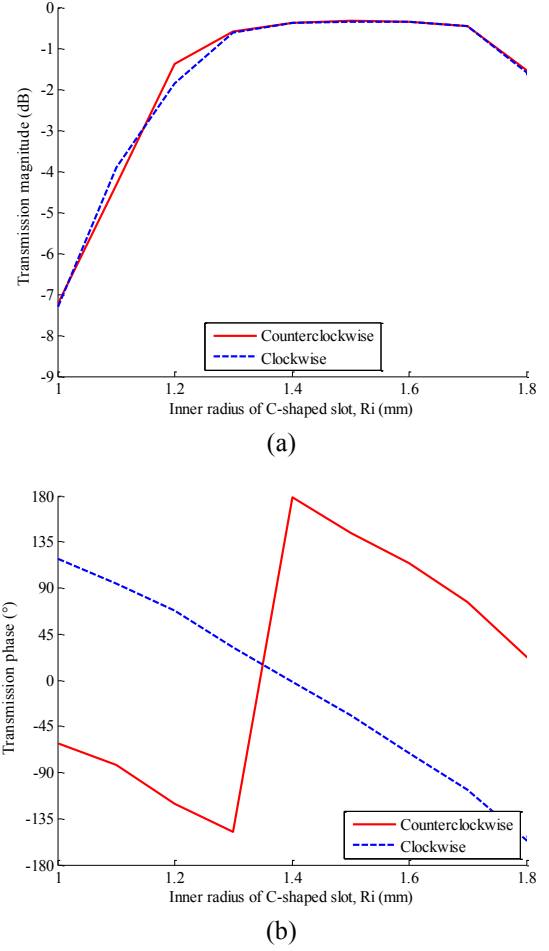


Figure 2. Transmission coefficients of clockwise and counter-clockwise structures at 29.5 GHz (a) Magnitude, and (b) Phase.

3. METAL-ONLY TRANSMITARRAY DESIGN

Various prototypes have been designed using our in-house computer-aided design (CAD) tools to synthesize the layout and to define the radiation performance, for example in [5]. The MOTAs have been also simulated using finite-element boundary-integral equations (FEBI) introduced by Ansys HFSS v.15. The 125-element MOTAs are based on the proposed unit-cell presented in Section 2 and are illuminated by a 15-dBi standard gain horn, which leads to an F/D equal 1.1. The focal length is optimized to maximize the gain at 29.5 GHz with a beam radiating at boresight. In this paper, two prototypes are considered: MOTA #1 exhibits a 30°-offset beam in H-plane while MOTA #2 steers the beam at 50° in E-plane. The phase layouts are shown in Fig. 3(a) and Fig. 4(a) for prototype #1 (MOTA #1) and prototype #2 (MOTA #2). The prototypes have been fabricated by ablating the C-shaped slots in thin copper foil sheets. The three metal layers are assembled using 3mm-thick foam spacers. The prototypes are shown in Fig. 3(b) and Fig. 4(b).

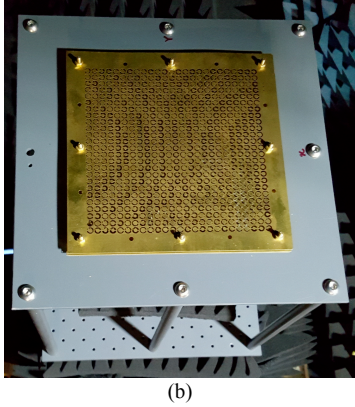
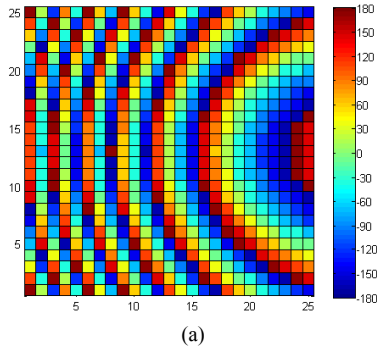


Figure 3. MOTA #1 with a main beam tilted at 30° in H -plane. (a) Phase across aperture at 29.5 GHz. (b) Prototype.

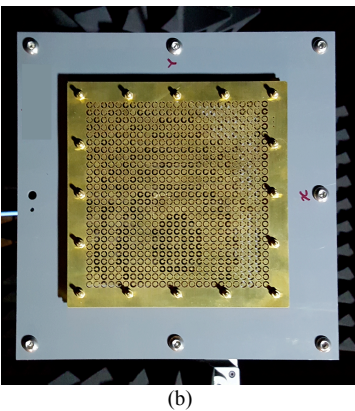
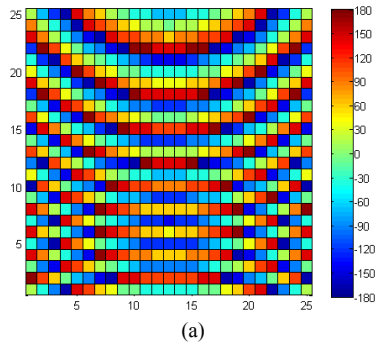


Figure 4. MOTA #2 with a main beam tilted at 50° in E -plane. (a) Phase across aperture at 29.5 GHz. (b) Prototype.

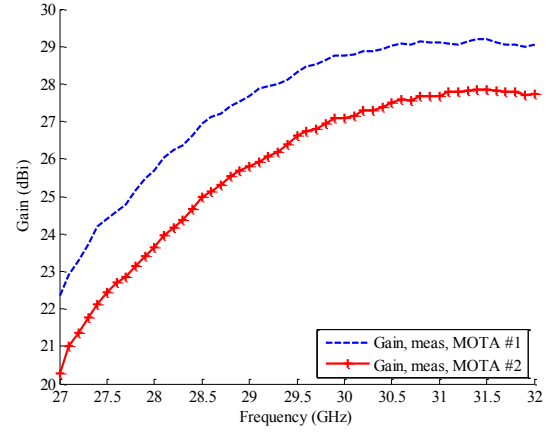


Figure 5. Measured gain versus frequency of MOTA #1 and MOTA #2 at Ka-band.

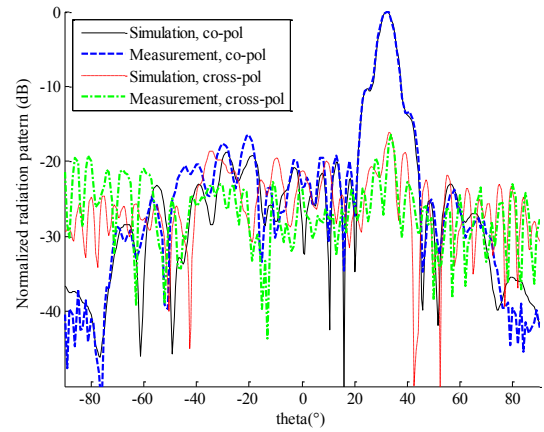


Figure 6. Normalized co- and cross-polarization components of MOTA#1 in H -plane at 27.5 GHz.

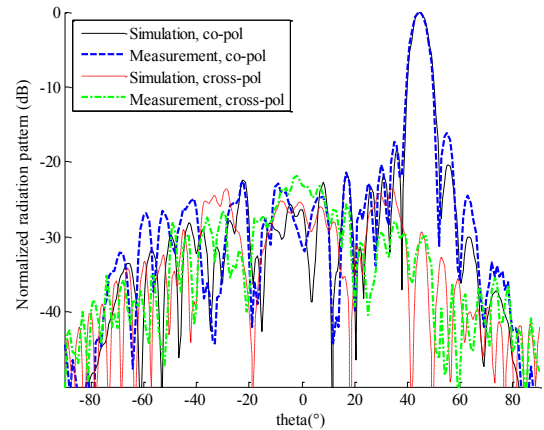


Figure 7. Normalized co- and cross-polarization components of MOTA#2 in E -plane at 32 GHz.

4. EXPERIMENTAL RESULTS

Experimental characterization of the fabricated prototypes demonstrate wide bandwidth and high

efficiency for a large scanning angle. The gain at 29.5 GHz is 28.3 dBi and 26.6 dBi for prototypes #1 and #2 respectively. The 3-dB bandwidth is 7.5 % around 29.5 GHz (Fig. 5). The measured and simulated patterns in co- and cross-polarization exhibit very good performance. For example, Fig. 6 illustrates the radiation of MOTA #1 at 27.5 GHz and Fig. 7 exhibits the radiation pattern in E-plane at 32 GHz.

5. CONCLUSIONS

The paper presents experimental results of low-cost TAs designed by using metal-only unit-cell to provide arbitrary beams. The unit-cell is based on C-shaped slot with transmission phase shifted with respect to the variation of the inner radius. Phase shift reaches 360° with insertion loss below 1 dB at 29.5 GHz

To conclude the proposed metal-only unit-cell and TAs are very attractive for 5G Satcom applications, both in ground and space segment due to their cheap implementation and robustness (resistant to weather conditions and temperature fluctuation).

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