Design of a 3-Facet Linearly-Polarized Transmitarray Antenna at Ka-band

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***Abstract*—This contribution presents the design of a 3-facet transmitarray operating at Ka-band. The proposed design methodology and initial numerical analysis are presented. The study is validated by electromagnetic (EM) simulation of a 400-element linearly-polarized 3-facet transmitarray antenna.**

Keywords—transmitarray; faceted arrays; Ka-band.

I. Introduction

A transmitarray (TA) is typically composed of a planar, faceted or conformal array realized in PCB (Printed Circuit Board) technology and illuminated by a focal source or a focal array (Fig. 1). The phase shift associated to each array element (unit-cell) is tuned to collimate the radiated beam in a specific direction. Various types of TAs have been introduced at millimeter waves, e.g. with high-gain fixed beam [1],[2], dual-band / dual-polarization [3] or beam-steering capabilities [4]. Thanks to their spatial feeding architecture and beamforming capability, TAs are an excellent candidate for the development of innovative low-profile antennas for SATCOM-on-the-move (SOTM) terrestrial terminals at Ka-band. From the array theory, it is well known that element radiation patterns and array geometry have an impact on the scanning capability and performance. As in the case of phased arrays and reflectarrays, the scan range of a TA could be increased using a conformal or faceted radiating aperture. Furthermore, a faceted architecture can enhance the aerodynamics when the antenna is mounted on the fuselage of an aircraft or reduce the visual impact of the antenna. Previous works on reflectarrays concluded that the use of a convex conformal architecture could increase the antenna bandwidth [5],[6].

The objective of this study is to investigate the feasibility of faceted TA and validate the proposed CAD tool through full-wave EM simulations.

II. Faceted Transmitarray: Design Methodology

To illustrate the design methodology, let us consider a 3-facet TA illuminated by a feed horn, as illustrated in Fig. 1. As well known, the relative phase of the electromagnetic wave radiated by unit-cell m can be written as

$$\varphi_m^{tr}(x_m, y_m, z_m) = \varphi_{FS}(\theta_m, \phi_m) - k_0 r_m + \varphi_m^{inc}(\theta_{FS}, \phi_{FS}) + ph(S_{21}^m), \quad (1)$$

where $\varphi_{FS}(\theta_m, \phi_m)$ is the phase radiated by the focal source towards the direction (θ_m, ϕ_m) of unit-cell m, k_0 is the wave number in vacuum at the center frequency f_0, $r_m = \sqrt{(F + z_m)^2 + x_m^2 + y_m^2}$ is the distance between the phase centers of the focal source and the unit-cell m, F is the focal distance, (x_m, y_m, z_m) are the coordinates of unit-cell m, $\varphi_m^{inc}(\theta_{FS}, \phi_{FS})$ is the phase of the radiation pattern of unit-cell m in the incident direction (θ_{FS}, ϕ_{FS}) from the focal source, and $ph(S_{21}^m)$ is the phase shift introduced by unit-cell m.

On the other hand, the main beam of a planar phased array can be steered in direction (θ_0, ϕ_0) using a simple linear phase distribution across the array aperture, as given by

$$\varphi_m(x_m, y_m, z_m) = -k_0 sin(\theta_0) cos(\phi_0) x_m - k_0 sin(\theta_0) sin(\phi_0) y_m - k_0 cos\theta_0 z_m \quad (2)$$

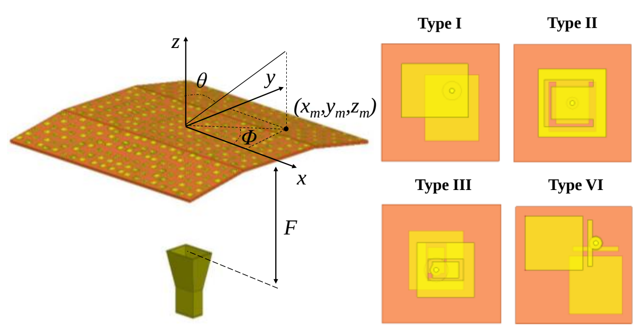

Fig. 1. Schematic view of the 3-facet TA and corresponding unit-cells.

By combining (1) and (2), the required phase shift for each unit-cell can be derived as

$$ph(S_{21}^m) = k_0(r_m - sin(\theta_0) cos(\phi_0) x_m - sin(\theta_0) sin(\phi_0) y_m - k_0 cos\theta_0 z_m) - \varphi_m^{inc}(\theta_{FS}, \phi_{FS}) - \varphi_{FS}(\theta_m, \phi_m) \quad (3)$$

Eqn. (3) is used to define the phase distribution over the TA aperture and scan the radiated beam in 2D over a large angular window. Ideally, a continuous 360° phase tuning range would be desired. Practically, the desired phase law is quantized to make a trade-off between unit-cell complexity (number of dielectrics and metal layers), fabrication tolerances, bandwidth, and aperture efficiency. In this paper, a 3-bit phase quantization is considered.

Table 1 reports the maximum gain of a 3-facet TA and compares its performance with the one of the planar array of same number of unit-cells. The TA is composed of 400

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elements arranged on a three-panel 20×20 lattice (the central panel and lateral panels contain 8×20 and 6×20 elements, respectively). Both lateral panels are inclined by an angle α with respect to the central panel. Here 3 values are considered for α: 10°, 30° and 70°. All numerical results have been obtained assuming ideal unit-cells and focal source ($cos^n\theta$, n=4) with 100% efficiency. The bandwidth of the different configurations is plotted in Fig. 2. For a strongly faceted array (α = 70° here), the beam scanning range and the bandwidth of the TA are improved, but a gain loss is observed compared to planar configuration.

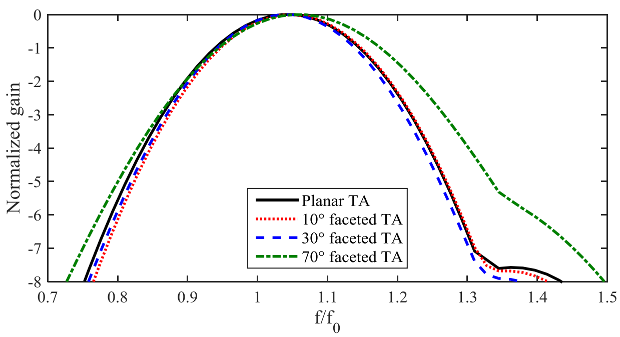

Fig. 2. Normalized gain versus frequency of the planar and 3-facet TAs.

TABLE I. MAXIMUM GAIN OF THE 3-FACET TA AS A FUNCTION OF THE DESIRED SCAN ANGLE

	Gain dBi (actual scan angle)			
Desired scan angle (°)	**Planar**	**3 facets α = 10°**	**3 facets α = 30°**	**3 facets α = 70°**
0	29.1 (0°)	29.2 (0°)	29.1 (0°)	27.4 (0°)
10	29.0 (10°)	29.0 (10°)	28.9 (10°)	27.2 (10°)
20	28.8 (20°)	28.8(20°)	28.7 (20°)	26.4 (19°)
30	28.5 (30°)	28.5 (30°)	28.3 (30°)	26.1 (30°)
40	27.9 (40°)	28.0 (40°)	27.7 (40°)	25.9 (40°)
50	27.1 (49°)	27.2 (50°)	26.8 (50°)	25.5 (50°)
60	26.1 (59°)	26.1 (59°)	25.2 (58°)	25.0 (60°)
70	24.7 (68°)	24.6 (68°)	23.9 (69°)	24.1 (70°)
80	22.9 (73°)	22.7 (74°)	22.0 (77°)	22.7 (78°)

III. 3-FACET TRANSMITARRAY

A. Linearly-Polarized 3-Bit Unit-Cell

The architecture of the unit-cells used in the study is based on three-metal layers (top patch, ground plane, and bottom patch) printed on two dielectric substrates. Four different architectures (Types I – IV, Fig. 1) have been used to implement the required phase states. As presented in [1] for each architecture, a 1-bit unit-cell is designed by physically rotating one patch by 180° around the metallized via used to connect the patch antennas printed on the top and bottom layer of the dielectric structure. The unit-cells exhibit transmission loss lower than 2 dB between 27 GHz and 32 GHz; the transmission phase between two consecutive states is around with a maximum error of 19°.

B. Transmitarray Simulation

Full-wave EM simulations have been performed to validate the theoretical methodology used to model faceted TAs. The 3-faceted (α = 10°) TA with 400 elements is based on the linearly-polarized unit-cells described in Section III.A. Comparison between the radiation patterns obtained with the numerical tool (Matlab) and full-wave simulations are presented in Fig. 3, and show excellent agreement. Additional results for different geometries and scanning angles will be presented at the conference.

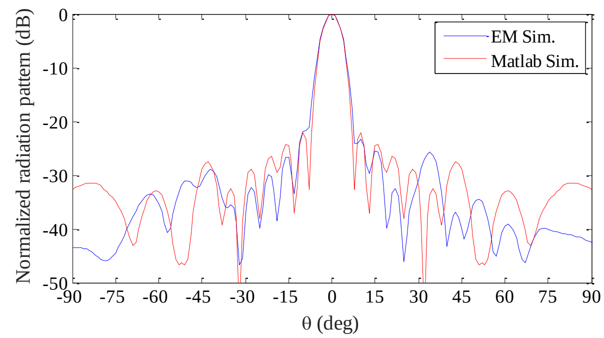

Fig. 3. Simulated normalized radiation pattern of the 3-facet TA computed on the E-plane at 29 GHz.

IV. CONCLUSIONS

In this paper, the principle of faceted transmitarrays has been described in detail. The numerical implementation of the 3-facet transmitarray was validated through 3-D electromagnetic simulations. Good agreement has been obtained between the theoretical and simulated results. We showed that for a certain angle of the faceting, the bandwidth and the scanning performance of the TA are improved at the cost of gain reduction. The objective of this paper, is to present and validate the proposed design methodology. Additional studies considering different array sizes will be presented during the conference.

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