Wideband Bifocal Dielectric Transmitarray

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***Abstract*—In this paper, some numerical results on the scanning capabilities of a bifocal dielectric transmitarray (TA) are presented. The TA surface has been discretized with three-layer unit cells: the central one presents a varying size square hole, used to control the phase of the transmission coefficient, while the two identical, external layers are characterized by a truncated pyramid hole and they act as matching elements. The computed antenna radiation patterns stay quite stable of an angular range of $\pm 40°$, keeping in each of the considered direction of maximum radiation a 1-dB gain bandwidth larger than 23%.**

***Index Terms*—Transmitarray, Wideband, Scanning beam.**

I. Introduction

In the last years, Transmitarrays (TAs) [1] have been considered as an effective alternative to reflectors and arrays for the realization of high gain antenna. They are good candidates for the realization of low-cost antenna for satellite communication, comprising the new 5G systems and radar, working at frequencies ranging from X to Ka bands. They can be made of several layers of metallic patches, printed on thin substrates, at their turn separated by air gaps, or they can be completely dielectric structures, consisting in a single or multiple layers of equal or different materials.

Recently, transmitarrays have been also considered for the realization of a beam-scanning system. The easiest way to achieve this goal is to introduce active elements as varactors [2] [3] or p.i.n. diodes [4], [5] in the unit-cell: the resulting radiating performances are good, but the antenna complexity increases. An alternative consists in using a passive TA, illuminated by a moving feed or by a feed array. In this case, the antenna performances deteriorate fast, especially because of the strong dependence of the unit-cell behavior from the direction of arrival of the incident field. This phenomenon is partially compensated using a unit-cell whose transmission coefficient is slightly affected by the angle of incidence of the incoming field. The unit-cell described in [6] provides such kind of features: it consists in a three-layer dielectric structure, where the central layer has a square hole whose size in changed to control the phase of S_{21} while the two external, identical ones present a tapered hole and act as broadband matching circuits. The transmission coefficient phase curves are essentially translated version on of the other when the angle of incidence changes, they keep linearity and almost the same slope. In view of these improved features, in [7] some numerical and experimental results are reported, related to the possibility of obtaining a scanning of the beam simply rotating the relative position of the feed and the TA itself. The results in [7] confirm that the adopted unit cell is able to provide radiation patterns slightly affected by the variation of the direction of arrival of the incident field on an angular range of $\pm 30°$, while beyond these values the antenna performances degrade.

In order to improve the scanning capabilities of the TA, a possible alternative consists in designing it so that it simulates the behavior of a bifocal lens; this solution has already been adopted for the realization of a single [10] or a dual transmitarray configuration [11]. This concept can be also extended to a multifocal configuration, as implemented in [11]. In this paper, it is used in conjunction with the unit-cell described above, to the design of a medium-size TA working at millimeter frequency. The preliminary results reported in Section II, where they are compared with those obtained with a conventional TA, are very promising: the radiation patterns are improved for larger scanning angles, in terms of maximum value, side lobes and beam width.

II. Bifocal Transmitarray

A. Dielectric unit-cell

The transmitarray designed in this paper is based on the dielectric 3D-printable unit-cell introduced in [6]. It is characterized by three perforated dielectric layers: a mid layer with a square hole, connected with two external matching layers that have linear tapered sections allowing to improve the operating bandwidth. The phase of the transmission coefficient can be controlled varying the size of the square hole. The unit-cell was designed to work in Ka-band at a frequency of 30 GHz, using as dielectric material the commercial photopolymer VeroWhitePlus$^{\text{TM}}$, which has a dielectric constant of $\varepsilon_r = 2.77$ and loss tangent tan$\delta = 0.02$ in Ka-band. In order to overcome the manufacturing limitations still keeping good performances of the unit-cell and in particular a range of $360°$ for the phase of S_{21}, the periodicity of the square lattice has been fixed to L $= 0.3\lambda_0 = 3$ mm, the total height of the cell is $T = 3.3\lambda_0 = 33$ mm, the mid layer hole size varies between 0.5 and 2.65 mm and a separating wall thick 350 μm has been added between two following cells.

TABLE I: Transmitarray performances comparison

θ_f	0°	±10°	±20°	±30°	±40°
Gain	29.97 dB	29.3 dB	27.96 dB	27.07 dB	23.4 dB
Gain (bifocal)	27.37 dB	27.25 dB	27.27 dB	27.17 dB	26.15 dB
1-dB BW	23.5% dB	24.5%	26%	23%	26.7%
1-dB BW (bifocal)	23.1% dB	23.1%	27.7%	25.6%	25.7%
SLL E-plane	-22.6 dB	-20.4 dB	-16.0 dB	-11.1 dB	-4.4 dB
SLL E-plane (bifocal)	-10 dB	-9.8 dB	-12.2 dB	-16.1 dB	-14.9 dB

B. Transmitarray design

The dielectric unit-cell has been adopted to design a square bifocal transmitarray with 52×52 elements, corresponding to a size $D = 15.6\lambda_0 = 156$ mm. The required phase distribution of a bifocal lens is derived as the average of two different phase distributions calculated considering a different focal point of the source. If the source is a feed horn, this can be seen as two feeds positioned with a different offset angle respect to the TA center. To have a symmetric system, the two offset angles have been chosen to be $\theta_{f_1} = -40°$ and $\theta_{f_2} = 40°$. Therefore, the required phase distribution for the (m, n)-th element of the bifocal configuration has been computed as $\phi_{BF}(m, n) = (\varphi_1(m, n) + \varphi_2(m, n))/2$, where $\varphi_1(m, n)$ is the phase distribution needed in a configuration with the feed rotated of θ_{f_1}, while $\varphi_2(m, n)$ is phase distribution related to the second offset angle θ_{f_2}. The feed is the same circular horn employed in [7] and introduced in [8]: it works in Ka-band and provides a gain of 17 dB at 30 GHz. The horn is located at focal distance of 156 mm ($F/D = 1$) and its radiation pattern has been approximated with a cosine model $cos^q(\theta)$, with $q = 12.5$.

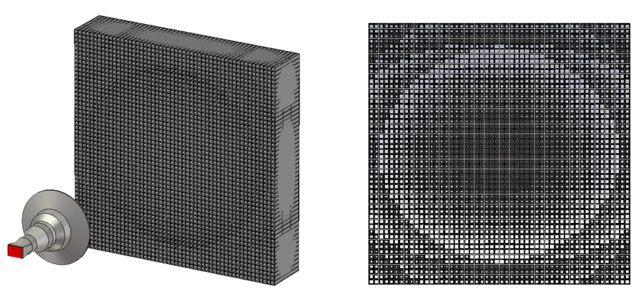

Fig. 1: CST model of the bifocal dielectric Transmitarray: **(a)** 3D view; **(a)** Front view of the dielectric transmitarray.

The bifocal transmitarray has been numerically simulated using CST MWS. The antenna radiation patterns have been evaluated for different positions of the feed in the angular range [-40,40]°, obtained moving the horn along a circular arc centered in the center of the TA itself. The 3D CAD model in CST of the structure is shown in Fig. 1, while the obtained radiation patterns in the E-plane computed at 30 GHz for different θ_f are shown in Fig. 2. They are compared with the measured radiation patterns obtained from the beam-scanning of the dielectric transmitarray designed in [7], which has the same size of the bifocal configuration here considered. As it can be seen from the curves, the maximum gain level of the bifocal TA remains almost flat in the scanning range between -40° and 40°, resulting in a scan loss of 1.2 dB. Comparing with the conventional center-fed TA that gives a scan loss of 6.6 dB in the same angular range, the bifocal configuration provides an improved scanning capability but lowering the maximum gain. A comparison of the radiation performances of both configurations is reported in Table I. Both TAs maintain the 1-dB gain bandwidth very large for all the scanning angle (>23%). The Side Lobe Levels (SLLs) are improved in the bifocal TA for the angles ±30° and ±40° and reduced for the angles 0°, ±10° and ±20°.

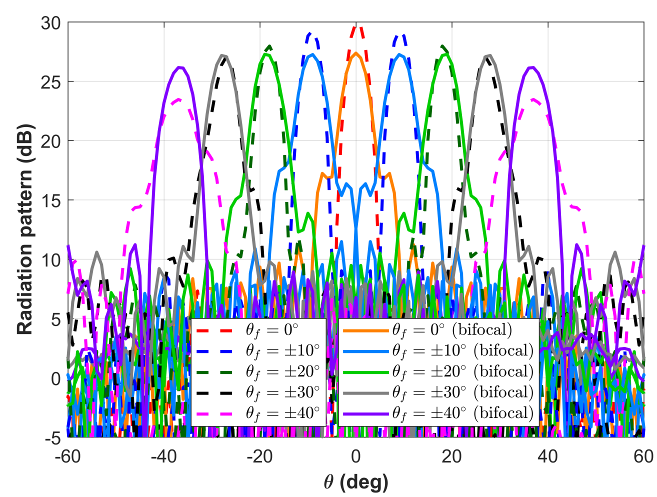

Fig. 2: Comparison of the radiation patterns (E-plane) at 30 GHz for different scanning angles.

III. Conclusion

In this work, the beam scanning capabilities of a dielectric bifocal transmitarray antenna have been analyzed and compared with those of a conventional center-fed TA. The numerical results about the radiation patterns for different scanning angles show good performances, presenting a flat gain level with a scan loss of 1.2 dB between the broadside direction and the maximum scanning angle. Besides the promising scanning capabilities, the bifocal TA provides a large 1-dB gain bandwidth over 23% for all the scanning angles.

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