Dual-Polarized Dual-Frequency Ka-band Transmitarray Lens

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***Abstract*—In this contribution, a new dual-frequency unit cell for transmitarrays is presented. This cell is based on a rectangular structure consisting of 4-stacked rectangular patches coupled 2-by-2 using a cross slot. One of the polarization is optimized to be transparent at 28 GHz, and the perpendicular one at 38 GHz. The cell provides a phase delay up to 300 degrees for each polarization at both frequencies. Furthermore, it allows to develop different radiation patterns for each frequency independently. In order to show the potential applications of this cell, a transmitarray antenna has been designed and simulated. The antenna can focus the energy on a near-field spot at 28 GHz using one polarization and it can also steer a beam to the broadside direction with the other polarization at 38 GHz.**

***Index Terms*—Near-Field, Far-Field, Transmitarray, Dual-Polarized, Dual-Frequency**

I. Introduction

Transmitarray (TA) [1] antennas have been gaining more attention in recent times, being their major advantages a lower profile and weight in comparison with other similar antennas like lenses or reflectors. In this sense, many designs have been proposed addressing different solutions for each application, being some of the most characteristic the ones presented in [2]-[5]. Nonetheless, in most cases, due to their resonant structure, they still present the drawbacks of narrow bandwidth and lack of versatility, although some improvements have been presented [6]-[8] in order to overcome these issues. Consequently, they are usually single-purposely designed. Therefore, if a system required two different working frequencies, two separate antennas would be necessary. This can limit the number of situations in which these antennas can be used, particularly in cases of embedded or weight-limited systems.

In order to overcome that limitation, a dual-polarized dual-frequency TA working at 28 and 38 GHz has been designed and validated, see Fig. 1. The dual-polarized dual-frequency unit-cell is based on a modification of a previous design [9], and was simulated using Full-Wave commercial software [10]. The results of that analysis are included in Section II. Then, in Sections III and IV a Near-Field (NF) and Far-Field (FF) dual-polarized dual-frequency antenna is designed and simulated to test the limitations of the structure. In this design, one of the polarizations, working at 28 GHz, behaves like a NF antenna focusing the energy at a point in the Z-Axis of the system, and the other, working at 38 GHz, presents a broadside FF radiation pattern. The results for this TA are analysed in Section IV, showing that it is feasible to combine these two different functionalities into a single antenna and therefore reduce the weight of the whole system. Conclusions are summarized in Section V.

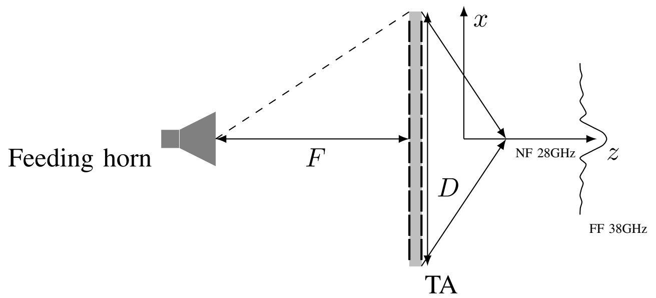


Fig. 1. Scheme of the Transmitarray antenna.

II. Unit Cell

The unit cell proposed for this work is a rectangular structure based on four-stacked rectangular patches coupled 2-by-2 by a cross, as shown in Fig.2. It is a modification of a previous design used to implement a dual-polarized antenna [9], where each side of the patches controls the phase-shift for each polarization. That design was chosen as the starting point for the proposed one because it had already proved to show good stability with frequency and the angle of incidence. In the new proposed unit-cell, each side of the patch works at a different frequency, that is, 28 GHz and 38 GHz. Hence, the physical periodicity of the structure is modified in order to maintain the electrical periodicity the same for each of the frequencies (0.35λ). For the dielectric layers, ROGERS™ 4003 ($\epsilon_r = 3.55$) is assumed, with a thickness of 18 mils.

This unit cell has been simulated using a commercial software [10], considering infinite periodicity in both directions and normal incidence. The results of this study can be seen in Figs. 3 and 4, showing that for both polarizations it is possible to obtain, at least for most cases, a 300-degree phase shift varying only the side of the patches that controls it, that is, s_x or s_y depending on the polarization. The cross-polar results have not been included since the structure has already shown good behaviour for that feature and each polarization works at a different frequency.

III. Lens Synthesis

Since the structure is dual-polarized dual-frequency, the synthesis of a TA will require to work with both polarizations

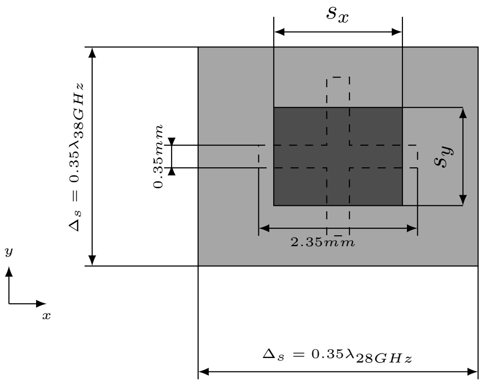
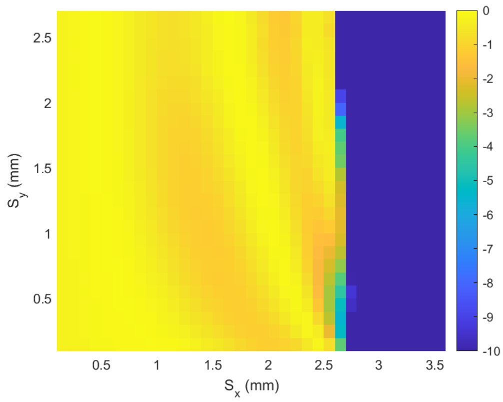
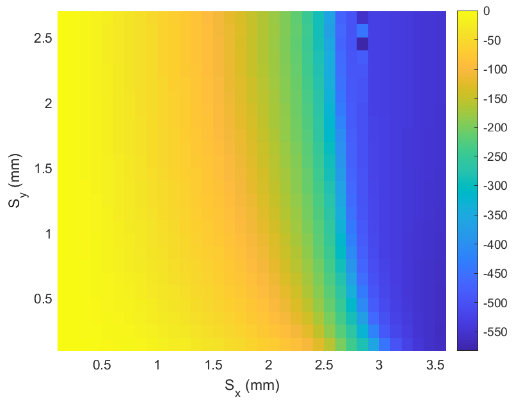


Fig. 2. Top view of the unit cell.



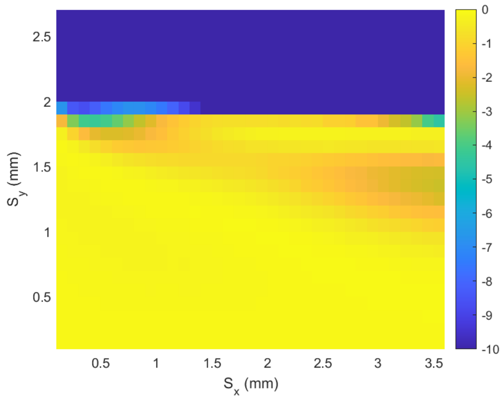
(a)



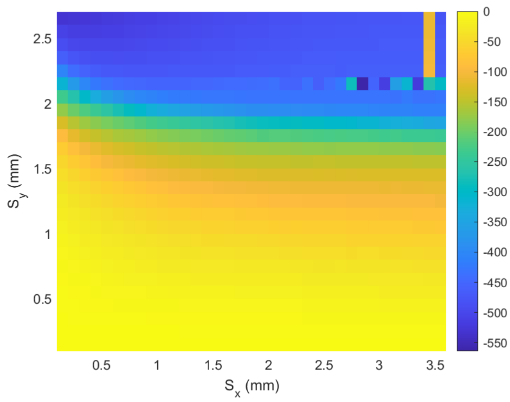
(b)

Fig. 3. Transmission coefficient simulated for the unit cell (28 GHz). (a) Module (dB). (b) Phase (degrees).

at the same time. Then, in the synthesis process the size of both sides of the rectangular patches is determined in order to minimize the combined phase error in each of the polarizations while maximizing the transparency of the unit cells, a procedure similar to the one used in [9]. Some details of this process are described in equations (1) to (3), where $\angle s_{21}^{xobj}$ and $\angle s_{21}^{yobj}$ are the necessary phase-shifts that each cell should introduce for each polarization, $\angle s_{21}^{xcell}$ and $\angle s_{21}^{ycell}$



(a)



(b)

Fig. 4. Transmission coefficient simulated for the unit cell (38 GHz). (a) Module (dB). (b) Phase (degrees).

are the achievable phase-shift for each combination of s_x and s_y; and, finally, $abs(s_{21}^{xcell})$ and $abs(s_{21}^{ycell})$ are the amplitude of the transmission coefficients. Thus the combination that minimizes (3) is the one chosen for each element of the TA surface.

$$\epsilon_x = \frac{|\angle s_{21}^{xobj} - \angle s_{21}^{xcell}|}{abs(s_{21}^{xcell})} \tag{1}$$

$$\epsilon_y = \frac{|\angle s_{21}^{yobj} - \angle s_{21}^{ycell}|}{abs(s_{21}^{ycell})} \tag{2}$$

$$\epsilon_{tot} = \epsilon_x + \epsilon_y \tag{3}$$

The expression is then similar to the one used in [9] for the dual-polarized antenna. However, since the structure of the unit-cell has changed due to the introduction of the frequency duality, it is necessary to prove again the stability of the synthesis process by simulating the prototype of an antenna.

IV. Prototype Simulation

The prototype simulated to test the potentiality of the synthesis procedure is a NF- and FF-antenna in which each

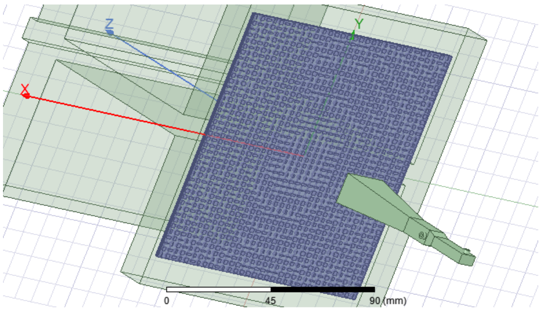
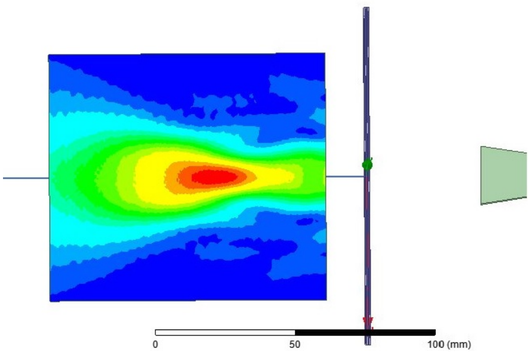
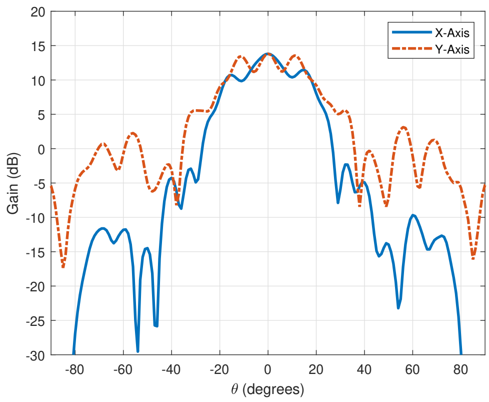


Fig. 5. Caption of the simulation.

polarization presents one of these two functionalities. Specifically, the TA, consisting of 32 by 42 elements (ca. 11 x 11 cm), works as a single-polarized NF-Transmitarray pointing at a distance of 110 mm from the lens surface at the lower frequency (28 GHz), and as a FF antenna presenting a broadside radiation pattern at the higher one (38 GHz). The simulation serves to prove both the versatility of the whole structure by combining two stand-alone single-polarized antennas in one single system and the synthesis procedure. That is, no lack of unit-cell periodicity or phase-error of the unit-cell cause any distortion in the performance of the TA.



(a)

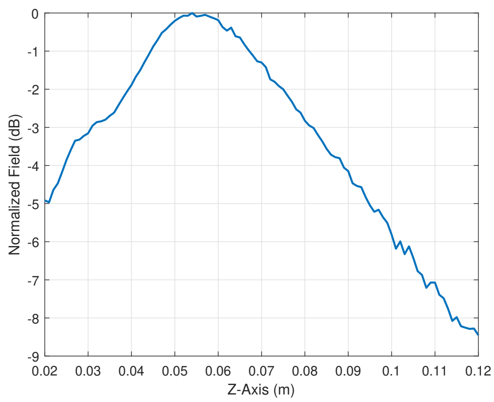


(b)

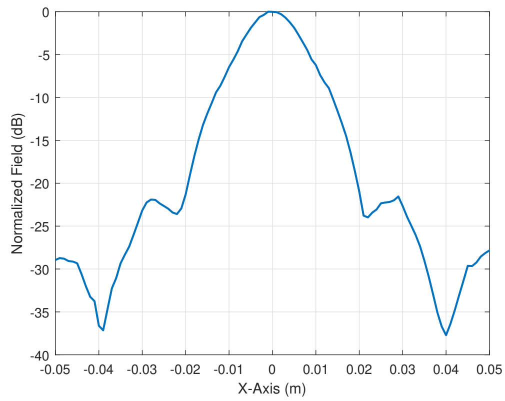
Fig. 6. TA simulation results (28GHz). (a) Near-Field. (b) Far-Field.

In combination with the presented TA prototype, a dual-frequency dual-polarized horn antenna is used to feed the system, similar to the one presented in [11], allowing for a more compact final design. The whole system has been simulated using the same commercial software as the unit-cell, as shown in Fig. 5.

The results of the simulation are depicted throughout Figs. 6a to 8b, showing that the antenna behaves as expected. On the one hand, Fig. 6 depicts the results for the X-Polarization working at 28 GHz, comparing its behaviour in the NF, see Fig. 6a, and the FF, Fig. 6b. It can be observed that the TA is focusing the radiated field at a point located in the NF of the antenna while, in comparison, its FF pattern is similar to that of the feeding horn. Moreover, in Fig. 7 the cuts of the NF of the antenna at 28 GHz in the Z- and X-Axis are shown. In these results, it can be seen that NF presents a maximum in the Z-Axis at 55 mm from the lens (Fig. 7a), closer than the initial focusing point, due to the small electrical size of the TA. In addition, along the X-Axis, Fig. 7b, the NF spot features a 3dB-beamwidth of 14 mm (1.3λ) at z = 55 mm. All these results show, therefore, that the NF behaviour can be validated.



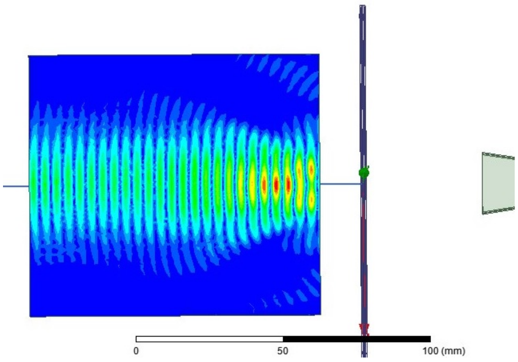
(a)



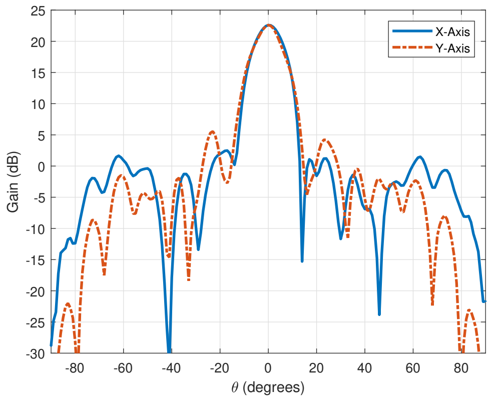
(b)

Fig. 7. Near-Field simulation results (28GHz). (a) Z-Axis. (b) X-Axis.

On other hand, Fig. 8 shows the results for the Y-



(a)



(b)

Fig. 8. TA simulation results (38GHz). (a) Near-Field. (b) Far-Field.

Polarization working at the frequency of 38 GHz. Contrary to the behaviour of the lower frequency, it can be seen in Fig. 8a that the TA does not focus the field in the NF of the structure, presenting the radiated field the characteristics of a plane wave propagating in the direction perpendicular to the plane of the TA. Moreover, these characteristics are supported by the radiation pattern of the antenna, shown in Fig. 8b. Thus, as for the lower frequency, the performance of the system for this second frequency is satisfactory, and therefore the prototype of a dual-polarized dual-frequency Near-Field Far-Field TA antenna is verified via simulations.

V. Conclusions

In this paper, a dual-polarized dual-frequency TA working simultaneously and independently, with each polarization, as a NF and a FF antenna is presented. Firstly, the unit-cell used in this structure has been validated, using a commercial software, in terms of stability and transmitted phase-shift, showing good behavior. A prototype TA was then designed and simulated in order to show that the entire system can perform properly. As a result, it could be possible to combine two different single-polarized TA working at different frequencies in a single complete system reducing the space and weight required for both applications.

Acknowledgment

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References

[1] D.M. Pozar, “Flat lens antenna concept using aperture coupled microstrip patches”, Electronics Letters, vol. 32, no. 23, pp. 2109 - 2111, Nov. 1996.
[2] S. Datthanasombat, A. Prata Jr, L.R. Amaro, and J.A.Harrel, “Layered lens Antenna”, 2001 Antennas and Propagation Symposium (APSURSI), pp. 777-780, 2001.
[3] A.H. Abdelrahman, F. Yang, A.Z. Elsherbeni, and A. Khidre, “Transmitarray antenna design using slot-type element”, 2013 Antennas and Propagation Symposium (APSURSI), pp. 1356-1357, 2013.
[4] R.H. Phillion and M. Okoniewski,“Lenses for circular polarization using planar arrays of rotated passive elements”, IEEE Transactions on Antennas and Propagation, vol. 59, no. 4, pp. 1217-1227, Apr. 2011.
[5] C.G.M. Ryan, M.R. Chararmir, J. Shaker, J.R. Bray, Y.M.M. Antar, and A. Ittipiboon, “A wideband transmitarray using dual-resonant double square rings”, IEEE Transactions on Antennas and Propagation, vol. 58, no. 5, pp. 1486-1493, May 2010.
[6] K. Pham, N. T. Nguyen, A. Clemente, L. Di Palma, L. Le Coq, L. Dussopt, and R. Sauleau, “Design of wideband dual linearly polarized transmitarray Antennas”, IEEE Transactions on Antennas and Propagation, vol. 64, no. 5, pp. 2022-2025, May 2016.
[7] Xi-Ji Yi, T. Su, B. Wu 2, J.-Z. Chen, L. Yang and X. Li, “A double-layer highly efficient and wideband transmitarray antenna”, IEEE Access, Vol. 7, pp 23285-23290, 2019.
[8] Y. Ge, C. Lin and Y. Liu, “Broadband folded transmitarray antenna based on an ultrathin transmission polarizer”, IEEE Transactions on Antennas and Propagation, Vol. 66, No. 11, pp 5974-5981, Nov. 2018.
[9] E. G. Plaza, G. León, S. Loredo, and F. Las-Heras, “Dual polarized transmitarray lens”, European Conference on Antennas and Propagation 2014, EuCAP, The Hague (Netherlands), Apr. 2014.
[10] ANSYS® Electromagnetics Suite , Release 2019 R1, Ansoft Corp., Pittsburgh, PA, USA, 2018.
[11] L. Li, Z. Shao, Y. Cheng, Q. Wang, and P. Li, “Design of a novel broadband compact dual polarized horn”, 2013 International Conference on Computational Problem-Solving (ICCP), Oct. 2013.