Contributions on Transmitarrays for Far-Field Applications

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***Abstract*—Different contributions made to the development of Transmitarrays (TA) for Far-Filed applications are presented in this contribution. Firstly, a unit cell, based on four patches couple by a slot or a symmetric cross, is introduced, and then, an array-based model used to analyze a system formed by a TA and a planar lens in a time-efficient manner without using a full-wave method. Thus, both features are used to design and analyze the different prototypes reviewed in this contribution. That is, an ultra-thin planar lenses based on a 2-bit unit cell and a dual-polarized TA that has been designed in order to be used in polarized agile antenna. Thus, by rotating the feed of the system, a linear polarized antenna, it is possible to obtain any kind of polarization, form linear to circular. Finally, this TA has been used in a multibeam application fed with a network of quasi-yagi antennas.**

***Keywords*—** Transmitarray, Far-Field, planar lens, unit cell, dual-polarized, multibeam, quasi-yagi antenna

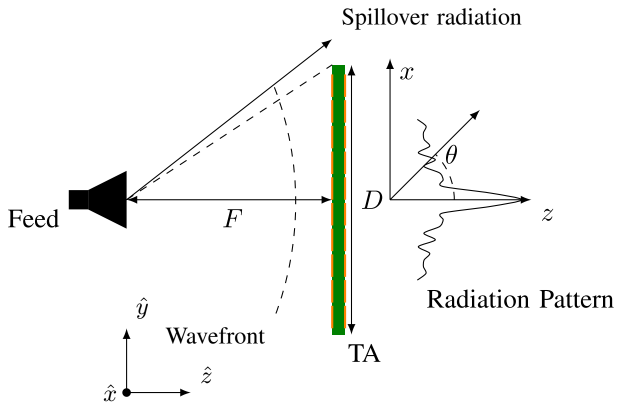


Fig. 1. Scheme of the complete structure.

I. Introduction

The importance of Transmitarray (TA) antennas have increased in recent times due to the necessity of creating a low-profile alternative to bulky dielectric lenses [1]-[2]. These planar lenses are formed by a quasi-periodic lattice based on the repetition of a unit cell, in which a specific parameter can be tuned in order to conform any kind of possible radiation pattern. for which it is necessary to obtain a 360-degree phase-shift. In this contribution, a TA unit cell based on four patches couple two by two by a slot or a symmetric cross, depending on the system polarization, is used, due to its practical independence of the angle of the incidence wave. Besides, a simple array-based model to carry out a fast and accurate study of the whole system, see Fig. 1, formed by the TA antenna and the feed has been developed. It provides a reliable set of results without having to use a full-wave commercial software, resulting in a significant reduction of the time consumed. During the ongoing research, several prototypes have been designed. The first one is an ultra-thin TAs based on a 2-bit unit cells, whose more important characteristic is that it has an even lower profile making it possible to use them in lighter structures in order to diminish the overall size of the whole system. Furthermore, a circular polarized antenna based on a TA fed by a linear polarized antenna. In this case, the phase-shift of both polarization is displaced 90° from each other so the final polarization of the whole antenna can be modify, from circular to linear, by rotation the feed antenna of the system. Finally, this TA is fed by a network formed by multiple quasi-yagi antennas in order to obtain a multi-beam antenna in which it is possible to change the polarization of the system.

II. Unit Cell

A structure, see Fig. 2, based on four stacked patches coupled two by two by a slot or a symmetric cross depending on whether the TA is single or dual polarized has been used as the basic structure of unit cell for all the antennas that have been designed. In the first case, the patches are always square, whereas in the second case each side of the patch is independently varied in order to match the phase-shift requirement for each polarization.

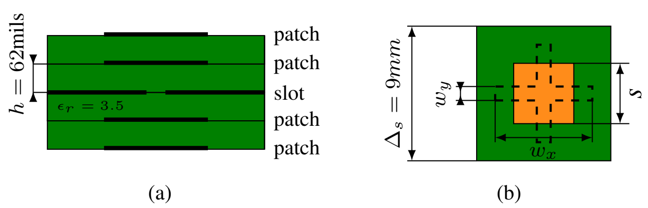


Fig. 2. Scheme of the unit cell. (a) Profile view. (b) Top view.

The analysis of the linear polarized structure regarding the incident angle and its bandwidth response has been studied in [3] using the commercial software HFSS. In this paper, it has been studied that it is possible to obtain a 360-degree phase-shift while the unit cell presents a stable behavior when the angle of incident is varied as well as a good bandwidth behavior.

III. Array-based model

The complete full-wave analysis of a whole set formed by a feeder element and a planar lens, see Fig. 1, is normally a task that consumes a high amount of time. To reduce this feature, a simple array-based model capable of analyzing these systems in a reduce amount of time has been presented in [4]. In this model, the different elements that form the whole antenna are modeled independently. First, the field of the feeder antenna is calculated by using a variation of a $cos^q\theta$ model in which the functions $C_E(\theta)$ and $C_H(\theta)$ are the values of the electric field in the main cuts at a certain distance of the antenna. This way, it is possible to introduce in the analysis of the system the different effects that could appear if the planar lens is placed in the Near-Field of the feed.

$$C_E(\theta) = f(\theta, \phi = 90^\circ) \tag{1}$$

$$C_H(\theta) = f(\theta, \phi = 0^\circ) \tag{2}$$

$$E^{YPol}(\theta,\phi) = \frac{jke^{-jkr}}{2\pi r}[\hat{\theta}C_E(\theta)\sin\phi + \hat{\phi}C_H(\theta)\cos\phi] \tag{3}$$

Once this element is modeled, its field is acquired in a regular rectangular mesh located at the plane of the TA, Fig. 3, which includes the part of the field that impinges in the planar lens and the most significant part of the spillover radiation, which propagates in the same direction as the field radiated from the TA and has an important effect in the variation of the secondary lobes. The field produced by each of the contributions is calculated independently as a planar arrays using eqs. (4) to (8).

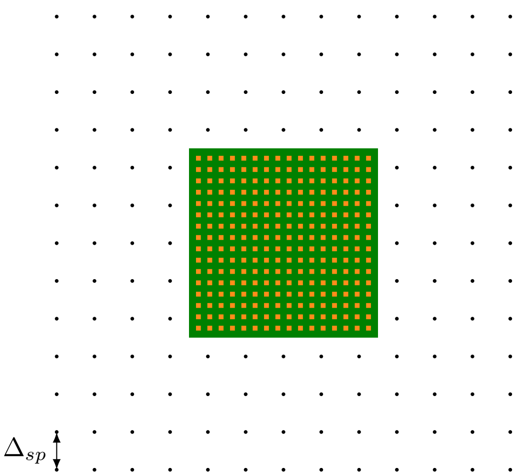


Fig. 3. Lens and spillover mesh($\Delta_{sp} = 0.3\lambda$)

Once both Far-Field contributions are calculated, they are summed together and multiplied by the radiation pattern of the single element that forms the mesh, i.e., a rectangular aperture in which the electric field is constant (9).

$$FA_{lens} = \sum_{n=1}^{N}\sum_{m=1}^{M} \tau(m,n)E_{horn}(m,n)e^{j(m-1)(\Delta_s k_x)}e^{j(n-1)(\Delta_s k_y)} \tag{4}$$

$$FA_{sp} = \sum_{n=1}^{Ns}\sum_{m=1}^{Ms} E_{horn}(m,n)e^{j(m-1)(\Delta_{sp} k_x)}e^{j(n-1)(\Delta_{sp} k_y)} \cdot u(m,n)$$

$$u(m,n) = \begin{cases} 1, \text{if outside the lens} \\ 0, \text{if inside the lens} \end{cases} \tag{5}$$

$$k_x = k_0 \sin\theta\cos\phi \tag{6}$$

$$k_y = k_0 \sin\theta\sin\phi \tag{7}$$

$$E^y_{total} = (FA_{lens} + FA_{sp})RP^y_{aper} \tag{8}$$

$$RP^y_{aper} = (1+\cos\theta)sinc(\frac{k_x\Delta_s}{2\pi})sinc(\frac{k_y\Delta_s}{2\pi})(\sin^2\phi\cos\theta + \cos^2\phi) \tag{9}$$

Moreover, in the case that the mesh separation is the same for both sources, they can be considered as a single source, and a FFT algorithm can be used in order to speed up the whole process.

IV. Ultra-thin transmitarray lens

A four-dielectric-layered TA is a low-profile alternative to a dielectric lens that allows a general reduction of the weight of the structure. Nevertheless, for some extra-compact applications, it may be necessary to use an antenna with a lower profile. In this case, the best alternative is to reduce the number of layer forming the TA lens. Since a 1- or 2-bit quantification are the ones that allowed to obtained a two-layer unit cell [5]-[6], a new unit cell design is introduced in Fig. 4. The results given by the analysis of the structure in HFSS are depicted in Table I. In this case, the 1-bit equivalent is straightforwardly obtained by using the case of 00 and 01 bits.

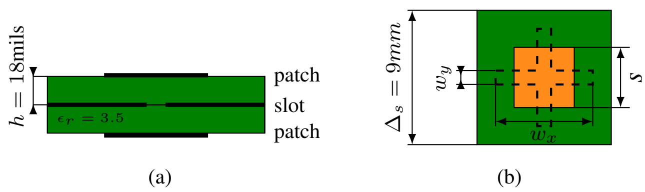


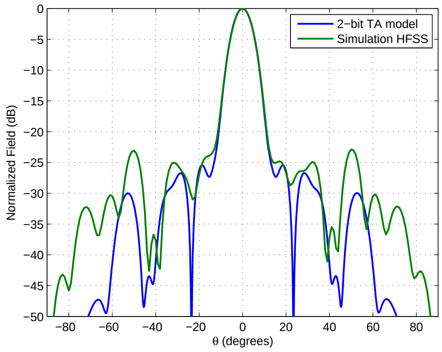
Fig. 4. Scheme of the unit cell. (a) Profile view. (b) Top view.

Using the current design of unit cell, a 2-bit Far-Field TA has been designed and simulated using the model presented beforehand in this paper comparing its results with the ones obtained with a full-wave commercial software.

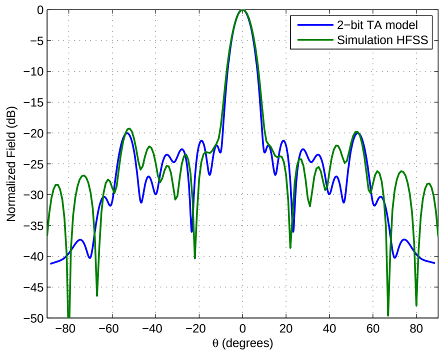
In Fig. 5, a comparison between the results of the model and the ones in simulation is depicted showing a good agreement.

TABLE I
UNIT CELL RESULTS AT @10 GHZ

Bit	w_x (mm)	w_y (mm)	S (mm)	$\mid S_{21} \mid$(dB)	$\angle S_{21}$(deg.)
00	7.1	0.75	1.79	-1.82	0.0
01	3.6	0.38	6.50	-2.24	-90.4
10	5.0	0.40	7.35	-0.53	-181.7
11	7.8	2.72	7.65	-3.62	-245.6



(a)



(b)

Fig. 5. Results 2-bit TA . (a) E-Plane. (b) H-Plane.

This way, it can be seen that up to a value of 20 dB below the maximum of the field the field given by the model proposed previously in this paper coincides with the one obtained using HFSS. Therefore, in the following analyses the TA will be characterized using only the present model. In terms of the results of the antenna, its performance can be considered rather satisfactory, since it is possible to obtain the same beamwidth of the radiation pattern than in the case of a 4-layer structure while the level of the secondary only increases under -20 dB, as it is depicted in Fig.6.

V. Circular polarizer

Using the dual-polarized version of 4-layer unit cell shown in this paper [7], the prototype of a circular polarizer based on a planar lens has been designed and manufactured. The working principle of this antenna is rather simple. A linear-polarized antenna is used as feed and the phase shift for both polarizations is calculated independently as in the case of a phase-correction application. In addition, the phase-shift of

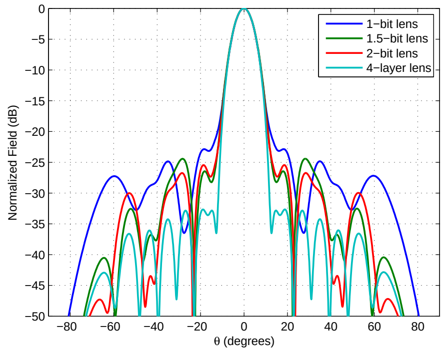


Fig. 6. Comparison of the number of bits used. E-Plane.

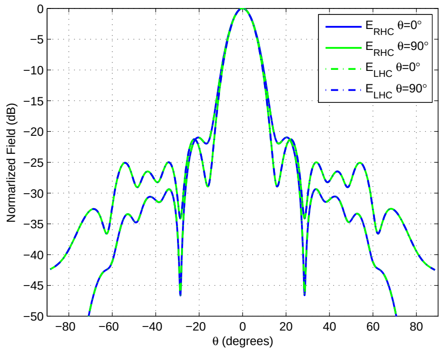
one of the polarization is added an additional value of 90 degrees, so when the antenna is rotated around the perpendicular axis of the lens, it is possible to obtain from linear to elliptical polarization, and thus a polarized-agile antenna is obtained. In this case, a circular polarized radiation pattern will be obtained when the antenna is rotated $45°$. The fact that this polarization is left- or rightward depends on the direction in which the feeder antenna is moved. In Fig. 7, the results obtained in the analysis of the circular polarizer based on a TA are depicted according to the rotation angle of the feed. Thus, it can be seen that when the rotation angle is $0°$ or $90°$, which is equivalent, both circular polarization have the same radiation pattern, which means that the overall polarization is a linear one. Besides, when this angle is exactly ± 45 degrees the polarization is RHC or LHC respectively, with a rather low lever of crosspolar of approximately -25dB.

VI. Multibeam circularly polarized TA

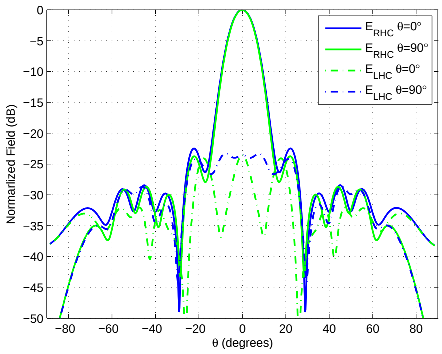
Finally, a multibeam antenna has been based on the planar lens presented in the previous section. The working principle of the system is the same that in the previous case. The feeder antenna is rotated around the perpendicular axis of the lens and, thus, the resulting polarization of the system is changed according to the rotation angle. The only difference is that the feed antenna is a network of five quasi-yagi antennas [8], therefore there will be five different beam for each rotation angle. In order to prove the function of the system, the analysis of the worst case scenario is carried out with the antenna placed at one of the sides when the rotation angle is 45 degrees. In Fig. 8, the analysis of the previously cited case is depicted showing that the behavior of the lens is not significantly changed, since the polarization is E_{RHC} and the crosspolar level is below $-20dB$, as in the case depicted in 7(b). Therefore, as the behavior is kept within the working limits, the structure has been validated to be used in this system. The crossover point at -3dB is not studied in this point since it is determined by the position of the quasi-yagi antennas, which is fixed for the linear polarized cases.

VII. Conclusions

In this paper, the different contributions made to the field of Far-Field Transmistarrays during the ongoing PhD Thesis



(a)



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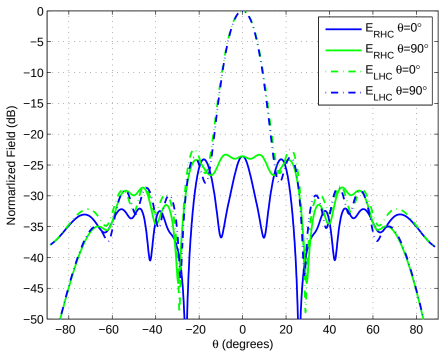
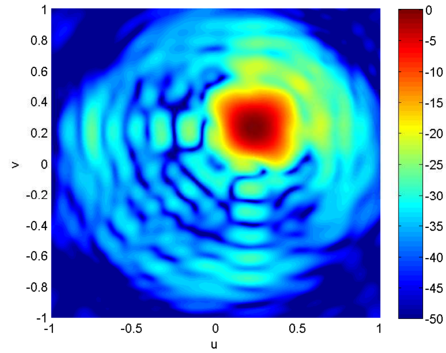


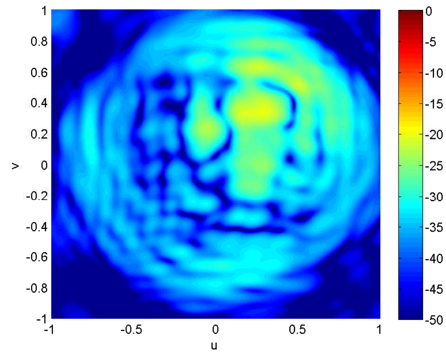
(c)

Fig. 7. Results obtained for the circular polarizer TA according the rotation angle of the feed. (a) 0 degrees. (b) 45 degrees. (c) -45 degrees.

have been presented. Using a 4-layer structure as unit cell and a model to analyze all the system in a timely fashion, several FF prototypes have designed and analyzed. This way, the first presented antenna is an ultra-thin TA, whose structure is formed by only 2 layers, that allows to reduce the overall weight of the whole structure while the behavior of the antenna is not significantly changed. Then, the dual-polarized version of cell is used as the periodic element of a circular polarized TA, which being fed by a linear polarized antenna can changed its polarization by rotating the feed or itself. Finally, this TA has been proposed to be used in multibeam application.



(a)



(b)

Fig. 8. Multibean circular polarizer TA. Case of the side antenna when rotation angle is 45 degrees. (a) E_{RHC}. (b) E_{LHC}.

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