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Duo WANG, Raphaël GILLARD , Renaud LOISON
European University of Brittany: Institute of Electronics and Telecommunications of Rennes, INSA, UMR CNRS 6164, 35708 Rennes, France, {duo.wang, raphaël.gillard, Renaud.loison}@insa-rennes.fr

***Abstract*—This paper presents the preliminary design of a 60GHz passive repeater endfire array with dielectric resonator antenna (DRA) elements. The proposed DRA element utilizes simple notches at opposite corners of a square DRA to obtain polarization-conversion. By combining two DRA with notches on opposite diagonals, endfire radiation can be obtained. A 6x1 linear array is optimized and simulated as an initial demonstration.**

***Index Terms*—60GHz, passive repeater, endfire array, notched dielectric resonator antenna.**

I. INTRODUCTION

Endfire antenna arrays play an important role in communication and radar [1] but their design meets many challenges. For example, microstrip patch arrays with ground plane do not easily provide endfire radiation due to the cancellation effect resulting from mirror image currents. Solutions using artificial magnetic conductors (AMC) or high impedance surfaces (HIS) [2] can address this issue but result in a quite complicated design and usually exhibit a reduced bandwidth. In this paper, we focus on the even more complex problem of planar reflecting surfaces with endfire radiation. The desired surface has to comply with two constraints: firstly, it must provide a full reflection of the incident wave (thus requiring a ground plane); and, secondly, it must produce a radiation parallel to the reflecting surface. Such a configuration may be encountered in passive repeaters [3] for indoor communications at 60 GHz, especially in the case of L- or T-shaped corridors [7]. Indeed, typical passive repeaters are of great attraction for their easy deployment, simple design and cost effectiveness.

In this paper, we propose to solve this problem by means of a reflector made of DRAs. One DRA in fundamental mode radiates like a magnetic dipole and can thus be backed by a ground plane [4-6]. Moreover, DRAs are particularly well suited for millimeter waves due to their intrinsic low loss [5], and they naturally exhibit a quite large bandwidth.

In [7], we demonstrated the possibility to obtain promising performance by loading consecutive square DRA with two different stub lengths coupled through slots in the ground plane. In the present paper, we propose a more simple solution requiring neither slot nor stub. The desired 180° phase shift between consecutive DRA is directly obtained thanks to notches in the dielectric material.

In section II, the modal analysis of a single notched DRA is carried out in order to obtain reflection with polarization conversion. Then, 2 DRAs with notches on opposite diagonals are combined to excite an orthogonal mode whose field configuration is compatible with endfire radiation. Finally, in section III, a preliminary 6x1 array is designed that reflects a large amount of power at endfire.

II. DESIGN OF DRA CELL

A. General Antenna Configuration

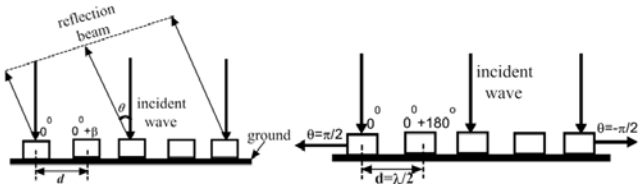
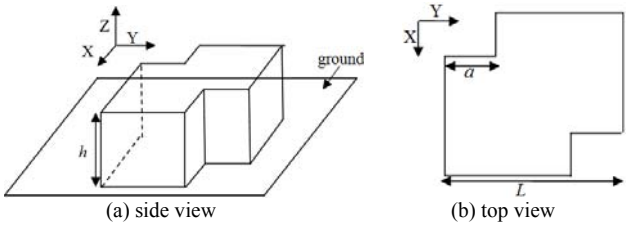


Fig. 1. (1) General working principle for passive repeater array based on DRA, (2) Proposed implementation for combined endfire/backfire radiation

Fig. 1 illustrates the typical foreseen configuration where DRA elements are regularly disposed over a ground plane and illuminated by an impinging plane wave under normal incidence. It is assumed this wave is produced by a remote source and the aim of the DRA reflector is to re-direct it at both endfire and backfire, as shown in [7]. Endfire and backfire radiation ($\theta = \pm \pi/2$) can be achieved with out-of-phase elements by using a half wavelength inter-element spacing ($d = \lambda/2$).

B. Notched DRA element design

In this paper, the required 180° phase shift between consecutive DRA is obtained using a principle similar to the one used in [8] for 1-bit reflectarrays. Firstly, the incident linearly polarized wave is reflected in the orthogonal polarization by diagonally loading the radiating element. Secondly, consecutive elements exhibit loadings on opposite diagonals so that their respective reflections are out of phase. In this paper, the chosen element is a square DRA (L= 1.5mm, ε_r=10, loss tangent=0.002, and h=1.35mm) with square notches (Fig. 2) at corners. The DRA is backed by a ground plane.

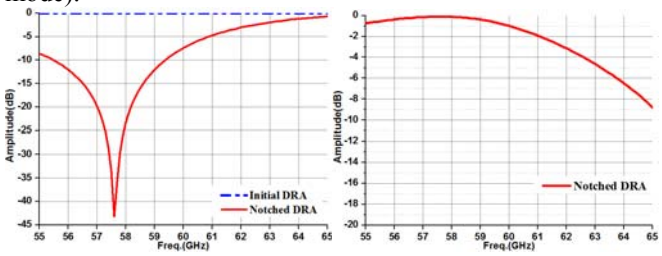


(a) side view (b) top view

Fig. 2. Schematic of diagonally notched DRA cell

The notched size a is optimized to achieve polarization conversion when reflection occurs. The simulation is realized with Ansoft HFSS 13.0 assuming local periodicity and normal incidence.

Fig. 3 presents the scattering parameters of the cell when a=0.6mm. S_{11} measures the reflection on polarization y for a y-polarized incident wave (TE_{00} Floquet mode) while S_{21} measures the reflection on polarization x (TM_{00} Floquet mode).



(a) S_{11} (b) S_{21}

Fig. 3. S parameters for notched DRA when a =0.6mm

The notched DRA cell obtains almost 100% polar-conversion at 57.6GHz (S_{11}=-43dB and S_{21}=-0.2dB), leaving a small margin from 60GHz. S parameters of this initial DRA are also given in Fig.3 for comparison (as S_{21}<-50dB, it is omitted in Fig.3 (b)), which of course demonstrates a full reflection whit no polar-conversion at all.

In order to go further, two DRAs with notches on opposite diagonals are now combined with a $\lambda_0/2$ element-spacing (S=2.5mm) as shown in Fig. 4. They are simulated again assuming local periodicity (the 2x1 unit-cell is now the combination of both DRAs) and normal incidence.

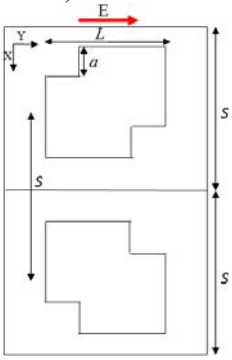


Fig. 4. Schematic for 2x1 unit-cell with opposite-notched DRA

Fig. 5 shows the field snapshots for a y-polarized incident wave (TE_{00} excitation). As can be seen, the best mode conversion is obtained at 61.2 GHz. This frequency shift may be explained by the differences in the coupling mechanisms (as one DRA is not surrounded anymore by identical neighbors).

At this frequency, the E-field distribution on two opposite-notched DRA shows opposite Ex components but identical Ey components. Since the x-spacing is $\lambda_0/2$, Ex components on the two cells would produce strong superposition at endfire ($\theta = \pm \pi/2$ for ϕ=0 or π), as desired. On the other hand, the Ey components will be responsible for the residual broadside radiation with y-polarization (same as the incident wave).

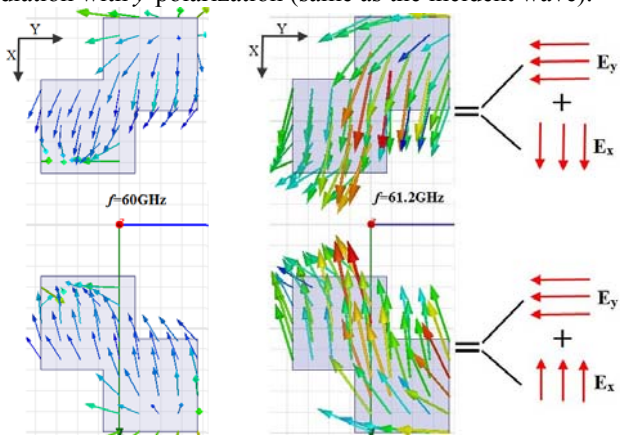


Fig. 5. E-field distribution for 2x1 unit-cell around 60GHz

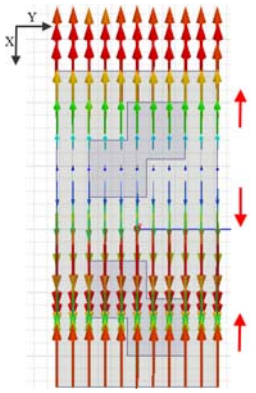
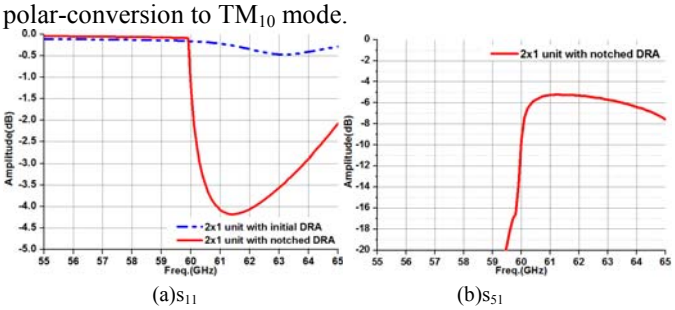


Fig. 6. E-field distribution of TM_{10} mode for incident wave

Regarding Floquet analysis, endfire radiation (with polarization conversion) is obtained when power is reflected back on the TM_{10} mode (see corresponding field snapshot in Figure 6). Then, Figure 7 presents the scattering parameters of the 2-DRA unit-cell. As before, S_{11} measures the power that is reflected on the incident TE_{00} mode, and S_{51} measures the polar-conversion to TM_{10} mode.



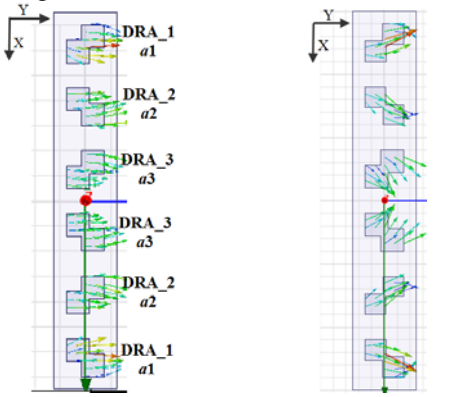
(a)s_{11} (b)s_{51}

Fig. 7. S parameters for 2x1 unit-cell

As these results confirm, the maximum polar-conversion is obtained at 61.2GHz (S_{11}=-4.2dB and S_{51}=-5dB). As comparison, the 2x1 unit-cell with initial DRA still demonstrates strong reflection (its S_{51}<-40dB is not included in Fig. 7(b)).

III. 6X1 ARRAY IMPLEMENTATION AND OPTIMIZATION

In this section, a preliminary 1-D linear array with 6 elements is considered, as shown in Fig. 8. Following the initial modal analysis of the previous section, the objective is now to optimize the radiation performance itself. The main parameter, namely the notch size a on each DRA, is used to maximize polarization conversion at endfire. Since the mutual coupling effects on the elements are districted symmetrically along x-axis, following discussion only considers the top half DRAs, marked as DRA_1, DRA_2 and DRA_3, with corresponding notched sizes $a1$, $a2$ and $a3$.



(a)before optimization (b)after optimization

Fig. 8. E-field distribution for 6x1 array at 60GHz

The optimized function measures the amount of reflection at broadside relatively to the amount of reflection at endfire. It is given as:

$$\Gamma = \frac{\left|E_{\varphi}\left(\text{broadside}\right)\right|}{\left|E_{\theta}\left(\text{endfire}\right)\right|} = \frac{\left|E_{\varphi}\left(\varphi=0,\theta=0\right)\right|}{\left|E_{\theta}\left(\varphi=0,\theta=\pm 90^{\circ}\right)\right|} \quad (1)$$

for a y-polarized wave under normal incidence. Logically, as we seek for minimum reflection at broadside and maximum endfire radiation, the smallest Γ would be our final optimization goal. In Fig. 9, an example is given to show how Γ helps to locate the optimal $a1$.

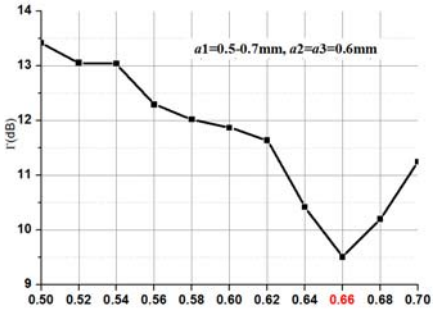


Fig. 9. Γ optimization of $a1$

The final optimization result for the 6x1 array is determined as $a1$=0.66mm, $a2$=0.7mm and $a3$=0.6mm. This leads to Γ =3.47dB and the corresponding E-field distribution is also given out in Fig.8 (b). For comparison, its performance is sketched in Fig. 10 with that of the initial array (i.e. $a1$=$a2$=$a3$=0.6mm as derived in section II) before optimization.

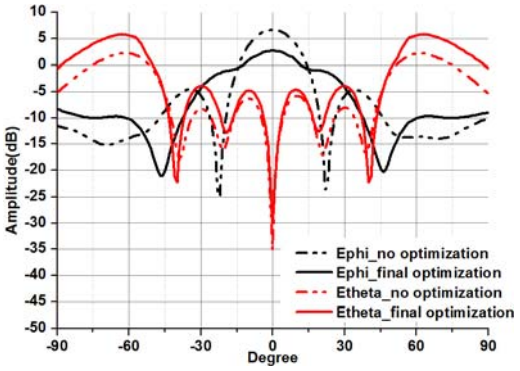


Fig. 10. E pattern comparison of initial dimension and final optimization(ϕ=0 plane)

As can be seen, the reflection at broadside has been reduced from 6.68 dB to 2.84 dB. In the meantime, the radiation at endfire has risen from -5.19 dB to -0.63 dB. Although the maximum radiation is not obtained at endfire but at ± 65°, a large amount of the reflected power is now redirected longitudinally.

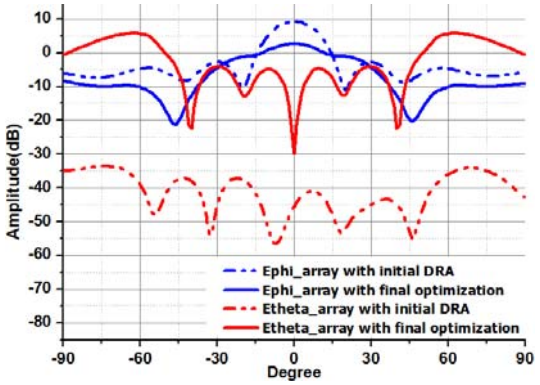


Fig. 11. Comparison of array with notched DRAs after final optimization and array with non-notch DRAs

In Fig. 11, the optimized 6x1 array is also compared to a similar array with the initial DRAs (L=1.5mm, h=1.35mm, a=0). This clearly demonstrates that a strong polar-conversion has been achieved thanks to the used DRA reflector. This also shows that most of the power is now directed close to endfire.

IV. CONCLUSION

This paper proposes a simple structure using notched DRA cells as a preliminary step towards a passive repeater array with endfire radiation. Based on the principle of polar-conversion, this structure transforms a normally incident plane wave into radiation close to endfire. The interest of the concept and an associated design methodology has been

validated in simulation for a quite simple 6x1 array demonstrator. Further steps are now required to provide results for a larger antenna and to perform an experimental validation.

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