Reconfigurable and Dual-Polarization Folded Reflectarray Antenna

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Abstract—**This paper proposes a novel version of folded reflectarray antenna that allows a full electronic reconfigurability of the radiation pattern. The reconfigurability is obtained adopting an elementary cell on the main reflector able to provide at the same time the required phase-shift to the incident field and the necessary twist of the incident polarization. Since in many applications an antenna with dual-polarization operation is required, the proposed design allows the reflectarray to manage at the same time two orthogonal linear polarizations in two adjacent frequency bands. This achievement is obtained by replacing the polarizing grid, as typically adopted, with a dual-band and dual-polarized FSS. As a proof of concept, two test antennas have been designed, manufactured and tested.**

Keywords-component; reconfigurable antenna, folded, reflectarray

I. INTRODUCTION

Planar reflectarrays represent a promising solution for the design of low-weight, low-cost and versatile antennas [1], [2]. Folded reflectarray antennas further improve the main features of the reflectarrays through a reduction of the overall weight and profile without affecting the antenna performance. The folded reflectarray principle, originally introduced in [3], is shown in Fig.1. The field radiated by a central feed is reflected by a polarizing grid, on the top of the antenna. A second reflection is performed by the main reflector in which the printed elements add the required phase shift, compensating for the free space delay occurred along the paths between them and the feed. A polarization twist of 90° is to be performed on the lower reflector together with the phase adjustment so that the wave can pass the grid.

The proposed principle of operation has been further developed in order to obtain scanning antennas. In [4] and [5] a mechanical tilting of the main reflector allows the continuous scanning of the radiation pattern in elevation, while the use of multiple feeds integrated in the main reflector allows to switch between multiple beams in azimuth. In [6] a first concept of an electronically reconfigurable folded reflectarray has been proposed: the beam-steering in a single dimension is provided by means a reconfigurable polarizing grid. The proposed solutions does not allow the complete electronic reconfigurability of the radiation pattern, and a 2-D scanning can be obtained just adopting a proper combination of the electronic or mechanical steering in one dimension with the multiple beam feeding in the other one. A complete control of the relative phase difference of the cells on the main reflector would provide an increased freedom in the shaping of the antenna pattern with all the advantages in term of agility and reduction of volumes given by the use of the electronic reconfigurability.

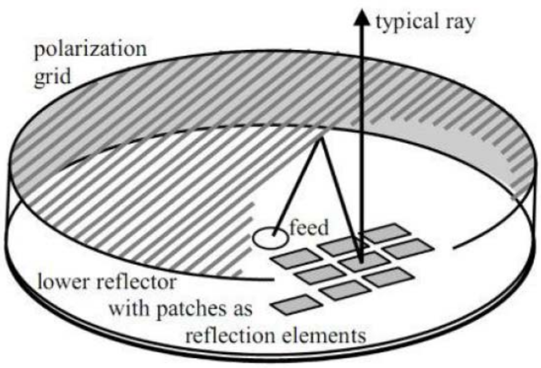


Figure 1. Principle of operation of a folded reflectarray antenna.

In order to reach this goal, an elementary cell capable of performing at the same time the phase reconfigurability and the polarization twist is required. To this purpose this paper presents a folded reflectarray based on a 1-bit reconfigurable elementary cell, already proposed in [7]: the cell realizes the required phase shift by means of a geometrical rotation of the incident field of +/- 90°, thus providing 0° or 180° of relative phase shift. A proof-of-concept reflectarray working at 35GHz has been designed, manufactured, and tested in order to confirm the proposed principle of operation.

The typical configuration of the folded reflectarrays is based on the use of a polarizing grid. The grid allows only a single linear polarization operation making the design of folded dual-polarized reflectarray impossible. In order to overcome this limitation an innovative solution is presented in this paper. The polarizing grid is replaced with a multilayer FSS (Frequency Selective Surface). The proposed solution adopts a periodic lattice of multilayer Patch-Aperture-Patch elliptical elementary cells.

The shape of the cell is optimized in order to emulate the effects of the polarizing grid for both the incident polarizations in two adjacent frequency channels (one for each polarization). The design and the principle of operation of the FSS are reported in this work along with an experimental validation through a far-field measured prototype. The results show the possibility to design a folded reflectarray able to radiate two orthogonal linear polarizations and perform, at the same time, an electronic reconfigurability of the radiation pattern.

II. 1-Bit Elementary Cell-Based Folded Reflectarray

The reconfigurable elementary cell, adopted for the presented solution, is based on the geometry already proposed in [7] and depicted in Fig.2 (a). It is made of a square patch antenna capable of two resonating modes corresponding to two orthogonal polarizations. The patch is designed to operate at 35 GHz, and is coupled to a 1-bit phase shifting circuit realized in slot-line technology on the backside of the cell. The phase shifting circuit is electronically reconfigured by two switches

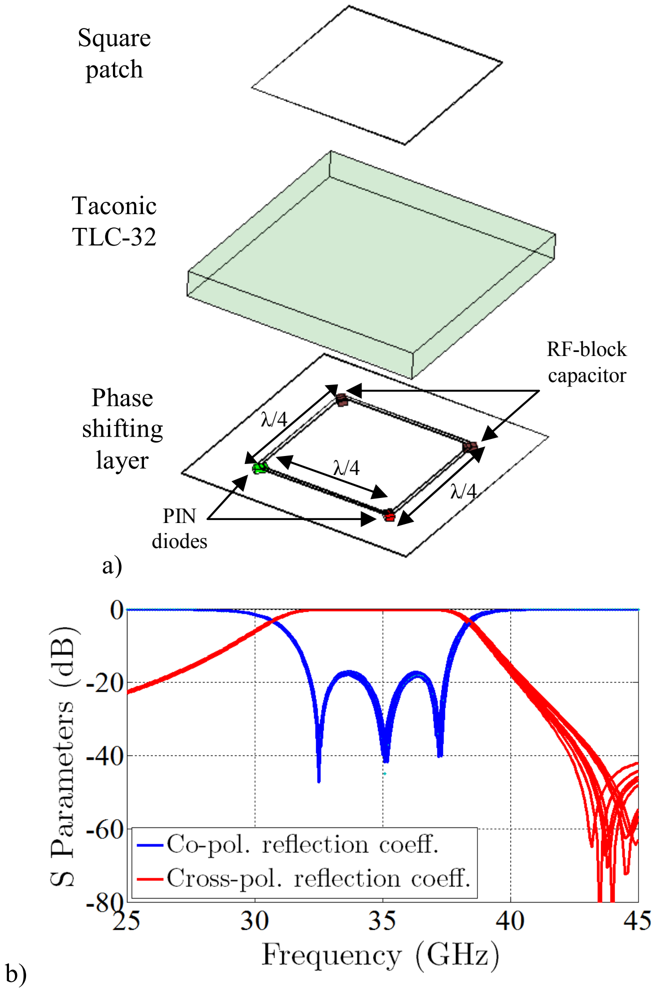


Figure 2. Exploded view of adopted elementary cell (a) and frequency response varying the incidence angle from 0° to 45° (step=5°).

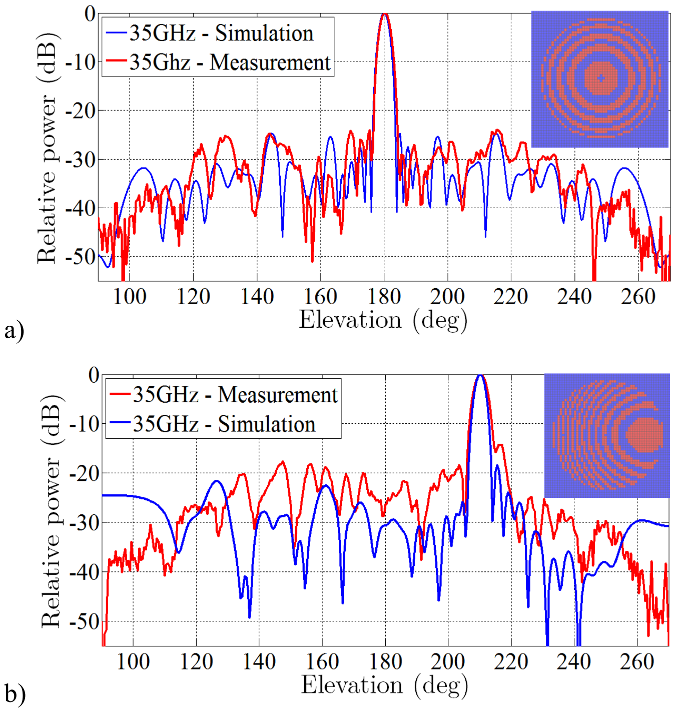


Figure 3. Calculated and measured E-plane patterns (35GHz) of the proposed antenna for the broadside pointing (a) and the 30° offset-beam (b).

(e.g. PIN-diodes or MEMS ohmic switches) and provides 0° or 180° of relative phase difference to the impinging signal. In both the possible states the cell reflects a field orthogonally polarized with respect to the incident one. Each cell can be controlled through a single signal thus drastically reducing the complexity of the biasing network necessary to control the antenna. Fig.2 (b) shows the simulated frequency response of the elementary cell in periodic boundary conditions varying the angle of the incident field from 0° to 45°in elevation.

Based on the described elementary cell in frozen configuration, two proof-of-concept folded reflectarrays have been designed fabricated and tested. The two reflectarrays use the same geometry and differs for the phase distribution of the cells on the main reflector: the first is designed for a broadside pointing, the second for an offset-beam of 30°.

The antenna diameter is 190mm, with a polarizing grid suspended 47.5mm above the main reflector. The synthesis of the main reflector has been carried out considering both the amplitude and phase distributions of the electric field on the main reflector, generated by the adopted feed (a circular waveguide with radius 7.1mm).

Fig. 3 shows the measurement results of the radiation pattern of the two reflectarrays, along with the simulated ones. A very good agreement can be observed in the E-planes of both the broadside and the offset-beam patterns. The maximum evaluated side lobe levels (SSL) are -24dB and -15dB, respectively.

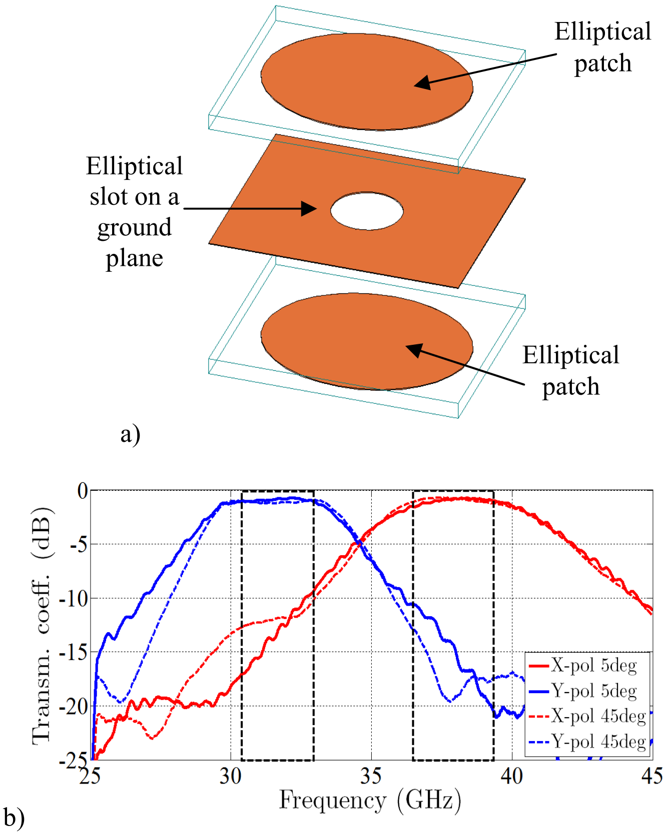


Figure 4. Exploded view of the FSS elementary cell (a) and its measured frequency response (b) in free-space setup varying the incidence angle.

Experimental results validate the possibility to design an electronically-controlled beam-scanning folded reflectarray adopting the 1-bit reconfigurable elementary cell proposed in [7].

III. Dual Polarization Folded Reflectarray

In order to design a dual-polarization folded reflectarray is necessary to replace the polarizing grid on the top of the antenna with a structure able to provide the same behavior for both the possible linear polarizations. The solution proposed in this work is a novel FSS based on the concept of a second order Patch-Aperture-Patch resonator. In [8] and [9] a single polarization P-A-P architecture is presented, while [10] shows a solution based on the same concept but employing elements with circular symmetry. The symmetry allows to obtain identical performance for both the incident polarizations.

Exploiting the same principle, this paper presents an elementary cell for the FSS properly adapted to work with dual-polarization. The proposed cell, depicted in Fig.4 (a) is made by two elliptical patches separated by a ground plane into which an elliptical slot is etched.

The cell is manufactured on two Duroid 5880 laminates (εr=2.2 h=0.254mm t=0.017mm tanδ=0.0009) bonded together with a Roger 3001 bonding-film (εr=2.28 h=0.03mm tanδ =0.003). The proposed elementary cell for the FSS has been optimized in Ansoft HFSS v12 using Floquet ports and periodic boundary conditions. The reflection and transmission coefficients of the cells are simulated considering a plane wave with a variable incidence angle. Optimizing the size of the axes of the elliptical patches and the slot is possible to obtain a cell that, in a lower frequency band (from 30GHz to 32GHz),reflects the vertical polarization and allows the orthogonal one to pass. The opposite behavior is obtained in the upper frequency band (from 37GHz to 39GHz).

The principle of operation of the proposed cell has been experimentally validated through the measurements of a FSS in a free-space setup. The setup uses two standard gain horn antennas with a test fixture for the FSS placed in between. The line of sight between the two antennas passes through the center of the fixture. In order to guarantee the incidence of a plane wave on the FSS, the two horn antennas are located about 40 cm apart from each side. In order to calibrate the frequency response of the FSS the transmission response has been evaluated first without the FSS in between. Measurements have been performed considering both the vertical and the horizontal polarizations incident on the FSS surface and varying the incidence angle between 5° and 45°. Results are shown in Fig.4 (b). Since the cells on the FSS are arranged in a rectangular lattice with reduced inter-element spacing, the transmission of the undesired polarization is maintained below -10dB in each band and the cell exhibits a constant behavior over a broad incidence angle range [11]. The measured loss of the FSS are roughly 1dB in both the lower and upper bandwidth.

IV. Measurement Results of the Dual Polarization Reflectarray

In order to experimentally validate the proposed design, a folded reflectarray using an FSS made up of a periodic array of identical cells has been manufactured and tested in a far-field measurement setup. The FSS has been designed in a circular shape with the same diameter of the main reflector (d=190mm) and has been used to replace the polarizing grid used for the measurement of the reflectarray described in previous section.

Fig.6 compares the measurement of the radiation patterns obtained by feeding the broadside-pointing reflectarray with both polarizations, equipped with the FSS, and the measurements performed employing a properly oriented polarizing grid. As expected the results shows that, adopting the FSS, the V-pol. is radiated in the lower channel (32GHz) while the H-pol. is radiated in the upper one (37GHz). As can be observed the agreement between the measurements with the grid or with the FSS is almost perfect thus confirming that the use of the FSS instead of the polarizing grid doesn't introduce distortions on the radiation patterns.

The use of the FSS instead of a polarizing grid provides an increased amount of the cross-polarized radiated field. In order to evaluate this effect a measurement of the cross-polarized radiation pattern has been performed in both the upper and lower bandwidth. Results are included in fig. 6. Levels of the cross-polarized radiated field are always -20dB lower than the co-polarized one in both the operative bandwidths.

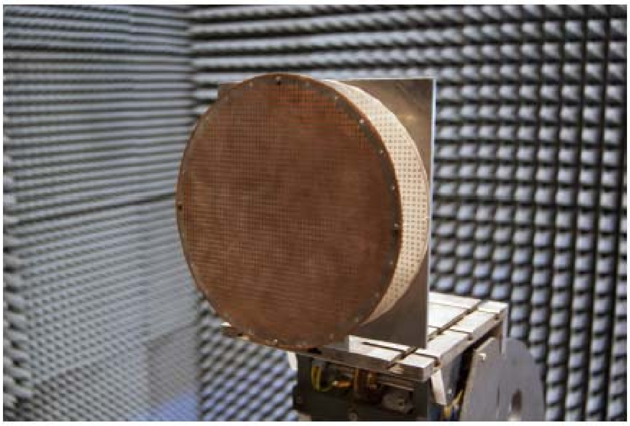
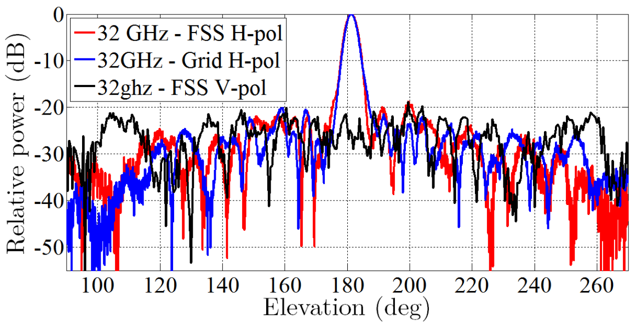
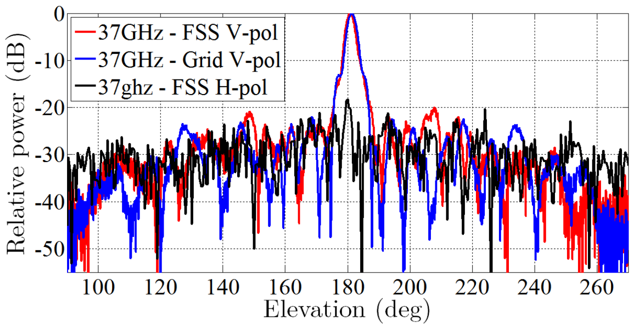


Figure 5. Manufactured Dual polarized folded reflectarray.



a)



b)

Figure 6. Comparison of measured radiation patterns of the folded reflector antenna with the FSS and the traditional grid at 32GHz (a) and 37GHz (b).

V. CONCLUSIONS

A novel folded reflectarray antenna has been presented. The novelty of the proposed design is given by the possibility to manage a dual linear polarization and, at the same time by the full-electronic reconfigurability of the main reflector. These properties are carried out respectively through the design of an innovative FSS geometry and the use of a polarization-twisting reconfigurable cell, suitable for the design of a folded reflectarray. The FSS cell is based on an elliptical geometry that allows the structure to behave as a polarizing grid for both the incident polarizations in two different frequency bands (lower band reflects a polarization while the upper band reflects the orthogonal one). This structure has been adopted for the design and manufacturing of a dual polarized reflectarray at 35GHz. The proposed approach has been validated through far-field measurements of a prototype antenna.

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