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A Novel Wideband Partially Reflective Surface for Antenna Gain Enhancement

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A novel wideband partially reflective surface (PRS) for printed antennas gain enhancement is proposed in this paper. The proposed PRS is constructed by two layers separated by an air-gap. It is composed by an inductive patch with a star flower-shaped aperture etched on the bottom faces of its two layers and a capacitive star flower-shaped patch that is placed on the top face of its upper layer. The presented PRS with a broadband operation extending from 7.76 GHz to 11.16 GHz is proposed to improve the gain of printed antennas operating around this band. The usefulness of the proposed PRS is examined by placing an array of 8 × 9 over a single-layer printed feeding antenna (FA). The gain of the considered FA is considerably enhanced after the implementation of the PRS. Hence, the usefulness of the designed PRS is demonstrated for enhancing the gain of printed antennas operating in X-band.

Keywords: Partially reflective surface (PRS), Feeding antenna (FA), Wideband, Gain enhancement.

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1. INTRODUCTION

Nowadays, due to the rapid expansion of wireless communication systems domain, the request of high-gain and wideband directive antennas has acquired great focus [1, 2]. To not refer to a complex feed network, the helpful and the simplest technique to improve the radiation performance of printed antennas is to implement a Fabry-Perot cavity; by placing electromagnetic-band-gap structures as a partially reflective surface (PRS) at a proper distance along their direction of propagation. Here, the role of the PRS is to create a partial blocking for the radiated waves emitted by the feeding antenna (FA). Accordingly, the radiated waves incur several reflections before their escape throughout the PRS as extremely directive emission [3-12]. Fabry-Perot cavity that was firstly introduced in 1956 by Von Trentini is well known for its aptitude to enhance the gain of printed antennas by the implementation of mightily reflective surfaces at a delicate altitude in order to create constructive wave interference between the direct rays radiated by the FA and the rays reflected by the PRS [13-19]. The reflection coefficient behavior of the PRS has significant influence on the radiation performance of the resulting electromagnetic-band-gap antenna [20]. Hence, there is a consistent need to design a novel PRS which has good behavior to enhance the performance of printed antennas.

In this paper, a broadband double-layer PRS having an enhanced inclining reflection phase in X-band is presented. An array formed by 8×9 of the designed PRS is placed over a single-layer printed FA to demonstrate its effectiveness for improving the gain of printed antennas. The entire designs were performed employing the commercial software Computer Simulation Technology (CST) Microwave Studio™.

2. PRS UNIT-CELL DESIGN

The proposed PRS unit-cell is composed of two layers separated by an air space of about 13.46 mm. An inductive patch including a star flower-shaped aperture is etched on the bottom face of two layers of the PRS. Furthermore, a capacitive star flower-shaped patch is placed on the top face of the upper layer of the PRS. The perspective view of the designed PRS unit-cell is presented in Fig. 1. The substrate of Rogers RT/Duroid 6002 ($\varepsilon_r = 2.94$, $\tan\delta = 0.0012$.) with a thickness of 0.762 mm is used to design the proposed PRS unit-cell. The overall size of the proposed unit-cell is $8 \times 8 \times 13.46$ mm^3. The configuration and the dimensions of the designed PRS unit-cell are presented in Fig. 2. All its optimized dimensions are specified as follows: $a_1 = 3.97$ mm, $b_1 = 7.5$ mm, $c_1 = 2.25$ mm, $a_2 = 4.02$ mm, $b_2 = 7.3$ mm, $c_2 = 2.25$ mm, $d = 3.36$ mm, $e = 6.88$ mm.

An unbounded configuration is considered in the optimization process in order to minimize the calculation resources. An increasing reflection phase over a broadband and a high reflection magnitude are required for the PRS to enhance the antennas gain over a wideband. Noting that the enhancement of the frequency band, in which the phase slope increases, causes the weakness of the reflectivity of the PRS. The complex reflection coefficient of the designed PRS is shown in Fig. 3. The reflection phase augments from 125.56° to 164.15° over a broadband extending from 7.76 to 11.16 GHz with reasonable reflection magnitude values predicting the enhancement of the gain of printed antennas over the whole frequency range. Noting that this achieved frequency range of 3.4 GHz, in which the reflection phase increases, is larger than the bands attained by the PRSs presented in [1] and in [3, 4].

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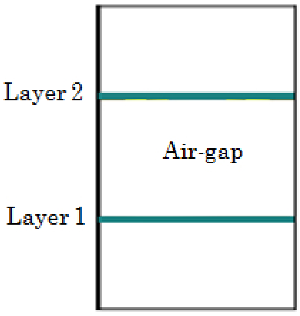


Fig. 1 – Perspective view of the proposed PRS unit-cell

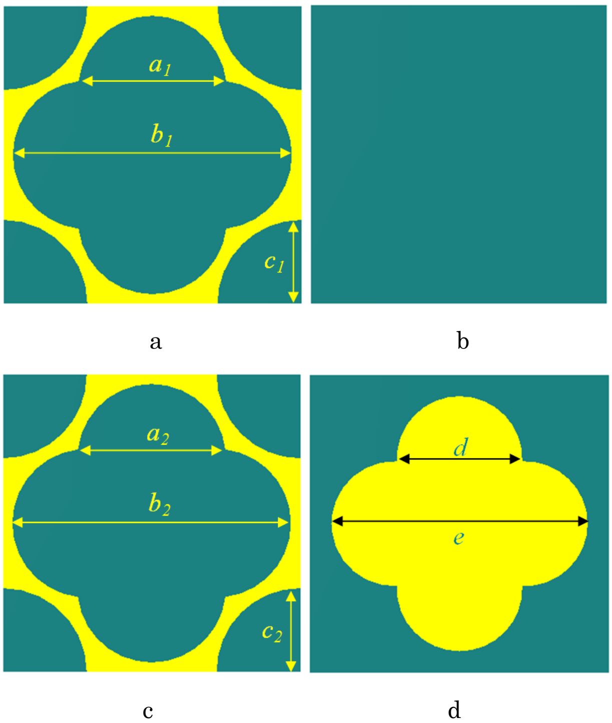


Fig. 2 – Configuration of the proposed PRS unit-cell, (a) bottom view of PRS layer 1, (b) top view of PRS layer 1, (c) bottom view of PRS layer 2, and (d) top view of PRS layer 2

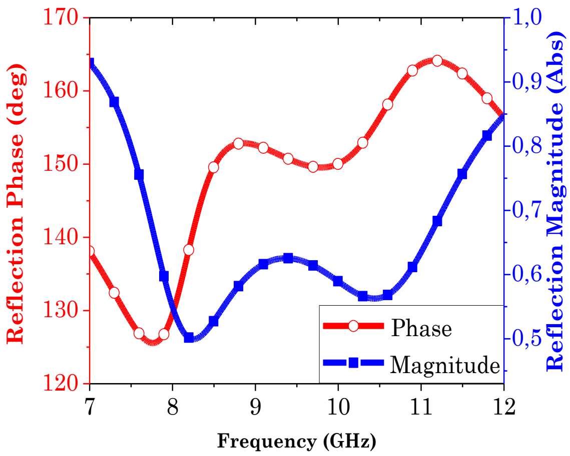
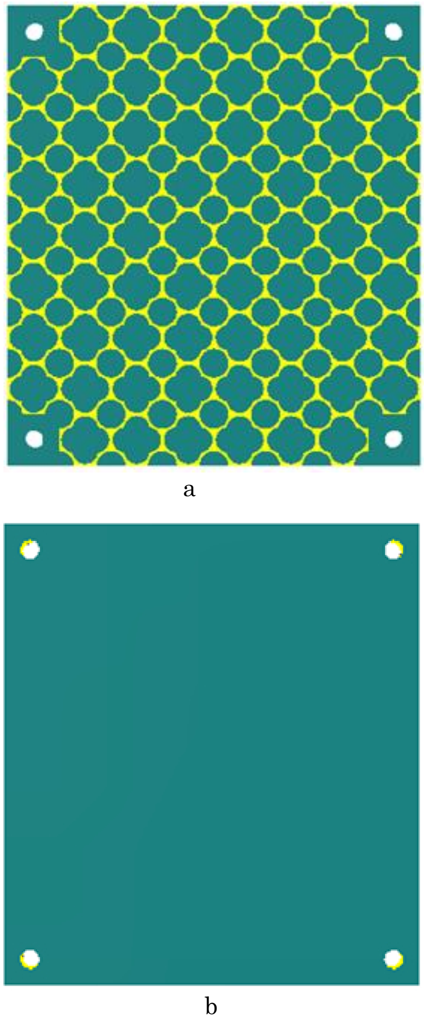


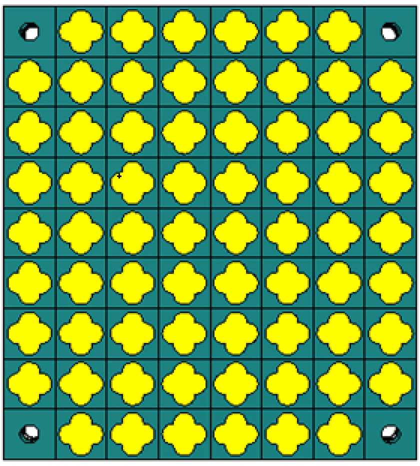
Fig. 3 – Complex reflection coefficient for the proposed wide-band PRS unit-cell

3. PRS IMPLEMENTATION AND TEST

In this section, the proposed PRS is implemented and tested to demonstrate its effectiveness for improving the gain of printed antennas. An array formed by 8×9 of the designed PRS unit-cell (Fig. 4) is implemented over a single-layer FA at an optimized elevation in order to enhance its gain. The geometry of the considered FA is presented in Fig. 5. The same substrate used to design the PRS with the same thickness is used to design the considered FA. The considered geometry of the FA is selected after an optimization process that permitted to enhance its operational bandwidth. The PRS and the considered FA were joined to each other at the required elevation by employing four nylon spacers (nylon 6/6, $\varepsilon_r = 2.94$ and radius = 1.46 mm). The total configuration of the assembled antenna is shown in Fig. 6. All its optimized dimensions are specified as follows: $w = 56$ mm, $g = 18$ mm, $k = 28$ mm, $l = 4$ mm, $m = 10$ mm, $n = 18$ mm, $o = 18$ mm, $p = 3$ mm, $q = 2$ mm, $r = 64$ mm, $s = 72$ mm, $u = 1.4$ mm, $v = 10.38$ mm, $x = 26.5$ mm, $y = 1.93$ mm, $h_1 = 15.71$ mm, $h_2 = 13.46$ mm.

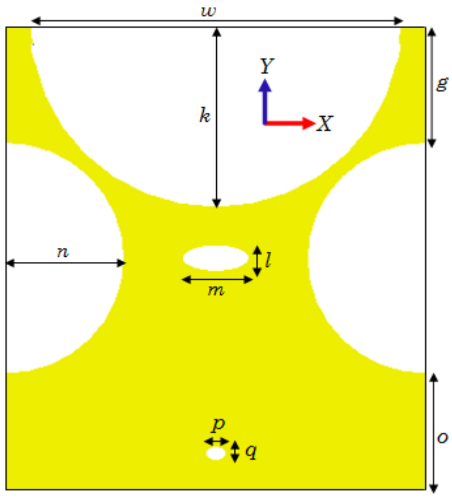
The two parameters gain and the reflection coefficient (S_{11} (dB)) of the considered FA were simulated with and without PRS. As shown in Fig. 7, the reflection coefficient of the FA is slightly improved by about 160 MHz after the implementation of the PRS. It extends from 9.08 GHz to 11.28 GHz, which equates to 21.61 %. Despite the cuts removed from the ground plane of the FA, Fig. 8 illustrates that the gain response of the considered FA is significantly improved after the





c

Fig. 4 – Configuration of the proposed PRS layers array: (a) bottom view of PRS layer 1 and PRS layer 2, (b) top view of PRS layer 1, and (c) top view of PRS layer 2



a

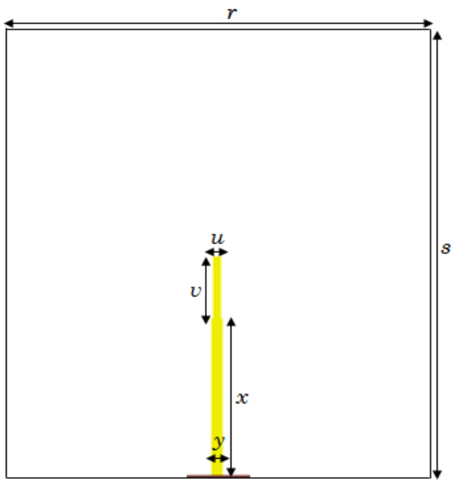


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Fig. 5 – Geometry of the considered FA: (a) top view and (b) bottom view

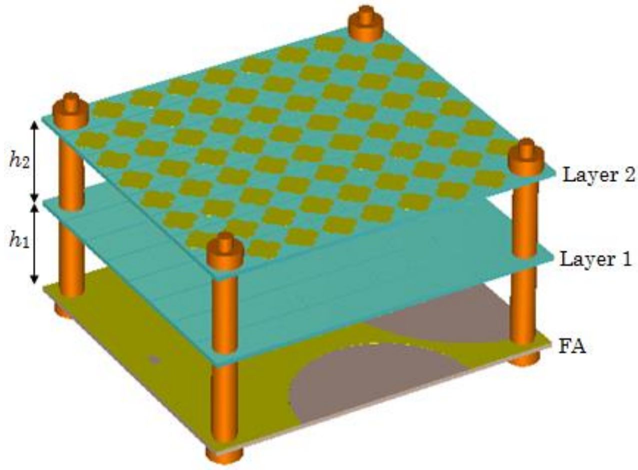

Fig. 6 – Perspective view of the proposed antenna with PRS layers

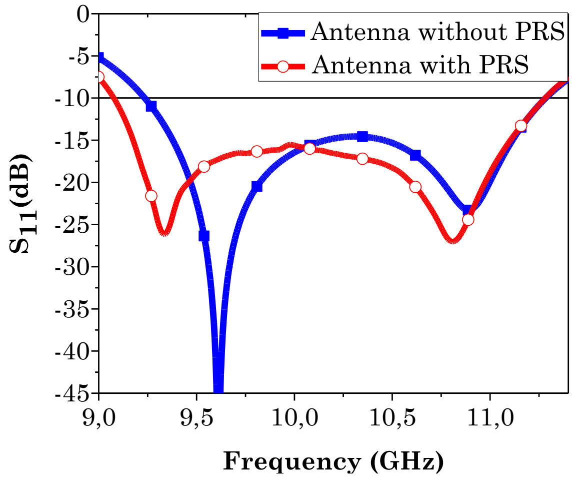

Fig. 7 – Influence of adding the designed PRS on the reflection coefficient of the considered FA

addition of the PRS; the gain increases by more than 2.51 dBi along the working band. Because high gain can be achieved by high reflection of electromagnetic waves between the FA and the PRS, the use of the same considered FA without cuts along the borders of its ground plane will enhance more its gain but unfortunately the operational bandwidth will dramatically lessen. Fig. 9 depicts the simulated far-field 2D radiation patterns of the antenna with PRS at 10.25 GHz. It is evidently perceived that the main radiated beam is along the broadside direction with reasonably symmetrical radiation.

4. CONCLUSIONS

A broadband dual-layer PRS for printed antennas gain enhancement has been proposed in this paper. The proposed dual-layer PRS operates in a wideband ranging from 7.76 GHz to 11.16 GHz. It is placed over a single-layer printed FA to demonstrate its effectiveness for antennas gain improvement along this band. The gain of the considered FA is considerably enhanced after the implementation of the PRS. Thus, the proposed PRS is useful for improving the gain of printed antennas operating in the X-band.

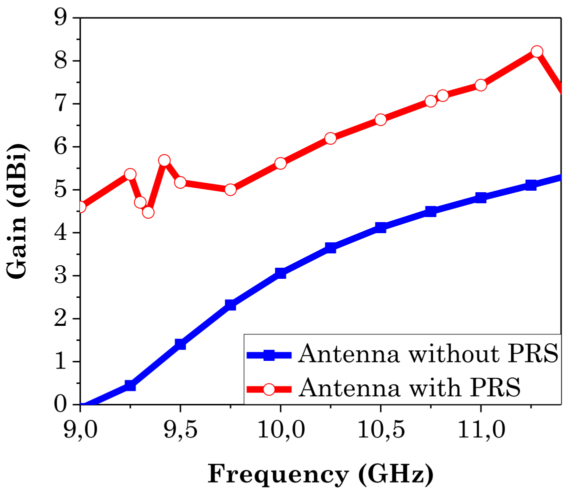

Fig. 8 – Influence of adding the designed PRS on the gain of the considered FA

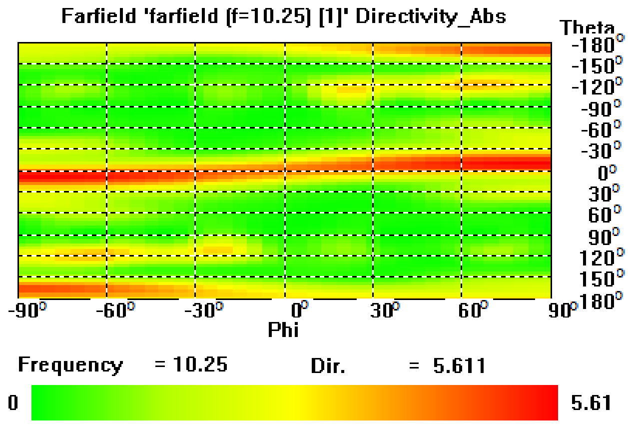

Fig. 9 – Far-field 2D radiation patterns at 10.25 GHz

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Нова широкосмугова частково відбиваюча поверхня для покращення коефіцієнта посилення антени

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У роботі запропонована нова широкосмугова частково відбиваюча поверхня (PRS) для покращення коефіцієнта підсилення друкованих антен. Запропонована PRS побудована з двох шарів, розділених повітряним зазором. Вона складається з індуктивного патчу з отвором у формі зірки або квітки, протравленого на нижніх гранях його двох шарів, та ємнісного патчу у формі зірки або квітки, розміщеного на верхній грані верхнього шару. Представлена PRS з функціонуванням у широкосмуговому діапазоні від 7,76 до 11,16 ГГц запропонована для покращення коефіцієнта підсилення друкованих антен, що працюють навколо цієї смуги. Корисність запропонованої PRS досліджується шляхом розміщення масиву 8×9 над одношаровою друкованою антеною. Коефіцієнт підсилення розглянутої антени значно покращується після впровадження PRS. Отже, корисність розробленої PRS демонструється для покращення коефіцієнта підсилення друкованих антен, що працюють в діапазоні частот Х-зони.

Ключові слова: Частково відбиваюча поверхня (PRS), Широкосмуговий діапазон, Покращення коефіцієнта підсилення.