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A Gain Enhanced Circularly Polarized Microstrip Antenna for RFID Readers Applications

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Abstract: - This paper presents a circularly polarized microstrip patch antenna with enhanced gain using a Uniplanar Compact-Photonic Band Gap (UC-PBG) structure for Ultra High Frequency (UHF) Radio Frequency IDentification (RFID) reader applications. The patch structure is designed with truncated corners and slit rectangular shapes. The performance of the antenna is tested using Computer Simulation Technology MicroWave Studio (CST MWS). The antenna patch is designed with an FR4 epoxy substrate and overall size of 180×180×1.6mm3. The substrate thickness is fixed at 1.6mm. An SMA port is used to feed the patch structure through the substrate and the ground plane to achieve a matching impedance of -19dB at the frequency of resonance (915MHz). The achieved gain is found to be 8.2dBi at 915MHz with a front to back ratio (F/B) of 13dB. The gain enhancement after adding the UC-PBG layers is found to be 3.4 dBi with a radiation efficiency of 87%. The obtained results are validated numerically using Ansoft's High Frequency Structure Simulator (HFSS). Finally, an excellent agreement is achieved between the obtained results from both of the numerical software packages.

Key words: - Circular polarization, RFID, UHF, UC-PBG.

I. INTRODUCTION

From several past years till now, RFID technology observed numerous attractive advancements for significant research aspects. The technology of the RFID uses the electromagnetic signals for automatic identification [1], where, it consists of three main sub-systems: Tag or transponder, Reader or interrogator, and Host/controller [1, 2]. The category of microstrip antennas may be considered a close matched for such technology due to their inherent advantageous such as thin profiles, low cost, and easy fabrication [3]. However, the microstrip antenna suffers from several drawbacks that are mostly presented by a significant fraction of radiation may be lost in the dielectric medium of the substrate and the electromagnetic diffractions from the edges [3]. Such problems are known as the surface- and leaky-waves inside the substrate that limit the antenna performances. Therefore, the use of the UC-PBG structure, where raised from optical concepts [4], and was employed to eliminate the effects of such waves [5]-[9].

Last decades, the applications of the UC-PBG structures, in the microwave devices [5] started to dominate over other passive structures. Generally, these structures were designed as a periodical crystal patterns and slots are etched in the ground planes [6]. Although, these configurations were already used for microstrip antenna designs, antennas experienced from strong backward radiation that reduces the bore-sight gain [7]. Therefore, many researchers were attracted to enhance antenna performance by applying UC-PBG structures. Among many others, Electromagnetic Band Gap (EBG) and/or UC-PBG were introduced in [5]-[9], to utilize an improvement in the antenna gain for their versatility and ease of fabrication.

In this paper, a microstrip antenna of a circular polarization with a high gain mounted underneath of a UC-PBG structure of double layers with 7×7 unit cell arrays is presented. The proposed UC-PBG structure is designed based on finite uniform 2D periodical metal structures to enhance the antenna gain. It is found that the combination of the UC-PBG structure with the microstrip antenna is appropriated to many applications in the UHF frequency band including the RFID readers. The antenna performance including the S_{11} spectra and radiation patterns, before and after adding the UC-PBG layers, is tested and simulated using FIT based on CSTMWS formulations. Finally, the obtained results are validated using FEM based HFSS software package.

II. ANTENNA DESIGN AND SPECIFICATIONS

A. The Microstrip Antenna Geometry

The geometry of the proposed antenna is constituted by a microstrip circularly polarized patch mounted on FR-4 epoxy substrate, permittivity of 4.3 and tan δ = 0.02, with thickness (*h*) of 1.6 mm. The patch geometry is fed with a coaxial SMA port of characteristics impedance of 50 Ω. The feed location is positioned at the patch length center with an offset from the patch width. The other dimensions details of the patch, substrate, and feed location are shown in Fig. 1 and listed in Table I.

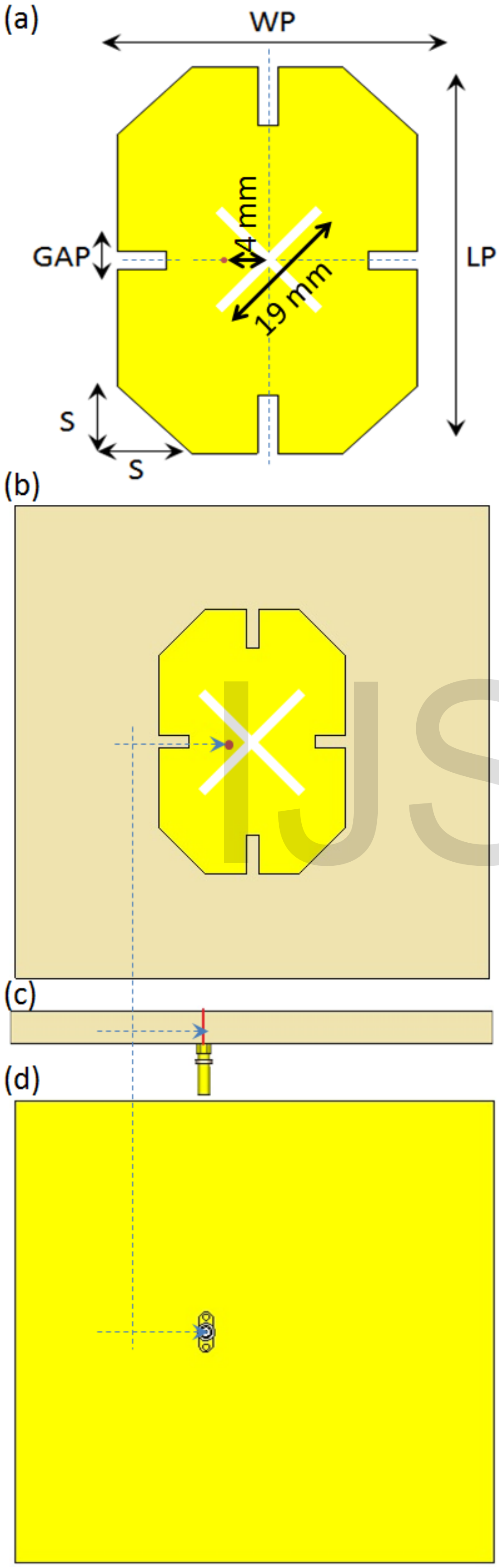

Figure 1: Antenna geometry: (a) patch structure, (b) front view, (c) side view and (d) back view.

Table.1 dimension details

Parameters	L	W	L_P	W_P	GAP	S
Dimensions (mm)	188	188	106	74	5	18.5

B. The Geometrical Details if the UC-PBG Layers

The UC-PBG structure is consisted of two layers; each layer consists of a 7×7 unit cells array. The unit cell structure is combined of two concentric rings; the outer ring is shaped as a continuous closed square trace. The second ring is performed as a split circle with a certain gap. Each ring functions as resonance window. The two rings are connected by two rectangle strip lines. The reason of choosing two different shaped-rings is to obtain two different resonances location at two different bands. Moreover, the geometry of each ring is performed as thin trace to reduce the capacitive coupling that may occur between the UC-PBG layers. The dimensions of the square ring is considered as 26 × 26 mm^2, while, the outer radius of circler ring is 10 mm. Both of the trace width and the gap distance are chosen to be 1 mm. The strip length that connects between the two rings is considered as 2mm. Each two adjacent unit cells are separated with 1 mm gap in their periodical lattice. To obtain the maximum gain, the first UC-PBG layer is located at 30 mm from the patch, while, the second layer is separated with 20 mm from the first one. The rest of the geometrical details of the proposed UC-PBG layers are depicted in Fig. 2.

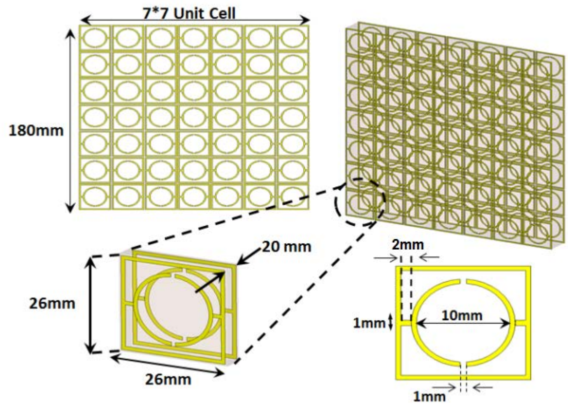

Figure 2: UC-PBG Geometry.

C. The Microstrip Antenna based on the UC-PBG Layers

The antenna structure based microstrip patch shown in Fig. 1 is combined to the UC-PBG layers as presented i1n Fig. 3. The UC-PBG layers are located at the focal point at 30 mm from the top of the patch. Such structure is applied to focus the radiation at the bore-sight (G_o) direction and obtain paraxial beam rays to get the maximum gain. This can be reached by

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minimizing the beam with on both ϑ- and φ- cut planes as shown the following relation: [3]

$$G_o \cong \frac{30{,}000}{\varphi\Theta} \quad (1)$$

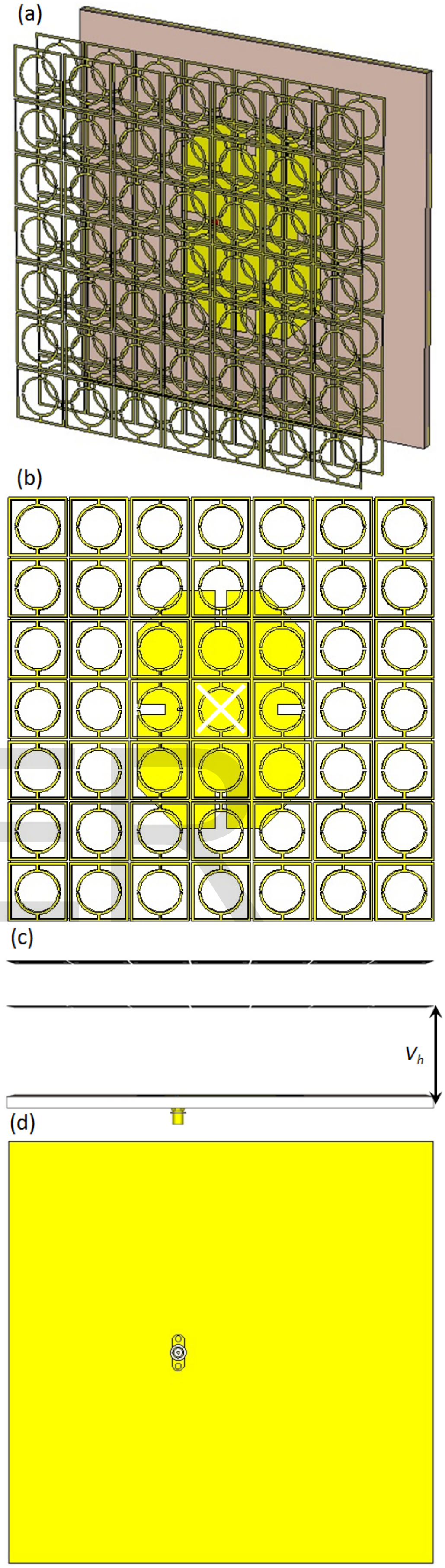

Figure 3: Microstrip antenna based on UC-PBG Layers: (a) 3D view, (b) Front view, (c) side view and (d) back view.

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III. RESULT AND DISCUSSIONS

In this section, the antenna structure is designed to provide the maximum matching at the resonance frequency of 915 MHz in the UHF band. The antenna performance is tested in terms of S_{11} spectra and radiation patterns.

A. Antenna Performance without UC-PBG Layers

A numerical study on the antenna performance without the UC-PBG layers is conducted. The patch dimensions and the feed location are optimized with respect to monitoring the S_{11} spectrum to obtain the maximum matching at 915 MHz. It is found that the antenna shows excellent matching of -11 dB with a bore-sight gain of 4.8 dBi. Fig. 4 shows the S_{11} spectrum and radiation patterns at the ϑ- and φ- planes.

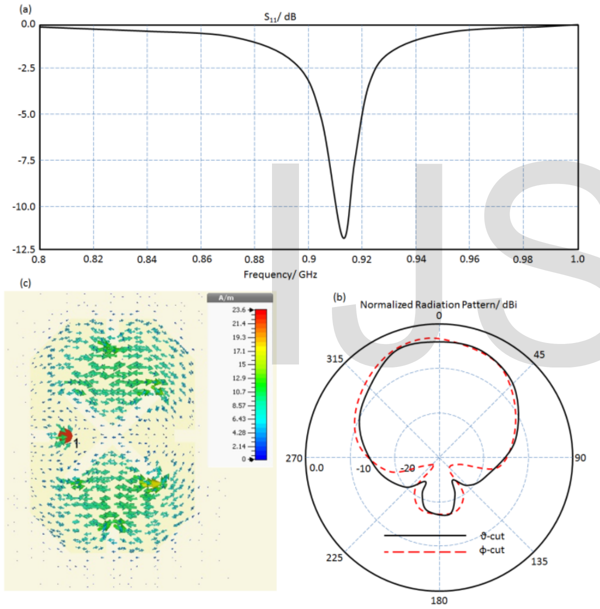

Figure 4: The performance of the proposed antenna without UC-PBG Layers: (a) S_{11}, (b) radiation Patterns, (c) current distribution.

The antenna is designed to provide a circular polarization to achieve polarization matching between transmitting and receiving antenna as seen in Fig. 4(c). This is achieved by using a cross slots at the center and truncated corners of the patch with rectangular slits along the length and the width.

B. The Parametric Study

The best location of the UC-PBG layers from the top of the patch is studied by running a parametric study on the vertical dimension (V_h) only. The value of V_h is changed from 10 mm to 70 mm with step of 10 mm. It is observed from Fig. 5(a), adding the UC-PBG structure leads to change the S_{11} spectrum. This change is attributed to capacitive coupling effects on the patch structure. It is found that the antenna performs the best gain at the bore-sight of 30 mm as can be seen in Fig. 5(b).

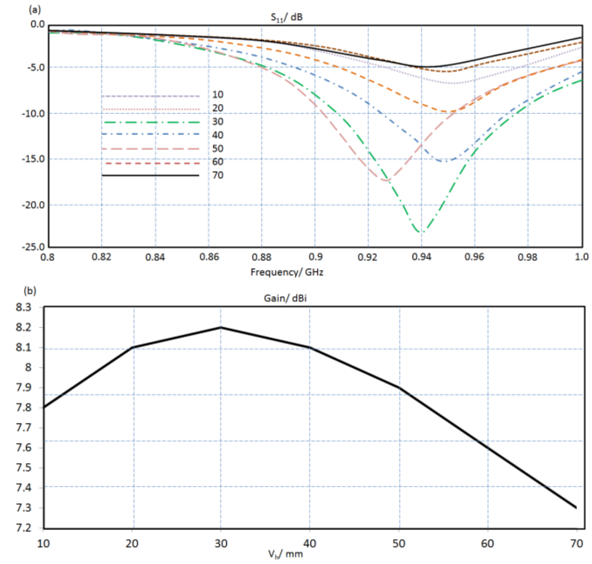

Figure 5: A parametric study of the proposed UC-PBG Layers from the antenna structure: (a) S_{11} and (b) bore-sight gain.

C. The Optimal Antenna Performance and Validation

As seen from Fig.5 (a), the antenna shows the maximum gain at V_h=30mm. However, the frequency resonance of the antenna is changed due to the introduction of the UC-PBG layers. Therefore, the dimensions of the antenna patch are re-adjusted to obtain the same resonance frequency (915 MHz). The obtained results of the microstrip antenna based UC-PBG layers are validated using FEM based on HFSS formulations. In Fig. 6, the antenna performance in terms of S_{11} and radiation patterns is presented. Improvement in antenna matching in terms of S_{11} is also clear. Excellent agreements are found between the obtained results from the CST MWS and HFSS software packages. The antenna shows a gain of 8.2 dBi at 915 MHz. Finally after introducing the UC-PBG layers, the size of the patch structure is reduced by a factor of 0.1 from the original one.

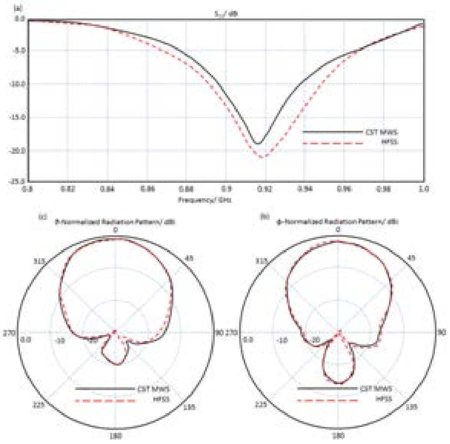

Figure 6: The proposed microstrip antenna based UC-PBG Layers: (a) S_{11} and (b) radiation patterns.

IV. CONCLUSION

In this article, a circularly polarized patch microstrip antenna based on UC-PBG structure for RFID applications is presented. The designed antenna structure provides a high gain at the UHF band. The patch structure is designed as truncated corners rectangle with slits mounted on an FR4 epoxy substrate and fed with a 50 Ω SMA connector. It is found that the antenna matching impedance is -19dB at the resonance frequency of 915MHz with G_o=8.2dBi and F/B of 13dB. The antenna gain without the UC-PBG layers is found to be 4.8 dBi. The obtained results are from CST MWS and validated numerically by HFSS. Excellent agreements are achieved between the results of the used numerical software packages.

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