

# An Equilateral Arm Inverted U-Slot and Notch Loaded UWB-CPMA with Rendered Ground Plane

Mukesh Kumar, Jamshed Aslam Ansari, Abhishek K. Saroj, Rohini Saxena



**Abstract:** In this paper, a microstrip fed modified circular patch monopole antenna (CPMA) with the rendered ground surface is presented for bandwidth enhancement. In order to extend the bandwidth of a demonstrated antenna, symmetrical slots and equilateral arms inverted U-slot are loaded on the partial ground and patch individually. For additional enhancement in the secured bandwidth, symmetrical notches are truncated from the bottom of the patch. The antenna has a dimension of  $30 \times 40 \times 1.6$  mm<sup>3</sup>, which is erected on low cost, FR-4 substrate with relative permittivity  $\epsilon_r = 4.4$ , permeability  $\mu = 1$  and loss tangent of  $\tan\delta = 0.02$ . The proposed design is analyzed and simulated using high frequency structure simulator (HFSS). The analyzed results are validated through experimented results. The proposed antenna offers a bandwidth of 140.2 % with a maximum radiation efficiency of 94 % over the frequency scope of 2.54 GHz to 14.47 GHz. The cross-polarization levels are also found to be 20-30 dB and 12-23 dB smaller than the co-polarized level for E-plane and H-plane respectively. For better execution and assessment of proposed antenna, a parametric study has been done to analyze the performance of antenna with variations in the length of a partial ground conductor beside the other parameters. The exhibited antenna is suitable for various applications incorporating WiMAX, WLAN, UWB, C-band, X-band and UWB.

**Keywords:** CPMA, MPA, MSA, UWB, Rendered Ground, Bandwidth Enhancement, Radiation Efficiency.

## I. INTRODUCTION

Microstrip patch antennas (MPAs) are expeditiously expanded in the ultra wide band (UWB) system applications. The Federal Communication Commission (FCC) allocated UWB frequency scope from 3.1–10.6 GHz for commercial applications [1-3]. It has salient features like huge bandwidth, less power consumption, simple hardware configuration that support high data rate primarily in short-range wireless technology for the wireless multimedia system, biomedical system, modern communication system, etc. [4]. There are different kinds of structure and techniques have been developed to accomplish UWB attributes. Quite a few of these conventional MPAs do not cover the entire bandwidth [5- 8]. Recently, monopole MSAs have become more popular due to its facile geometry, wide bandwidth, stable radiation pattern and greater radiation efficiency [9].

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Numerous geometries of monopole MPAs have been investigated for UWB applications such as microstrip fed circular patch antenna utilizing a partial ground surface for UWB operations with stable radiation characteristics [10-11]. Wide Band behaviour is reported due to circular- square linked notch [12] and Saturn-shaped notch [13] on the partial ground surface with slotted circular disk monopole antenna. An electrically small size coplanar waveguide (CPW) fed circular disk monopole antenna provided very large impedance bandwidth with a flat gain [14]. Bandwidth enlargement of the MPA is obtained through impedance matching by the appropriate amending the gap between radiating element and ground surface [15-17]. A modified square MPA is implemented to achieve wide band characteristics and stable radiation attribute along with appropriate cross-polarization level by the employing rectangular parasitic with the defected ground conductor [18]. Bandwidth expansion is accomplished by the properly adjusting couple of sleeves in the curved ground plane with elliptical patch monopole antenna [19]. Such a large bandwidth with high radiation efficiency is examined owing to the impedance matching by the appropriately embedding rectangular slot in a partial ground surface with annular ring monopole MPA [20] and with octagonal shape monopole MPA [21]. Broadband characteristics are achieved by loading a symmetrical rectangular slot in the partial ground conductor with symmetrical hexagonal monopole MPA [22]. A toppled trapezium-shaped monopole MPA is investigated which provide very large bandwidth along with high gain ranging from 7.1- 26 GHz [23]. Super wide band performance is realized by reason of familiarizing fractal geometry on the radiating patch with truncated ground plane [24]. Notwithstanding, during the time spent expanding the bandwidth, the greater part of the plan winds up immense in size or complex in structure. The aim of proposed structure relies upon a monopole antenna configuration and above mentioned literature to study how to overcome the hindrance of restricted bandwidth and achieve better radiation characteristics. In this paper, an equilateral arm inverted U-slot and notch loaded UWB-CPMA with rendered ground plane are studied and analyzed. The demonstrated antenna is excited from a microstrip feedline by selecting appropriate locations and dimensions of slots and notches on the patch for extending the bandwidth. A parametric variation is additionally studied for geometrical expansion. The simulated and measured outcomes agree well. Pair of symmetrical notches are truncated from the base of the patch for further improvement on the bandwidth and radiation characteristics.

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The introduced antenna covers the frequency band from 2.54 GHz to 14.47 GHz, which is approximately 140.2 % impedance bandwidth. Table 1 shows that comparison between above-mentioned antennas and proposed antenna

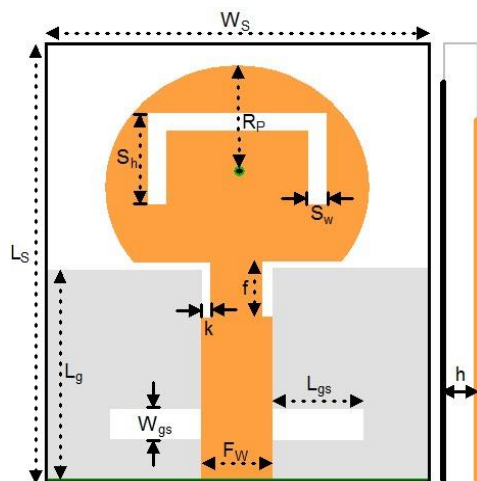
with their characteristics such as impedance bandwidth, gain, radiation efficiency along with substrate used for fabrication. Particulars of the antenna structure with their characteristics are illustrated in the next section.

**TABLE 1: A comparison between previously published monopole antennas.**

Ref.	Size (mm <sup>2</sup> )	Substrate	Bandwidth (%)	Maximum Gain (dB)	Maximum Efficiency (%)
10.	42x50	FR-4	111.4	6.7	Not Given
11.	46x52	FR-4	140	1.86	89.6
12.	22x28	FR-4	117.3	4	Not Given
13.	18x12	FR-4	114.5	2.04	Not Given
14.	35x30	FR-4	146.3	5	>80%
15.	46x52	FR-4	145.7	1.55	87.88
16.	30x30	FR-4	111.6	4.6	Not Given
17.	45x50	FR-4	107.6	6	96
18.	20x25	FR-4	110	5.1	89
19.	30x35	FR-4	117.8	6	97
20.	39x40	FR-4	129.3	5.52	91.2
21.	35 × 35	FR-4	139	1.7-5	95
22.	25x20	FR-4	118.8	5.1	Not Given
23.	30x40	Neltech	114.2	8.24	85
24.	62x64	FR-4	175.7	5.5	85
proposed	30x40	FR-4	140.2	4.75	94

## II. GEOMETRICAL SPECIFICATIONS OF ANTENNA

The outline of the implemented antenna with a rendered ground plane appears in Fig. 1. The antenna comprises of rectangular notched circular patch radiator with an inverted U-slot fed by 50-Ohms microstrip-line and a couple of horizontally symmetrical I-shaped slotted partial ground for bandwidth enhancement. The antenna is fabricated on FR-4 substrate with dielectric constant  $\epsilon_r = 4.4$  and loss tangent  $\tan\delta = 0.02$ . The radius of the patch is considered as 9 mm with 1.6 mm substrate height. The area of the substrate is  $L_s \times W_s$  with 17 mm of ground conductor.

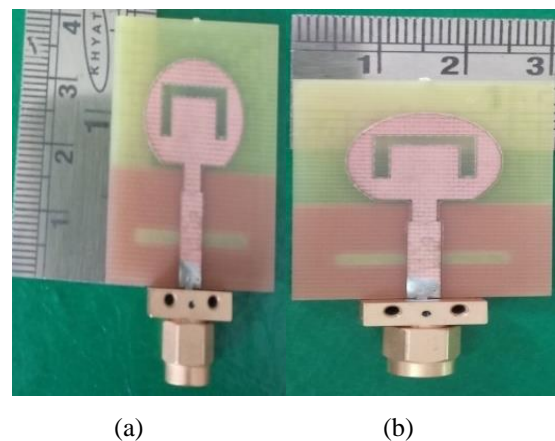


**Fig.1. Geometrical layout of the proposed antenna.**

**TABLE 2: Geometrical specifications of an antenna.**

Parameters	Rp	Ws	Ls	Fw	h	Lg
Dimensions(mm)	9	30	40	4	1.6	17
Parameters	Sh	Sw	Wgs	Lgs	k	f
Dimensions(mm)	8	2	2	8	0.5	4

The proposed geometrical specification of a demonstrated antenna is depicted in Table 2. The prototype of a fabricated antenna is exhibited in Fig. 2.



**Fig.2. (a) and (b) Dimension of fabricated antenna.**

III. DESIGN PROCEDURE AND PERFORMANCE

The evolution of the proposed antenna stages with their simulated performance in terms of reflection coefficient ( $S_{11} < -10$ ) are described and presented in Fig. 3. In the beginning, three frequency bands, 3.29-4.72 GHz, 6.54-9.25 GHz and 10.6 - 14.28 GHz are obtained, when a conventional edge fed circular patch with a finite ground conductor is selected with appropriate dimension. In the second stage, additional resonance is energized by the employing pair of horizontal I - shaped slots in the ground conductor and thus 74.15 % impedance bandwidth is achieved ranging from 6.55 - 14.72 GHz.

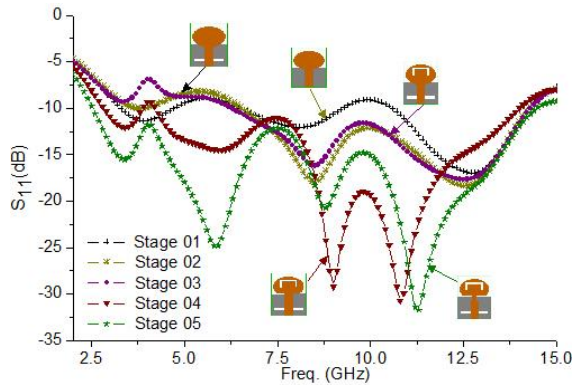


Fig.3. Simulated reflection coefficient of different stage.

For the instance of stage third, the current path length is increased when inverted U- slot is loaded on the patch section, which results in shifting the resonance at the lower bands and the frequency band reaches up to 6.3 GHz with 77.66 % impedance bandwidth. For the excitation of the lower order resonance, the pair of notches are employed at the base of the radiator in the stage fourth. This gap generates strong coupling between patch and ground plane, which results provide good impedance matching with enriched bandwidth of 29.85% and 106.96% ranging from 2.85 GHz - 3.85 GHz and 4.24 GHz - 13.99 GHz individually. Finally, when pair of vertical I- shaped slots are incorporated in feed line at the base of the patch in the stage fifth, the additional resonance excited with better impedance matching, which provides 140.2 % impedance bandwidth ranging from 2.54 GHz to 14.47 GHz.

IV. PARAMETRIC STUDY

In this section, a study of the various parameter of a demonstrated antenna is discussed and investigated sensitive parameters which are responsible for antenna performance. In the parametric study, only a single parameter is varied at a time while the others keep constant as given in Table 1. The impact of reflection coefficient for different estimations of antenna parameters patch radius, ground length, ground slot length, arm height of inverted U-slot are introduced in Fig. 4.

In Fig. 4 (a), it could be observed significant variation in bandwidth and impedance matching when the patch radius ( $R_p$ ) is varied from 8 mm to 9 mm with 1 mm interim. Dual frequency behavior is achieved (2.7-3.7 GHz and 4 GHz to 14.6 GHz) at 8 mm patch radius.

When the radius of the patch is increased by 1 mm, good impedance matching and bandwidth can be found and antenna radiated over the frequency range of 2.54 GHz to 14.47 GHz with 140.2 % bandwidth.

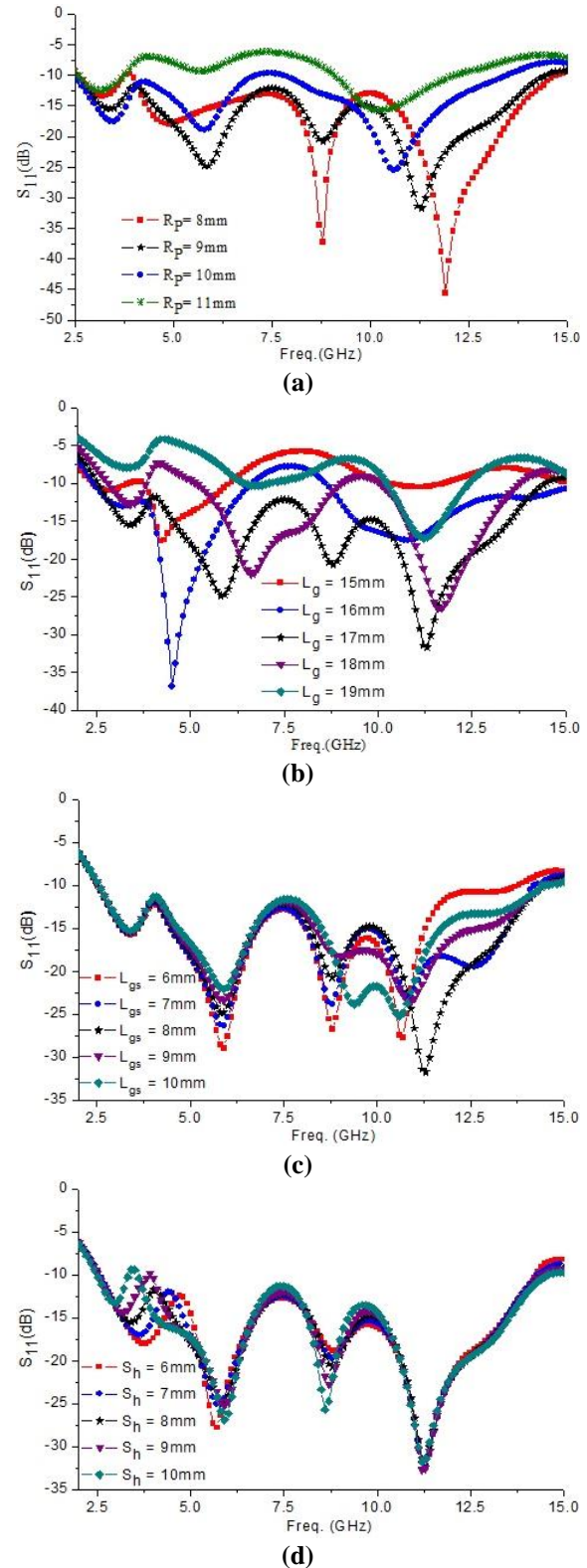


Fig.4. Simulated reflection coefficient variation for (a)  $R_p$ , (b)  $L_g$ , (c)  $L_{gs}$ , and (d)  $S_h$ .



Impedance matching and bandwidth are affected for further increment in patch radius.

The variation of ground length ( $L_g$ ) from 15 mm to 19 mm with 1 mm interim is shown in Fig. 4 (b). We accomplish better impedance matching at 17 mm which provides improved bandwidth. Further variations in ground length degraded impedance matching and bandwidth.

The impact of ground slot length ( $L_{gs}$ ) deviation from 6 mm to 10 mm with an interval of 1 mm is exhibited in Fig. 4 (c). The impedance matching and bandwidth are slightly varied with slot length. The overall bandwidth achieved 11.1 GHz, 11.5 GHz, 11.93 GHz, 11.75 GHz and 11.7 GHz for the slot length at 6 mm, 7 mm, 8 mm, 9 mm and 10 mm respectively. At the optimum value of 8 mm achieved improved bandwidth.

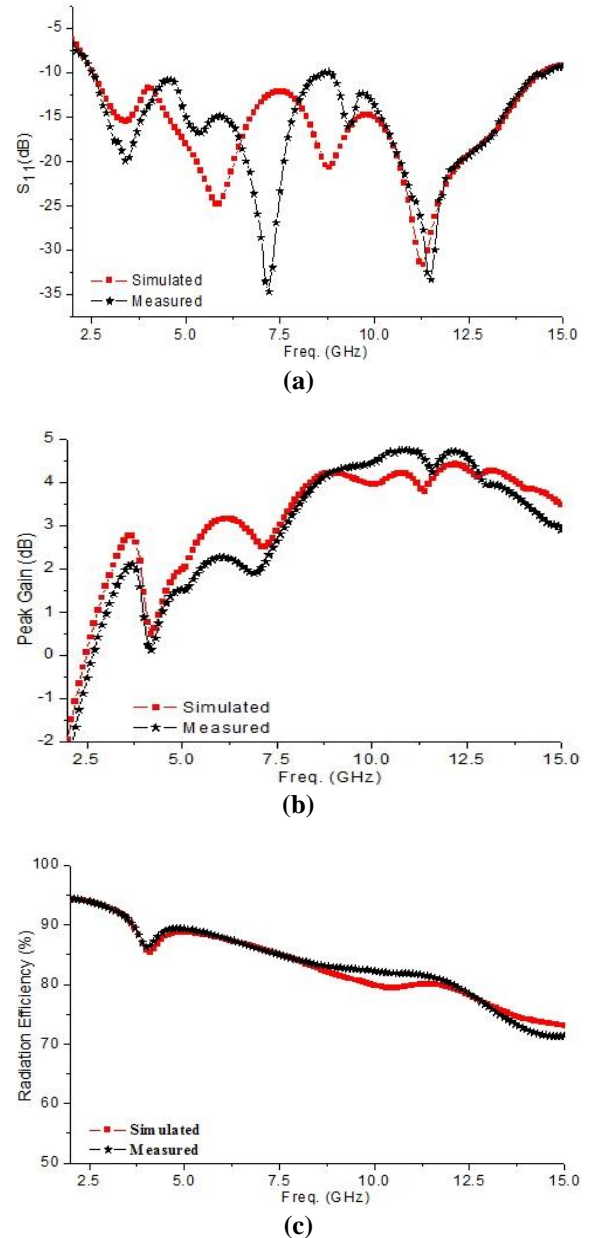
Different frequency bands are observed for different estimation of arm height of the inverted U-slot ( $S_h$ ) from 6 mm to 10 mm with 1 mm gap and depicted in Fig. 4 (d). At the height of " $S_h=6$  mm, 7 mm and 8 mm", antenna radiated over the frequency scope of 2.6 to 14.2 GHz, 2.6 to 14.27 GHz and 2.54 to 14.47 GHz respectively. At the height of " $S_h=6$  mm, 7 mm and 8 mm", antenna radiated over the frequency scope of 2.6 to 14.2 GHz, 2.6 to 14.27 GHz and 2.54 to 14.47 GHz respectively. As the height of " $S_h$ " is further increased from 8 mm to 9 mm and 9 mm to 10 mm, antenna shows dual frequency bands from 2.55 to 3.8 GHz and 4 to 14.4 GHz as well as 2.5 to 3.3 GHz and 3.6 to 14.6 GHz respectively. At the estimation of " $S_h=8$  mm" accomplished maximum bandwidth.

From figure 4, parametric variations of different extents of the offered antenna are examined and perceived, and the gap between patch ( $R_p$ ) and ground length ( $L_g$ ) plays a significant role for acquiring wide band features. The length of the ground plane controls the coupling between the ground and the patch. It acts as an additional impedance matching network. The gap size influences the impedance matching and selecting proper gap between radiator and ground plane, results in smooth transition from one resonant mode to another resonant mode and confirming good impedance matching over a frequency range of 2.54 GHz to 14.47 GHz.

## V. RESULT AND DISCUSSIONS

The proposed antenna is fabricated on FR-4 substrate using CNC machine and measurement is carried out using Agilent Vector Network Analyzer E5071C. Fig. 5 (a) demonstrates the correlation between simulated and experimental reflection coefficient ( $S_{11}$ ) of the proposed antenna. The simulated and experimental results are slightly shifted due to fabrication tolerances and software limitations in terms of modelling and simulating over a large bandwidth from 2.54 to 14.47 GHz. Fig. 5 (b) and 5 (c) illustrate the comparison of simulated and experimental gain and radiation efficiency (%) individually of the proposed antenna.

Gain is measured by two antenna strategy by utilizing horn antenna and proposed model antenna in an anechoic chamber. The maximum experimental gain of 4.75 dB at 10.9 GHz is achieved with more than 74 % radiation efficiency for the entire operating band.

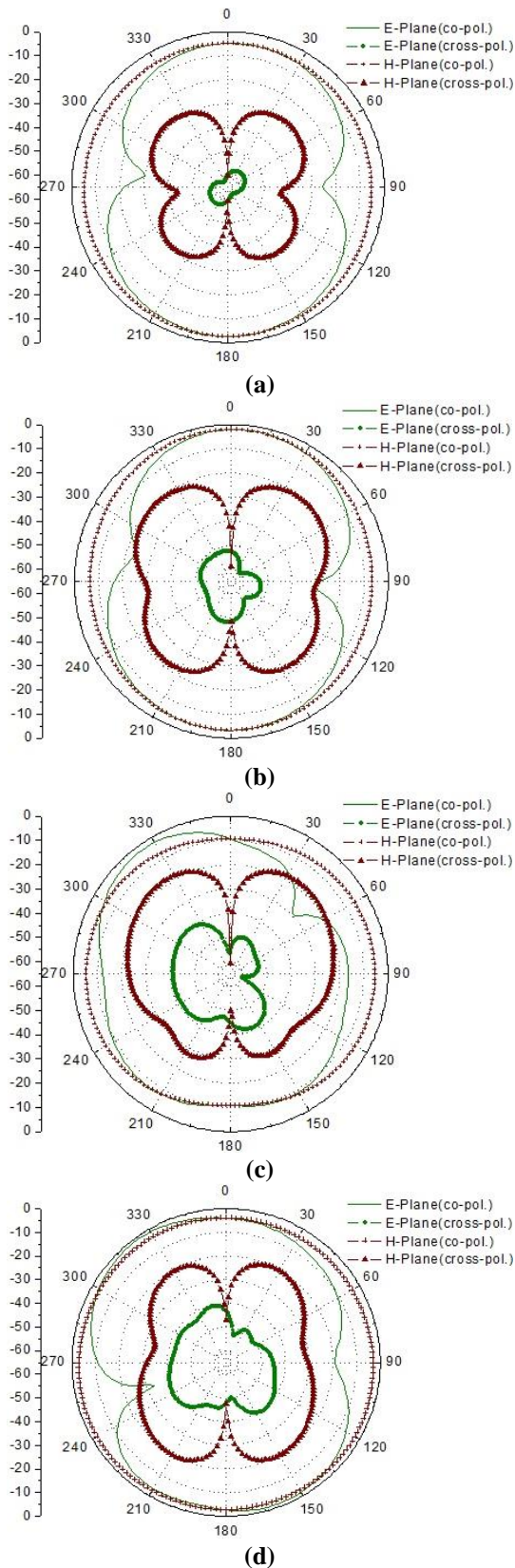


**Fig.5. Comparison of simulated and measured results of the proposed antenna for (a)  $S_{11}$ , (b) Gain, (c) Radiation efficiency.**



**Fig.6. Proposed antenna in anechoic chamber.**

It is observed that the radiation efficiency gradually decreases from lower to higher frequencies. At higher frequencies dielectric losses increases which cause a reduction in radiation efficiency. Anechoic chamber arrangement for the proposed antenna is appeared in Figure 6.



**Fig.7. Simulated radiation pattern of proposed antenna at different resonant frequencies (a) 3.4 GHz, (b) 5.8 GHz, (c) 8.8 GHz and (d) 11.3 GHz.**

Fig. 7 (a), (b), (c) and (d) shows the simulated 2D radiation patterns of co-polarization and cross-polarization for E-plane and H-plane at resonating frequency of 3.4 GHz, 5.8 GHz, 8.8 GHz and 11.3 GHz respectively.

The maximum cross-polarization level is -56.9 dB and -28.4 dB, -47.9 dB and -20 dB, -40 dB and -17.9 dB as well as -39 dB and -19.7 dB at 3.4 GHz, 5.8 GHz, 8.8 GHz and 11.3 GHz respectively for E-plane and H-plane. The cross-polarization values are 20-30 dB and 12-23 dB lower than the co-polarized values for E-plane and H-plane individually.

## VI. CONCLUSION

An inverted U-slot loading compact circular patch with the rendered ground plane is demonstrated for UWB applications. Due to selecting appropriate locations and dimensions of notch and slots on the patch and ground plane, bandwidth of the introduced antenna is expanded. The simulated and experimental results of the presented antenna are agreeable over the operating frequency scope of 2.54 GHz to 14.47 GHz. Peak gain of 4.75 dB and peak radiation efficiency of 94% have been achieved along with stable radiation attributes for the demonstrated antenna. From an aggregate perspective on radiation patterns, the antenna acts correspondingly to the ordinary printed monopoles. All the above properties demonstrate that the proposed antenna is proficient to deal with the necessities of UWB operations.

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