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RESEARCH PAPER

A compact elevated CPW-fed antenna with slotted ground plane for wideband applications

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In this paper, a miniaturized elevated-coplanar-waveguide-fed antenna with a slotted ground plane is proposed. This antenna has a compact size of 25 mm × 25 mm × 1.6 mm where the ground plane is reduced by etching a trapezoidal slot along with two extended slits. A −10 dB wide-impedance bandwidth of 126% ranging from 2.8 to 12.4 GHz is achieved for the proposed antenna. The proposed antenna is successfully manufactured and experimentally investigated. The measurement shows a good agreement with the simulation. The measured radiation characteristic shows a stable and nearly omnidirectional pattern over the operating bandwidth region. The effects of various parameters on the antenna performance are analyzed and discussed as well.

Keywords: Compact antenna, Slotted ground plane, Elevated CPW-fed, Wideband

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I. INTRODUCTION

With the rapid expansion of wireless communication systems and their applications, compact wideband antenna design has become the most demandable topic for the present day communication systems [1]. Printed wide slot antennas have recently been receiving a great deal of attention with their attractive features such as wide-impedance bandwidth, simple structure, compact size, low cost and easy integration with monolithic microwave integrated circuits [2, 3]. Many printed antennas have been proposed so far, which includes different slot structures such as triangle, circle, ellipse, square, hexagon, etc [4–8]. Furthermore, numerous techniques have been developed to enhance the bandwidth, which includes the basic concept of alternation of the slots, which is a radiating element. In [9], a square slot is rotated to enhance the bandwidth. In [10], by embedding a parasitic center patch, the bandwidth was significantly increased to 82.8%. However, the bandwidths are not sufficient to cover more wireless communication services.

Another approach to enhance the bandwidth of printed antenna involves the use of novel feed structure. A lot of designs have been reported so far [11–15]. In [16], the bandwidth is improved by introducing an *L*-shaped slot with a *W*-shaped feed stub. The design reported in [12] consists of a horizontal line, a square patch, and a vertical line, linked sequentially in an *L*-shaped arrangement. Bandwidth enhancement for wideband operation can also be obtained by using parasitic elements along the microstrip feed line. By adopting a pair of parasitic patches along the microstrip feed line, the impedance bandwidth was enhanced to a very good extent in [11]. As a result, the impedance bandwidth was found to be 136% ranging from 2.1 to 11.1 GHz with an antenna dimension of 37 mm × 37 mm × 1.6 mm. Different approaches to minimize the size of an antenna have been done and reported [4–17]. However, large size of an antenna is still a major problem in the field of wireless communication. Although, some of the reported antennas exhibit wide bandwidth, but are somewhat complicated in structure and have large physical size as shown in Table 1.

In this paper, a simple and compact elevated-coplanar-waveguide (ECPW)-fed antenna is presented. Size reduction, simple geometry, and bandwidth enhancement are the basic design aspects of the proposed antenna. The conventional rectangular printed antenna is taken as the basic structure. The ground plane of the proposed antenna is reduced by embedding a trapezoidal-shaped slot along with two extended slits. The size of the radiating patch on top side is minimized by etching symmetrical triangles, which results a *Y*-shaped patch radiator. The ECPW feeding technique is used in the proposed antenna [18–21]. The substrate area of the proposed antenna is 25 mm × 25 mm², which can be considered as a compact size. From the results, the impedance bandwidth is found to be 9.600 GHz ranging from 2.8–12.4 GHz. The proposed antenna is validated with the experimental measurement. Finally, the effects of the vital parameters of the antenna are studied and analyzed.

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Table 1. Comparison of size, bandwidth, gain of the proposed antenna with other references.

Reference	Size (mm^3)	ε_r	Frequency range (GHz)	Gain
[4]	25 × 25 × 1.5	3.38	2.9–11.6	–
[5]	52 × 62 × 0.787	2.33	2.4–15.0	≥0.5 dBi
[6]	72 × 72 × 1.5	4.7	2.6–10.22, 3.46–10.9 and 3.1–10.6, 3.75–10.3	2–7 dBi
[7]	30 × 30 × 1.6	4.4	2.9–18	4.2 dBi (max), 3.7 dBi (avg)
[8]	25 × 25 × 0.8	4.4	2.9–11.43	–
[9]	70 × 70 × 1.6	4.4	2.2–4.5	4.6–5.2 dBi at 3.4–4.5 GHz range 3.0–4.6 dBi at 4.5–5.6 GHz range
[10]	37 × 37 × 1.6	4.4	2.23–5.35	~5.2 dBi (max)
[11]	37 × 37 × 1.6	4.4	2.1–11.1	3.1–6.4 dBi
[12]	80 × 80 × 1.6	4.4	1.21–4.72	4.1 dBi (peak gain)
[13]	50 × 45 × 1.6	4.3	5.9–13.1	5.6 dB (max), 2.9 dB (min)
[14]	110 × 110 × 0.8	4.4	1.9–16.25	–
[15]	51.5 × 61 × 1.6	4.4	1.80–6.09	3.4 dB at 2.3–2.7 GHz, 4.5 dB at 3.3–3.8 GHz, 5 dB at 5.2–5.8 GHz
[16]	50 × 50 × 0.5	3.38	5.0–9.0	–
[17]	24 × 22 × 1.58	4.4	1.9–2.1, 3.22–3.38, 4.2–7.3	2.34 dBi (peak gain)
Proposed	25 × 25 × 1.6	4.4	2.8–12.4	2.3–4.5 dBi

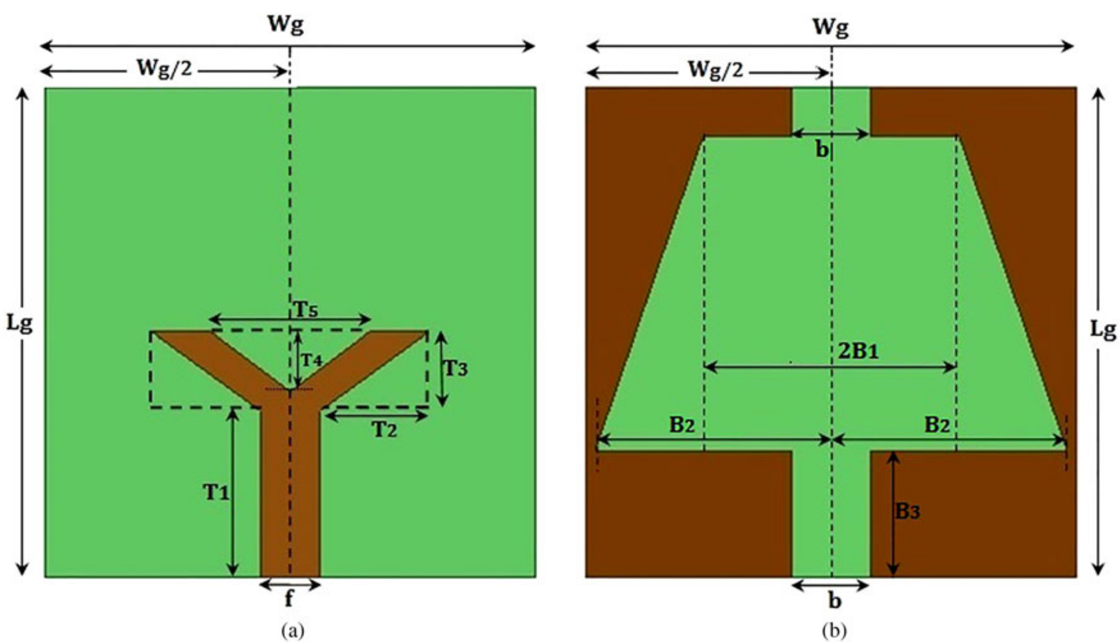

Fig. 1. Geometry of the antenna: (a) top side, (b) bottom side.

II. ANTENNA STRUCTURE

The geometry of the proposed antenna is illustrated in Fig. 1. The antenna is built on a FR4 substrate ($\varepsilon_r = 4.4$ and tan $\delta = 0.02$) with a thickness of 1.6 mm. The proposed antenna has a simple structure, which consists of a ground plane located in the *xy*-plane with $L_g \times W_g = 25$ mm × 25 mm surface. A trapezoidal slot is etched from the conducting ground plane with two elongated slits, which are open ended. The antenna is fed by a 50 Ω SMA, which is connected to the vertical arm of the *Y*-shaped radiator shown in Fig. 1(a).

The electromagnetic solver ANSYS High-Frequency Structure Simulator (HFSS) is used to numerically investigate and optimize the proposed antenna configuration. The optimized parameters are given in Table 2. The simulated −10 dB impedance bandwidth is found to be 9.62 GHz ranging from 2.78 to 12.4 GHz.

Table 2. Dimensions of the antenna parameters.

Parameters	Unit (mm)	Parameters	Unit (mm)
L_g	25	T_3	4
W_g	25	T_4	3
f	3	T_5	8
b	4	B_1	6.5
T_1	8.5	B_2	12
T_2	5.5	B_3	6

Figure 2 shows the design steps and voltage standing wave ratio (VSWR) curves for the respective steps of the proposed

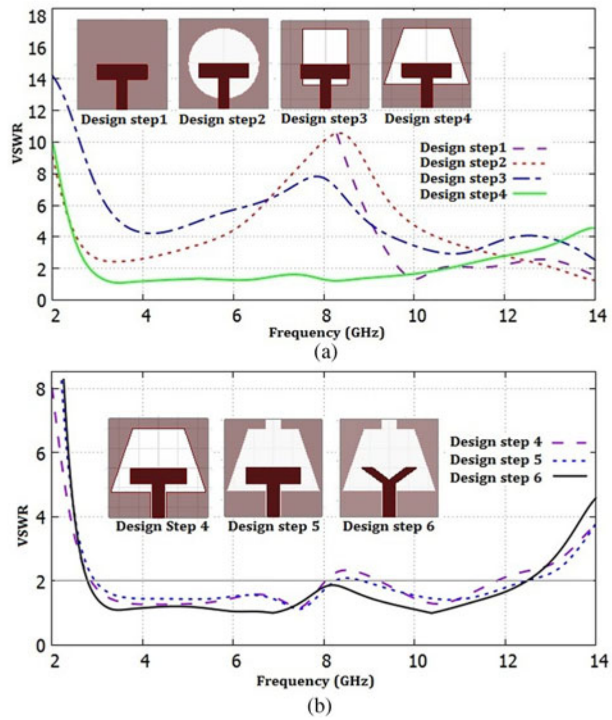

Fig. 2. Design steps of proposed antenna.

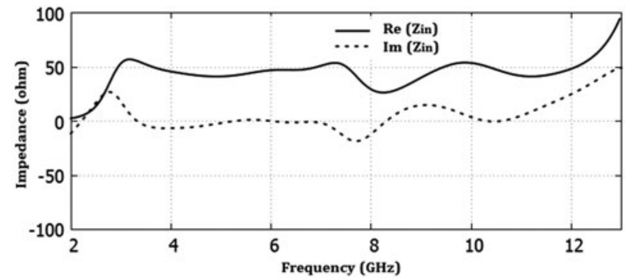

Fig. 4. Simulated input impedance of the proposed antenna.

antenna. The dark portion denotes the feed line and radiating patch, while the light portion is the design of ground plane. It is seen that the insertion of the circular and rectangular slots in the ground plane has no prominent effect on the impedance matching. The trapezoidal slot is designed by etching two triangular-shaped portions symmetrically beside the rectangular slot. It is observed from Fig. 2(a) that the trapezoidal slot in ground plane plays a vital role to enhance the bandwidth of the proposed antenna. The insertion of trapezoidal slot increases the gap between the radiating patch and the ground plane resulting in enhancement of impedance bandwidth. The effect of opened wide slots in the ground plane on the VSWR is clearly visible in Fig. 2(b). Using the open-ended slots in the ground plane, the antenna resonates at dual frequency bands with a shift in the higher frequency range. For the part of the patch radiator, the current has to flow around the slanting arms of the patch, which lengthened current path. As a result, currents along the edges of the arms introduce an additional resonance, which helps to increase the impedance matching. Thus, an enhanced impedance bandwidth has been achieved with the proposed antenna.

Figure 3 depicts the HFSS-predicted *E*-field and current distributions at sampling frequencies of 3.5, 6.8, and

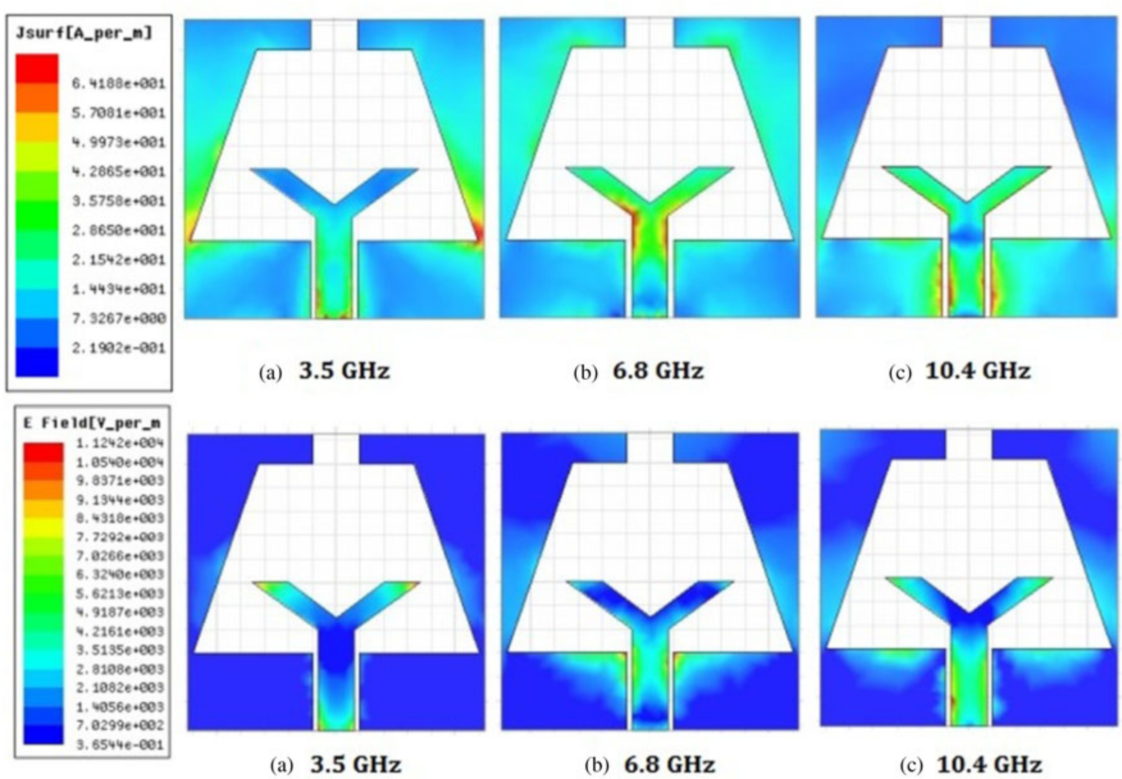

Fig. 3. Current distribution and electric field at sampling frequencies.

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10.4 GHz resonance frequencies, respectively. At the frequency 3.5 GHz, the current density is concentrated around the lower edge of the trapezoidal slot. It is observed that at 6.8 GHz, the current density is large around the upper edge of the trapezoidal slot and within the patch. At 10.4 GHz, it becomes higher in the lower edge and around the patch. Thus, there is continuity in the current distribution, which introduces a stable −10 dB impedance matching over the entire operating band. The impedance matching behavior is shown in Fig. 4.

III. ANTENNA PARAMETER STUDY

The proposed antenna is configured with various parameters, which may affect the performance of the antenna. In this section, the parameters are analyzed to understand the effects as well as to optimize them for the final design. The analysis is performed by varying one of the parameters with the other parameters keeping constant.

Figure 5 depicts the simulated VSWR curves for different values of patch parameters T_1, T_2, T_3, T_4, T_5; the ground

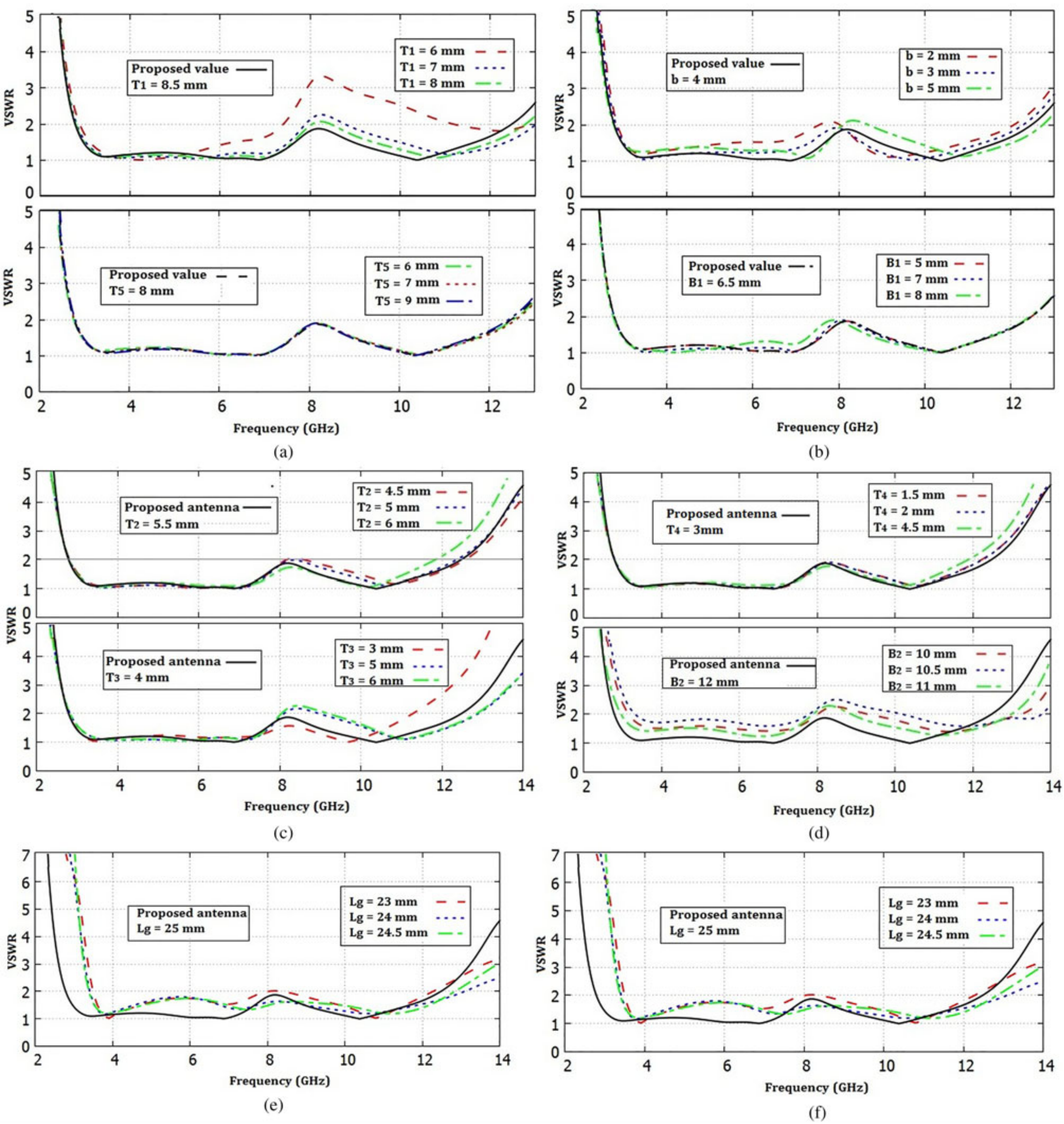

Fig. 5. Simulated VSWR of the proposed antenna for different values: (a) patch parameters T_1 and T_5, (b) ground plane parameters b and B_1, (c) patch parameters T_2 and T_3, (d) parameters T_4 and B_2, (e) ground plane size L_g, (f) ground plane size W_g.

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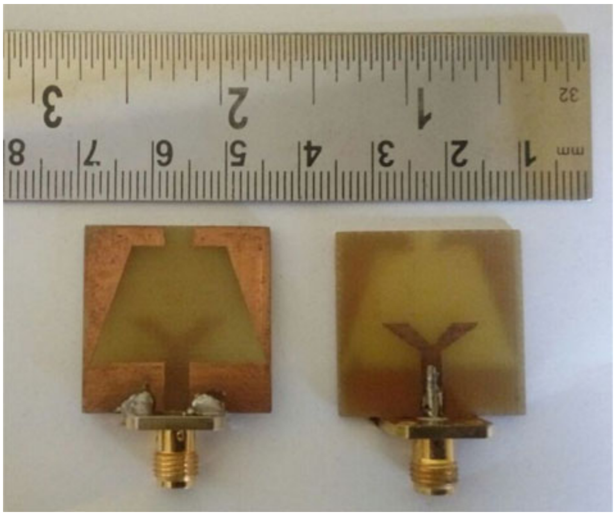

Fig. 6. Fabricated antenna: (a) front view, (b) back view.

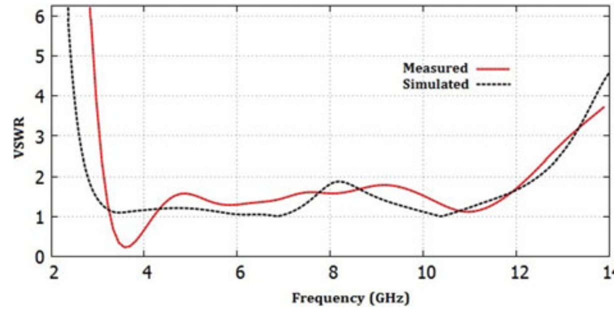

Fig. 7. Simulated and measured VSWR plot of the proposed antenna.

plane parameters b, B_1, B_2 and the substrate parameters L_g and W_g. It is observed that the impedance matching is quite good for the value of T_1 between 8 to 8.5 mm. As we gradually decrease the height of line T_1, the impedance matching at 8–10 GHz is distorted due to the shortened excitation line. Again if we increase T_1, the radiating patch becomes smaller in size, which results in a decreased bandwidth. Therefore, optimal adjustments are done to remove these distortions and the value of T_1 is chosen as 8.5 mm. Similar types of effects are observed in case of width b of the open-ended slits on the ground plane also. It shows that the impedance matching is better for the values 3 and 4 mm. However, the frequency bandwidth at 4 mm is greater than at 3 mm. Hence, it is selected as the optimum value.

The variation of the parameter T_3 shows that as we increase its value, the bandwidth becomes less. Moreover, the impedance matching is distorted as we decrease the value of T_3. Therefore, the optimum value is taken as 4 mm. Similarly, if we decrease the value of B_2, the bandwidth is found to be lesser than the proposed value. As the value of L_g is decreased, the lower cut-off frequency is shifted to higher range by decreasing the bandwidth.

The VSWR curves of T_2, T_4, T_5, B_1, and W_g show that there is no prominent effect for variations of these parameters. The impendence matching is found to be good for each variation. Therefore, the optimum values are chosen as given in the figure considering the widest frequency band. This provides that the proposed antenna leads to a minimal manufacturing error.

IV. RESULTS AND DISCUSSIONS

A prototype of the proposed antenna (shown in Fig. 1) with optimized geometrical parameters was fabricated and measured. The photograph of the fabricated antenna is shown in Fig. 6. The return loss is measured by using Agilent VNA E8362C. The measured and simulated return loss curves for the proposed antenna are shown in Fig. 7. As expected, a good agreement between the simulation and measurement is achieved. The measured impedance bandwidth is about 126% from 2.8 to 12.4 GHz with respect to the center frequency at 7.6 GHz. However, a small discrepancy is observed in the lower cut-off frequency of the VSWR curves. Because the experiments were done without any sort of transformer, the coaxial cables may have radiated freely at the low end of the operating band.

An Agilent MXG-N5183A signal generator was used as the source to feed the transmitting X- and C-band pyramidal horn, respectively, while the received power from the test antenna was measured by an Agilent U2000A USB power sensor mounted on the PC controlled turntable. Figure 8 shows the measured radiation patterns in the E-plane (yz-plane) and H-plane (xz-plane) for co-polarization and cross-polarization. It is observed that the radiation patterns are nearly identical at all three frequencies with omnidirectional pattern in xz-plane and bidirectional in yz-plane. This shows that the antenna exhibits a stable radiation pattern throughout the ultrawide operating band. However, due to the higher order current modes, a small deterioration of the pattern may be seen as the operating frequency increases. Figure 8(e) reveals this distortion in the xz-plane at frequency 11 GHz.

The antenna gains at different frequencies are also measured and shown in Fig. 9. The maximum gain is found to be 4.5 dBi, which is obtained at about 11 GHz. The average gain is calculated as 3.58 dBi with a variance of about 0.36 from the mean. Therefore, it is observed that the radiation pattern of the proposed antenna is nearly stable throughout the operating frequency band. The efficiency of the antenna is calculated using the values of measured gain and directivity of the antenna. Figure 10 represents the simulated and measured percentage antenna efficiency at different frequencies.

V. CONCLUSION

A compact wideband antenna with ECPW-fed line is presented in this paper. A reduced patch and a slotted ground plane are introduced in the proposed antenna geometry. The antenna has a compact dimension of 25 mm × 25 mm. Measured results confirm that the antenna shows wideband characteristics with a frequency range 2.8–12.4 GHz, which covers the various wireless communication bands. The antenna possesses stable and nearly omnidirectional radiation patterns throughout the operating band with acceptable performance in terms of gain. Due to the simple geometry and compactness, the proposed antenna will be an attractive candidate for modern wireless communication systems.

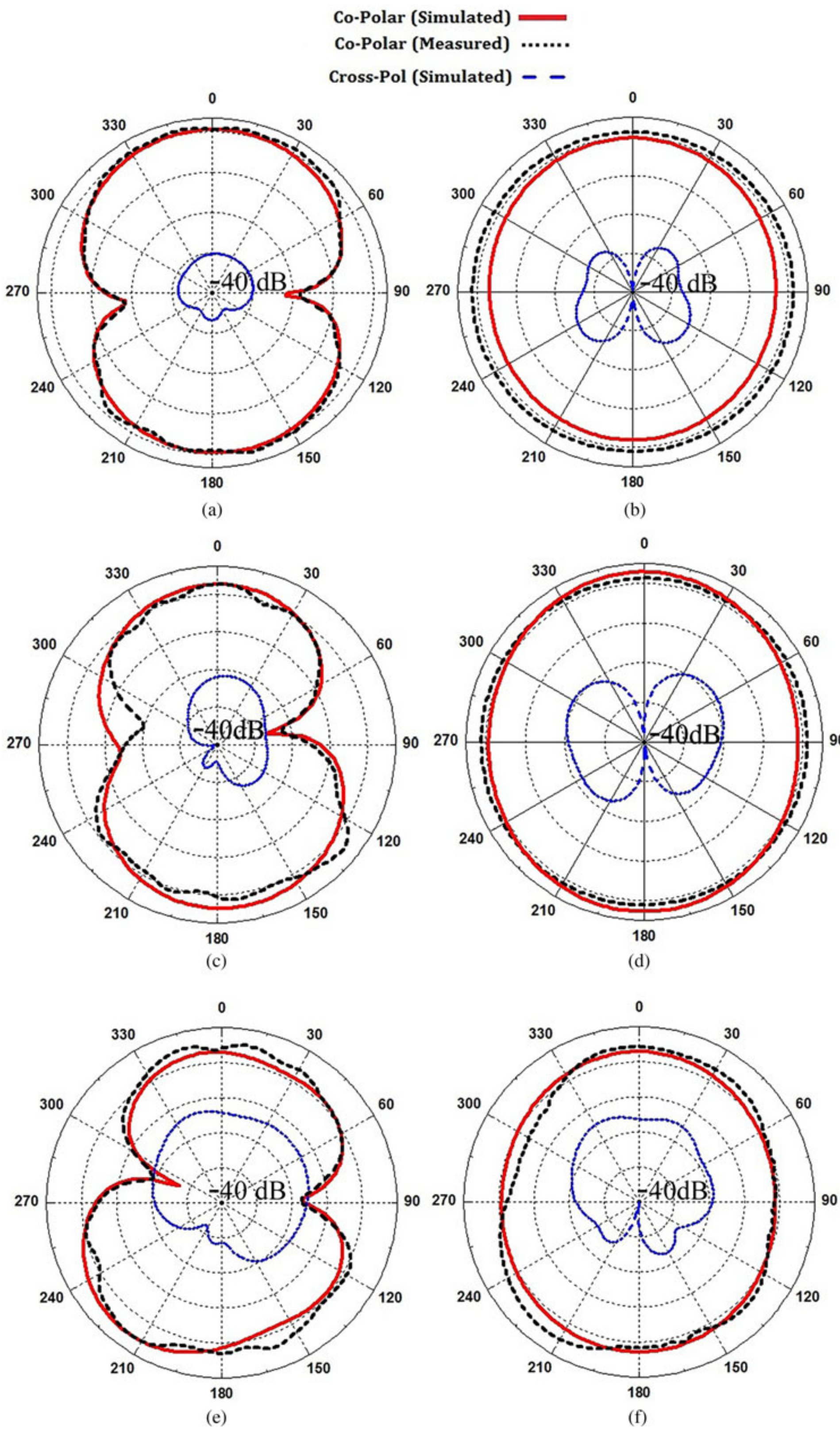

Fig. 8. Simulated and measured radiation patterns: (a), (c), (e) *yz*-plane at 3.98, 5.55, 11 GHz, respectively. (b), (d), (e) *xz*-plane at 3.98, 5.55, 11 GHz, respectively.

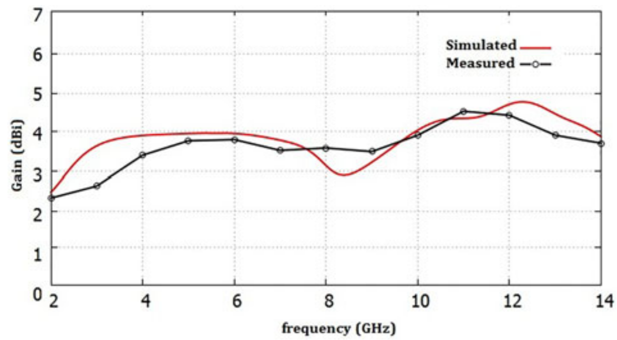

Fig. 9. Gain of the proposed antenna.

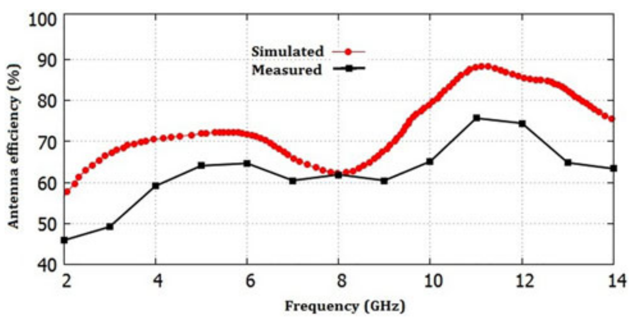

Fig. 10. Efficiency of the proposed antenna.

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