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Research Article

Design of CPW-Fed Antenna with Defected Substrate for Wideband Applications

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A CPW-fed defected substrate microstrip antenna is proposed. The proposed antenna shows wideband applications by choosing suitable defected crown shaped substrate. Defected substrate also reduces the size of an antenna. The radiating patch of proposed antenna is taken in the form of extended U-shape. The space around the radiator is utilized by extending the ground plane on both sides of radiator. Simulation of proposed antenna is done on Ansoft's High Frequency Structure Simulator (HFSS v. 14). Measured results are in good agreement with simulated results. The prototype is taken with dimensions 36 mm × 42 mm × 1.6 mm that achieves good return loss, constant group delay, and good radiation characteristics within the entire operating band from 4.5 to 13.5 GHz (9.0 GHz) with 100% impedance bandwidth at 9.0 GHz centre frequency. Thus, the proposed antenna is applicable for C and X band applications.

1. Introduction

In the rapid increasing technology of wireless communication, there is a great demand of compact, low profile, low cost, and light weight microstrip antenna [1]. Microstrip antennas are mostly used in military and commercial applications. However, the main disadvantage of microstrip antenna is narrow bandwidth that limits its applications. Enhancement in performance is necessary to cover the demand of wide impedance bandwidth. For obtaining wide impedance bandwidth, lots of techniques have been recommended such as defected structure shape, defected ground structure, slotted patch antenna, stacked patch antenna, and planar monopole antenna [2–7]. Several studies have been reported by the researchers on the microstrip patch antenna with defected ground structure for obtaining wideband/ultrawideband (UWB) [6, 8–11]. However, in these types of antenna, large space available on both sides of the radiator is not fully utilized and increases the cost of antenna. In these circumstances, coplanar waveguide (CPW) fed microstrip patch antennas play a vital role in utilizing the space available around the radiator [12–18]. In CPW-fed technique the radiating element and the ground plane are on the same side of the substrate. Small amount of work is also reported on defected substrate technique [19]. By making defected substrate, a new structure is formed that shows wideband characteristics.

In this paper, a defected crown shaped substrate wideband microstrip antenna is proposed and designed. The proposed antenna possesses a method to minimize the substrate size so that the overall size of the antenna can be minimized. The proposed antenna uses a crown shaped substrate over the conventional rectangular substrate for reducing the overall dimensions of patch antenna. The ground plane and the radiator plane are on single side of the substrate, so that the large space around the radiator can be fully utilized. In the next section the antenna geometry is discussed in detail. Section 3 covers the parametric study of proposed antenna in detail. Experimental results are discussed in Section 4. Section 5 covers all the discussion made in earlier sections.

2. Antenna Geometry

The geometry of the proposed antenna is shown in Figure 1. It has overall dimensions $L_s \times W_s$ and is fabricated on low cost FR4 substrate of thickness $h = 1.6$ mm, whose

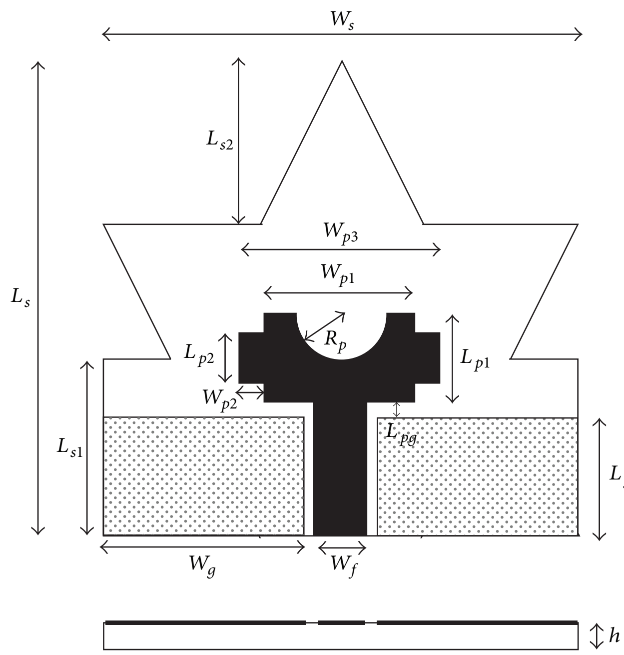

FIGURE 1: Schematic configuration of the proposed defected substrate CPW-fed wideband antenna.

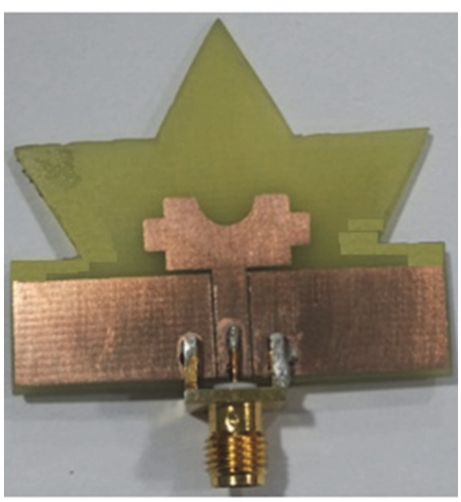

FIGURE 2: Photograph of the fabricated defected substrate CPW-fed wideband antenna.

relative permittivity $\epsilon_r = 4.4$ and loss tangent $\tan\delta = 0.0019$. A photograph of fabricated defected substrate CPW-fed wideband antenna is shown in Figure 2. The size of the proposed antenna is obtained by using mathematical formulation for patch antennas. In the proposed antenna the mathematical modelling is based on rectangular patch, but due to five cutting slots in radiating patch the overall size calculation is not as simple as rectangular patch antenna. Therefore it has been optimized by using electromagnetic solver, Ansoft HFSS simulation software [20]. Designing of radiating patch element includes the estimation of its

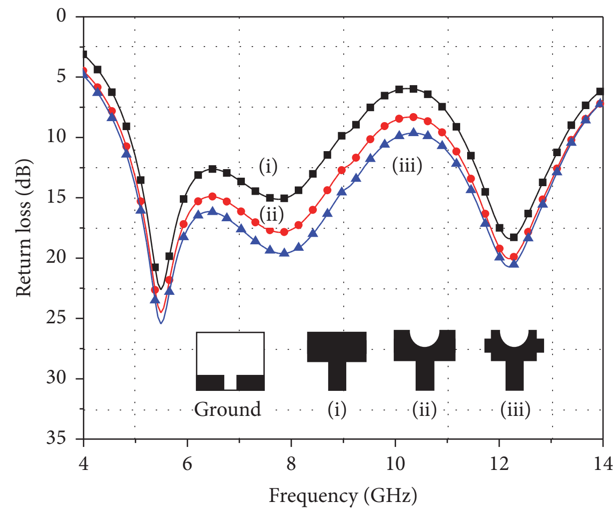

FIGURE 3: Simulated return loss against frequency for the (i) rectangle shape radiator, (ii) arc cut rectangle shape radiator, and (iii) proposed radiator of defected substrate wideband antenna.

dimensions. The patch width (W) has small effect on the resonance and it has been obtained by using the mathematical modelling as shown below [21].

$$W = \frac{v_0}{2f_r}\sqrt{\frac{2}{\epsilon_r + 1}}, \quad (1)$$

where v_0 is the speed of light in free space and ϵ_r is the relative permittivity of the substrate material of the proposed antenna. The microstrip patch is on the top of dielectric material; therefore the electromagnetic wave has an effective permittivity (ϵ_{eff}) which is given by [21]

$$\epsilon_{\text{eff}} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + \frac{10h}{W}\right]^{1/2}. \quad (2)$$

The length of the radiating patch (L) plays a major role in finding the resonant frequency and it is an important parameter in designing of patch antenna due to the inherent narrow bandwidth of the patch. The following value of L can be determined by using the following formula:

$$L = \frac{v_0}{2f_r\sqrt{\epsilon_{\text{eff}}}} - 2\Delta l, \quad (3)$$

where ϵ_{eff} is the effective permittivity of the substrate material of the proposed antenna. The additional line length on ΔL both ends of the patch length, due to the effect of fringing fields, is given by [22]

$$\frac{\Delta L}{h} = 0.412\left[\frac{\epsilon_{\text{eff}} + 0.3}{\epsilon_{\text{eff}} - 0.258}\right]\left[\frac{W/h + 0.264}{W/h + 0.813}\right]. \quad (4)$$

The effective length patch length L_e can be written as [21]

$$L_e = l + 2\Delta l. \quad (5)$$

The further variations in the radiator are shown in Figure 3, having dimensions listed as Table 1. The base of the microstrip

Table 1: Design parameters of the proposed defected substrate CPW-fed wideband antenna.

Parameters	Units (mm)
W_s	42
L_s	36
W_f	3
L_{s1}	12
L_{s2}	12
W_g	19.1
R_p	3
L_g	10
L_{pg}	0.8
L_{p1}	7
L_{p2}	3
W_{p1}	12
W_{p2}	2
W_{p3}	16

antenna is rectangular in shape which is shown in trace (i) of Figure 3. Initially the shape of the radiating patch antenna is taken as rectangular slot $L_{p1} \times W_{p3}$. The simulated result shows that this structure excites at resonating frequencies at 5.48, 7.86, and 12.17 GHz but does not cover the entire operating band from 4.5 to 13.5 GHz. After that a semicircular ring is etched in the middle of the radiating patch with radius R_p which is shown in trace (ii) of Figure 3; the simulated result shows that this structure improves the return loss condition but still does not cover the entire operating band. Finally, the edges having dimensions $(L_{p1} - L_{p2}) \times W_{p2}$ are etched on both sides of the radiating patch which is shown in trace (iii) of Figure 3; the simulated result shows that the proposed radiating patch obtains good return loss value but still the return loss is above 10 dB from 9.96 to 10.68 GHz. The detailed dimensions of the proposed defected substrate CPW-fed wideband antenna are listed in Table 1.

The ground plane is on the same plane as radiator with two rectangular slits having dimensions $W_g \times L_g$. The length of gap between the radiating patch and the ground plane is taken as L_{pg}. The width of CPW-fed line is fixed at W_f to achieve 50 ohm characteristics impedance. The gap between the feed and ground plane is taken as 0.4 mm. The radiator is surrounded by a ground plane with etched substrate that helps to reduce the area. The small gap between the radiator and the ground is a foremost factor to provide strong capacitive coupling.

The simulated surface current distributions on resonant frequencies of 5.48 GHz, 8.03 GHz, and 12.01 GHz are shown in Figure 4. When the microstrip patch antenna is provided with power, a charge distribution appears on the upper and lower part of the patch, as well as on the ground plane. Due to this charge distribution the current will flow at the top and bottom surface of the patch. From this closed analysis of the surface current distribution of the proposed antenna it is found out that at 5.48 GHz, 8.03 GHz, and 12.01 GHz resonant frequency the proposed antenna resonates in TM11 mode, TM21 mode, TM12 mode, respectively. The above mentioned mode can be explained on the basis of surface current distribution of the proposed antenna; from Figure 4(a) it can be observed that the direction of surface current is aligned by the side of circumference and terminated at one point on the circumference of patch; that is, at this location of patch negative node are located and on the opposite side of the patch positive node are located. Thus only one positive node and one negative node are located, which is the case of TM11 mode [23, 24]. Similarly, from Figure 4(b) it can be observed that the current is aligned and terminated at two points on the circumference of patch. Thus there are two positive and two negative nodes are located, which is the case of TM21 mode. While in Figure 4(c) it can be observed that the current is aligned towards tangential of circumference at two points, which is the case of TM12 mode.

The substrate is etched in the form of crown shape. The variation in substrate is shown in Figure 5, having radiator and ground plane dimensions as listed in Table 1. Initially, a rectangular substrate is taken as shown in trace (i). The simulated result shows that this structure excites at resonating frequencies at 5.48, 7.86, and 12.17 GHz but does not cover the entire operating band from 4.5 to 13.5 GHz as the return loss is above 10 dB from 9.96 to 10.68 GHz. However, when the substrate is taken in the form of triangle shape (trace (ii)), the simulated result shows better return loss but does not cover the entire operating band as return loss is above 10 dB from 10.13 to 10.46 GHz. At last, when the substrate is defected into crown shape, as shown in trace (iii), the simulated result covers entire operating bandwidth (4.5 to 13.5 GHz) with three resonating bands at 5.48, 8.03, and 12.01 GHz. Therefore, it is decided to take defected substrate (crown shaped) antenna for further investigations as it is smaller in size and improves the impedance matching conditions for the entire band.

3. Parametric Study of the Proposed Antenna

In this section, the influence of the different design parameters on proposed antenna performance is presented and discussed. At a time, variation in single parameter is done while others are kept constant. The optimization of parameters is helpful for the fabrication of the proposed defected substrate antenna. The effect of change in radiating patch length (L_{p1}, L_{p2}), width (W_{p1}, W_{p2}), inner circle radius (R_p), microstrip feed line (W_f), and length between radiating patch and ground plane (L_{pg}) is considered for parametric study.

Figure 6, shows the variation in length of radiating patch (L_{p1}) of the proposed antenna from 6 to 8 mm. When $L_{p1} = 6$ mm, the return loss remains lower than 10 dB but bandwidth is reduced (4.8 to 13.28 GHz). With further increase in $L_{p1} = 7$ mm, the return loss remains lower than 10 dB with improved impedance bandwidth from 4.5 to 13.5 GHz (9.0 GHz). However, as L_{p1} increases to 8 mm, the bandwidth for the return loss does not remain lower than 10 dB for the entire band. Therefore, it is decided to take $L_{p1} = 7$ mm as the optimum value from 4.5 to 13.5 GHz, covering the entire wideband.

The simulated results of the proposed antenna for patch length L_{p2}, from 1 to 4 mm are depicted in Figure 7. When $L_{p2} = 1$ mm, the bandwidth for the return loss does not

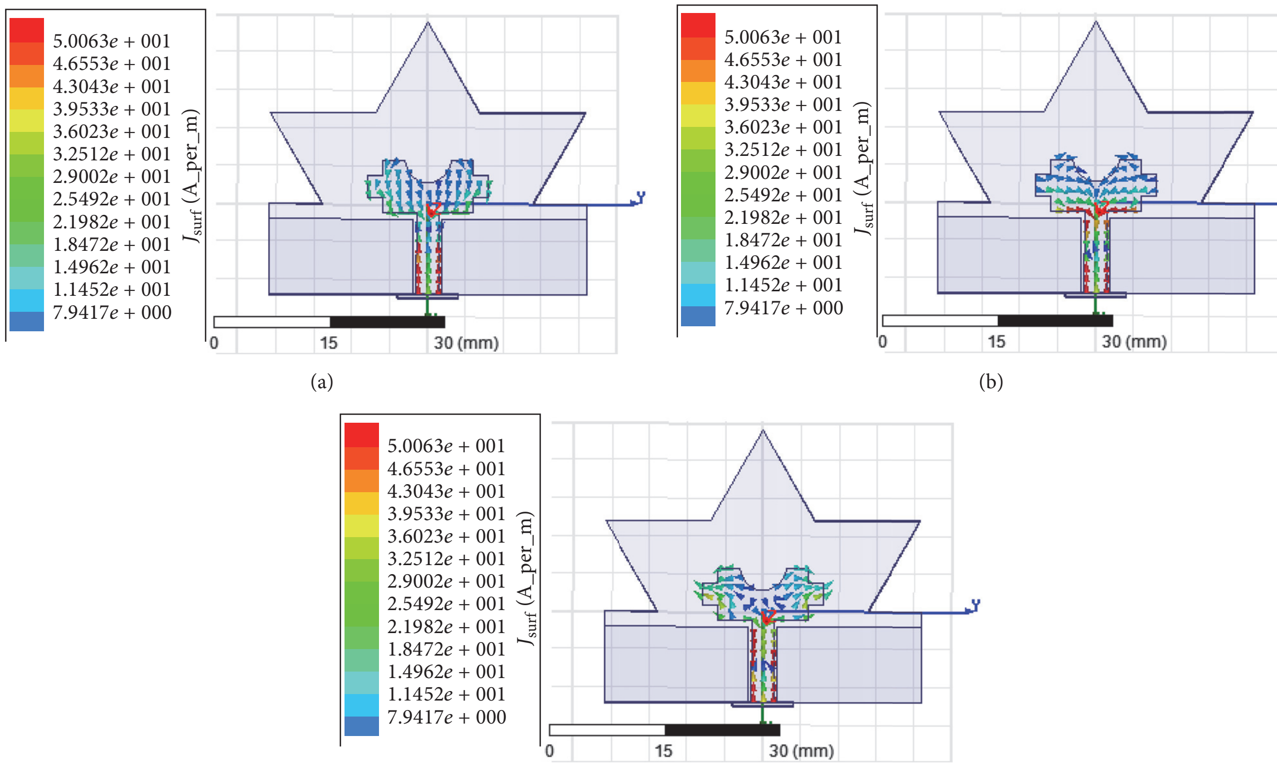

FIGURE 4: The surface current distribution on the proposed defected substrate wideband antenna at (a) 5.48 GHz, (b) 8.03 GHz, and (c) 12.01 GHz.

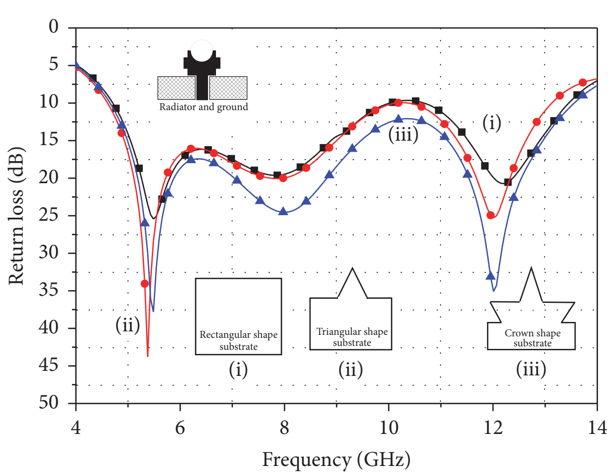

FIGURE 5: Simulated return loss against frequency for the proposed defected substrate (crown shaped) CPW-fed wideband antenna, defected substrate (triangle shape) CPW-fed antenna, and rectangular substrate CPW-fed antenna.

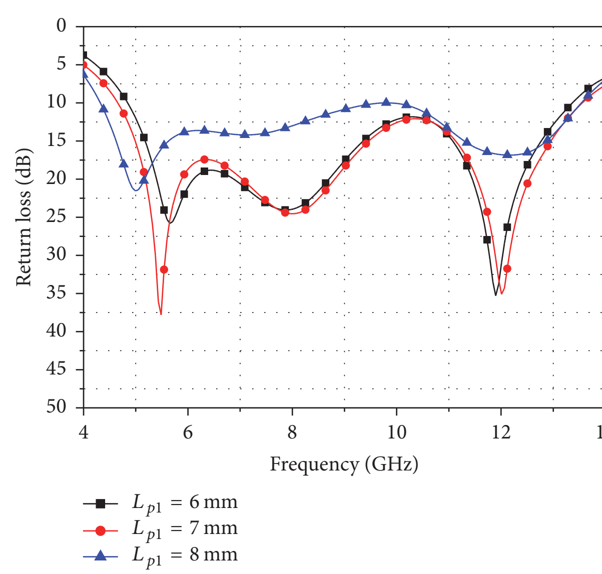

FIGURE 6: Simulated return loss against frequency for the proposed defected substrate wideband antenna with various L_{p1}; other parameters are the same as listed in Table 1.

remain lower than 10 dB for the entire band as it is above 10 dB between frequencies 9.41 and 10.90 GHz. When L_{p2} = 2 mm the return loss does not remain lower than 10 dB for frequencies between 10.24 and 10.60 GHz. For L_{p2} = 3 mm, the bandwidth improves significantly covering the entire band with improved impedance matching. On further increase in L_{p2} = 4 mm, the operational bandwidth decreases and a worse matching condition appears over the frequency band. Therefore, it is decided to take L_{p1} = 3 mm as the optimum value covering the band from 4.5 to 13.5 GHz, covering the entire wideband.

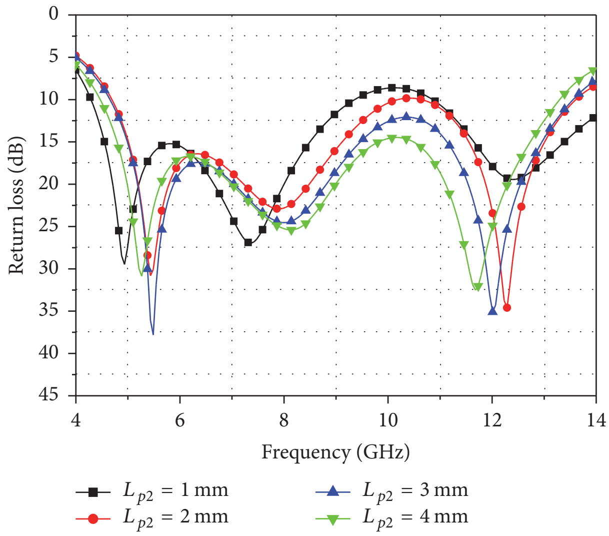

FIGURE 7: Simulated return loss against frequency for the proposed defected substrate wideband antenna with various L_{p2}; other parameters are the same as listed in Table 1.

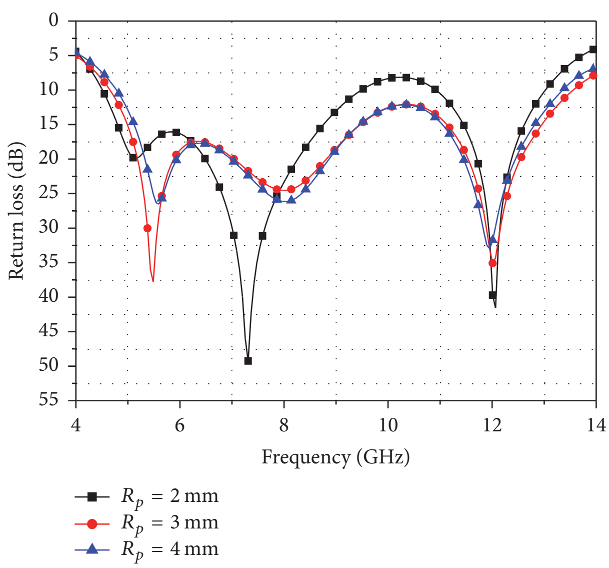

FIGURE 8: Simulated return loss against frequency for the proposed defected substrate wideband antenna with various R_p; other parameters are the same as listed in Table 1.

Figure 8 shows variation of radius of inner circle of radiating patch (R_p) of the proposed antenna from 2 to 4 mm. As R_p = 2 mm, it is observed that the bandwidth of antenna is above 10 dB from 9.52 to 11.01 GHz and does not cover the entire operating band. However, as the value of R_p increases to 3 mm, the impedance matching of the radiating patch and the input impedance improve and cover the entire bandwidth. On further increase of R_p = 4 mm, the impedance matching and input impedance of radiating patch deteriorate. Therefore, it is decided to take R_p = 3 mm as the optimum value with the bandwidth from 4.5 to 13.5 GHz.

The simulated results of the proposed antenna, with microstrip feed (W_f), varying from 2.9 to 3.1 mm are illustrated in Figure 9. It can be seen that the bandwidth of return

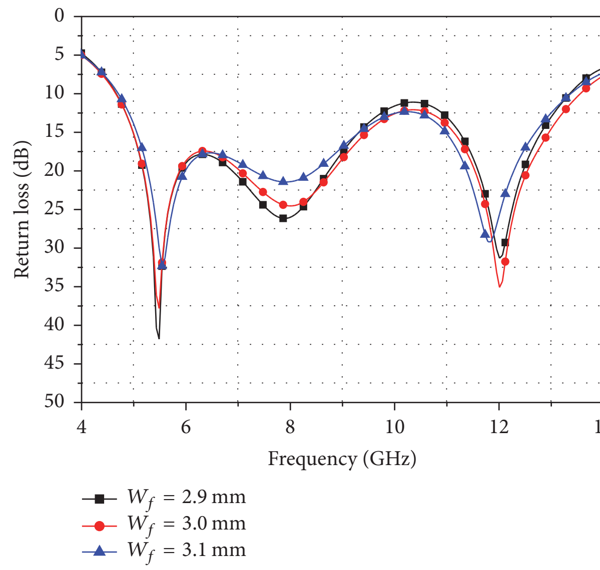

FIGURE 9: Simulated return loss against frequency for the proposed defected substrate wideband antenna with various W_f; other parameters are the same as listed in Table 1.

loss less than 10 dB of the antenna remains constant as W_f increases from 2.9 to 3.1 mm. However, as W_f increases from 2.9 to 3.0 mm, the impedance matching of the radiating patch and the input impedance of the frequency band from 11.20 to 12.32 GHz are improved significantly. With further enhancement in microstrip feed (W_f), it deteriorates. Therefore, it is decided to take W_f = 3.0 mm as the optimum value, with minimum mismatch at higher frequency range.

The variation in patch width (W_{p1}) from 10 to 13 mm is shown in Figure 10. For W_{p1} = 10 mm the bandwidth is above 10 dB for frequencies from 10.68 to 11.40 GHz and does not cover the entire operating band. For W_{p1} = 11 mm, the bandwidth of return loss remains less than 10 dB, but the total band is reduced from 4.5 to 11.40 GHz (6.9 GHz). However, as width W_{p1} increases to 12 mm, the impedance bandwidth significantly improves covering the entire band from 4.5 to 13.5 GHz. With further increase in W_{p1} = 13 mm, the bandwidth of return loss is higher than 10 dB from frequency 10.02 to 10.68 GHz. Therefore, it is decided to take W_{p1} = 12 mm as the optimum value for the bandwidth from 4.5 to 13.5 GHz, covering the entire bandwidth.

Figure 11, shows the variation of radiator patch width (W_{p2}) from 1.0 to 3.0 mm. As W_{p2} = 1.0 mm, the bandwidth of return loss remains less than 10 dB for the entire band from 4.6 to 13.8 GHz, but the impedance matching of the radiating patch with input impedance deteriorates at higher frequencies. When W_{p2} = 1.5 mm, the return loss does not remain less than 10 dB for the entire band as it is above than 10 dB from frequencies 9.7 to 10.8 GHz. As W_{p2} = 2.0 mm, the impedance matching of the radiating patch and the input impedance at the frequency improve covering the entire bandwidth from 4.5 to 13.5 GHz. With further increase in W_{p2} the bandwidth shrinks and remains between 4.3 and 12.26 GHz for W_{p2} = 2.5 mm; for W_{p2} = 3.0 mm the bandwidth remains 4.7 to 12.45 GHz and does not cover the

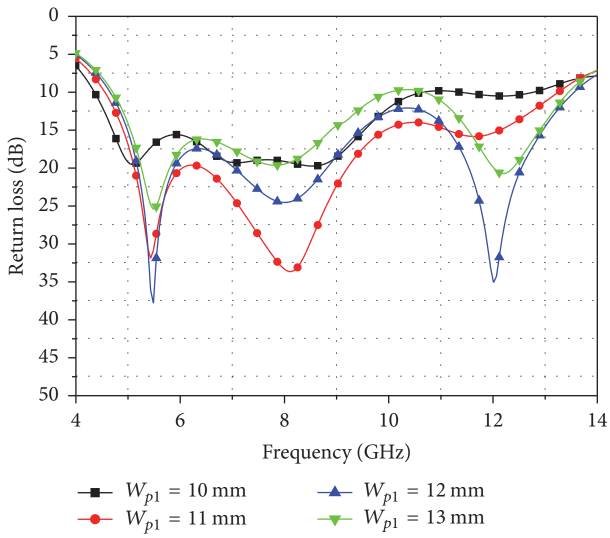

FIGURE 10: Simulated return loss against frequency for the proposed defected substrate wideband antenna with various W_{p1}; other parameters are the same as listed in Table 1.

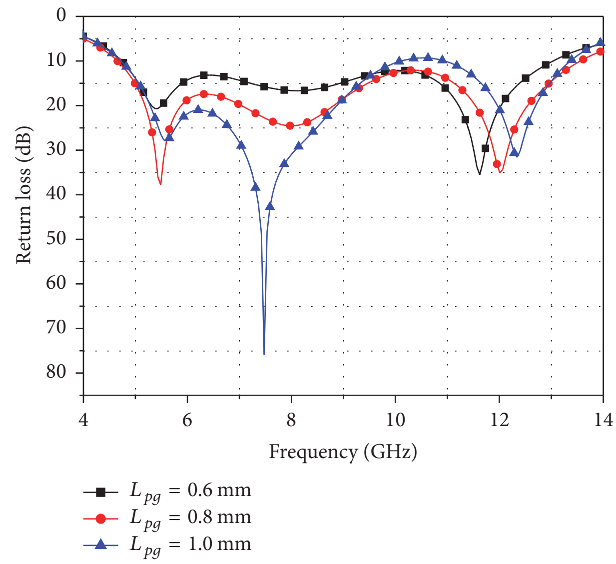

FIGURE 12: Simulated return loss against frequency for the proposed defected substrate wideband antenna with various L_{pg}; other parameters are the same as listed in Table 1.

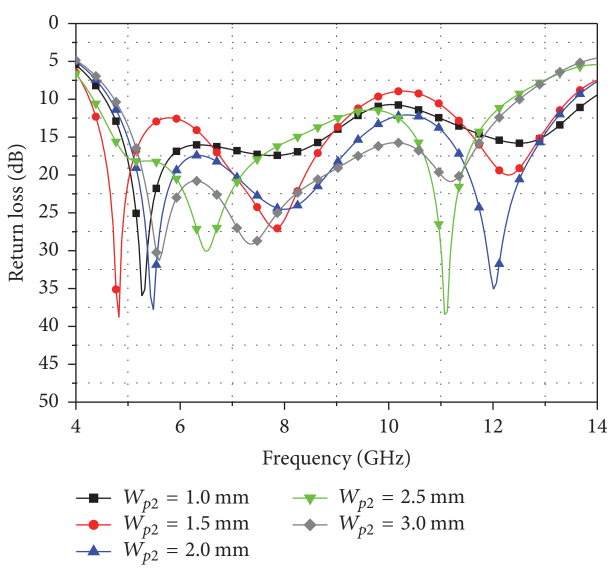

FIGURE 11: Simulated return loss against frequency for the proposed defected substrate wideband antenna with various W_{p2}; other parameters are the same as listed in Table 1.

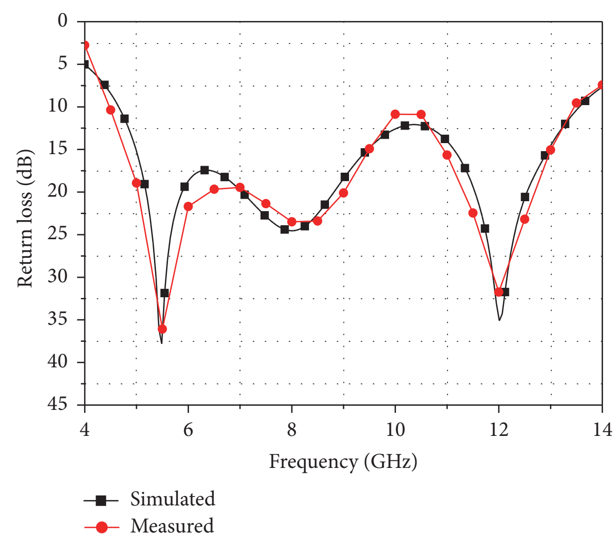

FIGURE 13: Simulated and measured return loss for the proposed defected substrate wideband antenna.

entire operating band. Therefore, it is decided to take W_{p2} = 2.0 mm as the optimum value covering the entire bandwidth from 4.5 to 13.5 GHz.

The variation in patch width (L_{pg}) from 0.6 to 1.0 mm is shown in Figure 12. When L_{pg} = 0.6 mm, the return loss is less than 10 dB but the bandwidth is 4.7 to 13.0 GHz which is less than the desired bandwidth. When L_{pg} = 0.8 mm the bandwidth of return loss remains less than 10 dB with good impedance matching between radiating patch and input impedance. On further increase of L_{pg} the bandwidth of the return loss is not less than 10 dB and does not cover the entire bandwidth. Therefore, it is decided to take L_{pg} = 0.8 mm as the optimum value with the bandwidth from 4.5 to 13.5 GHz, covering the entire wideband.

4. Experimental Results and Discussion

The performances of the proposed antenna such as return loss and radiation pattern are measured using Agilent 8757E scalar network vector analyzer. There is a good agreement between simulated and measured results of the proposed defected substrate CPW-fed wideband antenna as shown in Figure 13. The minute variation between measured and simulated result is due to the effect of SMA (subminiature version A) connector soldering and fabrication tolerance.

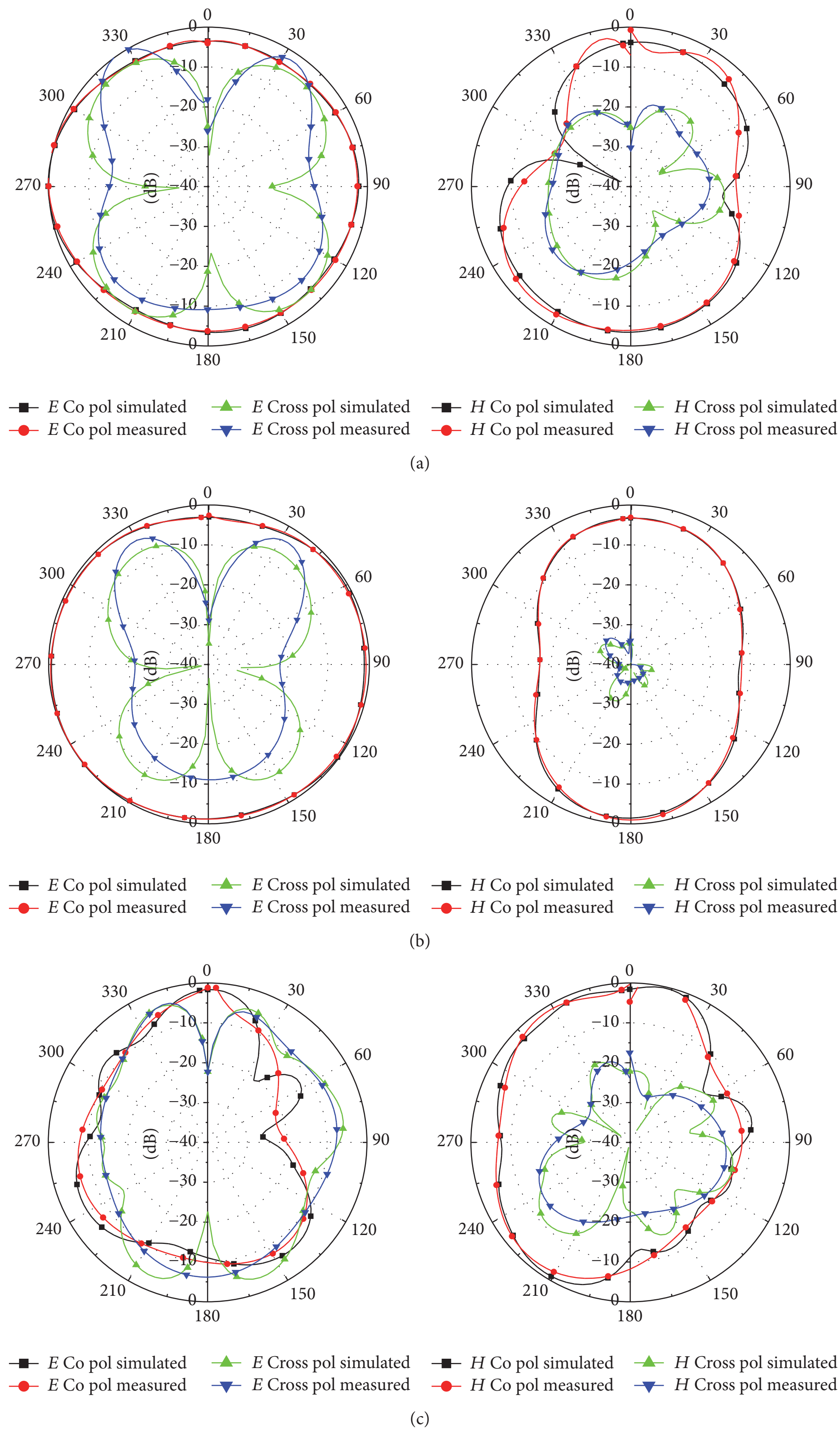

Figure 14: Radiation patterns at various frequencies of proposed defected substrate wideband antenna: (a) 5.48 GHz, (b) 8.03 GHz, and (c) 12.01 GHz.

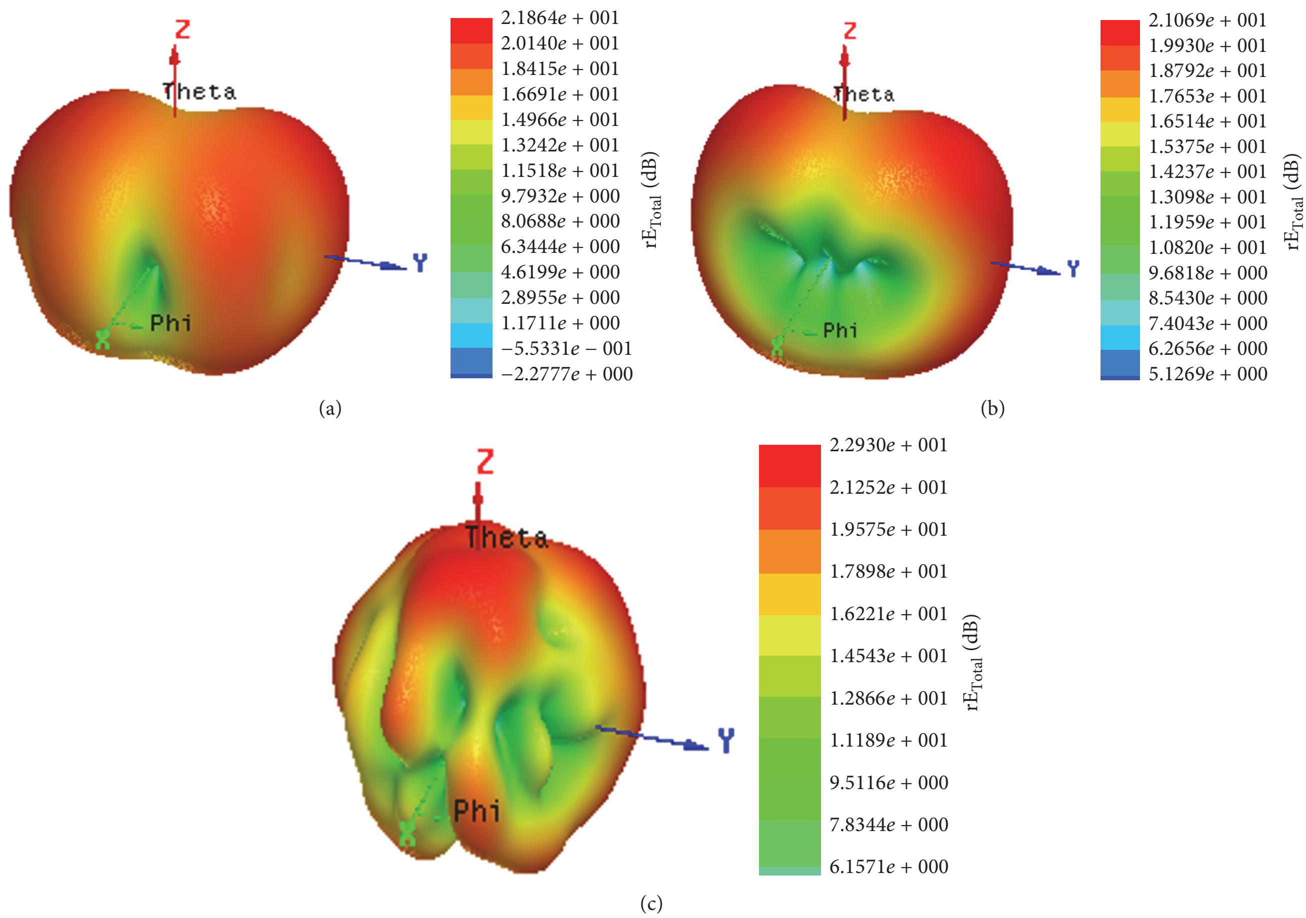

Figure 15: 3D polar plot at various frequencies of proposed defected substrate wideband antenna: (a) 5.48 GHz, (b) 8.03 GHz, and (c) 12.01 GHz.

The designed antenna offers a bandwidth of 9.0 GHz (4.5 to 13.5 GHz) that meets the bandwidth requirements for C and X band applications.

The proposed antenna illustrates good radiation pattern characteristics as shown in Figures 14(a)–14(c). The radiation patterns in H and E planes are at sampling frequencies of 5.48, 8.03, and 12.01 GHz, respectively. Patterns are distorted because the ground plane is a part of loop path; the surface current on the radiating plane changes the effective current distribution of the loop and results in distortion. These patterns are suited for application in numerous wireless communication systems, as expected. Measured and simulated results of radiation patterns show good agreement.

Figure 15 shows good results of 3D polar plot of proposed defected substrate wideband antenna at three resonant frequencies 5.48 GHz, 8.03 GHz, and 12.01 GHz. The 3D polar plot gives and additional view for the distribution of the power radiated in space.

Figure 16 illustrates the group delay of the proposed antenna. Group delay is a significant factor in the designing of wideband antenna as it tells about the distortion of the transmitted pulses in the wireless communication. It is observed that the group delay for the proposed antenna is stable and less than 1 ns for entire operating bandwidth 4.5 to 13.5 GHz. For distortion less transmission, group delay should be less than 1 ns in the wideband antenna.

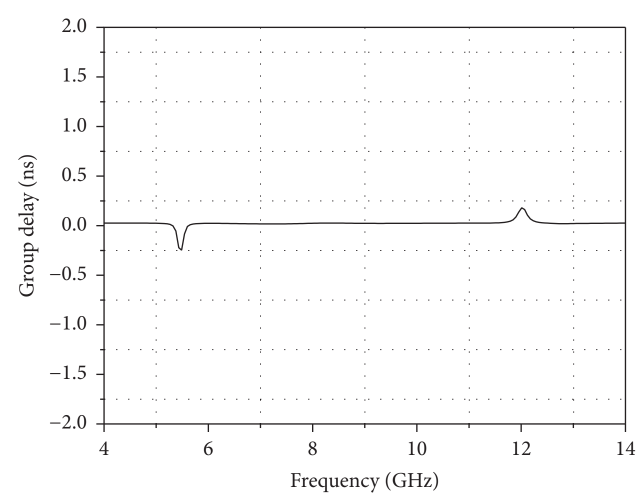

Figure 16: Group delay for the proposed defected substrate wideband antenna.

Gain is an important parameter in the designing of wideband microstrip patch antennas. Figure 17 demonstrates

Table 2: Comparison of reference antennas with proposed antenna.

S. number	Reference number	Antenna type	Overall size (mm^3)	Operating frequency band (GHz)	Relative dielectric constant (ϵ_r)	Applications
1	[1]	Wideband	32 × 30 × 1.58	3.32–6.5	4.4	WLAN/WiMAX
2	[2]	Wideband	25 × 25 × 1.6	2.96–7.95	4.4	S and C band
3	[4]	Wideband	38 × 25 × 1.6	2.4–6.0	4.4	WLAN/WiMAX
4	[13]	UWB	25 × 25 × 1.6	2.9–11.5	4.4	UWB
5	[19]	UWB	18 × 25 × 1.25	2.0–10.6	4.4	UWB
6	Proposed antenna	Wideband	42 × 36 × 1.6	4.5–13.5	4.4	C and X band

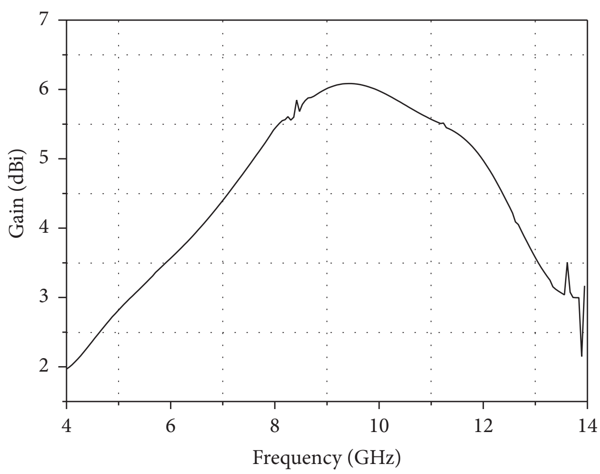

Figure 17: Gain for the proposed defected substrate wideband antenna.

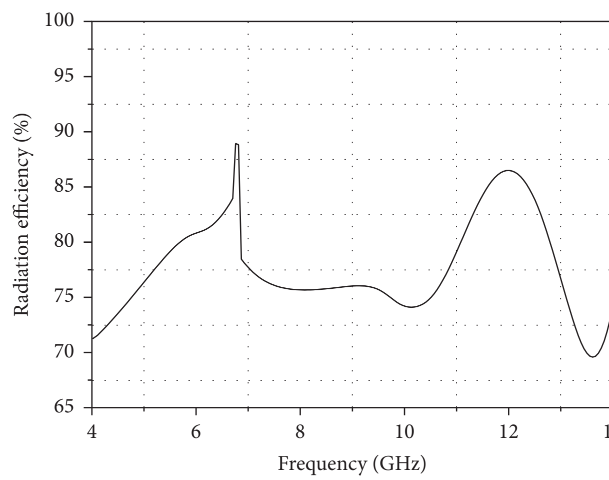

Figure 18: Radiation efficiency for the proposed defected substrate wideband antenna.

the gain of the proposed antenna. It was found out that the gain of the antenna varies within 1.9 to 6.08 dBi against the frequency band of 4.5 to 13.5 GHz.

Antenna radiation efficiency is defined as the ratio of power radiated to the input power. It is related to the gain and directivity of the patch antenna. Radiation efficiency also considers the conduction and dielectric losses. The radiation efficiency of the proposed antenna is shown in Figure 18. It exhibits 79.35%, 75.66%, and 86.44% radiation efficiency at three resonant frequencies 5.48 GHz, 8.03 GHz, and 12.01 GHz.

Table 2, illustrates the comparison between the proposed (defected substrate) antenna and some other existing antennas in terms of the antenna type, overall size, operating frequency band, dielectric constant and applications. The comparative chart shows that the proposed antenna has defected substrate and wideband applications with respect to other antenna of different dimension and shapes.

5. Conclusion

A novel CPW-fed defected substrate patch antenna is fabricated and proposed for wideband applications. The proposed antenna achieves good return loss, constant group delay, and good radiation patterns over the entire operating bandwidth from 4.5 to 13.5 GHz (9.0 GHz) with 100% impedance bandwidth. The gain of the proposed antenna reaches a peak value of 6.08 dBi, while the radiation efficiency of proposed antenna reaches a maximum value of 88%. The simulated and measured results of the projected antenna show balanced agreement. The proposed antenna can be used in numerous wireless applications.

Competing Interests

The authors declare that there are no competing interests regarding publication of this paper.

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