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A 3–12 GHz UWB PLANAR TRIANGULAR MONOPOLE ANTENNA WITH RIDGED GROUND-PLANE

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Abstract—A novel technique to increase the bandwidth of the conventional planar triangular monopole antenna (PTMA) is presented. With two symmetrical corrugations extended from the flat ground plane, a significant improvement on the impedance bandwidth up to about 4:1 can be achieved. The proposed antenna design is a modification from the conventional volcano smoke antenna (VSA) and can be more compact and easily fabricated. The HFSS 3-D EM solver is employed for design simulation. The effects of the ridged ground plane on the impedance bandwidth are studied. A printed PTMA is fabricated on the FR-4 PCB substrate. Measured VSWR of the printed PTMA with the ridged ground plane is less than 2 from 3 to 12 GHz which covers the UWB frequency band. The measured antenna patterns also show the monopole-type omni-directional radiation patterns from 3 to about 10 GHz.

1. INTRODUCTION

Owing to the low profiles and omni-directional radiation patterns, the thin-wire monopole antennas have been widely used and investigated for communication applications, except for the drawback of the narrow bandwidths. Lots of efforts have been devoted to increasing the bandwidth of monopole antennas. One simple but powerful technique is to replace the cylindrical wires with the plate elements, such as rectangular (square), elliptical (circular) shapes, triangular shapes, and others [1–18]. A typical impedance bandwidth of 75% at S band had been studied with a $25\,\mathrm{mm} \times 25\,\mathrm{mm}$ square metal plate above a 25 cm square ground plane [1]. And using a beveling technique, the impedance bandwidth of the square monopoles can be improved up to about 6:1 [2]. For the circular disc monopole antenna of 25-mm diameter over a $30\,\mathrm{cm} \times 30\,\mathrm{cm}$ ground plane, the bandwidth of more than 10:1 (1.17–12 GHz) had been achieved [5]. The triangular monopole antenna mounted above a ground plane is first experimentally investigated by Brown and Woodward [12]. And it is found that the impedance bandwidth of the triangular-shaped monopole antenna is dependent on the feeding gap and the flare angle. As reported, a typical bandwidth of the triangular monopole antenna is approximately 30% [13, 14]. Some variants and efforts on increasing the bandwidth, such as the tap monopole antenna (more than 50% bandwidth) [14], the staircase bow-tie monopole antenna with a novel impedance-matching technique (approximately 77% bandwidth) [15], and the tap monopole with a truncated ground plane and a split slot (up to 7.9:1 bandwidth) [16], have been studied. Even with other shapes, the planar monopole antennas also have a wide bandwidth as compared to the thin-wire configuration [17, 18].

Another way to increase the impedance bandwidth of the monopole antennas can be achieved by a modifying the ground plane. One well-known alternative is the sleeve monopole antenna. By determining the length and the distance of the sleeves, the dual-band or wide-band characteristics are introduced [17–23]. Another broadband but few discussed is the volcano smoke antenna (VSA). With a smooth transition from the feeding line to the radiator, the VSA yields a wideband performance [24–26]. However, it may not be suitable for easy integration into the current mobile communication systems because of the complicated structure. Other ways of modifying the ground plane, such as notching a slot surrounding the feeding line [27–29], forming a trapezoidal shape [30], and cutting or tapering the edges [31–34], have been investigated and achieved a satisfactory performance.

Among these planar monopole antennas with various shapes, only few studies about the printed-structure triangular monopole antennas for UWB applications are reported [16, 35, 36]. In [35], a CPW-fed triangular monopole antenna with two notched ground planes is presented, and reaches a measured $-10\,\mathrm{dB}$ impedance bandwidth of 9.8 GHz (from 3.05 to 12.85 GHz). In [36], a wideband triangular monopole antenna is achieved only by the proper selection of the feeding gap and flare angle. However, the bandwidth of the antennas reported in [16, 36] do not fully cover the 3–10 GHz UWB band.

In this paper, a novel technique of ridging the rectangular ground plane is presented to improve the bandwidth of the conventional PTMA to cover the UWB band. The ridged ground consists of two symmetrical corrugations extended from the top edge of the flat ground plane. Compared with the rectangular-shape ground plane, the ridged ground plane offers a more smoothing transition between the microstrip transmission line and the free space. Hence, a flat response of the input impedance (resistance or reactance) can be observed. The effects of geometric parameters of the ridged ground plane on the impedance bandwidth are studied extensively. Printed PTMAs with and without the ridged ground plane are fabricated on the FR-4 PCB substrate for experimental measurement. With the ridged ground plane, an bandwidth improvement from approximately 40% to about 4:1 ultrawide bandwidth (3 to 12 GHz) has been demonstrated. Moreover, the radiation patterns of the printed PTMA with ridged ground plane still maintain the monopole-like omni-directional characteristics.

2. ANTENNA DESIGN

Figure 1(a) shows a typical geometry of a printed PTMA which consists of a triangular-shaped radiator on the top and a rectangular-shaped ground plane on the backside of the substrate. It is realized on a FR-4 substrate ($\varepsilon_r = 4.7$) with a thickness of 1 mm. A 50-Ω center-fed microstrip line on the top layer of the substrate, with the width of 1.8 mm, is employed to excite the triangular radiator from its apex. The height and flare angle of the triangular radiator are denoted as h_{mono} and α, respectively. The length of the feeding gap is denoted as h_{gap}. The length h_{gap} and the flare angle α exhibit a significant influence on the impedance bandwidth of the printed PTMA [13, 36]. Here, the flare angle is set to be 90° and the optimum distance h_{gap} is 0.9 mm. The dimension of the rectangular-shaped ground plane on the backside of the substrate is 30 mm × 15 mm. All parameters of the printed PTMA are summarized in Table 1.

The impedance bandwidth of the above PTMA is not capable to cover the 3–10 GHz UWB band (see Figs. 3 and 5). In order to enhance the impedance bandwidth of the conventional PTMA, a novel and simple means of ridging the rectangular-shaped ground plane is presented. As shown in Fig. 1(c) and (d), the ridged ground planes with two symmetrically hillside-shaped corrugations, the triangle-ridged and trapezoid-ridged shapes, offer a smooth transition from the feeding line to the radiating element for achieving a wide impedance bandwidth. For the PTMA with the triangle-ridged ground planes,

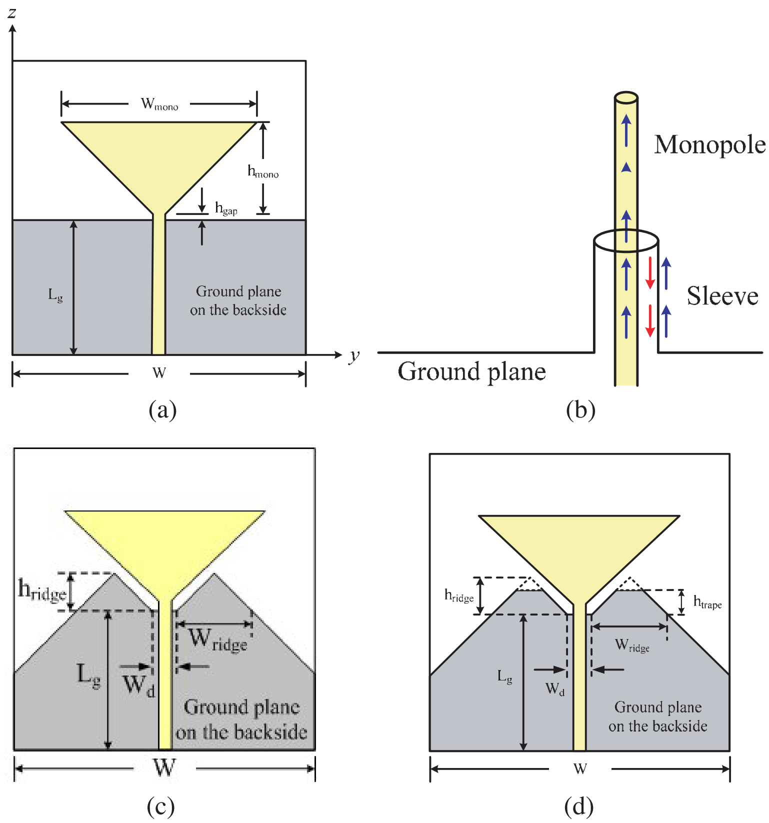


Figure 1. (a) The geometry of a printed PTMA with a rectangular-shaped ground, (b) illustration of a sleeve monopole antenna, (c) a printed PTMA with a triangle-ridged ground, and (d) that with a trapezoid-ridged ground.

the distance between these two symmetrical corrugations is defined as w_d. The width and the height of each corrugation are denoted as w_{ridge} and h_{ridge}, respectively. Since the triangle-ridged corrugation is a right-angle isosceles triangle, then $w_{ridge} = 2h_{ridge}$. The triangle-shaped corrugations of the ridged ground have a similar function to that of the sleeve in the sleeve monopole antenna (Fig. 1(b)) [19].

(A) As stated, the triangle-shaped corrugations of the ridged ground (region "I" in Fig. 2(a)) play a role similar to that of the sleeve of the sleeve monopole antenna and operate at the particular frequency determined by the dimension of the triangle-shaped corrugations. By properly selecting the height of the triangle-

Table 1. The parameters of the designed printed PTMA.

Parameters	Dimensions
W	30 mm
L_g	15 mm
W_{mono}	24 mm
h_{mono}	11.1 mm
h_{gap}	0.9 mm
α	90°

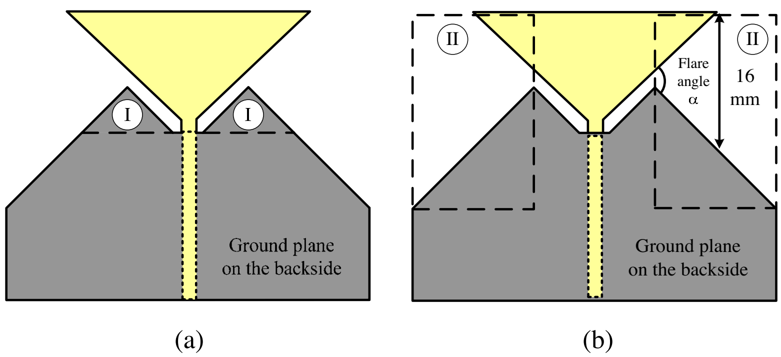


Figure 2. The illustrations of the ridged ground plane: (a) the triangle-shaped corrugations (regions "I") and (b) the antipodal tapered-slot structure (regions "II").

shaped corrugations, an additionally resonant mode above the fundamental one is generated with a good impedance matching. Since these two resonant modes are excited at the nearby frequencies, the dual-resonant response results in a broadband property. The additionally resonant mode at 5 GHz will be observed in the simulation and measurement results as shown in Table 2 and Fig. 5 (discussed later).

(B) It is also observed that the triangular plate (on the top plane) and the ridged ground plane (on the bottom) form two symmetrical antipodal tapered slot-structures antennas (ALTSA) [37, 38]. It is shown in the region "II" enclosed by the dashed rectangle in Fig. 2(b). This antipodal tapered-slot structure of the printed PTMA offers resonant modes of which the frequencies are mainly determined by the flare angle of the tapered slot. From [37, 38] and Fig. 2(b), the length of the line segment to the flare angle is 16 mm which is corresponding to resonant mode at 8.6 GHz (for a pure ALTSA). Hence, as shown in Table 2 and Fig. 5 (discussed later), it can be stated that the proposed printed PTMA results from its antipodal tapered-slot structures with minor effects of the extended down-hilled edges from the corrugation generate a third resonant modes near 8.8 GHz.

3. SIMULATION RESULTS

Figure 3(a) shows the simulated VSWR of the printed PTMA with different dimensions (w_{ridge}, h_{ridge}) of the ridged ground. Here, the distance (w_d) is fixed as 4 mm. As compared to the flat ground, it is found that the bandwidth is significantly enhanced by the ridged ground. A good impedance bandwidth is achieved by choosing h_{ridge} to be 3 mm, which is approximately a quarter of the height of the triangular monopole ($h_{mono} + h_{gap}$). Fig. 3(b) presents the simulated VSWR of the printed PTMA with different w_d between these two symmetrically ridges. The parameters of (w_{ridge}, h_{ridge}) are set as (6 mm, 3 mm). In the case of $w_d = 0$ mm, the E-field distributions between the radiator and the ground plane mainly concentrate on the bottom of the PTMA instead of radiating outward due to the adjacent ridges. As the distance (w_d) increases, however, the (separated) ridges behave a transition between the feeding line and the radiating element. In Fig. 3(b), it is observed that a wide-band performance can be achieved while the distance (w_d) is larger than 2 mm. Thus, the

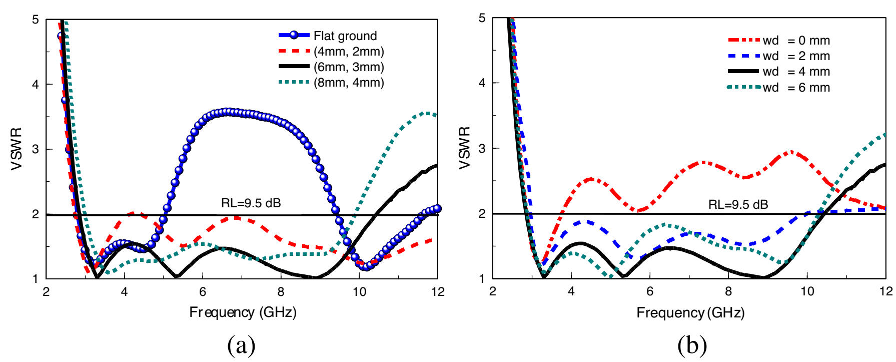


Figure 3. Simulated VSWR of a printed PTMA with a triangle-ridged ground with: (a) different ridge dimension (w_{ridge}, h_{ridge}) ($w_d = 4$ mm), and (b) different ridge distance (w_d) ($w_{ridge} = 6$ mm, $h_{ridge} = 3$ mm).

distance (w_d) is chosen as 4 mm. However, the impedance matching of the PTMA with a triangle-ridged ground becomes poor while the frequency is over 10 GHz. It may be caused by the reflection from the sharp truncation of the triangle. One alternative of reducing the reflections is to replace it by a curved configuration, such as the trapezoidal shape shown in Fig. 1(d), to form a more smooth transition from the feeding line to the free space. From the simulation, the impedance bandwidth of the PTMA with a trapezoid-ridged is improved up to 11 GHz.

As discussed, the PTMA with a ridged ground in principle can be treated as a combination of a sleeve monopole and an antipodal tapered-slot antenna. A nearby resonant mode beyond the fundamental one is excited with a good impedance matching by the hillside-shaped corrugations of the ridged ground, which works as a sleeve monopole. With properly selecting the dimension of the tapered slots, the ridged ground offers the desired higher-frequency resonant modes to enhance the whole bandwidth.

Table 2. The simulated resonant modes and their corresponding VSWR of the PTMA with the flat and ridged ground.

Ground	Resonant frequency / corresponding VSWR		
Flat	3.29 GHz/1.29	——	——
Ridged	3.37 GHz/1.04	5.42 GHz/1.08	8.82 GHz/1.02

Table 2 summarizes the simulated resonant modes and their corresponding VSWR of the PTMA with the flat and ridged ground. It is interesting to note that the high-order harmonic modes of the PTMA are excited with the good impedance matching by the ridged ground. The PTMA with the flat ground has a fundamental mode at 3.29 GHz with a good impedance matching (VSWR = 1.29). In the case of the ridged ground, the fundamental mode of the PTMA occurs at 3.37 GHz (VSWR = 1.04), which is close to that with a flat ground. Moreover, it can be observed that there exist other two high-order resonant modes at 5.42 and 8.82 GHz. The 5.42-GHz resonant-mode is generated by the hillside-shaped corrugations that work as a sleeve monopole, and the 8.82-GHz one is resulted from the tapered-slot structures of the ridged ground. Hence, it is concluded that the PTMA with a ridged ground contains three resonant modes and increases the impedance bandwidth, which covers the UWB band. The simulated current distributions on the triangular plate and ridged ground of the printed PTMA at 3, 5, 7, and 9 GHz are shown in Fig. 4. The current distributions presented in the figure correspond to the resonant modes discussed in Table 2.

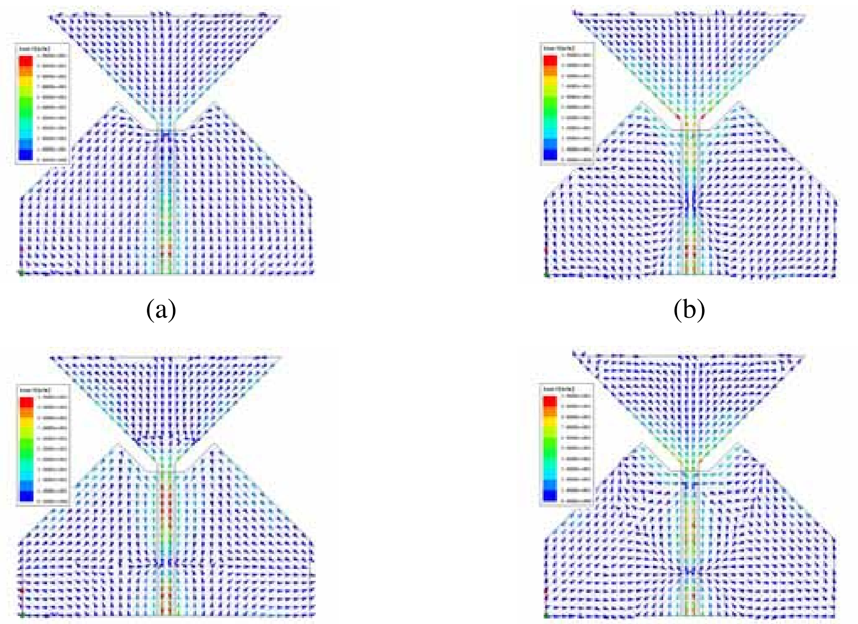
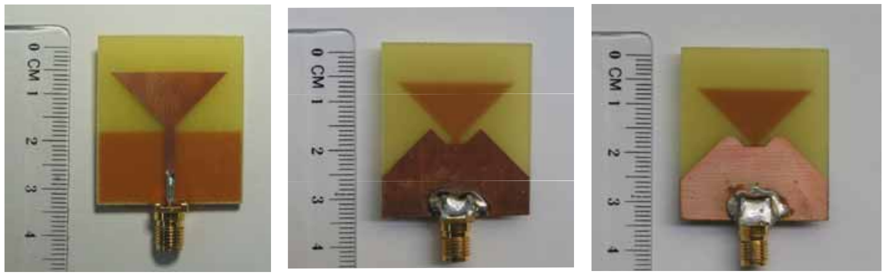


Figure 4. Simulated current distributions on the printed PTMA at: (a) 3 GHz, (b) 5 GHz, (c) 7 GHz, and (d) 9 GHz.

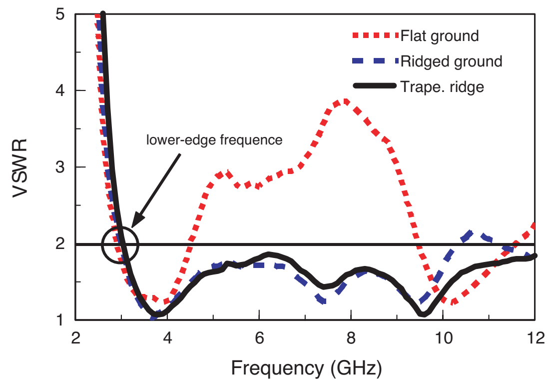
4. EXPERIMENTAL MEASUREMENT RESULTS

Figure 5 shows the photographs of the fabricated printed PTMA on a FR-4 substrate with a flat, a triangle-ridged and a trapezoid-ridged ground planes. Fig. 6(a) shows the measured VSWR of the printed PTMA with the flat, triangle-ridged and trapezoid-ridged ground planes from 2 to 12 GHz. All dimensions of the triangular monopole antennas are identical, except for the different configurations of the ground plane. From the figure, it can be observed that a significant improvement on the impedance bandwidth is achieved by the ridged ground plane. The measured impedance bandwidths (based on 2:1 VSWR) of the printed PTMA with the triangle-ridged and trapezoid-ridged ridged ground planes are 7.29 GHz (2.99–10.28 GHz) and 9.01 GHz (2.99–12 GHz), respectively. Both bandwidths are much wider than that of the printed PTMA with a flat ground plane. The impedance bandwidth can be enhanced up to 12 GHz by the trapezoid-ridged ground due to its smoothing geometry. Fig. 6(b) shows the measured resistance and reactance of the printed PTMA with the

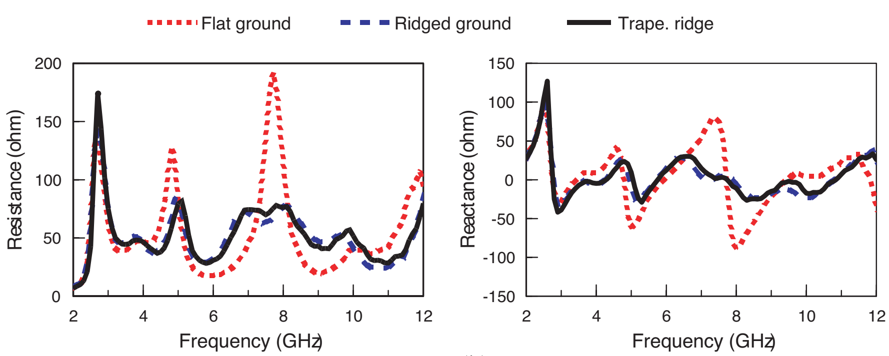


(a) (b) (c)

Figure 5. The photograph (backside view) of a fabricated PTMA on a FR-4 substrate with: (a) a flat, (b) a triangle-ridged and (c) a trapezoid-ridged ground plane.



(a)



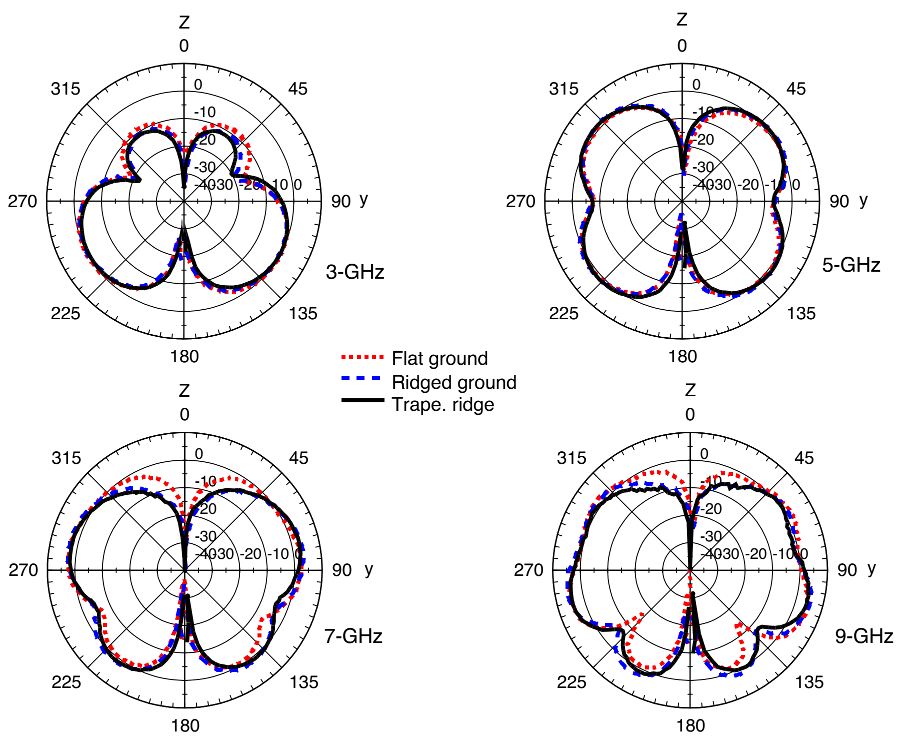
(b)

Figure 6. Measurements of a printed PTMA with a flat, triangle-ridged and trapezoid-ridged ground planes: (a) VSWR and (b) input impedance.

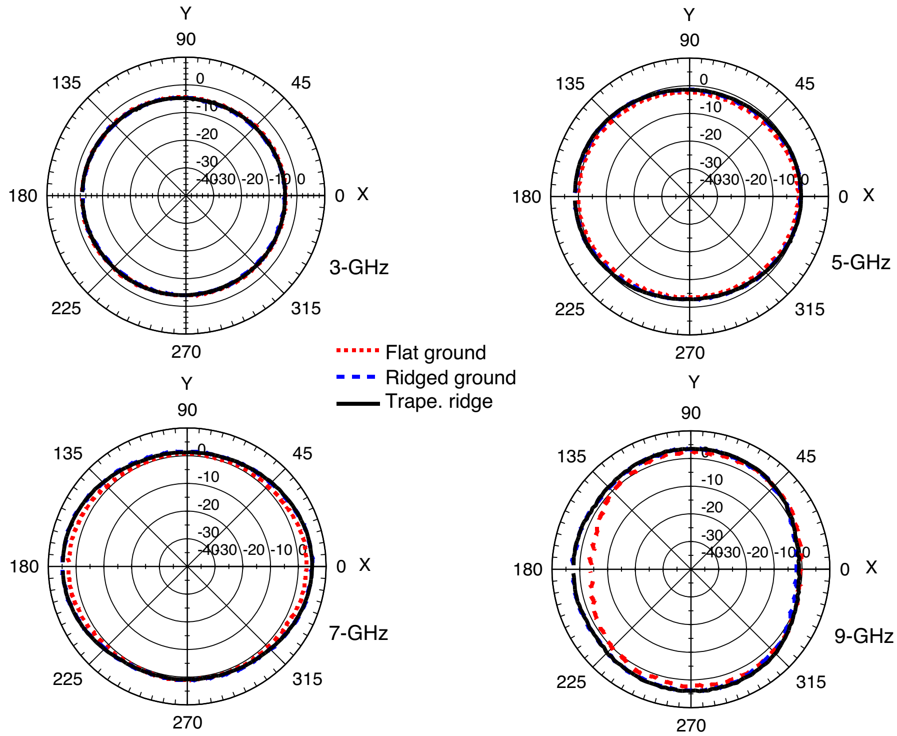
flat, triangle-ridged and trapezoid-ridged ground planes. Compared to the significantly fluctuated response of the printed PTMA with a flat ground plane, a smoothing performance of the impedance characteristics (the resistance and reactance) is achieved at the higher-frequency band. It is due to the additional resonant modes with the good impedance matching generated by the ridged ground. It is also noted that the measured lower-edge frequencies (determined from the 2:1 VSWR) of the printed PTMA with the flat, triangle-ridged and trapezoid-ridged ground planes are 2.91, 2.99 and 2.99 GHz, respectively. The ridged ground plane has a negligible effect on the lower-edge frequency of the PTMA.

Figure 7 shows the measured radiation patterns (E_θ field) of the printed PTMA with a flat, triangle-ridged and trapezoid-ridged ground plane in the E-plane (yz-plane) and H-plane (xy-plane) at 3, 5, 7, and 9 GHz. For all antennas, the nearly omni-directional radiation patterns in the H-plane can be observed over a very wide frequency band.

From the above results, some important characteristics of the



(a)



(b)

Figure 7. Measured radiation patterns of the printed PTMA with a flat, triangle-ridged and trapezoid-ridged ground plane: (a) in E-plane and (b) in H-plane.

printed PTMA with a ridged ground are summarized as follows:

a) The impedance bandwidth of the printed PTMA can be improved by utilizing a simple technique of ridging the ground plane. With properly selecting the parameters of the ridge dimension and the ridge distance, a 4:1 impedance bandwidth can be realized.
b) The effect of the ridged ground plane on the lower-edge frequency is not significant. It means that the same design rules of the conventional PTMA can be used for that with a ridged ground.
c) The radiation patterns of the printed PTMA with the flat, triangle-ridged and trapezoid-ridged ground plane are highly similar. Note that the printed PTMA with the ridged ground plane has the slightly higher antenna gains.

d) The bandwidth of the printed PTMA with a trapezoid-ridged ground plane (3–12 GHzVSWR $<$ 2) is sufficiently wide to employ it in UWB applications.

5. CONCLUSION

This paper presents a novel and simple technique to enhance the bandwidth of a conventional planar triangular monopole antenna (PTMA). A significant improvement can be achieved with two symmetrical corrugations extended from the flat ground plane, which is from 40% to 4:1 bandwidth. The PTMA with a ridged ground plane is regarded as a combination of the sleeve monopole and the ALTSA, and it features a more compact geometry and easy fabrication capacity. From HFSS design simulation, the optimum parameters of the ridge dimension (w_{ridge}, h_{ridge}) and the ridge distance (w_d) are (6 mm, 3 mm) and 4 mm, respectively. The printed PTMA with the ridged ground plane is realized on the FR-4 PCB substrate. The measured VSWR of the printed PTMA with the triangle-ridged ground plane is less than 2 from 3 to 10 GHz, which almost covers the UWB communication band. The H-plane patterns are nearly omni-directional over the desired frequency band. Moreover, with the trapezoid-ridged ground plane, the higher-edge frequency of the impedance bandwidth can be improved from 10 GHz up to 12 GHz. The antenna patterns of the PTMA with the triangle-ridged and trapezoid-ridged ground plane ridged resulted to be very similar. This technique of ridging the ground plane offers a way to enhance the bandwidth of the printed triangular monopole antenna for the UWB communication application.

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