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A Novel Miniaturized Planar Ultra-Wideband Antenna

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ABSTRACT A novel miniaturized planar ultra-wideband antenna is proposed. The antenna design comprises an electromagnetically coupled structure and a tapered radiating slot, while a triangular slot is etched on the ground plane. The antenna miniaturization is realized by adopting an electromagnetically coupled structure formed by the notched half-ellipse patch and the strip attached to the ground. The proposed antenna can yield a large 10-dB impedance bandwidth ranging from 1.5 to 10.4 GHz with satisfactory radiation properties. It also features a physical size of 37.4 mm × 64 mm, equivalent to a compact electrical size of $0.19\lambda \times 0.32\lambda$ at 1.5 GHz. The important design parameters are analyzed to comprehend the operating principle of the antenna. A good agreement between the simulated and measured results is achieved.

INDEX TERMS Ultra-wideband antenna, compact antenna, planar antenna, antenna miniaturization.

I. INTRODUCTION

Miniature UWB antennas have been widely used in body-centric wireless communications [1], [2], wireless universal serial bus [3], asset tracking [4], and microwave imaging [5]. Researches and investigations on the miniaturization of UWB antennas are therefore carried out extensively from both academia and industries [6]–[13]. For example, a compact planar super wideband monopole antenna was realized by etching a semi-elliptically fractal-complementary slot on the asymmetrical ground plane [9]. It provides a large bandwidth of 1.44 GHz – 18.8 GHz with a small footprint size of 35 mm × 77 mm. The antenna miniaturization was also achieved by adopting a modified "taegeuk" structure [10]. The measured 10-dB S11 bandwidth covers 0.2 GHz to 10 GHz and the length of the antenna is decreased by 22.8% compared to that of a half-wavelength dipole antenna operating at 0.2 GHz. A compact UWB antenna using a quarter circular patch with tapered microstrip feed line was proposed in [11]. The design features a physical size of 35 mm × 25 mm and its working band ranges from 3.1 GHz to 16.3 GHz. In [12], a compact coplanar waveguide (CPW)-fed umbrella-shaped UWB antenna was developed. The design is based on an umbrella-shaped radiating patch and a modified ground plane. The antenna presents a total size of 35 mm × 30 mm with a wide impedance bandwidth covering 3.1 GHz to 13.1 GHz. Additionally, a compact wideband planar antenna was proposed in [13]. The wideband characteristics are realized by using a microstrip coupling line to feed two elliptical arms of the antenna. The measurements demonstrate that the free-standing planar antenna can provide a broadband performance spanning from 2.7 GHz to 9.5 GHz with a physical size of 64 mm × 64 mm.

In this paper, a novel miniaturized planar UWB antenna is proposed and investigated. The antenna miniaturization is achieved by employing an electromagnetically coupled structure formed by the notched half ellipse patch in front and the strip etched on the ground plane in back. The results demonstrate that the proposed antenna can yield a large 10-dB impedance bandwidth of 1.5 GHz – 10.4 GHz alone with reasonable radiation performances. Critical geometric parameters of the antenna are investigated to understand the antenna working mechanism. The design also has a physical size of 37.4 mm × 64 mm, equivalent to a small electrical size of $0.19\ \lambda \times 0.32\lambda$ at 1.5 GHz.

This article is organized as follows. Section II illustrates the miniaturized planar UWB antenna design and analyzes the effects of critical geometric parameters on the antenna behavior. Section III gives the results of the design. Section IV presents the conclusion of the study.

II. ANTENNA CONFIGURATION AND ANALYSIS

A. ANTENNA CONFIGURATION

The configuration of proposed miniaturized planar UWB antenna is illustrated in Fig. 1. The design is initially evolved from an elliptical dipole which can provide a wide operating bandwidth. In this work, a microstrip line-fed notched quasi half ellipse patch is etched on the top of the substrate while a quarter ellipse shaped ground connected with a strip is etched on the bottom side of the substrate. The notched half ellipse in front and the strip printed on the ground in back form an electromagnetically coupled region for the antenna miniaturization. Additionally, a triangular slot is embedded on the ground to enhance the impedance matching. A 1mm-thick F4BM substrate with relative permittivity 2.2 and loss tangent 0.0007 was used in this study. W and L denote the width and the length of the F4BM substrate, respectively.

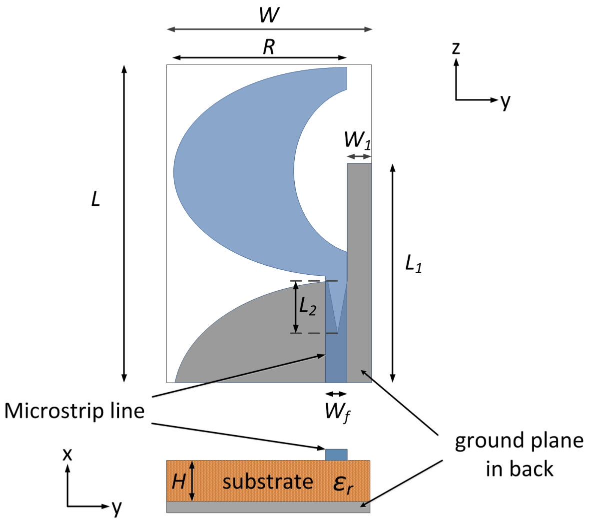


FIGURE 1. Geometry of the miniaturized planar UWB antenna.

B. EFFECTS OF DESIGN PARAMETERS

The simulations were performed by using the CST Microwave Studio. It has been shown in the simulations that the dimensions of the strip on back, the triangular slot on ground, and the tapered slot formed by quasi half and quarter ellipses, present a significant influence on antenna impedance matching. Consequently, critical geometric parameters such as L_1, L_2, and R are optimized for a good performance.

1) EFFECT OF L_1 OF THE STRIP ON BACK

Figure 2 depicts the simulated return loss performance with various values of strip height ($L_1 = 37, 42, 47$, and 52 mm) while other parameters are fixed. It is observed that the impedance matching changes significantly with the variation of L_1. When L_1 is changed, the location of the first resonance doesn't change markedly whereas the higher resonances vary significantly, resulting in different impedance bandwidth of the antenna, as shown in Fig. 2. The optimal strip height is found to be at $L_1 = 42$ mm.

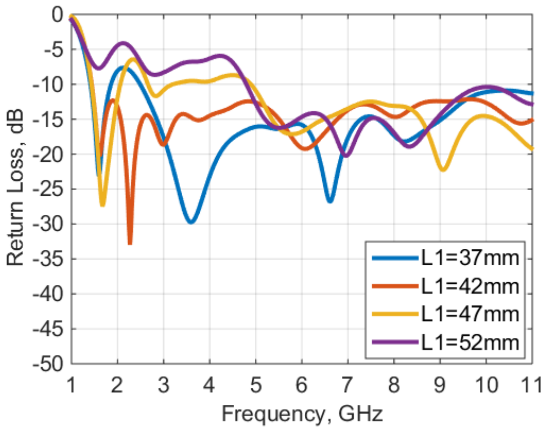


FIGURE 2. Return loss performance for various L_1 of the strip on back.

2) EFFECT OF L_2 OF THE TRIANGULAR SLOT

The return loss performance for various values of triangular slot height L_2 when other parameters remain unaltered is displayed in Fig. 3. It is noticed that the impedance matching at the lower and mid-band does not change dramatically with the variation of L_2. However, the matching at the higher band is significantly affected by the height of triangular slot. When L_2 equals to 8.5 mm, an ultra-wide bandwidth is achieved; however, when L_2 either reduces to 3.5mm or rises to 13.5 and 18.5 mm, the higher band matching becomes degraded. The optimal triangular slot height is found to be at $L_2 = 8.5$ mm.

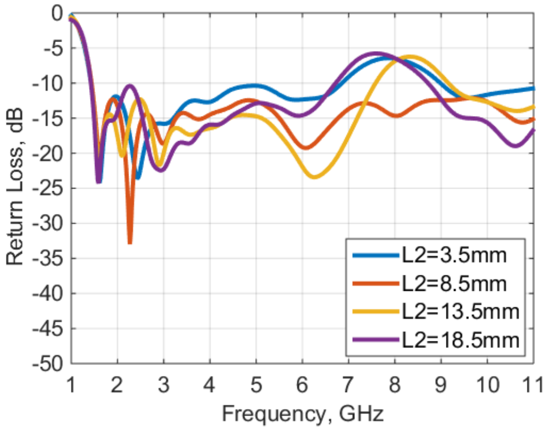


FIGURE 3. Return loss performance for various L_2 of the triangular slot.

3) EFFECT OF R OF THE TAPERED SLOT

Figure 4 presents the return loss performance for various R of the tapered slot. As can be seen, the return loss changes remarkably at the lower band with different values of R. With the increase of R, the lower band matching improves; whereas the matching at the mid and higher bands do not change significantly. The optimal R of the tapered slot is found to be at $R = 32.5$ mm.

Figure 5 illustrates the simulated current distributions at 1.5 GHz, 5 GHz, and 9.5 GHz, respectively. As can be

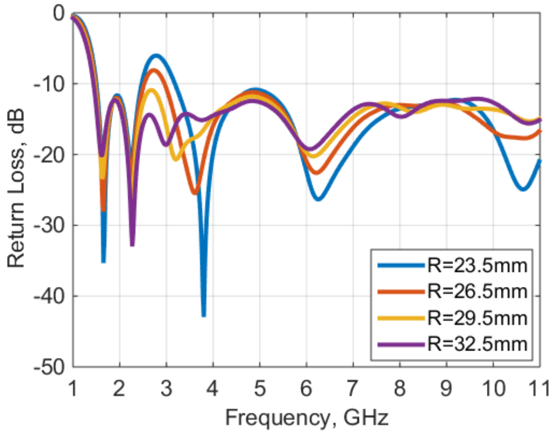


FIGURE 4. Return loss performance for various *R* of the tapered slot.

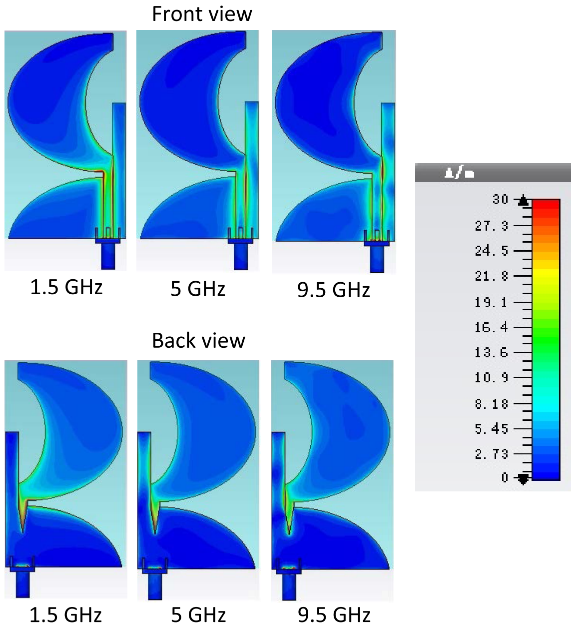
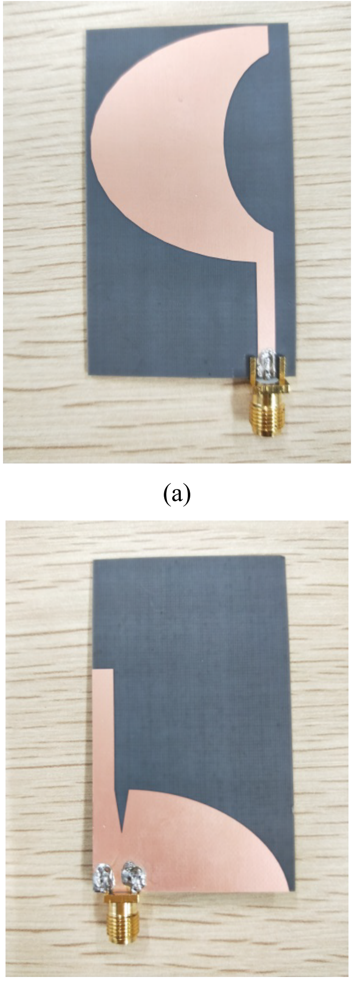


FIGURE 5. Simulated current distributions at 1.5 GHz, 5 GHz, and 9.5 GHz.

seen in Fig. 5, at lower frequencies, the currents are mainly concentrated on the electromagnetically coupled region as well as on the tapered slot. When frequency rises, decreased currents are observed in above-mentioned areas. At the higher frequencies, increased currents migrate to the triangular notch on the ground plane and traveling wave distributions are also spotted in the region of the tapered slot.

III. RESULTS AND DISCUSSION

The prototype of the proposed antenna with final design, i.e. $W = 37.4$ mm, $L = 64$ mm, $W_f = 3$ mm, $W_1 = 4$ mm, $L_1 = 42$ mm, $L_2 = 8.5$ mm, and $R = 32.5$ mm, was fabricated as shown in Fig. 6. The return loss performance was tested by using a Rohde & Schwarz ZVA40 network analyzer and radiation patterns were measured inside an anechoic chamber.



(a)

(b)

FIGURE 6. Prototype of the proposed antenna. (a) top side and (b) bottom side.

Figure 7 shows the simulated and the measured return losses of the antenna. The simulated bandwidth spans from 1.44 GHz to 11 GHz onwards while the measured bandwidth covers 1.5 GHz to 10.4 GHz, which validates the ultra-wideband characteristic of the antenna.

Figure 8 displays the simulated and measured radiation patterns at 1.5 GHz, 5 GHz, and 9.5 GHz, respectively. It is observed that the measured patterns are in good agreement with those simulated ones. The minor discrepancy at the lower frequency is due to the feeding cable effect. It is shown that the radiation patterns are satisfactory over the ultra-wide bandwidth. The increased cross-polarization level for higher bands is owing to the diversified current distributions on the antenna. The peak gain and efficiency of the design are depicted in Fig. 9. It is noticed that a reasonable gain performance is obtained and the efficiency is above 90% through the entire band.

Simulated group delay of the antenna is plotted in Fig. 10. It is observed that a relatively flat response is achieved.

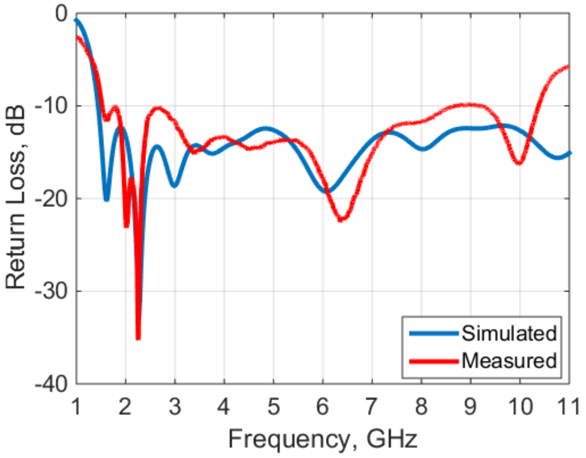
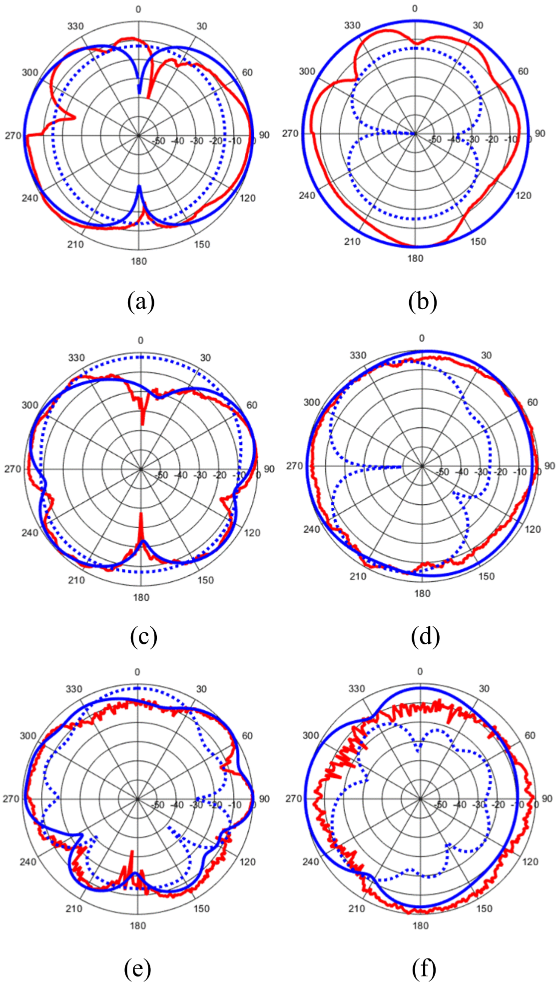


FIGURE 7. Simulated and measured return losses of the proposed design.



(a) (b)

(c) (d)

(e) (f)

FIGURE 8. Simulated (blue line) and measured (red line) co-polarization (solid line) and cross-polarization (dotted line) radiation patterns. (a) *E*-plane, $f = 1.5$ GHz. (b) *H*-plane, $f = 1.5$ GHz. (c) *E*-plane, $f = 5$ GHz. (d) *H*-plane, $f = 5$ GHz. (e) *E*-plane, $f = 9.5$ GHz. (f) *H*-plane, $f = 9.5$ GHz.

Table 1 shows a comparison between the proposed design and other designs reported in [6]–[13]. It is observed that the proposed antenna features more compact electrical dimension with broad impedance bandwidth. Compared with the wideband antenna presented in [13], this miniaturized planar UWB antenna provides not only an even smaller electrical and physical size, but also a remarkably wider impedance bandwidth.

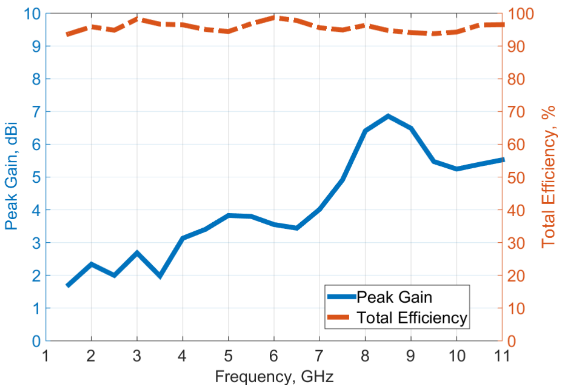


FIGURE 9. Peak gain and efficiency of the proposed design.

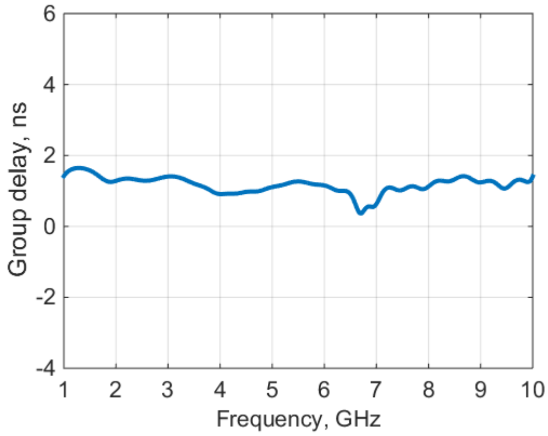


FIGURE 10. Group delay of the proposed antenna.

TABLE 1. Comparison of proposed design and various published designs.

Ref.	Physical size	Electrical size $\lambda = c / f_{low}$	10-dB BW (GHz)
[6]	33mm × 33mm	0.35λ × 0.35λ	3.15–12.03
[7]	33mm × 30mm	0.33λ × 0.3λ	3–14
[8]	40mm × 30mm	0.48 λ × 0.36λ	3.6–14.6
[9]	77mm × 35mm	0.37λ × 0.17λ	1.44–18.8
[10]	540mm × 450mm	0.36λ × 0.3λ	0.2–10
[11]	35mm × 25mm	0.36λ × 0.26λ	3.1-16.3
[12]	35mm × 30mm	0.36λ × 0.31λ	3.1-13.1
[13]	64mm × 64mm	0.58λ × 0.58λ	2.7-9.5
Proposed	**64mm×37.4mm**	**0.32λ×0.19λ**	**1.5-10.4**

IV. CONCLUSION

A miniaturized planar UWB antenna is designed and investigated in this article. The antenna demonstrates a large return loss bandwidth of 1.5 GHz – 10.4 GHz with satisfactory radiation properties. The proposed design presents a physical size of 37.4 mm × 64 mm, corresponding to a small electrical size of 0.19 $\lambda \times 0.32\lambda$ at 1.5 GHz. The important design parameters are studied to gain an insight into the antenna operation. The results indicate the proposed antenna is a suitable candidate for UWB applications.

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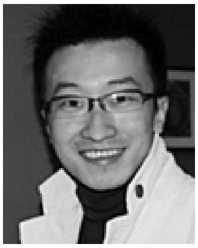

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