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PLANAR MULTI-TRAPEZOIDAL ULTRA-WIDEBAND ANTENNA AND ITS PARAMETRIC ANALYSIS

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Abstract—A compact ultra-wideband (UWB) planar monopole antenna is proposed. Multiple trapezoids and a semicircle are connected to form the patch of the monopole. The compact antenna not only has low return loss, but also has omni-directional radiation pattern over the ultra-wide bandwidth. Both the simulated and measured results are given and they are in reasonable agreement. The group delay, which is an indication of linearity between two proposed antennas, is also good. Parametric analysis on the patch shape has been performed to give some helpful design information.

1. INTRODUCTION

Ultra-wideband (UWB) communications have become a hot spot in the academic and industrial areas since 3.1–10.6 GHz frequency spectrum was allocated by the Federal Communications Commission (FCC) of the USA. Since antennas are indispensable components in communication systems, so UWB antennas have attracted a lot of research interests in antenna fields. In this area, planar monopole antenna is becoming a competitive candidate because it is a likely wideband antenna and has advantages of low profile, light weight, easy fabrication and integration with planar microwave circuitry [1–5]. It has found applications in many UWB communication applications, such as RFID devices, sensor networks, radar and location tracking, some of which usually require for antennas with small size, non-dispersive and ultra-wide bandwidth properties.

A planar monopole antenna with staircase on the patch can obtain broad bandwidth [2, 3], at the same time, round corners on the patch

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and ground plane can also improve the impedance matching of an antenna [1, 6]. Since a trapezoid is a general geometrical pattern, it can be optimized to achieve different flare angle, even to be a rectangle or a triangle. By connecting multiple trapezoids together, the edges of different trapezoids can produce a similar effect to the staircases, which is helpful to improve impedance matching over a wide frequency band. Moreover, since a planar trapezoidal monopole can achieve a bandwidth of more than 80% by adjusting the top and bottom edge lengths [5], multiple trapezoids connected can thus maintain the wideband characteristics. Usually the lower edge frequency of bandwidth is the main factor to affect the size of an antenna. A semicircle at the top of the patch will help to increase the height of the antenna and then decrease the lower edge frequency of bandwidth and will not increase much of the antenna size.

In [7], an UWB planar monopole antenna based on three adjacent isosceles trapezoids and a semicircle, with round corners on the metal ground plane is optimized by a novel Genetic Algorithm. By optimizing the heights and lengths of the top and bottom parallel sides of the three trapezoids, the radius of the semicircle, and the shape of the ground plane, a set of UWB antennas with small size and omni-directional radiation pattern are obtained. In this paper, besides the frequency performance, the time-domain performance of one optimized antenna is given, and some parametric analysis has been done, to give some helpful design information.

2. ANTENNA STRUCTURE

The proposed microstrip-fed planar monopole antenna has a metal patch, which contains three adjacent isosceles trapezoids and a semicircle, as shown in Fig. 1. The microstrip feedline is excited through a 50-Ω SMA connector. The antenna patch and the feedline are printed on one side of a Duroid 6002 substrate, which has a thickness of 0.76 mm and dielectric constant of 2.94. The width of the microstrip w_1 is 2 mm, which is determined to make the impedance of feedline being 50 Ω. The heights of three trapezoids from the bottom to the top are b_1, b_2 and b_3, respectively, and the lengths of the bottom and top parallel sides of them are a_1 to a_6. The semicircle has a radius of r_1. The rectangular metal ground plane of the microstrip feedline is located on the other side, which has two top round corners with radius of r_2. The distance between the bottom side of the patch and the top side of the ground plane is h.

An omni-directional pattern is usually desired for an antenna that will be applied in UWB communication systems. It is hope that the

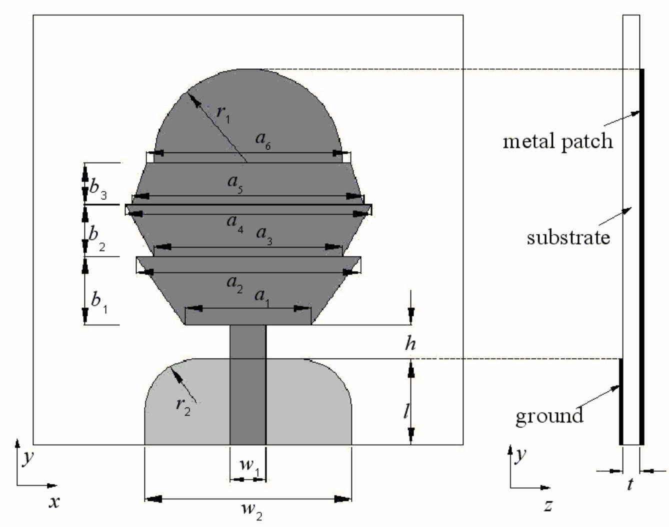


Figure 1. Scheme of the planar monopole antenna. The parameters of the fabricated antenna are as follow: $a_1 = 7.8$, $a_2 = 26.7$, $a_3 = 26.7$, $a_4 = 28.5$, $a_5 = 28.5$, $a_6 = 23.6$, $b_1 = 7.0$, $b_2 = 4.2$, $b_3 = 4.3$, $r_1 = 9.7$, $r_2 = 8.7$, $w_1 = 2.0$, $w_2 = 30.2$, $l = 14.7$, $h = 0.5$, $t = 0.76$. (units: mm)

antenna can produce symmetric and smooth radiation patterns over the ultra-wide frequency band. By taking parameter optimization, a set of compact antennas with high performance in impedance matching and radiation pattern characteristics over 3.1–10.6 GHz frequency band are obtained [7]. The parameters of one of the antennas are shown in Fig. 1.

3. SIMULATED AND MEASURED RESULTS

The compact planar UWB antenna is fabricated on a sheet of Rogers Duroid 6002 substrate with a size of 50 mm × 50 mm. An HP 8510C network analyzer and a compact range with an HP 85103C antenna measurement system are used to measure the frequency and time domain performances of the antenna. The simulation is performed by using IE3D and HFSS.

3.1. Frequency-domain Performance

Both S parameters and input impedance are depicted in Fig. 2. It is shown that the simulated and measured S parameters are in reasonable

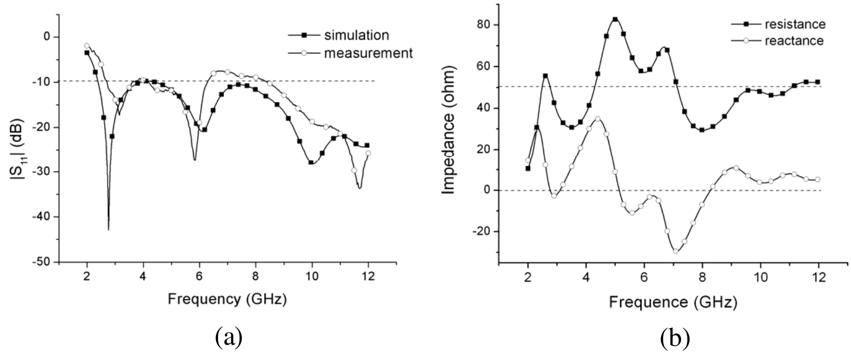


Figure 2. (a) Measured and simulated S parameters of the planar monopole antenna. (b) Simulated input impedance of the planar monopole antenna.

agreement except around 7–8 GHz, where the measured result is higher than −10 dB but lower than −7.5 dB. The discrepancy between simulation and measurement can be caused by the experimental tolerances, the fabricating tolerances, as well as the numerical errors of the software. It can be seen that the proposed antenna has three resonance frequencies around 3, 6, and 10 GHz.

The measured and simulated radiation patterns in xz-plane (H-plane) and yz-plane (E-plane) at different frequencies are shown in Fig. 3, and each pattern is normalized. It can be seen that the patterns are nearly omni-directional at different frequencies, especially in the H-plane.

3.2. Time-domain Performance

UWB wireless communication is to transmit digital signals transformed into impulse signals, which have rapidly time-varying performance. As shown in the previous section, the proposed antenna presents a very wide operating frequency band. However, as far as an UWB antenna is concerned, the good frequency-domain performances cannot necessarily mean good time-domain performances. Therefore, group delay must be investigated. Group delay is one of the crucial parameters in UWB antenna properties, which indicates the quantity of pulse distortion and far-field phase linearity. The group delay is defined as [2]

$$\tau = -\frac{\partial \varphi}{2\pi \partial f} \tag{1}$$

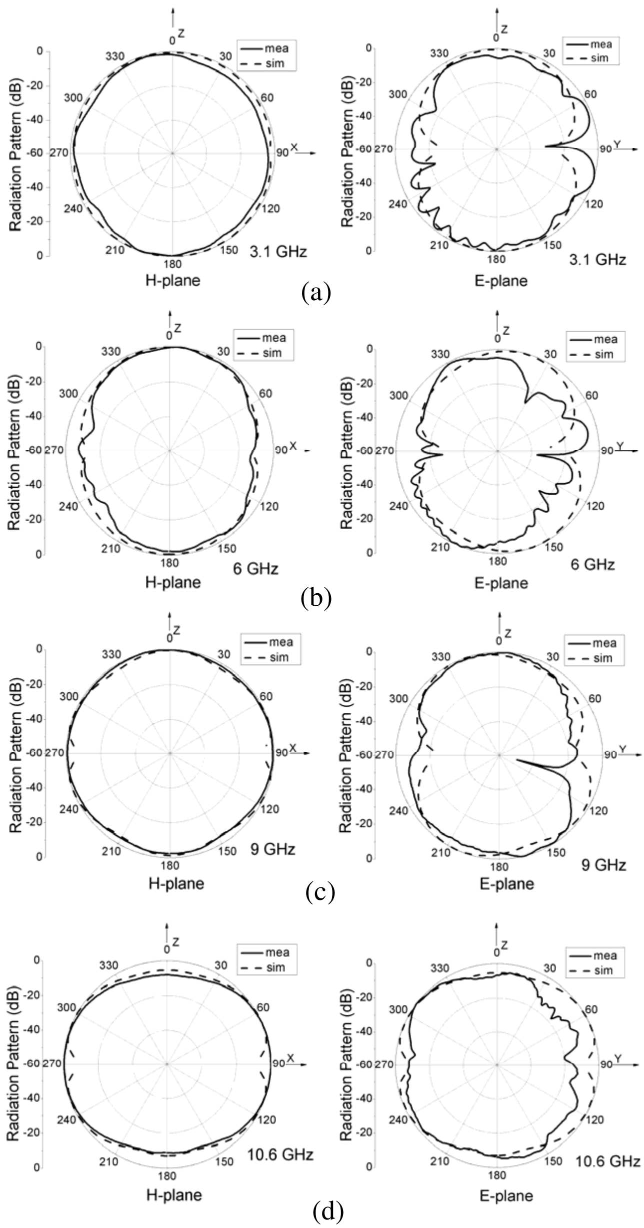


Figure 3. Measured and simulated patterns of the planar monopole antenna at different frequencies. (a) 3.1 GHz, (b) 6 GHz, (c) 9 GHz, (d) 10.6 GHz.

where φ is the far-field phase and f is the frequency.

The transmit characteristic in time domain is measured by putting two identical proposed antennas face to face in a distance of 40 cm. The measured group delay of S_{21}, as shown in Fig. 4, indicates far-field phase linearity and a quality of a pulse distortion. The group delay variation is within 0.6 ns across the whole band of 3.1–10.6 GHz. It proves a good time-domain characteristic and a small pulse distortion as well.

4. PARAMETRIC ANALYSIS OF THE ANTENNA

The parametric analysis on the patch shape is performed to give some design information. Since the monopole patch consists of three adjacent trapezoids at the bottom side and a semicircle at the top side, variety of the trapezoids and semicircle will affect the electromagnetic coupling between the patch and the ground plane, as a result, affect the performance in impedance matching and radiation of the antenna. The effect of the patch shape on the impedance matching of the monopole antenna has been investigated.

Top shape: In this study, two variations of monopole are formed by substituting the semicircle with two different shapes and the other parts of the antenna remains unchanged. The first alternative is a rectangle, and the second is a trapezoid. The rectangle has a height of r_1, and a length of $2r_1$, which are the radius and diameter of the semicircle respectively. In this way, the changed antenna has the same height as the original one. In the second alternative, the top section is formed just by extending the two nonparallel sides of the original top trapezoid, making the height of this trapezoid increased from b_3 to

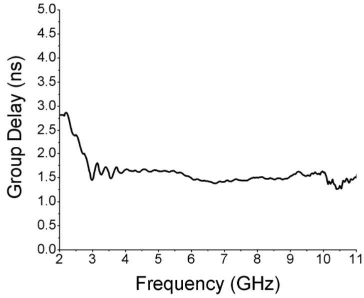


Figure 4. Measured group delay of the planar monopole antenna.

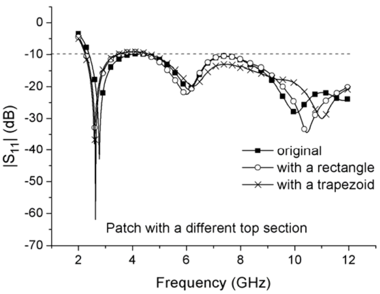
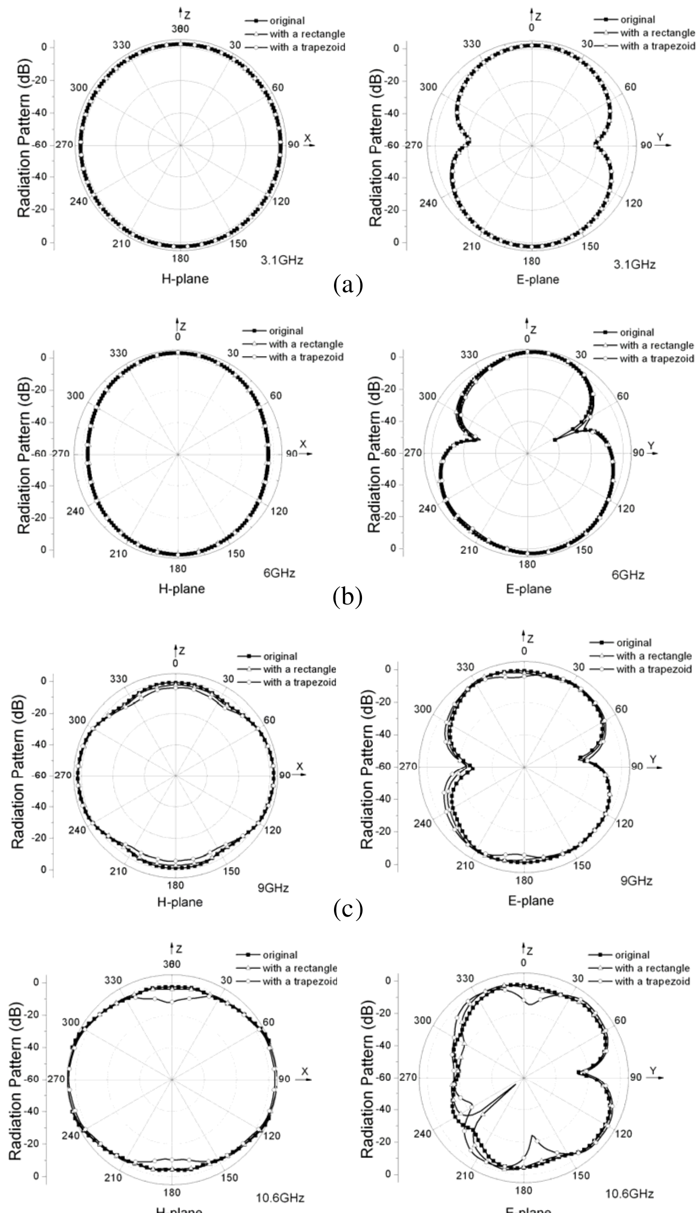


Figure 5. Comparison of S parameters for three cases with different top sections.



(a)

(b)

(c)

(d)

Figure 6. Comparison of radiation patterns for three cases with different top sections.

$b_3 + r_1$, and the top parallel side accordingly shortened. As a result, the height of the monopole patch remains unchanged.

The simulated S parameters and radiation patterns of the two variations and the original one are compared in Figs. 5 and 6. From Fig. 5, it can be seen that the three antennas have similar impedance characteristics, especially in the lower frequency band. From Fig. 6, it is clear that the three antennas have nearly the same radiation pattern at the lower frequency bands, but the original one has a better omni-directional pattern at the higher frequency bands. It reveals that different top shapes of the monopole only affect the higher resonance characteristics.

Bottom edge length of the bottom trapezoid: By varying the length of bottom edge a_1 and maintaining the height and top edge of the bottom trapezoid, the flare angle of the trapezoid is changed. Accordingly, the electromagnetic coupling between the patch and ground plane is different, thus the performance of the antenna changes. Fig. 7 shows the S parameters of four cases with different length of bottom edge. It is clearly seen that a change in the bottom edge length of the bottom trapezoid affects the impedance matching significantly. Consequently, the bottom shape of the trapezoidal patch should be one of the most important considerations in the antenna design.

Height of the patch: By removing top sections of the patch and retaining the three, two and one bottom trapezoid, respectively, the height and shape of monopole patch changed while the bottom patch shape maintained. Fig. 8 depicts the S parameters of the three variations and original one. It is evidently shown that with the decrease of the patch height, the lowest resonant frequency shift upward. Due

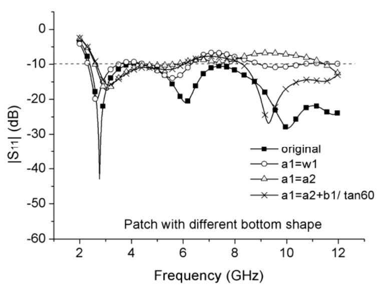


Figure 7. Comparison of S parameters for four cases with different bottom edge length of the bottom trapezoid.

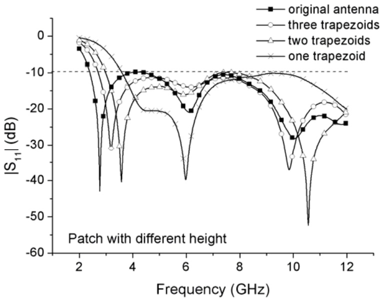


Figure 8. Comparison of S parameters for four cases with different height.

to the maintenance of the bottom trapezoid shape, the bandwidths of all four cases are very wide. This has vividly demonstrated the good performance in impedance matching of the planar trapezoidal monopole antenna.

5. CONCLUSION

An UWB planar multi-trapezoidal monopole antenna has been proposed. It has low return loss, small size and omni-directional radiation pattern. Simulated and measured results in frequency domain and time domain are given. The less than 0.6 ns group delay of the antenna makes it possible to transmit digital signals without distortion due to the enhanced phase linearity. These characteristics make it attractive for application in many UWB systems. The parametric analysis has been performed to provide helpful design information as well.

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