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AN OMNI-DIRECTIONAL AND BAND-NOTCHED ULTRA WIDEBAND ANTENNA ON DOUBLE SUBSTRATES CROSSING

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Abstract—A novel Ultra Wideband (UWB) antenna on double substrates crossing is presented in this paper. Based on conical antenna and microstrip patch UWB antenna, the proposed antenna is omni-directional, band-notched and easy to be fabricated. It operates from 2.6 GHz to 12 GHz with low Voltage Standing Wave Ratio (VSWR $<$ 2), excluding a notch-band of 5.8 GHz. Except for good performance of VSWR, the proposed antenna keeps its radiating beam at about $\theta = 45^\circ$ in E-plane through the whole band. The UWB antenna is fed by a coaxial probe through a SMA connector. The length of the proposed monopole element above the ground is slightly less than $\lambda/4$ of the lowest frequency. The simulated and measured results of the VSWR, the gain and the radiation patterns for the proposed antennas are presented and discussed. Good agreement between simulated and measured results is demonstrated.

1. INTRODUCTION

Ultra Wideband (UWB) technique has become one of the most fascinating technologies in indoor communications. It has the merits of high speed transmission rate, low power consumption and simple hardware configuration over conventional wireless communication systems [1, 2]. However, interference is a serious problem for UWB application. It is necessary to ensure the rejection of interference with existing wireless local area network (WLAN) technologies such as IEEE 802.11a (5.15–5.35 GHz, 5.725–5.825 GHz) [3, 4].

Either omni-directional or notch-band characteristic is important to UWB antenna. Microstrip UWB antenna exhibits a good band-notched characteristic. But its omni-directional characteristics and

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radiation patterns are not stable through the whole band [1–7]. Additionally, conical antenna provides a good omni-directional feature, but it's difficult to achieve band-notched characteristics. Moreover, it is time-consuming in fabrication and tuning [8].

Usually, finite biconical antenna (Fig. 1(a)) which is self-similar has performance of frequency-independent and omni-directional in horizontal plane [1, 9]. By replacing one of the cones with the finite ground plane, the biconical antenna (Fig. 1(b)) is extended to be finite mono-cone, which is also frequency-independent and omni-directional [10]. Due to the advantages of easy fabrication and high precision of PCB processing, a patch is used to replace the cone antenna (Fig. 1(c)). Microstrip antenna is always used to obtain good structural characteristics [11]. Unlike conical antenna, microstrip antenna (Fig. 1(d)) is hard to achieve a good omni-directional pattern [2–7].

According to the discussion above, a novel UWB antenna combined the features of microstrip antenna and conical antenna is presented in this paper. The radiators are printed symmetrically on a low-cost FR4 substrate with thickness of 1 mm and the dielectric constant of 4.4. Two crossing substructures, which form a cone-shape, are applied to conquer the common cone antenna's drawback in fabrication. Unlike the common compact antennas, good performance in omni-direction is gained, which is better than those results in Refs. [2–7]. Four L-shape slots are symmetrically etched on each substructure to obtain a band-notched characteristic. Besides, the proposed antenna has the advantages of low-cost, small size and easy fabrication. For the proposed antenna (Fig. 1(e)), VSWR is below 2 through the whole band from 2.6 GHz to 12 GHz, excluding the

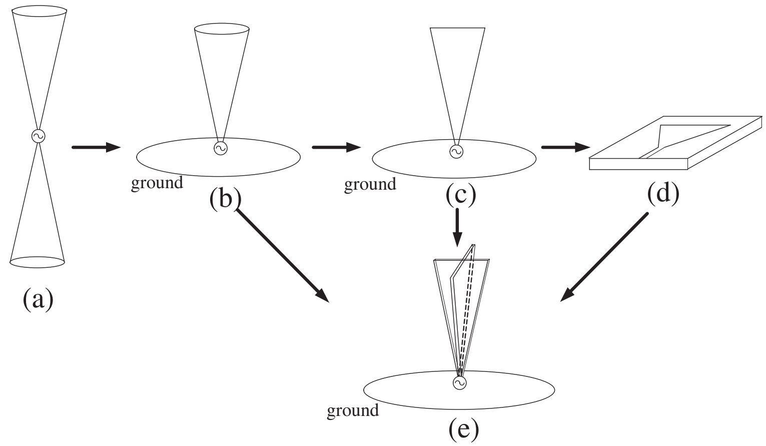


Figure 1. Abridged general view of antenna designing.

band-notched from 5.1 GHz to 6.2 GHz. Besides, it gives good omni-directional results and the dominated radiation direction is maintained at the angle of about $\theta = 45^\circ$ in E-plane above the ground plane through the whole band. Both the simulated and measured results show good agreements with the requirement.

2. ANTENNA DESIGN AND STRUCTURE

An abridged view of the antenna designing is showed in Fig. 1. Two substructures with permittivity of 4.4 and thickness of 1 mm are vertically organized to form a taper-shape antenna. By introducing slits in the two patches, a band-notched is achieved. By adjusting the dimension and the location of the slits, the band-notched can be augmented. For comparison, the 3D structure of the single substructure monopole antenna and the proposed antenna are depicted in Fig. 2. The simulated radiation patterns of the single substructure monopole antenna by HFSS are given in Fig. 3, which reveals that the single substructure monopole antenna cannot guarantee a steady omni-directional characteristic among the whole band. To improve the feature of omni-directional, two substructures crossing are used to replace the single substructure.

The proposed antenna is fed by a 50 Ω coaxial probe through a SMA connector. The inner conductor of the coaxial and the patch are connected by a SMA connector, while the outer conductor of the coaxial and the 100 mm ground plane are jointed. The detailed dimensions and the related parameters are given in Fig. 4 and Table 1, respectively. In Fig. 4, the structure of (b) is used for the single

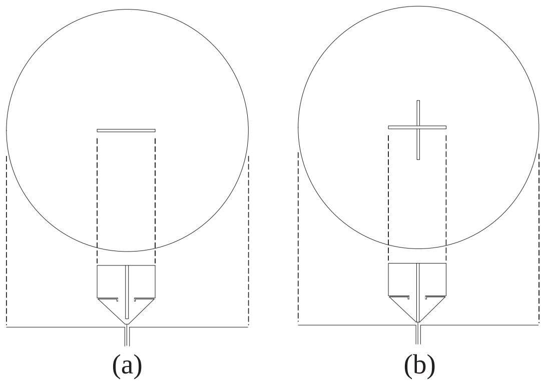
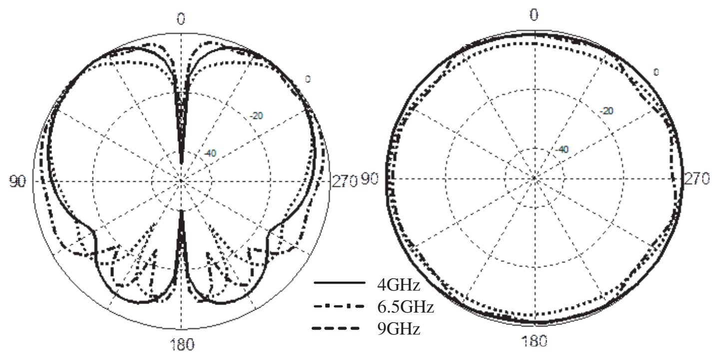


Figure 2. Structures of Single substructure (a) monopole antenna and (b) Proposed antenna.

Table 1. Parameters of the proposed antenna.

Parameters	W	W_1	W_2	W_3
Units (mm)	28	13.3	0.5	0.5
Parameters	W_4	W_5	W_6	W_7
Units (mm)	8	7	1.15	0.467
Parameters	L	L_1	L_2	L_3
Unitsmm	20.5	9.5	0.929	16.244
Parameters	L_4	L_5	L_6	
unitsmm	1	21	15.475	



(a) (b)

Figure 3. Radiation patterns of the patch monopole antenna at different frequencies: (a) E-plane; (b) H-plane.

substructure monopole antenna while the structure composed of (a) and (b) for the proposed antenna. The front end component of the substructure is an isosceles triangle with the purpose of obtaining a gradual-change frequency characteristic. A taper-shape antenna is formed by crossing the two substructures. A rectangular structure is employed in the back component of the substructure to save the slopping length, without affecting the performance. To make them easy to be installed, two substructures are designed in different height.

The radiation length of UWB monopole antenna is:

$$\frac{1}{4}\lambda_{\max} = l \tag{1}$$

where, $\lambda_{\max}$ is the wavelength of the lowest frequency; l is the total length of the antenna and the effective length is actually $0.23 \sim 0.24\lambda$. The sum of L_1, L_2 and L_3 is approximately the 0.23λ at 2.6 GHz, determining the low frequency of the proposed antenna. The

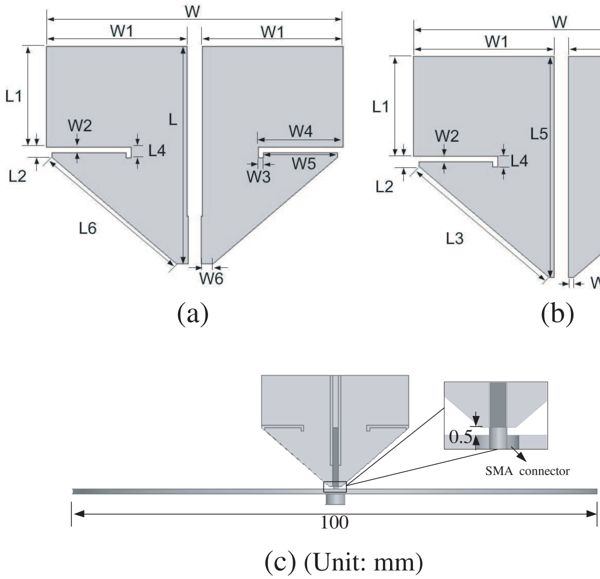


Figure 4. Dielectric patch structures.

Table 2. Center frequency of band-notched corresponding to various dimension of the slits.

Parameters	Theoretical results	Simulation results
$W_4 = 8,\ L_1 = 9.5$	5.80 GHz	5.80 GHz
$W_4 = 7,\ L_1 = 9.5$	6.18 GHz	6.18 GHz
$W_4 = 9,\ L_1 = 9.5$	5.70 GHz	5.24 GHz
$W_4 = 8,\ L_1 = 10.5$	6.18 GHz	6.28 GHz
$W_4 = 8,\ L_1 = 8.5$	5.70 GHz	5.66 GHz

wavelength of the center frequency of band-notched is given as

$$\frac{1}{2}\lambda = k \tag{2}$$

where, k is represented by

$$k = L_1 + L_3 + W_4 \tag{3}$$

On the condition of keeping L_3 unchanged, different dimensions of W_4 and L_1 lead to variation of the center frequency of band-notched. As shown in Table 2, the theoretical values of the center frequency of band-notched match with the simulated values using HFSS, which demonstrated the design formula. Fig. 5 depicts the simulated VSWR

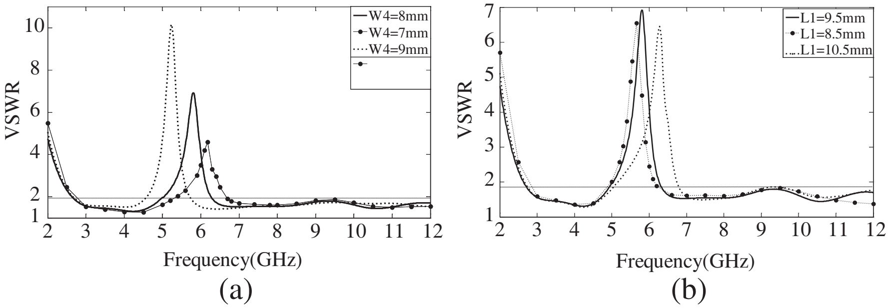


Figure 5. Effect of the variation of W_4 and L_1 on the band-notched frequency: (a) Variation of W_4; (b) Variation of L_1.

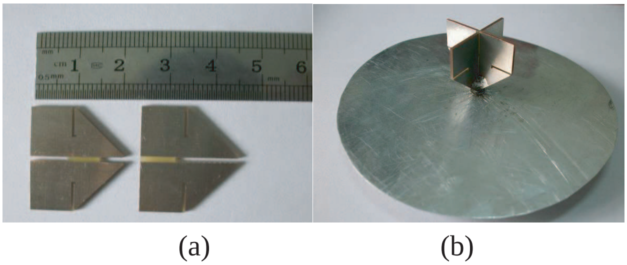


Figure 6. Photograph of the fabricated prototype. (a) The dielectric patch; (b) the entire antenna.

of the antenna for different W_4 and L_1. As observed, the adjustment of the center frequency of band-notched can be done by reducing W_4 or raising L_1. By decreasing W_4 from 9 mm to 7 mm (Fig. 5(a)), the center frequency of band-notched shifts from 5.24 GHz to 6.18 GHz, while increasing L_1 from 8.5 mm to 10.5 mm causes center frequency variation of band-notched from 5.66 GHz to 6.28 GHz.

3. RESULTS AND DISCUSSIONS

The photograph of the fabricated antenna is shown in Fig. 6, and the two substructures were soldered together. The performance of the proposed antenna is simulated using high-frequency structure simulator (HFSS) and the VSWR is measured by a Wiltron37269. The VSWR is less than 2 covering the whole band from 2.6 GHz to 12 GHz, excluding a band-notched from 5.1 GHz to 6.2 GHz among which VSWR is about 6.9 at 5.8 GHz. The simulated and measured results of VSWR are shown comparatively in Fig. 7. Simulated result

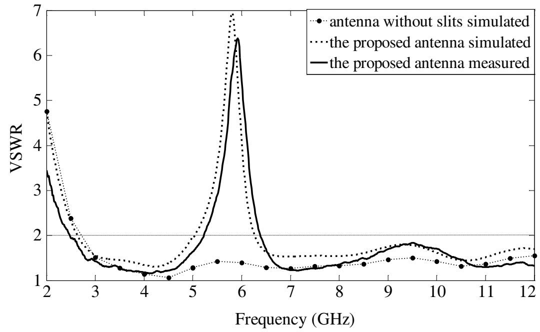


Figure 7. VSWR of the proposed antenna.

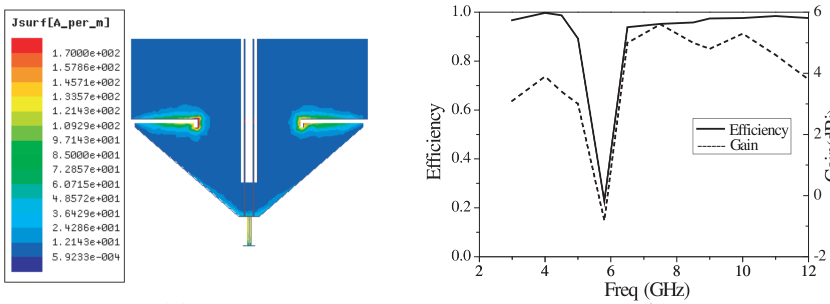


Figure 8. (a) Simulated current distribution of the propose antenna at 5.8 GHz and (b) gain and efficiency of the propose antenna.

of VSWR for the antenna without slits is given to be compared with the VSWR of the proposed antenna. It is revealed that the band-notched can be realized by inserting slits with proper dimension and location in the substructures. Although there is a little difference in VSWR between the simulated and the measured results, the two results show a great identity among the whole band.

Figure 8(a) illustrates the simulated current distribution at 5.8 GHz. It can be observed that the majority of the electric currents concentrate around the slot at the notch frequency. In this case, destructive interference for the excited surface currents in the antenna occurs and the impedance changes acutely making large reflection at the desired notch frequency. Fig. 8(b) shows the gain and the efficiency of the proposed antenna among the whole band. Both the gain and efficiency decrease rapidly in the vicinity of 5.8 GHz.

In Table 3, it is revealed that the dominated radiation beam above the ground plane is regulated about $\theta = 45°$ in E-plane among the whole band. A far-filed measuring system was applied to obtain the gain and the patterns, and a network analyzer of HP8720 is the major part. The measured antenna radiation patterns at the frequency of 4.0 GHz, 6.5 GHz and 9.0 GHz are plotted in Fig. 9, Fig. 10 and Fig. 11 respectively. Comparing with the radiation patterns of the single substructure in Fig. 3, the proposed antenna performs a better omni-directional characteristic. In addition, it exhibits a band-notched from 5.1 GHz to 6.2 GHz. Table 4 shows the gains of the proposed antenna at the frequency of 4.0 GHz, 6.5 GHz and 9.0 GHz. It is revealed that the gain is about 4 dB covering the whole band.

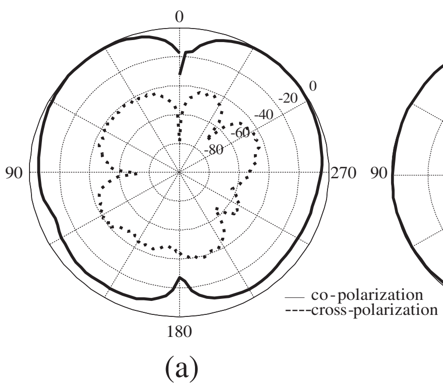


Figure 9. Measured antenna radiation patterns at 4 GHz: (a) E-plane; (b) H-plane.

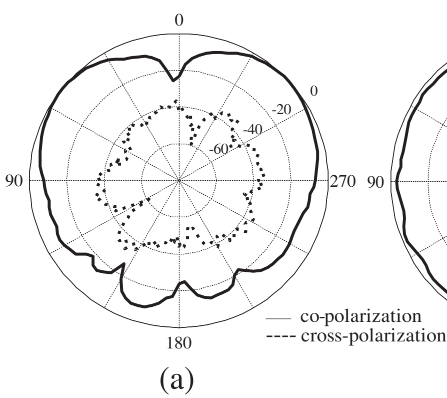


Figure 10. Measured antenna radiation patterns at 6.5 GHz: (a) E-plane; (b) H-plane.

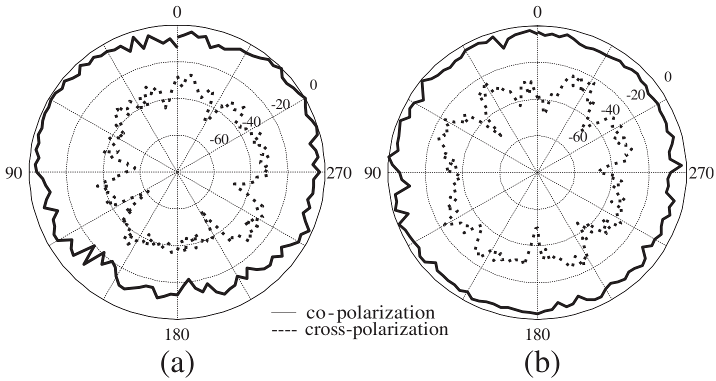


Figure 11. Measured antenna radiation patterns at 9 GHz: (a) E-plane; (b) H-plane.

Table 3. Main lobe direction of the proposed antenna.

Frequency (GHz)	3	4	4.5	5	6.5	7.5	8.5	9	10	11	12
Beam position (deg)	45	41	41	55	49	46	45	52	53	49	45
Half-power beam width (deg)	57.5	59.4	66.6	68.7	39.5	35.9	39.1	41.7	31.3	31.1	64.4

Table 4. Gain of the proposed antenna.

Frequency	4 GHz	6.5 GHz	9 GHz
Gain (simulation)	3.9 dBi	5.0 dBi	4.8 dBi
Gain (measurement)	3.8 dBi	4.8 dBi	4.9 dBi

4. CONCLUSION

A new UWB antenna combining the advantages of the microstrip patch antenna and the conical antenna is presented in this paper. The proposed antenna has the feature of omni-directional in H-plane. Moreover, the dominated radiation direction is maintained at the angle of about $\theta = 45°$ in E-plane above the ground plane among the whole band. Measured results show that the VSWR is less than 2 covering the whole band from 2.6 GHz to 12 GHz, with a band-notched from

5.1 GHz to 6.2 GHz where the maximum VSWR is 6.9. There is a good agreement between the measured and the simulated results.

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