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DUAL BAND-NOTCHED ULTRA-WIDEBAND PLANAR MONOPOLE ANTENNA WITH M- AND W-SLOTS

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Abstract—A compact ultra-wideband microstrip-fed planar monopole antenna with dual band-notch characteristic is presented. Dual notched frequency bands are achieved by embedding an M-slot in the radiating patch and a W-slot in the ground beneath the feeding line. And the characteristics of the dual band-notched can be controlled by adjusting the length and position of the corresponding slot. Experimental results show that the proposed antenna, with compact size of $35 \times 35\,\mathrm{mm}^2$, has an impedance bandwidth of $2.75 \sim 11.30\,\mathrm{GHz}$ for VSWR less than 2.0, except two notched bands of $3.25 \sim 4.20\,\mathrm{GHz}$ and $5.23 \sim 6.10\,\mathrm{GHz}$. Moreover, this antenna exhibits good omnidirectional radiation patterns in the H-plane, stable antenna gains over the operation band, and perfect group delay in the time-domain.

1. INTRODUCTION

Recently, ultra-wideband (UWB) system design and application have become the focus of wireless communication [1]. However, over the designed frequency band, there exist some narrow bands for other communication systems, such as WLAN ($5.15 \sim 5.825\,\mathrm{GHz}$), WiMAX ($3.3 \sim 3.6\,\mathrm{GHz}$) and C-band satellite communication($3.7 \sim 4.2\,\mathrm{GHz}$), which may cause electromagnetic interference with the UWB system. To solve this problem, the UWB antenna with band-notch characteristic goes into our sight. Some band notched antennas with various shaped slots have been studied, such as C-shaped slot, L-shaped slot and so on [2–8]. However, most of these antennas do not have high Q value and the VSWR performance in the notched band is neither sharp enough.

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In this paper, a novel UWB planar monopole antenna with two high Q-value slot resonators is proposed. By embedding an M-slot in the radiating patch and a W-slot in the ground beneath the feeding line, the desired dual notched bands centered at 3.625 GHz and 5.5 GHz have been achieved. Details of the antenna design are presented; measured results such as voltage standing-wave ratio (VSWR), radiation patterns, antenna gains, and group delay are given below.

2. ANTENNA DESIGN

The dimensions of proposed antenna and slot resonators are shown in Fig. 1. The proposed antenna is fabricated on FR4 with loss tangent of 0.02, relative permittivity of 4.4 and thickness of 1.6 mm. As shown, a circular monopole is used as the base antenna [9] and to obtain better VSWR performance over the whole UWB band, two filleted corners and a square slot are employed in this design.

The M-slot is embedded in the radiating patch, which can yield a notched band centered at 3.625 GHz. It is formed by two vertical slots with length $L1$, two tilted slots with length $L2$, and two horizontal slots with length $W1$. The length $L = 2^*(L1 + L2 + W1)$ is adjusted to be about half-wavelength at the desired notched frequency $f_1 =$ 3.625 GHz, in order to make the input impedance singular [2]; and the horizontal slots are introduced here to exempt the undesired litter parasitic resonance at $8 \sim 9$ GHz. The Q value is largely dependent on the width of these slots and the distance D between the vertex A of M-slot and the lower edge of the circular radiating patch. The W-slot

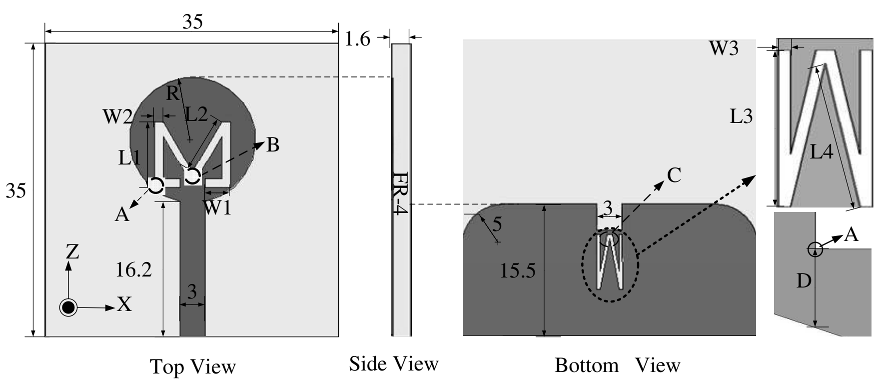

Figure 1. Geometry of the proposed antenna and slot resonators (Unit: mm).

is etched in the ground of the feeding line to achieve another notched band centered at 5.5 GHz. It is formed by two vertical slots with length $L3$ and two tilted slots with length $L4$. The resonance frequency $f_2 = 5.5$ GHz is determined mainly by the length $L = 2^*(L3+L4+W3)$, which is about half-wavelength of the resonance frequency. The Q value is determined largely by the width of the slots. A prototype is fabricated to verify the design concept, displayed in Fig. 2.

3. PARAMETRIC STUDY FOR THE TWO NOTCHED BAND

3.1. Study of 3.625 GHz Notched Band

Figure 3 shows the simulated VSWR of the proposed antenna with different $W1$. It can be seen that the length of the slot determines

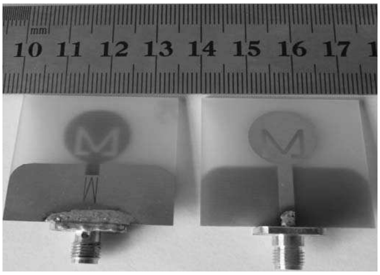

Figure 2. Photograph of the fabricated prototype.

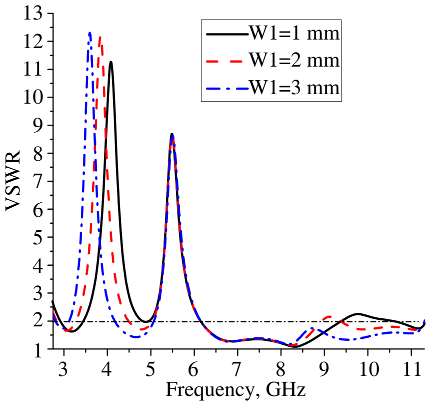

Figure 3. The effect of length $W1$ on 3.625 GHz notched band

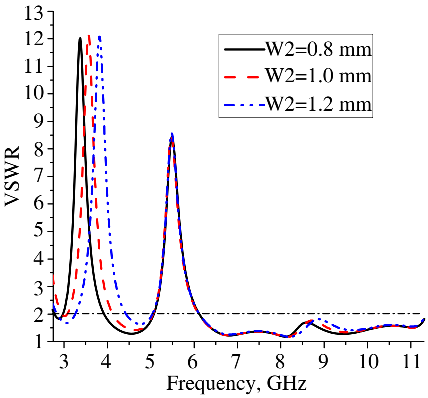

Figure 4. Return loss of a circular corrugated horn

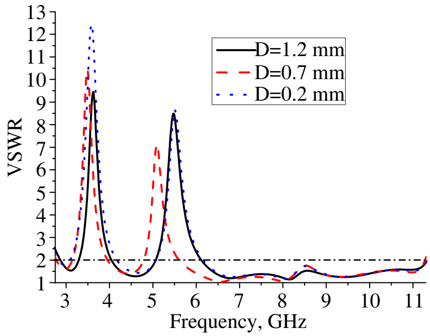

Figure 5. The effect of distance D on 3.625 GHz notched band.

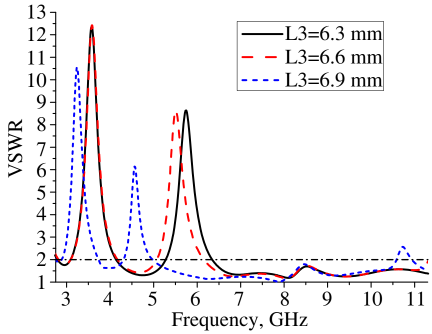

Figure 6. The effect of width $L3$ on 5.5 GHz notched band.

Table 1. Optimized parameters of the proposed antenna.

Parameter	R	$L1$	$L2$	$L3$	$L4$	$W1$	$W2$	$W3$	D
Value (mm)	7.5	7.5	6.7	6.6	6.2	3.0	1.0	0.2	0.2

the frequency range of the notched band. As $W1$ increases, the centre frequency of the notched band shifts toward lower band and the VSWR performs better at $8 \sim 11.3$ GHz.

Figure 4 displays the effect of $W2$ on the notched band. It is observed that the center frequency of notched band is increased with increasing $W2$. The optimized parameters of M-slot resonator are listed in the Table 1. Thus, the specific notched band can be achieved by adjusting the slot length and width.

Figure 5 displays the simulated VSWR of the proposed antenna with different D. It can be seen that as the distance D decreases, the Q value becomes higher and the notched band goes shaper.

3.2. Study of 5.5 GHz Notched Band

Figure 6 shows the simulated VSWR of the proposed antenna with different $L3$. It can be seen that the length of the vertical slot has great influence on the frequency range of the notched band. As $L3$ increases, the centre frequency of the notched band moves toward lower band.

Figure 7 displays the effect of $W3$ on the notched band. It is observed that as $W3$ increases, the peak VSWR value in the notched band increases and also the centre frequency of the notched band shifts toward upper band, which is maybe due to the intersection of the vertical slots and the tilted slots becomes longer while the slot width $W3$ increases.

We have also studied how the position of vertex C affects the Q and the resonance frequency band. From Fig. 8, we can see that the resonance frequency band shifts towards upper band and the peak VSWR value in the stop-band increases while the vertex C moves down.

Through the parametric study, we have finally obtained the optimized values to achieve dual band-notch characteristic. The optimized values are listed in Table 1.

4. EXPERIMENTAL RESULTS AND DISCUSSION

The antenna is simulated using high-frequency structure simulation (HFSS^{TM} V.12), and the VSWR of the proposed antenna is measured using a WILTRON 37269A network analyzer. The simulated and measured results are shown in Fig. 9. The measured results show that the proposed antenna exhibits two narrow notched frequency bands of 3.25–4.20 GHz and 5.23–6.10 GHz, while maintaining wideband

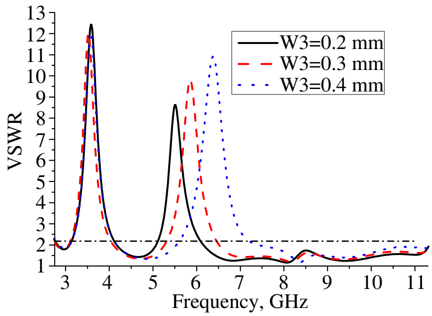

Figure 7. The effect of width $W3$ on 5.5 GHz notched band.

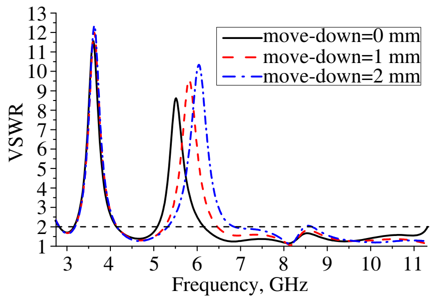

Figure 8. The effect of vertex C on 5.5 GHz notched band.

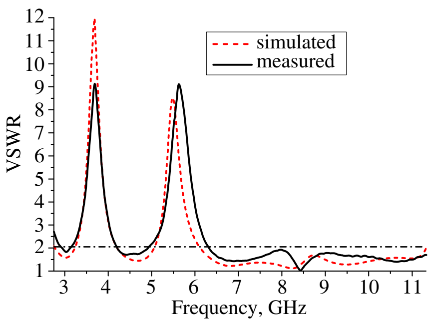

Figure 9. Measured and simulated VSWR of the proposed antenna.

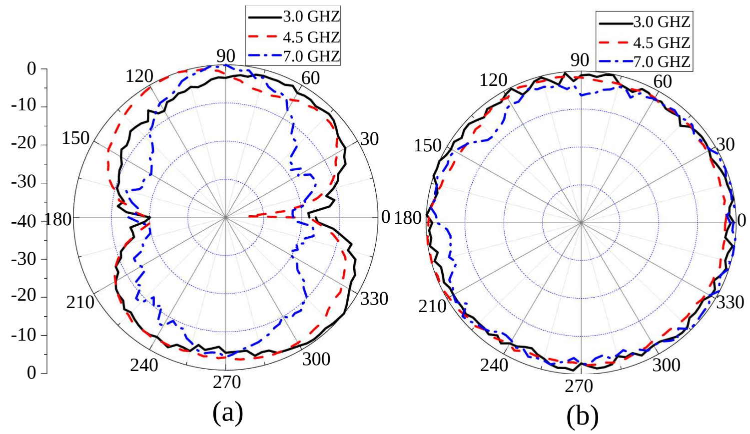

Figure 10. Measured radiation patterns at 3, 4.5 and 7 GHz. (a) E-plane. (b) H-plane.

performance from 2.75 to 11.3 GHz for VSWR $<$ 2. It also shows that the measured VSWR at $f_1 = 3.625$ GHz is less about 3.0 than the simulated one, and the measured upper notched band is about 100 MHz higher than the simulated result. These discrepancies could be due to the tolerance in manufacturing, because the characteristics of the notched band are sensitive to the length and position of the corresponding slot. Moreover, the measured upper notched bandwidth is slightly wider than the simulated, it maybe due to a larger $\tan\delta$ of the substrate.

The measured radiation patterns of the proposed antenna operating at 3.1, 4.5 and 7.0 GHz are shown in Figs. 10(a) and (b). Each pattern is normalized with respect to the peak gain of the corresponding plane. It can be found that the antenna has relatively stable radiation patterns over its operating band. Moreover, the antenna shows omnidirectional radiation patterns in the H-plane and dipole-like radiation patterns in the E-plane.

The measured gains are shown in Fig. 11. As expected, much lower gains in the notched bands are achieved.

Figure 12 shows the measured group delay in the time-domain. If the group delay variation exceeds 1.0 ns, the phases are no longer linear in the far-field region, and pulse distortion is caused. This can be a serious problem in a UWB communication system [10]. In this study, a pair of identical antennas served as the transmitting and receiving antennas, which were connected to the double ports of the analyzer in the face-to-face orientations, with a distance of 30 cm between them.

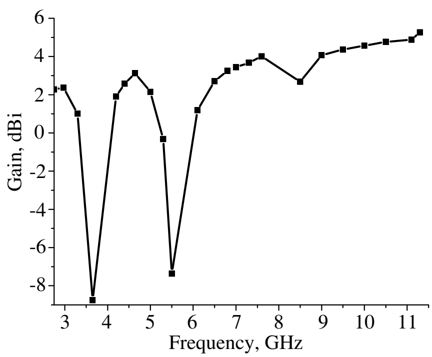

Figure 11. Measured gains of the proposed antenna.

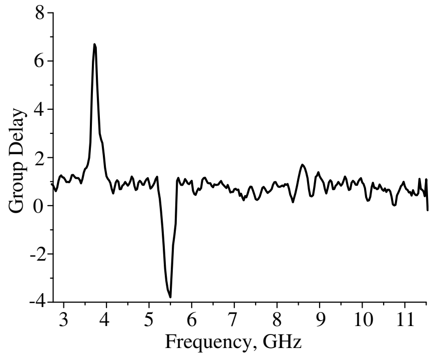

Figure 12. Measured group delay of the transfer system.

As can be seen from Fig. 12, the variation of the group delay is within 1.0 ns in UWB band, except in the notched bands where the maximum group delay is more than 5 ns.

5. CONCLUSION

A circular monopole antenna having dual band-notch characteristic is proposed for UWB applications. Dual notched bands are achieved by embedding an M-slot in the radiating patch and a W-slot in the ground of the feeding line. Both simulated and measured results show that the antenna not only has dual notched bands as expected but also has a good radiation pattern and good group delay performance over the ultra-wide operation band. And as far as we have learnt, the M- and W-slot resonators are both the first time being put forward and used in the UWB applications, so this paper can provide wider sight and more choices for engineers in the UWB communication field.

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