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COMPACT DUAL BAND-NOTCHED UWB ANTENNA WITH PARASITIC MICRO-STRIP LINES AND T-SHAPE STUB

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Abstract—In this study, a novel dual band-notched ultra-wideband (UWB) antenna has been proposed and discussed. The proposed antenna is fed by a micro-strip line and in the square-etched radiation patch a T-shape parasitic stub is attached. On the other hand, a pair of parasitic parallel micro-strip lines are also added on the ground plane, one of which is shorted to the radiation patch by a short-pin through dielectric substrate. The two parasitic units are to achieve band-notched characteristics at 3.3–3.7 GHz and 5.15–5.85 GHz, respectively. In order to realize impedance matching over the ultra-wideband, two arc-shape cuts are made symmetrically at the junction of feed-line and radiation patch. The simulated and measured results, including return loss, radiation pattern, group-delay and peak gains are in good agreement with theory analysis which validates our design concept.

1. INTRODUCTION

Ultra-wideband (UWB) systems have drawn lots of interests since the Federal Communications Commission (FCC) released the unlicensed frequency band of 3.1–10.6 GHz for commercial UWB applications [1]. Also for their high data rates, great capacity, low complexity and low operating power level, UWB system becomes a hot topic which will bring us great potential interests [2]. The UWB systems are usually used in home networking as a convenient way for personal wireless communications. As one of the most essential parts of the UWB systems, UWB antennas have drawn more and more researching interests. Besides the advantages that UWB system bring to us, it also

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carry troubles. One of the troubles is the interference between UWB system and other communication system, such as local area network (WLAN, 5.15–5.825 GHz), worldwide interoperability for microwave access (WiMAX, 3.3–3.7 GHz) IEEE802.11a in the United States (5.15–5.35 GHz, 5.725–5.825 GHz) and HIPERLAN/2 in Europe (5.15–5.35 GHz, 5.47–5.725 GHz) [3]. The traditional way to solve problem like this is insert a filter in the receive terminal, but this will make the UWB system more complex, especially for portable devices. UWB antenna as the key component of UWB system, and also based on the antenna theory, researchers found the best way to eliminate this trouble is design the filter and the UWB antenna together, which is called band-notched UWB antenna.

In recent researches, many UWB antennas with band-notched characteristics have been proposed and studied. The conventional and effective way to achieve the notch-band is inserting a slot on the patch or on the ground plane [4–7]. While there are also many other ways to create band-notched characteristics on a UWB antenna, such as using parasitic structures [8–12], embedding a slit in the feed-line [13, 14], or adding split ring resonator (SRR) coupled to the feed-line [15–17]. These slots, stubs or branches are in different shapes, but the common point they all share is the same that is introducing a perturbation into the UWB antenna. And they are all near $\lambda/2$ or $\lambda/4$ resonant lengths corresponding their notched frequencies. So in a band-notched antenna designing procedure, perturbation structures with proper resonant length is the key point of the antenna design.

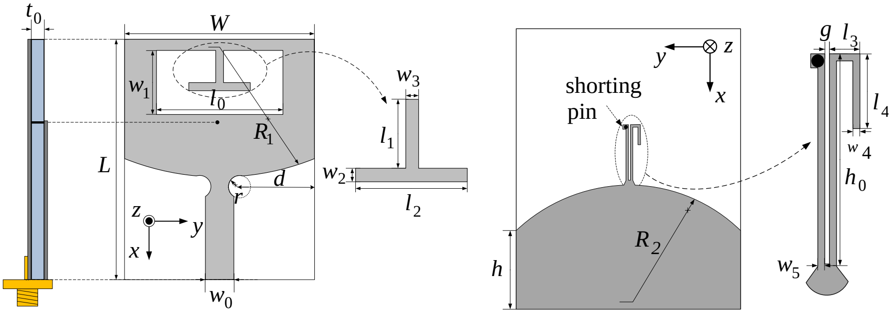
In this study, a novel UWB monopole antenna with notched band at 3.3–3.7 GHz (WLAN) and 5.15–5.825 GHz (WiMAX) is developed. The antenna is mainly composed of an arc-shaped ground plane, a arc-shaped monopole radiation patch. While the structures for band-notched functions are a T-shape stub in the square-etched radiation patch and a pair of micro-strip lines that start from the ground plane with one of them shorted to the radiation patch at the end. The T-shape stub is to achieve notch-band at 3.3–3.7 GHz and the micro-strip lines are for 5.15–5.825 GHz. The function of the T-shape stub is as a resonator at 3.5 GHz, while the micro-strip lines work as a band-pass filter at 5.5 GHz. In order to illustrate them clearly, the equivalent circuit of these structures are also given and analyzed. To achieve better performances, some key parameters, which affect the notch bands significantly, are specially studied. After the band-notched structures are added, the impedance matching is stirred. To eliminate this, two arc-shape cuts are made symmetrically at the feed point of the radiation patch. Finally, the proposed antenna is designed, fabricated and measured. The simulated and measured results are also compared and discussed, which shows the theoretical analysis and the practice match well. The proposed antenna has stable radiation pattern and good omni-directional performances over the entire operating band, which validates our design concept and theoretical analysis.

This paper mainly consists of four parts. Firstly, the configuration of the proposed antenna is given. Secondly, the equivalent circuits of the antenna are proposed, and some key parameters are studied and discussed. Thirdly, the simulated and measured results are compared and analyzed. Finally, the paper is summarized.

2. ANTENNA DESIGN AND ANALYSIS

2.1. Antenna Configuration

The configuration and geometrical parameters of the proposed antenna are depicted in Figure 1, and its overall dimensions are $30 \times 24\,\mathrm{mm}^2$. The antenna is printed on a 1.2-mm-thick substrate with dielectric constant of 4.4 and loss tangent of 0.02.



(a) (b)

Figure 1. Geometry of proposed antenna. (a) Top side. (b) Bottom side.

It mainly consists of five parts: radiation patch, ground plane, a $50\,\Omega$ micro-strip line with width of 3.6 mm, a T-shape stub and a pair of micro-strip lines. As Figure 1 shows, the edges of radiation patch and ground plane are all arc-shaped, which is to achieve impedance matching over the entire ultra-wideband (UWB). As to realize band-notched characteristics, the radiation patch of original antenna was cut by a rectangle which makes space for the T-shape stub and generate notch-band at 3.3–3.7 GHz. On the other hand, a pair of parallel micro-strip lines is also added to the ground plane with one shorted to the patch at the end, and it is also zoomed in and depicted clearly in Figure 1(b). The micro-strip lines will perform an effect just like a band-pass filter which can only pass frequencies at 5.15–5.825 GHz from the patch to the ground plane.

All the dimension values are given in Table 1, and several of these design parameters will be studied in following discussions. The numerical analysis and geometry refinement of the proposed antenna are performed by using ANSOFT HFSS 13.0.

Table 1. Dimensions of the proposed antenna.

Parameters	L	W	l_0	l_1	l_2	l_3	l_4	w_0
Value (mm)	30	24	16	4	8	0.95	2	3.6
Parameters	w_1	w_2	w_3	w_4	w_5	h	h_0	g
Value (mm)	8	1	1	0.2	0.2	8.6	5.7	0.3
Parameters	R_1	R_2	r	t_0	d			
Value (mm)	31.8	17.4	1.4	1.2	9.5			

2.2. Equivalent Circuit and Analysis

2.2.1. Analysis of the T-shape Stub

As mentioned previously, to achieve a notch-band at 3.3–3.7 GHz, the radiation patch is cut by a square and a T-shape stub is added. Then, part of the cut edge and T-shape stub are united as a resonator at 3.5 GHz. When the proposed antenna operates at 3.5 GHz, the electromagnetic energy is coupled strongly to this resonator. For the radiation is mainly based on the arc-shape edge of the monopole, the energy will have no chance to radiate out when it is coupled to the resonator. As Figure 2 shows, there is a $\lambda/4$ current path near the T-shape stub at 3.5 GHz. The comparison of original antenna with and without T-shape stub is shown in Figure 3.

2.2.2. Analysis of the Pair of Micro-strip Lines

To realize a series LC resonator, one usually uses a $\lambda/4$ open-circuited micro-strip stub, which is fully illustrated in [2]. The stub consists of a part of transmission micro-strip line with electronic length of θ and an open-end quarter wavelength micro-strip line, while the θ and $\lambda/4$ in length corresponds their center operating frequency. The way it works is a quarter wavelength transformer which is opened at the end, but will generate a short path at the connection point. This structure

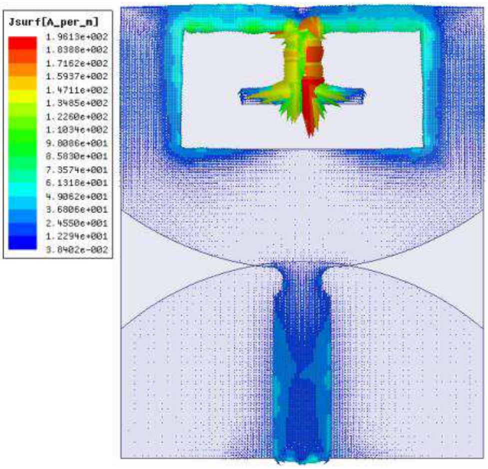


Figure 2. Current path near the T-shape stub.

operates like a band-pass filter which passes frequencies around the center frequency. In this study, the idea of parallel micro-strip lines operate as a band-pass filter is coming from this. When the micro-strip lines are added to the original antenna, the notch-band at 5.15–5.825 GHz is achieved, as Figure 3 shows. The length of a quarter wavelength open-end micro-strip line can be obtain by using equations below,

$$l \approx \frac{c}{4f\sqrt{\varepsilon_{\mathit{eff}}}} \tag{1}$$

$$\varepsilon_{\mathit{eff}} \approx \frac{\varepsilon_r + 1}{2} \tag{2}$$

where c is the speed of light in free space, ε_r the dielectric constant of the substrate, $\varepsilon_{\mathit{eff}}$ the efficiency dielectric constant, and f the center frequency of notched bands. For frequency at 5.5 GHz, the theoretically calculated length of the open-end line is $l \approx 8.3$ mm, while the practical length is 8.65 mm. This indicates that the theoretical and practical values match well, except a little of inaccuracy. The inaccuracy between the theory and the practice mainly comes from the properties of dielectric, which are changing with the frequency.

Notably, when one adds an extra structure to the original antenna, it will break the already matched impedance at some places over the entire band. So in order to achieve better impedance matching, there are lots of work to do after the micro-strip lines, T-shape stub or both of them are added.

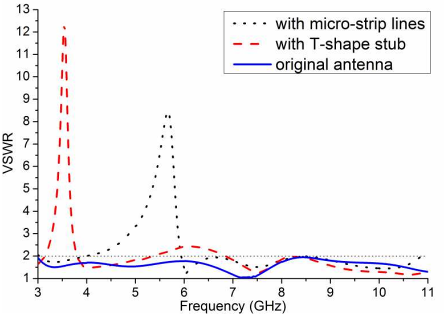


Figure 3. Simulated VSWRs of original antenna with micro-strip lines, T-shape stub and nothing.

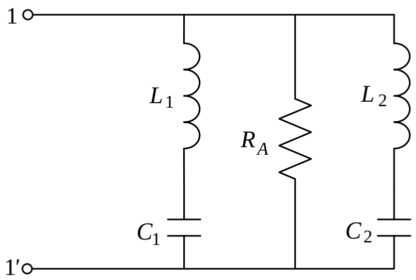


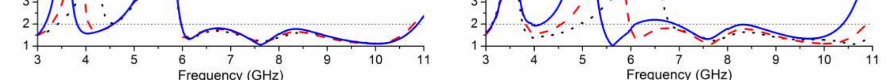
Figure 4. Equivalent circuit of the proposed antenna.

2.2.3. Equivalent Circuit of the Proposed Antenna

When one investigates the proposed antenna from a circuit aspect, both the T-shape stub and the micro-strip lines can be regarded as a kind of series LC resonator. Figure 4 gives the final equivalent circuit of the proposed antenna, and R_A is the radiation resistance of the proposed antenna. The equivalence is based on each structure generating a short path at certain frequency, when one looks into the proposed antenna from feed port.

2.3. Study of Key Parameters

The dimensions of T-shape stub and micro-strip lines are the main factors that influence the notch-band characteristics. So we choose l_2 and h_0 as optimal objects. Figure 5(a) gives the simulated VSWR



(a) (b)

Figure 5. Simulated VSWRs with changing (a) l_2 and (b) h_0.

varied with l_2, and Figure 5(b) is for h_0. From Figure 5(a), one can see that notch-band shifts to higher positions as l_2 decreases. This is mainly due to the reduction of resonate current path which impacts its operating frequency dramatically. With increasing h_0, the center operating frequency of the open-circuited stub will descend, i.e., notch-band shifts to lower frequencies, which is validated by simulated results and shown in Figure 5(b).

2.4. Impedance Matching

When we introduce new structures into the original antenna, they not only generate notch-bands but also affect the antenna's impedance characteristics. And most of the times, they will make it worse. This may be due to the impedance discontinuity between the feed line and the radiation patch, so the way to improve the impedance match is making the impedance change gradually. After many tries, we find the arc-shape cut at the feed point of the radiation patch is a proper choice. The size and positions of the cuts also influence the impedance match which needs a lot of work. So two proper arc-shape cuts are made after the antenna has been notched. The comparison of the notched antennas with and without the arc-shape cut is shown in Figure 6. It shows the impedance match improved as we predicted.

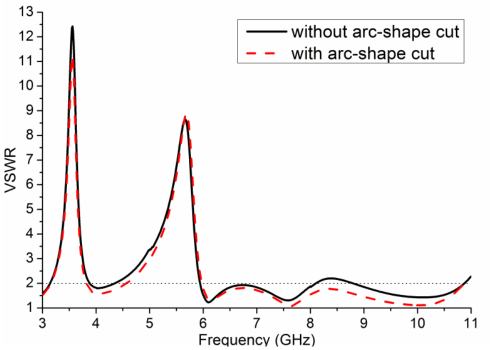
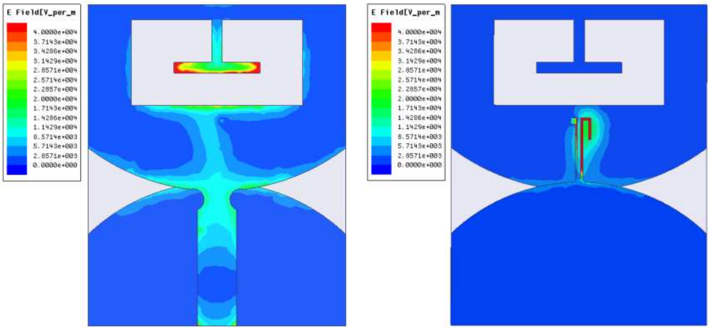


Figure 6. Simulated VSWRs of the notched antenna with and without arc-shape cut.

3. RESULTS AND DISCUSSIONS

Figure 8 shows the surface current distributions of the proposed antenna, Figure 7(a) for 3.5 GHz and Figure 7(b) for 5.5 GHz. It is observed that electromagnetic energy is strongly coupled to the



(a) (b)

Figure 7. Surface current distributions of the proposed antenna. (a) 3.5 GHz. (b) 5.5 GHz.

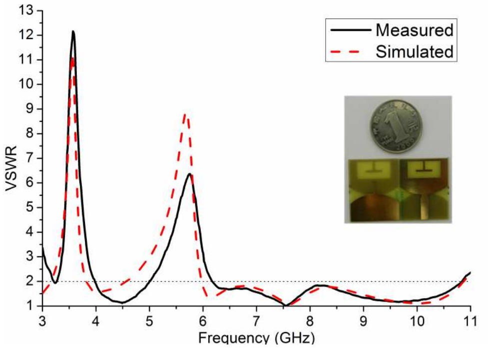
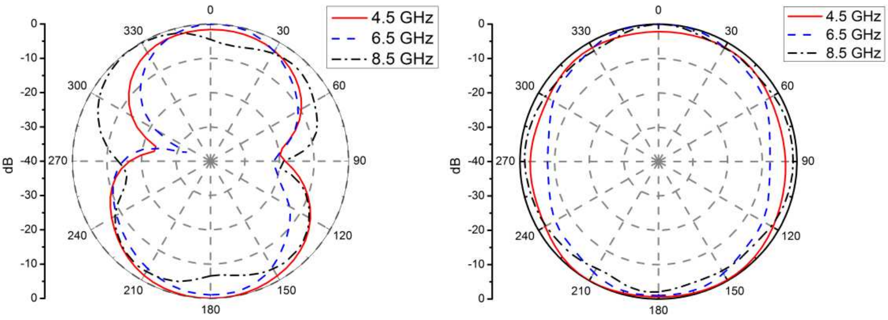


Figure 8. Measured and simulated VSWR of the proposed antenna.

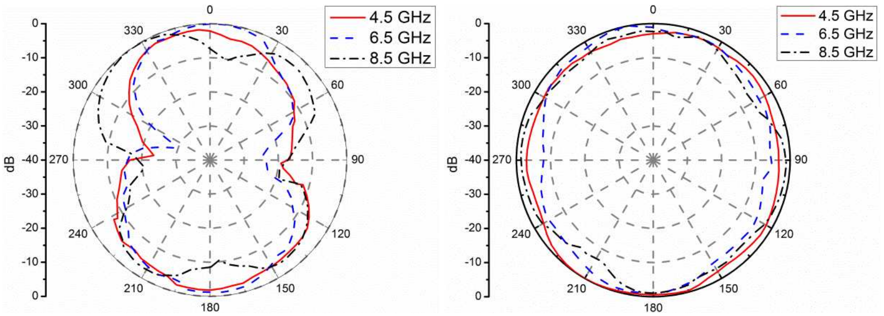
T-shape stub at 3.5 GHz while it is coupled strongly to the micro-strip lines at 5.5 GHz. This indicates that each structure has its own controlled notch-band, and the notch-bands have little interference each other.

According to our design concept and the dimensions given above, the prototype of the proposed antenna is fabricated and measured. The practical voltage standing wave ratio (VSWR) of the proposed antenna is measured with Agilent N5230A vector network analyzer, and compared with the simulated VSWR which is shown in Figure 8. It can be seen that the measured and simulated results match well. And the notch-bands at 3.3–3.7 GHz for WiMAX and 5.15–5.825 GHz for WLAN are achieved by adding T-shape stub and micro-strip lines, respectively, as we discussed previously.



xoz-plane (*E*-plane) *yoz*-plane (*H*-plane)

(a)



xoz-plane (*E*-plane) *yoz*-plane (*H*-plane)

(b)

Figure 9. (a) Simulated and (b) measured radiation patterns at 4.5 GHz, 6.5 GHz and 8.5 GHz.

The radiation patterns of the proposed antenna are also simulated and measured. Figures 9(a) and (b) illustrate both the simulated and measured far-field radiation patterns in xoz-plane (E-plane) and yoz-plane (H-plane). These results are obtained at frequencies of 4.5 GHz, 6.5 GHz and 8.5 GHz, respectively. Figure 9 illustrates that the proposed antenna has good properties of bi-directional radiation patterns in E-plane and omni-directional radiation patterns in H-plane at relative low frequencies. But the distortions occurred at higher frequencies, which may be because the higher frequencies are more sensitive to the antenna structures.

In order to examine the time-domain performances, group-delay of the proposed antenna is measured by placing two identical antenna, face to face at the distance of 30 cm. Figure 10 shows the measured group-delay, and two distortions can be seen at 3.5 GHz and 5.8 GHz.

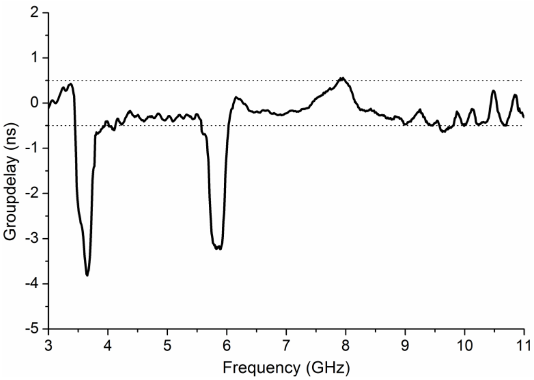
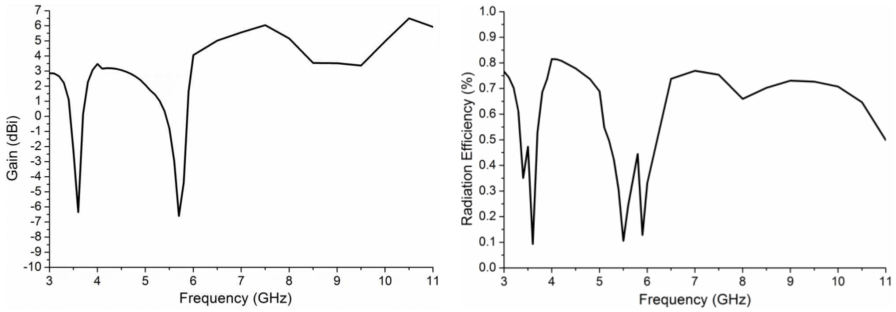


Figure 10. Measured group-delay.



(a) (b)

Figure 11. (a) Measured peak gains. (b) Measured radiation efficiency.

But there are also a few fluctuations at higher frequencies, which may be because higher frequencies are more sensitive to the antenna structures as it occurs in radiation pattern. All these fluctuations are in a range of 1 ns which can cater the time-domain behavior standard. The peak gains and radiation efficiencies are also shown in Figures 11(a) and (b), respectively. As shown obviously in Figure 11(a), two sharp gain reductions are obtained at 3.5 GHz (WiMAX) and 5.5 GHz (WLAN). Correspondingly, the radiation efficiencies in Figure 11(b) also have two notch-bands at 3.5 GHz and 5.5 GHz. For the frequencies outside the notched bands, the gains reach as high as 6.5 dBi.

4. CONCLUSION

A novel UWB antenna with band-notched characteristics is proposed. The design methodology is simply adding a T-shape stub into the radiation patch and a pair of micro-strip lines to the ground plane. Two effective and controllable notched bands are achieved by properly tuning the dimensions of the corresponding parts. Moreover, the existence of notch-band structures has little effect on the antenna. Good agreement is observed between the measured and simulated results, which demonstrates that the proposed antenna is a good candidate for UWB communication systems.

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