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DUAL-BAND PLANAR MONOPOLE ANTENNA FOR BLUETOOTH AND UWB APPLICATIONS WITH WIMAX AND WLAN BAND-NOTCHED

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Abstract—A small-sized, low-cost, and planar integrated Bluetooth and ultrawideband (UWB) monopole antenna with band-notched characteristics in the 3.5 GHz WiMAX and 5.2/5.8 GHz WLAN band is proposed. It is fed by a microstrip line and built on a FR-4 substrate with a whole size of $18 * 30\,\text{mm}^2$. This proposed antenna consists of a slot on the edge of the radiation patch, which not only makes it achieve Bluetooth and UWB performance but also produces a high isolation between them. Additionally, two split rectangular ring resonators (SRRR) are placed close to the microstrip line to reject the WLAN band. Measured S_{11} is $\leq -10\,\text{dB}$ over 2.28–2.52, 3.66–5.02, and 6.05–12 GHz. The group delay characteristic indicates good transient response in the working band. The antenna shows acceptable gain flatness with stable omnidirectional radiation patterns across the integrated Bluetooth and UWB (3.1–10.6 GHz) band.

1. INTRODUCTION

Ultrawideband (UWB) system has attracted both academia and industrial's great attention for its advantage of high date rate (more than 100 Mb/s) over short ranges, large information capacity, low cost and power, etc.. The Federal Communication Commission (FCC) announced to open the permit of 3.1 GHz to 10.6 GHz for UWB application in February, 2002 [1]. Since then, significant UWB researches have been done and reported rapidly. The performance and miniaturization of UWB antennas are main topics which have been studied much in recent years [2–5]. Besides UWB, Bluetooth covering

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the 2.40–2.484 GHz band is used widely in today's portable devices. It is essential to integrate multiple bands for use in one device. The antennas for dual band (Bluetooth and UWB) applications are also mentioned in [6–8], of which the smallest size is $20 * 46\,\mathrm{mm}^2$, still having a request and space to reduce. On the other hand, there are already several other existing communication systems over the UWB band, such as: IEEE 802.11a WLAN system operating at 5.15–5.35 and 5.725–5.825 GHz and IEEE802.16 WiMAX system covering the 3.3–3.6 GHz, which may cause potential electromagnetic interference to the UWB system. Thus, it is desirable to design UWB antennas with band-notched characteristics in those frequencies to ease this problem. Therefore, the UWB antennas with one or dual even triple notched bands are reported in recent years [9–17]. In references [6, 7], the authors designed a dual band antenna, but not filter out the potential interference. In reference [8], the author just notched the 5.2/5.8 GHz WLAN system. So, to design a dual band antenna for Bluetooth and UWB applications with 3.5 GHz WiMAX system and 5.2/5.8 GHz WLAN system notched is necessary.

The traditional way to generate an extra Bluetooth band is to add a strip resonance [6, 7] or design an antenna working at 2.25–10.75 GHz and filters out the unnecessary band between the Bluetooth and UWB band [8]. In this design, a new method etching a slot on the current route is adopted to engender the Bluetooth band. It is well known that the notched band can be achieved by etching slots of quarter-wavelength or half-wavelength corresponding to the designed notched frequencies [12–16]. In [18], the author etched a slot on the radiator to increase the effective current route, thus reducing the overall size of the antenna at the same required lower frequency. In [20], the author etched a slot on the Vivaldi antenna to produce a pass band. It means one slot should homologize to one notched band or pass band. In this design, a slot is etched on the appropriate current route, it acquires a notched band, introduces another current route to obtain a new frequency band.

In order to study the above hypothesis, this paper proposes a small-sized planar monopole antenna that covers both the Bluetooth and UWB band with WiMAX and WLAN band-notched. A slot is etched on the current route, which produces a 2.28–2.52 GHz Bluetooth band and a high isolation between the Bluetooth and UWB band. The 3.3–3.6 GHz band for WiMAX is also notched. The desired notched band frequencies can be easily achieved by adjusting the total length of the embedding slot. Moreover, by changing the widths and locations of the slot, the notched bandwidths can be efficiently controlled. To realize a notch at the center frequency of the 5.5 GHz WLAN band,

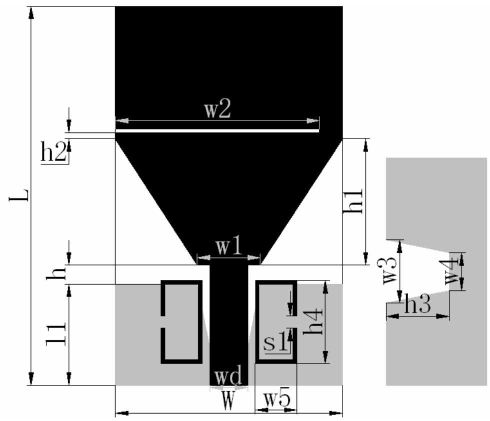


Figure 1. The geometry of the proposed antenna.

two symmetrical split rectangular ring resonators (SRRR) are built to couple with microstrip line. The proposed antenna is smaller in size compared to the antenna reported in [6–8]. Details of the antenna design, simulated and measured results are discussed below.

2. ANTENNA DESIGN AND DISCUSSION

2.1. Structure of the Antenna

In order to miniaturize the size of the antenna for the application of the portable devices, we propose a planar monopole structure with a microstrip feed line. Figure 1 shows the geometry of the proposed antenna. This antenna is built on a FR-4 substrate with a relative permittivity of $\varepsilon_r = 4.4$ and a loss tangent of 0.02. The transverse dimension of this antenna is $18 * 30\,\text{mm}^2$. This antenna provides dual-band operation due to the slot etched on the edge of the radiation patch. This slot expands the bandwidth and at the same time produces a notched band to prevent the interference between the Bluetooth and UWB band. Two symmetrical split rectangular ring resonators (SRRR) are built to make the WLAN band notched. A trapezoid section has been etched on the ground plane to match the radiation patch's resistance with the microstrip feed line.

The optimal parameters of the proposed antenna are shown in Table 1. The width of the slot is $d = 0.1\,\text{mm}$, the width of the SRRR is $ds = 0.3\,\text{mm}$, and the distance between the SRRR and microstrip feed line is $ws = 0.4\,\text{mm}$.

Table 1. Parameters of the proposed antenna (see Figure 1).

Parameter	W	$w1$	$w2$	$w3$	$w4$	$w5$	wd	L
Value (mm)	18	5	16.5	5	3	3.3	3	30
Parameter	$l1$	h	$h1$	$h2$	$h3$	$h4$	$s1$	-
Value (mm)	8	1.5	10	0.5	5	6.6	1	-

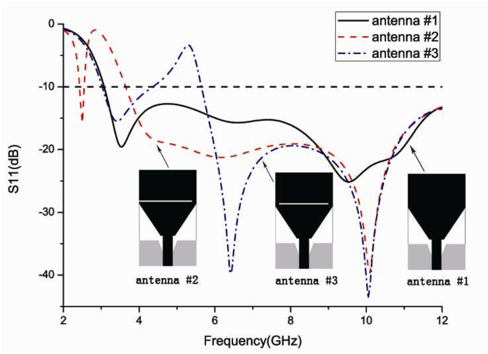


Figure 2. Simulated reflection coefficients of the three antennas.

2.2. Design of the Antenna

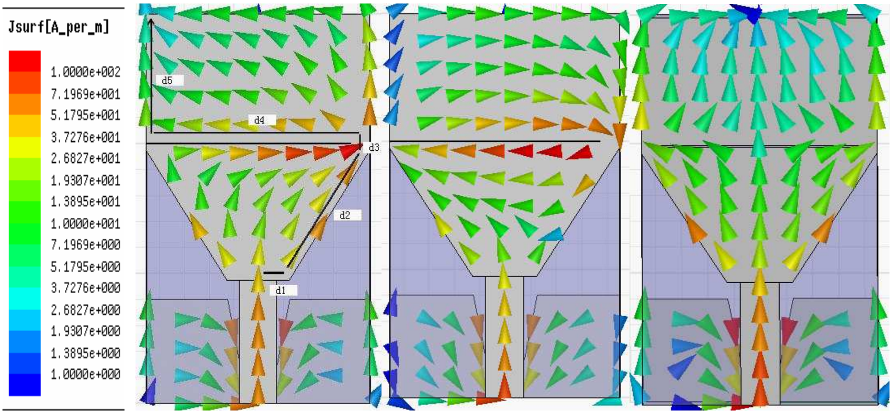
2.2.1. Design of Antenna for Bluetooth and UWB Applications

According to the substrate's relative dielectric constant $\varepsilon_r = 4.4$ and thickness $hs = 1.6\,\text{mm}$, we can calculate the required width $wd = 3\,\text{mm}$ of the microstrip feed line for a characteristic impedance of $50\,\Omega$, and this is used as the starting point of our design.

The next step is to calculate the dimensions of the radiation patch. The lowest frequency of the antenna f_l can be obtained approximately by [2]:

$$f_l = \frac{0.25 \times 300}{h + h_1 + (W + w1)/4\pi} \tag{1}$$

The key to this design is to etch a slot on the edge of the radiation patch. In [21], the authors explain the theory of generating a notched band. Since then, a variety of slots have been etched on the radiation patch to notch out the unnecessary bands [12–16]. According to the theory, the lowest resonant frequency f_l, of a planar monopole antenna in its symmetrical and basic form can be estimated by the longest effective current path $L = \lambda_l/2$, where λ_l is the wavelength at f_l [18, 19]. We supposed that if the slot is etched on the appropriate



(a) (b) (c)

Figure 3. The current distribution of the antennas. (a) Antenna #2 at 2.4 GHz. (b) Antenna #2 at 2.8 GHz. (c) Antenna #3 at 2.4 GHz.

position, it can create a notched band and an extra pass band simultaneously. This has been validated by simulated and measured results shown in Figures 2 and 7(b). This also can be explained by Figures 3(a) and (c), in which the introducing of the slot on the edge changes the current route. Figure 3(b) shows that the current mainly centralizes on the notch. From the electric current distribution on the antenna at the lower frequency at 2.4 GHz, the whole length of the electric current path is $d1 + d2 + d3 + d4 + d5 = 41.5\,\text{mm}$. Thus, f_l ($= c/\lambda_l$ where λ_l can be calculated by Equation (2) and c is the speed of light) is 2.2 GHz. The simulated result is 2.39 GHz and the measured result is 2.28 GHz.

$$\lambda_l = 2L\sqrt{(\varepsilon_r + 1/2)} \tag{2}$$

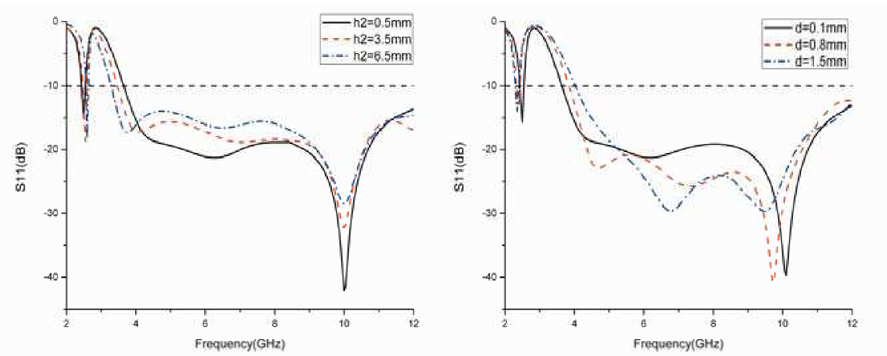
The length of the slot can be obtained by:

$$l = \frac{c}{4f_{\text{center}} \cdot \sqrt{\varepsilon_{eff}}} \tag{3}$$

where f_{center} is the central frequency of the notched band; ε_{eff} is the effective dielectric constant; c is the speed of light. We can use Equation (3) to predict the length of the slot, then, optimize the parameter l with full wave simulation.

The band of 3.1–3.3 GHz can be negligible compared to the whole UWB band. To miniaturize the complex of the antenna and reduce the potential interferences between UWB and WiMAX system, the bandwidth of 2.5–3.6 GHz is suggested to be filtered out. The characteristics of three designs, namely without slot (antenna #1), with slot at the edge of the radiation patch (antenna #2) and with slot in the middle of the radiation patch (antenna #3), are compared to understand the function of the slot in the design. In order to examine the effect of the slot on the impedance matching, the return loss of the antennas are simulated and compared in Figure 2. The simulated results are carried out by EM software Ansoft HFSS V12. It can be seen that antenna #1 is only able to achieve a lower edge frequency of 3.05 GHz, while the antenna #2 can achieve a lower edge frequency of 2.39 GHz and produce a notched band from 2.56–3.61 GHz. The maximum value of S_{11} at this bandwidth is -0.94 dB. It is clear that the slot on the right position not only reduces the effect of the ground plane on the antenna's performance but also achieves a high isolation dual-band antenna. And the antenna #3 is also presented to accentuate the importance of the slot in the right position. It can achieve a lower edge of 3.01 GHz and generate a notched band at 4.36–5.66 GHz.

The performance of the dual-band antenna is mainly affected by two parameters: height ($h2$) on the radiation patch and width (d) of the slot. Figure 4 depicts the simulated reflection coefficient of the antenna with different $h2$ and d. Figure 4(a) shows that with the slot's height on the radiation patch increased, the performance of the notched band becomes worse and the bandwidth also decreases. In Figure 4(b), increasing the width of the slot makes the performance of the notched band better (the maximum value of S_{11} at notched center frequency increases). However, the bandwidth of the notched band also increases, which can misappropriate the useful information of the UWB band. To satisfy the bandwidth requirement and performance



(a) (b)

Figure 4. Simulated reflection coefficients of the antenna with slot. (a) With different $h2$. (b) With different d.

of the notched band simultaneously, $h2 = 0.5\,\text{mm}$ and $d = 0.1\,\text{mm}$ are chosen.

2.2.2. Design of Antenna for Bluetooth and UWB Applications with WLAN Band Notched

To reject the probable interference of the WLAN system, two symmetrical split rectangular ring resonators (SRRR) are built to couple with the microstrip feed line. In Reference [8], the author once used one SRRR coupled with the microstrip feed line to achieve good performance of notched band. However, when one SRRR is used on this antenna, the performance of the notched band is bad,

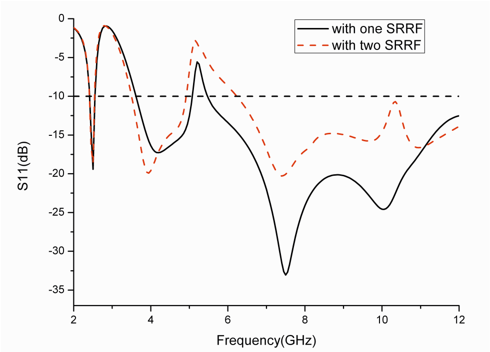


Figure 5. Simulated reflection coefficients of the antenna with one and two SRRRs.

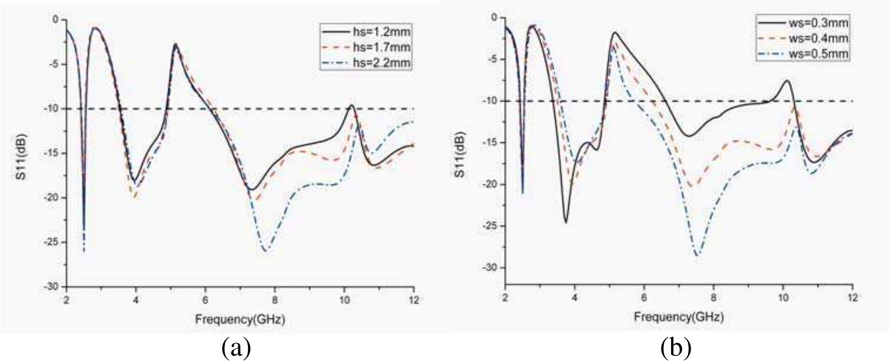
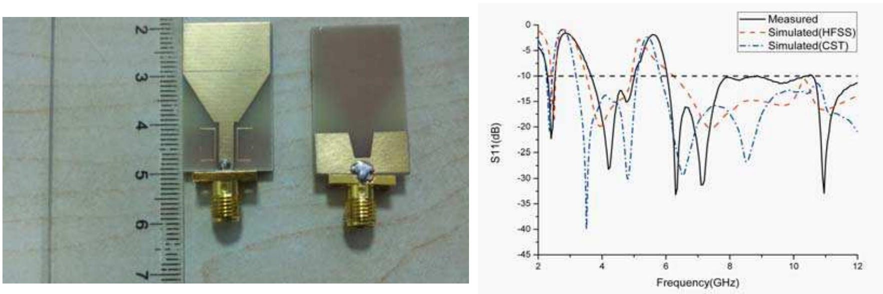


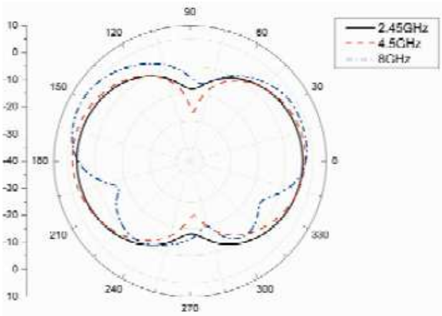
Figure 6. Simulated reflection coefficients of the antenna with two SRRRs. (a) With different hs. (b) With different ws.



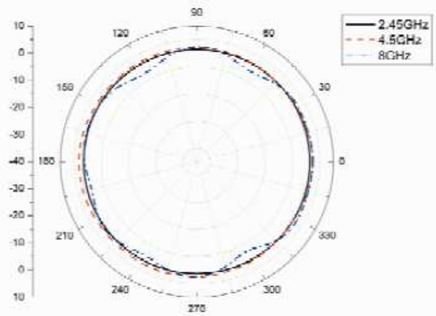
(a) (b)

Figure 7. (a) Photograph of the proposed antenna. (b) Measured and simulated return loss of the proposed antenna.

as it is shown in Figure 5. In Reference [12], the author provided a new way that was using two sets of compound structures to enhance the performance of the notched band. So two symmetrical SRRRs are adopted in this design. It can be seen from Figure 5 that the performance of the notched band is improved obviously. The size of the SRRR is 3.3 mm $*$ 6.6 mm with a 1 mm split, and the width of the ring is 0.3 mm. The S parameter at the center frequency of the notched band increases from -5.5 dB to -2.5 dB and the bandwidth increases from 5.06–5.45 GHz to 4.92–6.20 GHz. It is seen clearly from Figure 6(a) that the distance between the SRRR and the bottom of the antenna has a little effect on the performance of the notched band, but the performance of the high frequency is significantly influenced. Too short distance can make the high frequency performance worse. Figure 6(b) shows that with SRRRs away from the microstrip feed line, the performance of the notched band declines and the bandwidth also reduces. When the SRRRs are too close to the microstrip feed line, they can affect the impedance matching of the antenna that makes the bandwidth of the first notched band decrease and the high frequency impedance mismatched. Note that when the band-notched designs are applied to the antenna, there is no retuning work required for the previously determined dimensions of the antenna. To make a balance between the first and the second notched band, $hs = 1.7$ mm and $ws = 0.4$ mm are selected. The cases for many other dimensions are also investigated but not included in Figure 6 for simplicity.



(a)



(b)

Figure 8. Simulated radiation pattern of the proposed antenna at 2.45, 4.5, and 8 GHz. (a) E-plane. (b) H-plane.

3. RESULTS AND DISCUSSIONS

The antenna for dual band Bluetooth and UWB applications with 3.5 GHz WiMAX and 5.2/5.8 GHz WLAN band notched are fabricated and measured using Agilent E8363B vector network analyzer (VNA). The photograph of the fabricated antenna is shown in Figure 7(a). The measured and simulated reflection coefficients of the antenna are plotted in Figure 7(b). The simulated bandwidth is 2.39–2.53 and 3.5–12 GHz except for 4.9–6.22 GHz, and the measured result is 2.28–2.52 and 3.66–11 GHz except for 5.02–6.05 GHz. The simulated notched bands' center frequencies are 2.8 and 5.15 GHz, and the maximum values of S_{11} are -0.9 and -2.5 dB. The measured notched bands' center frequencies are 2.85 and 5.6 GHz, and the maximum values of S_{11} are -1.6 and -1.9 dB. That means the notched bands have high efficiency to filter out the unwanted bandwidth. The measurements and simulations match well. Due to the fabrication accuracy, the second resonant frequency is shifted a little. The dielectric constant and dissipation factor are not stable with frequency increasing, so there are some differences between simulations and measurements in high frequency.

The Simulated E-plane (YOZ) and H-plane (XOZ) radiation pattern at 2.45, 4.5, and 8 GHz are normalized and plotted in Figure 8. It can be seen that the proposed antenna has monopole-like patterns in the E-plane and almost omnidirectional radiation patterns in the H-plane. It is noticed that the omnidirectivity of the H-plane radiation patterns is generally good but will be deteriorated when in high frequency. The peak gain and efficiency of the antenna are shown in Figure 9. Sharp gain and efficiency decrease occur when it operates

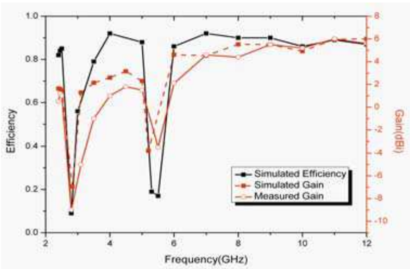


Figure 9. Peak gain and efficiency of the antenna.

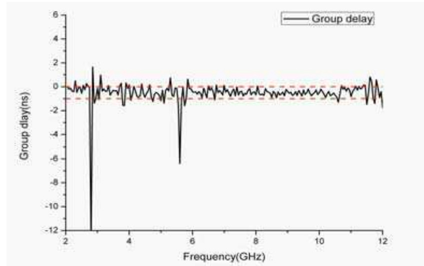


Figure 10. Measured group delay.

in the designed rejected-band as expected, which indicates the high efficiency of the notched bands clearly. The difference between the simulated and measured gain is caused by the indoor measurement environment and the effect of the SMA connector.

Furthermore, the group delay of the antenna is also measured and discussed. The two antennas are connected to the two ports of the vector network analyzer indoors and they are placed face to face with a distance of 30 cm. The measured group delay of the proposed antenna is presented in Figure 10. It can be seen that the variation of the group delay is almost within 1 ns across the working band except 12 ns at 2.8 GHz and 6.2 ns at 5.6 GHz. It confirms that the proposed antenna exhibits phase linearity at desired UWB frequencies.

4. CONCLUSION

In this paper, a novel dual band antenna for Bluetooth and UWB applications with 3.5 GHz WiMAX and 5.2/5.8 GHz WLAN bands notched is proposed and investigated. The antenna can operate in the 2.28–2.52, 3.66–5.02, and 6.05–12 GHz. The interference of WLAN & WiMAX can be reduced. The realized methodologies are by etching a slot on the current route and placing two symmetrical split rectangular ring resonators (SRRR) to couple with microstrip feed line, respectively. The slot not only produces a 2.28–2.52 GHz Bluetooth band but also notches out the unnecessary band between the Bluetooth and UWB band with high efficiency. The omnidirectional radiation patterns are very stable across the Bluetooth and UWB band. The group delay is less than 1 ns in the working band, which indicates that the proposed antenna is suitable for Bluetooth and UWB applications.

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