A Dual-band WLAN Antenna with Reactive Loading

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Abstract **─** Dual-band antenna is very essential for multiple band communication systems like wireless local area network (WLAN) with lower and upper operating bands. In this paper, a dual-band antenna is proposed and analyzed for the WLAN applications. The proposed antenna fed by coplanar waveguide (CPW) consists of an L-shaped, reversed L-shaped strips and two inverted U-shaped loadings that are to implement the reactive characteristics. The reactive loadings can adjust the bandwidth and performance of the dual-frequency WLAN antenna that is verified by the simulation and measurement, respectively. The results demonstrate that the -10dB impedance bandwidth of the proposed dual-band antenna can cover the two WLAN frequency bands from 2.4 GHz to 2.484 GHz and from 5.15 GHz to 5.35 GHz, respectively. Moreover, the proposed antenna has omnidirectional radiation patterns at the two operating bands.

Index Terms **─** Dual-band, reactive loading, WLAN.

I. INTRODUCTION

With the increasing contribution and growing of wireless communication technology, more and more communication systems are created for various purpose. To meet these requirements, the modern communication systems are constructed to support more than one frequency band such as mobile communication and the wireless local area network (WLAN) communication systems. Thus, single-band antenna cannot be able to satisfy the requirement of the modern wireless communication system with more than one operating band. As a straightforward approach to solve these problems, dual-band antenna has been widely developed and considered for different purpose application for various terminals, which can reduce the cost of design and enhance the performance of the entire communication system [1].

A dual-band wireless communication system like WLAN has attracted more and more attention for researchers to study due to its high date transmission rate in short and mobility areas [2, 3]. Furthermore, the WLAN system has been used for a long time, which operates at two frequency band to meet the application according to the IEEE 802.11 a/b/g/n/ac standards. Thus, it is vital for us to design a dual-band WLAN antenna.

So far, many dual-band WLAN antennas have been proposed. Generally, the previous designed dual-band WLAN antennas are realized by carving slots or adding the parasitic branches to achieve dual-band characteristics. In [4-11], dual-band slots antennas are reported and investigated. In [12-19], the dual-band antennas are designed using parasitic branches. However, some of these antennas are large or other antennas are complex in structure. In [20], a compact asymmetric coplanar strip-fed dual-band antenna for 2.4/5.8 GHz WLAN applications is proposed and measured. Two loaded capacitance terminations are utilized to reduce the size of the antenna. But the structure of the proposed antenna is too complex, and the gain is very low.

In this paper, a dual-band antenna with reactive loading for WLAN applications is proposed and investigated by using simulation and measurement. The proposed antenna fed by coplanar waveguide (CPW) is composed of an L-shaped, reversed L-shaped strips and two inverted U-shaped branches. Two inverted U-shaped branches are loaded to the L-shaped, reversed L-shaped strips to form the coupling capacitors to reduce the size of the WLAN antenna. The coupling capacitor depends on the gap between the inverted U-shaped branches and the L-shaped or the reversed L-shaped strip. By adjusting the gap and the length of the U-shaped branches, the operating band can be flexibly controlled. The results present that the dual-band antenna can operate at 2.43

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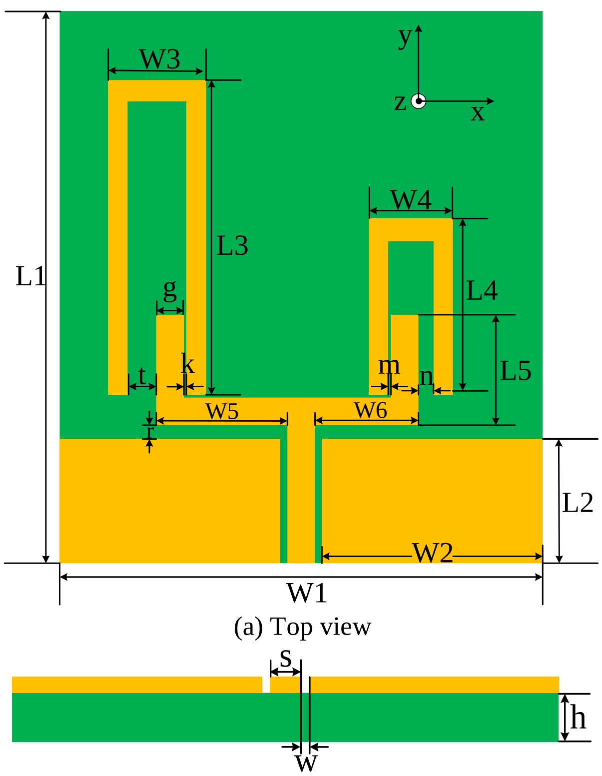
GHz with the bandwidth from 2.36 GHz to 2.5 GHz and 5.25 GHz with the bandwidth from 5.15 GHz to 5.35 GHz, which can cover the WLAN frequency bands. Moreover, the proposed antenna has omnidirectional radiation patterns at the two operating bands with simple and adjustable structure.

II. DESIGN OF THE PROPOSED DUAL-BAND WLAN ANTENNA

The geometry of the proposed antenna is described in Fig. 1, which is printed on a dielectric substrate with a relative permittivity of 4.4, a loss tangent of 0.02 and a thickness of h=1.6 mm. The designed dual-band WLAN antenna is fed by the CPW. The width of the feeding line and the gap between the feeding line and the ground can be calculated by the tool of coplanar waveguide calculation. From the calculation, the width s and the gap w are obtained and designed to be 1.4 mm and 0.3 mm, respectively.



(a) Top view

(b) Side view

Fig. 1 Geometry structure of the proposed antenna.

To get the good impedance matching, the length L2 of the ground plane and the width of the L-shaped or the reversed L-shaped branch can be properly adjusted. In addition, the parameter r is also providing an important effect on the designed antenna. Thus, the performance can be adjusted by controlling the dimensions of the antenna for the lower and upper WLAN bands.

To better understand the principle of the designed dual-band antenna operating at the two WLAN bands, the equivalent circuit for each inverted U-shaped reactive loadings are given in the Fig. 2.

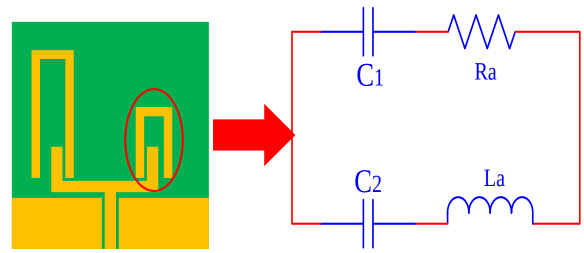


Fig. 2. Equivalent circuit of inverted U-shaped reactive loading.

The equivalent circuit of each inverted U-shaped reactive loading consists of two capacitors C1 and C2, an inductor La and a resistor Ra. Therefore, the resonance center frequency f can be calculated by considering the equivalent circuit, which is presented in formula (1) and (2):

$$2\pi f L_a = \frac{1}{2\pi f C_1} + \frac{1}{2\pi f C_2}, \tag{1}$$

where

$$f = \frac{1}{2\pi}\sqrt{\frac{1}{L_a}\left(\frac{1}{C_1} + \frac{1}{C_2}\right)}. \tag{2}$$

Thus, each frequency band of the designed antenna can be obtained by adjusting the La, C1 and C2. The values of C1 and C2 are depended on the coupling between the L-shaped or reversed L-shaped strip and the reactive loadings, namely the parameters L5, t, k, m, n. The value of La is obtained by the length of the strips and of the U-shaped loadings. In this design, the gaps between the (inverted) L-shaped strip and the loading can be regarded as equivalent capacitors, while the total effective length of the (inverted) L-shaped strip and the loading can be regarded as equivalent inductor. The dimensions of the devised antenna are obtained using the HFSS and are given in Table 1.

Table 1: Dimensions of the dual-band WLAN antenna (Unit: mm)

Parameters	W1	W2	W3	W4	W5	W6
Values	26	12	5.05	4.26	5.4	4.9
Parameters	r	g	m	n	t	k
Values	0.6	1.4	0.16	0.7	1.5	0.15
Parameters	L1	L2	L3	L4	L5	
Values	30	8	16.34	7.54	5	

Finally, the designed dual-band antenna can operate at the interested frequency bands by the optimization of these dimensions, where the optimized dimensions are listed in the Table 1.

III. ANALYSISES AND EXPERIMENTAL RESULTS

The proposed dual-band WLAN antenna is analyzed based on the HFSS. To verify the analysis effectiveness, the designed dual-band WLAN antenna is fabricated and measured. The fabricated dual-band WLAN antenna is given in Fig. 3. The comparison of the simulated and measured reflection coefficients (S11s) is demonstrated in Fig. 4, where the measured S11 is obtained by using the Keysight PNA-X Microwave Network Analyzer N5244A.

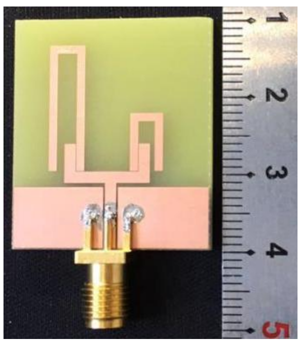


Fig. 3. Photograph of the fabricated dual-band WLAN antenna.

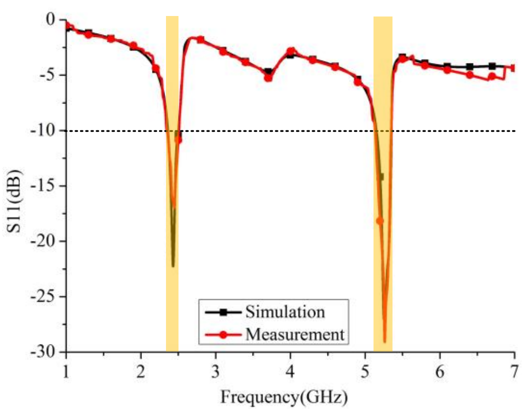
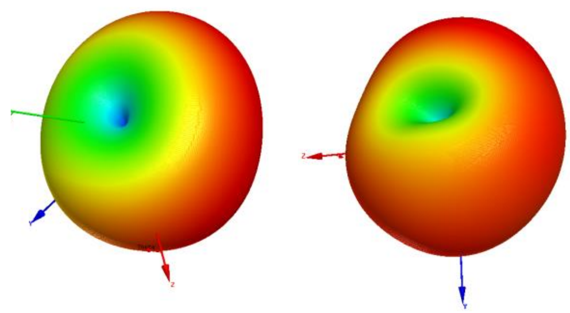


Fig. 4. S11 of the proposed dual-band antenna.

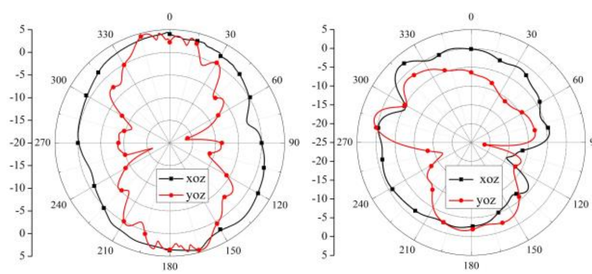
From Fig. 4, we can see that the dual-band antenna can operate well at the desired two frequency bands for WLAN applications. The lower band operates at 2.43 GHz with a -10dB impedance bandwidth of 140 MHz ranging from 2.36 GHz to 2.5 GHz to cover 2.4 GHz WLAN, and the upper band operates at 5.25 GHz with -10dB impedance bandwidth of 200 MHz ranging from 5.15 GHz to 5.35 GHz for serving for 5.25 GHz WLAN. The measurement result agrees well with the simulated S11, which helps to verify the effectiveness of the simulations. The discrepancies may be caused by the stability of the FR4 substrate, fabrication error and the soldering in the experiments. The 3D radiation patterns of the proposed dual-band antenna are presented in Fig. 5, while the measured radiation patterns of the proposed dual-band antenna are shown in Fig. 6. It can be found the designed antenna has omnidirectional radiation patterns at 2.43 GHz and 5.25 GHz.

For better understanding, the principle behind the designed dual-band antenna, the current distribution at 2.43 GHz and 5.25 GHz is given in Fig. 7. At 2.43 GHz, the current distribution focuses on the CPW signal feeding line, ground plane and the left U-shaped reactive loading, while the current distribution on the right reactive loading is very small. When the designed antenna operates at 5.25 GHz, the current distributed on the CPW structure and the right U-shaped reactive loading. From the current distributions, we can also see that the current distributions at the lower and upper bands are from different reactive loading, which is also depending on the resonance length of the two current paths.



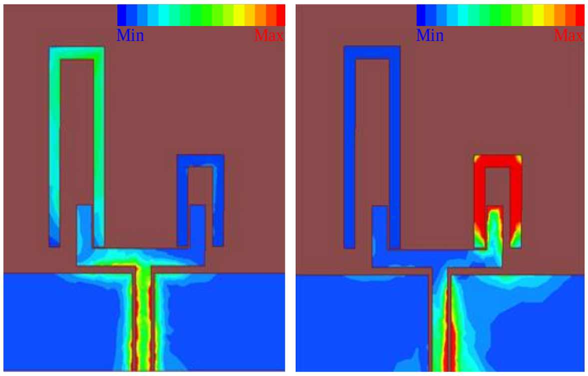
(a) 2.43 GHz (b) 5.25 GHz

Fig. 5. The simulated 3D radiation patterns of the proposed dual-band antenna.



(a) 2.43 GHz (b) 5.25 GHz

Fig. 6. The measurement radiation patterns of the proposed dual-band antenna.



(a) 2.43 GHz (b) 5.25 GHz

Fig. 7. The current distribution of the proposed dual-band antenna.

To investigate the effects of the dimensions, the two key parameters L3 and L4 are selected to discuss their center controlling for the two frequency bands. Figure 8 demonstrates the effect of L3 on the impedance bandwidth of the proposed dual-band WLAN antenna. It is found that the center resonance frequency at lower band shifts to low frequency when we increase L3, while the resonance frequency of upper band is almost unchanged. Figure 9 shows the effect of L4 on the S11 of the proposed dual-band antenna. It can be concluded that the resonance frequency of upper band moves towards to low frequency with the increasing L4, while the resonance frequency at lower band is almost fixed.

In fact, it is easy to explain the effect of L3 and L4 on the center resonance frequency of the proposed dual-band antenna by using the formula (2). When the length of L3 and L4 are adjusted, the inductor La will be changed, while the capacitors C1 and C2 are unchanged because of the weak coupling. Hence, the center resonance frequency can be controlled by choosing the length of L3 and L4.

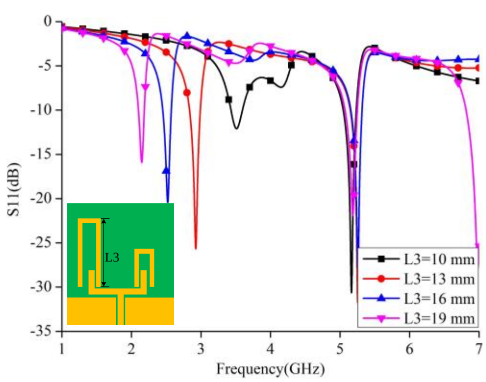


Fig. 8. Effect of L3 on the impedance of the proposed dual-band antenna.

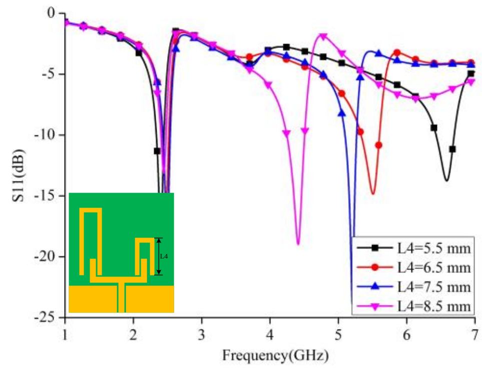


Fig. 9. Effect of L4 on the impedance of the proposed dual-band antenna.

The gain and the radiation efficiency are also essential for an antenna, which have been measured and presented in Table 2. The gain and the radiation efficiency measured are 4.95 dBi, 66% and 2.73 dBi, 72% at 2.43 GHz and 5.25 GHz respectively as shown in the Table 2. In order to know the advantage of the proposed dual-band antenna, we compare the proposed dual-band WLAN antenna and the previously reported dual-band WLAN antennas. The comparison for the resonance frequencies, size and gains of these antenna is presented in Table 3. From the above discussions, we can see that the proposed antenna can cover the lower WLAN band and 5.25 GHz WLAN band.

Table 2: The performance of the designed dual-band antenna

Size (mm^2)	26×30	
Resonant Frequency (GHz)	2.43	5.25
Bandwidth (MHz)	140	200
Gain (dBi)	4.95	2.73
Efficiency	66%	72%

Table 3: Comparison of the proposed antenna and the early reported antennas

	Resonant Frequency (GHz)	Size (mm^2)	Gain (dBi)
[5]	2.4 and 5.56	40×40	1.5 and 4
[21]	2.4 and 5.2	30×50	1.9 and 4.3
[22]	2.4 and 5.2	64.5×75	1.6 and 2.1
[23]	2.45 and 5.24	48×16	2.39 and 1.77
[24]	2.4 and 5.2	45×35	2.24 and 3.87
This work	2.43 and 5.25	26×30	4.95 and 2.73

From Table 3, we found that the proposed antenna has the smallest size, two resonance frequencies, good gains, making the developed antenna suitable for WLAN applications. In addition, the proposed antenna has a radiation efficiency of 66% and 72% at the lower and upper bands.

IV. CONCLUSION

In this paper, a dual-band WLAN antenna is proposed, and its performance is analyzed and discussed in detail. The antenna operates at 2.43 GHz with a bandwidth of 140 MHz and 5.25 GHz with bandwidth of 200 MHz, which can cover WLAN band. The proposed antenna is simulated, optimized, fabricated and measured, the proposed antenna has two resonance frequencies, good omnidirectional radiation patterns and gains. Additionally, the proposed antenna has a compact size which can be integrated into a terminal device. In the future, the antenna can be easily developed to be a reconfigurable antenna. Moreover, we will design dual-band MIMO antenna to reduce the coupling between the closely set antenna elements [25-35].

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