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A DUAL-BAND OMNI-DIRECTIONAL MICROSTRIP ANTENNA

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Abstract—Omni-directional antennas are useful for variety of wireless communication devices as well as capable of handling the additional different frequency bands since the radiation pattern allows good transmission and reception from a mobile unit. However, to implement the two frequencies on a single antenna with wide bandwidth can be significant because of the presence of mutual coupling and interference effects between the two radiating elements. In this paper, a novel method of combining dual-band frequencies onto a single layer board with wide bandwidth is described. A dual-band printed dipole antenna is designed in this study by combining a rectangular and two "*L*" shaped radiating elements and are embedded on a single layer structure with relatively small size. The obtained results show that the proposed dual-band omni-directional microstrip antenna achieves high antenna efficiency and provides better bandwidth while maintaining the structural compact size.

1. INTRODUCTION

Wireless Local Area Network (WLAN) application provides communication between a Local Area Network (LAN) and a client device. According to the IEEE standard for WLAN, the network works at

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low band (2.4 GHz to 2.5 GHz) and high band (4.9 GHz to 5.875 GHz). Therefore, the antenna provided from WLAN must work in these frequencies. One antenna that can work in these frequencies is more efficient than having many antennas for each frequency band. There are many devices that require the implementation of the dual-band wireless antenna. An example of internet service that utilizes the use of dual-band networks is Wi-Fi. If a computer has a wireless card, it is most likely Wi-Fi compatible, where wireless card transmits to a wireless router, which is connected to a network, cable modem or DSL modem. Several printed antennas for WLAN applications have been reported in [1–15].

A dual dipole structure, with short element providing resonance at upper frequency band in parallel with a long element resonating at a lower frequency band, is presented for WLAN 2.4/5 GHz application in [1]. Insufficient bandwidth to cover all the cellular bands is however obtained, and no dual-band (or wideband) characteristic is achieved. The measured bandwidth in [1] at the lower and upper frequency bands are 9.3% and 5.1%, respectively, which is insufficient for the targeted applications in this study. In [6], the author proposes the use of a spiraled dipole structure as a compact dual-band WLAN 2.4/5.8 GHz antenna, including a tapered feature. However, the bandwidth is too narrow (17% and 10% at 2.4 GHz and 5.8 GHz, respectively) to cover all the WLAN bands, and the radiation pattern exhibits two extra deep nulls compared to a standard dipole. According to the theoretical investigation, the total effective length of radiating arms is usually as half as that of the operating wavelength. Therefore, reducing the size of the dipole antenna is significant for the practical WLAN applications.

In this paper, a new method of combining dual-band frequencies onto a single layer board with wide bandwidth is presented. The slots between radiating elements are employed in this study to achieve the dual-band effect and the wide bandwidth. By optimizing the radiating element with tapering feature, the printed dipole antenna covering 2400–2500 MHz and 4900–5875 MHz can completely support two standards of IEEE for WLAN. The proposed concept has been demonstrated with an implementation on low-cost FR-4 (Flame Resistant) substrate that covers 2400–2500 MHz and 4900–5875 MHz frequency bands. This study addresses the issue of bandwidth enhancement for a single-sided printed dipole antenna. The proposed antenna has the advantage of being inherently capable of larger bandwidth as well as occupying less area in the substrate. Design details of the radiating elements together with the measured and the simulated results are provided in the subsequent sections. Finally, a conclusion is presented at the end of the paper.

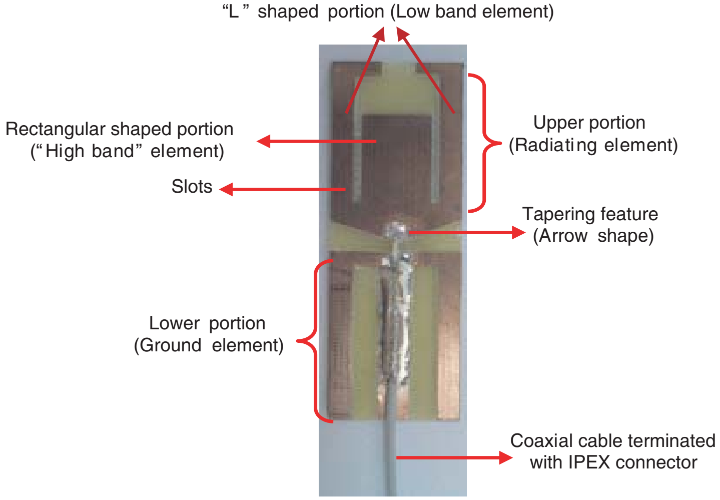
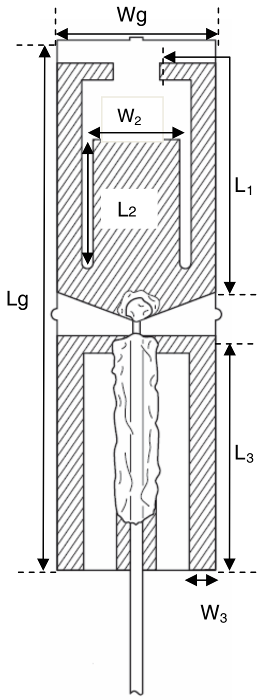


Figure 1. The proposed antenna design.

2. ANTENNA DESIGN

The upper portion as shown in Figure 1 consists of both high band and low band radiating elements, where the high band element consists of a rectangular shape that is connected to the tapering feature, such that the rectangular and tapering feature cooperatively define an arrow shape. The low band radiating element includes two "*L*" shaped separated portions and spaced apart from the rectangular portion of the "high band" radiating element by the slot portions. By adjusting the length and the width for each radiating element, the resonant frequency can be controlled. The lower portion of the antenna operates as a ground element, which permits the antenna to be ground independent. Thus, the antenna does not depend on a separate ground element or ground plane. This includes three elements, which comprise two outer radiating elements with ground element disposed between the two radiating elements. The elements are generally parallel with each other and extended perpendicular in a same direction.

Figure 2 shows the embodiment of an omni-directional dual-band antenna, which includes the upper and lower portions such that the antenna is operable to a standard half wavelength dipole antenna at a first frequency range (2.4 GHz to 2.5 GHz) with the upper and lower portions each of having an electrical length of about $\lambda/4$, where λ is the resonant frequency. At a second frequency range or high band (4.9 GHz to 5.875 GHz), the antenna is operable essentially to a



Geometry	Parameter	Size
"L" Shaped Element	L_1	29 mm
Rectangular Shaped Element	L_2	12.5 mm
	W_2	8.8 mm
Ground Element	L_3	24 mm
	W_3	3 mm
Overall Length	L_g	51 mm
Overall Width	W_g	16 mm

Figure 2. Geometry and dimension of the proposed antenna.

wavelength dipole antenna with the upper and lower portions each of having an electrical length of about $\lambda/2$. As presented in the figure, the antenna structure consists of two conductive portions, first is the radiating element (upper portion) and second is the ground element (lower portion). The geometry of the proposed antenna occupies a volume of 51 mm × 16 mm, which mainly consists of two radiating arms and a rectangular element in between that is connected to the tapering feature.

The antenna is fabricated onto a single-sided FR-4 printed circuit board (PCB) with substrate thickness of 0.8 mm, tangent factor of 0.025, and permittivity (dielectric constant) of 4.3. Theoretically, a quarter wavelength (without considering losses) can be calculated using following equation.

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{2.4 \times 10^9} = 125\,\mathrm{mm} \tag{1}$$

where λ is the wavelength, c is the speed of light in vacuum, and f is the frequency of 2.4 GHz. Therefore, the quarter wavelength obtained is $\frac{\lambda}{4} = 31.25\,\text{mm} \approx L_1$.

Since the antenna is printed on the surface of a substrate, the substrate's permittivity will influence the resonant length. To get a good performance, it is required that the resonant dipole to be designed slightly less than half a wavelength long. A good assumption is 0.47 times the wavelength as reported in [16]. The length of the resonant dipole rd can be calculated by using the following Equation (2).

$$rd = 0.47 \times \lambda = 0.47 \times \frac{v}{f} \tag{2}$$

where v denotes the actual propagation speed on the dipole radials. This speed depends on the effective dielectric constant of the substrate. The speed can be calculated by using Equation (3) as follows.

$$v = \frac{c}{\sqrt{\varepsilon_{\mathit{eff}}}} \tag{3}$$

where $\varepsilon_{\mathit{eff}}$ is the effective dielectric constant of the substrate. Using Equations (2) and (3), a printed dipole for 2.4 GHz is designed.

For $f = 2.4\,\text{GHz}$, the speed on the radials can be calculated using Equation (3) as follows.

$$v = \frac{3 \times 10^8}{\sqrt{4.3}} = 1.45 \times 10^8\,\text{m/s}$$

With this speed, the length of the resonant printed dipole rd can be obtained using Equation (2) as follows.

$$rd = 0.47 \times \frac{1.45 \times 10^8}{2.4 \times 10^9} = 28.39\,\text{mm} \approx L_1$$

Therefore, the overall length of "L" shaped element is $L_1 = 29\,\text{mm}$, which is approximately equal to the value of rd.

In summary, the characteristics of this antenna can be enumerated as follows:

(i) By varying the length of L_1 and L_2, the wideband operation of the microstrip printed dipole antenna can be excited with good impedance matching. Based on the obtained simulation results of Figures 3 and 4, as the length of L_1 ("L" shaped element) and L_2 (rectangular shaped element) increases, both low band and high band resonant frequencies will be shifted to the right. Therefore, the length of L_1 and L_2 is tuned for the optimum antenna performance.

(ii) At low band frequency range of 2.4 GHz, the antenna is operable such that the "L" shaped radiating element has electric length of about $\lambda/4$. However, the electrical length of rectangular element

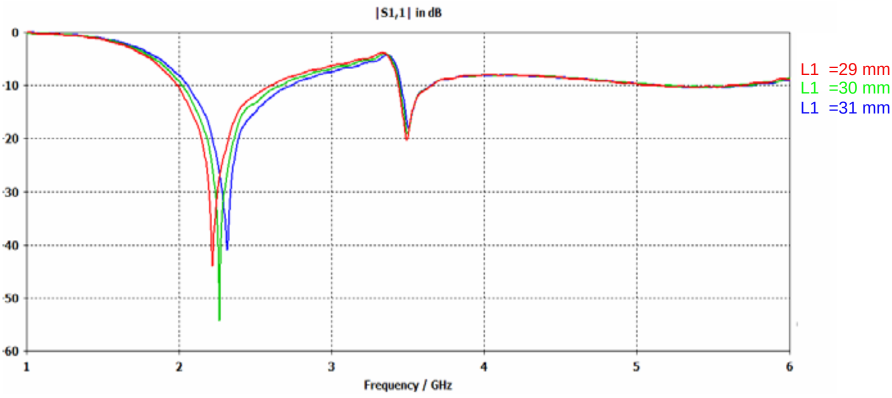


Figure 3. Simulated return loss of the radiating element for various L_1.

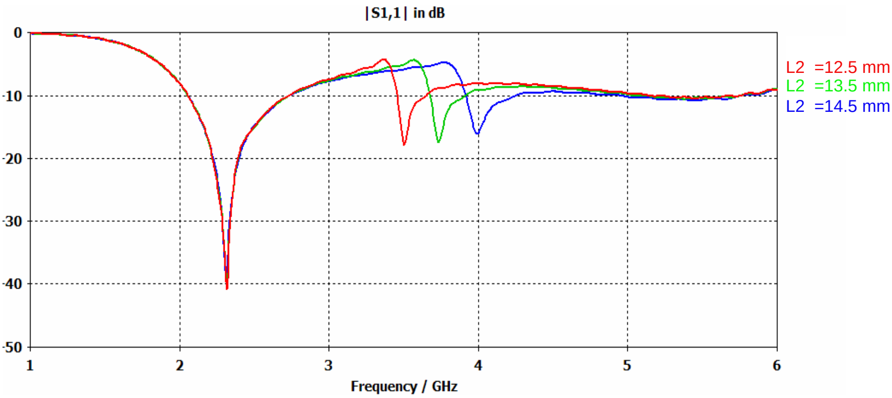


Figure 4. Simulated return loss of the radiating element for various L_2.

is relatively small; therefore, it is not considered as an effective radiating element at low frequency range. Accordingly, only "L" shaped element is essentially radiating at the low frequency range.

(iii) At the high band frequency range of 5 GHz, both "L" and "rectangular" radiating elements are effective radiators with the "L" shaped radiating element having an electrical wavelength of about $\lambda/2$ and the rectangular radiating element having an electrical wavelength of $\lambda/4$.

(iv) The slots are generally an absence of electrically-conductive material between the radiating elements. The slots are introduced

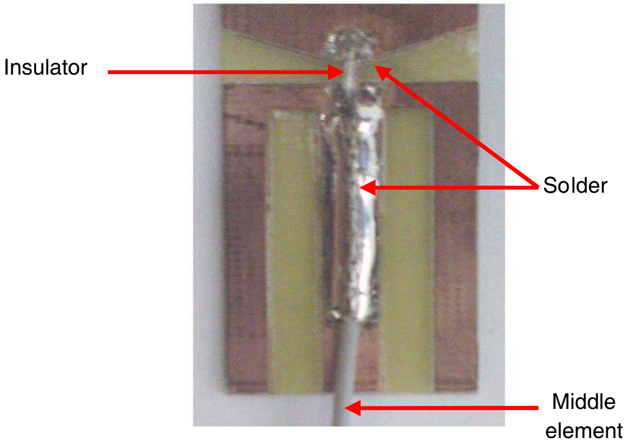


Figure 5. Feeding technique on the ground element.

to upper radiating elements, which enable dual-band operation of the antenna. The slots are carefully tuned so that the antenna can be operable at low and high frequency bands. The tapering feature ("V" shaped) of the upper portion is designed for impedance matching. For the lower portion of the antenna, the slots are introduced to achieve wider and deeper bandwidth at low band (2.4 GHz).

(v) Referring to Figure 5, the coaxial cable is soldered directly to the middle element to provide the additional strength and to avoid current leaking into the outer surface of the coaxial cable. The outer conductor is soldered along a one and half length of the middle element. The core of the coaxial cable is soldered to the feed location, adjacent on a portion of the tapering feature of the upper portion.

3. RESULTS AND DISCUSSION

The return loss and impedance measurements are obtained using network analyzer (Agilent E5062A) and are presented together with the simulation results in Figure 6. The proposed antenna has a bandwidth (defined by -10 dB return loss) from $FL_1 = 2.2$ GHz to $FH_1 = 2.7$ GHz for low band frequency and from $FL_2 = 4.4$ GHz to $FH_2 = 6.2$ GHz for high band frequency, which covers the IEEE standard for WLAN.

It is observed from Figure 6 that the simulated and the measured

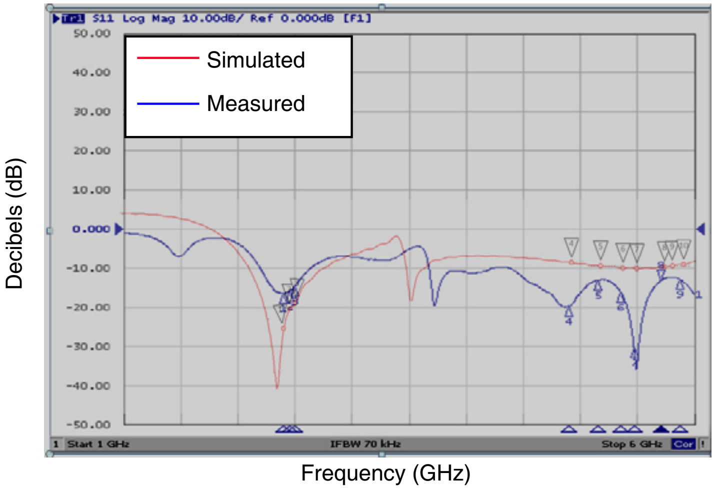


Figure 6. Comparison between simulated and measured return loss.

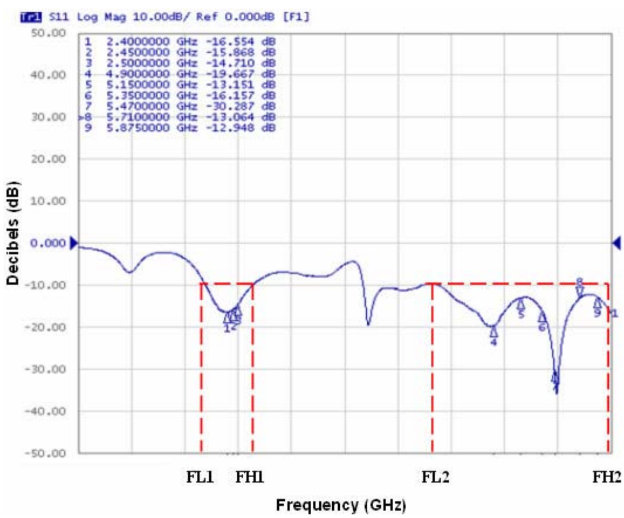


Figure 7. Bandwidth calculation.

results are in excellent agreement, apart from the upper frequency band that being broader than expected. It is due to the overall length of the coaxial cable that is excluded during the simulation.

-10 dB bandwidth for low band:

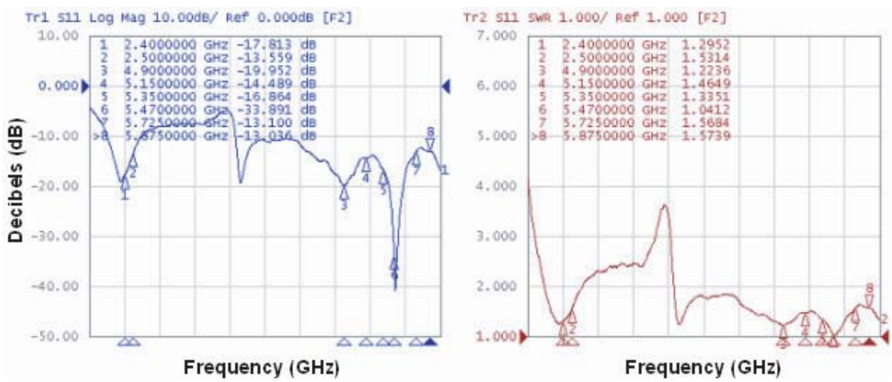
$$\text{Bandwidth, } BW = \frac{FH_1 - FL_1}{FC_1} \times 100\% = \frac{2.7-2.2}{2.45} \times 100\% = 20\%$$

$-10\,\mathrm{dB}$ bandwidth for high band:

Bandwidth, $BW = \frac{FH_2 - FL_2}{FC_2} \times 100\% = \frac{6.2-4.4}{5.3} \times 100\% = 33\%$

Based on the bandwidth calculation (see Figure 7), the $-10\,\mathrm{dB}$ bandwidth of 20% covers frequencies from 2.4 GHz to 2.5 GHz, whereas for 5 GHz band, a wide bandwidth of 33% covers frequencies as shown from 4.9 GHz to 5.875 GHz.

Referring to return loss S_{11} in Figure 8(a), the antenna has a good return loss ($> 10\,\mathrm{dB}$) across all bands, which will improve the radiating efficiency of the antenna. Based on the VSWR (Voltage Standing Wave Ratio) measurement results shown in Figure 8(b), it is observed that



(a) (b)

Figure 8. (a) Return loss S_{11} and (b) measured VSWR.

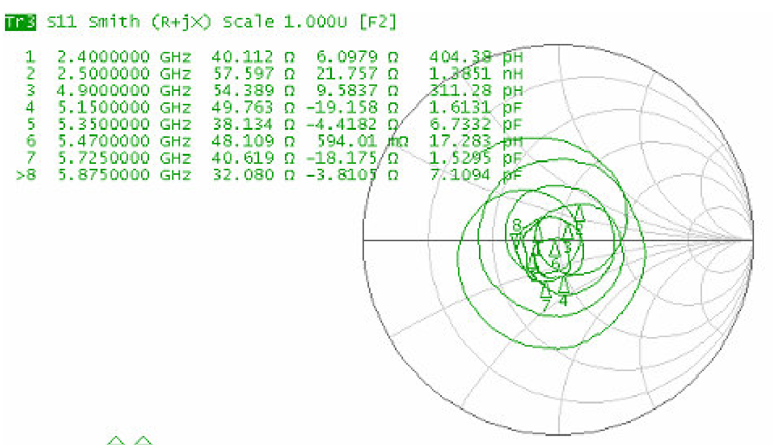


Figure 9. Measured Smith chart.

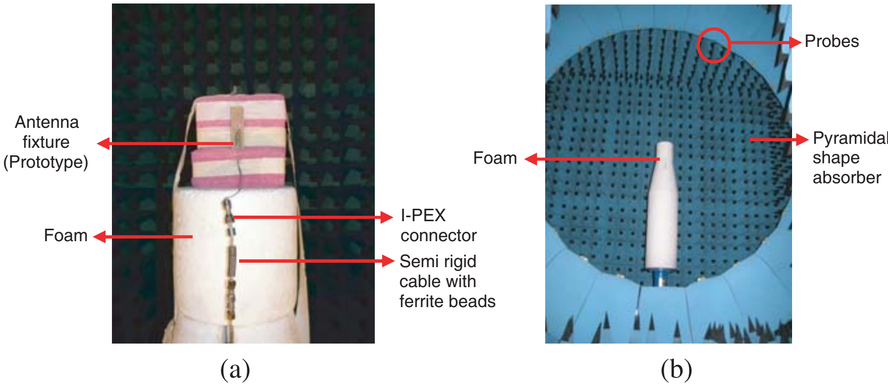


Figure 10. (a) Inside view of the 3D chamber and (b) test method.

the impedance bandwidth of VSWR ratio of 2 : 1 have been achieved for both the frequency bands. Moreover, the impedance matching of $50\,\Omega$ is achieved based on Figure 9 as the frequencies across the bands are located at the center of the impedance locus.

Radiation pattern for the prototype antenna is measured in a semi-anechoic 3D chamber with the experimental setup (test manner) as presented in Figures 10(a) and 10(b). The three main planes that can be measured are the Azimuth plane $\theta = 90°$ (Theta 90°), the Elevation plane $\Phi = 90°$ (Phi 90°), and the Elevation plane $\Phi = 0°$ (Phi 0°).

Figures 11(a) and 11(b) show the Azimuth (Theta 90°) and Elevation 0° radiation patterns for 2450 MHz while Figures 11(c) and 11(d) show the Azimuth and Elevation 0° radiation patterns for 4900 MHz to 5780 MHz. The radiation pattern for the Azimuth plane for both low and high bands is considered to be omni-directional. Therefore, the proposed antenna is able to detect the signal coming from every direction.

It can be observed that, the radiation patterns of the Azimuth plane for both low and high bands are considered omni-directional compared to the conventional dipole radiation characteristic because it generally radiates power uniformly in one plane with a directive pattern shape in a perpendicular plane, where this pattern is usually termed as "donut shaped". The antenna has a surface peak gain of 2.28 dBi for low band and 6.25 dBi for high band, which is much higher than the existing technique reported in [17], meaning that the proposed antenna has good directional characteristic, which enables to radiate or receive equally well in all directions.

It can be also observed from Figure 11 that, the radiation patterns of Elevation 0° on the horizontal plane for both bands are very directive as those are squinted vertically, where there is a present of side lobes.

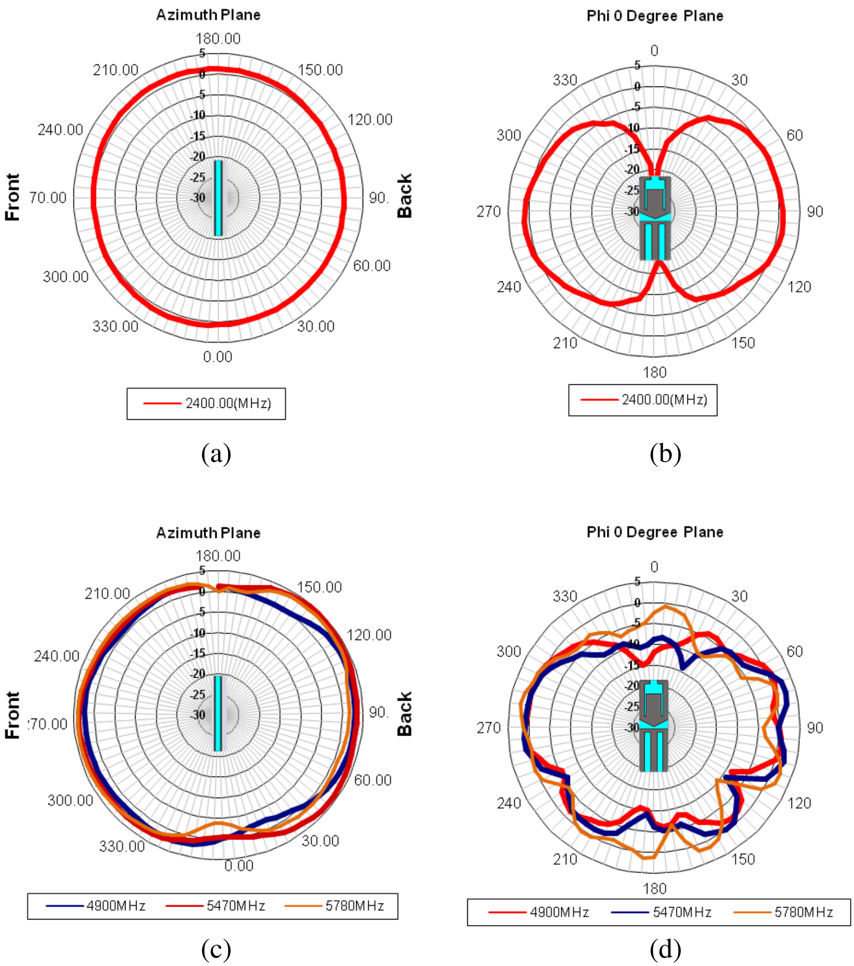


Figure 11. For 2450 MHz (low band). (a) Azimuth radiation pattern. (b) Elevation 0° radiation pattern; for 4900–5780 MHz (high band). (c) Azimuth radiation pattern. (d) Elevation 0° radiation pattern.

Upper portion slots from the antenna must be carefully tuned to avoid the antenna radiation pattern from squinting downward and also to make the radiation patterns tilt at horizontal. The feeding network might also have some influences on the gain variation.

The antenna is configured to achieve of about 2 dBi gain for 2.4 GHz and about 3 dBi to 6 dBi for 5 GHz band. The proposed antenna is designed with relatively small size and can be easily

Table 1. Performance summary.

Frequency (MHz)	3D		Azimuth		Elevation 0°		Elevation 90°		−10 dB Bandwidth (%)
	Efficiency (%)	Max Gain, dB	Max Gain, dB	Average Gain, dB	Max Gain, dB	Average Gain, dB	Max Gain, dB	Average Gain, dB	
2400	84%	1.91	1.36	0.71	1.31	−4.60	1.91	−4.52	20%
2450	84%	2.28	1.73	0.47	1.66	−4.09	1.99	−4.24	
2500	78%	1.94	1.42	−0.21	1.75	−3.94	1.66	−4.30	
4900	79%	3.26	3.11	1.48	1.17	−4.17	2.91	−4.13	33%
5150	74%	3.29	3.12	1.38	1.20	−4.67	2.96	−5.08	
5350	87%	4.13	3.74	231	1.31	−4.23	3.84	−4.19	
5470	96%	5.11	4.42	2.79	2.65	−3.81	4.95	−3.38	
5710	96%	5.00	4.10	1.20	3.77	−1.57	4.82	−1.82	
5780	99%	5.00	4.17	2.03	2.50	−2.25	4.15	−1.81	
5875	94%	6.25	2.71	0.48	5.16	−1.38	6.21	−1.76	

manufacturable as compared to manufacture of back-to-back dipole antennas that utilize a double-sided printed circuit board. Referring to Table 1 below, the low band frequencies of 2.4 GHz until 2.5 GHz have an average efficiency of 82% while 89% for the high band frequencies of 4.9 GHz until 5.875 GHz. The reduction of efficiency at the lower frequency band could be further improved by using a more expensive microwave substrate rather than a standard low-cost FR-4. The typical gain for low band and high band is 1.94 dBi and 6.25 dBi, which is sufficient enough to cover a wide range.

4. CONCLUSION

This study proposes a new dual-band omni-directional antenna configuration for WLAN usage. The configuration has several desirable features, such as planar configuration, small footprint, and single layer fabrication. This paper describes the design in detail and provides sufficient parametric study results, as well as simulation and actual measurement results to validate the antenna performance. Both the simulated and the measured results show similar characteristic. With the proposed design, the achieved bandwidth of the prototype antenna is measured at 20% and 33% at low band and high band, respectively, operating over frequency ranges from 2400–2500 MHz and 4900–5875 MHz, for an acceptable VSWR ratio of 2 : 1.

The enhanced bandwidth is achieved with parasitic elements, only by optimizing the length of the radiating elements, thus providing better bandwidth while maintaining the structural compact size. The measured radiation pattern for the Azimuth plane has shown omni-directional characteristic with peak gain of 1.73 dBi and 2.71 dBi at low band and high band, respectively. Most importantly, the proposed antenna provides a fair omni-directional coverage judging from the average gain on the Azimuth plane, which is 0.48 dBi at 5.875 GHz according to Table 1. Despite of using low-cost substrate, high antenna efficiency has been obtained in this study. The overall dimension of the antenna is 51 mm $\times$ 16 mm; hence, this antenna can be easily integrated in embedded systems and is suitable for the IEEE standard (802.11b/g and 802.11a) of WLAN or other wireless applications. The antenna proposed in this study has not only dual-band characteristic but also has wide band characteristic at frequency of 5 GHz.

REFERENCES

1. Zhang, Z., M. F. Iskandar, J. C. Langer, and J. Mathews, "Dual-band WLAN dipole antenna using an internal matching circuit," *IEEE Transactions on Antennas and Propagation*, Vol. 53, 1813–1818, 2005.
2. Su, S. W. and J. H. Chou, "Low-cost flat metal-plate dipole antenna for 2.4/5-GHz WLAN operation," *Microwave. Opt. Tech. Lett.*, Vol. 50, 1686–1687, 2008.
3. Liu, W. C., "Optimal design of dual-band CPW-fed G-shaped monopole antenna for WLAN application," *Progress In Electromagnetics Research*, Vol. 74, 21–38, 2007.
4. Wu, Y.-J., B.-H. Sun, J.-F. Li, and Q.-Z. Liu, "Triple-band omni-directional antenna for WLAN application," *Progress In Electromagnetics Research*, Vol. 76, 477–484, 2007.
5. Jolani, F., A. M. Dadgarpour, and H. R. Hassani, "Compact m-slot folded patch antenna for WLAN," *Progress In Electromagnetics Research Letters*, Vol. 3, 35–42, 2008.
6. Chen, H. -M., J.-M. Chen, P.-S. Cheng, and T.-F. Lin, "Feed for dual-band printed dipole antenna," *IEE Electron. Lett.*, Vol. 40, No. 21, 1320–1322, 2004.
7. Kim, M. J., C. S. Cho, and J. Kim, "A dual-band printed dipole antenna with spiral structure for WLAN application," *IEEE Microwave and Wireless Components Letters*, Vol. 15, No. 12, 910–912, 2005.
8. Su, S.-W. and J.-H. Chou, "Compact coaxial-line-fed flat-plane dipole antenna for WLAN applications," *Microwave and Optical Tech. Lett.*, Vol. 50, 420–422, 2008.
9. Alkanhal, M. A. S., "Composite compact triple-band microstrip

antennas," *Progress In Electromagnetics Research*, Vol. 93, 221–236, 2009.
10. Ren, W., "Compact dual-band slot antenna for 2.4/5 GHz WLAN applications," *Progress In Electromagnetics Research B*, Vol. 8, 319–327, 2008.
11. Geng, J. P., J. J. Li, R. H. Jin, S. Ye, X. L. Liang, and M. Z. Li, "The development of curved microstrip antenna with defected ground structure," *Progress In Electromagnetics Research*, Vol. 98, 53–73, 2009.
12. Wang, C.-J. and S.-W. Chang, "Studies on dual-band multi-slot antennas," *Progress In Electromagnetics Research*, Vol. 83, 293–306, 2008.
13. Si, L.-M. and X. Lv, "CPW-fed multi-band omni-directional planar microstrip antenna using composite metamaterial resonators for wireless communications," *Progress In Electromagnetics Research*, Vol. 83, 133–146, 2008.
14. Behera, S. and K. J. Vinoy, "Microstrip square ring antenna for dual-band operation," *Progress In Electromagnetics Research*, Vol. 93, 41–56, 2009.
15. Roy, J. S. and M. Thomas, "Design of a circularly polarized microstrip antenna for WLAN," *Progress In Electromagnetics Research M*, Vol. 3, 79–90, 2008.
16. Stutzman, W. L. and G. A. Thiele, *Antenna Theory and Design*, John Wiley and Sons, 2003.
17. Li, X., L. Yang, S.-X. Gong, and Y.-J. Yang, "Dual-band and wideband design of a printed dipole antenna integrated with dual-band balun," *Progress In Electromagnetics Research Letters*, Vol. 6, 165–174, 2009.