Published in IET Microwaves, Antennas & Propagation
Received on 24th May 2012
Revised on 22nd November 2012
Accepted on 7th December 2012
doi: 10.1049/iet-map.2012.0286

ISSN 1751-8725

Development of a directional dual-band planar antenna for wireless applications

Xulin Quan[1], *RongLin Li*[1], *Guiping Jin*[1], *Manos M. Tentzeris*[2]
[1]*School of Electronic and Information Engineering, South China University of Technology, Guangzhou 510641, People's Republic of China*
[2]*School of Eectrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30308, USA*
E-mail: lirl@scut.edu.cn

Abstract: A new type of directional dual-band antenna is developed for 2.4/5 GHz wireless applications. The dual-band antenna consists of a longer dipole for the lower band and a pair of shorter dipoles for the upper band. A simple coupling microstrip line is employed to excite the dipoles. Both the dual-band antenna and the feeding microstrip line are printed on the same substrate, leading to a fully planar structure. The dual-band planar antenna achieves a desirable directional radiation pattern with an antenna gain of near 8 dBi for the lower band and 9–10 dBi for the upper band. A comprehensive analysis and design for the development of the directional dual-band antenna is presented.

1 Introduction

Over the last 10 years, a lot of dual-band antennas have been developed for wireless applications, particularly for 2.4/5 GHz wireless local area networks (WLANs) communications [1–14]. However, most of these dual-band antennas have an omnidirectional radiation pattern, which are most suitable for mobile terminals, such as cellular phones or laptop computers. For indoor wireless access points (APs) or point-to-point communications, it is sometimes required that the radiation pattern is directional to allow mounting the antenna against a wall or a ceiling surface [15, 16]. It is desirable for the antennas mounted on a wall/ceiling surface to have a low profile. A number of directional dual-band antennas have been investigated in recent years. Nevertheless, these directional dual-band antenna structures either have a stacked configuration [17–21] or a high profile [22].

In this paper, we propose a new planar directional dual-band antenna with a low profile. The dual-band antenna consists of a single dipole for the lower band and a pair of dipoles for the upper band. All of these dipoles are printed on the same substrate and excited by a simple coupling microstrip line. The new dual-band antenna achieves a desirable directional radiation pattern in both of the lower band and the upper band with antenna gains of −8 and 9–10 dBi, respectively. A comprehensive analysis and design for the development of the directional dual-band antennas is described.

2 Antenna configuration

The configuration of a directional dual-band antenna is depicted in Fig. 1. The dual-band antenna consists of a longer dipole and a pair of shorter dipoles, which are designed for operation at the 2.4 GHz ISM band (2.4–2.5 GHz) and the 5 GHz UNII band (5.1–5.9 GHz), respectively. The dipole for the lower band has a length $L_{Lo} = 60$ mm $(-\lambda_{Lo}/2$, where λ_{Lo} is the free-space wavelength at the centre frequency of the 2.4 GHz band) whereas the pair of dipoles for the upper band has a length $L_{Up} = 30$ mm $(-\lambda_{Up}/2$, where λ_{Up} is the free-space wavelength at the centre frequency of the 5 GHz band). The two shorter dipoles are separated by a distance $D = 26$ mm and are connected by a coplanar stripline with a spacing $S = 1$ mm. All dipoles are printed on the bottom side of a thin RT/Duroid 5880 substrate with a dielectric constant $\varepsilon_r = 2.2$ and a thickness $t = 0.5$ mm. The printed dipoles are placed at a height (H) above a ground plane (100 mm × 60 mm) and excited by a coupling microstrip line of length $L_m =$ 10.5 mm across the coplanar strip. The height H mainly affects the bandwidth for the lower band (i.e. the 2.4-GHz band). To cover the 2.4 GHz ISM band (2.4–2.5 GHz) and keep a low profile, we choose $H = 12$ mm $(-0.1\lambda_{Lo})$. The coupling microstrip line is printed on the top side of the substrate and fed through a 0.084′ semi-rigid coaxial line at the inner side of the coplanar strip. The linewidths of the printed dipoles, the coplanar strip, and microstrip line are $W_{Lo} = 5$ mm, $W_{Up} = 2$ mm, $W_s = 13$ mm and $W_m = 1.5$ mm, respectively.

3 Analysis and design

To demonstrate the operating principle of the dual-band antenna, we decompose the antenna structure into a single dipole for the 2.4 GHz band and a two-dipole array for the 5 GHz band, as illustrated in Fig. 2. We assume that the dual-band antenna is excited by a voltage source. The

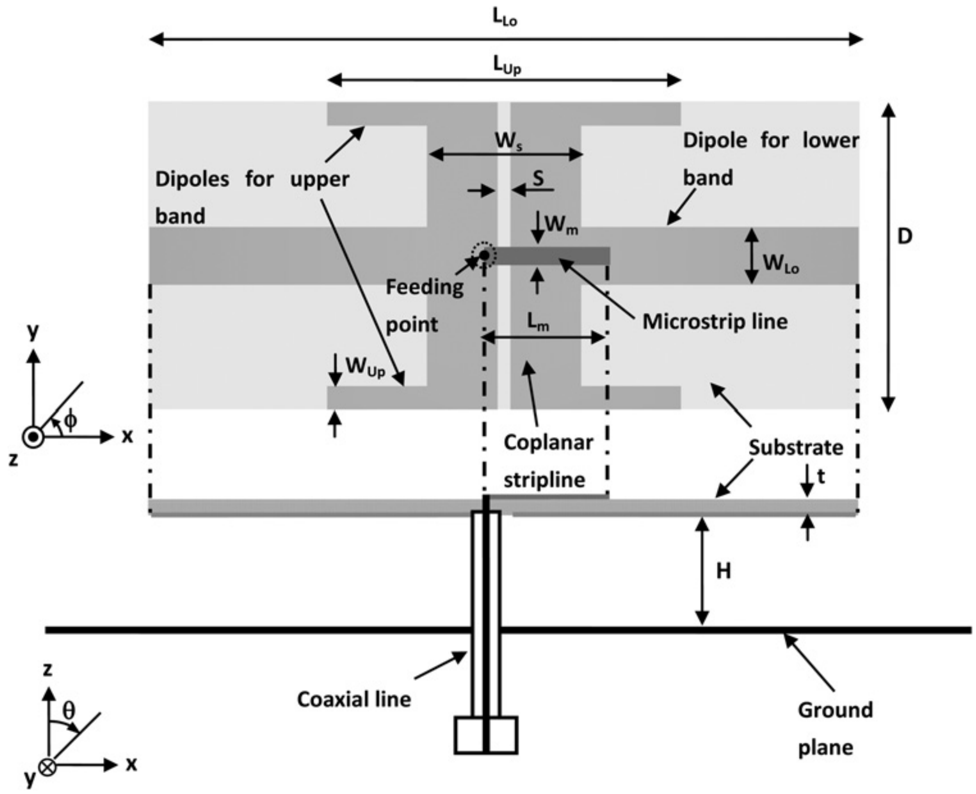

Fig. 1 *Configuration of a directional dual-band antenna*

voltage-source excited dual-band antenna was simulated using 'CST Microstripes 7.5'. The antenna can also be simulated using other solvers. In fact, we simulated the antenna using 'HFSS' and similar results were obtained. The simulated return loss (RL) is plotted in Fig. 3. We can see two resonances: one in the 2.4 GHz band and the other in the 5 GHz band. To examine the operating modes at the resonances, we insert the three-dimensional (3D) radiation patterns for the 2.4 and 5 GHz bands in Fig. 3. It is seen that both radiation patterns are directional and similar to those radiated by a single dipole for the 2.4 GHz band and by a two-dipole broadside array for the 5 GHz band, respectively, backed by a metal reflector. This confirms that the dual-band antenna can be considered as a combination of a dipole for the 2.4 GHz band and a two-dipole array for the 5 GHz band.

It is observed that the impedance matching is not good for the dual-band antenna which is directly excited by a voltage source (RL < 5 dB for the 2.4 GHz band and RL < 10 dB for the 5 GHz band). Therefore we introduce a coupling feed which is simply a piece of opened microstrip line. Fig. 4 demonstrates the effectiveness of the coupling feed: good impedance matching is achieved in the 2.4 GHz band (RL > 10 dB from 2.38 to 2.52 GHz) and in the 5 GHz band (RL > 10 dB from 5.06 to 6.0 GHz) whereas the radiation patterns still remain directional.

To understand the impedance matching for the coupling feed, an equivalent circuit model is presented in Fig. 5. The input impedance of the dual-band antenna as excited by a voltage source (the coupling microstrip line has not been introduced yet) is denoted by Z_a (also see Fig. 2). The capacitive coupling between the coplanar stripline and the microstrip line can be represented as an ideal transformer that has a turn ratio of n. Following the transformer, the impedance Z_a is transformed into Z_c

$$Z_c = n^2 Z_a \tag{1}$$

where n^2 is called the impedance transformer coefficient. The input impedance (Z_{in}) looking into the microstrip line at the feed point is obtained by taking into account the opened microstrip line, which gives

$$Z_{\text{in}} = Z_c - \text{j}Z_0 \cot \beta_0 l_{\text{o}} \tag{2}$$

where Z_0, β_0 and l_{o} are the characteristic impedance, phase constant and the length of the opened microstrip line, respectively.

Since it is difficult to calculate the impedance transformer coefficient n^2, we obtain Z_c by exciting the dual-band antenna with a two-port microstrip line across the coplanar stripline. Then Z_c is determined from the S-parameters of the two-port network enclosed in Fig. 5, which can be expressed as [23]

$$Z_c = Z_0 \frac{(1 + S_{11})(1 + S_{22}) - S_{12}S_{21}}{2S_{21}} \tag{3}$$

The results for Z_a and Z_c are given in a Smith chart as shown in Fig. 6. We can see that Z_a is far away from the centre of the Smith chart for the lower band and close to the standing wave ratio (SWR) = 2:1 circle for the upper band, which means a bad impedance matching for the lower band and a slightly better impedance matching for the upper band. Following the transformer, the impedance Z_a is transformed into Z_c. For the lower band, Z_c is still outside the SWR = 2:1 circle.

doi: 10.1049/iet-map.2012.0286

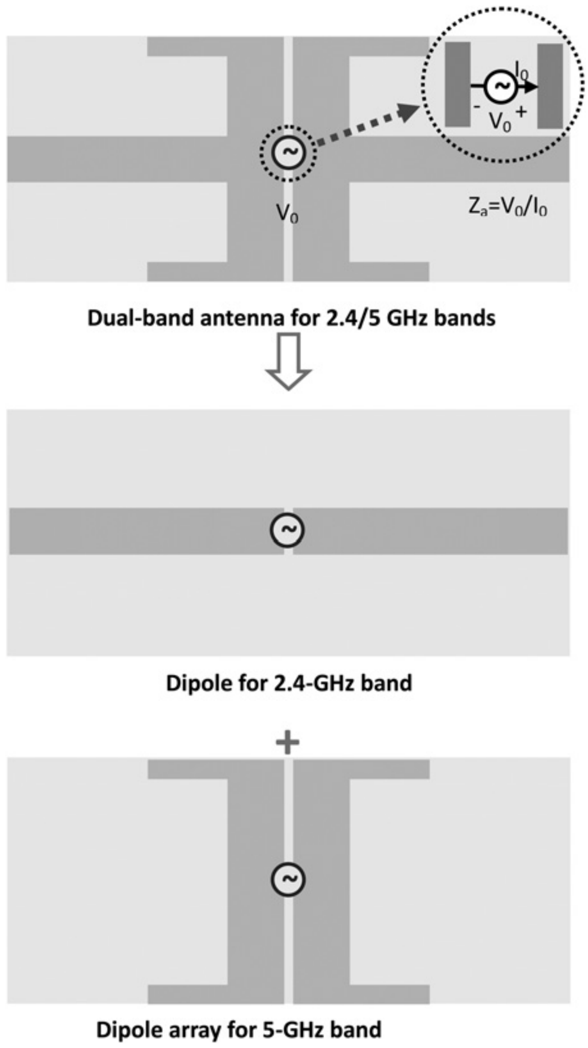

Fig. 2 *Directional dual-band antenna for 2.4/5-GHz bands decomposed into a dipole for the 2.4 GHz band and a two-dipole array for the 5 GHz band*

However, for the upper band, Z_c has moved to the inside of the SWR = 2:1 circle. After the introduction of the coupling microstrip line, we obtain the input impedance Z_{in} from (2). From Fig. 6, we can see that Z_{in} for the lower band has got to the inside of the SWR = 2:1 circle; thus good impedance matching is achieved. For the upper band, Z_{in} still remains

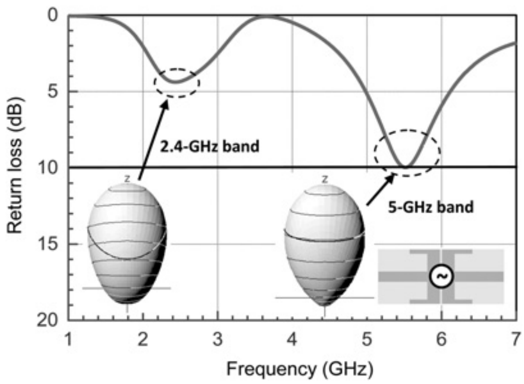

Fig. 3 *RL of the directional dual-band antenna with an excitation of voltage source (insets are the 3D radiation patterns at resonances)*

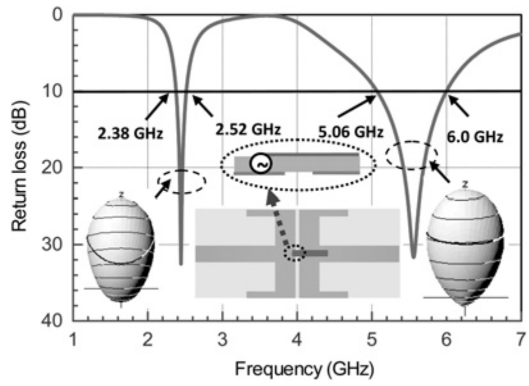

Fig. 4 *RL for the directional dual-band antenna with coupling feed (insets are the 3D radiation patterns at resonances)*

inside the SWR = 2:1 circle. From the above analysis, we have the following conclusions:

1. The impedance matching for the lower band is dominated by the impedance Z_a and the length of the microstrip line. The coplanar stripline is less important.
2. The impedance matching for the upper band is determined by the impedance Z_a and the coplanar stripline. The length of the microstrip line is less important.

The input impedance Z_{in} calculated using (2) is compared with simulation results in Fig. 6. It can be seen that the calculated and simulated results are in good agreement, thus validating the equivalent circuit analysis.

The operating frequencies for the dual-band antenna can be adjusted by changing the lengths of the dipoles. Fig. 7 shows the variation of RL as the length of the shorter dipoles for the upper band. It is seen that the impedance matching for the lower band is not affected. As expected, the resonant frequency for the upper band increases as the length (L_{Up}) of the dipoles decreases. It is also observed that the impedance matching becomes worse because of the change of the impedance Z_a for the upper band. The impedance Z_a is sensitive to the electrical length of the height (H), which is usually required to remain as low as possible for a low-profile configuration. A better impedance matching may be achieved by adjusting the coplanar stripline.

Fig. 8 reveals the variation of the operating frequency for the lower band. It is seen that the resonant frequency changes

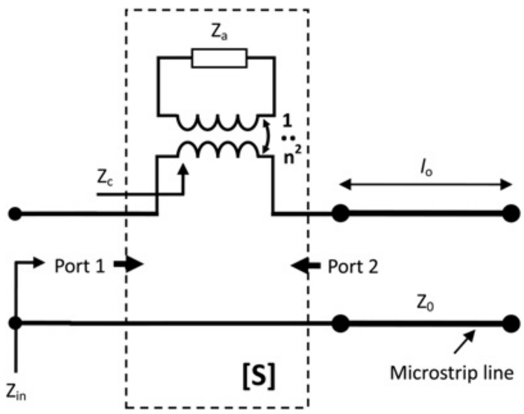

Fig. 5 *Equivalent circuit for the coupling feed ($l_o \cong L_m$–S)*

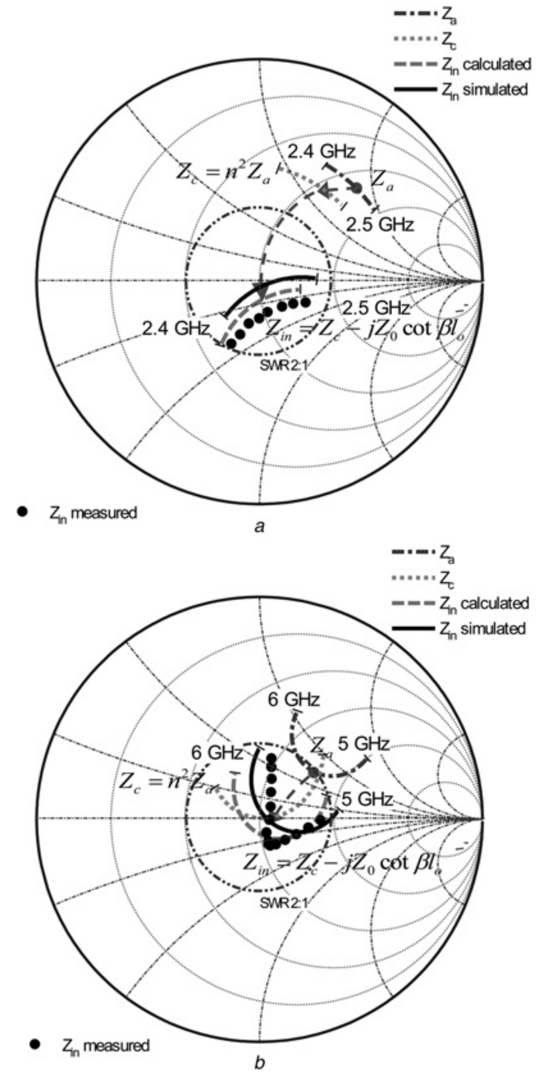

Fig. 6 *Impedance matching of the directional dual-band antenna*
a 2.4 GHz band
b 5 GHz band

with the length of the longer dipole and the impedance matching remains acceptable. There is no effect on the upper band. Therefore the operating frequency for the lower band can be adjusted freely by changing the length L_{Lo} of the longer dipole. It is seen that the adjustable frequency range can be as low as 1.5 GHz and as high as 4 GHz,

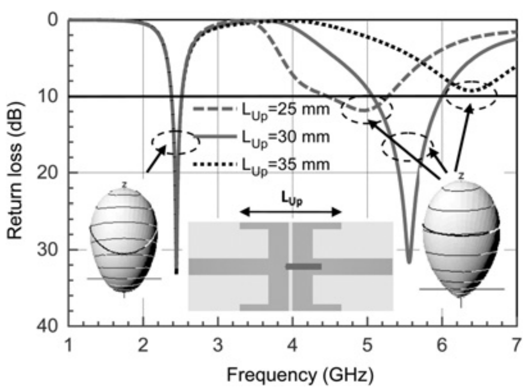

Fig. 7 *Variation of RL of the directional dual-band antenna with the length of the shorter dipoles for the upper band*

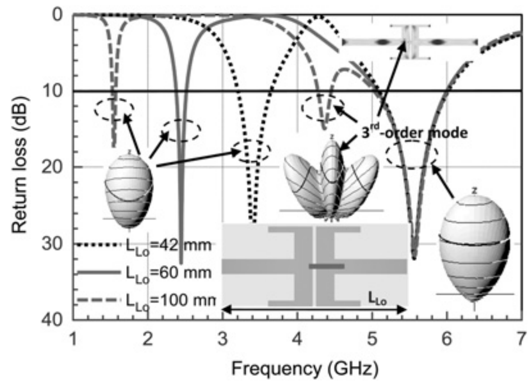

Fig. 8 *Variation of RL of the directional dual-band antenna with the length of the longer dipole for the lower band*

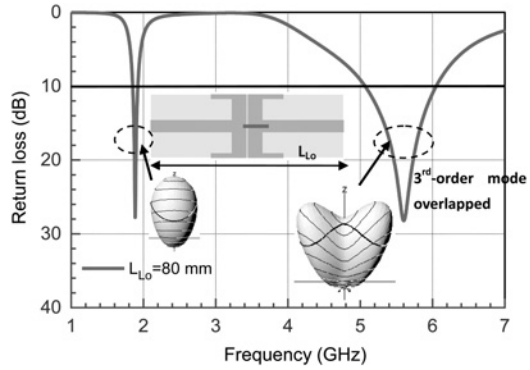

Fig. 9 *Situation where the third-order mode from the dipole for the lower band contaminates the radiation pattern for the 5 GHz band*

which may cover the 3.5 GHz band WiMax/WLAN applications. It should be noted that as the length L_{Lo} increases to $L_{\mathrm{Lo}} = 100$ mm, the third-order mode will appear above 4 GHz, which leads to a multi-directional radiation pattern as seen in the inset of Fig. 8. It is also observed that as $L_{\mathrm{Lo}} = 80$ mm, the third-order mode will overlap with the 5 GHz band, which will contaminate the radiation pattern for the 5 GHz band, as demonstrated in Fig. 9. This situation should be prevented for a directional dual-band antenna.

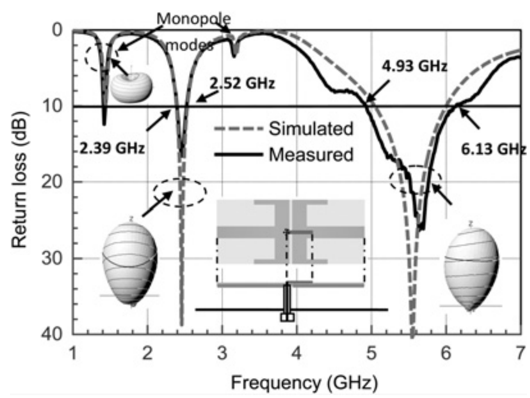

Fig. 10 *Measured RL for the directional dual-band antenna compared with simulated result (insets are the 3D radiation patterns at resonances)*

doi: 10.1049/iet-map.2012.0286

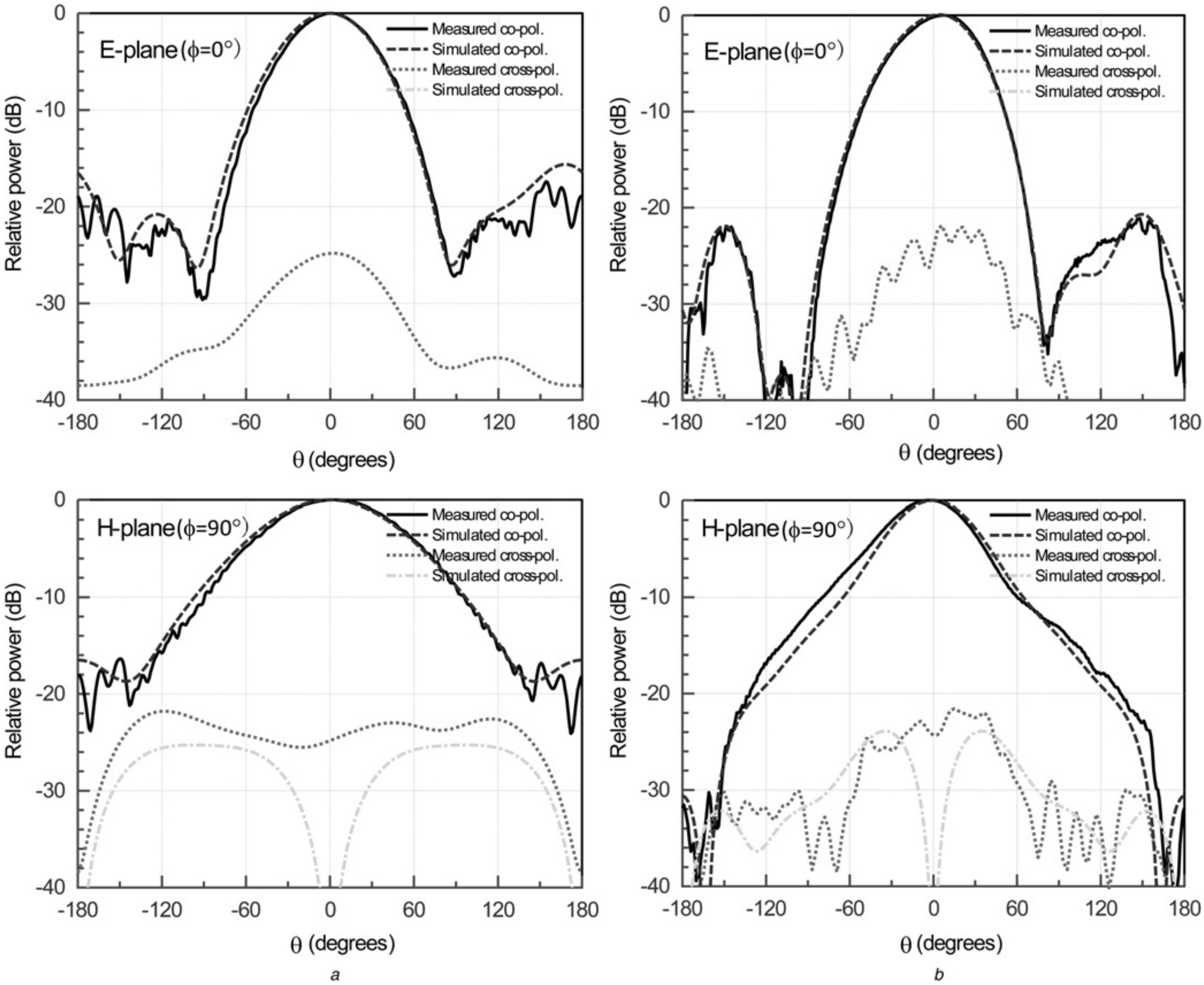

Fig. 11 *Radiation patterns of the directional dual-band antenna*
a At 2.45 GHz
b At 5.5 GHz

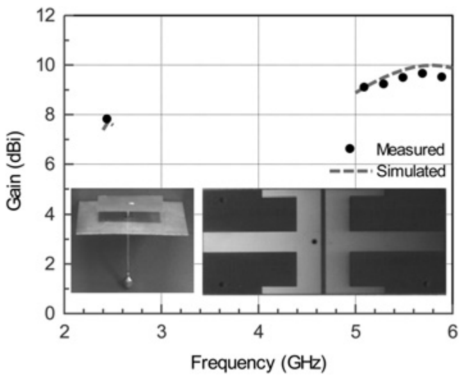

Fig. 12 *Gains of the directional dual-band antenna (inset is the antenna prototype)*

4 Experimental results

Measured input impedance is compared with theoretical results in Fig. 6. Agreement is observed. Slight difference is due to the effect of the feeding coaxial line which causes some calibration error. The RL measured for the directional dual-band antenna is compared with the simulation result in Fig. 10. The measured bandwidths for 10 dB RL are 2.39–2.52 GHz for the 2.4 GHz band and 4.93–6.13 GHz for the 5 GHz band, which cover the 2.4-GHz ISM band and the 5 GHz UNII band. Note that there is a spurious resonance around 1.4 GHz. This resonance is due to the outer conductor of the feeding coaxial line which forms a top-loaded vertical monopole with the dual-band antenna. The omnidirectional radiation pattern at 1.4 GHz (see the inset of Fig. 10) is due to the currents on the outside of the coaxial line, confirming the vertical monopole mode. Note that the coaxial line has little effect on the radiation patterns for the 2.4 and 5 GHz bands.

Radiation patterns measured and simulated at 2.45 and 5.5 GHz are plotted in Fig. 11. Good directional radiation patterns are observed for both frequencies. Cross-polarisation level is more than 20 dB lower than the copolarisation. The half-power beamwidths (HPBWs) in the *E*-plane are approximately 60° for both the 2.4 and 5 GHz bands. But the HPBWs in the H-plane are approximately 100° and 60°, respectively, for the 2.4 and 5 GHz bands. The narrower beamwidth for the 5-GHz band is due to the configuration

doi: 10.1049/iet-map.2012.0286

of two-dipole broadside array. The antenna gains for the directional dual-band antenna are, respectively, about 8 dBi for the 2.4-GHz band and 9–10 dBi for the 5 GHz band as shown in Fig. 12, which are adequate for applications in wireless APs. The beamwidths in the *E*-plane and *H*-plane and maximum gains approximately satisfy the empirical relations given in [24].The higher gain in the upper band is due to the narrower beamwidth in the *H*-plane. The higher-gain characteristic in the upper band is desirable for wireless applications because radio signals experiences a higher path loss at a higher frequency.

5 Conclusion

A new type of directional dual-band antenna has been proposed and analysed. The dual-band antenna consists of a single dipole for the lower band and a two-dipole array for the upper band. All dipoles are printed on the same thin substrate. The printed dipole antenna is excited by a simple coupling microstrip line. The operating frequencies for the directional dual-band antenna can be easily adjusted for different wireless applications. The directional dual-band planar antenna achieves a desirable directional radiation pattern with a gain of -8 dBi for the 2.4 GHz band and 9–10 dBi for the 5 GHz band, thus may find applications in wireless APs for high-speed WLANs.

6 Acknowledgments

This paper was supported in part by the National Natural Science Foundation of China (grant number 60871061), in part by the Guangdong Province Natural Science Foundation (grant number 8151064101000085) and in part by the Specialized Research Fund for the Doctoral Programme of Higher Education (grant number 20080561). The authors also acknowledge SATIMO in Atlanta, GA, USA, for radiation pattern measurement.

7 References

1 Kuo, Y.-L., Wong, K.-L.: 'Printed double-T monopole antenna for 2.4/5.2 GHz dual-band WLAN operations', *Antennas Propag., IEEE Trans.*, 2003, **51**, (9), pp. 2187–2192
2 Jan, J.-Y., Tseng, L.-C.: 'Small planar monopole antenna with a shorted parasitic inverted-L wire for wireless communications in the 2.4-, 5.2-, and 5.8-GHz bands', *Antennas Propag., IEEE Trans.*, 2004, **52**, (7), pp. 1903–1905
3 Wong, K.-L., Chou, L.-C., Su, C.-M.: 'Dual-band flat-plate antenna with a shorted parasitic element for laptop applications', *Antennas Propag., IEEE Trans.*, 2005, **53**, (1), pp. 539–544
4 Chen, S.-B., Jiao, Y.-C., Wang, W., Zhang, F.-S.: 'Modified T-shaped planar monopole antennas for multiband operation', *Microw. Theory Tech., IEEE Trans.*, 2006, **54**, (8), pp. 3267–3270
5 Chou, L.-C., Wong, K.-L.: 'Uni-planar dual-band monopole antenna for 2.4/5 GHz WLAN operation in the laptop computer', *Antennas Propag., IEEE Trans.*, 2007, **55**, (12), pp. 3739–3741
6 Lin, X.-C., Yu, C.-C.: 'A dual-band CPW-fed inductive slot-monopole hybrid antenna', *IEEE Trans. Antennas Propag.*, 2008, **56**, (1), pp. 282–285
7 Callaghan, P., Batchelor, J.C.: 'Dual-band pin-patch antenna for Wi-Fi applications', *Antennas Wirel. Propag. Lett., IEEE*, 2008, **7**, pp. 757–760
8 Lin, S.-J., Row, J.-S.: 'Monopolar patch antenna with dual-band and wideband operations', *Antennas Propag., IEEE Trans.*, 2008, **56**, (3), pp. 900–903
9 Zhang, H.-L., Xin, H.: 'A dual-band dipole antenna with integrated-balun', *Antennas Propag., IEEE Trans.*, 2009, **57**, (3), pp. 786–789
10 Lizzi, L., Viani, F., Massa, A.: 'Dual-band spline-shaped PCB antenna for Wi-Fi applications', *Antennas Wirel. Propag. Lett., IEEE*, 2009, **8**, pp. 616–619
11 Midrio, M., Boscolo, S., Sacchetto, F., Someda, C.G., Capobianco, A. D., Pigozzo, F.M.: 'Planar, compact dual-band antenna for wireless LAN applications', *Antennas Wirel. Propag. Lett., IEEE*, 2009, **8**, pp. 1234–1237
12 Chang, T.N., Jiang, J.-H.: 'Meandered T-shaped monopole antenna', *Antennas Propag., IEEE Trans.*, 2009, **57**, (12), pp. 3976–3978
13 Chu, Q.-X., Ye, L.-H.: 'Design of compact dual-wideband antenna with assembled monopoles', *Antennas Propag., IEEE Trans.*, 2010, **58**, (12), pp. 4063–4066
14 Chen, Y.-C., Chen, S.-Y., Hsu, P.: 'Modification of radiation patterns of first harmonic mode of slot dipole for dual-frequency operation', *Antennas Propag., IEEE Trans.*, 2011, **59**, (7), pp. 2707–2710
15 Gardelli, R., La Cono, G., Albani, M.: 'A low-cost suspended patch antenna for WLAN access points and point-to-point links', *Antennas Wirel. Propag. Lett., IEEE*, 2004, **3**, (1), pp. 90–93
16 Medeiros, C.R., Lima, E.B., Costa, J.R., Fernandes, C.A.: 'Wideband slot antenna for WLAN access points', *Antennas Wirel. Propag. Lett., IEEE*, 2010, **9**, pp. 79–82
17 Lu, J.-H.: 'Broadband dual-frequency operation of circular patch antennas and arrays with a pair of L-shaped slots', *Antennas Propag., IEEE Trans.*, 2003, **51**, (5), pp. 1018–1023
18 Oh, K., Kim, B., Choi, J.: 'Design of dual and wideband aperture-stacked patch antenna with double-sided notches', *Electron. Lett.*, 2004, **40**, (11), pp. 643–645
19 Li, P., Luk, K.M., Lau, K.L.: 'A dual-feed dual-band L-probe patch antenna', *Antennas Propag., IEEE Trans.*, 2005, **53**, (7), pp. 2321–2323
20 Mahmoud, M.N., Baktur, R.: 'A dual band microstrip-fed slot antenna', *Antennas Propag., IEEE Trans.*, 2011, **59**, (5), pp. 1720–1724
21 Fang, X.S., Leung, K.W.: 'Designs of single-, dual-, wide-band rectangular dielectric resonator antennas', *Antennas Propag., IEEE Trans.*, 2011, **59**, (6), pp. 2409–2414
22 Tefiku, F., Grimes, C.A.: 'Design of broad-band and dual-band antennas comprised of series-fed printed-strip dipole pairs', *Antennas Propag., IEEE Trans.*, 2000, **48**, (6), pp. 895–900
23 Pozar, D.M.: 'Microwave engineering' (John Wiley & Sons, Inc., 2005, 3rd edn.), pp. 183–189
24 Balanis, C.A.: 'Antenna theory: analysis and design' (John Wiley & Sons, Inc., 2005, 3rd edn.), pp. 50–55

doi: 10.1049/iet-map.2012.0286