International Journal of Microwave and Wireless Technologies, 2016, 8(1), 81–87.
doi:10.1017/S1759078714001329

RESEARCH PAPER

Planar compact dual-band monopole antenna with circular polarization for WLAN applications

JUI-HAN LU AND HAO-SHIANG HUANG

A planar circularly polarized (CP) monopole antenna (MA) with dual-band operation for the IEEE 802.11a/b/g wireless local area network (WLAN) is proposed. By introducing dual strip-sleeves shorted at the ground plane, the excitation of dual-resonant modes can resemble the 2.4/5.2 GHz bands required for WLAN operations. The obtained impedance bandwidths (RL ≧10 dB) across the operating bands approach 260/988 MHz and the 3 dB axial-ratio bandwidth of about 103/710 MHz for 2.4/5.2 GHz bands, respectively. The model proposed in this study reflects more advantages in physical implementation as its overall volume is only 40 × 40 × 0.8 mm^3, 22% smaller than other conventional CP MAs. The measured peak gain and radiation efficiency are about 4.1/3.3 dBic and 94/84%, respectively, and demonstrate nearly bidirectional patterns in the XZ- and YZ-planes.

Keywords: Monopole antenna, Dual-band, Circular polarization, WLAN

Received 9 May 2013; Revised 2 September 2014; Accepted 5 September 2014; first published online 2 October 2014

I. INTRODUCTION

Recently, owing to tremendous growth in Wireless Communication Technology, especially for the IEEE 802.11a/b/g WLAN standards in the 2.4 GHz (2400–2484 MHz), 5.2 GHz (5150–5350 MHz), and 5.8 GHz (5725–5825 MHz) bands, dual-band printed monopole antenna (MA) has attracted high attention because it has the merit of low profile and can provide the feature of multi-band operation. Besides, another great advance in the communication system can be obtained using circularly polarized (CP) antennas to reduce the loss caused by the multi-path effects between the transmitter and receiver antennas. Many CP MAs have been investigated, such as the annular ring MA [1, 2], a circular MA [3], the rectangular patch MA with an L-shaped slit inset into the ground plane [4, 5], an asymmetrical dipole antenna [6] and an asymmetric-fed rectangular patch MA with the stub shorted at the ground plane [7]. However, the above-mentioned CP antennas are focused on the single-band operation and a common limitation of these is their bulky size like [1], and/or complex structure like [2, 3]. Moreover, there is an increasing demand for antennas having more compact size to be suitably embedded in the practical portable devices for the multi-input/multi-output (MIMO) system. Therefore, in this paper, we propose a novel planar dual-band MA with circular polarization operation for wireless local area network (WLAN) communication. By appropricately introducing dual asymmetrical strip-sleeves shorted at the ground plane [8], different from the other designs using the inset slit [2, 4, 5], the proposed dual-band CP design can provide the impedance bandwidth (RL ≧10 dB) of about 260/988 MHz and the 3 dB axial-ratio (AR) bandwidth of about 103/710 MHz for 2.4/5.2 GHz WLAN applications, respectively. As a result, a symmetry pattern of bidirectional CP radiation has been observed. This paper is organized as follows: the design concept of the proposed MA is described in Section II, and Section III presents the results of performance tests of the proposed antennas, including both simulation results and actual measurement data. Simulation results related to antenna performance, e.g., operating bandwidth and antenna gain, are also discussed. Finally, Section IV summarizes the findings and conclusions of the study. Details of the proposed antenna design and experiment results are presented and discussed in the related sections.

Department of Electronic Communication Engineering, National Kaohsiung Marine University, Kaohsiung, Taiwan 81157, Republic of China. Phone: +886-7-3617141#3310
Corresponding author:
J.-H. Lu
Email: jhlu@webmail.nkmu.edu.tw

II. ANTENNA DESIGN

To provide the dual-band capability needed for operation in WLAN application, this study proposes a novel planar compact MA. Figure 1 illustrates the geometrical configuration of the proposed planar dual-band CP antenna for WLAN application. A 50 Ω microstrip line is etched as the feeding structure on the inexpensive FR-4 substrate with the overall volume of 40 × 40 × 0.8 mm^3, dielectric constant

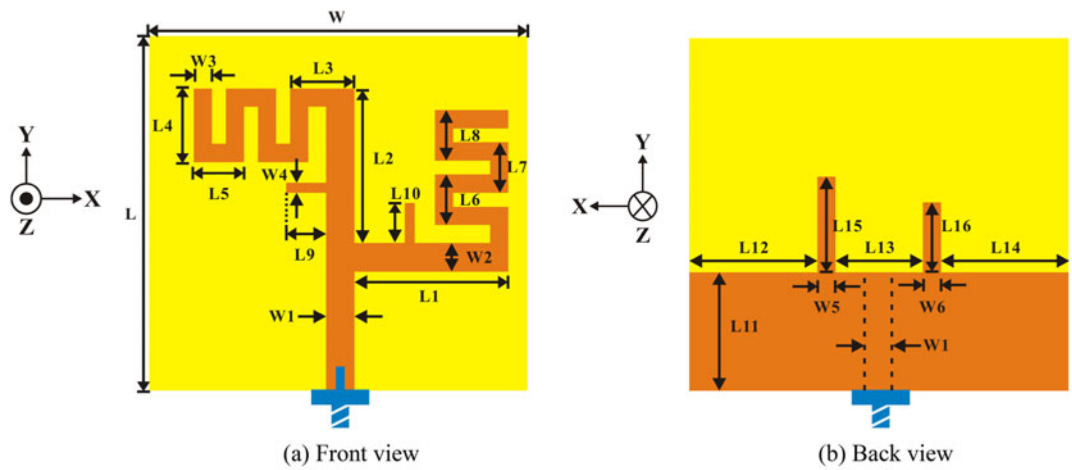

Fig. 1. Geometry of the proposed dual-band CP MA with dual asymmetrical strip-sleeves for WLAN application. (a) Front view. (b) Back view.

$\epsilon_r = 4.4$ and loss tangent tan $\delta = 0.0245$. The proposed antenna consists of a pair of orthogonal F-shaped meander monopoles with dual asymmetrical strip-sleeves shorted at the ground plane. For compact operation, the longer arm of the F-shaped monopole strip is meandered to obtain smaller dimension, which is used to generate the fundamental resonant mode at approximately 2450 MHz. The longer strip-sleeve of L15 × W5 is introduced to disturb the surface current on the ground plane, which is different from the CP design using the L-shaped slit inset into the ground plane [2, 4, 5]. Meanwhile, the right-hand circular polarization (RHCP) can be obtained by exciting the two orthogonal linearly polarized modes with a 90° phase offset, which is due to this proposed longer strip-sleeve perpendicular to the x-directional F-shaped monopole strip. Moreover, to obtain high-band operation, the shorter arm of the F-shaped strip is added to generate the fundamental resonant mode at approximately 5200 MHz. Similarly, a shorter strip-sleeve of L16 × W6 is utilized and placed at the mirror side of the above longer one with respective to the y-axis for the excitation of the left-hand circular polarized (LHCP) wave in the $+z$-direction. Moreover, the antenna is optimized according to the above guidelines and using Ansoft HFSS, a commercially available software package based on the finite-element method [9]. Then, return loss is measured with an Agilent N5230A vector network analyzer. Figure 1 displays the design parameter values obtained by the above strategy. In addition, the results are simultaneously optimized by applying the following setting in Ansoft HFSS: $L = 40$ mm, $L1 = 14$ mm, $L2 = 14$ mm, $L3 = 6.5$ mm, $L4 = 6$ mm, $L5 = 5$ mm, $L6 = 5$ mm, $L7 = 5$ mm, $L8 = 5$ mm, $L9 = 4$ mm, $L10 = 1.5$ mm, $L11 = 15$ mm, $L12 = 14$ mm, $L13 = 8$ mm, $L14 = 14$ mm, $L15 = 10$ mm, $L16 = 5.5$ mm, $W = 40$ mm, $W1 = 3$ mm, $W2 = 3$ mm, $W3 = 1.5$ mm, $W4 = 0.5$ mm, $W5 = 2$ mm, and $W6 = 2$ mm.

III. RESULTS AND DISCUSSIONS

Figure 2 shows the related simulation and experimental results for return loss in the proposed dual-band CP MA. The lower band reveals a measured 2:1 VSWR (10-dB return loss) bandwidth of 260 MHz (2390–2650 MHz), whereas the upper band has a bandwidth of 988 MHz (4600–5588 MHz). Dual bands can comply with the bandwidth requirements needed for dual-band WLAN (2.4/5.2 GHz) application. Since the dielectric constant and loss tangent of the FR4 substrate fluctuate with the operating frequency [10, 11], the measured resonant frequencies and input impedance for the proposed antenna slightly differ from the simulated results obtained at

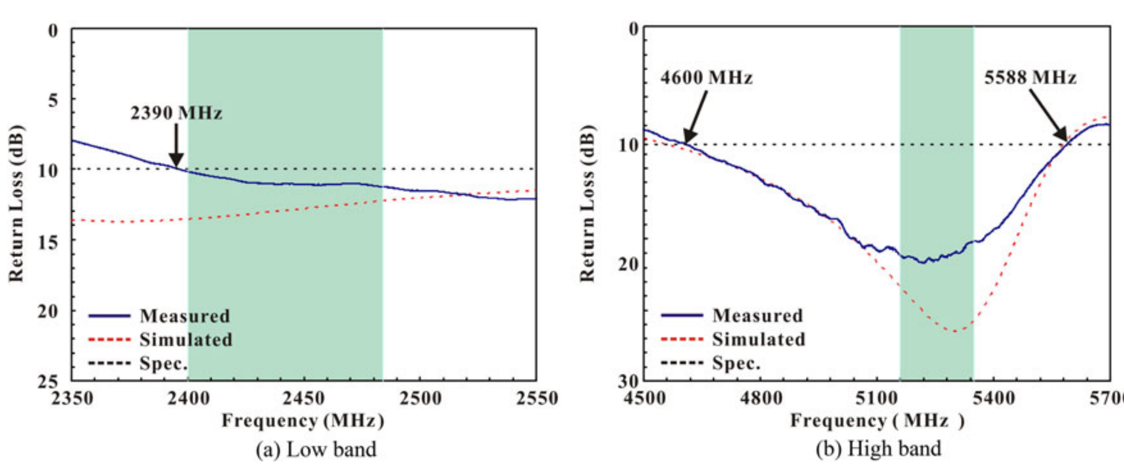

Fig. 2. Simulated and measured return loss against frequency for the proposed dual-band CP MA. (a) Low band. (b) High band.

https://doi.org/10.1017/S1759078714001329 Published online by Cambridge University Press

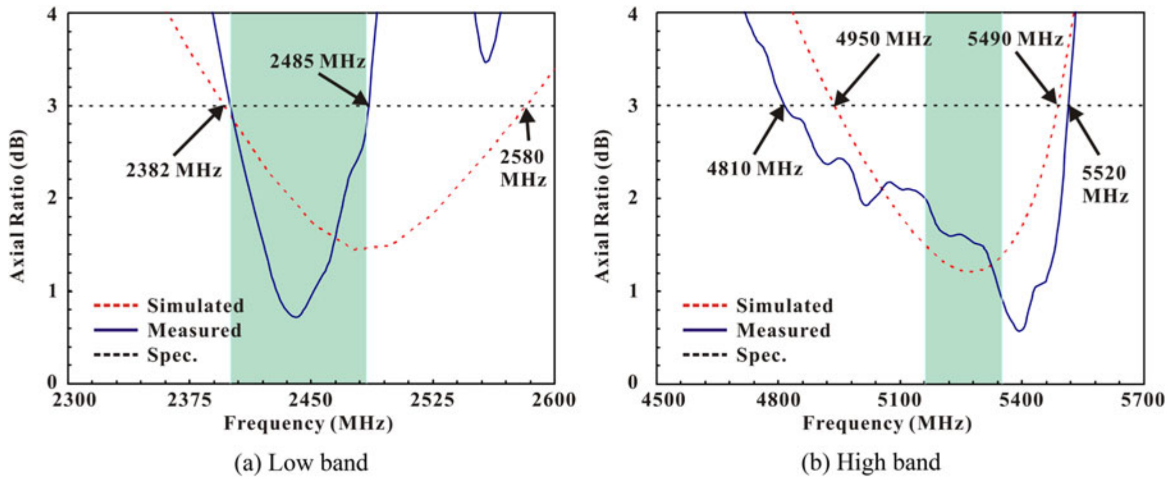

Fig. 3. Simulated and measured AR against frequency for the proposed dual-band CP MA. (a) Low band. (b) High band.

some substrate parameter settings. Figure 3 shows the related simulated and experimental results of the axial ratio (AR, in the boresight direction) for the proposed dual-band CP antenna of Fig 1. From the related results, the measured operating bandwidth (3-dB AR) can reach about 103 MHz (2382–2485 MHz) and 710 MHz (4810–5520 MHz) at 2.4/5.2 GHz

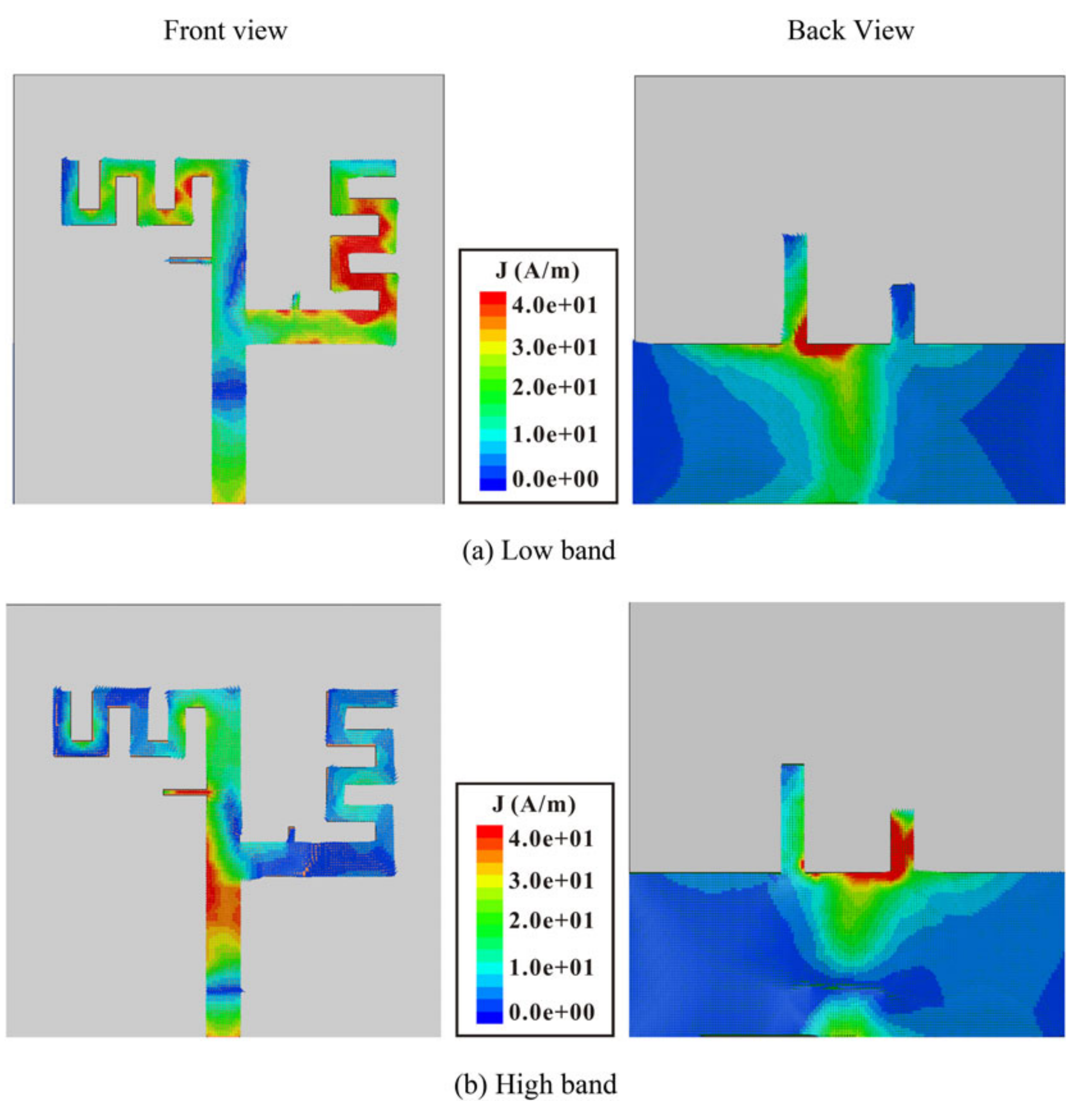

Fig. 4. Simulated surface current distributions on the major metal pattern of the proposed dual-band CP monopole antenna. (a) Low band. (b) High band.

https://doi.org/10.1017/S1759078714001329 Published online by Cambridge University Press

bands, respectively, which agrees well with the HFSS-simulated results. For a clear understanding of the excitation in each WLAN band, Fig. 4 shows the simulated surface current distributions on the proposed antenna at dual operating bands. First, Fig. 4(a) shows the surface current distribution along the meander longer arm of the F-shaped monopole strip excited at its fundamental mode at 2450 MHz with a 0.5 wavelength surface current distribution. Meanwhile, in Fig. 4(b), the surface current at 5200 MHz band is distributed along the shorter arm of the F-shaped monopole strip with a 0.25 wavelength surface current distribution.

In order to achieve the desired AR and impedance match, we need to slightly modify corresponding parameters in cooperating with the antennas modification from which the CP radiation is generated. Return loss and AR performance are mainly affected by the dimensions of the F-shaped monopole strip and the shorted strip-sleeves to ensure a phase lag or leading for the proposed dual-band CP antenna. Figure 5 shows the simulated results of return loss and AR against frequency for the proposed CP antenna with various antenna structures for comparison. From the related return loss in Fig. 5(a), it is obviously observed that good impedance matching at 2.4 GHz band is obtained for each antenna structure; however, the performance at 5.2 GHz band are significantly affected by the asymmetric shorted strip-sleeves, which can only provide better impedance matching for the proposed antenna. Moreover, from the related AR results in Fig. 5(b), we find that the introduced shorted strip-sleeves make the CP performance become better simultaneously at dual-operating bands. Then, to realize the CP operation at 2450 and 5200 MHz bands, the effect of the asymmetric strip-sleeves for four phase angles of 0°, 90°, 180°, and 270°, respectively, has also been investigated and shown in Fig. 6. For the lower operating (2450 MHz) band, it is found that,

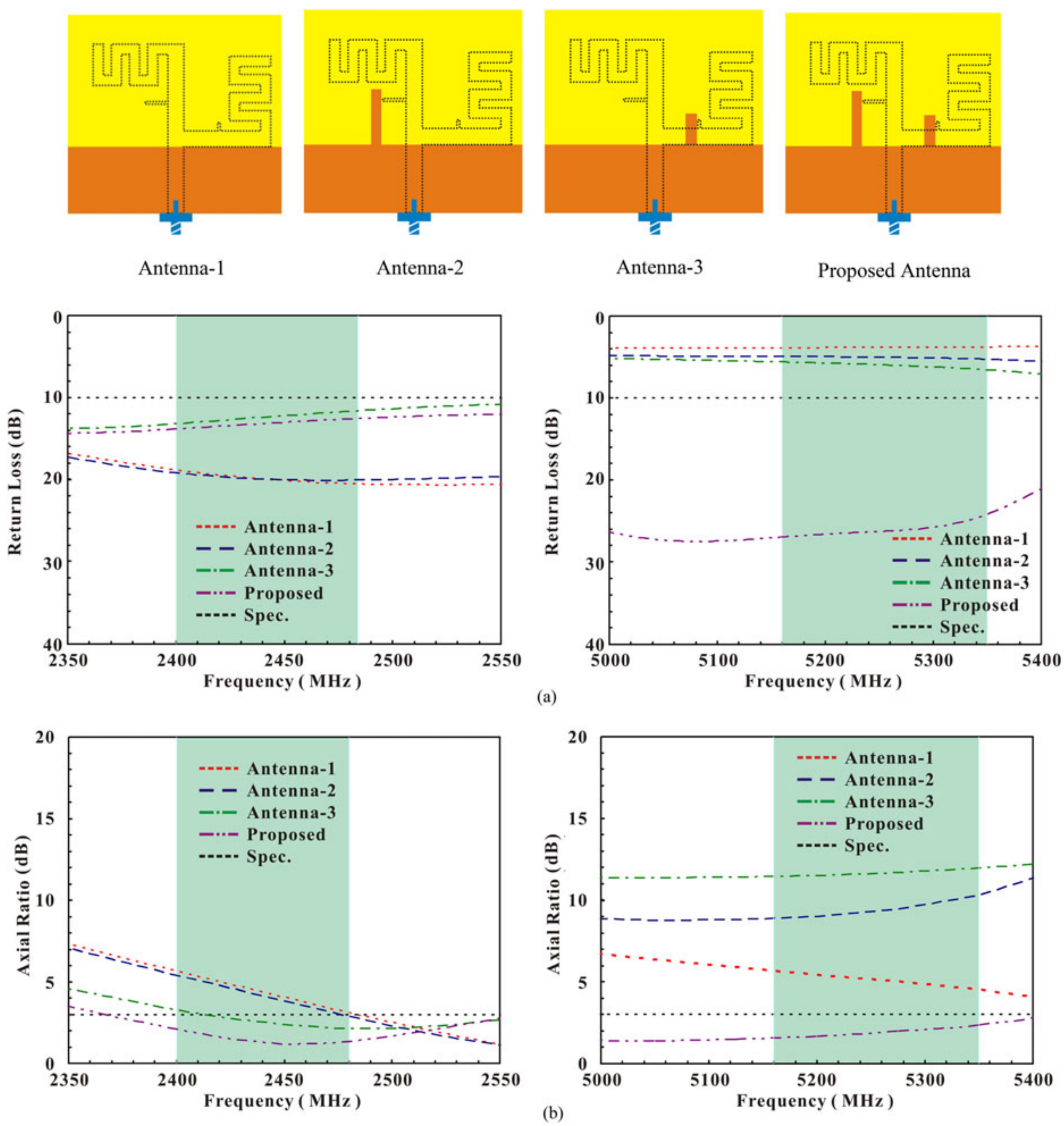

Fig. 5. Simulated return loss and AR against frequency for various antenna structures.

https://doi.org/10.1017/S1759078714001329 Published online by Cambridge University Press

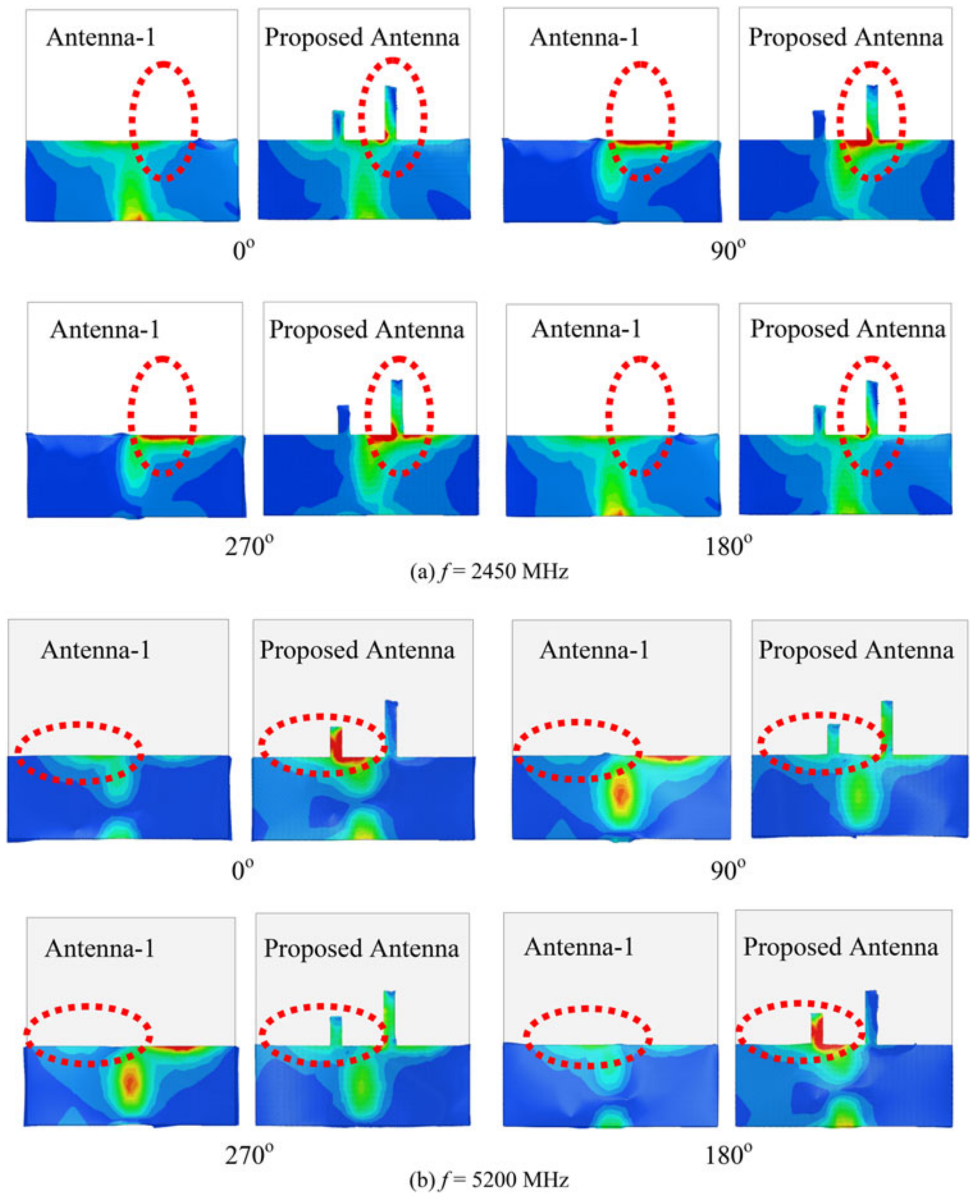

Fig. 6. Simulated surface current distribution on the ground plane for the proposed dual-band CP MA with the asymmetrical strip-sleeves or not. (a) $f = 2450$ MHz. (b) $f = 5200$ MHz.

at the same position (dashed circle in the figure), the longer strip-sleeve disturb the surface current distribution on the ground plane in Fig. 6(a) for each phase angle to obtain RHCP operation. Likewise, by adding the shorter strip-sleeve, the surface current distribution difference on the ground plane between Antenna-1 and the proposed antenna at the higher operating (5200 MHz) band can be observed in Fig. 6(b). Therefore, the LHCP wave radiates in the $+z$-direction.

For a complete study of the far-field performance of the proposed compact antenna inside an anechoic chamber, an Agilent N5230A vector network analyzer and a computer workstation running three-dimensional (3D) NSI 800F far-field measurement software were used according to generally applied methodologies for measuring antenna gain, directivity, and efficiency as described in the IEEE Standard Test Procedures for Antennas: ANSI/IEEE-STD149–1979 [12]. The proposed compact MA is arranged on the test platform to receive power radiated from the transmitted double-ridged horn antenna (DRHA) with a 1–18 GHz operating frequency. The measured peak gain is then obtained using the gain transfer method by utilizing a standard gain horn antenna as a reference. The calculation for radiation efficiency was the ratio of radiated power to total power supplied to the radiator at a given frequency [12]. Figure 7 plots the measured antenna gain and efficiency (including mismatching loss, [13]) for the proposed printed antenna. This figure also shows the simulation results for comparison. The measured antenna gain is approximately 3.5–4.1 dBi for frequencies over the 2.4 GHz bands, while approximate 2.5–3.3 dBi of that for the 5.2 GHz band. The measured antenna efficiency is about 91–94% over the 2.4 GHz bands, whereas the value of that for 5.2 GHz is about 60–84%. The radiation patterns of the proposed CP antenna at 2.4 and 5.2 GHz bands are plotted in Fig. 8, and a good symmetry of bidirectional radiation has been observed. Since a CP MA radiates a bidirectional

https://doi.org/10.1017/S1759078714001329 Published online by Cambridge University Press

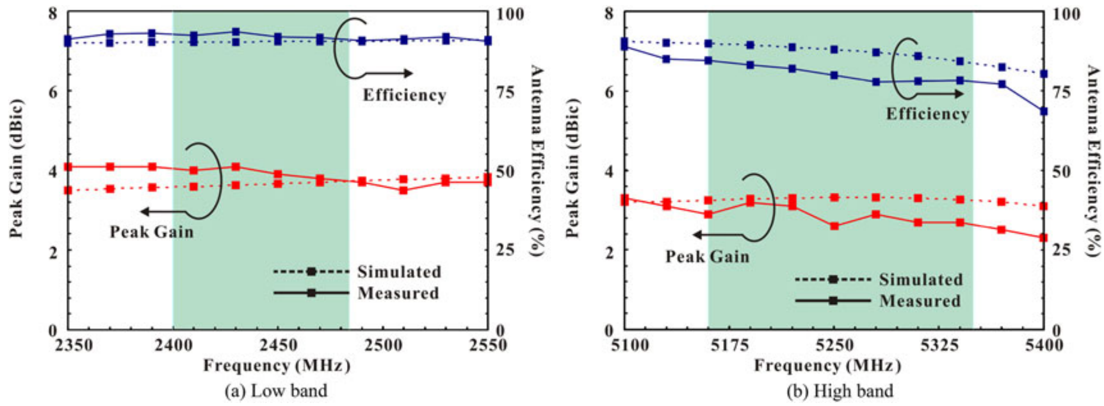

Fig. 7. Measured and simulated antenna gain and efficiency for the proposed dual-band CP MA studied in Fig. 2.

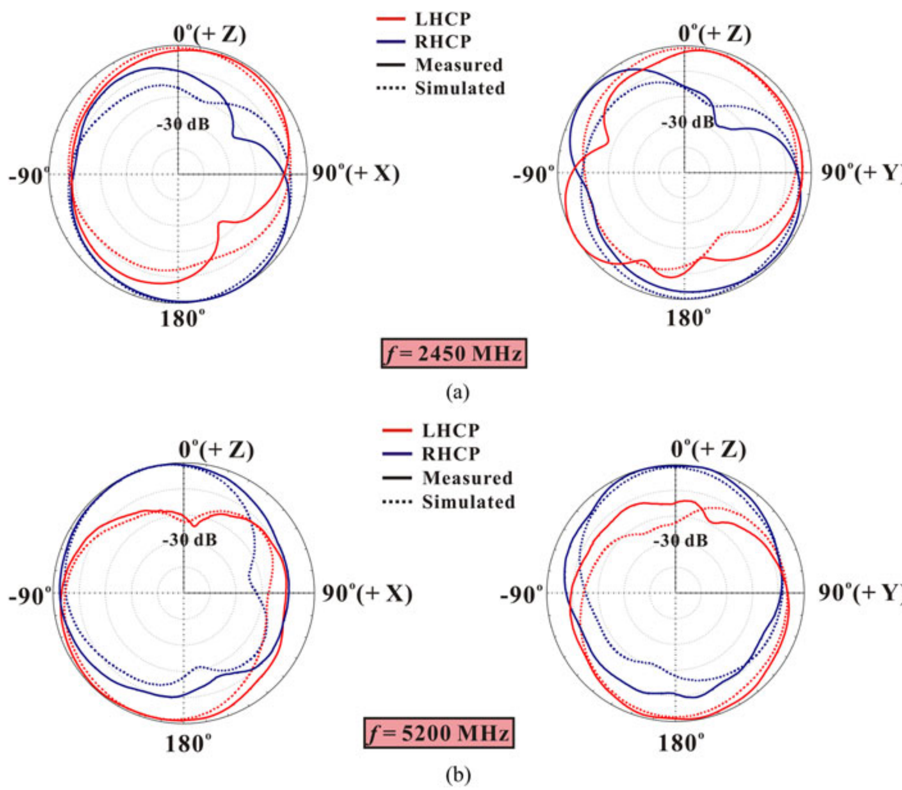

Fig. 8. Simulated and measured two-dimensional (2D) radiation patterns for the proposed dual-band CP MA.

wave, the radiation patterns on both sides of the proposed CP MAs are almost the same, in which a contrary circular polarization is produced; the front-side radiates LHCP, whereas the back-side radiates RHCP. In a result, there are evidences that the coherence exists between the measured and simulated data. Meanwhile, by verifying arguments of the proposed antenna, it has successfully achieved a cross = polarization discrimination of 15 dB on a wide azimuth range.

IV. CONCLUSION

This paper exhibits a planar dual-band MA with circular polarization by introducing dual sleeve-shaped strips shorted at the ground plane. This innovative design achieved dual-band operation at 2.4/5.2 GHz bands in the application of the WLAN system, with the impedance bandwidth (RL ≧10 dB) close to 260/988 MHz and the 3 dB AR bandwidth of about 103/710 MHz, and its overall volume of 40 × 40 × 0.8 mm^3 is over 20% smaller than that of comparable CP antennas. It also provided nearly bidirectional radiation patterns with peak gain and radiation efficiency of about 4.1/3.3 dBic and 94/84 %, respectively, across the operating bands in the *XZ*- and *YZ*-plane. The practical numerical results approve that this antenna design is well conformed to the WLAN system for the IEEE 802.11a/b/g specifications.

ACKNOWLEDGEMENTS

It is a particular pleasure to acknowledge the grant and support of the Ministry of Science and Technology

(MOST), Taiwan Republic of China (Reference no. NSC101-2221-E-022-011-MY2).

REFERENCES

[1] Phang, S. P.; Chen, N.W.: Annular ring monopole antenna with switchable polarization. IEEE AP-S Int. Symp. Digest, (2012), 1–2.

[2] Li, G.; Zhai, H.; Li, T.; Li, L.; Liang, C. H.: A compact antenna with broad bandwidth and quad-sense circular polarization. IEEE Antennas Wirel. Propag. Lett., **11** (2012), 791–794.

[3] Rezaeieh, S.A.: Dual band dual sense circularly polarised monopole antenna for GPS and WLAN applications. Electron. Lett., **47** (2011), 1212–1214.

[4] Wu, J.W.; Jou, C.F.; Wang, C.J.: A dual-band circularly polarized monopole antenna for WLAN application. *Int. Workshop on Antenna Technology*, (2009) 346–349.

[5] Jou, C. F.; Wu, J. W.; Wang, C. J.: Novel broadband monopole antennas with dual-band circular polarization. IEEE Trans. Antennas Propag., **57** (2009), 1027–1034.

[6] Bao, X. L.; Ammann, M. J.; McEvoy, P.: 'Microstrip-fed wideband circularly polarized printed antenna. IEEE Trans. Antennas Propag., **58** (2010), 3150–3156.

[7] Wu, J. W.; Ke, J. Y.; Jou, C. F.; Wang, C. J.: Microstrip-fed broadband circularly polarised monopole antenna. IET Microw. Antennas Propag., **4** (2010), 518–525.

[8] Wu, J. W.; Wang, Y. D.; Hsiao, H. M.; Lu, J. H.: T-shaped monopole antenna with shorted L-shaped strip-sleeves for WLAN 2.4/5.8 GHz operation. Microw. Opt. Technol. Lett., **46** (2005), 65–69.

[9] http://www.ansoft.com/products/hf/hfss, Ansoft Corporation HFSS.

[10] Namba, A. et al.: A simple method for measuring the relative permittivity of printed circuit board materials. IEEE Trans. Electromagn. Compat., **43** (2001), 515–519.

[11] Djordjevic, A.R.; Biljic, R.M.; Likar-Smiljanic, V.D.; Sarkar, T.K. Wideband frequency-domain characterization of FR-4 and time-domain causality. IEEE Trans. Electromagn. Compat., **43** (2001), 662–519.

[12] IEEE Standard Test Procedures for Antennas: ANSI/ IEEE-STD149-1979, Sec. 12–13, 94–112.

[13] Huang, Y.; Boyle, K.: Antennas from Theory to Practice, Wiley, 2008, 326.

Jui-Han Lu has received the Ph.D. degree in Electrical Engineering from the National Sun Yat-sen University, Kaohsiung, Taiwan in 1997. In 2001, for his published SCI papers highly cited, he received the ISI (Institute for Scientific Information) Citation Classic Award for "Honoring Excellence in Taiwanese Research" from ISI and the National Science Council of Taiwan. In 2003, he became a Full Professor and was elected as Ten Outstanding Young Persons in Taiwan in 2005 for his contributions in antenna researches and academic–industry cooperation. From 2007 to 2010, Professor Lu served as the Dean of the College of Ocean Engineering at National Kaohsiung Marine University. In 2013, with contributions in EM Theory teaching and Mobile Antenna researches, he received MOE (Ministry of Education) Outstanding Teaching and Research Award. He presently serves as Chair of IEEE AP-S Tainan Chapter (2013–2014) and is the Awards Committee Chair of 2013 NST (National Symposium on Telecommunications in Taiwan) and 2014 ISAP (International Symposium on Antennas and Propagation). He is a life member of IAET (Institute of Antenna Engineers of Taiwan) and a Senior Member of the IEEE.

Hao-Shiang Huang has received the B.S. and M.S. degrees in Electronic Communication Engineering from the National Kaohsiung Marine University, Kaohsiung, Taiwan in 2012 and 2014, respectively. His current research interests include antenna design and microwave circuit.

https://doi.org/10.1017/S1759078714001329 Published online by Cambridge University Press