Progress In Electromagnetics Research C, Vol. 40, 257–267, 2013

NOVEL WIDEBAND OMNIDIRECTIONAL ANTENNA FOR WIRELESS APPLICATIONS

Yun-Qi Zhang*, **Jian-Wei Rong, Xi Li, Lin Yang, and Shu-Xi Gong**

National Key Laboratory of Antenna and Microwave Technology, Xidian University, Xi'an , Shaanxi 710071 , People's Republic of China

Abstract—This paper presents the design of a novel wideband omnidirectional antenna with the usable bandwidth enhanced. The antenna is designed for wireless applications and proposed to operate within WLAN (2.4 GHz–2.484 GHz) and WiMAX (2.3 GHz, 2.5 GHz and 3.5 GHz) frequency bands. The bandwidth is enhanced through the use of balun, while the radiation patterns remain stable. This antenna has a much wider VSWR band (47.5% for VSWR < 2) with high radiation pattern stability compared with printed dipole antennas. Details of design, simulated and experimental results of this omnidirectional antenna are presented and discussed. The measured results confirm the validity of this design which meet the requirements of wireless applications.

1. INTRODUCTION

Antennas with an omnidirectional radiation pattern in the azimuthal plane can cover a large service area and have a wide applications in the mobile, world interoperability for microwave access (WiMAX) and wireless local area network (WLAN) systems [1]. To meet these radiation pattern requirements, the planar dipole array antenna for WLAN operations has been demonstrated in [2]. The cylindrical omnidirectional patch array antenna was designed [3, 4]. The omnidirectional array antenna achieved a higher gain, but the bandwidth was much too narrow (about 5%). A printed dipole array omnidirectional antenna employed double side dipoles and added some stubs for impedance matching [5]. But the bandwidth for VSWR < 2 is only around 19%. The applications in wireless

Received 4 May 2013, Accepted 31 May 2013, Scheduled 4 June 2013

* Corresponding author: Yun-Qi Zhang (johnny_5@126.com).

communication technologies are placing greater demands on wider impedance bandwidth and smaller antenna size. The antenna shown in [6] performs ultra-wide band work, but the structure is complex and not easy to fabricate. Though the parallel feeding omnidirectional array antenna shown in [7] has a wider bandwidth than that in [2], the feeding line to it is not given. The dual band omnidirectional antenna in [8] is too large in size. These radiation patterns of antennas for WiMAX and WLAN were not stable and the ellipticity of the azimuthal plane is too high [9, 10]. The advantages and disadvantages of these antennas above are shown in Table 1.

Table 1. The advantages and disadvantages of these antennas in references.

Type of antenna	Omnidirectional array antenna [2–4]	Dipole array [5]	Ultra-wide or dual band antenna [6, 8]	Multiband antenna [9, 10]
Advantages	Good omnidirectional radiation, high gain	Bandwidth enhanced	Wide bandwidth	Multiband operation
Disadvantages	Bandwidth is too narrow	Bandwidth not wide enough	Structure is complex, or too large in size	Radiation pattern is not stable

Due to the rapid development of mobile communications, the need for omnidirectional antennas with multi-band or wideband operation has increased considerably [11, 12]. The wireless local area network (WLAN) operates at 2.4 GHz to 2.5 GHz (IEEE 802.11b and IEEE 802.11g), and world interoperability for microwave access (WiMAX) operates at 2.3 GHz, 2.5 GHz and 3.5 GHz. Therefore, we propose a novel design method of the wideband omnidirectional planar microstrip antenna. By using the wideband balun, the proposed antenna can cover the desired bands for WLAN and WiMAX applications. Details of the proposed antenna design and the experimental results are demonstrated.

2. ANTENNA GEOMETRY

The proposed antenna consists of two printed dipoles. These two elements are cross-fed by parallel broadside coupled lines to actualized impedance match. The wideband operation is realized by adding the balun and wider dipole.

2.1. Basic Antenna Structure

For a dipole with different lengths, as shown in Fig. 1, the electric and magnetic field components in the far field are written as

$$E(\theta) = j\frac{60I_M}{r}\frac{\cos(kl\cos\theta) - \cos kl}{\sin\theta}e^{-jkr}\hat{\theta} \tag{1}$$

$$H(\theta) = j\frac{I_M}{2\pi r}\frac{\cos(kl\cos\theta) - \cos kl}{\sin\theta}e^{-jkr}\hat{\phi} \tag{2}$$

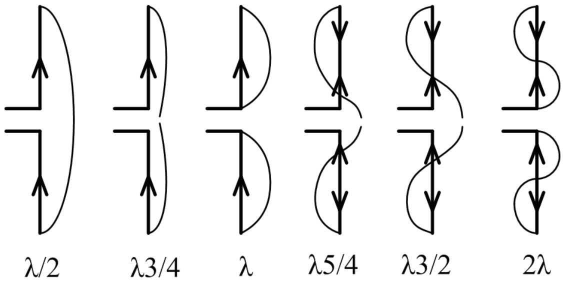

Figure 1. The current distribution of different length.

The most useful type of dipole is half-wavelength dipole, assuming that the current is of uniform magnitude and in-phase along the entire length of a $\lambda/2$ linear element. By letting $l = \lambda/2$, the electric field component is reduced to

$$E_\theta \approx j\eta\frac{I_0 e^{-jkr}}{2\pi r}\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta} \tag{3}$$

where r is the distance between the dipole and the observe points, l the length of the dipole, I_M a coefficient of the current maximum, and η the intrinsic impedance ($377 \approx 120\pi$ ohms for free-space) [13].

Seen from Equation (3), the half-wavelength dipole is a omnidirectional antenna with a omnidirectional radiation pattern in the H plane. So in the paper we chose the half-wavelength as the basic structure. The main parameters of printed dipole are the width and length of the arms. Generally, the bandwidth increases with the width. The center frequency of the antenna mainly depends on the length. Practically the length of the arms is less than half-wavelength. Normally the length of the arms should multiply the factor of 0.8. The thickness of the substrate influences the bandwidth. The thicker the substrate is, the wider the bandwidth is.

The geometry of the printed dipole antenna is shown in Fig. 2. The two arms of the printed dipole are settled on each side of the substrate. In order to obtain more stable radiation patterns and decrease the ellipticity, parasitical arms are printed on the other side of the substrate and connected by metal pins. The parallel broadside coupled lines are used as the feeding line. A 180° phase difference is brought in between the lines.

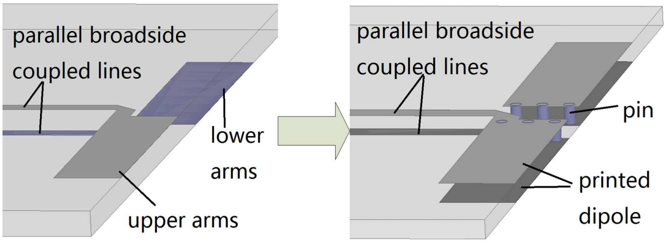

Figure 2. The basic structure of the printed dipole antenna.

2.2. Coupled Lines Feed

The feed to the half-wavelength dipole is the coupled lines. The resistance of the coupled lines can be calculated through microstrip lines with the same width and half thickness of the substrate. As shown in Fig. 3, the voltage between the microstrip lines and the ground plane is U, while the current is I, and the resistance can be defined as $Z_c = U/I$. For coupled lines, the voltage is $2U$, the current I, and the resistance $Z_0 = 2U/I = 2Z_c$.

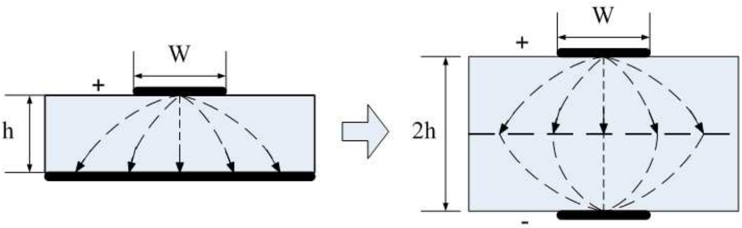

Figure 3. The calculation of the coupled lines resistance.

2.3. Proposed Antenna Design

Figure 4 shows the configuration of the proposed antenna. Two half-wavelength dipoles are printed on both sides of the substrate. The parasitical elements are connected to the fed ones by metal pins. The antenna is fed by coupled lines. A balun is added to increase the VSWR bandwidth. All the values of the parameters are shown in Fig. 4. The process of design will be given in Section 3.

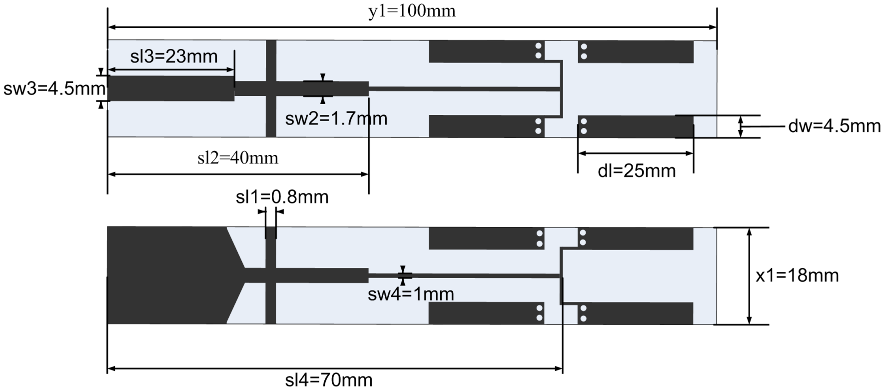

Figure 4. Top and bottom view of the proposed antenna.

3. ANTENNA DESIGN

This antenna is designed to cover the two bands of WLAN (IEEE 802.11 a/b/g wireless local area network, 2.4 GHz) and WiMAX (World Interoperability for Microwave Access, 2.3 GHz, 2.5 GHz, 3.5 GHz), with 50 Ω input impedance. The gain is supposed to be greater than 0 dBi, while the ellipticity is less than 3 dB. As the WLAN and WiMAX frequencies are close to each other, we design the center frequency at 2.95 GHz.

The antenna without balun is simulated first. As shown in Fig. 5, the operation frequency of the antenna varies with different values of dl. It is seen from the figure that the longer the arms of the dipole are, the lower center frequency will be. The length of arms is optimized 25 mm as the operation frequency settles at 2.95 GHz. The input impendence of the antenna without balun is shown in Fig. 6. The real part of the input impedance is smaller than 50 Ω, while the imaginary part is much lower than zero. Adding the balun meliorate the real part much, as shown in Fig. 7, the real part is around 50 Ω. The imaginary part

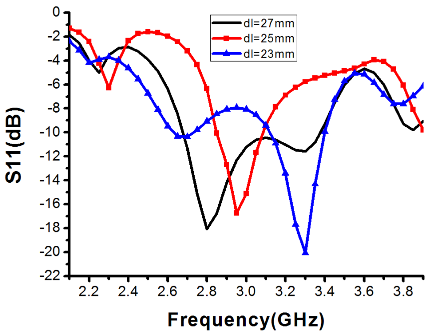

Figure 5. The simulated S_{11} with different values of *dl*.

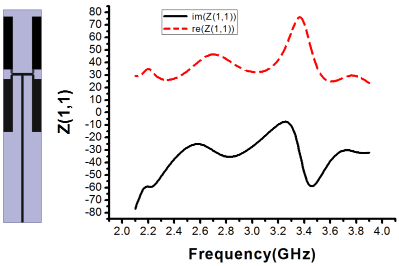

Figure 6. The input impendence of the antenna without balun.

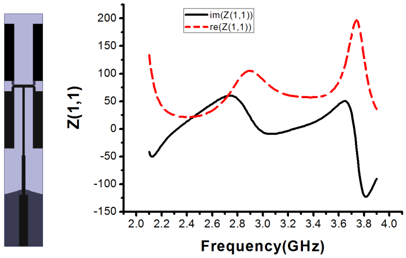

Figure 7. The input impendence of the antenna with balun.

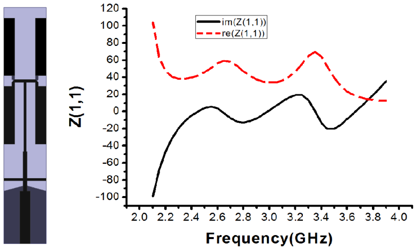

Figure 8. The input impendence of the proposed antenna.

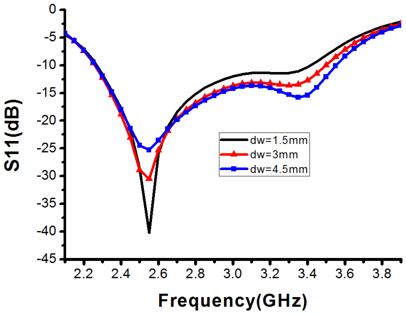

Figure 9. The simulated S_{11} with different values of *dw*.

is turned up to zero by adding the branch line, as shown in Fig. 8, which indicates the wideband characteristics of this antenna. Fig. 9 shows the simulated S_{11} with different widths of the arms. As seen, the simulated bandwidth is broadened with the increase of dw when $dw < 4.5$ mm. We chose $dw = 4.5$ mm, because a bigger value will influence the ellipticity of H plane. The simulated VSWR of the proposed antenna is shown in Fig. 10. The bandwidth for VSWR < 2 is about 45.2% (2.25 GHz–3.56 GHz), which covers the bands of the WLAN and WiMAX.

The radiation patterns of the proposed antenna remain stable in the whole band. Meanwhile, the ellipticity of the H-plane is smaller than 3 dB. In addition, it is worth mentioning that the length of the proposed antenna is only 100 mm, which is approximately equivalent to 0.89 free wavelength at the center frequency.

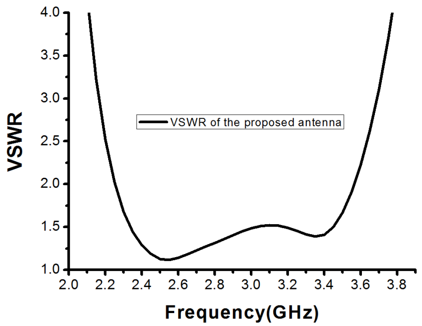

Figure 10. The VSWR of the proposed antenna.

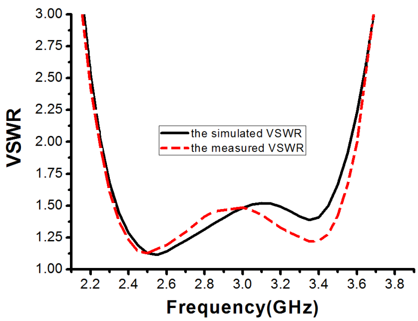

Figure 11. The measured VSWR of the proposed antenna.

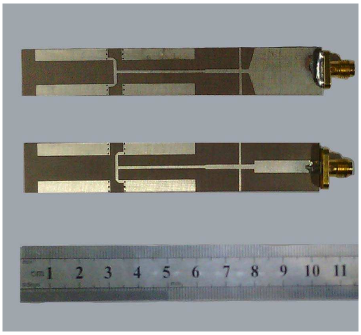

Figure 12. The top view of the proposed antenna.

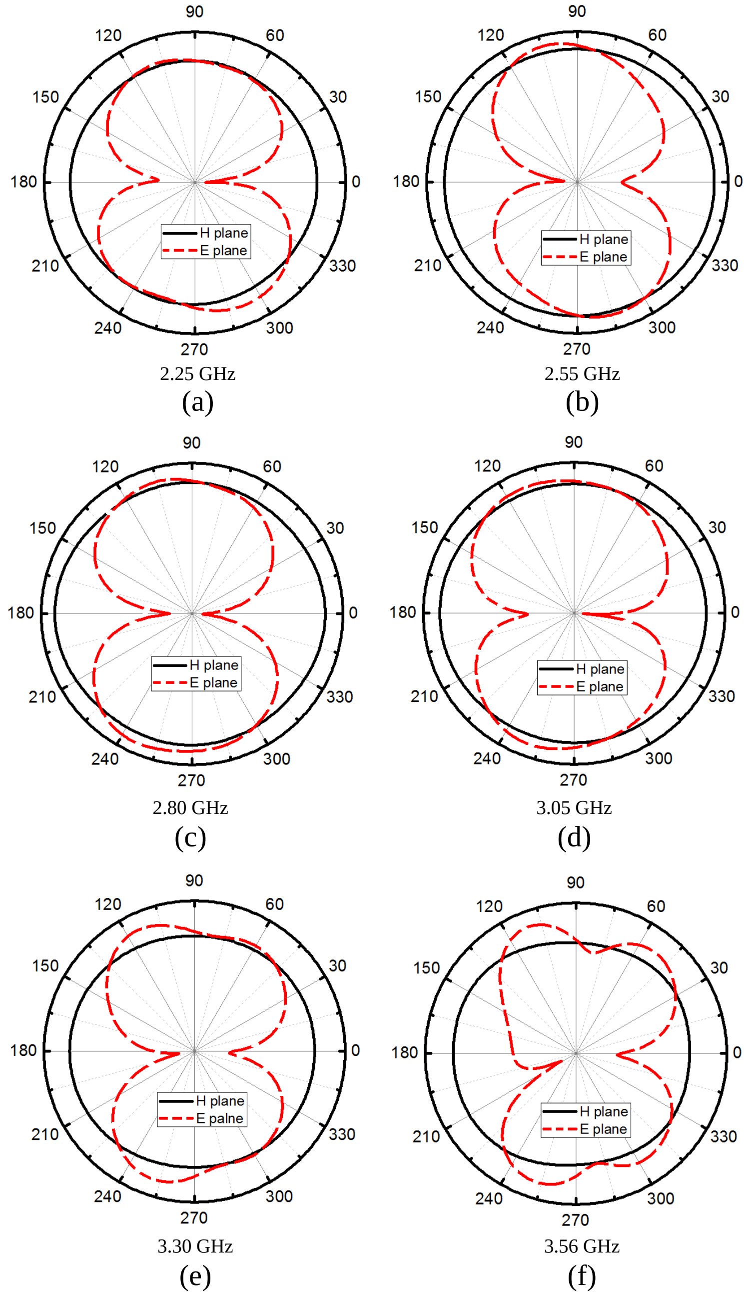

Figure 13. The measured radiation pattern of each frequency.

4. SIMULATION AND MEASUREMENT RESULTS

Figure 11 shows the measured VSWR of the proposed antenna. As shown, the measured and simulated data are in good agreement. The bandwidth for VSWR < 2 is 47.5% (2.21 GHz–3.59 GHz), which shows the wideband character of the antenna.

The actual prototype of the fabricated antenna is shown in Fig. 12. The measured radiation patterns of each frequency are shown in Fig. 13. For the omnidirectional antenna, the most attractive characteristic is the ellipticity of the H-plane. The ellipticity means the max gain variation of the H plane. We measured the proposed antenna emplaced vertically as the transmit antenna, and the receive antenna measured the gain of H plane, as shown in Fig. 14. The ellipticity becomes worse with increasing frequency. The measured ellipticity and gain of each frequency are shown in Table 2. The measured ellipticity is less than 3 dB within the band. The gain is higher than 1 dBi. The measured results confirm the validity of this design, which meet the requirements of our design.

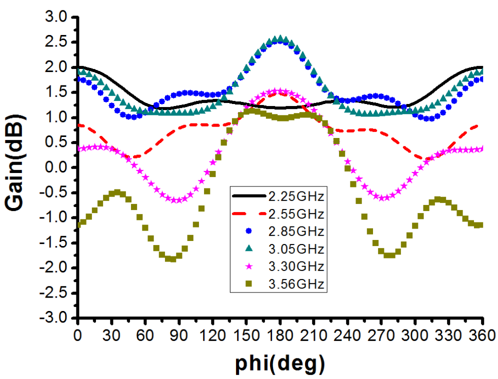

Figure 14. The measured ellipticity of each frequency.

Table 2. The measured ellipticity & gain of the antenna.

Frequency (GHz)	2.25	2.55	2.80	3.05	3.30	3.56
Ellipticity (dB)	0.81	1.31	1.56	1.50	2.18	2.96
Gain (dBi)	1.19	1.47	2.52	2.57	1.52	1.02

5. CONCLUSION

This paper introduces a new design of wideband omnidirectional microstrip antenna with stable radiation patterns and gain for wireless communication. Compared to the conventional dipole antenna, this antenna owns wider bandwidth in both VSWR and ellipticity. Using a wideband balun, the bandwidth has been enhanced much. The antenna provides a wide usable bandwidth of 47.5%. To meet the requirements of the IEEE 802.11 a/b/g wireless local area network (WLAN) and world interoperability for microwave access (WiMAX), a simple prototype follows the design that operates at 2.21 GHz–3.59 GHz with VSWR < 2 and ellipticity less than 3 dB. Moreover, the volume is small, and the cost is low. We present a detailed analysis of this antenna. From the measured results, it is seen that the proposed antenna achieves good omnidirectional performance, which will meet the requirements of WLAN and WiMAX applications.

REFERENCES

1. Hsiao, F.-R. and K.-L. Wong, "Omnidirectional planar folded dipole antenna," *IEEE Trans. Antennas and Propagation*, Vol. 52, No. 7, 1898–1902, Jul. 2004.
2. Wong, K.-L., F.-R. Hsiao, and T.-W. Chiou, "Omnidirectional planar dipole array antenna," *IEEE Trans. Antennas and Propagation*, Vol. 52, No. 2, 624–628, Feb. 2004.
3. Herscovici, N., Z. Sipus, and P.-S. Kildal, "The cylindrical omnidirectional patch antenna," *IEEE Trans. Antennas and Propagation*, Vol. 49, 1746–1753, Dec. 2001.
4. Jayakumar, I., R. Garg, B. K. Sarap, and B. Lal, "A conformal cylindrical array for producing omnidirectional radiation pattern," *IEEE Trans. Antennas and Propagation*, Vol. 34, 1258–1261, Oct. 1986.
5. Chen, Y., W. Hong, X. Zhu, and Z. Kuai, "A new printed dipole array omnidirectional antenna with bandwidth enhancement," *Proceedings of International Symposium on Signals, Systems and Electronics (ISSSE2010)*, 1–3, 2010.
6. Zhang, Y., J. Qiu, W. Guo, and C. Yang, "Novel ultra-wide band omni-directional dipole antenna," *International Conference on Microwave and Milimeter Wave Technology (ICMMT)*, 1–4, 2012
7. Ma, C., Z. Kuai, X. Zhu, and C. Liu, "A parallel feeding omnidirectional array antenna," *2012 IEEE Antennas and*

Propagation Society International Symposium (APSURSI), 1–2, 2012.

8. Wei, K. P., Z. J. Zhang, and Z. H. Feng, "Design of a dualband omnidirectional planar microstrip antenna array," *Progress In Electromagnetics Research*, Vol. 126, 101–120, 2012.
9. Saghati, A. P., M. Azarmanesh, and R. Zaker, "A novel switchable single- and multifrequency triple-slot antenna for 2.4 GHz bluetooth, 3.5 GHz WiMax, and 5.8 GHz WLAN," *IEEE Antennas and Wireless Propagation Letters*, Vol. 9, 534–537, 2010.
10. Hu, W., Y.-Z. Yin, P. Fei, and X. Yang, "Compact triband square-slot antenna with symmetrical L-strips for WLAN/WiMAX applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 10, 462–465, 2011.
11. Li, J.-Y. and Y.-B. Gan, "Multi-band characteristic of open sleeve antenna," *Progress In Electromagnetics Research*, Vol. 58, 135–148, 2006.
12. Alkanhal, M. A. S., "Composite compact triple-band microstrip antennas," *Progress In Electromagnetics Research*, Vol. 93, 221–236, 2009.
13. Constantine, A. B., *Antenna Theory Analysis and Design*, John Wiley & Sons, New York, 2005.