A Dual-Loop Antenna in a Cage Structure for Horizontally Polarized Omnidirectional Pattern

Yi Zhang, *Student Member, IEEE*, Zhijun Zhang, *Senior Member, IEEE*, Yue Li, *Member, IEEE*, and Zhenghe Feng, *Fellow, IEEE*

***Abstract*—In this letter, we have presented a horizontally polarized antenna with a cage-like structure for omnidirectional coverage in the azimuthal plane, which can be used in the occasion that it is close to the metal box. The proposed antenna consists of dual crossed loops and a 90° hybrid coupler feeding. The dual crossed loops are arranged in a cage structure, which shows the merits of simple construction and easy fabrication with compact volume. The overall volume of the proposed antenna is only $52 \times 19 \times 19$ mm^3, with a gain variation less than 1.1 dB in the azimuthal plane. The size of the cross section is small. A prototype of the proposed antenna is built at 2.4-GHz wireless local area network (WLAN) band. The measured results show that the 10-dB reflection coefficient bandwidths cover the desired WLAN band of 2.4–2.48 GHz, with a constant gain better than 2.7 dBi.**

***Index Terms*—Antenna feed, antenna radiation pattern, loop antenna.**

I. Introduction

RECENTLY, with the rapid progress in the wireless communication technology, omnidirectional antennas have led to a wide range of applications in modern wireless communications such as wireless local area network (WLAN) systems. In the urban or indoor wireless environment, after complicated multiple reflections or scattering, the polarization of the propagating radio waves may change significantly. It has been predicted in [1] and [2] that a receiver with an additional horizontally polarized omnidirectional antenna can obtain up to 10 dB diversity gain than a receiver with only a vertically polarized antenna. Furthermore, the horizontally polarized antenna is needed in the polarization diversity systems for improving the reliability of a communication link. Therefore, the horizontally polarized omnidirectional antennas are preferable for WLAN applications.

Vertically polarized dipole-like antennas with an omnidirectional pattern have been most commonly used for many years, wherein the antennas radiate equally in the H-plane [3]. However, the design of the horizontally polarized antenna with an omnidirectional pattern is much more challenging because it is required to radiate equally in the E-plane.

To obtain the horizontally polarized radiation pattern, electrically small loop antennas with uniform current distribution are considered. An electrically small loop antenna will have a very small radiation resistance but a high reactance, which is difficult to be matched and has low radiation efficiency. A large loop antenna can be matched easily, but it cannot generate omnidirectional patterns [4]. To overcome this contradiction, some design methods are reported. In [5]–[9], metamaterials are used to keep the current on a loop antenna in phase, thus enabling one to generate horizontally polarized omnidirectional radiation. The Alford loop antenna can also generate the desired pattern keeping the current in phase along the large loop. However, the complicated structure and the difficulty in manufacturing are the fundamental problems in such designs, and it requires large board area [10]. The radiation capacity is poor when the loop antennas are mounted on the metal box. In [11], a high-gain periodic leaky-wave antenna array with horizontally polarized omnidirectional pattern is proposed.

In this letter, a novel compact antenna design with horizontally polarized omnidirectional pattern is proposed. The main radiation elements of the proposed antenna are two orthogonally placed dual-loop strips arranged in a cage structure, which are compact in the cross section size and easy in fabrication. By utilizing the currents of equal magnitude but in-phase quadrature on the strips, the horizontal polarization and the omnidirectional pattern are obtained. Both simulations and measurements are carried out, and detailed data are presented.

II. Antenna Structure and Design

The geometry and coordinate system of the proposed cage antenna are shown in Fig. 1. The antenna is designed for operation at 2.44 GHz. Two orthogonally placed dual-loop strips, which act as the radiating elements, are unconnected at the intersection. Their terminals are soldered to the metal plane on one side of an FR4 ($\varepsilon r = 4.4, \tan\delta = 0.02$, thickness $t = 0.5$ mm) substrate. To feed the metal strips, a square cross-H-shaped slot is etched on the same metallized ground plane, as shown in Fig. 1(a). A compact 90° hybrid coupler on the other side of the substrate, as shown in Fig. 1(b), is used to excite the H-shaped

Manuscript received June 20, 2013; revised August 19, 2013; accepted September 18, 2013. Date of publication September 26, 2013; date of current version October 09, 2013. This work was supported by the National Basic Research Program of China under Contract 2009CB320205, in part by the National High Technology Research and Development Program of China (863 Program) under Contract 2011AA010202, the National Natural Science Foundation of China under Contract 61271135, the China Postdoctoral Science Foundation under Project 2013M530046, and the National Science and Technology Major Project of the Ministry of Science and Technology of China under 2013ZX03003008-002.

Y. Zhang is with the State Key Laboratory on Microwave and Digital Communications, Tsinghua National Laboratory for Information Science and Technology, Department of Electronic Engineering, Tsinghua University, Beijing 100084, China, and also with the Zhengzhou Information Science and Technology Institute, Zhengzhou 450002, China.

Z. Zhang, Y. Li, and Z. Feng are with State Key Laboratory on Microwave and Digital Communications, Tsinghua National Laboratory for Information Science and Technology, Department of Electronic Engineering, Tsinghua University, Beijing 100084, China (e-mail: zjzh@tsinghua.edu.cn).

Color versions of one or more of the figures in this letter are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/LAWP.2013.2283543

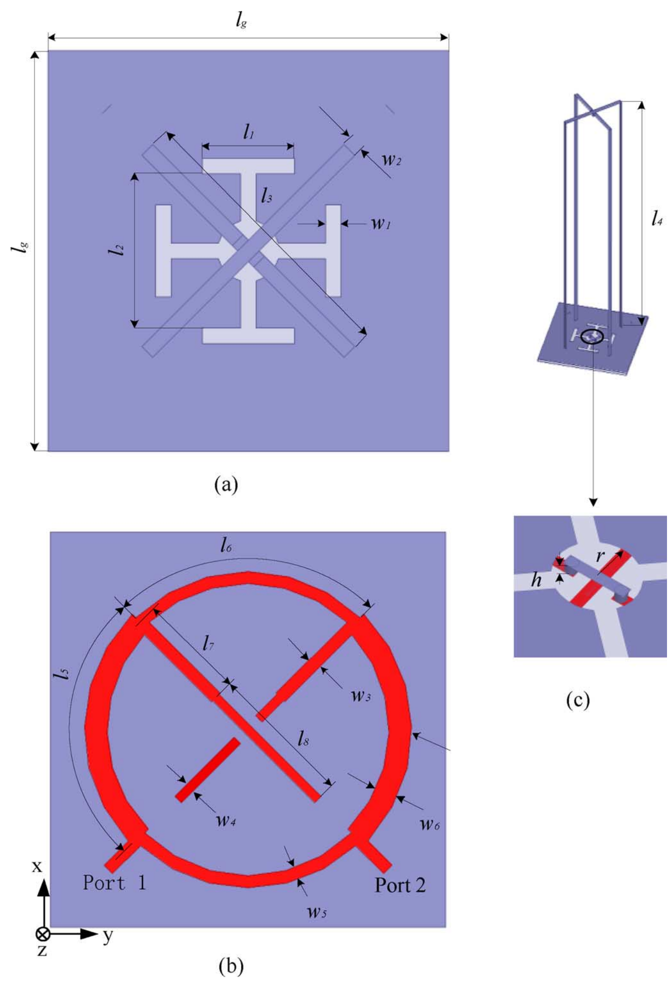

Fig. 1. Geometry of the proposed antenna. (a) Top view. (b) Bottom view. (c) Side view.

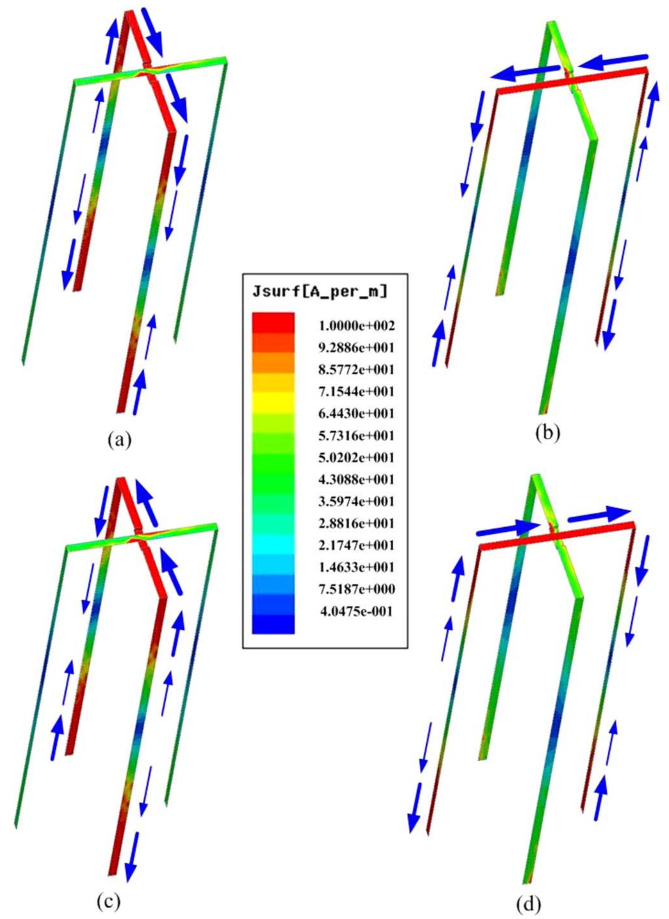

Fig. 2. Simulated surface currents distributions of the proposed antenna at 2.44 GHz, (a) $t = 0$, (b) $t = T/4$, (c) $t = T/2$, and (d) $t = 3T/4$.

slot. There is no electrical connection between the hybrid coupler and the dual-loop strips. The parameters are shown in the following. The dual-loop strips have the height l_4 and the width l_3. The length and width of the transmission lines connecting the ports are 5 and 1.4 mm, respectively. The lengths of four 90° sector metal strips are l_5, l_6. The widths w_5 and w_6 are set for the characteristics impedance of $Z_0(50\ \Omega)$ and $Z_0/\sqrt{2}$, which is based on the substrate of the transmission lines. Two output arms of the hybrid coupler with length $l_7 + l_8$ are crossed over. For clarity, the crossover section is shown in Fig. 1(c).

To achieve a horizontally polarized omnidirectional pattern, the design method of a turnstile antenna is applied [4]. In our design, the circumference of each loop metal strip, which is used as the main radiator, is about 1 λ. The currents on two vertical arms of the strip are of same amplitude but opposite phase. Because the distance of two vertical arms is small (about 1/10 λ), the radiated field is canceled in the far field. Subsequently, only the horizontal arms can radiate in the far field. When the current phase difference between the two feeding ports is 90°, the currents on the horizontal portion of two orthogonal rectangular metal strips are orthogonal with 90° phase difference; therefore, it can radiate horizontally polarized omnidirectional pattern. For clear comprehension of the principle of radiation of the crossed rectangular metal strips, the current distributions are simulated in the electromagnetic simulator Ansoft HFSS and shown in Fig. 2.

It is worth mentioning that the traditional turnstile antennas are crossed dipole arrays for increasing the directivity. Moreover, the radiation directivity is poor in the horizontal plane when only a turnstile unit is used as the radiating element. That is because the radiation of a turnstile unit is observed not only in the azimuth plane, but also along the broadside direction (perpendicular to the turnstile unit). Also, the radiation on the vertical plane is canceled with several turnstile units stacked at about $\lambda/2$ intervals. However, the proposed antenna offers an important advantage comparable to the turnstile unit, where the horizontally polarized omnidirectional radiation is obtained using only a cage antenna unit.

To feed the orthogonal metal strips with currents of equal magnitude but in-phase quadrature, a 90° hybrid coupler is needed to make the magnitude and phase in the strips optimized. Two input ports are symmetrical, and when port 1 is excited, port 2 must be terminated with the impedance of 50 Ω for isolation. When compared to the traditional hybrid coupler design, the maximum difference is that the output arms are inner crossover to feed the cross-H-shaped slot for compact ground size design. All configuration parameters for the proposed antenna are shown in Table I.

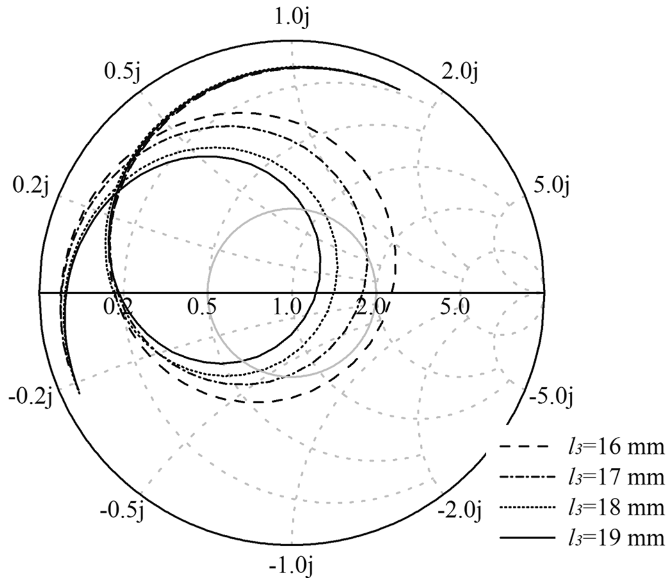

Fig. 3. Simulated impedance profile with different l_3 (without 90° hybrid feeding network).

TABLE I
DIMENSIONS OF THE ANTENNA (UNITS: mm)

l_g	h	l_1	l_2	l_3	l_4	l_5	l_6
26	0.5	6	10	19	52	19	19
l_7	l_8	w_1	w_2	w_3	w_4	w_5	w_6
8	11	1.2	1	1.2	0.6	0.8	1.6

III. SIMULATION AND MEASUREMENT RESULTS

A. Parametric Study of the Proposed Antenna

To analyze the performance of the proposed antenna, a parametric study is implemented in electromagnetic simulator HFSS. We found that the performance of the proposed antenna is sensitive to the dimension of the rectangular metal strip, especially the resonant frequency and the impedance bandwidth. For simplicity and clarity, the 90° hybrid coupler is not included in the simulation.

The simulated impedance profiles with the different lengths of l_3 are shown in Fig. 3. We found that the factor of quality is lower when the horizontal arm of the rectangle strip is increased. Then, the impedance bandwidth is wider. However, we also found that when the horizontal arm is increased while the length of $l_3 + 2l_4$ is constant, the gain and the beamwidth in the vertical plane are deteriorated. For the tradeoff of the impedance bandwidth and the directivity or the beamwidth, the length of l_3 is 19 mm. The different resonant frequencies with the different lengths of l_4 are shown in Fig. 4. When the length of l_4 is increased, the resonant frequency is decreased. For the required operating frequency, the length of l_4 is 52 mm.

B. Measurement Results

According to the design details mentioned above, a prototype of the proposed horizontal polarized antenna with omnidirectional radiation pattern was fabricated, as shown in Fig. 5. The performance of the proposed antenna was measured. In Fig. 6, the measured and simulated reflection coefficients of the constructed prototype are presented. It is clear that the measured reflection coefficients of two ports are in accordance with the simulation. The discrepancy was caused by the asymmetry and the manufacturing tolerance.

The simulated and measured $|S_{21}|$ are shown in Fig. 7. When the 90° hybrid coupler is used to feed the cage antenna, the radiation capacity cannot be demonstrated by only the test results of the reflection coefficients in the two ports. Because when the 90° hybrid coupler is well matched, the energy of the input port is radiated by the cage antenna or is absorbed by the load in the

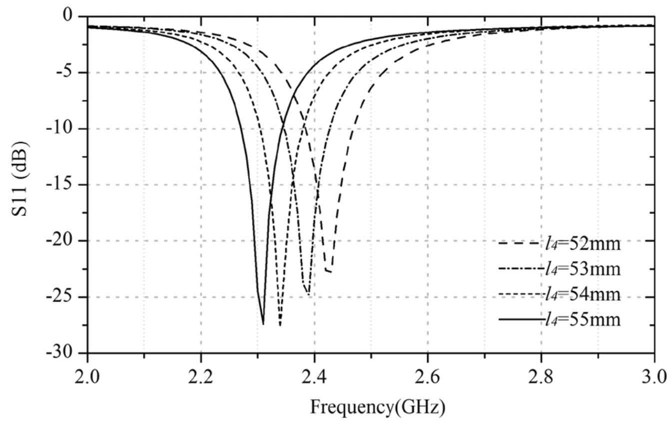

Fig. 4. Simulated return loss with different l_4 (l_3 is 19° mm, without 90° hybrid feeding network).

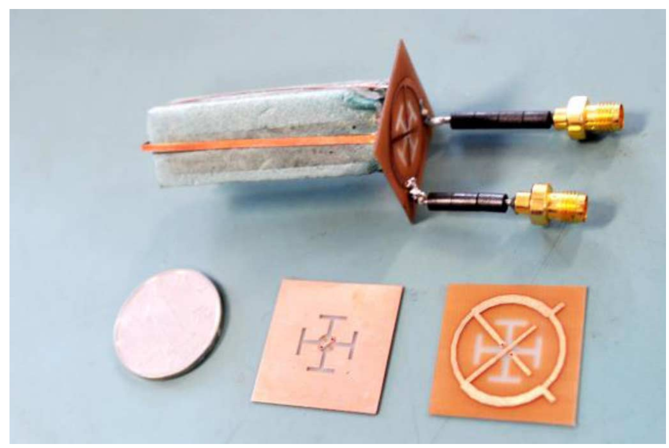

Fig. 5. Photograph of the proposed antenna prototype.

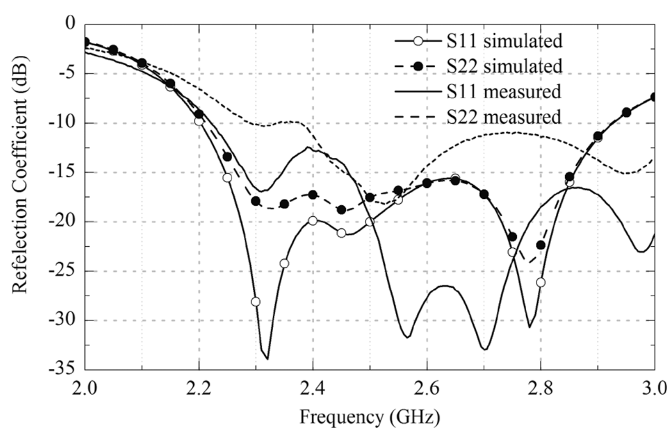

Fig. 6. Measured and simulated reflection coefficient of the proposed antenna.

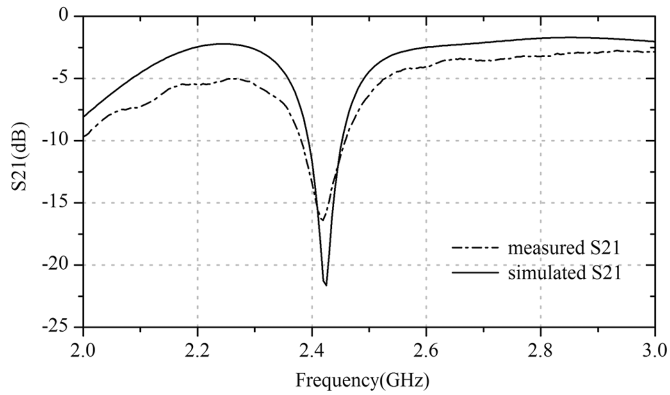

Fig. 7. Measured and simulated S_{21} of the proposed antenna.

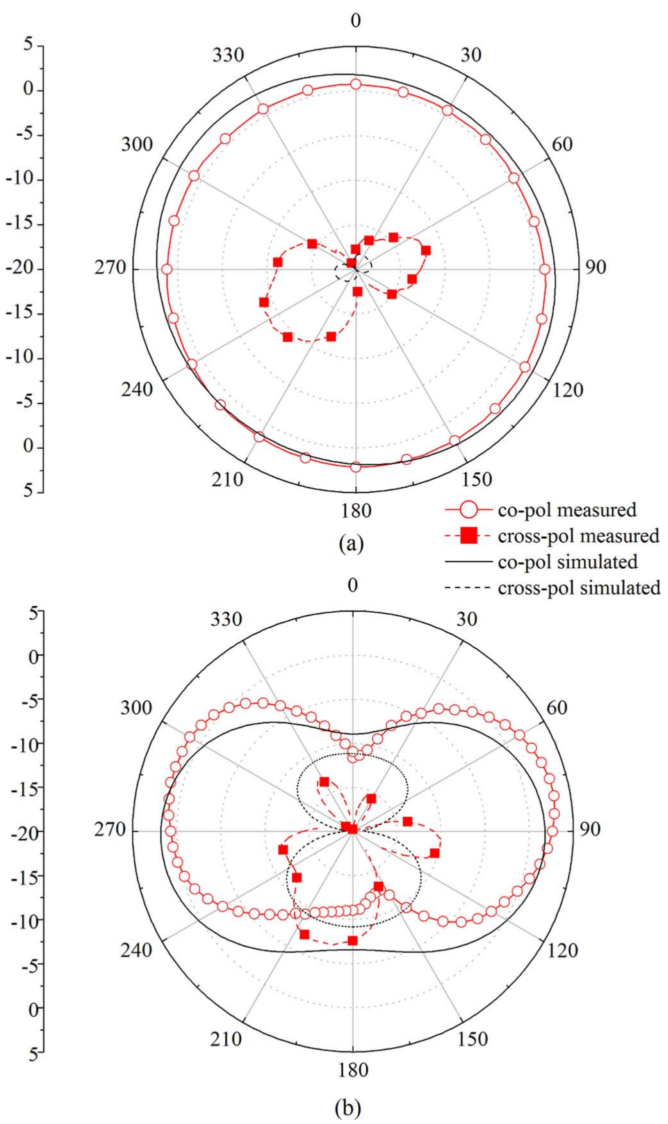

Fig. 8. Measured and simulated radiation pattern of the proposed antenna at 2.44 GHz. (a) Azimuth plane. (b) Elevation plane.

isolation port, thus we cannot verify the radiation capacity of the antenna. In Fig. 7, it is clear that the measured result is in accordance with the simulation.

Fig. 8 shows the simulated and measured radiation pattern of the proposed antenna. Only the center frequency is presented. Measurements at other operating frequencies across the bandwidth (not shown here for brevity) also present similar radiation patterns as those plotted here. It is clear that good omnidirectional radiation with horizontal polarization in the azimuth plane is obtained, which is shown in Fig. 8(a). The radiation patterns in the elevation plane show a quasi-eight shape.

The measured and simulated gain and the 3-dB beam width at the center frequency are shown in Fig. 8. The measured beamwidth and gain at the center frequency are 45° and 2.7 dBi, respectively. The losses of the metal and the dielectric cause the tolerance between the simulated and measured results. The anti-omnidirectionality is defined as the gain variation (maximum to minimum) in the azimuth plane. As we can see from the figure, good horizontally polarized omnidirectional radiation is obtained in the E-plane with small gain variation less than 1.1 dB.

IV. Conclusion

This letter proposed a novel cage antenna with horizontally polarized omnidirectional pattern in the azimuthal plane. Two orthogonal placed dual-loop strips in a cage structure are designed to provide horizontal polarization. By utilizing the currents of equal magnitude but in phase quadrature on the loop metal strips, the omnidirectional pattern is achieved. The proposed antenna is easy to be matched with simple and low-cost configuration, which is compact in the cross-section size and a good candidate for WLAN applications.

References

[1] D. Chizhik, J. Ling, and R. A. Valenzuela, "The effect of electric field polarization on indoor propagation," in *Proc. IEEE Int, Conf. Univ. Pers. Commun.*, Oct. 1998, vol. 1, pp. 459–462.

[2] C. Soras, M. Karaboikis, G. Tsachtsiris, and V. Makios, "Analysis and design of an invited-F antenna printed on a PCMCIA card for the 2.4 GHz ISM band," *IEEE Antennas Propag. Mag.*, vol. 44, no. 1, pp. 37–44, Feb. 2002.

[3] K. L. Wong, J. W. Lai, and F. R. Hsiao, "Omnidirectional planar dipole array antenna for 2.4/5.2-GHz WLAN access points," *Microw. Opt. Technol. Lett.*, vol. 39, pp. 33–36, Oct. 2003.

[4] C. A. Balanis, *Antenna Theory: Analysis and Design*, 3rd ed. Hoboken, NJ, USA: Wiley-Interscience, 2005.

[5] Q. X. Lin and L. R. Lin, "Broadband dual-polarized omnidirectional antennas," in *Proc. IEEE APSURSI*, 2012, pp. 1–2.

[6] Q. X. Lin and L. R. Lin, "Novel broadband omnidirectional antennas," in *Proc. APMC*, 2012, pp. 1334–1336.

[7] X. M. Qing and Z. N. Chen, "Horizontally polarized omnidirectional segmented loop antenna," in *Proc. 6th EuCAP*, 2012, pp. 2904–2907.

[8] K. P. Wei, Z. J. Zhang, and Z. H. Feng, "Design of a wideband horizontally polarized omnidirectional printed loop antenna," *IEEE Antennas Wireless Propag. Lett.*, vol. 11, pp. 49–52, 2012.

[9] K. P. Wei, Z. J. Zhang, Z. H. Feng, and M. F. Iskander, "A MNG-TL loop antenna array with horizontally polarized omnidirectional patterns," *IEEE Trans. Antennas Propag.*, vol. 60, no. 6, pp. 2702–2710, Jun. 2012.

[10] C. C. Lin, L. C. Kuo, and H. R. Chuang, "A horizontally polarized omnidirectional printed antenna for WLAN applications," *IEEE Trans. Antennas Propag.*, vol. 54, no. 11, pp. 3551–3556, Nov. 2006.

[11] K. P. Wei, Z. J. Zhang, Z. H. Feng, and M. F. Iskander, "Periodic leaky-wave antenna array with horizontally polarized omnidirectional pattern," *IEEE Trans. Antennas Propag.*, vol. 60, no. 8, pp. 3165–3173, Aug. 2012.