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RESEARCH PAPER

Broadband circular patch antenna with monopolar radiation pattern for indoor wireless communication

XI WANG DAI, SHENG WEN MAO AND TAO ZHOU

A circular patch antenna with wide impedance bandwidth and monopolar radiation pattern for indoor wireless communication is proposed and analyzed in this paper. The antenna is a combination of circular patch and four capacitive feeds. By incorporating a cross-connected shorted conducting strip over the circular patch, the proposed antenna provides an enhanced impedance width of 65.4%, ranging from 1.46 to 2.88 GHz. Four capacitive feeds improve the design flexibility and make the ripple of horizontal radiation pattern less than 3 dB. A prototype of the proposed structure has been fabricated and measured. Both the simulated and measured results show that the proposed design has a stable monopolar radiation pattern over a wideband frequency range and a peak gain of 5.0 dBi, which can be widely applied for indoor wireless communication such as GSM1800, CDMA2000, WCDMA, and TD-LTE systems.

Keywords: Circular patch antenna, Monopolar radiation pattern, Capacitive feed, Shorted conducting strip

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I. INTRODUCTION

Nowadays, monopolar antennas have been widely applied in many mobile communication systems. Antenna with conical beam can transmit or receive the electromagnetic wave in all directions for 360° full coverage of a surrounding environment [1, 2]. Such antennas can be mounted to the ceiling of an office to radiate/receive the wireless communication signal. They usually need to operate at a wide impedance bandwidth since they can provide the multiple wireless system services, such as GSM, CDMA2000, WCDMA, and TD-LTE system [3, 4]. The discone antenna and biconical antenna are widely used for their simple structure, however, the antenna performance may be changed when it operates at a wide frequency range. Many efforts have been made to broaden the impedance bandwidth of antenna.

An UWB conical monopole antenna is presented for multi-service wireless application in [5]. Consisting of a cone and a cylindrical block (disc), the antenna displays a fractional bandwidth of 8.3:1. However, the performance of antenna varies greatly over a wide impedance frequency band, and the maximum ripple of *H*-plane radiation pattern has reached ±7 dB. The performance of biconical antenna with unequal cone angle also has been studied with theoretical method in [6].

Institute of Antenna and Microwave Technology, Hangzhou Dianzi University, Hangzhou, Zhejiang, 310018, China. Phone: +86-0571-86919150
Corresponding author:
X.W. Dai
Email: xwdai@hdu.edu.cn

Circular patch with broadside beam has been widely applied with its fundament TM11 mode. However, TM01 mode can be excited with the center fed probe for the circular patch, which can radiate a conical beam. A prototype of circular patch antenna with a very narrow bandwidth of about 1.5% was fabricated by Economou and Langley [7]. Following this work, annular ring coupled circular patch is applied to broaden the impedance bandwidth. Annular ring coupled circular patch with the center feed provides a wide bandwidth of 12.8% in [8]. Juhua Liu proposed a broadband circular patch antenna with a wide impedance bandwidth of 18% and a maximum gain of 6 dBi in [9]. A circular patch is concentrically shorted with a set of conductive vias and fed in the center.

Single feed technology makes the antenna design less flexible, and the performance varies largely over a wide frequency band [10, 11]. Thus multipoint feed technology has been proposed for extending the design methods of antenna with a conical beam. A circular patch antenna with four open loops produces a monopole-like pattern in [12]. However, the loop feed structure complicates the assembly of the proposed antenna due to the orthogonal placement and welding of ground. With four capacitive coupled feeds, a dual-polarized patch antenna is presented in [13]. Even though it achieves a wide impedance bandwidth, patch antenna produces a directional radiation pattern for application.

In this paper, a wideband vertical polarized antenna with a monopole-like radiation pattern is proposed. It consists of a radiating circular patch, a cross-connected shorted strip, and a four-way power divider. Four capacitive feeds are used to connect top and bottom substrates and enhance the design flexibility. The proposed antenna exhibits an impedance bandwidth of 65.4%, ranging from 1.46 to 2.88 GHz, a peak gain of 5.0 dBi and a small ripple less than 3 dB. The antenna provides a conical beam with small ripple in horizontal plane due to the in-phase magnetic current distribution along the circular patch. Simulated and measured results show the stability of radiation pattern in a wide impedance bandwidth.

II. ANTENNA DESIGN AND GEOMETRY

The configuration of proposed antenna is illustrated in Fig. 1. It mainly consists of two substrates and a cross-connected shorted strip over the circular patch. Both substrates have a relative permittivity of 2.65, a thickness of 1.0 mm and a substrate loss tangent of 0.002. The distance between them is H. The radius of the circular patch and the ground are R_p and R_g, respectively.

The diameter of bottom substrate is 126 mm, and the height of proposed antenna is 41 mm, as shown in Fig. 1(a). The antenna can be used for GSM1800, WCDMA, and TD-LTE systems. The proposed antenna is fed by a 50 Ω coaxial cables with connector, and can be mounted on the rooftop for the indoor scenario.

One side of top substrate consists of four arc conducting strips with the angle of α and the width of W_s, which are rotation oriented along *z-axis* over the circular patch. The other side of the substrate is printed with a circular patch with the radius R_p. A broadband four-way power divider is printed on one side of bottom substrate, which can provide the electromagnetic wave with uniform amplitude and 0 phase shift. The divider consists of four stepped impedance transformers, shown in Fig. 1(b). Four conducting posts are used to connect conducting strips and four-way power divider. Thus four capacitive feeds can couple the electromagnetic energy from the source to the circular radiating patch.

The detailed sizes of top shorted strip are shown in Fig. 1(c). Because the top strip is shorted to the ground with four legs, the inductive loading is introduced. The capacitive coupling is formed by arc conducting strips and circular patch, so the working frequency of proposed antenna is lowered. The simulated reflection coefficient of the proposed antenna and the antenna without top shorted strip loading are compared in Fig. 2. It can be clearly seen that the proposed antenna has a wide-band operation characteristic from 1.44 to ~2.78 GHz for $S_{11} < -10$ dB, while the antenna without top shorted strip loading has a narrow operation band with the reflection coefficient of only −8.6 dB. Without top shorted strip, the resonant frequency of proposed antenna is determined by the circular patch. If the radius of the patch decreases, the resonant frequency increases. However, the input impedance for the circular patch itself is high because of strong electric filed and weak magnetic field at the center of the patch. It can be observed that there is a shift of resonant frequency when the antenna is loaded with the shorted strip, shown in Fig. 2. This is due to the coupling between the patch and the

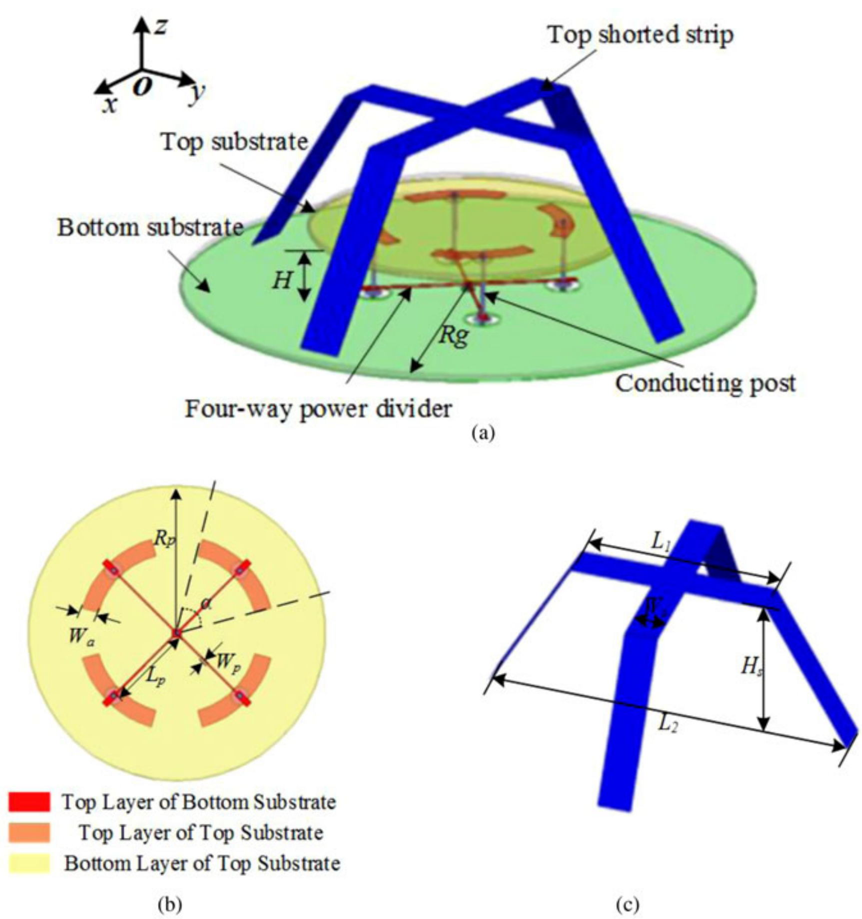

Fig. 1. Geometry of the proposed antenna: (a) over view, (b) bottom view of power divider and top substrate, (c) cross-connected shorted conducting strip.

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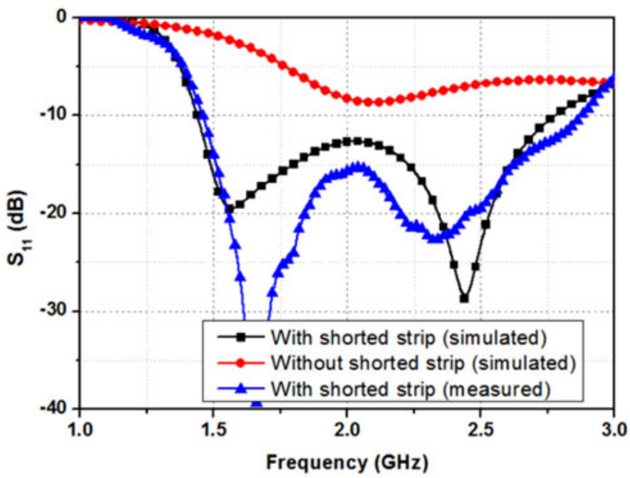

Fig. 2. Simulated and measured reflection coefficients of proposed antenna at different cases.

shorted strip. Because of coupling, the quality factor Q of the antenna decreases, which results in a wide bandwidth.

Electromagnetic wave from the input port is split into four parts with equal power and in phase by the four-way power divider. Then electromagnetic wave is coupled to the radiating patch, and equivalent magnetic current distribution along the circular patch can be formed. Figure 3 shows the magnetic field and surface current distributions along the circular patch of proposed design at 2.0 GHz. It can be seen that the magnetic field propagates along the φ-direction, which is similar with that of a circular patch operating in TM01 mode. The surface current along the radial direction is divided into four parts, which are located at the place of capacitive feeds. The distributions of magnetic field and surface current gives rise to omnidirectional radiation at horizontal plane.

III. PARAMETRIC STUDY

To analyze the design mechanism of the proposed antenna, the key parameters study for input impedance has been carried out using commercial full-wave electromagnetic software High Frequency Structure Simulator (HFSS). There are three key parameters for designing the antenna including radius of circular patch (R_p), the height of long conducting post (H), and the height of top shorted strip (H_s). All other parameters remain unchanged unless specified.

Figure 4 shows the effect of different structure parameters on the simulated input impedance Z_{in} of the proposed antenna. It can be seen that when the radius of circular patch varies from 25 to 40 mm, the real part of Z_{in} changes slightly and its peak value changes from 38 to 180 Ω, while the imaginary part of Z_{in} gradually decreased from 15 to −2 Ω at 2.0 GHz. The proposed antenna has a better impedance matching at $R_p = 35$ mm for its imaginary part of Z_{in} is nearby zero. Figure 4(b) shows the effect of H_s on the performance of antenna. It should be noticed that H_s has a strong effect on the first resonant frequency, and a slight effect on the second resonant frequency. When the value of H_s varies from 30 to 45 mm, the real part and imaginary part of Z_{in} change greatly at the first resonant frequency, and they remain the same at the second resonant frequency. The parameter of H has a great influence on the real part of Z_{in} and the first resonant frequency, as shown in Fig. 4(c). When the value of H varies from 11 to 14 mm, the real part of Z_{in} decreases and the imaginary part of Z_{in} changes largely at the first resonant frequency, while it keeps the same at the second resonant frequency.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

According to the above discussion and analysis, the geometric parameters of the wideband circular patch antenna are summarized in Table 1. The unit of all parameters is *mm*, except that the unit of α is *deg*. A prototype of proposed antenna is simulated, fabricated, and measured. Figure 5 shows the photograph of the fabricated antenna and the bottom of top substrate. A wideband four-way power divider is printed on the bottom substrate, and the cross-connected strip are located over the top substrate.

The simulated and measured reflection coefficients of the proposed antenna are shown in Fig. 2. The measured impedance bandwidth for $S_{11} < -10$ dB is 65.4% from 1.46 to 2.88 GHz, which covers the GSM1800, WCDMA, CDMA2000, and TD-LTE systems for indoor wireless communication system. The difference between the simulated and measured S_{11} is mainly due to the errors of manufacturing and assembling.

The simulated and measured radiation patterns of the proposed design are shown in Fig. 6. Radiation patterns in the azimuth plane with the unroundness less than 3.0 dB are

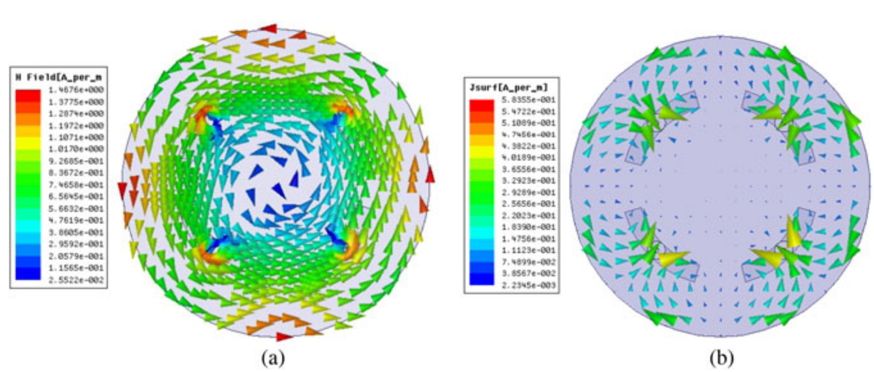

Fig. 3. Magnetic fields and surface current distribution on the circular patch. (a) Magnetic fields, (b) surface current.

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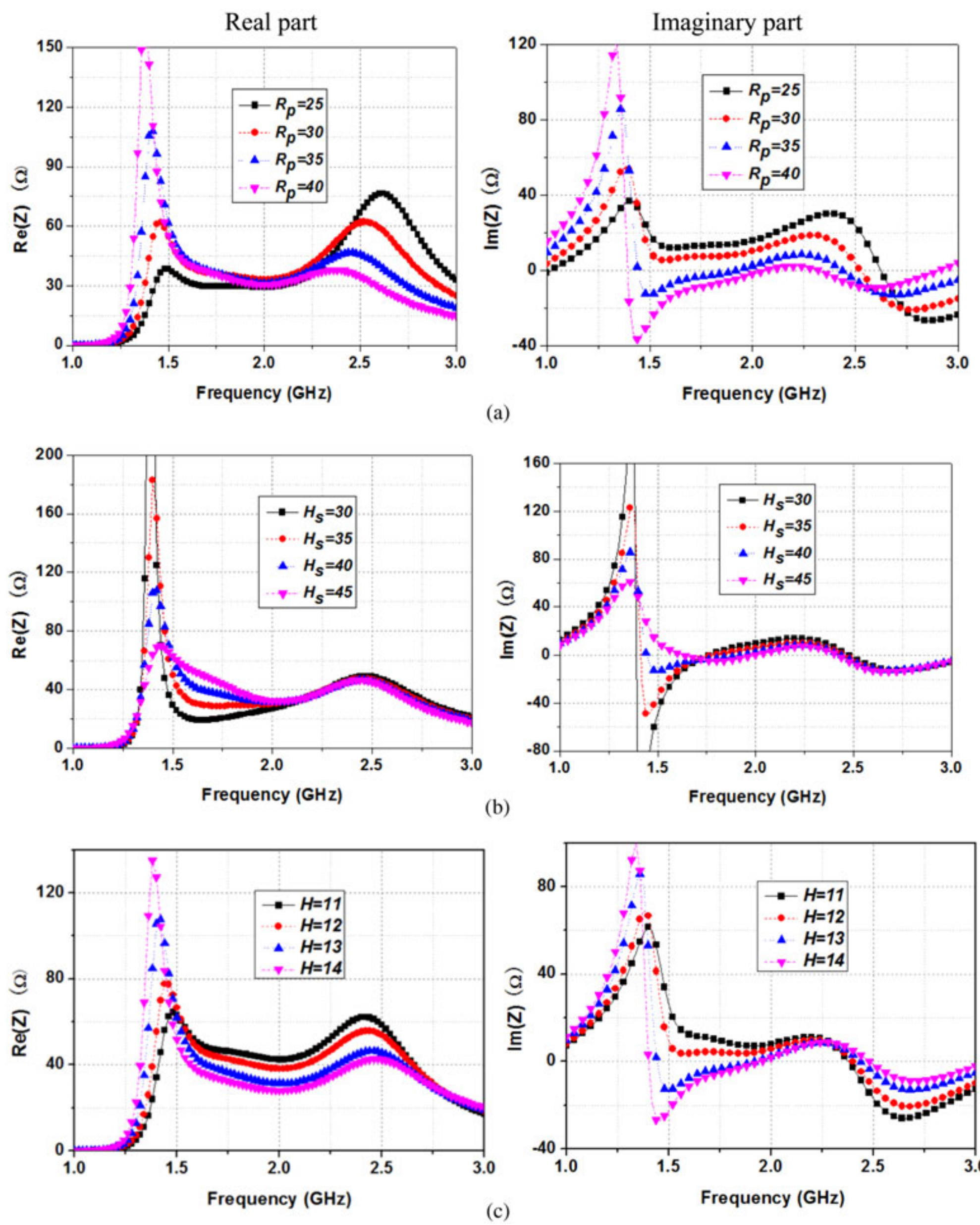

Fig. 4. Simulated input impedance Z versus frequency with different values of structural parameters. (a) R_p, (b) H_s, (c) H.

observed at the frequencies of 1.5, 2.0, and 2.5 GHz. The omnidirectional property attributes to the in-phase feed and magnetic field distribution on the circular patch. It can be clearly seen that there is a deep null at $\theta = 0$ direction for the elevation radiation patterns in *XOZ*-plane. The directions of maximum radiation are tilted several degrees from the

Table 1. Geometric parameters of proposed antenna.

Parameter	Value (mm)	Parameter	Value (mm)
R_p	35	R_g	53
W_p	0.3	L_p	20
W_a	4	H	13
W_s	10	H_s	40
L_1	60	L_2	110
α	60 (deg)		

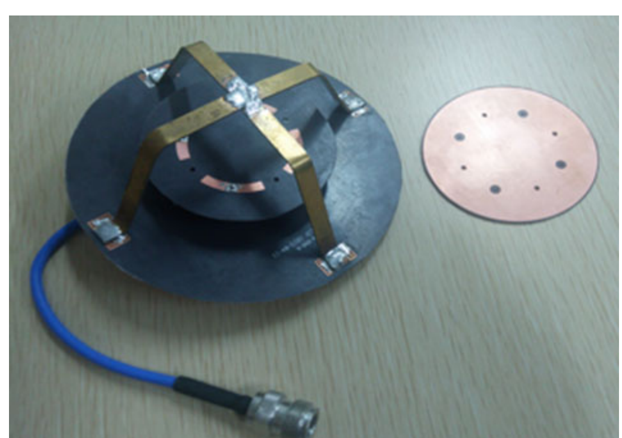

Fig. 5. Photograph of fabricated antenna and top substrate.

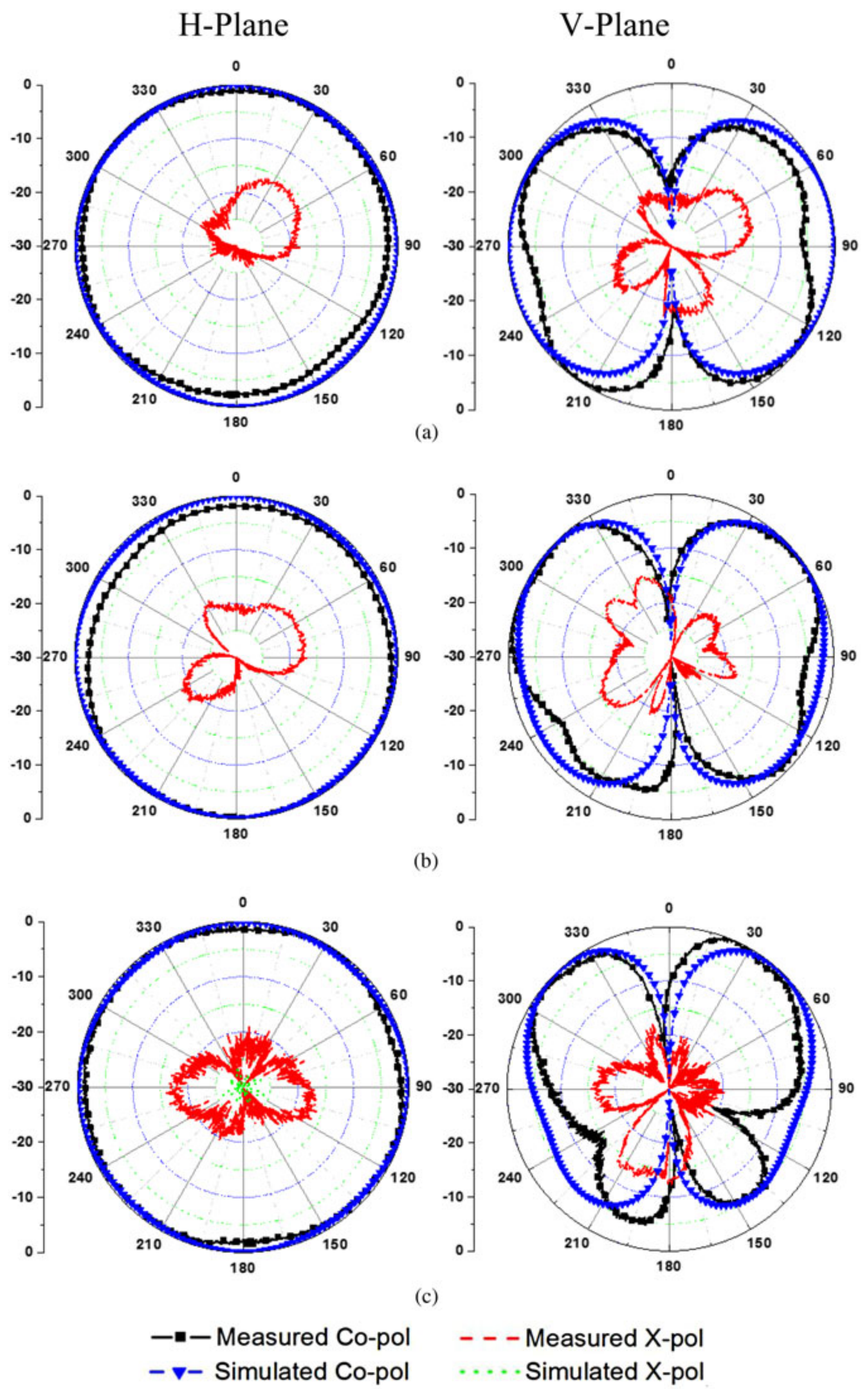

Fig. 6. Simulated and measured radiation patterns of proposed antenna at different frequencies. (a) 1.5 GHz, (b) 2.0 GHz, (c) 2.5 GHz.

horizon in the elevation plane, which arises due to the circular ground on the back of the bottom substrate. It also can be found that the cross-polarization level is lower than 15 dB over the wide frequency band.

Figure 7 shows the simulated and measured gains of the proposed antenna. It can be seen that the gain varies from 0.9 to 5.0 dBi in the frequency range of 1.46–2.88 GHz. It can be noticed that good agreement with a difference of less than 1.0 dB is achieved between the simulated and measured results. There are some differences between the simulated and measured models. For example, connectors and cables are not included in the simulation model. Meanwhile, some undesired effects in the measurement setup are attributed to the differences between simulated and measured results.

V. CONCLUSION

A wideband circular patch antenna with multi-fed technology is proposed in this paper. The antenna is composed of two substrates and a cross-connected shorted strip. A broadband four-way power divider is used to provide signal with

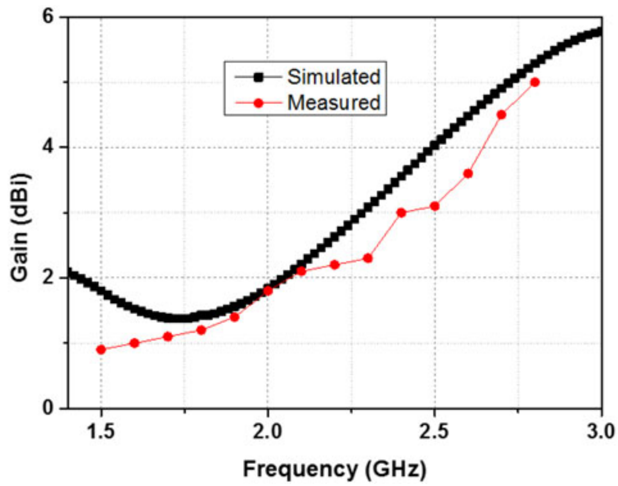

Fig. 7. Comparison of simulated and measured gains of proposed antenna.

uniform amplitude and 0 phase shift to four capacitive feeds. Magnetic field and surface current are studied to analysis the mechanism of proposed structure. Simulated and measured results show that the proposed design yields a wide impedance bandwidth of 65.4%, a peak gain of 5.0 dBi and a stable conical radiation pattern. The proposed antenna has a potential for wide application in indoor wireless communication such as GSM1800, WCDMA, CDMA200, and TD-LED systems.

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REFERENCES

[1] Dai, X.W.; Wang, Z.Y.; Liang, C.H. et al.: Multiband and dual-polarized omnidirectional antenna for 2G/3G/LTE application. IEEE Antennas Wireless Propag. Lett., **12** (2013), 1492–1495.

[2] Wei, K.; Zhang, Z.; Feng, Z.: Design of a wideband horizontally polarized omnidirectional printed loop antenna. IEEE Antennas Wireless Propag. Lett., **11** (2012), 49–52.

[3] Wu, B.Q.; Luk, K.M.: A wideband, low-profile, conical-beam antenna with horizontal polarization for indoor wireless communications. IEEE Antennas Wireless Propag. Lett., **8** (2009), 634–636.

[4] Dai, X.W.; Zhou, T.; Cui, G.F.: Dual-band microstrip circular patch antenna with monopolar radiation pattern. IEEE Antennas Wireless Propag. Lett., **15** (2016), 1004–1007.

[5] Yeoh, W.S.; Rowe, W.S.T.: An UWB conical monopole antenna for multiservice wireless applications. IEEE Antennas Wireless Propag. Lett., **14** (2015), 1085–1088.

[6] Samaddar, S.N.; Mokole, E.: Biconical antennas with unequal cone angles. IEEE Trans. Antennas Propag., **46** (1998), 181–193.

[7] Economou, L.; Langley, R.J.: Patch antenna equivalent to simple monopole. Electron. Lett., **33** (1999), 727–729.

[8] Al-Zoubi, A.; Yang, F.; Kishk, A.: A broadband center-fed circular patch-ring antenna with a monopole like radiation pattern. IEEE Trans. Antennas Propag., **57** (2009), 789–792.

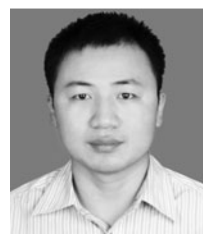
[9] Liu, J.H.: Xue, Q.; Wong, H. et al.: Design and analysis of a low-profile and broadband microstrip monopolar patch antenna. IEEE Trans. Antennas Propag., **61** (2013), 11–18.

[10] Ramahi, O.; Eiken, S.D.; Mittra, R.: Multi-feed passive antennas for VHF/UHF. Proc. IEEE AP-S Symp., 1993, 144–147.

[11] Wong, K.L.: Compact and Broadband Microstrip Antennas, John Wiley & Sons, Inc., New York, 2002.

[12] Cui, L.; Wu, W.; Fang, D.G.: Wideband circular patch antenna with conical radiation pattern. IEEE Antennas Wireless Propag. Lett., **14** (2015), 458–461.

[13] Zhu, F.; Gao, S.; Ho, A.T. et al.: Ultra-wideband dual-polarized patch antenna with four capacitively coupled feeds. IEEE Trans. Antennas Propag., **62** (2014), 2440–2449.



Xi Wang Dai was born in Caoxian, Shandong, China. He received the B.S. and M.S. degrees in electronic engineering from Xidian University, Xi'an, Shaanxi, China, in 2005 and 2008. And he received Ph.D degree of electromagnetic fields and microwave technology at Xidian University in 2014. From March 2008 to August 2011, he worked at Guangdong Huisu Corporation as a manager of antenna department. Now, he is working at the Hangzhou Dianzi University, Hangzhou, China. His current research interests involve metamaterials, omni-directional antenna, MIMO antenna, multi-beam antenna, and low-profile antenna.

Sheng Wen Mao was born in Fengcheng, Jiangxi, China. He received the B.S. degree in electronic information engineering from Jiangxi Agricultural University, Nanchang, Jiangxi, China, in 2015. Now, he is pursuing the M.S degree in Hangzhou Dianzi University, Hangzhou, China. His current interest is Antenna, absorber, and microwave device.

Tao Zhou was born in Jiangxi province, china, in 1983. He received the B.S. degree and the M.E. degree from Xidian University, Xi'an, China, in 2005 and 2008 respectively, and the Ph.D. degree from the institute National des Sciences Appliquées de Lyon,France, in 2012. He is currently a lecturer with the Institute of Electronic and Information Engineering, Hangzhou Dianzi University, China. His major research interests include the Metamatrials, the composite left/right handed transmission lines, near-field antennas, and graphene THz components.