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A Wideband Horizontally Polarized Omnidirectional Antenna with Coupling Lines

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Abstract—A novel wideband horizontally polarized omnidirectional antenna with coupling lines is proposed for indoor wireless base station applications. It consists of four microstrip dipoles, a tune disk with four square-shaped perturbations and four pairs of tapered parallel transmission lines. Each right arm of the microstrip dipole has been engraved with a coupling line. The measured 10 dB return loss relative bandwidth is 51% (1.6–2.72 GHz). In horizontally plane, the proposed antenna has an omnidirectional radiation pattern and an average gain of 2.4 dBi.

1. INTRODUCTION

Omnidirectional antenna has been widely applied in wireless communication systems since it can receive or transmit electromagnetic wave equally in 360° of the radiation plane. Although vertically polarized antenna has been used widely in current wireless communication systems, a horizontally polarized antenna is a necessary part of a polarization diversity system. And a wireless base station demands wideband.

A horizontally polarized omnidirectional (HPO) antenna can be achieved by a circular-loop with uniform current distribution. The electrical small loop antenna is an appropriate one. However, such an antenna is quite difficult to match impedance [1]. In [2] and [3], those types of Alford-loop antennas were researched to achieve the HPO pattern. But poor impedance matching is the fatal problem in such a design, which leads to narrow bandwidth (less than 11% typically). A left-handed loading zeroth-order resonator antenna was shown in [4] to achieve HPO pattern, and a modified one was shown in [5]. This type of antenna has a narrow bandwidth about 100 MHz. Its radiation efficiency and gain are low. In [6], a printed periodical capacitive loading loop antenna was presented, which had a relative bandwidth of 31.2%. Capacitive loading is conducive to retain uniform current distribution along the loop and improve the impedance bandwidth.

Besides, a circular-loop can be formed by a dipole array. A broadband HPO antenna which had four arc dipoles and achieved 31% relative bandwidth was proposed in [7] for applications of 2G/3G base station. A modified arc dipole array with parasitic elements was presented in [8] which had wideband of 1.71–2.69 GHz for return loss (RL) > 15 dB. But the gain was around 0 dBi. Yu et al. proposed an antenna constituted by four pairs of symmetrical flag-shaped radiators, shown in [9]. Its relative bandwidth was 41%. Zhang et al. proposed a similar antenna with a reflector in [10], and its relative bandwidth was about 43%.

The antenna proposed in this paper can achieve wideband of 1.12 GHz (1.6–2.72 GHz, 51%) and an HPO pattern. Table 1 lists the contrast with some published results. Observe that the design proposed in this work offers a wideband, small size and high gain antenna, which is important for indoor wireless base station applications. Simulated and measured results are presented.

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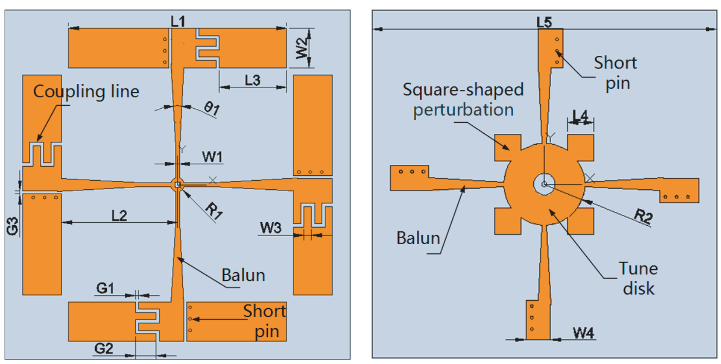
Table 1. Comparison of references and the proposed antenna.

Group	Relative Bandwidth	Size	Average Gain
[6]	31.20%	$R = 25$ mm	2.5 dBi
[7]	31%	$R = 50$ mm	0.9 dBi
[8]	59%	$R = 70$ mm	0 dBi
[9]	41%	$R = 50$ mm	Not Given
[10]	43%	84 mm × 84 mm	2 dBi
This Work	51%	85 mm × 85 mm	2.5 dBi

2. ANTENNA DESIGN

Inspired by the wideband HPO antenna presented in [6] and [9], a novel wideband HPO antenna is designed. It improves the bandwidth by introducing coupling lines. The structure of the HPO antenna is shown in Figure 1.



(a) (b)

Figure 1. Structure of the proposed antenna. (a) Front side. (b) Backside.

The proposed antenna is composed of four microstrip dipoles, four pairs of wideband baluns and an impedance matching network. They are arranged at 0°, 90°, 180° and 270° on the front side of substrate in turn. The four dipoles form a square-loop for HPO radiation pattern in the far field. In Figure 1(a), each left arm of microstrip dipole links the backside part of wideband balun by short pins. Meanwhile, the front side part of wideband baluns links the right arms of microstrip dipoles which have been engraved with coupling lines. In Figure 1(b), the backside part of wideband baluns is connected to tune disk, and four square-shaped perturbations are inserted into the tune disk. Wideband baluns are two tapered parallel transmission lines. The impedance matching network consists of a microstrip circuit on the front side and a tune disk with four square-shaped perturbations on the backside. Table 2 lists the structure parameters of the proposed HPO antenna.

Table 2. Structure parameters of the proposed HPO antenna.

$L1$ (mm)	54.6	$R1$ (mm)	2	$W4$ (mm)	6
$L2$ (mm)	29.5	$R2$ (mm)	10	$G1$ (mm)	0.8
$L3$ (mm)	16.5	$W1$ (mm)	1	$G2$ (mm)	5
$L4$ (mm)	8	$W2$ (mm)	4	$G3$ (mm)	0.5
$L5$ (mm)	85	$W3$ (mm)	1.8	$\theta1$ (°)	6.2

As we know, square-loop has a same radiation pattern in the far field with circular-loop. When the HPO antenna is excited, the quasi-TEM waves lead to four pairs of microstrip dipoles through the tapered parallel transmission lines which have the opposite current directions on different sides. The antenna current distributions at 1.8 GHz and 2.2 GHz are depicted in Figure 2. The currents flow synchronously in the same direction on the arms. Therefore, the proposed antenna can achieve a HPO radiation pattern.

(a) (b)

Figure 2. Simulated current distribution of the proposed antenna at (a) 1.8 GHz and (b) 2.2 GHz.

3. SIMULATION AND MEASUREMENT

All simulations in this letter are carried out using CST MICROWAVE STUDIO. Figure 3 shows the simulated RL of different lengths of $L1$. As we expected, the length of the arm of microstrip dipole is longer, lowers the first resonant frequency and lowers RL value of the second resonant. Therefore, 54.6 mm is the right length of $L1$. Figure 4 shows the simulated RL of different widths of $G1$. It is found that as the width of $G1$ becomes wider, RL at 1.95 GHz is the highest, but RL at 2.55 GHz is the lowest. When $G1$ equals 0.8 mm, it gives the best impedance match. Figure 5 shows the simulated RL of different lengths of $L4$. Suitable square-shaped perturbation can increase the bandwidth of the antenna. When $L4$ equals 8 mm, the antenna has the maximum bandwidth.

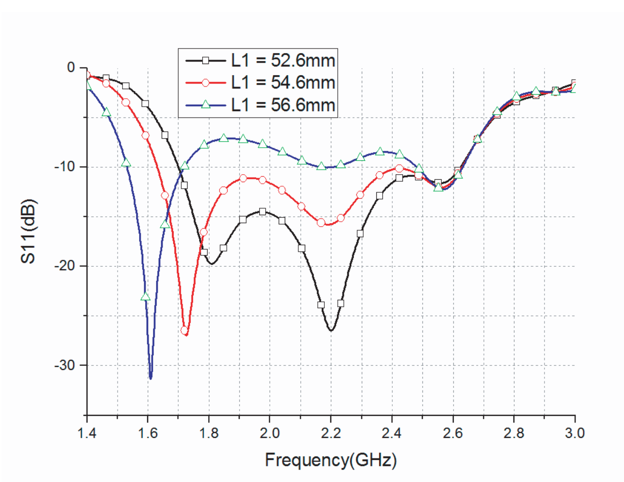


Figure 3. Simulated RL of different lengths of $L1$.

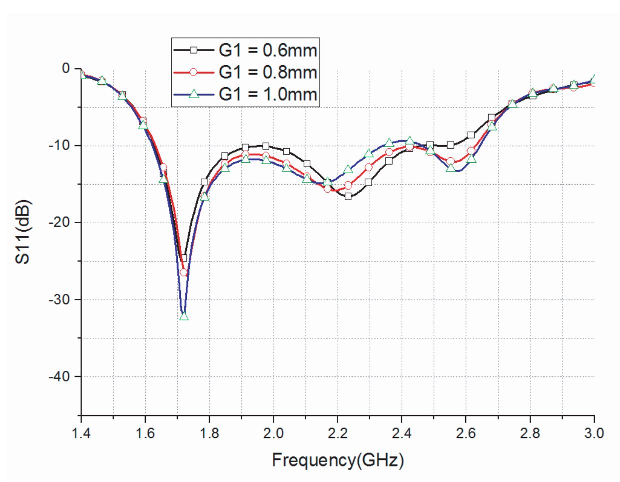


Figure 4. Simulated RL of different widths of $G1$.

The prototypes of the proposed antenna and the original antenna which is not carved coupling lines are fabricated. They are printed on a low-cost FR4 substrate (thickness = 2 mm, $\varepsilon_r = 4.2$, $\tan\delta = 0.0018$). This type of antenna is fed by 50 Ω coaxial cable with SMA connector from center

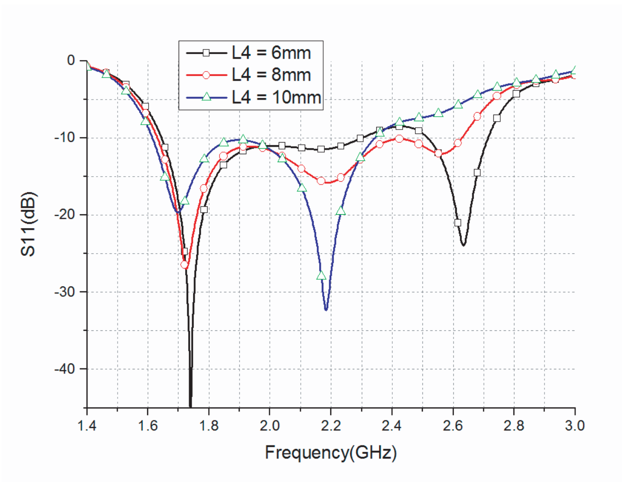


Figure 5. Simulated RL of different lengths of $L4$.

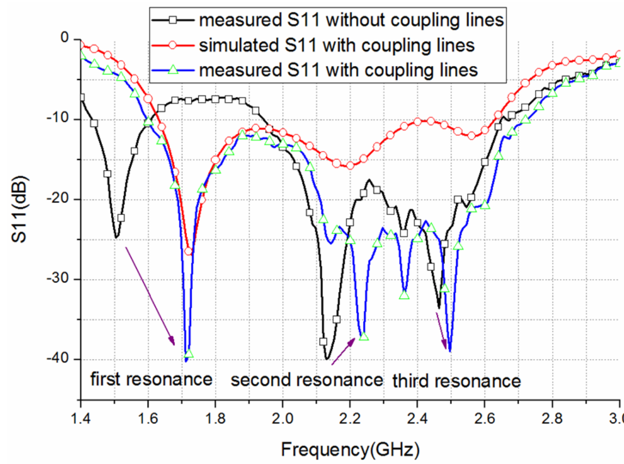


Figure 6. Simulated and measured RL of the proposed antenna and measured RL the original antenna.

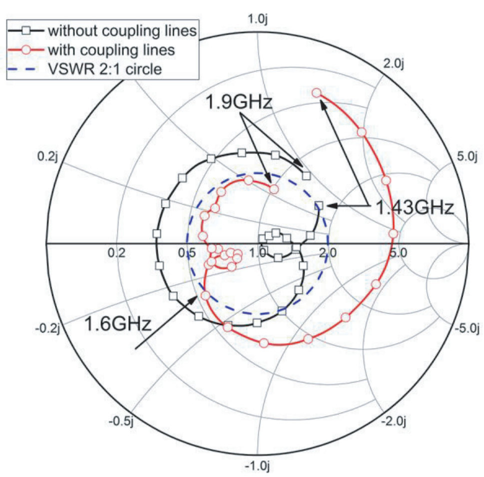


Figure 7. Measured input impedance from 1.43 to 1.9 GHz for the original antenna and the proposed antenna.

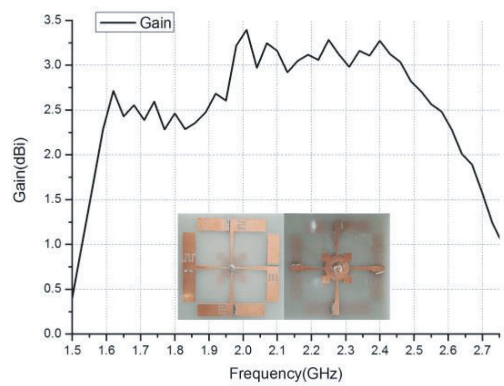
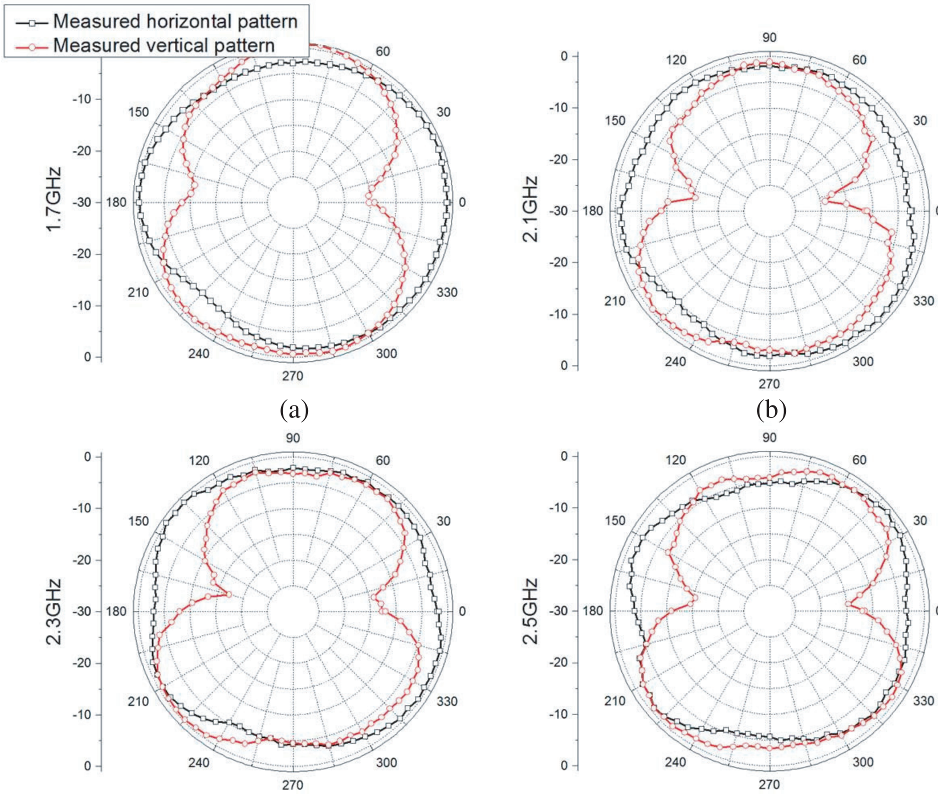


Figure 8. Measured gain of the proposed antenna.

of the substrate. RL of the proposed antenna and the original antenna are measured by KEYSIGHT ENA E5080A, and radiation patterns are measured by an anechoic chamber.

Figure 6 shows the simulated and measured RL of the proposed antenna and measured RL of the original antenna. Obviously, the measured result has a better performance than the simulated one. The measured RL curves of the original antenna and the proposed antenna are both not smooth from 2.1 to 2.6 GHz. The discrepancy may be attributed to the welding points of the short pins which are not flat. Note that the original antenna and the proposed antenna both have three significantly resonances. The first resonance of the original antenna shifts right about 200 MHz, and second resonance shifts right about 100 MHz compared with the proposed antenna. It is successful to improve the bandwidth of the proposed antenna by shifting resonances close to each other.

Figure 7 shows the measured Smith chart of input impedance from 1.43 to 1.9 GHz of the original antenna and the proposed antenna. The coupling line is a kind of capacitive loading; it offsets the inductance of the original antenna around 1.85 GHz. In addition, it increases the radiation resistance of the original antenna, but the matching gets worse from 1.4 to 1.6 GHz.



(a) (b) (c) (d)

Figure 9. Measured radiation patterns of the fabricated prototype. (a) 1.7 GHz. (b) 2.1 GHz. (c) 2.3 GHz. (d) 2.5 GHz.

The measured gain of the proposed antenna is shown in Figure 8. Across the operating band, its gain value is in the range about 1.75 $\sim$ 3.25 dBi. Its measured radiation patterns at 1.7 GHz, 2.1 GHz, 2.3 GHz and 2.5 GHz are plotted in Figure 9. Measurements at other operating frequencies also present similar performances to those shown in Figure 9. In the azimuth plane, the gain variations are less than ± 2.5 dB. The discrepancy may be attributed to the rough surfaces of the welding points of the short pins.

4. CONCLUSION

A novel wideband HPO antenna is designed by combining an impedance matching network, wideband baluns and four microstrip dipoles which have been carved coupling lines. Its measured result shows that the proposed HPO antenna has a relative bandwidth of 51% (1.6–2.72 GHz) for $RL > 10$ dB. Its average gain value is higher than 2.4 dBi in the omnidirectional plane. The proposed HPO antenna may be used in indoor wireless base station applications.

REFERENCES

1. Balanis, C. A., *Antenna Theory: Analysis and Design*, 3rd Edition, Wiley-Interscience, Hoboken, NJ, 2005.
2. Lin, C. C., L. C. Kuo, and H. R. Chuang, "A horizontally polarized omnidirectional printed antenna for WLAN applications," *IEEE Trans. Antennas Propag.*, Vol. 54, No. 11, Pt. 2, 3551–3556, Nov. 2006.

3. Lin, C. C. and H. R. Chuang, "A 2.4 GHz planar printed antenna with omni-directional horizontally polarized pattern for WLAN applications," *Proc. 33rd Eur. Microwave Conf.*, 1275–1278, Munich, 2003.
4. Borjia, A. L., P. S. Hall, and Q. Liu, "Omnidirectional loop antenna with left-handed loading," *IEEE Antennas Wireless Propag. Lett.*, Vol. 6, 495–498, 2007.
5. Locatelli, A., A. Capobianco, S. Boscolo, D. Modotto, M. Midrio, and C. D. Angelis, "Low-pro file CRLH omnidirectional loop antenna for mobile wireless communications," *Proc. 42nd Eur. Microw. Conf.*, 401–403, Oct. 2012.
6. Wei, K., Z. Zhang, Z. Feng, and M. F. Iskander, "Periodic leaky-wave antenna array with horizontally polarized omnidirectional pattern," *IEEE Trans. Antennas Propagat.*, Vol. 60, No. 7, 3165–3173, Jul. 2012.
7. Quan, X. L., R.-L. Li, J. Y. Wang, and Y. H. Cui, "Development of a broadband horizontally polarized omnidirectional planar antenna and its array for base stations," *Progress In Electromagnetics Research*, Vol. 128, 441–456, 2012.
8. Zhu, Q., S. Yang, and Z. Chen, "A wideband horizontally polarized omnidirectional antenna for LTE indoor base stations," *Microwave Opt Technol. Lett.*, Vol. 54, 2112–2116, 2015.
9. Yu, Y., F. Jolani, and Z. Chen, "A wideband omnidirectional horizontally polarized antenna for 4G LTE applications," *IEEE Antennas Wireless Propag. Lett.*, Vol. 12, 686–689, 2013.
10. Zhang, X.-Y., X. Zhong, Z. Liu, and B. Li, "A horizontally polarized omnidirectional antenna with a reflector for ceiling-mounted indoor applications," *Progress In Electromagnetics Research Letters*, Vol. 54, 27–32, 2015.