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A Horizontally Polarized Omnidirectional Antenna with a Reflector for Ceiling-Mounted Indoor Applications

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Abstract—A novel wideband horizontally polarized omnidirectional antenna (HPOA) with an electrical conductor reflector is proposed for the 4th generation (4G) Long Term Evolution (LTE) applications. The proposed antenna consists of four pairs of printed dipoles distributed on the front and back of the substrate, and a star-shape patch integrated with stepped parallel strip lines constitutes a balun for the unbalance-balance transition from the coax feeding to the antenna. Both simulated and measured reflection coefficients (S_{11}) demonstrate a wide -10 dB impedance bandwidth of 39.6%, from 1.82 to 2.72 GHz. This band covers PCS, UMTS, LTE 2300, LTE 2500, WLAN and Bluetooth bands. The presented antenna has a peak gain of 3.2 and 4.0 dBi at 1.95 and 2.48 GHz, respectively, and an omnidirectional radiation pattern in E-plane. HPOA may be suitable for ceiling-mounted indoor 4G applications.

1. INTRODUCTION

In the urban or indoor wireless environment, the polarization of the propagating radio wave may change significantly due to complicated multiple reflection and scattering. High-gain antennas with horizontal polarization and omni-direction have gained great interests. As reported in [1, 2], the transmitters and receivers with horizontal polarization could save more than 10 dB power, compared with their vertically polarized counterparts. The drawback of horizontally polarized antenna is the requirement of omni-directivity in azimuthal plane.

To achieve a horizontally polarized radiation pattern, a small loop antenna with a uniform current distribution, acting as a magnetic dipole, is firstly taken into account. However, a small loop antenna has a very small radiation resistance and a high reactance. This will cause difficulties in impedance matching. A large loop antenna has a reasonable radiation resistance; however, the current distribution along the loop becomes non-uniform. Hence it cannot yield the desired horizontally polarized omnidirectional pattern [3]. The Alford loop antenna achieving a horizontally polarized omnidirectional wave was first reported in [4] and has been extensively investigated in recent years [5]. However, this kind of antenna has a narrow bandwidth less than 10%. With the development of the technology, several wideband horizontally polarized omnidirectional antennas have been proposed. A modified printed Alford-structure loop antenna with dual band at 2.45 and 3.9 GHz was presented in [6]. A planar antenna, consisting of four dipoles on a circular substrate, was proposed in [7], and its bandwidth is from 2.3 GHz to 2.7 GHz. A printed loop antenna, using periodical capacitive loading and a parallel stripline as an impedance transformer and covering the frequency range of 2.17–2.97 GHz, was proposed in [8] and a HPOA for base stations covering 1.67–2.35 GHz in [9]. So far, no reported HPOA can provide adequate bandwidth to meet the requirement for 4G LTE applications.

In this paper, we present a novel wideband planar HPOA with wide bandwidth for 4G LTE applications. The proposed antenna provides a wide impedance bandwidth of about 0.9 GHz from

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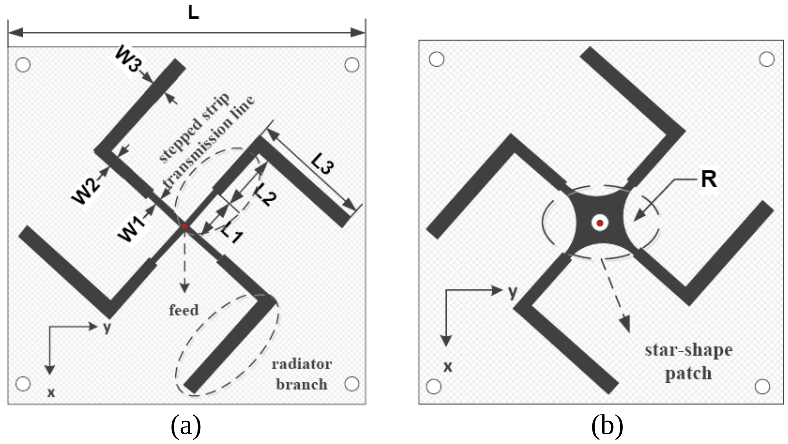

Figure 1. Geometry of proposed antenna, (a) top plane, (b) bottom plane.

Table 1. Optimized geometric parameters for the planar HPOA. (Unit: millimeter).

L_1	L_2	L_3	W_1	W_2	W_3	W_4	R
42	15	20	21.3	1.0	2.5	3	14.5

1.82 GHz to 2.72 GHz and an omnidirectional radiation pattern in E-plane. Details of the antenna design are presented, and return loss, bandwidth, radiation patterns, and gain of the antenna are studied.

2. ANTENNA CONFIGURATION AND DESIGN

The basic geometry of the proposed wideband HPOA is shown in Figure 1. The antenna consists of four pairs of printed dipoles distributed on antipodal sides of an FR4 substrate with a dimension of $84 \times 84 \times 1.6\,\text{mm}^3$. Figure 1(a) shows the top plane of the antenna. Four stripped radiator branches, in turn, arms of the four dipoles, are printed on the top of the substrate, and they are connected to stepped strip transmission lines, then connected at the center. As depicted in Figure 1(b), the antipodal radiator branches are printed on the bottom plane and connected to a star-shape patch.

The optimized parameters of the proposed HPOA are listed in Table 1. The length of each dipole is 42.6 mm, which is about $0.5\lambda_{eff}$ at 2.1 GHz. The star-shaped patch at the center of the bottom plane is tuned for impedance matching. The star-shaped patch integrated with the stepped parallel strip lines constitutes a balun for the unbalance-balance transition from the coax feeding to the antenna. Furthermore, the stepped strip transmission lines on the top and bottom sides of the FR4 substrate may generate a higher-order mode [10, 11], and the mode can be adjusted by changing the length and width of the transmission lines. So a wide bandwidth is achieved by combining the two modes.

A $50\,\Omega$ coaxial cable with SMA connector is used to feed the antenna from the center of bottom plane. The quasi-TEM waves are guided to four pairs of four stripped radiator branches through the stepped strip transmission lines due to the opposite current directions on both sides when the antenna is excited.

3. RESULTS AND DISCUSSION

According to the parameters given in Table 1, the proposed antenna was fabricated and measured. Figure 2 shows the fabricated prototype of the HPOA. In Figure 3, the measured and simulated S_{11} of the constructed prototype are presented. The simulated and measured S-parameters are in good agreement. It can be found that the antenna generates two resonant modes at 1.98 GHz and 2.46 GHz, respectively, which is consistent with previous analysis. The VSWR $2:1$ dB ($S_{11} < -10$ dB) impedance

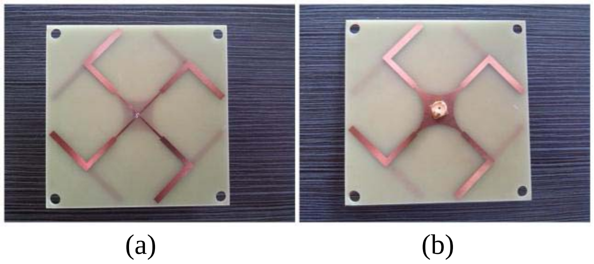

Figure 2. Fabricated prototype of the HPOA, (a) is front side and (b) is backside.

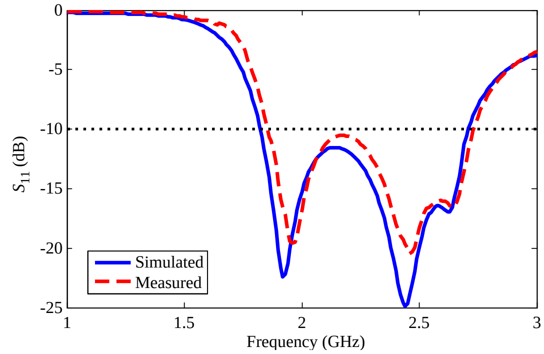

Figure 3. Simulated and measured S_{11} values of the proposed HPOA.

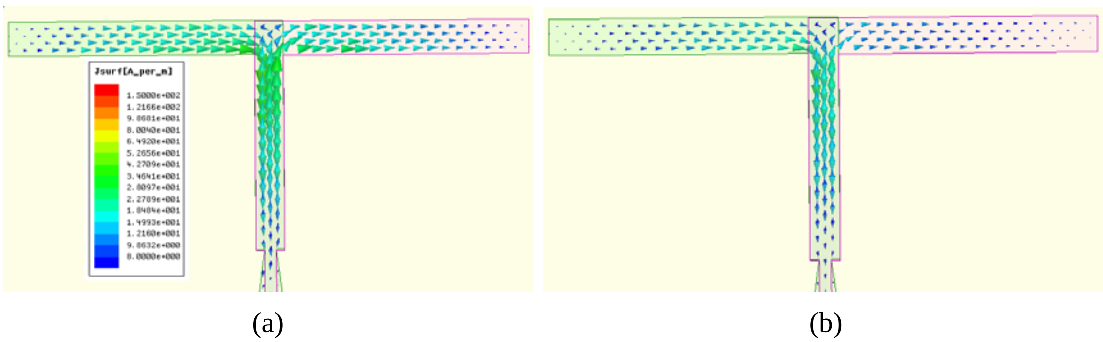

Figure 4. The simulated current distributions of the proposed HPOA at (a) 1.98 GHz and (b) 2.46 GHz.

bandwidth is measured as large as 0.88 GHz from 1.85 GHz to 2.73 GHz, covering PCS, UMTS, LTE 2300, LTE 2500, WLAN and Bluetooth bands.

To intuitively investigate the radiation pattern of the proposed antenna, the surface currents distributions of the HPOA at 1.98 GHz and 2.46 GHz are shown in Figure 4. The current on the stripped radiator branch flows in the same direction, while the current on the stepped strip transmission line flows in the opposite direction. Due to the symmetry of stripped radiator branches, the current flows synchronously in a clockwise direction, similar to the current of a small loop antenna. Therefore, the antenna can be considered close to a magnetic dipole to achieve a horizontally omnidirectional radiation pattern.

To optimize the HPOA, antenna dimensions are swept. Effects of length L_1 of stepped strip transmission lines are studied in Figure 5(a). The value of $|S_{11}|$ decreases significantly when L_1 increases due to the impedance match. There is almost no influence on lower resonant frequency, while there are bigger effects on higher resonant frequency, which demonstrates that the lower resonant mode is generated by stripped radiator branches, and the stepped strip transmission lines can adjust the higher-order mode. The effects of width W_1 are also studied in Figure 5(b). The value of S_{11} changes significantly due to the variation of the input impedance.

The radiation characteristics of the HPOA were also studied. Figure 6 illustrates the measured radiation patterns of the antenna in two principal planes, E-plane (xy-plane) and H-plane (yz-plane) at 1.98 GHz and 2.46 GHz. From the results, the co-polarization and cross-polarization correspond to the radiated electric field in the Φ-direction and in the θ-direction, respectively. As can be seen from all the xy-plane, omnidirectional radiation with horizontally polarization is obtained. The radiation patterns at the elevation plane (yz-plane) is like a shape of quasi-eight. Therefore, the radiation patterns of the proposed antenna are very similar to a magnetic dipole. The omni-directivity becomes slightly distorted because the current on the stripped radiator branches did not form a closed loop. The cross polarization gets larger as frequency increases, which might be due to the coupling between the stepped

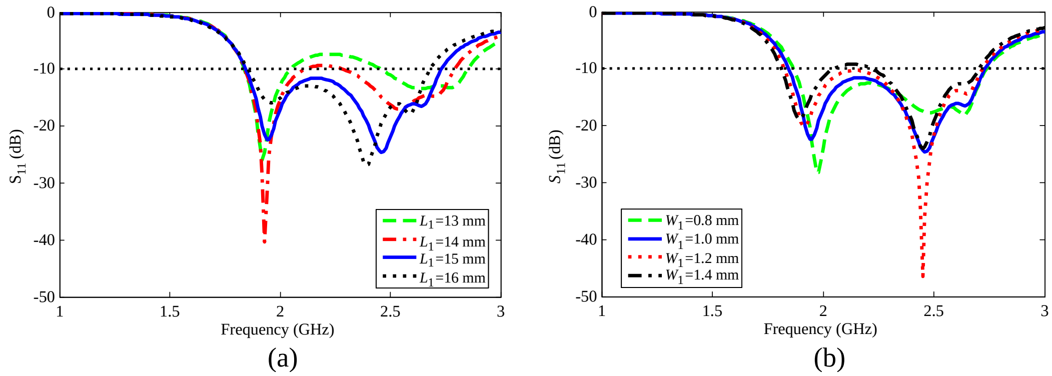

Figure 5. Simulated S_{11} of L_1 and W_1 of stepped strip transmission line. (a) for L_1 and (b) for W_1.

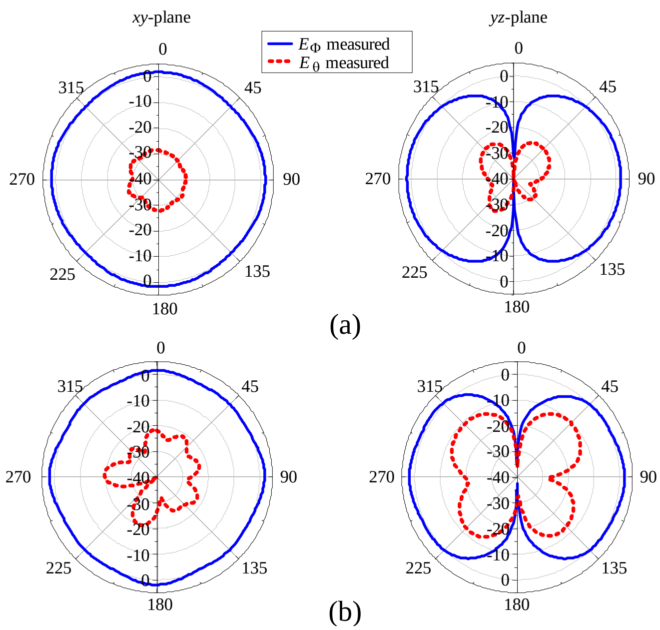

Figure 6. Measured radiation patterns of HPOA. (a) 1.98GHz and (b) 2.46 GHz.

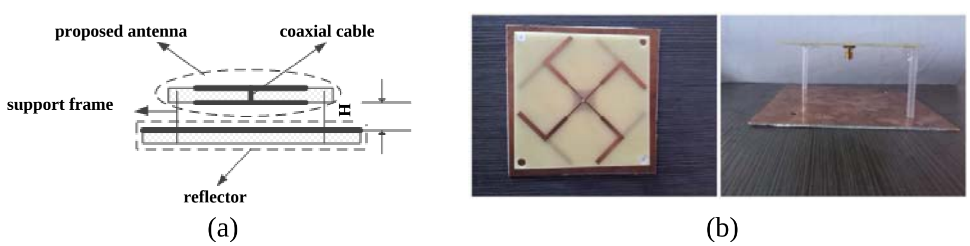

Figure 7. Geometry and photos of the HPOA with reflector, (a) lateral structure diagram, (b) photos of fabricated antenna.

strip transmission lines at antipodal sides. The proposed antenna has a gain of 1.8 and 2.0 dBi at 1.98 GHz and 2.46 GHz respectively.

In order to improve the gain of the proposed antenna, an electrical conductor reflector is placed under the antenna with a distance of H. The reflector uses the same substrate as the antenna with dimension of $150 \times 150 \times 1.6\,\text{mm}^3$, and the top plane is covered with copper. Side view and fabricated prototype are shown in Figure 7. Several papers have researched the impact of different heights [12], and the results demonstrate that the height (H) of a quarter wavelength is suitable. The optimized height of H in this design is 43 mm which is about 0.25λ at 1.82 GHz. Figure 8 shows the measured and simulated S_{11} of the antenna with a reflector. The impedance bandwidth is almost the same as the HPOA without reflector, from 1.82 GHz to 2.72 GHz, and reasonable agreement between the measurement and simulation is observed. For the purpose of studying whether the reflector has impacts on the omni-directivity, the measured radiation patterns are shown in Figure 9. The results indicate that the reflector does not affect the omni-directivity, and the antenna still obtains a good omnidirectional radiation with horizontal polarization in the azimuthal plane, just the values changed, which are compared to the consequences shown in Figure 6.

The measured gain for the proposed antenna is shown in Figure 10. The antenna is tested in a far-field anechoic chamber. The proposed antenna with a reflector gets a peak gain of 3.2 and 4.0 dBi at 1.95 and 2.48 GHz, respectively, much higher than the antenna without a reflector. Enhanced gain and omnidirectional radiation pattern in E-plane makes it suitable for ceiling-mounted indoor 4G applications.

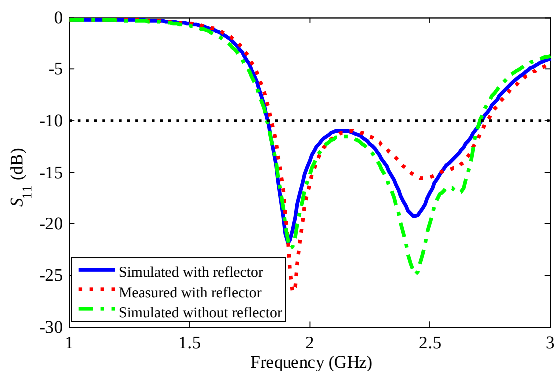

Figure 8. Simulated and measured S_{11} of the proposed HPOA with reflector.

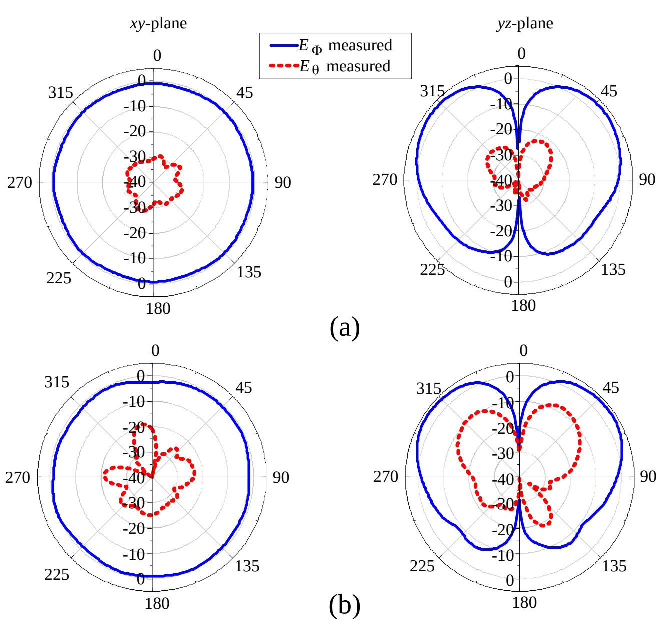

Figure 9. Measured radiation patterns of HPOA with a reflector, (a) 1.98 GHz and (b) 2.46 GHz.

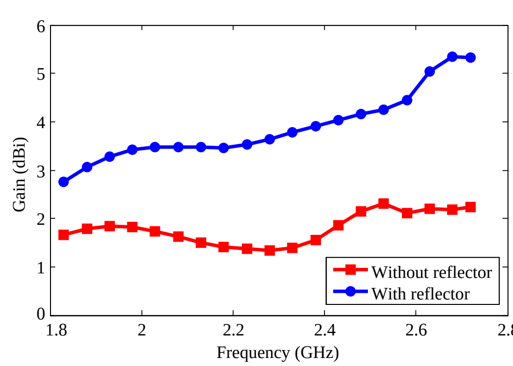

Figure 10. Measured antenna gain for the proposed antenna.

4. CONCLUSION

A wideband HPOA with an electrical reflector was reported for 4G LTE applications. The proposed antenna addresses a wideband from 1.82 GHz to 2.72 GHz, and a return loss less than -10 dB. The fabricated HPOA can provide an omnidirectional radiation pattern in E-plane, and a peak gain of 3.2 and 4.0 dBi at 1.95 and 2.48 GHz, respectively. The experimental results show that this design is ideally practical for ceiling-mounted indoor applications, including PCS, UMTS, LTE 2300, LTE 2500, WLAN and Bluetooth bands. Consequently, the proposed antenna is suitable for multi-frequency applications of wireless communication systems.

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