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Wideband Vertical Planar Printed Unidirectional Antenna

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Abstract—A new wideband vertical planar printed unidirectional antenna is presented. The proposed antenna is composed of a bowtie electric dipole, a loop antenna and a microstrip-to-coplanar stripline balun. All of them are printed in the same plane perpendicular to the ground. The antenna has a wide impedance bandwidth of 88.9% for SWR ≤ 2 from 3.3 to 8.58 GHz and a stable gain of 7.3 ± 1.5 dBi over the operating frequencies. What's more, stable unidirectional radiation pattern with low back-lobe radiation, low cross polarization and nearly identical E- and H-plane patterns was also demonstrated over the frequency of interest. A prototype was fabricated and measured. The measured results indicate that the antenna is suitable for wideband wireless communication system.

1. INTRODUCTION

The rapid development of wireless communication system demands excellent electrical characteristics of wideband unidirectional antenna, such as wide impedance bandwidth, low back-lobe radiation, and stable gain across the entire bandwidth. Many different methods have been proposed to achieve good electrical characteristics. Several types of antennas, such as log-periodic, horn, and reflector antennas [1, 2], are limited by their bulky structures. The patch antennas with an L-probe [3], a meandering probe [4], or parasitic loops [5] can provide unidirectional patterns and increase impedance bandwidth, but the radiation pattern varies over the operation frequencies of these designs. Thus, the complementary antenna concept was employed to develop wideband unidirectional antennas through the last couple of years.

Recently, a wideband complementary antenna called magneto-electric (ME) dipole has attracted wide attention and in-depth studies [6–10], which has low back-lobe radiation, symmetric radiation patterns and stable gain over the operating band. In [6], Prof. Luk firstly presented a magneto-electric dipole with impedance bandwidth of 43.8% by combining a planar electric dipole that works as an electric dipole and a shorted patch antenna works as a magnetic dipole. Some improved designs have been presented later [11–15].

However, almost all of the existing magneto-electric dipole antennas are horizontally implemented and designed in large electrical size, which requires relatively large space if an antenna array is composed for either E- or H-plane beam steering, so magneto-electric dipoles with vertical planar printed structure were proposed. A printed antenna composed of a dipole and a loop was proposed in [16], but it only achieves impedance bandwidth of 7.4% and low measured peak gain of 4.3 dBi, as well as not-so-good radiation patterns. In [17], a novel vertical planar printed magneto-electric dipole was presented with a stable gain of around 6.5 dBi, but the impedance bandwidth is just 17.1% and the size ($78 \times 66\,\text{mm}^2$) is too large to fulfill the stringent requirements of some modem wireless communication systems.

In this paper, a wideband vertically oriented unidirectional antenna is proposed based on the structure of the magnetic-electric dipole. In order to solve the problems mentioned above, a novel feeding structure is utilized to achieve wider impedance bandwidth. For improving the antenna performance, a

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bowtie-shaped dipole that works as an electric dipole and a half-rectangular loop works as a magnetic dipole are introduced, so stable gain and symmetric radiation patterns in the E- and H-planes can be achieved. Meanwhile, these printed structures are implemented on a single PCB substrate perpendicular to a horizontal rectangular ground plane, in this way, the requisite space is reduced significantly, low back-lobe radiation and relatively high gains are achieved.

2. ANTENNA CONFIGURATION

The geometry of the proposed antenna is shown in Figure 1(a). The whole antenna consists of a bowtie-shaped dipole, a loop antenna, a microstrip-to-coplanar stripline (MS-to-CPS) balun and a rectangular ground. To excite the antenna, a MS-to-CPS balun is employed, it is similar to the one mentioned in [18], except for tiny dimension changes. By connecting it to the SMA connector, it can excite the proposed antenna with a broadband impedance matching. Specifically, the input port is converted from a microstrip line at the top layer to a slotline at the bottom layer by a wideband microstrip-to-slotline transition shown in Figure 1(b), the circular microstrip and circular slot are used to enhance the impedance matching. Then, the slotline is coupled to a coplanar stripline using another slotline-to-microstrip transition. As a result, the bowtie-shaped dipole works as an electric dipole, and the half-rectangular loop works as a magnetic dipole, as explicated in Figure 2.

It is a common knowledge that when an electric and a magnetic dipole are co-excited with proper amplitude and phase, symmetric radiation patterns in the E- and H-planes can be realized because of

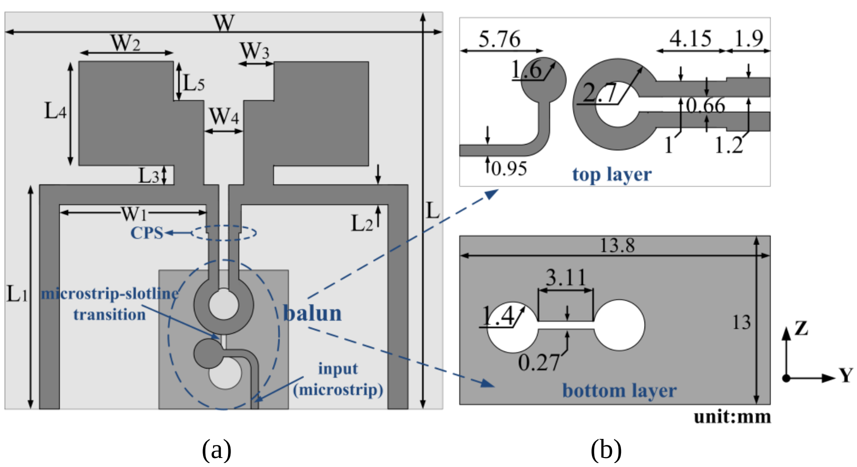


Figure 1. Proposed antenna. (a) Geometry of proposed antenna. (b) Top and bottom layer of balun.

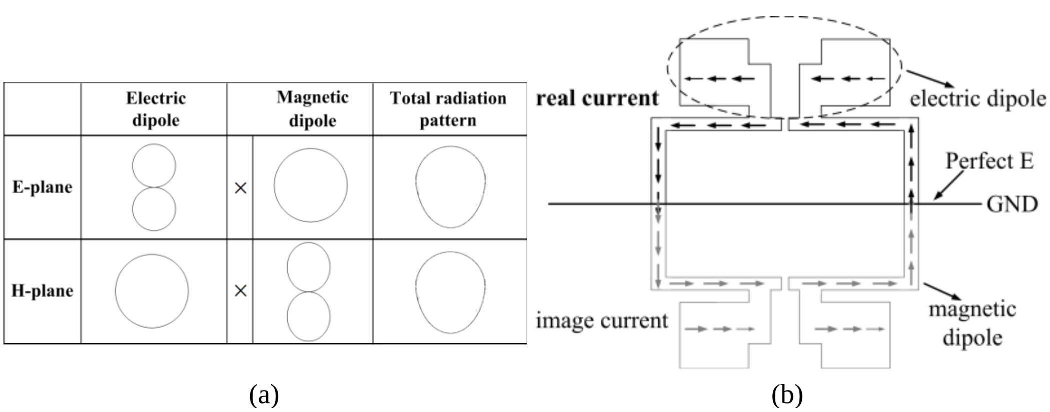
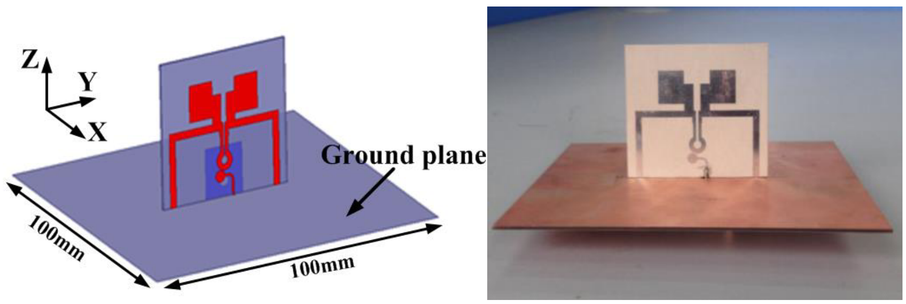


Figure 2. (a) Principle of identical of E-plane and H-plane. (b) Ideal current distribution of the electric dipole and magnetic dipole.



(a) (b)

Figure 3. (a) 3-D view of the proposed antenna. (b) Fabricated antenna.

the complementarity of their radiation patterns, i.e., figure-8 shape in the E-plane and figure-O shape in the H-plane for the electric dipole, whereas figure-O shape in the E-plane and figure-8 shape in the H-plane for the magnetic dipole, as shown in Figure 2(a). So in Figure 2(b), the bowtie-shaped dipole with its image dipole enhancement works as the electric dipole, and the current of the loop with its image current together contribute to an equivalent magnetic dipole, which is located orthogonal to the electric dipole. Thus, stable gain and symmetric radiation patterns in the E- and H-planes can be achieved with this structure.

This design of the magneto-electric dipole is based on the idea in [17]. As shown in Figure 3(a), this structure is made up of a bowtie-shaped electric dipole and a loop antenna, both of which are printed on the top layer of the substrate instead of on both sides in [17]. The proposed antenna has a structure printed on a vertical single-layer Rogers RT 6010 dielectric substrate (thickness = 0.635 mm, $\varepsilon_r = 10.2$ and a loss tangent of 0.0023), and is perpendicular to a rectangular ground plane of $100 \times 100\,\text{mm}^2$. The detailed design parameters of the optimised antenna are: $W = 44$ mm, $L = 40$ mm, $W_1 = 15.8$ mm, $W_2 = 8$ mm, $W_3 = 3$ mm, $W_4 = 2$ mm, $L_1 = 20.36$ mm, $L_2 = L_3 = 2$ mm, $L_4 = 10$ mm, $L_5 = 4$ mm.

3. RESULTS AND DISCUSSION

The simulation was accomplished using Ansoft HFSS, and in order to verify the simulated results, a prototype of the antenna as shown in Figure 3(b) was built and tested. The SWR of the fabricated antenna was measured by an Agilent N5230A network analyser. Figure 4 shows the simulated and measured SWRs and they are in good agreement. The measured impedance bandwidth is 88.9% (SWR ≤ 2) from 3.3 to 8.58 GHz. Figure 4 also illustrates the fat gain curves of the antenna. It can be observed that the simulated gain is about 7.3 ± 1.5 dBi within the operating band, while the measured gain varies

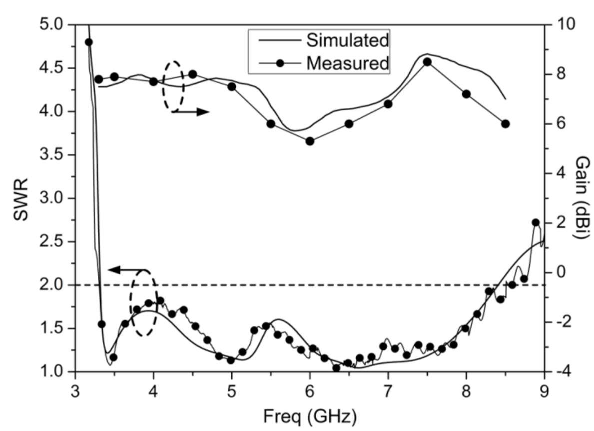


Figure 4. Simulated and measured SWRs and gains against frequency.

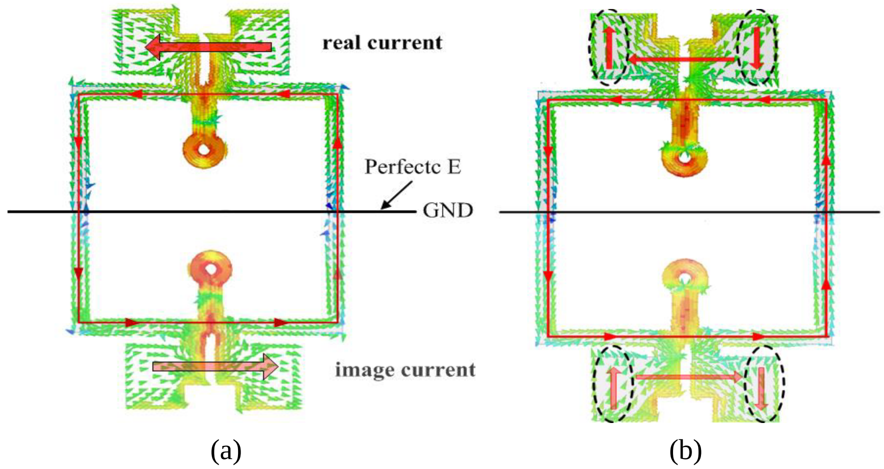


Figure 5. Surface current distribution of the antenna, (a) at 4 GHz (half-wavelength = 37.5 mm), (b) at 6.3 GHz (half-wavelength = 23.8 mm).

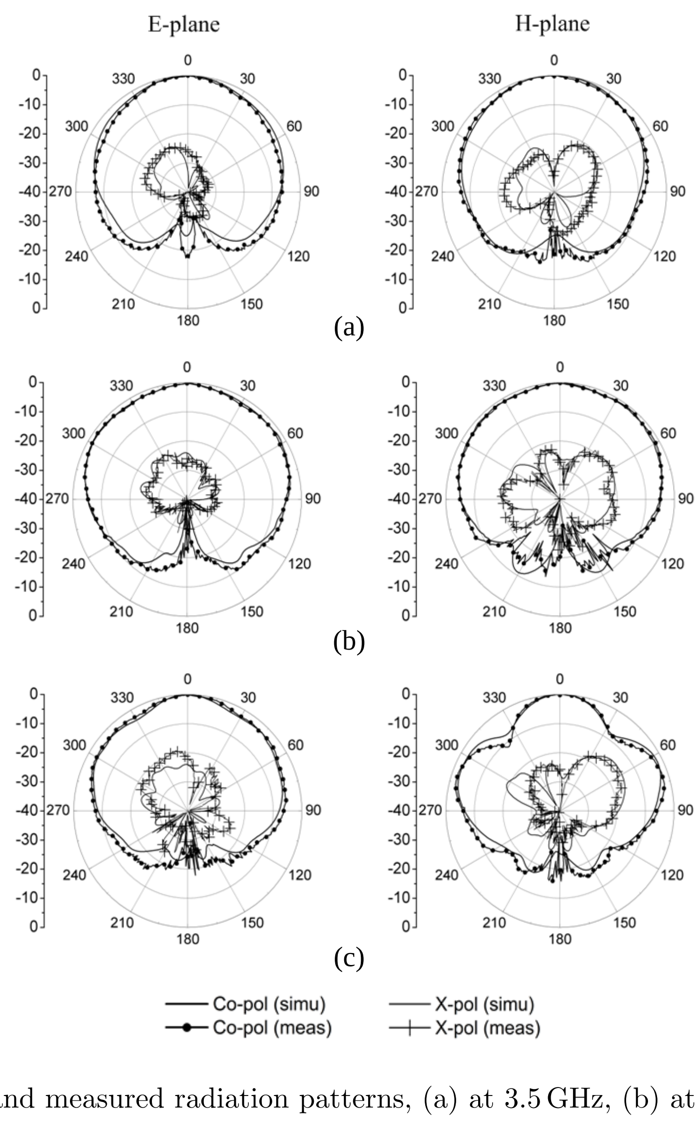


Figure 6. Simulated and measured radiation patterns, (a) at 3.5 GHz, (b) at 5.7 GHz, (c) at 7 GHz.

between 5.3 and 8.5 dBi with 3.2 dB variation. The discrepancy of the measured and simulated gains is mainly caused by the SMA soldering inaccuracy and fabrication tolerance.

As shown in Figure 4, the gain from 3.3 GHz to 5 GHz is very high and stable, while it drops from 5 GHz to 7.2 GHz and becomes relatively low. So we observe the surface current distribution of the antenna at 4 GHz and 6.3 GHz in Figure 5 to explain this phenomenon. The bowtie-shaped dipole and its image make up the electric dipole, and the loop antenna with its image works as the magnetic dipole. The surface current distribution at 4 GHz shows the electrical characteristics of the magneto-electric dipole with a high gain. However, when the antenna functions at 6.3 GHz, the high-order mode is excited. Besides the electric dipole mentioned above, the resulting current perpendicular to the ground on the edge of the bowtie-shaped dipole and its image function as new electric dipoles perpendicular to the ground, as marked with the black circle in Figure 5(b). Because of the orthogonal situation and the radiation patterns of the two electric dipoles parallel and perpendicular to the ground, a low gain in the endfire direction is produced. It's a common disadvantage of the broadband magneto-electric antenna, fact is presented in papers [14, 15].

The measured and simulated radiation patterns at frequencies of 3.5, 5.7, and 7 GHz, respectively, are shown in Figure 6. It can be seen that the simulated and measured patterns agree well with each other over the operating frequencies. Because of the complementary structures, the measured front-to-back ratio of the proposed antenna is above 15 dB, the cross polarization levels in the E- and H-planes are both below 20 dB and almost equal radiation patterns in the E- and H-planes are obtained over the whole operating band. In addition, the broadside radiation patterns are stable and symmetric in the E- and H-planes below 6 GHz. As frequency increases to over 6 GHz, two side lobes appear both in the E-plane and H-plane.

4. CONCLUSION

A new wideband vertical planar printed unidirectional antenna composed of a bowtie electric dipole and a loop antenna has been designed, fabricated and tested. A microstrip-to-coplanar stripline is used as a balun to feed the antenna. Measurements demonstrate that the designed antenna has a wide impedance bandwidth of 88.9% and a stable gain varies between 5.3 and 8.5 dBi. The unidirectional radiation patterns are stable and symmetric over the frequency of interest, with low back-lobe radiation and low cross polarization. Meanwhile, the small single-layer printed structure ($44 \times 40\,\mathrm{mm}^2$) and good radiation performance make itself a proper candidate in some wideband unidirectional wireless systems.

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