Dual-Mode Loop Antenna With Compact Feed for Polarization Diversity

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***Abstract*—Design, prototyping, and testing of a dual-polarization loop antenna is presented for possible use in wireless local area network (WLAN) applications. The antenna design consists of a rectangular loop, a coplanar waveguide (CPW), and a microstrip line. The loop antenna operates in two orthogonal one-wavelength modes, which are excited by one CPW feed structure. The overall dimension of the prototype is only 40×53 mm^2, including the feed structure. The measured −10-dB reflection coefficients bandwidth of the two modes are 770 MHz (32.1%) and 730 MHz (30.4%) at the operating frequency of 2.4 GHz. In the WLAN band, the ports isolation is better than −21.3 dB. Gains of the two modes are better than 2.9 and 4.1 dBi. Radiation patterns are measured and compared to simulation results. The proposed antenna has the advantages of compact dimension, wide bandwidth, good ports isolation, and low cross polarization.**

***Index Terms*—Antenna diversity, antenna feeds, loop antennas.**

I. Introduction

With the rapid progress of wireless communication, antennas with polarization diversity performance are widely studied and adopted, especially in the multiple-input–multiple-output (MIMO) application. Such a type of antenna is particularly suitable for mitigating fading in multipath propagation environments. The channel capacity improvements are widely studied with proven advantages when adopting antennas with polarization diversity [1]–[3]. Therefore, antennas with dual polarizations, wide bandwidth, good port isolation, and compact dimension are highly desirable for modern wireless communication applications. Several antenna designs providing polarization diversity have been designed, and their characteristics were published in recent papers [4]–[9]. This includes designs based on dipoles [4], patch antennas [5], [6], slot radiators [7], [8], and loop antennas [9]. Specifically, in [4], two crossover folded dipoles were used to provide two orthogonal polarizations. The reported bandwidth was sufficiently wide, but the dimensions were relatively large. Lower profile design was achieved by adopting patch antennas, such as the use of a single patch [5] and nested patches [6] with two different feed structures. The isolation and the reduction in the antenna dimensions were improved, but this was associated with degradation in the achievable bandwidth. Wider bandwidth with bidirectional radiation patterns was achieved by using slot antennas without ground planes [7], [8]. The dimensions, in this case, were still large with the operating electric length of a half-wavelength, similar to the dipole and patch antenna designs. To achieve compact dimension, the loop antenna was considered as an effective solution, as its operating mode utilizes one-wavelength designs. In a study by Baek *et al.* [9], two orthogonal polarizations were provided using electric and magnetic loop antennas. The magnetic loop antenna was realized using slotted patch and spiral slots on a ground plane. While resonating at its zeroth-order frequency, the dimensions of this antenna were more compact than earlier designs, but the bandwidth and gain were both worse [4]–[8]. From the above discussion, it is clear that the design of a dual-polarizations antenna with wide bandwidth, good ports isolation, and compact dimensions is quite challenging.

For the above-mentioned purpose, a rectangular loop antenna with polarization diversity for wireless local area network (WLAN) application is proposed. Compared to the design

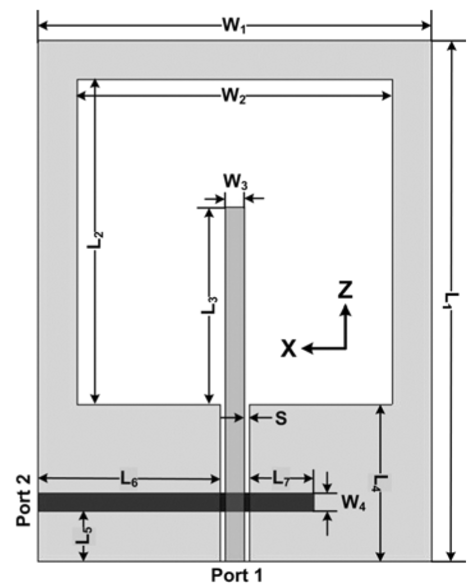

Fig. 1. Geometry and dimensions of the proposed antenna.

Manuscript received January 21, 2011; accepted January 25, 2011. Date of publication February 10, 2011; date of current version March 14, 2011. This work was supported in part by the National Basic Research Program of China under Contract 2009CB320205, the National Science and Technology Major Project of the Ministry of Science and Technology of China 2010ZX03007-001-01, and Qualcomm.

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Digital Object Identifier 10.1109/LAWP.2011.2112752

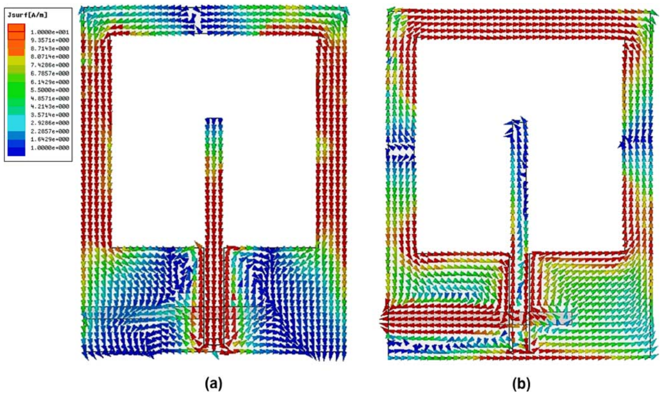

Fig. 2. Current distribution in loop antenna fed through (a) port 1 and (b) port 2.

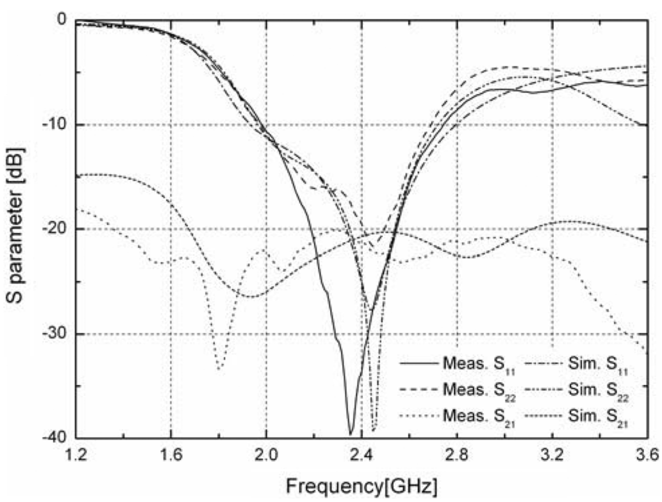

Fig. 3. Simulated and measured S-parameters of the proposed antenna.

TABLE I
DETAILED DIMENSIONS OF THE PROPOSED ANTENNA

Parameter	L_1	L_2	L_3	L_4	L_5	L_6
Value (mm)	53	33	20	16	5.1	18.5
Parameter	L_7	W_1	W_2	W_3	W_4	S
Value (mm)	6.5	40	32	2	1.9	0.5

in [8], the geometrical structure appears similar, but the work principle is different, which is explicitly discussed in this letter. A loop is adopted here instead of the slot with a large ground [8] for the purpose of dimension decrease. The compact feed in [8] is proved to feed the dual orthogonal one-wavelength perimeter modes of the loop both with good impedance matching. With the reduction of the size of the ground, the cross polarization is much smaller than [8]. The proposed antenna not only inherits the merits of wide bandwidth, high ports isolation, and bidirectional radiation, but it also has the advantages of compact dimension and low cross polarization.

II. ANTENNA CONFIGURATION AND DESIGN

The geometry of the proposed antenna is shown in Fig. 1. The antenna consists of a rectangular loop, a coplanar wave-

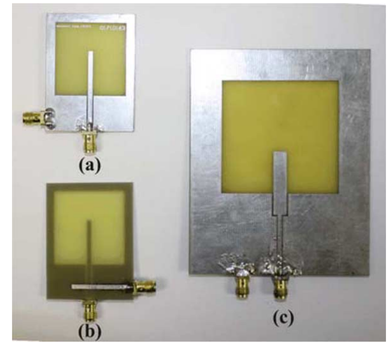

Fig. 4. Photograph of the proposed antenna. (a) Front view. (b) Back view. (c) Slot antenna in [8] working at 2.4 GHz.

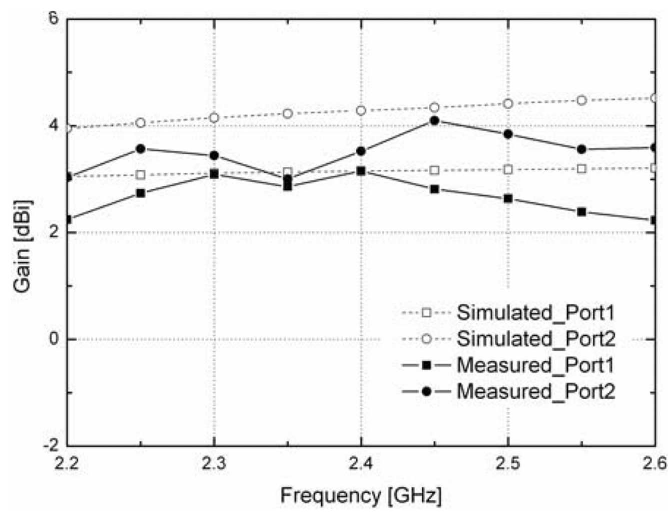

Fig. 5. Simulated and measured gain of the proposed antenna.

guide (CPW), and a microstrip line supported by an FR4 ($\varepsilon_r = 4.4, \tan\delta = 0.01$) board with the thickness of 1 mm. The loop has width of 4 mm, and its circumference is approximately one wavelength. The loop and CPW are etched on the front side, and the microstrip line is printed on the back side. Fig. 1 also shows the feed ports 1 and 2.

A. Dual-Mode Operation of Loop Antenna

For the same application in WLAN at 2.4 GHz, a slot antenna with a compact feed is designed in [8]. A rectangular slot is etched in a large ground. The slot's length and width are approximately a half-wavelength. For a typical slot mode, the width of extended ground is a quarter-wavelength or smaller. If the size of the surrounded ground decreases to some level, the slot becomes a loop with the frequency shift. A loop antenna typically works at one-wavelength perimeter mode, and the current distributes with two peaks and two mulls along the edges, shown in Fig. 2, which is different from the slot at the same frequency. A loop has four edges with the total length being one wavelength. Therefore, the dimension of a rectangular loop antenna is much smaller than the slot with large ground. However, the antenna in [8] is well adopted in the array design in the same ground for special requirements.

From the above discussion, the loop antenna is a good candidate to achieve compact antenna dimension. The current distri-

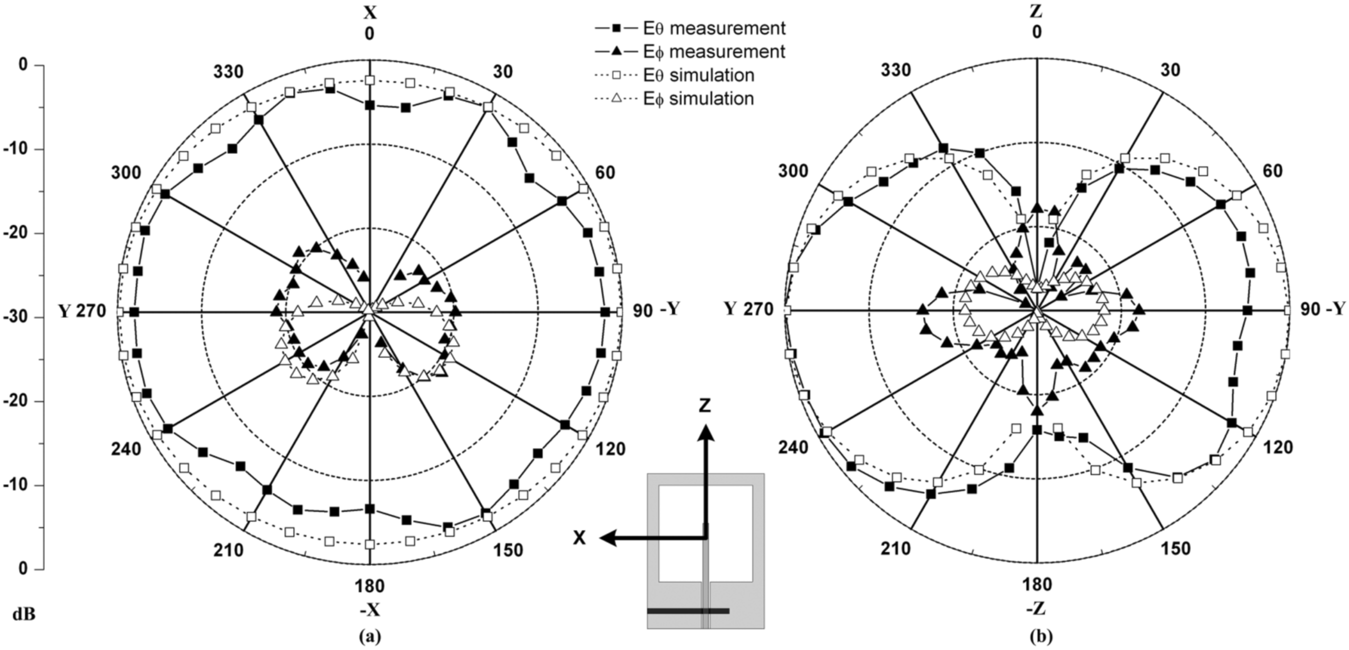

Fig. 6. Simulated and measured radiation patterns of the proposed antenna fed through port 1 at 2.4 GHz. (a) xy plane. (b) yz plane.

bution of its one-wavelength perimeter mode is determined by the position of feed, and feed should not be arranged at the null of current. In order to excite two orthogonal one-wavelength perimeter modes, it is common to arrange two feeds at two orthogonal positions, which will make the overall dimension even larger [10]. A compact size could be achieved if such two modes of operation are fed at only one position. The compact CPW feed backed with microstrip line described in [8] is an effective solution to feed the dual mode of a loop antenna. When the loop is fed through port 1, the CPW operates at its typical symmetrical mode, which is noted as the even mode. In this mode, the vertical polarization of the loop antenna is excited, as shown in Fig. 2(a). The inner conductor works as a monopole with the vertical polarization. The energy is coupled from monopole to the loop, exciting the vertical polarization mode. The radiation consists of two modes, a one-wavelength perimeter mode of the loop and a monopole mode. When the loop is fed through port 2, the energy is coupled from the microstrip line to the CPW. The CPW works as a slot line, which supports the odd mode, and this excites the horizontal polarization of the loop antenna, as shown in Fig. 2(b). The feed is exactly at the maximum of the current, and the horizontal mode is clearly excited in this configuration. Considering the even and odd modes in the CPW are also orthogonal, good isolation is achieved between two ports.

B. Impedance Matching of Dual Mode

To realize wide bandwidth for the two modes discussed, the impedance matching strategy is described in this section. An extensive numerical analysis is carried out in the parameter optimization by using the software Ansoft High Frequency Structure Simulator (HFSS). The matching method has three steps. First, by tuning the value of S, the characteristic impedance of the CPW is set to 50 Ω. For vertical mode, impedance matching is achieved by tuning the values of L_3 and W_2. L_3 determines the operating frequency of monopole, and $\lambda/4$ (λ is the resonant wavelength) is set as the starting value. Due to the loading effect of the loop, L_3 is smaller than $\lambda/4$. W_2 affects the couple between monopole and loop, with the starting value of $\lambda/4$. Tuning L_2 is to make sure the loop operates in the one-wavelength mode. Second, for the horizontal mode, values of L_5 and L_7 are tuned for impedance matching, and W_4 is fixed to achieve 50 Ω microstrip line. The microstrip line with the offset length (L_7) serves as a shunt inductance and starts with $\lambda/8$. The values of L_5 and L_7 have little effect on the vertical mode. S also affects the coupling between the microstrip line and the slot in the CPW. As S changes, the impedance of the CPW is no longer 50 Ω. Thus, L_4 must be tuned in the third step. Therefore, the CPW operates as an impedance transformer between the input impedance of the port and radiation resistance of the loop antenna. Detailed values of the optimized parameters shown in Fig. 1 are listed in Table I. Simulation results with these values are shown in Fig. 3. The overall dimension of the antenna is 40×53 mm^2, including the feed structure. In [8], the slot antenna also operates at 2.4 GHz with the dimension of 70×86 mm^2. Compared to the prior design in [8], it is clear that the area of the proposed antenna is only 35.2% of the previous one and even with an achievable broader bandwidth.

III. Experiment Results

Fig. 4(a) and (b) shows the fabricated antenna, in front and back views, respectively. Fig. 4(c) shows, for size comparison, the slot antenna design described in [8], which also operates in the same band. Once again, a significant size reduction is achieved using the new design. Measured S-parameters are illustrated in Fig. 3, and as it may be seen, measured results agree well with the simulation data. The center operating frequency for both of the two modes is 2.4 GHz. The −10-dB bandwidth of the reflection coefficients are 770 MHz (1.98–2.75 GHz, 32.1%) for vertical mode and 730 MHz (1.96–2.69 GHz,

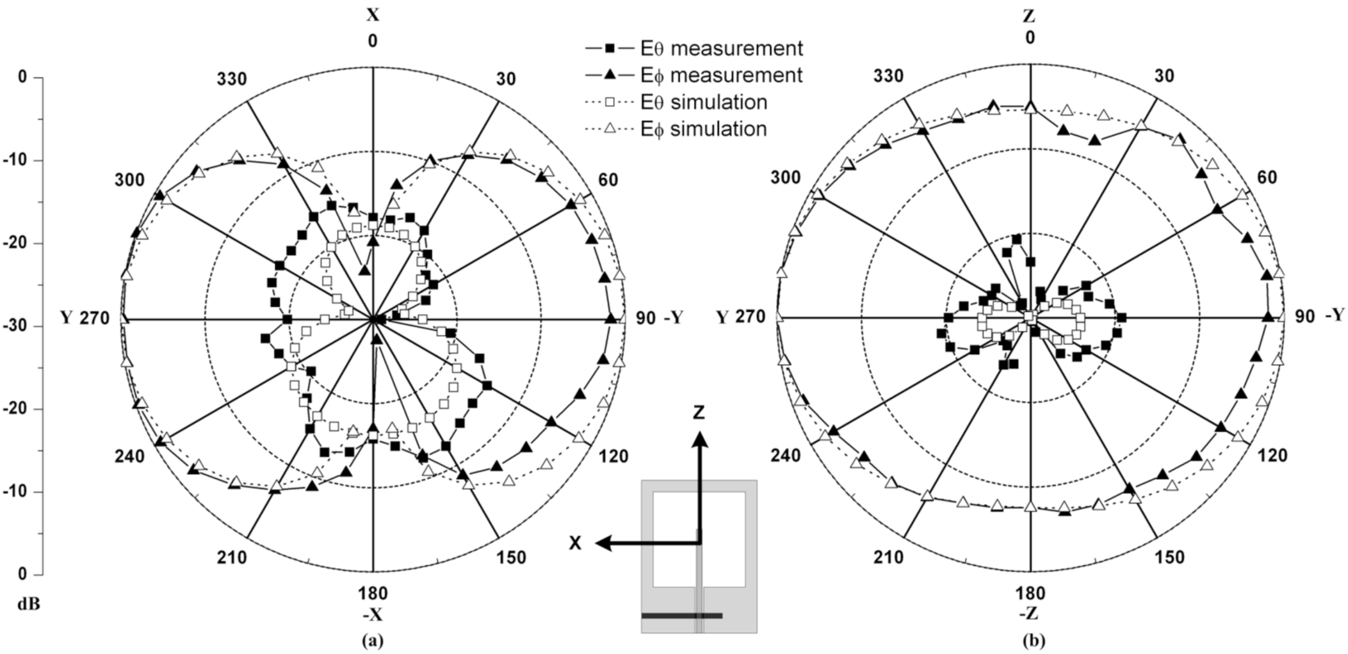

Fig. 7. Simulated and measured radiation patterns of the proposed antenna fed through port 2 at 2.4 GHz. (a) xy plane. (b) yz plane.

30.4%) for horizontal mode, both covering the WLAN band of 2.4–2.48 GHz. The isolation in this band is better than −21.3 dB.

The measured gains of dual modes are shown in Fig. 5, together with the simulation results. In the WLAN band of 2.4–2.48 GHz, the measured gains are better than 2.9 and 4.1 dBi, and the average gains are about 0.4 and 0.5 dB lower than simulation results. As it may be noted from Fig. 5, there is approximately a 1-dB gain difference between the vertical and horizontal polarization modes. The reason is that the horizontal polarization is totally contributed by the loop, and current on the monopole is almost zero, shown in Fig. 2(b). However, the vertical polarization is radiated from the loop as well as the monopole. The phase of the monopole's current is different from the loop. As a result, the gain of vertical polarization is lower than that of horizontal polarization.

The simulated and measured normalized radiation patterns in xy and yz planes at 2.4 GHz of the proposed antenna are shown in Figs. 6 and 7. The measured results agree well with the simulation data. From Figs. 6 and 7, it can clearly be seen that the directivity in the H-plane (xy plane) of the vertical mode is lower than that in the H-plane (yz plane) of the horizontal mode. The level of cross polarization is much lower than that in [8], showing excellent diversity performance. The nearly omnidirectional radiation patterns of the proposed antenna demonstrate the potential use as an access point in WLAN applications.

IV. CONCLUSION

In this letter, a loop antenna design with polarization diversity for WLAN application is described. A different working principle of the loop, which is different from the slot design described in [8], is discussed.

By adopting the compact feed structure in [8] at one edge of the loop, two orthogonal one-wavelength-perimeter modes of the loop antenna are excited, thus providing vertical and horizontal polarizations. The proposed antenna shows the advantages of compact overall dimension, wide bandwidth, good ports isolation, and low cross polarization. The measurement results agree well with simulation data and illustrate excellent diversity performance.

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