Low-Profile Planar Tripolarization Antenna for WLAN Communications

Xu Gao, Hua Zhong, Zhijun Zhang, *Senior Member, IEEE*, Zhenghe Feng, *Senior Member, IEEE*, and Magdy F. Iskander, *Fellow, IEEE*

***Abstract*—A tripolarization and low-profile planar antenna is designed, prototyped, and tested for WLAN application. The developed three-port antenna provides three orthogonal polarization radiations. Two slot-coupled microstrip antennas and a disk-loaded monopole are integrated into one structure. The total height of the antenna is 5.8 mm. Obtained gain for the two slot-coupled directive elements at 2.42 GHz is 7 dBi, while the gain for the monopole omnidirectional element is 2.5 dBi. The bandwidths of the three elements are 2.35–2.52, 2.3–2.54, and 2.38–2.49 GHz, respectively. Simulation results of the radiation patterns are presented and validated by experimental measurements.**

***Index Terms*—Low-profile, planar, tripolarization antenna.**

I. Introduction

IN MANY applications involving multiple antennas, including those based on multiple-input–multiple-output (MIMO) systems, polarization diversity of electromagnetic wave is considered an important resource in enhancing system performance. Traditionally, it is believed that an extra factor of 2 is the limit to enhancing the antenna system performance using polarization diversity. This is due to two independent polarizations within a uniform planar wave. However, it has been shown [1] that in rich multipath propagation environments, a total factor of 3 can be obtained in channel capacity because a maximum of three independent polarizations can be used in rich scattering and multipath communication environments. To take full advantage of this promising polarization diversity, it is necessary to design antennas with tripolarization characteristics. As early as 1979, a tripolarization antenna composed of two orthogonal slots and a monopole was proposed [2]. Recently, there has been increasing interest in designing multipolarization antennas. For example, a three orthogonal polarizations (DRA)-monopole ensemble that used a DRA to provide two orthogonal polarizations and a monopole for the third polarization was recently reported by Gray and Watanabe [3]. Another tripolarization antenna formed by a patch antenna and a monopole was introduced in an experiment [4]. Furthermore, a vector antenna constructed with three orthogonal dipoles and a loop was proposed in another work [5].

In several studies [2]–[4], quarter-wavelength monopoles have been employed for vertical polarization, which have resulted in high-profile three-dimensional antenna structures. A relatively low-profile tripolarization antenna that uses disk-loaded monopole to reduce height was proposed in another study [6]. Although this design effectively reduced the height of the antenna, the monopole structure still extruded from the top plane layer of the antenna structure. The reported total height was 10.8 mm, which is still relatively high for application at 2.4 GHz.

In this letter, a novel planar, low-profile, and tripolarization antenna operating at 2.4–2.5 GHz is proposed. The total height of the proposed antenna is 5.8 mm, which is approximately half the height of the antenna reported in a past study [6]. The low-profile and planar structure features make this proposed tripolarization antenna much more practical. The measured −6-dB impedance bandwidths are 2.35–2.52, 2.34–2.54, and 2.38–2.49 GHz for the three ports. The measured isolations between the three ports, in the frequency range from 2.4 to 2.48 GHz, are better than 24, 30, and 30 d B. These, as well as other design features and characteristics of this antenna, are described in the following sections.

II. Antenna Design and Radiation Characteristics

The configuration of the proposed tripolarization antenna is shown in Fig. 1. There are three layers to this antenna. The top and bottom layers are dielectric substrates of the same thickness with an air layer in between. A dual-polarized circular ring microstrip patch is placed on top of the uppermost substrate, while two orthogonal microstrip feed lines are placed on the bottom of the lower substrate and the ground plane is placed on the top side of this lower substrate. Two H-shaped slots are etched on the ground plane (top surface of the lower substrate) to excite the ring patch on the top substrate. The two ports of microstrip lines are indicated in Fig. 1 as P1 and P2. A circular patch is placed in the empty area inside the ring patch, and a disk-loaded monopole is constructed above the ground plane. The monopole is fed by a coaxial line with its outer connector joined to the ground plane and the inner connector to the circular patch (disk loading) on the top of the upper substrate. This monopole port is marked as M3 in Fig. 1(b). The circular patch is introduced to reduce the height of monopole antenna, and the associated increase in capacitive component of the input impedance is com-

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X. Gao, H. Zhong, Z. Zhang, and Z. Feng are with State Key Lab of Microwave and Communications, Tsinghua National Laboratory for Information Science and Technology, Tsinghua University, Beijing 100084, China (e-mail: zjzh@tsinghua.edu.cn).

M. F. Iskander is with Hawaii Center for Advanced Communications, University of Hawaii at Manoa, Honolulu, HI 96822 USA (e-mail: iskander@spectra.eng.hawaii.edu).

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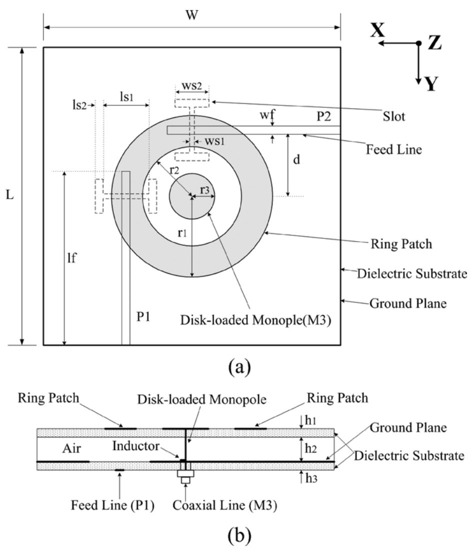

Fig. 1. Geometry of the tripolarization antenna: (a) top view; (b) side view.

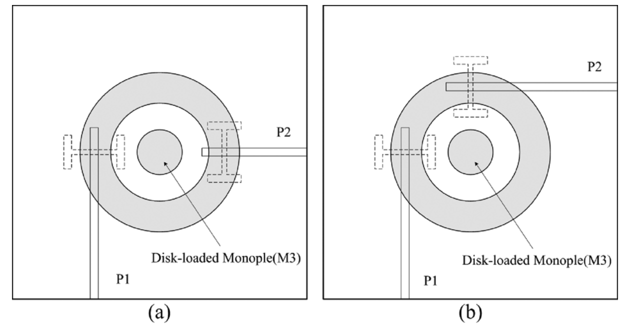

Fig. 2. Two different feeding configurations for P1 and P2: (a) T-shaped arrangement of slots; (b) L-shaped arrangement of slots.

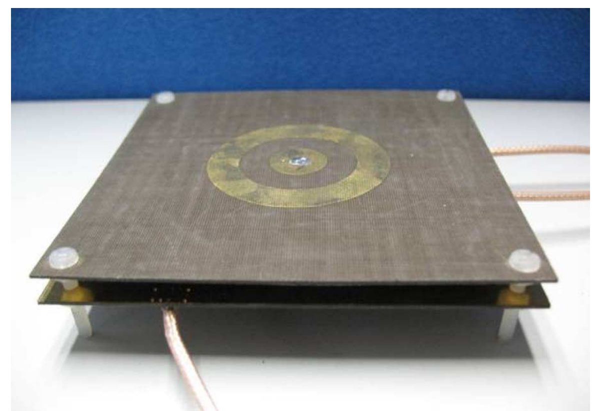

Fig. 3. Photograph of the proposed antenna.

pensated by introducing a 1-nH shunt inductor in the matching circuit for M3.

The F4B substrates (produced by Taixing Microwave Material Factory) with relative permittivity of 2.6 and dielectric loss tangent of 0.0005 are used for the two substrate layers. Each substrate is 0.8 mm in height. As shown in Fig. 1, the dimensions of the top plane are defined as W, L, $r1$, $r2$, and $r3$. The slot dimensions on the ground plane are defined as $ls1$, $ls2$, $ws1$, and $ws2$. The dimensions of microstrip feed lines are defined as lf and wf. The distance between the microstrip line and the center of the patch is defined as d. Each of the coupling slots is symmetrically arranged with respect to its feed microstrip line.

With three ports of this antenna working independently, the far field of this antenna has three orthogonal linear polarizations. Specifically, the E-field radiated by the ring patch is parallel to the ground plane and can provide two orthogonal polarizations excited through P1 and P2, while the monopole provides the vertical polarization component and an isotropic radiation in the azimuth plane. The coordinate system is shown in Fig. 1. The radiating electric fields independently excited by P1 and P2 are parallel to the y- and x-axes, respectively. Meanwhile, the electric field excited by M3 is parallel to the z-axis. Therefore, the three ports of this antenna radiate three polarized fields that are orthogonal to one another. In application, this proposed tripolarization antenna is preferred to be used with each port transmitting independent signals.

In the design shown in Fig. 2(b), the two slots in the ground plane are arranged in an "L" shape rather than opposite to each other, as shown in Fig. 2(a). This design is based on results of the numerical simulations, which showed that the arrangement in Fig. 2(b) provides improved isolation among the three ports. If the only consideration is the isolation between P1 and P2, the T-shaped arrangement of slots in Fig. 2(a) would have been the preferred arrangement. However, in this case, the isolation between P2 and M3 in Fig. 2(a) is unacceptably low, while isolation between P1 and M3 is much higher. This is because the slot of P2 port cuts off (perpendicular to) the current on the ground plane of the monopole mode, while the slot of P1 is along the radial current flow on the ground plane. Therefore, by considering the overall isolation performance of three ports, the L-shaped arrangement of slots is employed as it provides acceptable and balanced isolation among three ports.

The parameters of the fabricated antenna are as follows: $W = L = 94$ mm, $h1 = h3 = 0.8$ mm, $h2 = 4.2$ mm, $r1 = 21.5$ mm, $r2 = 14$ mm, $r3 = 6.8$ mm, $ls1 = 10$ mm, $ls2 = 2$ mm, $ws1 = 1$ mm, $ws2 = 8$ mm, $lf = 54$ mm, $wf = 2$ mm, and $d = 19.8$ mm. Fig. 3 shows a photograph of the fabricated antenna.

III. Simulation and Measurement Results

To verify the simulated design, a prototype antenna was fabricated and tested, and the measured data was compared to the simulated results. The measured and simulated S-parameters are shown in Fig. 4. As shown in Fig. 4(a), the measured data of return loss of the three are in good agreement with the simulation results. The small discrepancy of magnitude value might be caused by the manufacturing tolerance. The measured -6-dB impedance bandwidths are 2.35–2.52 GHz for P1, 2.34–2.54 GHz for P2, and 2.38–2.49 GHz for M3, respectively. The -10-dB bandwidths are 2.38–2.49 GHz for P1, 2.38–2.5 GHz for P2, and 2.4–2.47 GHz for M3. The measured isolation results between each two ports are presented in Fig. 4(b). The isolation between the P1 and P2 in the operational bandwidth is better than -24 dB, and the isolations between

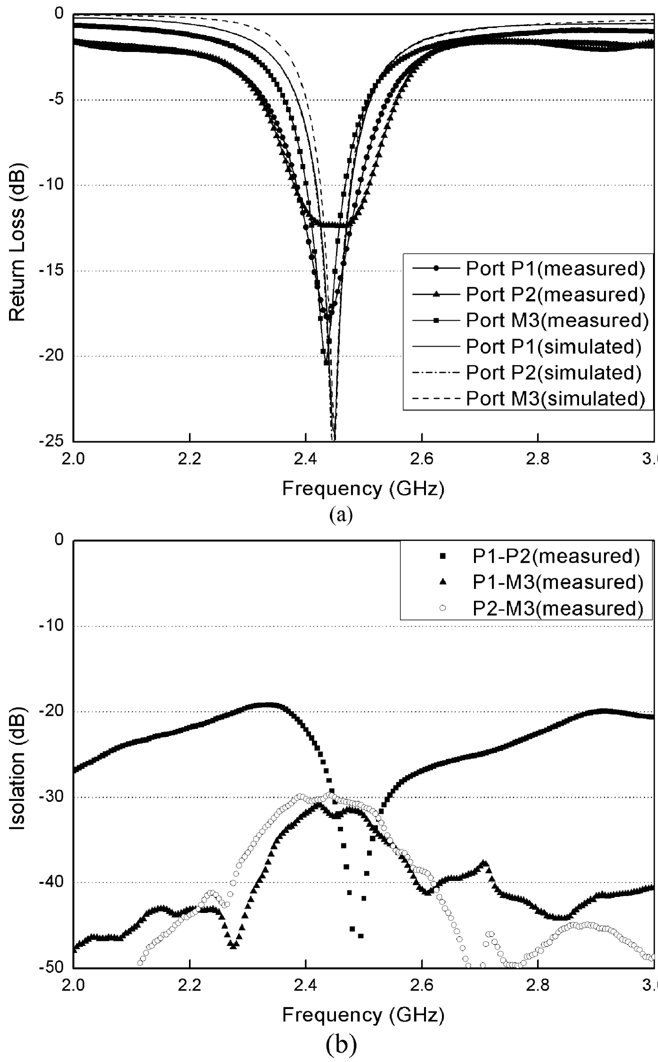

Fig. 4. Measured and simulated S-parameters of the tripolarization antenna ports: (a) return loss; (b) isolation.

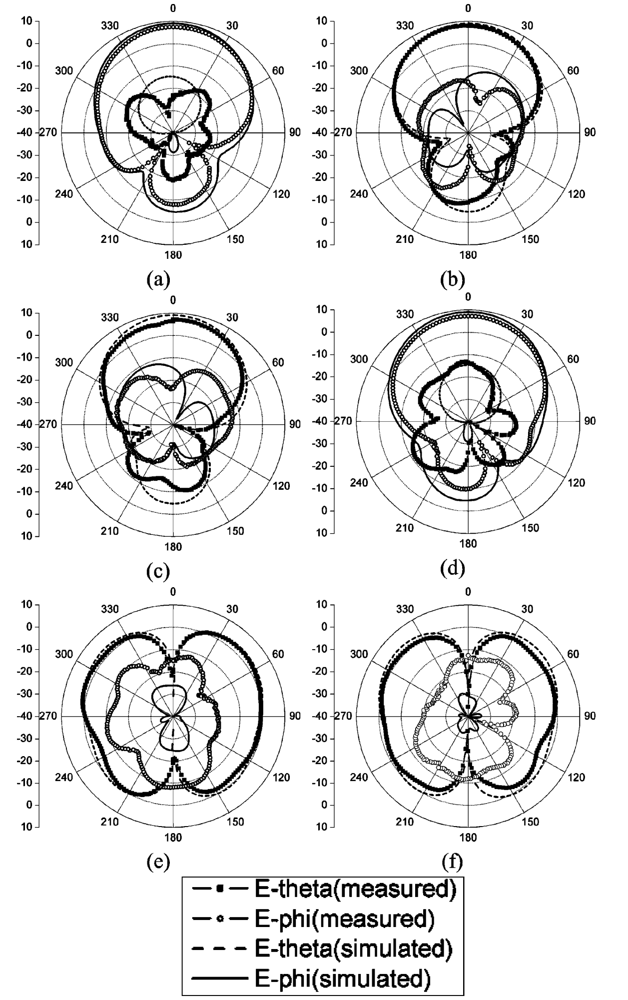

Fig. 5. Measured and simulated gain patterns of the tripolarization antenna. (a) Port P1, xz plane. (b) Port P1, yz plane. (c) Port P2, xz plane. (d) Port P2, yz plane. (e) Port M3, xz plane. (f) Port M3, yz plane.

M3 and the other two ports are both better than −30 dB. These results show that the proposed tripolarization antenna has good isolation among the three ports.

The radiation patterns were measured by exciting the tripolarization antenna from each individual port with the other ports terminated by 50-Ω loads. For example, the patterns of P1 were measured by exciting P1 and connecting both P2 and M3 with 50-Ω loads. Fig. 5 shows the comparison between the measured and simulated radiation patterns of the tripolarization antenna at 2.42 GHz. The measured results also agree with the simulated results. The radiation pattern results in Fig. 5 show that the electric fields excited by P1 and P2 are parallel to the y- and x-axes, respectively. Meanwhile, the electric field excited by M3 is parallel to the z-axis. Thus, these results effectively validate the property of tripolarization of the proposed antenna. The cross-polarization levels are better than 20 dB for P1 and P2 at the boresight direction. The average cross-polarization level for M3 is better than 15 dB. There is some discrepancy between simulated and measured cross-polarization patterns of M3, which should be caused by the manufacturing tolerance. During the process of making the prototype antenna, the vertical wire of the disk-loaded monopole was fabricated separately, so it was difficult to make sure that the vertical part was perfectly straight and upright. This should be the reason why the measured cross-polarization level of M3 port is obviously larger than that of simulation results. The gains of the directional slot-fed antennas at 2.42 GHz are 7 dBi for P1 and 7 dBi for P2, while the gain of the omnidirectional coaxial-fed disk-loaded monopole fed by M3 is 2.5 dBi. The main reason for the lower gain of M3 compared to the gains of other two ports is the differing radiation properties between monopole and patch antennas, which is the omnidirectional radiation property that gives the monopole mode lower gain compared to the directional patch mode.

IV. Conclusion

This study proposes a planar, low-profile, and tripolarization antenna for polarization diversity applications of multiantenna communication systems. The total height of the antenna is 5.8 mm, which is approximately half the height of the antenna reported in a previous study [6]. The designed prototype was fabricated and tested, and measured data validating simulation results were compared. The bandwidths of the three ports are 2.35–2.52, 2.34–2.54, and 2.38–2.49 GHz. The isolation between each two ports is better than 24, 30, and 30 dB. The achieved gains for the two directional and slot-fed ports at 2.42 GHz are both 7 dBi, while the gain for the omnidirectional coaxial-fed monopole is 2.5 dBi.

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