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Wideband Double-Layered Dielectric-Loaded Dual-Polarized Magneto-Electric Dipole Antenna

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Abstract—This paper proposes a wideband dual-polarized magneto-electric dipole antenna composed of two pairs of vertical shorted patches and two pairs of horizontal double-layered planar dipoles. To achieve dual-polarization radiation, two orthogonal Γ-shaped stepped-impedance strip feed lines are designed to excite the antenna. The regions between the vertical shorted patches are loaded by dielectric materials to reduce the antenna profile. In addition, the antenna is backed with a rectangular cavity-shaped reflector to improve radiation pattern stability and diminish back radiation. Experimental results demonstrate that the proposed antenna has obtained a wide impedance bandwidth of 57.1% from 1.5 to 2.7 GHz and high port isolation of better than 30 dB within the bandwidth. The average antenna gain is about 9.7 dBi with a variation of below ±1.5 dB, and the radiation patterns are unidirectional, symmetric with low back radiation and low cross-polarization radiation across the entire operating band.

1. INTRODUCTION

Recent tremendous development of modern wireless communications has boosted significant demand for wideband and low-profile unidirectional antennas, which should simultaneously satisfy numerous stringent electrical characteristics such as wide impedance bandwidth, stable gain, low back radiation, and low cross-polarization radiation. Therefore, many studies have been conducted to achieve the above objectives in the literature [1–7]. However, some types of antennas, such as log-periodic antennas, horn antennas, and reflector antennas [1], are disadvantageous as a result of their cumbersome structures. The microstrip patch antennas possess unidirectional radiation patterns and advantages of low profile, light weight, and ease of fabrication and integration. However, they have an inherent drawback of narrow bandwidth. Although many techniques have been investigated to improve the impedance bandwidths of microstrip patch antennas by introducing single/double U-slotted patch [2, 3] and L-shaped probe [4], these antennas have neither stable gains nor symmetric radiation patterns across the operating frequencies. Recently, Luk et al. proposed a wideband magneto-electric dipole antenna by combining a vertical shorted quarter-wavelength patch and a horizontal planar dipole [5, 6]. This kind of antenna exhibits excellent electrical characteristics of symmetric E- and H-plane radiation patterns, low back radiation, low cross-polarization radiation, and stable beamwidth and gain within the operation band. Therefore, they have found extensive applications in wireless communications [7] and radar systems [8].

Dual-polarized antennas can increase the number of communication channels and offer polarization diversity to combat multipath fading, and therefore enhance channel capacity [9]. High port isolation and low cross-polarization radiation are prerequisites for dual-polarized antennas to operate effectively. Several researches on investigating dual-polarized antennas can be found in the literature [10–14]. Although microstrip patch antennas employing probe feed [10] and microstrip line feed [11] can obtain

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dual-polarized operation, these antennas suffer from narrow bandwidth, poor port isolation, and high cross-polarization radiation. In [12], the proposed aperture-coupled microstrip patch antenna obtained low cross-polarization radiation and high port isolation at the cost of increased back radiation. Two dual-polarized magneto-electric dipole antennas have been studied recently [13, 14]. Both antennas show good characteristics in bandwidth, port isolation, and cross-polarization. The measured 10-dB impedance bandwidth of the antenna reported in [13], however, has been reduced to be 24.9% due to loading dielectric substrate between the vertical shorted patches. Seo and Kishk overcame this issue by using complicated twin Γ-shaped probes and placing dielectric substrate outside the active region and behind the planar dipole [14], and hence a measured bandwidth of above 44% has been obtained.

In this paper, we present a wideband double-layered dielectric-loaded magneto-electric dipole antenna for dual-polarization operation. It is composed of two pairs of vertical shorted patches, two pairs of horizontal planar dipoles, two orthogonal Γ-shaped stepped-impedance strip feed lines, and a rectangular cavity-shaped reflector. Both of planar dipoles have double layers to enhance the impedance matching within the lower range of the operating bandwidth. Loaded between the vertical shorted patches are dielectric materials to reduce the profile of the antenna [13]. The conventional cavity-shaped reflector is introduced to further suppress the back radiation and improve the stability in radiation patterns across the operation band [8]. Measured results show that a wide impedance bandwidth of 57.1% has been achieved for the proposed antenna, i.e., more than twice of its counterpart in [13]. The port isolation maintains above 30.0 dB within the bandwidth. Besides, the radiation patterns are stable over the operating frequencies with low back radiation and low cross-polarization radiation.

2. ANTENNA DESIGN

The schematic configuration of the proposed dual-polarized magneto-electric dipole antenna is presented in Figure 1. The proposed antenna is composed of two pairs of vertically oriented shorted patches and two pairs of horizontal planar dipoles. Each horizontal planar dipole has double layers, i.e., pentagon-shaped lower layer and trapezoid-shaped upper layer, connected through metallic cylinders with radius

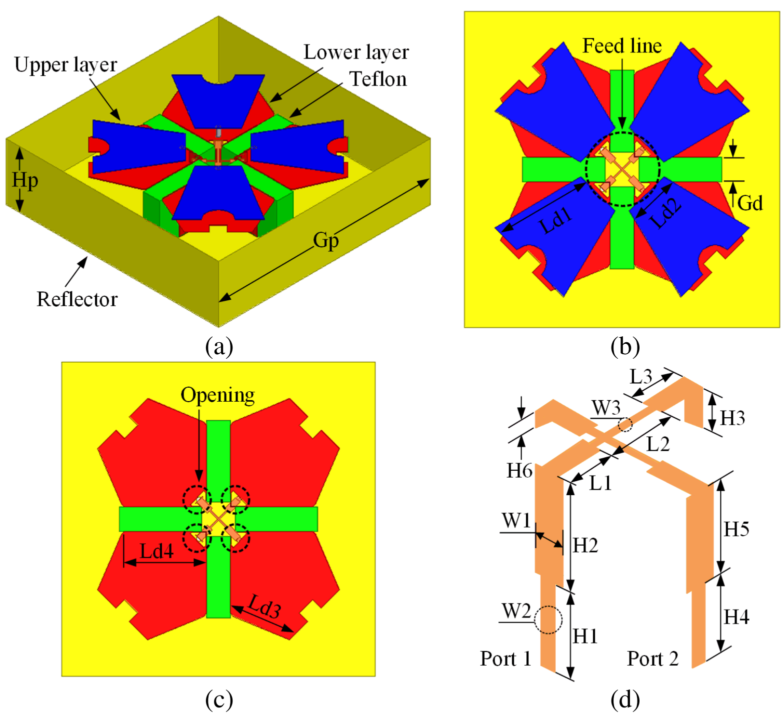

Figure 1. Schematic configuration of the proposed dual-polarized magneto-electric dipole antenna. (a) Overview. (b) Top view. (c) Top view without the upper planar dipoles. (d) Feed line.

of 1.0 mm and height of 5.0 mm. In addition, four rectangular (length of 7.8 mm and width of 5.0 mm) and four semi-circular (radius of 7.2 mm) notches are introduced in the lower and upper planar dipoles, respectively, in order to finely adjust the resonant frequency and impedance matching. The lower pentagon-shaped dipoles are shorted to the ground plane by four L-shaped metallic vertical walls with height of 25 mm. Filled within the regions between the vertical walls are Teflon dielectric material with relative permittivity $\varepsilon_r = 2.2$ to reduce the antenna profile. The antenna is symmetrically mounted with respect to a 200 mm × 200 mm × 35 mm rectangular cavity-shaped reflector. The antenna is made of copper with thickness of 0.3 mm. Details of the antenna configuration can be referred to [5].

To achieve dual-polarization radiation, two orthogonal Γ-shaped stepped-impedance strip feed lines are designed to excite the antenna. The structures of the strip feed lines are given in Figure 1(d). Rather than [5] and [13], the Γ-shaped strip feed lines are positioned behind the planar dipoles. Four small openings are introduced both in the vertical walls and the lower horizontal dipoles to accommodate each metallic strip feed line. Furthermore, the horizontal portions of the strip feed lines are narrowed to reduce mutual coupling between the two input ports. The lower end of each strip feed line is soldered to a 50 Ω SMA connector mounted underneath the ground plane. Specifically, Port 1 is for −45° polarization, and Port 2 is for +45° polarization. The proposed antenna has been simulated and optimized by full-wave electromagnetic simulation software package Ansoft HFSS [15], and the optimal geometrical parameters are determined as follows (unit: mm): $G_p = 200.0$, $H_p = 35.0$, $L_{d1} = 41.2$, $L_{d2} = 20.0$, $G_d = 10.0$, $L_{d3} = 26.0$, $L_{d4} = 35.0$, $H_1 = 12.0$, $H_2 = 14.0$, $H_3 = 5.6$, $H_4 = 10.5$, $H_5 = 12.5$, $H_6 = 2.2$, $L_1 = 6.3$, $L_2 = 10.0$, $L_3 = 6.3$, $W_1 = 4.0$, $W_2 = 2.0$, and $W_3 = 1.0$.

3. EXPERIMENTAL RESULTS

To validate the design concept, an antenna prototype was fabricated and measured with the aid of an Agilent E8363B vector network analyzer. A photograph of the fabricated antenna prototype is shown Figure 2. To support the antenna structure, foam materials with dielectric constant nearly equal to the air are introduced between the lower and upper horizontal planar dipoles. Figure 3 and Figure 4 show the simulated and measured reflection coefficients of the proposed antenna at Port 1 and Port 2, respectively, and reasonable agreement can be observed. Experimental results show that the antenna can cover from 1.5 to 2.7 GHz with a fractional bandwidth of 57.1% ($|S_{11}| \leq 10$ dB) both for Port 1 and Port 2, which implies that the antenna can operate for DCS, PCS, UMTS, LTE 2300, and LTE 2500 mobile communication systems.

Differences between measurements and simulations are primarily due to the fact that the prototype antenna was constructed and assembled manually in the experiments. As shown in Figure 2, some deformation can be observed for the horizontal planar dipoles. Furthermore, the reflection coefficients of the antenna with and without the upper horizontal planar dipoles also have been simulated and compared in Figure 3 and Figure 4. The efficacy of the upper planar dipoles to enhance the return loss within the lower range of the operation frequency band can be obviously identified. Thus, the overall impedance bandwidth can be significantly improved for the proposed antenna.

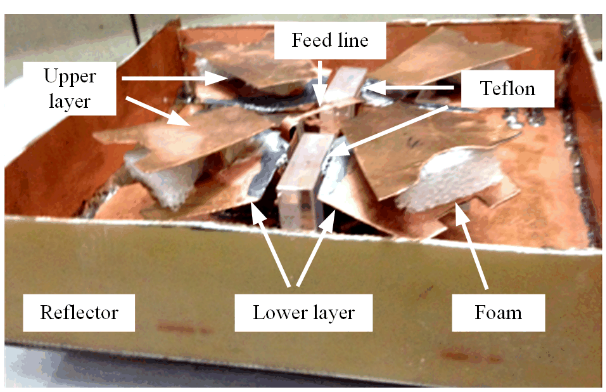

Figure 2. Photograph of the fabricated dual-polarized magneto-electric antenna.

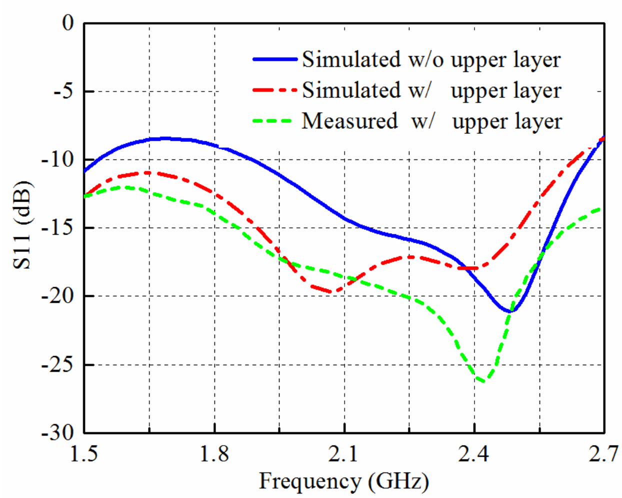

Figure 3. Simulated and measured reflection coefficients at Port 1 of the proposed antenna.

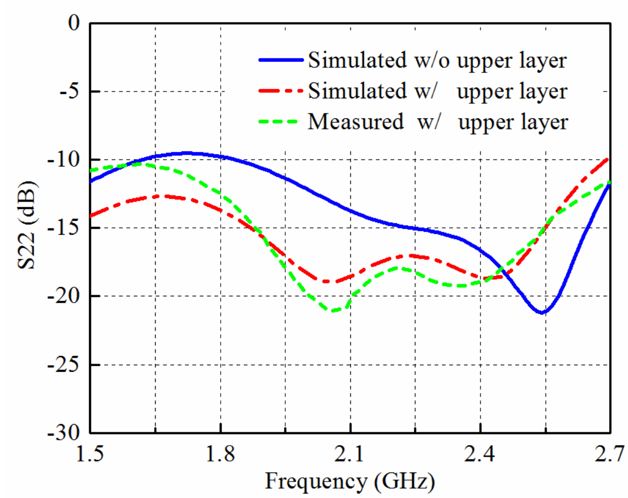

Figure 4. Simulated and measured reflection coefficients at Port 2 of the proposed antenna.

The simulated and measured isolations between the two input ports against frequency are presented in Figure 5. The measured port isolation is maintained larger than 30.0 dB over the entire frequency band. Figure 6 gives the simulated and measured gains of the dual-polarized antenna. It can be observed that the measured antenna gains are from 8.2 to 10.7 dBi for Port 1 and from 8.4 to 10.9 dBi for Port 2 within the impedance bandwidth. The average gain is around 9.7 dBi and the variation is less than ± 1.5 dB for both ports across the operation band.

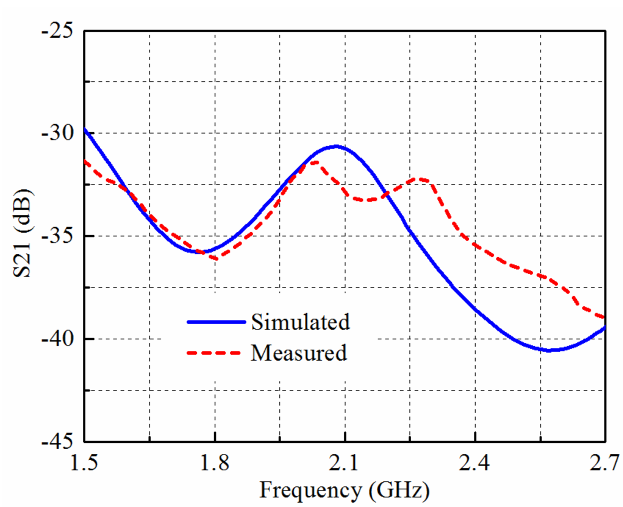

Figure 5. Simulated and measured port isolation for the proposed dual-polarized antenna.

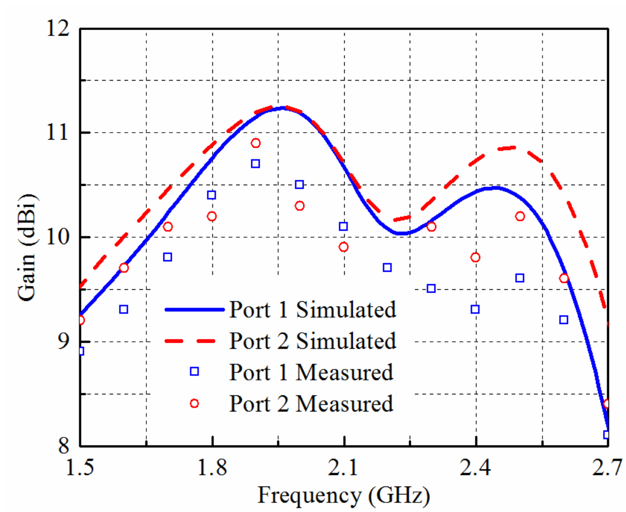

Figure 6. Simulated and measured antenna gain for the proposed dual-polarized antenna.

The far-field radiation patterns of the proposed dual-polarized antenna were measured in an anechoic chamber. The measured radiation patterns for both input ports at 1.5, 2.1, and 2.7 GHz are normalized and plotted in Figure 7. It can be clearly seen that the radiation patterns exhibit unidirectional and symmetric with respect to the boresight direction for both principal planes. It is also worth to mention that slight asymmetry can be observed in certain radiation patterns, which should be owing to the misalignment between the transmitting and receiving antennas in the measurements.

Table 1 summarizes the details of the radiation characteristics for the proposed antenna in terms

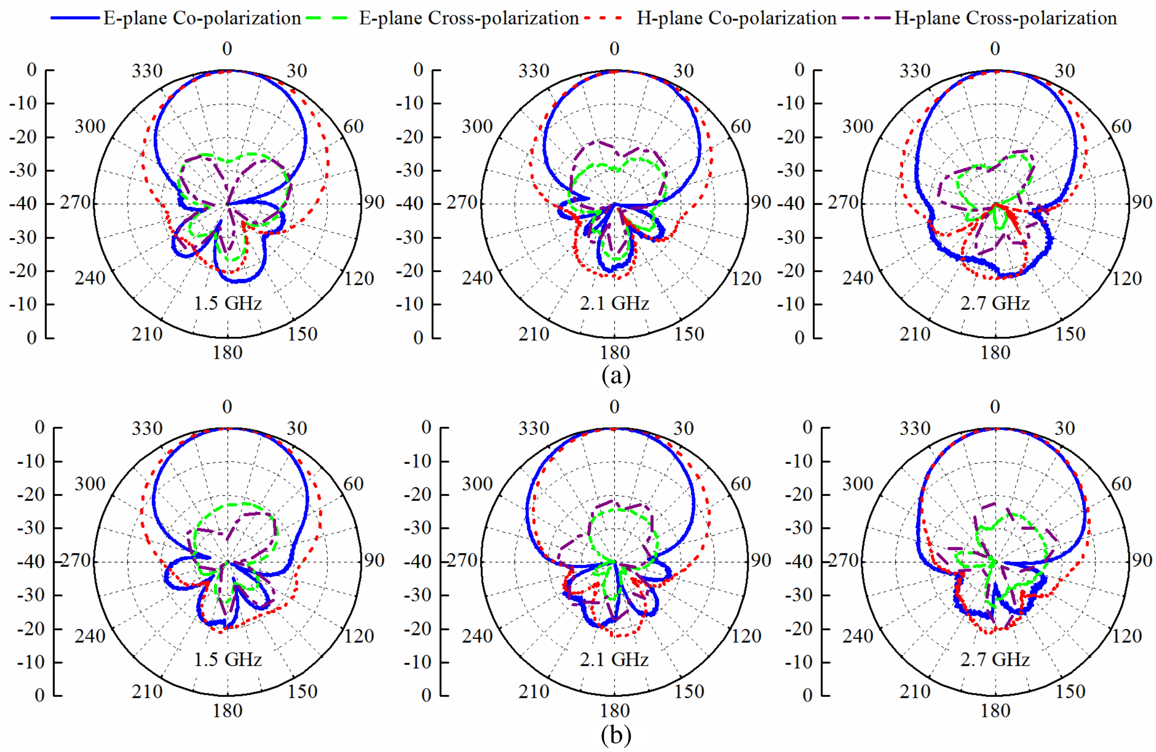

Figure 7. Measured farfield radiation patterns for the proposed dual-polarized antenna. (a) Port 1. (b) Port 2.

Table 1. Radiation performance of the proposed dual-polarized antenna.

Frequency (GHz)	Port 1				Port 2			
	HPBM (°)		FBR (dB)	XPD (dB)	HPBM (°)		FBR (dB)	XPD (dB)
	E-plane	*H*-plane			*E*-plane	*H*-plane		
1.5	52.7	68.2	−17.6	−20.5	54.4	64.5	−20.8	−20.3
2.1	56.1	62.8	−18.4	−22.9	59.8	62.4	−18.1	−23.9
2.7	50.5	61.9	−20.5	−23.6	53.6	59.3	−21.7	−24.1

of half-power beamwidth (HPBM), front-to-back ratio (FBR), and cross-polarization radiation level (XPD). In detail, the half-power beamwidths are changed only several degrees for both two polarizations. The front-to-back ratio is maintained larger than 17.0 dB across the operation band. Moreover, the cross-polarization radiation is more than 20.0 dB, lower than the co-polarization radiation.

4. CONCLUSION

A wideband double-layered magnetic-electric dipole antenna with dielectric loading has been proposed and successfully implemented for dual-polarization operation. The antenna achieves a wide impedance bandwidth of 57.1% ranging from 1.5 to 2.7 GHz, which can be operated for DCS, PCS, UMTS, LTE 2300, and LTE 2500 mobile communication standards. Within the entire operation band, high port isolation above 30.0 dB, an average gain of 9.7 dBi with variation less than ±1.5 dB, unidirectional radiation patterns with low back radiation and low cross-polarization radiation were validated. The excellent electrical characteristics make the proposed antenna an attractive candidate for modern wireless communication systems such as cellular base station applications.

REFERENCES

1. Balanis, C. A., *Antenna Theory: Analysis and Design*, Wiley, New York, 2005.
2. Lee, K. F., K. M. Luk, K. F. Tong, S. M. Shum, T. Huynh, and R. Q. Lee, "Experimental and simulation studies of the coaxially fed U-slot rectangular patch antenna," *IEE Proc. Microw. Antennas Propag.*, Vol. 144, No. 5, 354–358, 1997.
3. Guo, Y. X., K. M. Luk, K. F. Lee, and Y. L. Chow, "Double U-slot rectangular patch antenna," *Electron. Lett.*, Vol. 34, No. 19, 1805–1806, 1998.
4. Chen, Z. N. and M. Y. W. Chia, "Broadband suspended plate antennas fed by double L-shaped strips," *IEEE Trans. Antennas Propag.*, Vol. 52, No. 9, 2496–2500, 2004.
5. Luk, K. M. and H. Wong, "A new wideband unidirectional antenna element," *Int. J. Microw. Opt. Technol.*, Vol. 1, No. 1, 35–44, 2006.
6. Ge, L. and K. M. Luk, "A low-profile magneto-electric dipole antenna," *IEEE Trans. Antennas Propag.*, Vol. 60, No. 4, 1684–1689, 2012.
7. An, W. X., H. Wong, K. L. Lau, S. F. Li, and Q. Xue, "Design of broadband dual-band dipole for base station antenna," *IEEE Trans. Antennas Propag.*, Vol. 60, No. 3, 1592–1595, 2012.
8. Li, J. X., A. X. Zhang, J. G. Liu, and Q. H. Liu, "Cavity-backed wideband magneto-electric antenna for through-the-wall imaging radar applications," *Proc. 2016 IEEE Radar Conf.*, 62–64, 2016.
9. Wong, K. L., *Compact and Broadband Microstrip Antennas*, Wiley, New York, 2002.
10. Alarjani, B. M. and J. S. Dahele, "Feed reactance of rectangular microstrip patch antenna with probe feed," *Electron. Lett.*, Vol. 36, No. 5, 388–390, 2000.
11. Huang, J., "A parallel-series-fed microstrip array with high efficiency and low cross-polarization," *Microw. Opt. Technol. Lett.*, Vol. 5, No. 5, 230–233, 1992.
12. Chiou, T. W. and K. L. Wong, "Broadband dual-polarized single microstrip patch antenna with high isolation and low cross polarization," *IEEE Trans. Antennas Propag.*, Vol. 50, No. 3, 399–401, 2002.
13. Siu, L., H. Wong, and K. M. Luk, "A dual-polarized magneto-electric dipole with dielectric loading," *IEEE Trans. Antennas Propag.*, Vol. 57, No. 3, 616–623, 2009.
14. Seo, H. J. and A. A. Kishk, "Wideband magnetic-electric antenna with linear single or dual polarization," *Progress In Electromagnetics Research*, Vol. 155, 53–61, 2016.
15. Ansoft High Frequency Structural Simulator (HFSS), Framingham, MA, USA, Ansoft Corp., 2006.