A Low-Profile Magneto-Electric Dipole Antenna

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***Abstract*—A new low-profile magneto-electric dipole antenna composed of a horizontal planar dipole and a vertically oriented folded shorted patch antenna is presented. The antenna is simply excited by a coaxial feed without the need of an additional balun. A rectangular cavity-shaped reflector is introduced for enhancing the stability in radiation pattern over the operating frequencies. A parametric study is performed for providing practical design guidelines. A prototype with a thickness of 0.173λ was designed, fabricated and measured. Results show that an impedance bandwidth of 54.8% for SWR $\leq$ 1.5 from 1.88 to 3.3 GHz was achieved. Stable radiation pattern with low cross polarization, low back radiation and an antenna gain of 8.6 $\pm$ 0.8 dBi was found over the operating frequencies. In addition, the antenna is d.c. grounded, which satisfies the requirement of many outdoor antennas.**

***Index Terms*—Low profile, magneto-electric dipole, unidirectional patterns, wideband antenna.**

I. Introduction

WITH the rapid development of modern wireless communications, wideband and low-profile unidirectional antennas with high performance, such as low cross polarization, low back radiation, and stable gain, are in great demand. Many different methods were proposed to achieve good electrical characteristics in the literature. Several types of antennas, such as log-periodic, horn, and reflector antennas [1], are disadvantageous by their bulky structures. The patch antennas [2]–[4] can provide unidirectional patterns and have major advantages of low profile, light weight, and easy fabrication, but their impedance bandwidth is not wide enough for modern wireless communication systems. Although some attractive techniques have been proposed to increase the impedance bandwidth of patch antennas by using an L-probe feed [5], [6] or a U-slot patch [7], the radiation pattern varies substantially over the operating frequencies of these designs [5]–[7].

To achieve equal radiation patterns in the E- and H-planes and stable performance, the concept of exciting an electric dipole and a magnetic dipole simultaneously was proposed by Clavin [8], [9]. A wideband unidirectional antenna composed of a shorted bowtie patch antenna and an electric dipole is available in [10]. Equal radiation patterns in the E- and H-planes are obtained over a wide operating frequency band, but the antenna gain is not stable and the structure is complex. Recently, a wideband unidirectional antenna with 43.8% impedance bandwidth $(\mathrm{SWR} \leq 1.5)$, designated as the magneto-electric dipole, was proposed by Luk *et al.* [11]. By combining a magnetic dipole and an electric dipole, good electrical characteristics such as low back radiation, stable antenna gain over the operating frequency band, and symmetric radiation patterns are achieved. Based on these previous works, a novel wideband unidirectional antenna is presented in this paper. The antenna comprises a pair of horizontal planar patches and a pair of vertically oriented folded shorted patches, which works as an electric dipole and a magnetic dipole, respectively. A coaxial feed is designed to feed the antenna, which makes the antenna d.c. grounded, satisfying the requirement of many outdoor antennas. To obtain low back radiation and stable pattern beamwidth, a rectangular cavity-shaped reflector is introduced.

A prototype was built and tested. Experimental results agree well with simulations. Based on simulation results by HFSS [12], the effects of various parameters on the performance of the proposed antenna are discussed.

II. Antenna Geometry

Fig. 1 shows the geometry of the proposed antenna with detailed dimensions. Basically, the antenna consists of a rectangular cavity-shaped reflector, a pair of horizontal planar patches, a pair of vertically oriented folded shorted patches, and a coaxial feed. The rectangular cavity-shaped reflector with dimensions of 112 mm $\times$ 112 mm $\times$ 20 mm (0.967λ by 0.967λ by 0.173λ) is used to adjust the back radiation. The two horizontal planar patches (each with width $W = 0.518\lambda$, and length $L = 0.259\lambda$) together operate as an electric dipole. These two horizontal planar patches are attached at the top of the two folded shorted patches which are placed normal to the ground. Each vertically oriented folded shorted patch (with $L_1 = 0.016\lambda$, $L_2 = 0.095\lambda$, $L_3 = 0.148\lambda$) is made by folding a planar metallic patch. The overall electrical length of a folded shorted patch equals to 0.259λ close to that of the horizontal patch. The two vertical patches are separated by a small gap of S = 5.4 mm.

To excite the antenna at the junction between the two basic elements, a coaxial feed is employed. This feed consists of a coaxial cable and a copper strip. One end of the coaxial cable connects to a SMA connector, which is located underneath the ground. To firmly fix the feeding structure, the outer conductor of the coaxial cable is bonded to the vertical portion of the shorted patch. The inner conductor of the other end of the coaxial cable is connected to one end of a horizontal copper strip. With 1 mm separation from the horizontal planar dipole, the copper strip extends along one arm of the planar dipole, across the gap, and then directly connects to the other arm of the planar dipole. This feeding structure has the advantage of making the antenna d.c. grounded, which is a requirement in some practical applications, such as the design of outdoor base station antennas for mobile communications.

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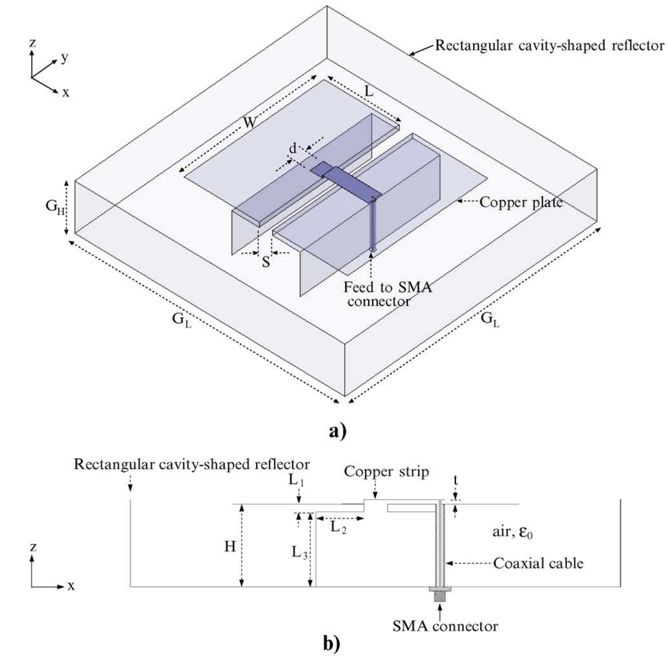


Parameters	W	L	L_1	L_2	L_3	H
Values/mm	60 (0.518λ)	30 (0.259λ)	1.8 (0.016λ)	11 (0.095λ)	17.2 (0.148λ)	19 (0.164λ)
Parameters	S	d	t	G_L	G_H	
Values/mm	5.4 (0.047λ)	5.7 (0.049λ)	1 (0.009λ)	112 (0.967λ)	20 (0.173λ)	

λ is the free-space wavelength at the center frequency

Fig. 1. Geometry of the proposed antenna: a) 3D view and b) side view.

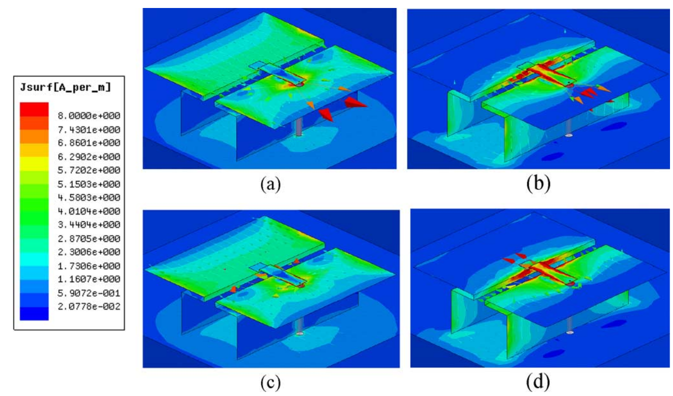


Fig. 2. Current distributions of the proposed antenna at different times. (a) $\mathrm{t} = 0$; (b) $\mathrm{t} = \mathrm{T}/4$; (c) $\mathrm{t} = \mathrm{T}/2$; and (d) $\mathrm{t} = 3\mathrm{T}/4$.

III. Principle of Operation

It is well known that the radiation pattern of an electric dipole is like a figure "8" shape in the E-plane and "O" shape in the H-plane, whereas the radiation pattern of a magnetic dipole is like a figure "O" shape in the E-plane and "8" shape in the H-plane. If an electric dipole and a magnetic dipole are excited simultaneously with proper amplitudes and phases, the radiating power can be reinforced in the broadside direction but suppressed in the back side [8]. Therefore, a uniform unidirectional radiation pattern can be achieved by combining the two patterns. In our design as depicted in Fig. 1, the antenna is a combination of a horizontal planar dipole (electric dipole) and a vertically oriented folded shorted patch antenna (magnetic dipole).

To understand the operation principle better, the current distributions of the proposed antenna at different times are analyzed as shown in Fig. 2. At time $\mathrm{t} = 0$, the horizontal current on the planar dipole is dominated in one direction, and the currents on two vertically oriented folded shorted patches are minimized. Therefore, the electric dipole mode is strongly excited at time $\mathrm{t} = 0$. At time $\mathrm{t} = \mathrm{T}/4$, where T is a period of time, the horizontal current is minimized, and the currents on two vertically oriented folded shorted patches are dominated in opposite directions. Therefore, the current loop that radiates as a magnetic dipole is strongly excited at $\mathrm{t} = \mathrm{T}/4$. At time $\mathrm{t} = \mathrm{T}/2$, the electric dipole mode is strongly excited again with opposite current direction to the mode at $\mathrm{t} = 0$. At time $\mathrm{t} = 3\mathrm{T}/4$, the magnetic dipole mode is excited again with opposite current direction to the mode at $\mathrm{t} = \mathrm{T}/4$. The differences in amplitudes and phases between the two modes can be controlled by the dimensions of the antenna structure. With appropriate dimensions, stable unidirectional radiation patterns with low back radiation can be achieved over a wide frequency range. It is expected that the antenna in this proposed form can achieve stable gain and low back radiation over the operating frequency band.

It should be mentioned that the structure of the proposed antenna is topologically similar to that of a planar dipole fed by means of a Pawsey Stub balun (folded balun) [13]. However, our design changes the usual proportions to enhance significantly the radiation pattern and bandwidth performance, as well as placing the dipole in a shallow cavity.

IV. Antenna Performance

A prototype of the antenna as shown in Fig. 1 was built to verify the proposed design. Simulation was accomplished using Ansoft HFSS. Measured results of SWR, antenna gain and radiation patterns were obtained by an Agilent E5071C network analyzer and a Satimo Starlab near-field measurement system.

A. SWR and Gain

Fig. 3 shows the simulated and measured S parameters with good agreement. The measured impedance bandwidth is 54.8% for SWR ≤ 1.5 from 1.88 to 3.3 GHz. Fig. 3 also shows that acceptable gain is achieved for the proposed antenna. Within the operating frequency band from 1.88 to 3.3 GHz, the measured gain is about 8.6 with 0.8 dBi variation, which agrees well with the simulated result of 9.5 ± 1 dBi.

B. Radiation Pattern

The simulated and measured radiation patterns at frequencies of 1.9, 2.6, and 3.3 GHz, respectively, are shown in Fig. 4. Good agreement between measured and simulated radiation patterns is achieved. The antenna exhibits good unidirectional radiation patterns. Over the operating frequency band, the simulated and measured front-to-back ratios of the proposed antenna are both over 14 dB and the cross-polarization levels in the E- and H-planes are below -30 and -20 dB, respectively. Almost equal radiation patterns in the E- and H-planes are obtained over

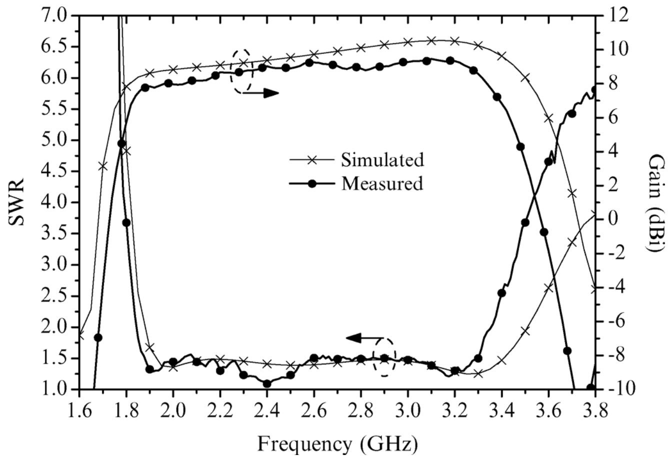


Fig. 3. Simulated and measured SWRs and gains against frequency.

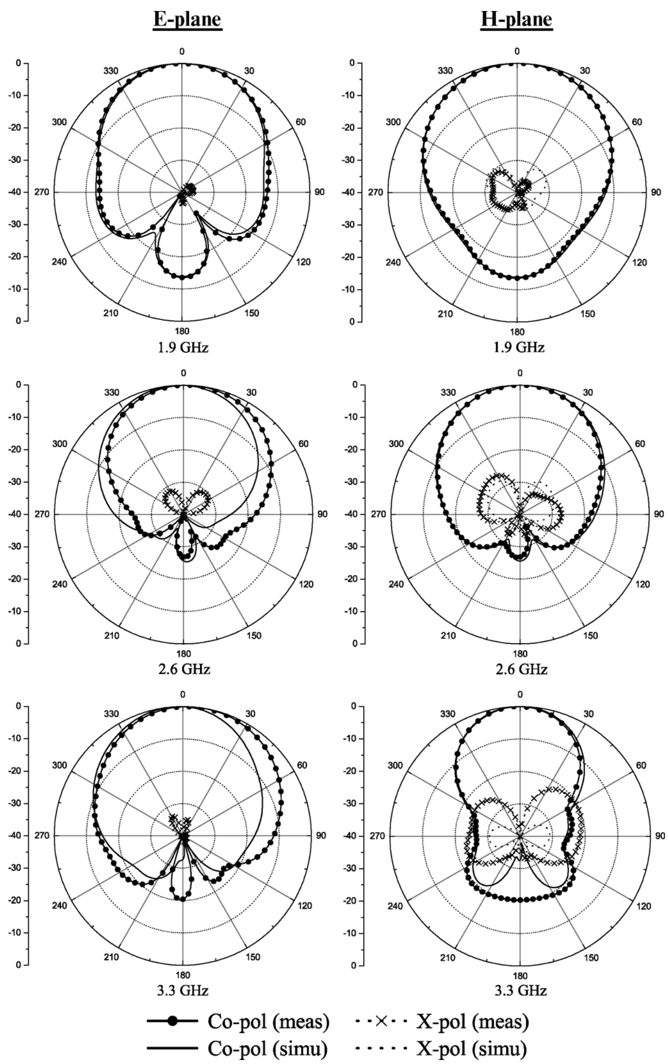


Fig. 4. Simulated and measured radiation patterns at 1.9, 2.6, and 3.3 GHz.

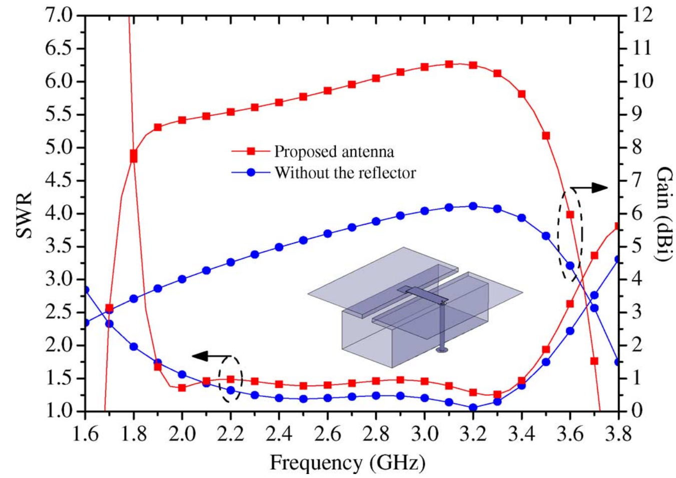


Fig. 5. SWRs and gains of the antenna without reflector compared with the proposed antenna.

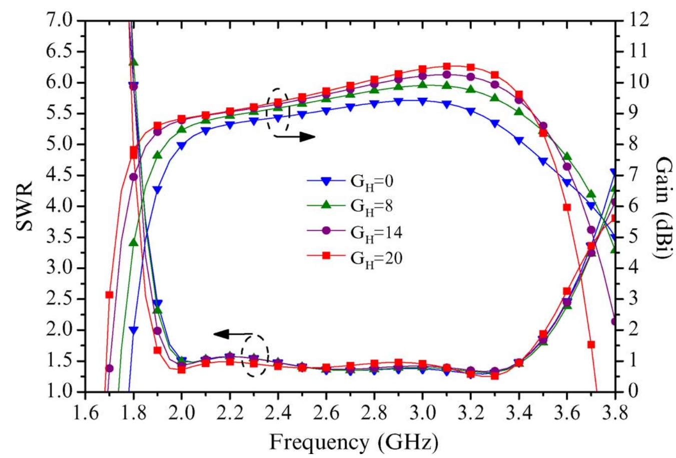


Fig. 6. Effects of G_H (height of the rectangular cavity-shaped reflector, in mm).

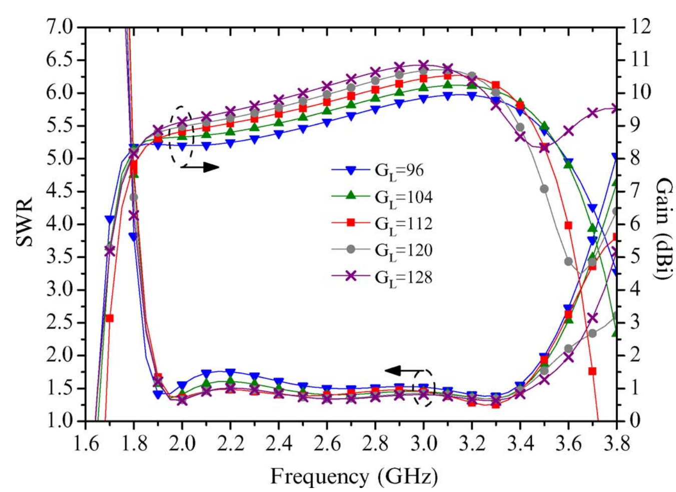


Fig. 7. Effects of G_L (length of the rectangular cavity-shaped reflector, in mm).

the operating frequency band. In the E-plane, the broadside radiation patterns are stable over the operating frequency band. In the H-plane, the broadside radiation patterns are stable and symmetric at lower frequencies, but the main beam becomes narrower at higher frequencies.

V. Parametric Study

To understand how the dimensions of the antenna affect the performances, a parametric study was performed using HFSS. Throughout the study, the metallic layers are assumed to have

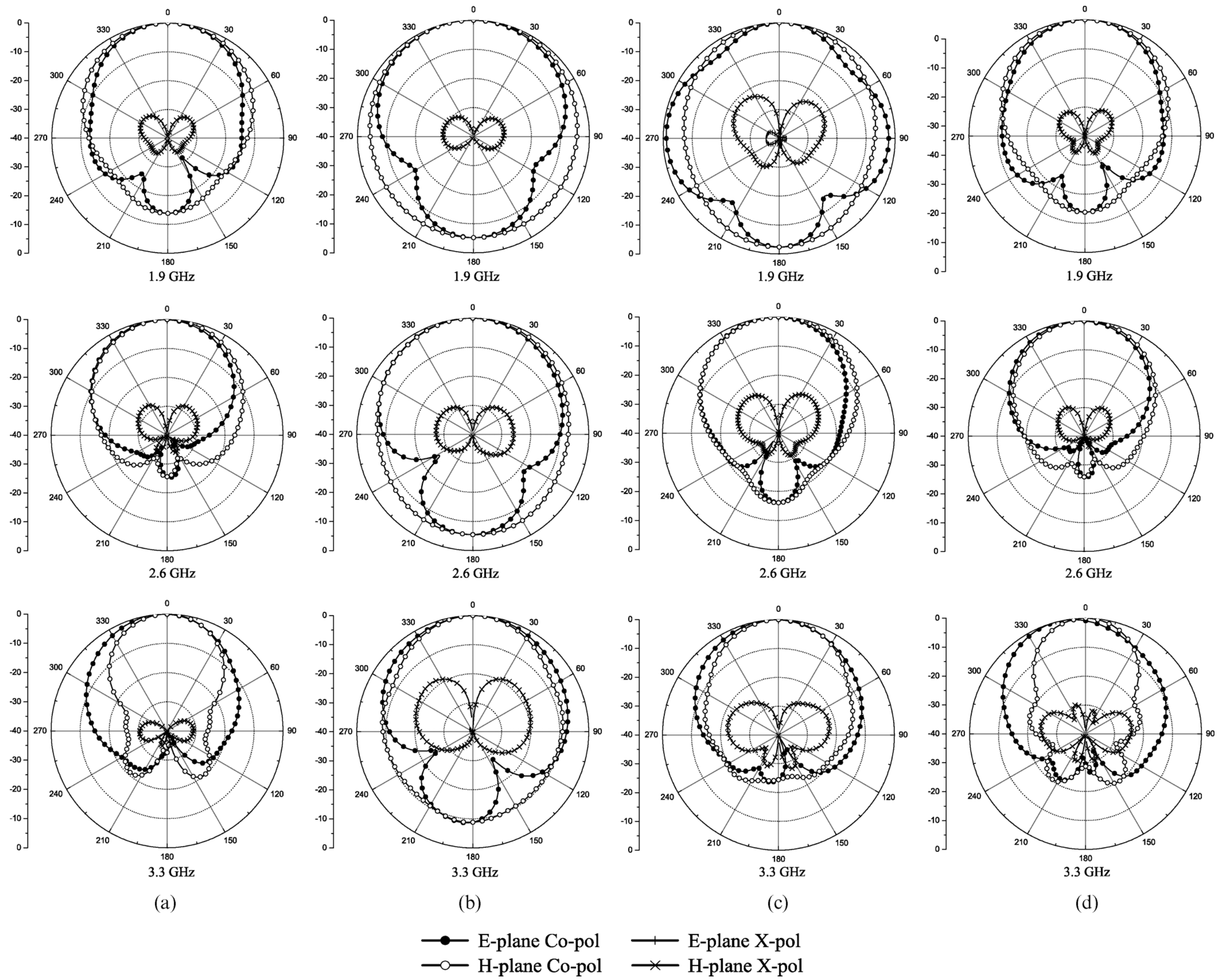


Fig. 8. Comparison of radiation patterns between the antennas with proposed cavity-shaped reflector, without reflector, with planar reflector and with large cavity-shaped reflector. (a) With proposed cavity-shaped reflector; (b) without reflector; (c) with planar reflector ($G_H = 0$); and (d) with large cavity-shaped reflector ($G_L = 128$ mm).

zero thickness for relatively fast computation. When one parameter is studied, the others are kept constant. The results provide a useful guideline for practical design.

A. Rectangular Cavity-Shaped Reflector

In order to know the usefulness of the rectangular cavity-shaped reflector, the antenna without the reflector was analyzed as shown in the insert of Fig. 5. From the figure, the impedance matching is slightly changed compared to that of the proposed antenna. In Fig. 8, a comparison of radiation patterns at different frequencies between the antennas with proposed cavity-shaped reflector, without reflector, with planar reflector and with large cavity-shaped reflector is presented. It can be observed from Fig. 8(b) that a high back-lobe level of -5 dB to -10 dB is obtained when the reflector is removed. As a result, the antenna gain is only $4 \sim 6$ dBi in the operating frequency band, which is 4 dBi less than that of the proposed antenna. Thus, a rectangular cavity-shaped reflector is necessary to achieve stable radiation patterns with low back radiation and high gain with good stability.

The first parameter studied was the height of the rectangular cavity-shaped reflector G_H. As shown in Fig. 6, the impedance matching is slightly influenced by G_H. However, the gain variation tends to be larger as G_H increases. It can be observed from Fig. 8(a) and (c) that lower back radiation and cross polarization can be obtained when the proposed cavity-shaped reflector was used. Hence, $G_H = 20$ mm was selected for achieving good radiation patterns and a low profile structure.

The second parameter studied was the length of the rectangular cavity-shaped reflector G_L. Fig. 7 shows the simulated SWR and gain versus G_L. It can be seen that smaller size G_L gives more stable gain but larger SWR. On the other hand, larger size G_L produces better impedance matching, in spite of larger gain variation. More important, radiation patterns at lower frequencies are insensitive to G_L as shown in Fig. 8(a) and (d), while a large G_L results in unstable radiation patterns at higher frequencies because of the unstable gain. Thus, a tradeoff has to be made between stable gain and good impedance matching.

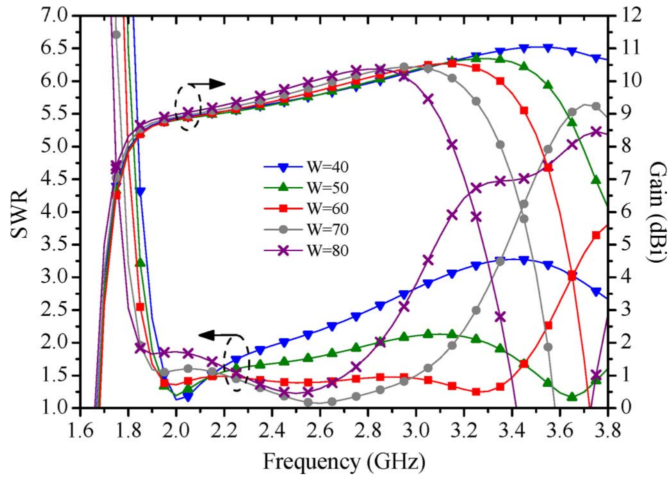


Fig. 9. Effects of W (width of the planar dipole and folded shorted patches, in mm).

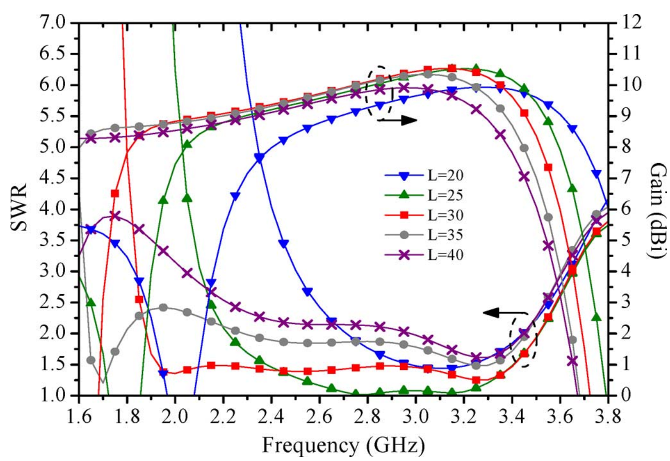


Fig. 10. Effects of L (length of the horizontal planar dipole, in mm).

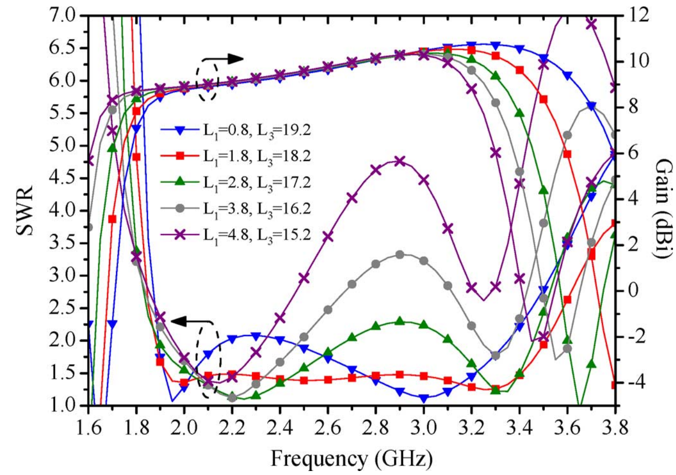


Fig. 11. Effects of L_1 while keeping $L_1 + L_3 = H = 19$ mm (in mm).

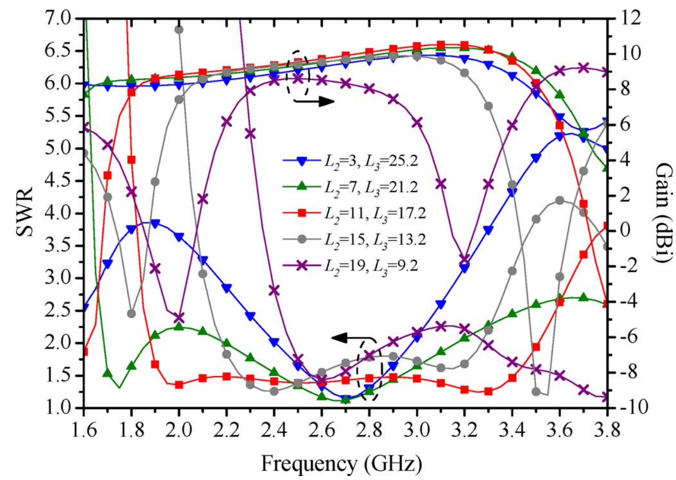


Fig. 12. Effects of L_2 while keeping $L_2 + L_3 = 28.2$ mm (in mm).

B. Antenna

The first parameter studied was the width of the planar dipole and folded shorted patches W. It is seen from Fig. 9 that the antenna performance at lower frequencies is insensitive to the variation of W. However, a smaller W enlarges the gain bandwidth to cover higher frequencies, but worsens the in-band SWR. For the proposed prototype, $W = 60$ mm was chosen to achieve good impedance matching over a wide frequency band.

The second parameter studied was the length of each arm of the planar dipole L. As shown in Fig. 10, antenna performances at higher frequencies are slightly influenced by L. A larger L enlarges the gain bandwidth to cover lower frequencies, while worsens the impedance matching. Moreover, the operating bandwidth reduces dramatically when L is too small. Therefore, $L = 30$ mm was selected for large gain bandwidth and good in-band matching.

The third parameter studied was the height from the horizontal portion of the folded shorted patch to the arms of the planar dipole L_1 (keeping $L_1 + L_3 = H = 19$ mm). This parameter determines the antenna gain more than the impedance matching. To observe the influence of L_1 easily, $L_1 + L_3$ was set to be 19 mm as the optimized value. Fig. 11 shows the simulated SWR and gain versus L_1 and L_3. The gain bandwidth shifts to lower frequencies when L_1 increases. The impedance bandwidth is slightly influenced by L_1, while the fluctuation of the input impedance changes with L_1. To achieve a stable gain within the impedance bandwidth, $L_1 = 1.8$ mm was selected.

The fourth parameter studied was the length of the horizontal portion of the folded shorted patch L_2. It was found that the gain bandwidth and SWR bandwidth are very sensitive to this parameter. To observe the influence of L_2 more clearly, $L_2 + L_3$ was set to be 28.2 mm as the optimized value. It can be observed from Fig. 12 that a smaller L_2 produces larger gain bandwidth, at the expense of SWR performance. When L_2 is too large, the bandwidth reduces dramatically. Thus, $L_2 = 11$ mm was selected to obtain good impedance matching over a wide frequency band.

The fifth and sixth parameters studied were the width of the gap S and the width of the copper strip d. As depicted in Figs. 13 and 14, S and d are very critical for the impedance matching; however they have little effect on the antenna gain. We also observed that the radiation patterns change little with S and d. A good SWR can be achieved if $S = 5.4$ mm and $d = 5.7$ mm are selected.

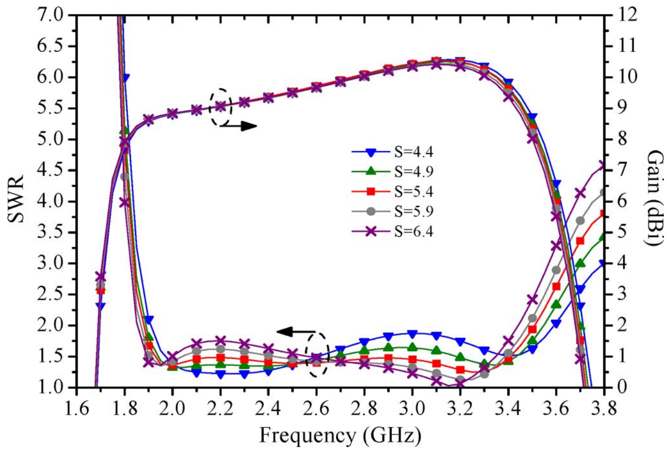


Fig. 13. Effects of S (width of the gap, in mm).

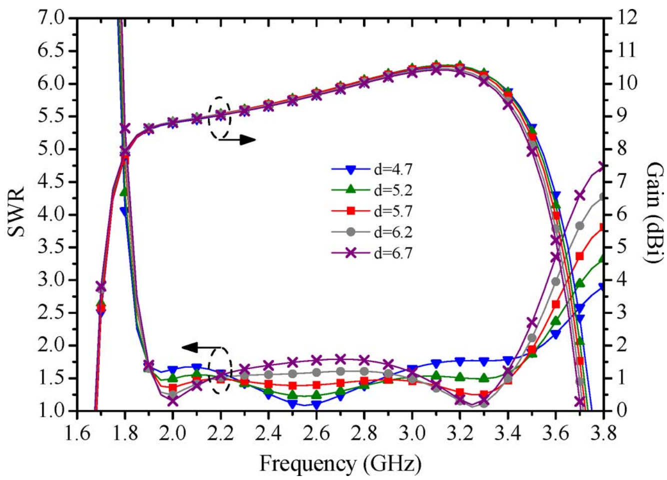


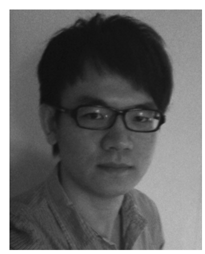
Fig. 14. Effects of d (width of the copper strip, in mm).

VI. Conclusion

A novel wideband magneto-electric dipole antenna composed of a horizontal planar dipole, a vertically oriented folded shorted patch antenna, and a cavity-shaped reflector has been investigated. The antenna can be excited by a coaxial feed, which makes the antenna d.c. grounded. A prototype with center frequency of 2.59 GHz was designed, fabricated, and measured. More than 54% impedance bandwidth for SWR ≤ 1.5, an average gain of 8.6 dBi, unidirectional radiation patterns with low cross polarization and low back radiation were demonstrated. Moreover, the antenna has a low profile structure of 0.173λ in thickness. A design guideline is provided for practical applications.

References

[1] C. A. Balanis, *Antenna Theory: Analysis and Design*. New York: Wiley, 2005.
[2] H.-W. Lai and K.-M. Luk, "Design and study of wide-band patch antenna fed by meandering probe," *IEEE Trans. Antennas Propag.*, vol. 54, no. 2, pp. 564–571, Feb. 2006.
[3] H.-W. Lai and K.-M. Luk, "Wideband stacked patch antenna fed by meandering probe," *Electron. Lett.*, vol. 41, no. 6, pp. 297–298, Mar. 2005.
[4] K.-L. Lau and K.-M. Luk, "Wideband folded L-slot shorted-patch antenna," *Electron. Lett.*, vol. 41, no. 20, pp. 1098–1099, Sep. 2005.
[5] C.-L. Mak, K.-M. Luk, K.-F. Lee, and Y.-L. Chow, "Experimental study of a microstrip patch antenna with an L-shaped probe," *IEEE Trans. Antennas Propag.*, vol. 48, no. 5, pp. 777–783, May 2000.
[6] K.-M. Luk, C.-L. Mak, Y.-L. Chow, and K.-F. Lee, "Broadband microstrip patch antenna," *Electron. Lett.*, vol. 34, no. 15, pp. 1442–1443, Jul. 1998.
[7] K.-F. Lee, K.-M. Luk, K.-F. Tong, S.-M. Shum, T. Huynh, and R.-Q. Lee, "Experimental and simulation studies of coaxially fed U-slot rectangular patch antenna," *Proc. Inst. Electr. Eng.—Microw. Antennas Propag.*, vol. 144, no. 5, pp. 354–358, Oct. 1997.
[8] A. Clavin, "A new antenna feed having equal E- and H-plane patterns," *IRE Trans. Antennas Propag.*, vol. 2, no. 3, pp. 113–119, Jul. 1954.
[9] A. Clavin, D. A. Huebner, and F. J. Kilburg, "An improved element for use in array antennas," *IEEE Trans. Antennas Propag.*, vol. 22, no. 4, pp. 521–526, Jul. 1974.
[10] H. Wong, K.-M. Mak, and K.-M. Luk, "Wideband shorted bowtie patch antenna with electric dipole," *IEEE Trans. Antennas Propag.*, vol. 56, no. 7, pp. 2098–2101, Jul. 2008.
[11] K.-M. Luk and H. Wong, "A new wideband unidirectional antenna element," *Int. J. Microw. Opt. Technol.*, vol. 1, no. 1, pp. 35–44, Jun. 2006.
[12] "HFSS: High Frequency Structure Simulator Based on the Finite Element Method," Ansoft Corp. [Online]. Available: http://www.ansoft.com/
[13] T. A. Milligan, *Modern Antenna Design*. New York: McGraw-Hill, 1985.



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Prof. Luk was the General Co-Chairman of iWAT2011 held in Hong Kong in March 2011. He was Chairman of 2006 IEEE Region 10 Conference held in Hong Kong in October 2006. He was Technical Program Co-Chair of ISAP2010 held in Macau in November 2010. He was the Technical Program Chairperson of PIERS 1997 held in Hong Kong in January 1997. He was the General Vice-Chairperson of the 1997 and 2008 Asia-Pacific Microwave Conference held in Hong Kong. He was a member of the Scientific Board, EC Network of Excellence in Antennas, Europe. He is the Chief Guest Editor of a Special Issue on Antennas in Wireless Communications for the PROCEEDINGS OF THE IEEE to appear in 2012. He is the Deputy Editor-in-Chief for the *Journal of Electromagnetic Wave Applications*. He received Best Paper Awards at the International Symposium in Antennas and Propagation held in Taipei in November 2008 and at the Asia Pacific Microwave Conference held in Chiba, Japan, in December 1994. He was awarded the very competitive Croucher Award in Hong Kong in 2000, and he received the Applied Research Excellence Award in the City University of Hong Kong in 2001. He is a Fellow of the Chinese Institute of Electronics, PRC, a Fellow of the Institution of Engineering and Technology, U.K., and a Fellow of the Electromagnetics Academy, USA.