A Directional Differential-Fed UWB Antenna with Stable Radiation Pattern

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Abstract: A directional ultra-wideband (UWB) antenna with improved radiation patterns is presented. The proposed sheme comprises a differential-fed microstrip antenna and a rectangular cavity. The hexagon-shaped slot and four triangle-cut corners on the ground plane of the planar antenna are used to improve the impedance matching within the UWB frequency range. A rectangular cavity is used as the reflector for the planar microstrip antenna, so as to achieve directed radiation. The measured results indicate that the designed antenna exhibits a stable broadside directional radiation patterns within the entire operating frequency band. Furthermore, thanks to the differentially driven technique, the cross-polarization is greatly decreased and the polarization purity is maintained in a high level.

Key words: differential-fed; ultra wide band; microstrip antenna

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0 Introduction

Thanks to the advantages of high date rate, great capacity, simplicity, and low cost, ultra-wideband (UWB) short-range wireless technology has attracted more and more attention since the Federal Commercial Commission (FCC) released the frequency band 3.1—10.6 GHz for commercial UWB systems[1]. As an important component of UWB system, UWB antenna holds appealing features of simple structure, wide impedance bandwidth (BW), stable radiation patterns, and constant gain in the desired direction. So far, various planar UWB antennas have been presented[2-6]. However, those planar antennas exhibit omnidirectional radiation patterns. In some applications that require unidirectional radiation patterns, the planar antennas will waste radiation power in needless directions. Thus, UWB antennas with stable directional radiation patterns are needed. Although some directed UWB antennas have been proposed[7-9], most of them have a common deficiency: Radiation pattern degrading in high frequency band. Most degradations mean splitting the radiation pattern, low polarization purity of the radiation pattern in the high frequency band, etc.

Recently, the differential-fed antennas have been increasingly popular, thanks to their easy integration with the differential devices, low cross polarization and so on[10-16]. A differential-fed directional UWB antenna with improved radiation patterns is presented. The proposed antenna comprises a differentially driven microstrip antenna and a rectangular cavity. The rectangular cavity, working as a reflector, unidirectional reflect radiation within the entire operation frequency band. Furthermore, thanks to the differentially excited strategy, the cross-polarization level is maintained less 20 dB than co-polarization over the whole UWB frequency range, which results in high polarization purity of radiation patterns. All

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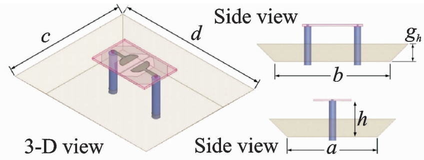
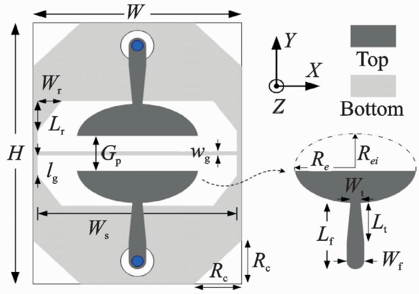
the simulated results are drawn by using the software of ANSYS high frequency structure simulator (HFSS), a commercial 3-D full-wave electromagnetic simulation tool.

1 Antenna Configuration

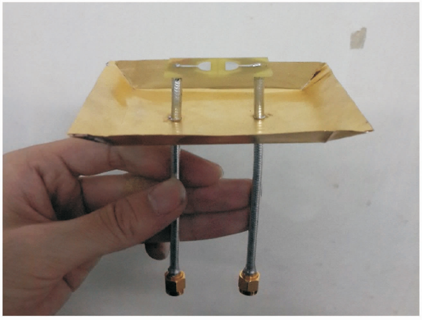
Fig. 1 shows the configuration of the differential-fed planar antenna backed by a rectangular cavity. The proposed differentially driven microstrip antenna is printed on FR4 substrate with thickness of 1 mm, relative dielectric constant of 4.4, and loss tangent of 0.02. As shown in Fig. 1(b), on top of the substrate, the differential microstirp feeding lines are etched, loading with two partially cut elliptical patches. The width of the feeding lines is chosen as 1.86 mm to achieve the characteristic impedance of 50 Ω. For good impedance matching, part of the feeding lines taper from 1.86 mm to 1 mm. The ground plane with central hexagon-shaped slot is printed on the bottom side of the substrate. Four corners of the ground plane are cut to further ameliorate the impedance matching, especially in the high frequency band. To realize the stable wideband directional radiation patterns, the proposed planar antenna is backed by an inverted pyramidal cavity with a inverted pyramidal cross section which occupies a volume of 70 mm×85 mm×10 mm. Two coaxial cables are used to conveniently feed the differential antenna. The coaxial inner conductor is connected to the feedline of top planar patch, while the outer conductor is connected both the ground of the top patch antenna and the backed cavity. Based on the optimized parameters on Table 1, an antenna prototype is designed and fabricated as shown in Fig. 1(c).



(a) 3-D and side view



(b) Top view



(c) Prototype

Fig. 1 Configuration of the proposed antenna

Table 1 Optimized antenna parameters

Parameter	Symbol	Parameter value / mm
The maximum width of ground	W	21
The maximum length of ground	H	34
The maximum length of central hexagon-shaped slot	W_s	20
The length of the short side of right triangle witch connected to hexagon	W_r	4.5
The length of the long side of right triangle witch connected to hexagon	L_r	5.25
The right-angle-side length of the four corners cut from the ground plane	R_c	6
The gap of the two hexagon-shaped slots	w_g	0.5
The gap between the two semi-elliptical radiation	G_p	5
A half of major axis of radiation patch	R_e	5.25
A half of minor axis of radiation patch	R_{ei}	3.75
The length of the feeding line	L_f	8
The maximum width of feeding line	W_f	1.86
The length of the gradual change of feeding line	L_t	4.5
The minimum width of feeding line	W_t	1.1
The bottom width of cavity	a	50
The bottom length of cavity	b	65
The top width of the cavity	c	70
The top length of cavity	d	85
The distance between substrate and cavity	h	20
The depth of the cavity	g_h	10

2 Antenna Design and Analysis

2.1 Differential-fed microstrip antenna

A differential-fed antenna can be regarded as a two-port differential device, excited by two signals with equal amplitude and out of phase. Thus the reflection coefficient of the differentially driven can be defined as

$$S_{11}=\frac{1}{2}(S_{11}-S_{12}-S_{21}+S_{22}) \qquad (1)$$

where S_{11} is the reflection coefficient of port-1; S_{12} the reverse transmission coefficient of port-2 to port-1; S_{21} the forward transmission coefficient of the port-1; S_{22} the reflection coefficient of the port-2. S_{11} is equivalent to the reflection coefficient of the input port of the anti-phase divider, while the two output ports of the divider are connected with two ports of the differential-fed antenna respectively. Fig. 2 shows the evolving process of the proposed planar differential-fed antenna. The corresponding simulated $|S_{d11}|$ results of Ant A, B, and C are shown in Fig. 3. It can be seen that the impedance matching of Ant A is terrible both in low and high frequency bands. The simulated result indicates that, with the addition of four triangle patches, a gradual impedance transformation exists in the ground plane. The resonant mode at low frequencies is changed, and the low resonant frequency at 2.5 GHz is increased to 3.1 GHz, which results in the improvement of the impedance matching at low frequencies. In Ant C, four isosceles right triangles are cut from the corners of the ground plane. Hexagon ground plane leads to the generation of a new resonant frequency at 8 GHz, so that the impedance matching in the high frequency band is greatly ameliorated. In a word, due to the gradual change of the ground, which effects the distribution of the surface current, $|S_{d11}|$ is changed. Finally, the differential-fed microstrip antenna (Ant C), with UWB impedance band of 3—12 GHz, is proposed.

2.2 Proposed directional UWB antenna

Fig. 4 shows the simulated three-dimensional radiation plots of the planar differential-fed antenna without backed cavity. It can be observed that the main beams of the antenna are stabilized in the broadside direction within the whole frequency range. This stable radiation property may somewhat avoid splitting radiation pattern, especially in the high frequency band, when the proposed antenna is backed with a reflector. Here, instead of a planar reflector, an inverted pyramidal cavity, which is placed 21 mm away from the ground plane of the microstrip antenna, is used to realize the directional radiation patterns. Fig. 5 shows the comparison of gains in the broadside direction for the antenna backed by a planar reflector and the proposed cavity with a same horizontal area. It can be seen that by using the inverted pyramidal cavity as the reflector, the realized gain of the antenna, especially in the high frequency band, can be increased to some extent. Fig. 6 shows the simulated $|S_{d11}|$ results of the differential-fed antenna with and without the cavity in their optimized parameters, which indicates that the impedance matching would degraded both in the low and high frequency bands for introducing the cavity.

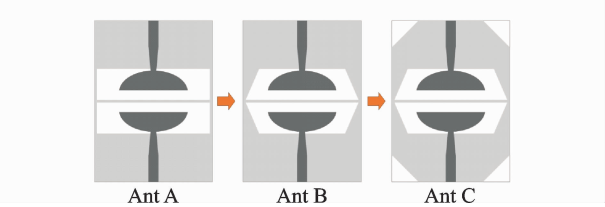


Fig. 2 The evolving process of the top planar patch

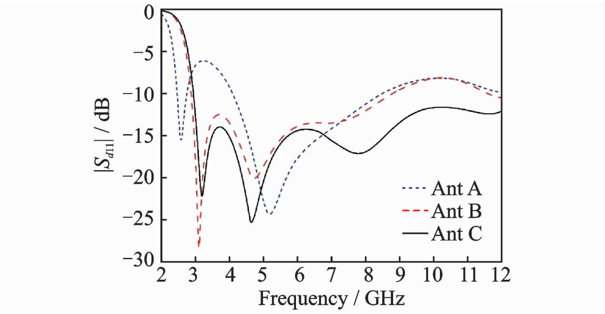


Fig. 3 The simulated $|S_{d11}|$ results of Ants A, B, and C

2.3 Measured result and discussion

An Agilent N5230A vector network analyzer

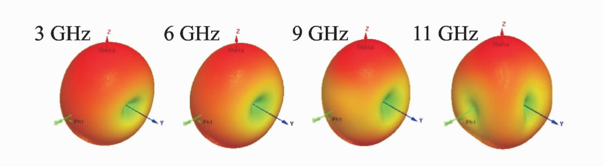


Fig. 4 The simulated 3-D radiation plots of the top planar antenna

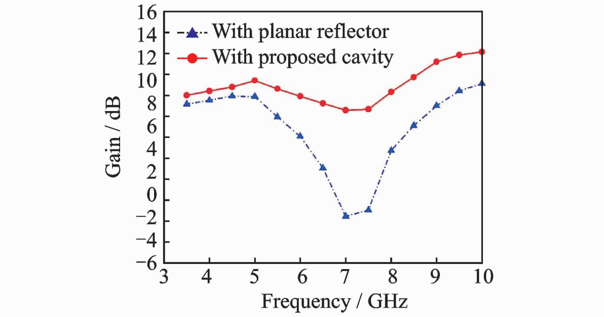


Fig. 5 The gain comparison for the antenna backed by a planar reflector and the proposed cavity

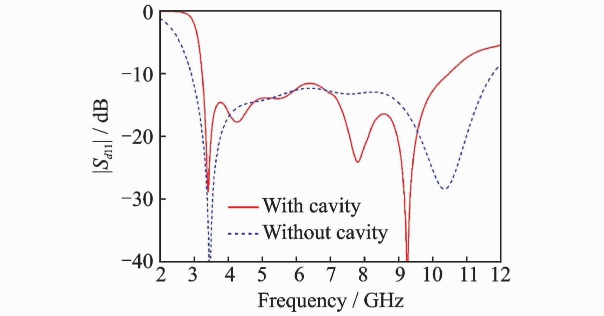


Fig. 6 The simulated $|S_{d11}|$ results of the antenna with and without the cavity

is used to measure the S-parameter: S_{11}, S_{22}, S_{12}, and S_{21} for the proposed antenna. Then the differential reflection coefficient $|S_{d11}|$ can be obtained by using Eq. (1). Fig. 7 shows the measured and simulated results of the designed directional differential-fed UWB antenna. It can be seen that the fabricated antenna can achieve an UWB performance from 3.3 to 10.4 GHz for $|S_{d11}|<-10$ dB. The discrepancy between the simulated and the measured results is probably owing to the fluctuation constant or process tolerance.

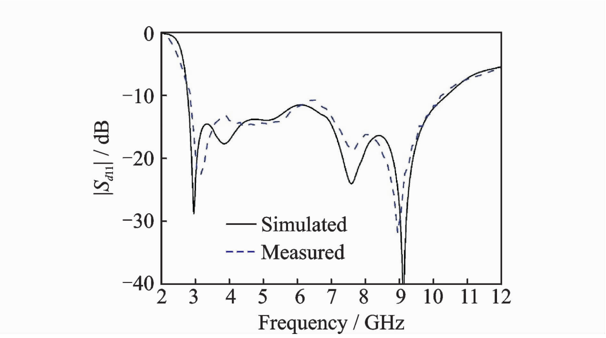
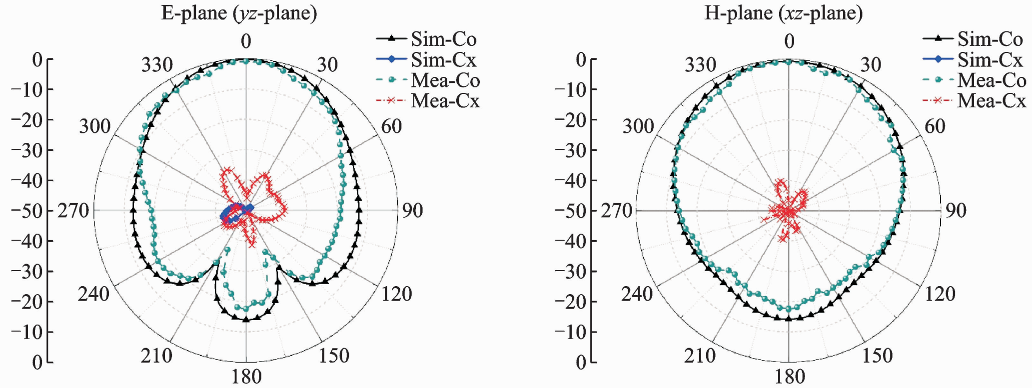
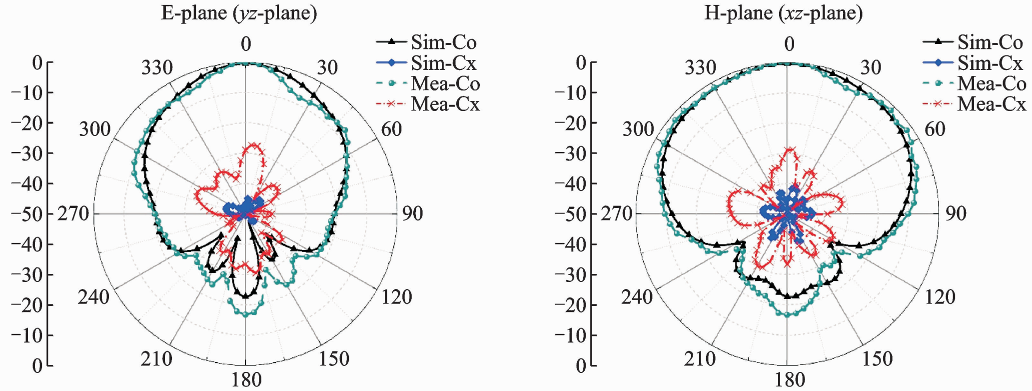


Fig. 7 The measured and the simulated results of the proposed antenna

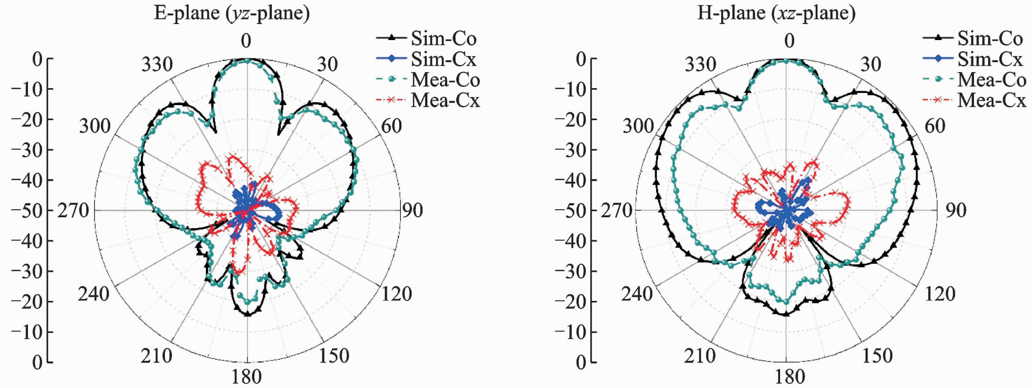
In the radiation pattern measurement, because the differential excited signals are hard to be implemented directly, a UWB anti-phase power hybrid coupler Krytar 4020180 is used to measure the radiation characteristics of the proposed differentially driven antenna. The radiation patterns in the E- and H-plane at 3.5, 6, 8, and 10 GHz are plotted in Fig. 8, where Sim-Co represents the simulation result of main polarization of radiation pattern; Sim-Cx the simulation result of cross-polarization of radiation pattern; Mea-Co the measurement result of main polarization of radiation pattern; Mea-Cx the measurement result of cross-polarization of radiation pattern. It can be seen that the proposed antenna exhibits a stable directional radiation patterns within the entire operating frequency band. Moreover, all the measured cross-polarization levels of the designed antenna are less −20 dB than the cross-polarization, which means that the polarization purity can be maintained in a high level across the whole UWB frequency range. Fig. 9 shows the simulated and the measured gains of the antenna in the broadside direction. It should be noted that the measured gains have been amended by removing the transmission loss of the power hybrid coupler. From 3.5 to 10.5 GHz, the measured gain is confined between 7 and 11 dB, while the simulated gain varied in the range of 7.3—12.5 dB. Since the 180° power hybrid coupler may not be perfect, there exists a disagreement between the simulated and the measured results.



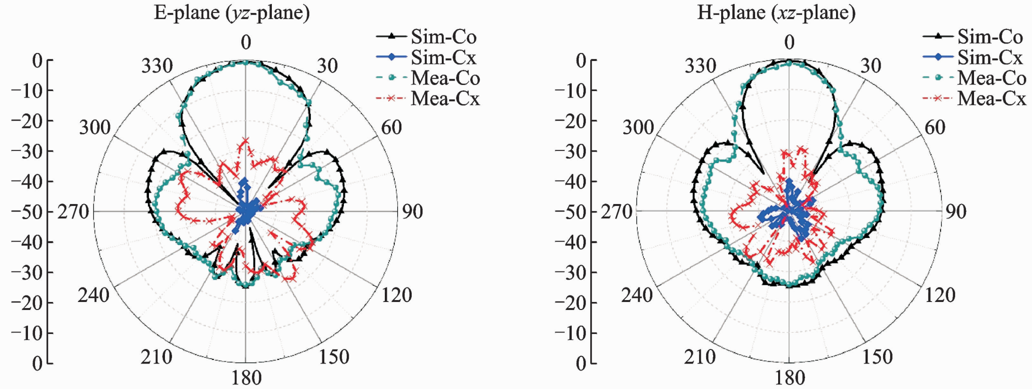
(a) 3.5 GHz



(b) 6 GHz



(c) 8 GHz



(d) 10 GHz

Fig. 8 The radiation patterns in the E- and H-planes at different frequencies

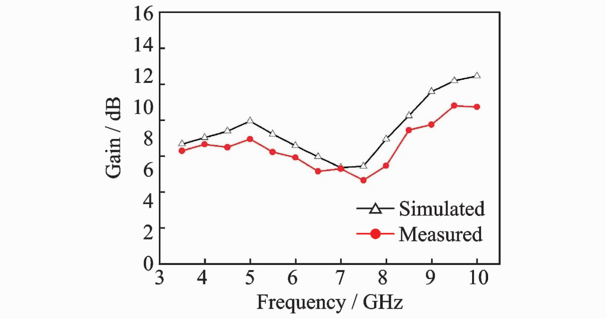


Fig. 9 The simulated and the measured gains of the proposed antenna in the broadside direction

3 Conclusions

In this study, a directional differential-fed antenna is presented for some UWB communication systems. Thanks to the hexagon-shaped slot in the central part of the ground plane, the impedance matching of the antenna is greatly improved, especially in the low frequency band. To further improve the impedance matching at high frequencies, four symmetrical isosceles right triangles are cut from the four corners of the ground plane. An inverted pyramidal cavity is used as the reflector for the planar antenna so that the stable directional radiation patterns is obtained. More importantly, thanks to the differentially driven strategy, the cross-polarization is kept in a low level within the whole operating frequency range, which results in high polarization purity of the antenna. Therefore, the simple structure and improved radiation patterns lead the proposed antenna to a broader future of various UWB utilizations.

Acknowledgements

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References:

[1] Federal Communications Commission (FCC). ET-Docket FCC02-48, Revision of part 15 of the commission's rules regarding ultra-wideband transmission systems FCC [S]. Washington, D. C.: [s. n.], 2002.

[2] LIANG J X, CHIAU C C, CHEN X D, et al. Study of a printed circular disc monopole antenna for UWB systems[J]. IEEE Transactions on Antennas and Propagation, 2005, 53(11): 3500-3504.

[3] LIN Y C, HUNG K J. Compact ultrawideband rectangular aperture antenna and band-notched designs [J]. IEEE Transactions on Antennas and Propagation, 2006, 54(11):3075-3081.

[4] SIM C, CHUNG W T, LEE C H. Compact slot antenna for UWB applications[J]. IEEE Antennas and Wireless Propagation Letters, 2010, 9: 63-66.

[5] LI D T, MAO J F. A Koch-like sided fractal Bow-Tie dipole antenna: Antennas and propagation[J]. IEEE Transactions on Antennas and Propagation, 2012, 60(5): 2242-2251.

[6] HUANG X D, CHENG C H, ZHU L. An ultrawideband (UWB) slotline antenna under multiple-mode resonance[J]. IEEE Transactions on Antennas and Propagation, 2012, 60(1): 385-389.

[7] MOODY R A, SHARMA S K. Ultrawide bandwidth (UWB) planar monopole antenna backed by novel pyramidal-shaped cavity providing directional radiation patterns[J]. IEEE Antennas and Wireless Propagation Letters, 2011, 10: 1469-1472.

[8] ELSHERBINI A, SARABANDI K. Directive coupled sectorial loops antenna for ultrawideband applications[J]. IEEE Antennas and Wireless Propagation Letters, 2009, 8: 576-579.

[9] NAIR S M, SHAMEENA V A, DINESH R, et al. Compact semicircular directive dipole antenna for UWB applications[J]. Electronics Letters, 2011, 47 (23): 1260-1262.

[10] MA C Y, LI Z G. Beamforming of whole airspace phased array TT & C system based on linear subarrays [J]. Transactions of Nanjing University of Aeronautics and Astronautics, 2015, 32(1): 128-132.

[11] HUM S V, HUI Y X. Analysis and design of a differentially-fed frequency agile microstrip patch antenna[J]. IEEE Transactions on Antennas and Propagation, 2010, 58 (10):3122-3130.

[12] ZHANG Y P. Design and experiment on differentially-driven microstrip antennas[J]. IEEE Transactions on Antennas and Propagation, 2007, 55 (10):2701-

2708.

[13] XUE Q, ZHANG X L, CHIN C H K. A novel differential-fed patch antenna[J]. IEEE Antennas and Wireless Propagation Letters, 2006, 5(1): 471-474.

[14] WU H W, ZHANG J, YAN L Y, et al. Differential dual-band antenna-in-package with T-shaped slots [J]. IEEE Antennas and Wireless Propagation Letters, 2012, 11:1446-1449.

[15] SIM C, CHANG C C, ROW J S. Dual-feed dual-polarized patch antenna with low cross polarization and high isolation[J]. IEEE Transactions on Antennas and Propagation, 2009, 57(10): 3321-3324.

[16] JIN K, ZHAN D W, YANG Y, et al. Design of compact and high gain differential micro-strip antenna[J]. Journal of Nanjing University of Aeronautics and Astronautics, 2015, 49(6): 911-916. (in Chinese)

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