

Research Article

A Wideband Waveguide Antenna with Nearly Equal E- and H-Plane Radiation Patterns

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A novel wideband waveguide antenna with excellent performance is proposed, which is composed of a coaxial-waveguide transition and an open-ended rectangular waveguide loaded with a pair of horizontal umbrella-shaped metallic brims. The brims perpendicular to two broad walls of the waveguide are constructed to modulate the antenna to radiate nearly identical E- and H-plane radiation patterns. A wideband impedance matching performance is achieved with a fractional bandwidth of 40% through the introduction of short-stepped ladders. The antenna has the advantages of simple structure, symmetric radiation pattern, low-cross polarization, moderate back lobe, and almost constant beamwidth.

1. Introduction

The demand for the wideband, low-profile antennas with stable gain as well as symmetrical radiation patterns is on the rise with the fast growth of microwave and millimeter-wave wireless communication systems. Up to date, the pursuing of these high-performance antennas has attracted much attention and long-held interest. Microstrip patch antennas exhibiting the advantages of low profile, light weight, low cost, easy fabrication, and high integration with other devices have been widely adopted for electric systems. However, their impedance bandwidths are not sufficient, and also the gains are impossible to remain stable across a broad frequency range, which restricts considerably the practical applications. Although some impedance bandwidth enhancement techniques have been developed such as multilayer structure [1], U-slot loading [2], and L-probe feeding [3], the stability of radiation patterns are essentially difficult to be held. Some modified planar monopole antennas [4, 5] have been proposed with ultrawide bandwidths but they still do not satisfy the rigorous requirement because of their unstable radiation patterns. Other wideband antennas including the planar spiral, log-periodic, Vivaldi, Yagi antenna, and double-ridged

horn have been implemented after a survey of available literature. However, they are apparently with the drawback of large profile or complicated configurations.

Dipole is a fundamental radiator and is often used as an equivalent source in the analysis of antenna. It is evident that unequal radiation patterns are achieved in the two principal planes for both an electric dipole and a magnetic dipole. This is because interchanged radiation patterns of figure-0 and figure-8 are obtained between both dipoles. To implement equal E- and H-plane radiation patterns with low back radiation, Clavin and his coworkers presented the idea of complementary antennas [6, 7] where nearly equal E- and H-plane radiation patterns were achieved by incorporating an electric dipole and a magnetic dipole with appropriate amplitude and phase. Recently, Luk et al. advanced a step forward who were enlightened by the concept of magnetoelectric dipole and proposed a series of wideband unidirectional antennas with stable gain. In their design, the antennas were mainly composed of a vertically oriented quarter-wave-shorted patch and a horizontal planar dipole excited by Γ -shaped strip probes [8, 9, 10, 11] or a coaxial feed [12]. Of them, however, some structures are somewhat complicated especially for their feeding which is typically associated with

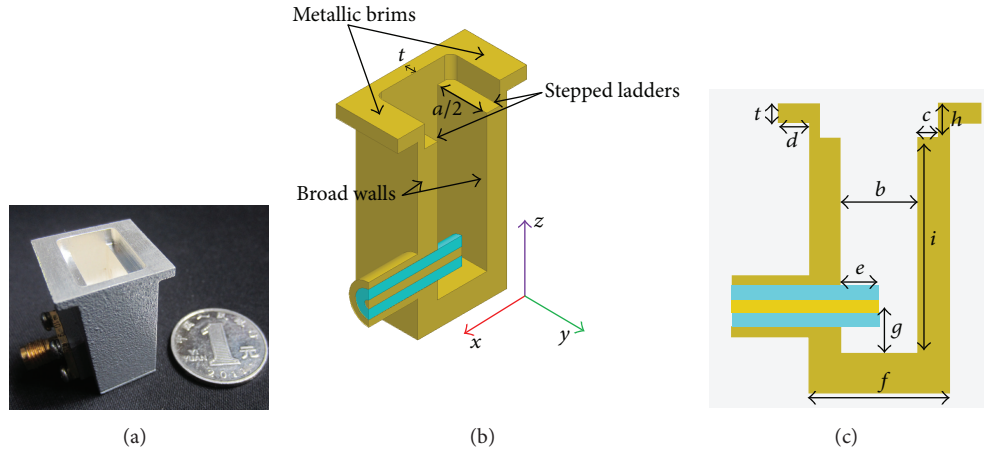


FIGURE 1: The fabricated prototype and topology of the proposed antenna. (a) The photograph of the prototype antenna. (b) The cut-open view of the proposed antenna. (c) The cross-section along E-plane of the proposed antenna. The detailed dimensions (unit: mm) are $a = 15.8$, $b = 7.9$, $c = 2.1$, $d = 2.7$, $e = 3.9$, $f = 14.3$, $g = 4.85$, $h = 3.5$, $i = 22$, and $t = 2$.

a complicated design and thus may be hard to be popularized into practical applications, making an alternative, improved strategy a challenging and pressing task.

In this paper, a simplified feed is introduced to excite the complementary antenna which is evolved from the open-ended rectangular waveguide antenna. Unlike the complicated corrugated conical horns [13], the proposed antenna not only overcomes the drawback of conventional open-ended rectangular waveguide antenna whose beamwidth in E-plane is usually unequal to that in H-plane [14] but also is with very simple structure which is often related with an easy design and fabrication. It thus should be a good candidate in the modern wireless and satellite communication systems. In addition, due to its unique radiation characteristics, the proposed antenna can also be well applied to illuminate a circular aperture such as circular paraboloid [6] or lens.

2. Antenna Structure and Design

2.1. Geometry of the Waveguide Antenna. Figure 1 illustrates the structure and the geometrical dimensions of the proposed waveguide antenna which consists of an open-ended rectangular waveguide, stepped ladders along the broad walls, and umbrella-shaped metallic brims. Notice that beamwidth of the conventional open-ended rectangular waveguide in E-plane is wider than that in H-plane. To obtain an equal E-plane and H-plane radiation pattern, a complementary antenna with beamwidth in E-plane narrower than that in H-plane is necessary. For this purpose, the rectangular waveguide is loaded with a pair of horizontal umbrella-shaped metallic brims which functions as a planar electric dipole whose beamwidth in E-plane is narrower than that in H-plane (see Figure 4). In the present work, the antenna is designed to operate in the whole Ku-band ranging from 12 GHz to 18 GHz. The geometrical parameters are optimized and detailed in Figure 1, in which a and b are the length and width of the waveguide cross-section, c and h are the

height and length of the stepped ladder, and t in conjunction with d are the thickness and length of the metallic brims, respectively.

The rectangular waveguide antenna is simply excited by a coaxial probe with the diameter of 1.27 mm, which is accompanied by a dielectric and a coaxial-waveguide transition. The dielectric in the SMA connector covering the probe has a relative permittivity of $\epsilon_r = 2.08$. The metal that is utilized in the design and fabrication is copper with the conductivity of $\sigma = 5.8 \times 10^7$ S/m, and silver is adopted to cover the surface inside the waveguide to reduce the transmission loss.

2.2. Input Impedance Matching Performance. As an antenna, a conventional open-ended rectangular waveguide cannot be well matched to free space over the entire operating frequency band [15]. Hence extensive simulations have been performed, which demonstrate that the impedance bandwidth of the waveguide antenna is determined by two factors. The first factor is the transition from coaxial to rectangular waveguide. The second is the reflection at the end of the waveguide which exhibits a capacitive reactance. To show the corresponding result, the relative input impedance of conventional open-ended WR62 waveguide on a Smith chart obtained from commercial EM full-wave simulator HFSS is shown in Figure 2. As can be seen, an obvious capacitive reactance is confirmed. Moreover, the real part of input impedance approximates to unity. According to the transmission line theory, the complex input impedance including the real (resistive) and imaginary (reactive) components can be transformed to a pure resistive one through a portion of transmission line with appropriate length. In this particular case, a pair of stepped ladders along the broad walls is introduced, and the length h of them is selected about one eighth of the waveguide wavelength (λ_g) corresponding to the center frequency 15 GHz to cancel out the capacitive reactance. Moreover, the stepped ladders

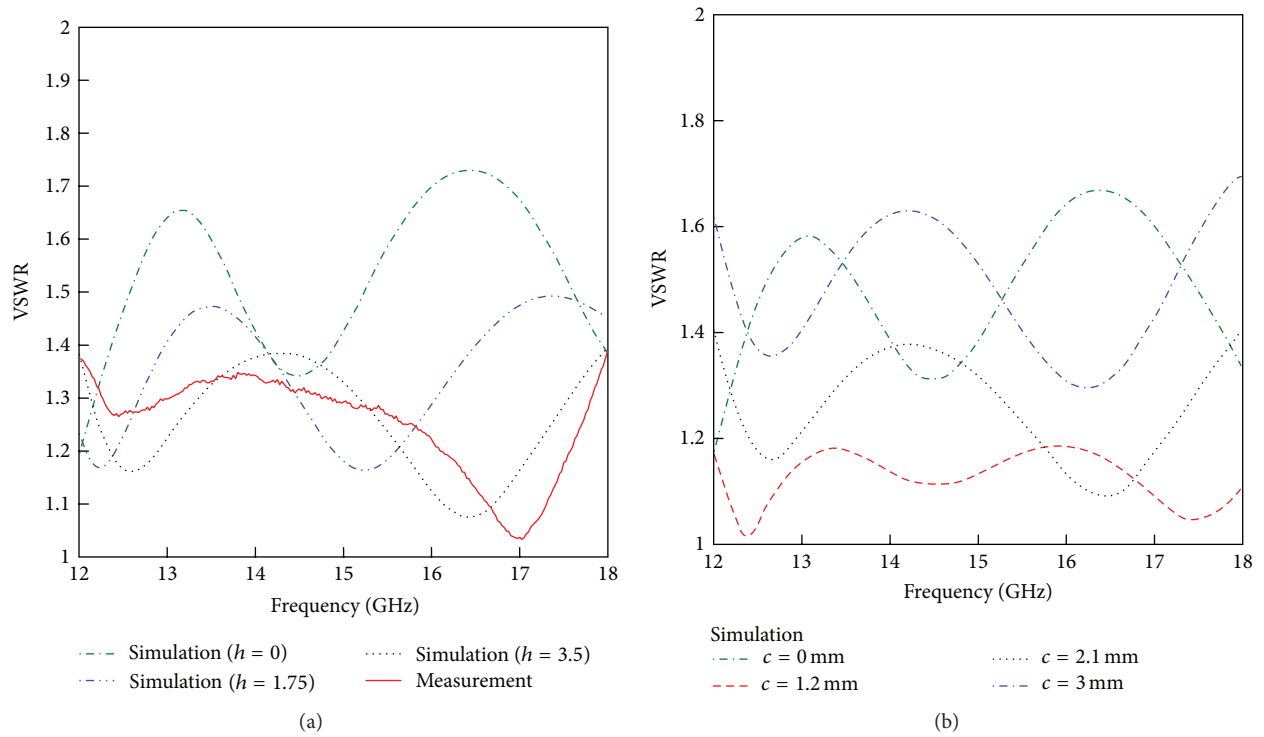


FIGURE 3: Simulated and measured VSWRs of the proposed antenna versus the dimensions of the stepped ladders (a) as a function of h , (b) as a function of c .

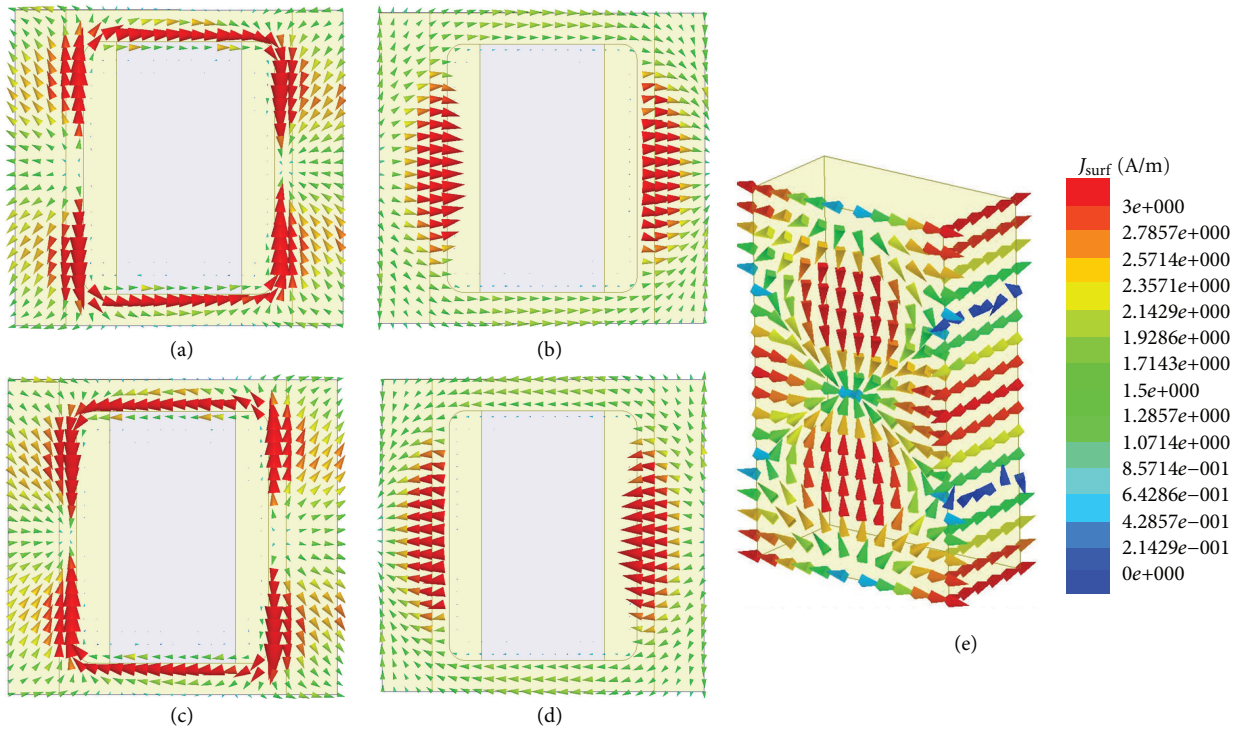


FIGURE 4: Surface current distributions of the proposed antenna in the case of different excitation phases. Aperture current distributions in the case of (a) $\phi = 0^\circ$; (b) $\phi = 90^\circ$; (c) $\phi = 180^\circ$; (d) $\phi = 270^\circ$; and (e) inside surface current of TE_{10} mode in the case of $\phi = 0^\circ$.

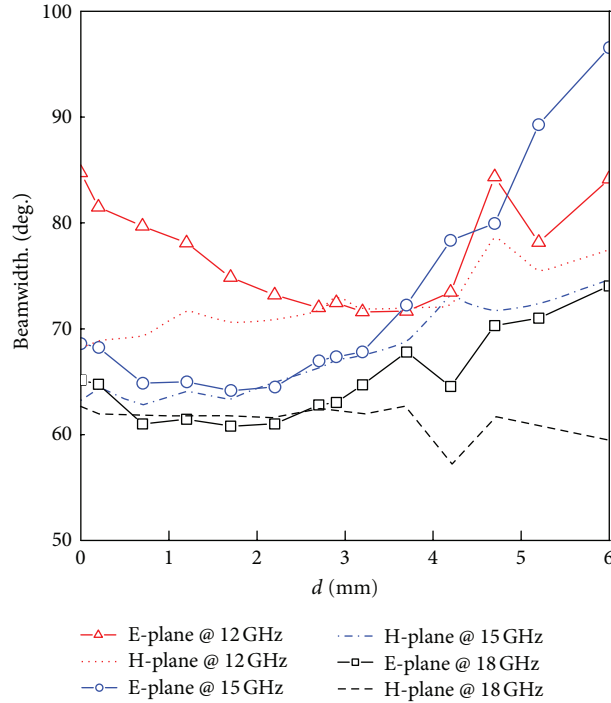
FIGURE 5: Comparison of beamwidths in E- and H-planes as functions of d .

TABLE 1: Simulated and measured 3-dB beamwidths and gains of the proposed antenna.

Freq. (GHz)	3-dB beamwidth (deg.)			Gain (dBi)		
	Simulation		Measurement	Simulation		Measurement
	E-plane/H-plane ($d_y = 0$ mm)	E-plane/H-plane ($d_y = 3$ mm)	E-plane/H-plane ($d_y = 0$ mm)	$d_y = 0$ mm	$d_y = 3$ mm	$d_y = 0$ mm
12	72/71.6	72.6/70.8	70.5/65.8	8.16	8.36	7.47
15	67/66.3	60.9/61.7	60.6/64.2	8.95	9.76	8.7
18	62.8/62.5	60.9/57.7	68.6/65.1	9.73	9.95	9.36

$d_y = 0$ mm represents the situation that the width of the brim is equal to the width of the waveguide.

radiation patterns versus different d . It can be observed that the metallic brims introduced here can suppress the back radiation of the waveguide antenna. According to Figure 6, the back radiation has been significantly suppressed when d increased from 0 to 10 mm. Moreover, the back radiation levels can be reduced to below -20 dB across the whole Ku-band when d takes 10 mm. This level of back radiation is very comparable to that reported in [6, 7, 8, 9] with a ground plane. However, in this case the beamwidth of the far-field pattern in E-plane is wider than that in H-plane. Since the equal E- and H-plane radiation patterns are the main concentration in this paper, d is finally chosen as 2.7 mm. In this case, the back radiation level of the proposed antenna is less than -11 dB within the whole Ku-band.

3. Results and Discussions

For numerical characterization, the proposed antenna is simulated using commercial software Ansoft HFSS. For verification, a prototype of the antenna is fabricated (see Figure

1) and measured using an Agilent N5230C network analyzer. The measured VSWR is also shown in Figure 3 and is in reasonable agreement with the simulated one. Measured result implies that the impedance bandwidth (VSWR < 1.4) covers the whole Ku-band. Therefore, the matching performance of the waveguide antenna across the operating bandwidth has been improved dramatically by the introduction of the stepped ladders with appropriate dimensions.

The antenna radiation patterns are measured through the far-field measurement system in an anechoic chamber. Figure 7 illustrates the simulated and measured radiation patterns. As can be seen, the proposed antenna presents nearly identical beamwidths in E- and H-planes. Both simulated and measured results indicate that the cross-polarization (normalized to the copolarization) is considerably low in the entire frequency range. Furthermore, the backward radiation levels are less than -11 dB across the entire operating band and are smaller in the upper frequency band than those in the lower frequency band. It is worth mentioning that the simulated cross-polarization levels are all less than -35 dB

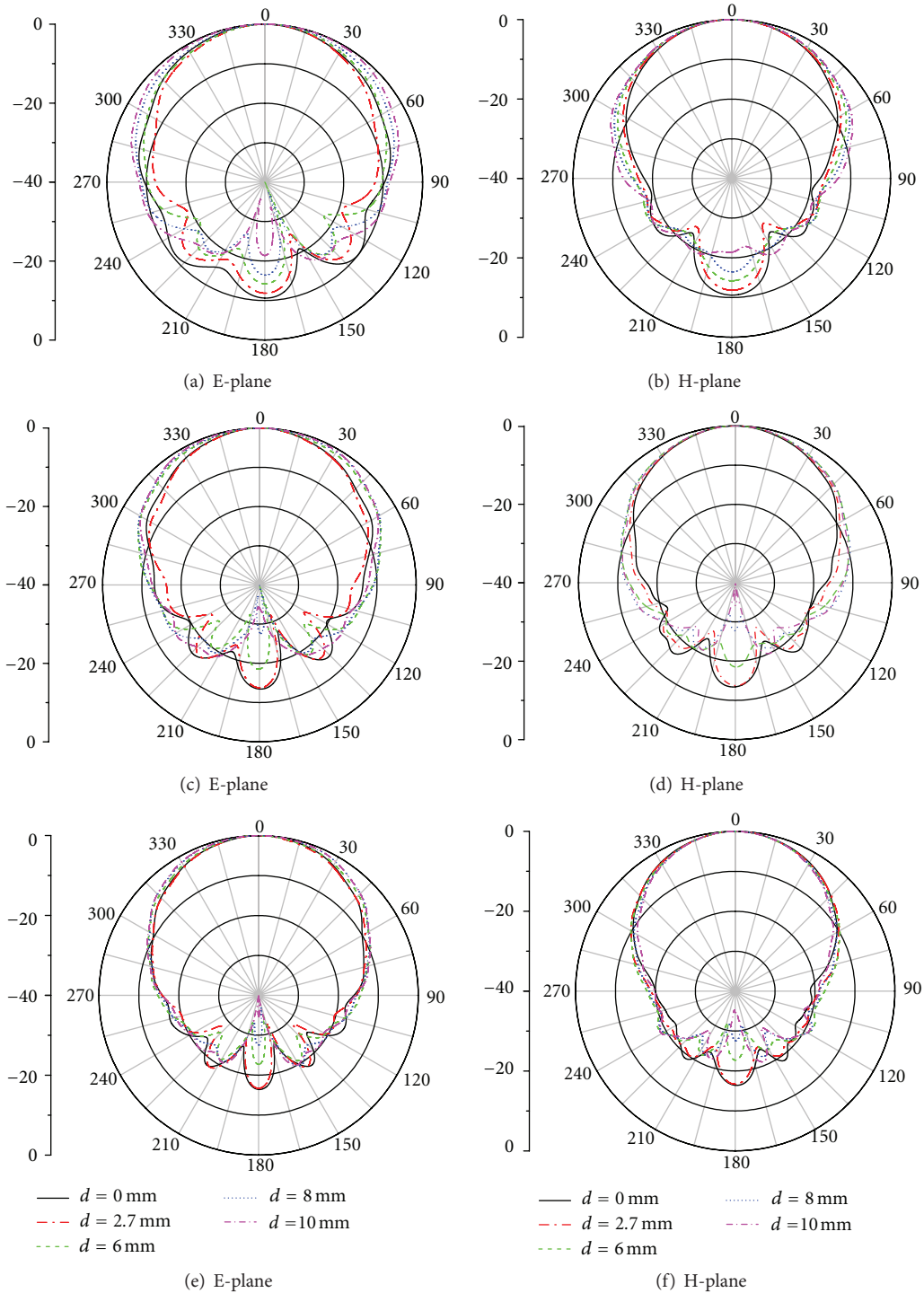


FIGURE 6: Study of variations in radiation patterns versus the changes of lengths of metallic brims at 12, 15, and 18 GHz, respectively. (a)-(b) E-plane and H-plane at 12 GHz, (c)-(d) E-plane and H-plane at 15 GHz, and (e)-(f) E-plane and H-plane at 18 GHz.

while the measured ones are less than -25 dB across the entire operating frequencies. The relatively large cross-polarization levels in measurements may be attributable to three factors: the first factor is the received weak signal which is on the order of the system noise and this is especially true for measuring the very low cross-polarization; the second factor is

the large cross-polarization that is inherently induced by the transmitting horn, and this is especially true for the double-ridged horn which is used for measurement; the third factor is the tolerances of the pose for the transmitting and measured antennas which are impossible to be placed rigorously orthogonal. The tolerances can be reduced; however, they are

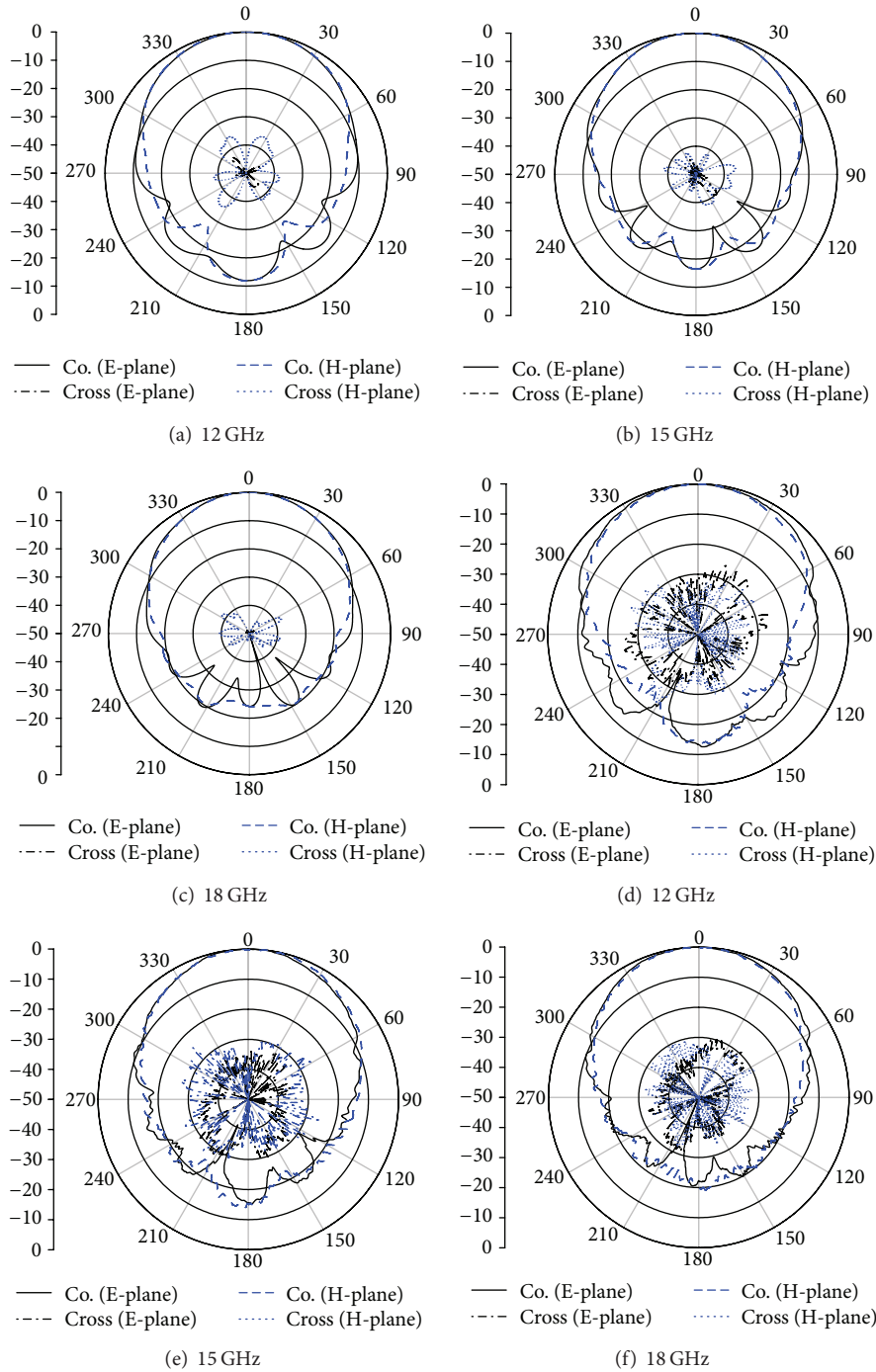


FIGURE 7: Simulated (a)–(c) and measured (d)–(f) radiation patterns of the proposed antenna at 12, 15, and 18 GHz, respectively.

hard to be eliminated. The detailed antenna performances including the gains and 3-dB beamwidths for both E- and H-planes at 12, 15, and 18 GHz are summarized in Table 1. Clearly, the 3-dB beamwidth of the proposed antenna varies within 10 degrees across the observed frequency range, and the gain varies less than 2 dB when the frequency changes from 12 to 18 GHz. Therefore, the antenna exhibits a stable performance.

4. Conclusion

A novel open-ended rectangular waveguide antenna has been proposed, which features wide bandwidth, low cross-polarization, moderate backward radiation, and uniform pattern bandwidth (almost identical E- and H-plane patterns) across the whole Ku-band. Furthermore, the proposed antenna exhibits a simple structure and is conceptually easy

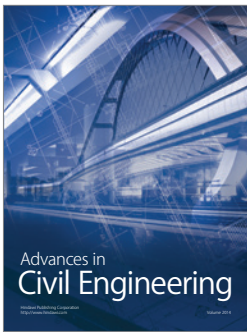
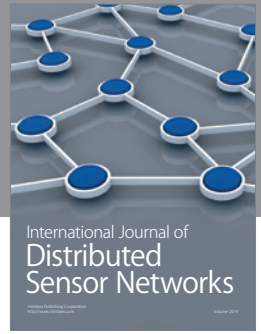
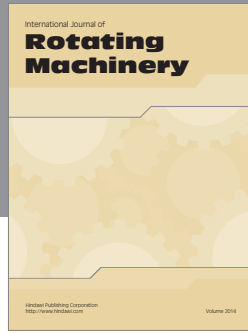
to design. Hence, it can be widely employed as an efficient feed for circular-aperture antennas to obtain the desired pencil-beam radiation patterns.

Acknowledgments

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References

- [1] Z. F. Liu, P. S. Kooi, L. W. Li, M. S. Leong, and T. S. Yeo, "A method for designing broad-band microstrip antennas in multilayered planar structures," *IEEE Transactions on Antennas and Propagation*, vol. 47, no. 9, pp. 1416–1420, 1999.
- [2] K. F. Tong, K. M. Luk, K. F. Lee, and R. Q. Lee, "A broad-band U-slot rectangular patch antenna on a microwave substrate," *IEEE Transactions on Antennas and Propagation*, vol. 48, no. 6, pp. 954–960, 2000.
- [3] K. M. Luk, C. L. Mak, Y. L. Chow, and K. F. Lee, "Broadband microstrip patch antenna," *Electronics Letters*, vol. 34, no. 15, pp. 1442–1443, 1998.
- [4] Y. J. Cho, K. H. Kim, D. H. Choi, S. S. Lee, and S. O. Park, "A miniature UWB planar monopole antenna with 5-GHz band-rejection filter and the time-domain characteristics," *IEEE Transactions on Antennas and Propagation*, vol. 54, no. 5, pp. 1453–1460, 2006.
- [5] R. Zaker, C. Ghobadi, and J. Nourinia, "Novel modified UWB planar monopole antenna with variable frequency band-notch function," *IEEE Antennas and Wireless Propagation Letters*, vol. 7, pp. 112–114, 2008.
- [6] A. Clavin, "A new antenna feed having equal E- and H-plane patterns," *IRE Transactions on Antennas and Propagation*, vol. 2, no. 3, pp. 113–119, 1954.
- [7] A. Clavin, D. A. Huebner, and F. J. Kilburg, "An improved element for use in array antennas," *IEEE Transactions on Antennas and Propagation*, vol. 22, no. 4, pp. 521–526, 1974.
- [8] K. M. Luk and H. Wong, "A new wideband unidirectional antenna element," *International Journal of Microwave and Optical Technology*, vol. 1, no. 1, pp. 35–44, 2006.
- [9] L. Siu, H. Wong, and K. M. Luk, "A dual-polarized magneto-electric dipole with dielectric loading," *IEEE Transactions on Antennas and Propagation*, vol. 57, no. 3, pp. 616–623, 2009.
- [10] B. Q. Wu and K. M. Luk, "A broadband dual-polarized magneto-electric dipole antenna with simple feeds," *IEEE Antennas and Wireless Propagation Letters*, vol. 8, pp. 60–63, 2009.
- [11] B. Q. Wu and K. M. Luk, "A magneto-electric dipole with a modified ground plane," *IEEE Antennas and Wireless Propagation Letters*, vol. 8, pp. 627–629, 2009.
- [12] L. Ge and K. M. Luk, "A low-profile magneto-electric dipole antenna," *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 4, pp. 1684–1689, 2012.
- [13] B. M. Thomas, "Design of corrugated conical horns," *IEEE Transactions on Antennas and Propagation*, vol. 26, no. 2, pp. 367–372, 1978.
- [14] F. Hyjazie and R. Paknys, "On the radiation from a large, open-ended waveguide," *IEEE Antennas and Propagation Magazine*, vol. 44, no. 6, pp. 98–100, 2002.
- [15] K. T. Selvan, "Studies on the classical gain approximations and the aperture-reflection coefficient of rectangular waveguide antennas," *IEEE Transactions on Electromagnetic Compatibility*, vol. 40, no. 4, pp. 343–347, 1998.



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