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Wideband and Low-Profile Linear Array of *H*-Plane Horns on a Conducting Ground Plane

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Abstract—This paper presents a design of wideband and low-profile linear array of H-plane horn antennas. In order to construct the linear array in H-plane, the aperture size of the horn antenna in the H-plane should be comparable with one wavelength in the free space, which leads to a poor impedance matching especially in the lower frequency range. The approach to the problem is removing the side walls of the flare part of the antennas. The array is fed by a wideband 4-way ridged SIW power divider. The designed array operates from 5.6 GHz to 18 GHz for VSWR 2.5 and exhibits stable radiation beam with a narrow beam-width in H plane over the same frequency rang while retaining the antenna array height of only 4 mm ($0.17\lambda_0$ at the center frequency). The designed array is fabricated and tested. It is observed that measured results agree well with simulated ones.

1. INTRODUCTION

The rapid growth of wireless communications demands more frequency bands made available. Wideband antenna arrays with low-profile characteristic have attracted a considerable amount of interest from modern communication and detecting systems which have limited space to mount the antennas [1–4].

In the open literature, numerous antenna arrays were designed for wide band applications [5–8]. A microstrip patch array reported in [9] achieved a high gain. However, the array required complicated feeding technique. Its bandwidth was narrow, and its volume was huge. Some patch antenna arrays such as the one designed in [10] can also operate in a wide frequency range but with complicate structure. A dielectric loaded array of H-plane horn antennas achieving a very narrow frequency bandwidth of 2% was introduced in [12]. The thickness of the substrate was $0.22\lambda_0$ at the center frequency.

There are few reports about the wideband and end-fire antenna array with low-profile structure. In this letter, a wideband and low-profile array of H-plane horns is proposed based on our previous work [13]. As the aperture size of the horn is decreased to be comparable with one wavelength in the free space to construct a linear array in the H-plane, the impedance matching in the lower frequency range is destroyed. The solution based on removing the side walls of the flare part of the horn is employed to improve the matching. In the meanwhile, the thickness of the array is extended to 4 mm from 3.175 mm in [13] to overcome the problem of poor impedance matching further which is caused by the antenna's low-profile.

Due to the above solutions, a wide operating frequency range from 5.6 GHz to 18 GHz is achieved. The proposed array formed by four elements can achieve a narrow beamwidth in H plane. The antenna array is fed by a wideband ridged SIW power divider. The low profile of the proposed array makes it suitable for flush-mount applications. A Teflon substrate with dielectric constant of 2.08 and thickness of 4 mm is used to implement the proposed array. Simulated and measured results of the designed antenna are presented and discussed. The antenna's radiation pattern is acceptable over the wide frequency range.

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2. DESIGN OF THE WIDEBAND AND LINEAR ARRAY OF THE *H*-PLANE HORN ANTENNAS

The proposed wideband linear array of H-plane horn antennas is shown in Fig. 1. It consists of a wideband ridged SIW power divider and four H-plane horn antennas. The horn antenna element is quite similar to that introduced in [13], which is constructed of a ridged flare part and a dielectric slab extending along the horn aperture with an arc-shaped taper printed on the upper surface. W and L are the width and length of the substrate. A is the aperture size of the horn antenna, S the space between two adjacent elements, w_r the width of the ridge, and l_n and h_n are the length and width of the stepped ridge, respectively ($n = 2$, 3, 4, 5).

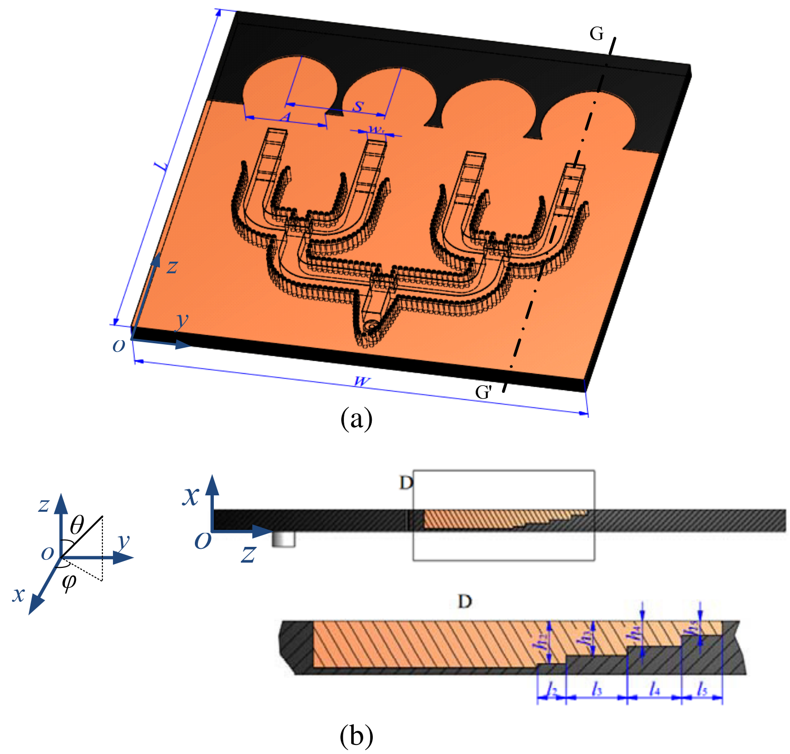

Figure 1. Configuration of the proposed array of H-plane horn antennas. (a) 3D view. (b) G-G' cut plane.

2.1. Design of the Wideband Ridged SIW Power Divider

The configuration of the proposed wideband ridged SIW power divider is shown in Fig. 2. The 4-way power divider is constructed by three T-junction power dividers. In this equal power split design, three cuts of the ridge are placed at the centerline of the input ports of the ridged SIW. Meanwhile, in order to achieve a smooth transition from a coaxial line to the ridged SIW, a cone-shaped probe is imbedded into the substrate, as shown in Fig. 2(b).

The transition from a coaxial line to the ridged waveguide is critical to achieving such a wide frequency band. A parabolic reflecting wall following $y = 6x^2$ is utilized to transform the cylindrical wave excited by the coaxial line to quasi-plane wave in the ridged waveguide. Considering the actual implementation, a cylindrical air cavity is perforated at the bottom of the dielectric to support the probe. Fig. 3 shows the simulated VSWR of the designed power divider. It can be seen that the power divider can work in the frequency range from 6 GHz to 18.3 GHz for VSWR less than 2.

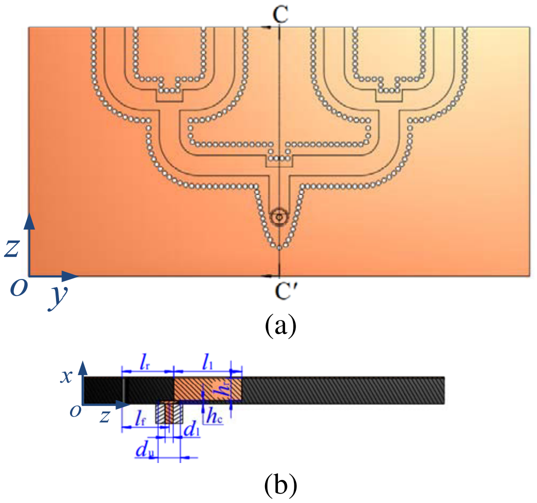

Figure 2. Geometry of the proposed 4-way ridged SIW power divider. (a) Top view. (b) C-C' cut plane.

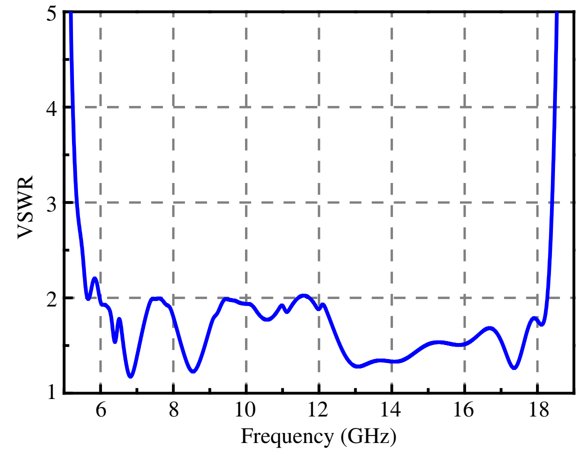

Figure 3. Simulated VSWR of the proposed 4-way ridged SIW power divider.

2.2. Design of the Linear Array

The small thickness of the low-profile H-plane horn antenna leads to a poor impedance matching in the low frequency range in the previous work. In order to improve the matching, the thickness of the proposed horn antenna h is slightly increased to 4 mm ($0.17\lambda_0$ at the center frequency) in this paper. As shown in Fig. 1, a five-step ridge is utilized to widen the operating frequency range and an arc-shaped taper employed to smoothen the transition from the horn aperture to the free space.

In order to construct a linear array in the H-plane, the size of the horn aperture should be decreased to be comparable with one free-space wavelength in the H-plane within the operating frequency range [14]. In this design, considering the very wide frequency band, the size of the aperture A is chosen as 19 mm, which is much less than the wavelength at the lowest operating frequency. The horn with such a small aperture size has difficulty in achieving a good impedance matching in the lower frequency range. One solution based on removing the side walls of the flare part is introduced to overcome this problem. The electric field distribution in the flare part is affected by removing the side walls. The impedance matching between the power divider and horn antenna can be improved. The array is formed by four H-plane antennas fed by a 4-way wideband ridged SIW power divider. The final parameter values can be found in Table 1.

Table 1. Optimized dimensions of the fabricated array.

Parameter	A	S	w_r	W	L	d_1	d_u	h_c	h_r	l_1
Value (mm)	19.2	23.5	4.5	110	105	1.3	3.4	0.5	3.5	10.4
Parameter	h_2	h_3	h_4	h_5	l_2	l_3	l_4	l_5	l_f	l_r
Value (mm)	3.2	2.6	1.9	1.1	2.1	4.5	4	3	6.8	7.5

3. SIMULATED AND MEASURES RESULTS OF THE PROPOSED ANTENNA ARRAY

The fabricated prototype of our designed antenna is shown in Fig. 4. The stepped ridge is realized by carving a stepped groove with gold plating. The antenna elements are fed by a ridged SIW power divider. The proposed antenna array can be mounted on a large ground plane.

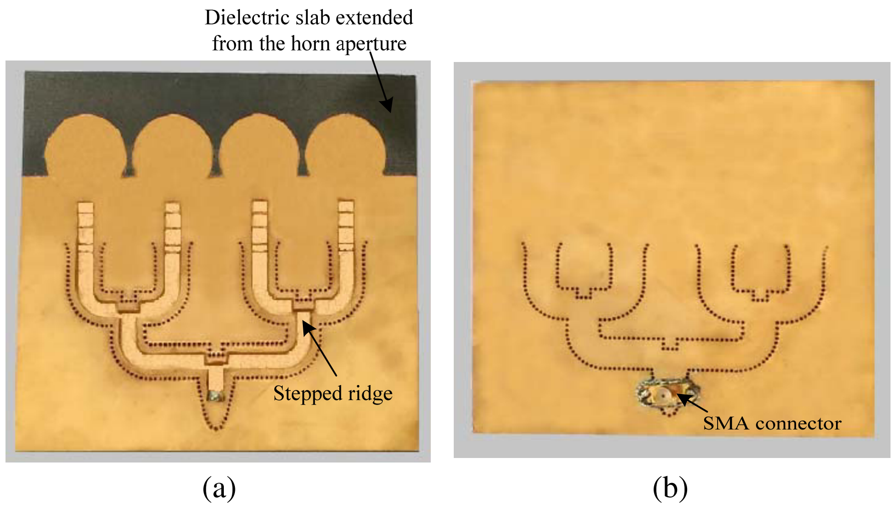

Figure 4. Fabricated prototype of the linear array of H-plane horn antennas, (a) top view, (b) bottom view.

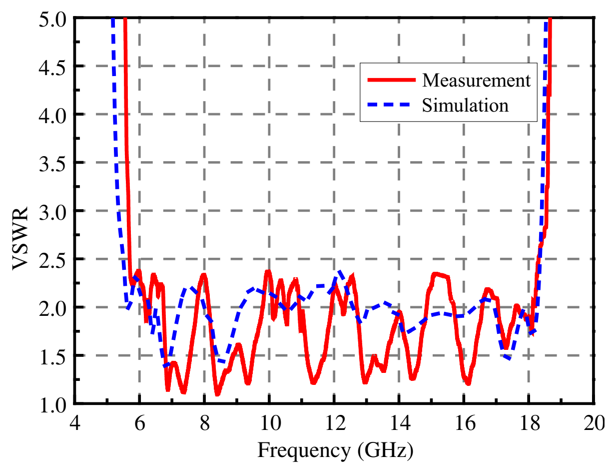

Figure 5. Simulated and measured VSWR of the proposed array of H-plane horn antennas.

The simulated and measured VSWRs of the proposed array are shown in Fig. 5. It is seen that the measured and simulated results are in good agreement. The measured VSWR is less than 2.5 within the frequency band from 5.6 GHz to 18 GHz. Fig. 6 shows the simulated and measured normalized radiation patterns of the presented antenna array in both E- and H-planes at different frequencies. The measured patterns agree well with the simulated ones. It is seen that the radiation beam in the H-plane stays well. It is worth noting that the beam in the E-plane is tilted with an angle arout 30° towards the $+z$-axis as the ground plane.

Figure 7 shows the simulated and measured peak gain results of the array at different frequencies. It is seen that acceptable gain values are obtained over the whole frequency band. The side-lobe level is more than 5 dB over the same frequency range. The simulated gain result versus frequency is shown in Fig. 7. Fig. 8 shows the front-to-back ratio (FTBR) and side-lobe-level (SLL) results of the fabricated antenna.

The designed H-plane horn antenna array achieves a wider bandwidth than many reported H-plane horn antennas with a very low profile. A comparison is made in Table 2 showing the fractional bandwidth with different profile sizes of various antenna designs reported so far. It can be seen that the bandwidth of our designed antenna is among the widest with a lower height than most of the antennas listed. The design in [3] has a much narrower bandwidth, though its height is a little smaller than ours.

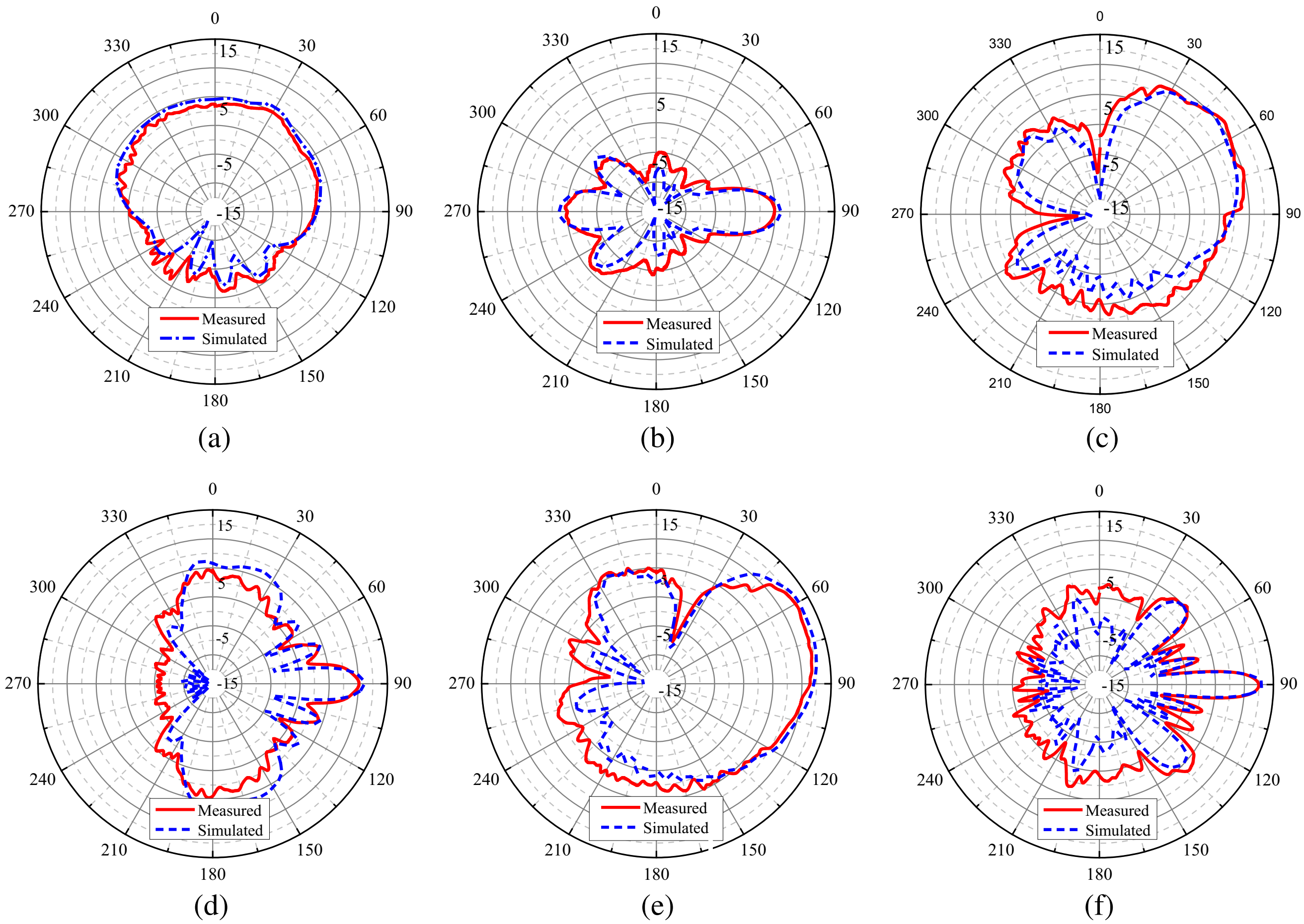

Figure 6. Simulated and measured normalized radiation patterns of the proposed array of H-plane horn antennas at different frequencies. (a) 6 GHz, $\varphi = 0°$, (b) 6 GHz, $\varphi = 90°$, (c) 12 GHz, $\varphi = 0°$, (d) 12 GHz, $\varphi = 90°$, (e) 18 GHz, $\varphi = 0°$, (f) 18 GHz, $\varphi = 90°$.

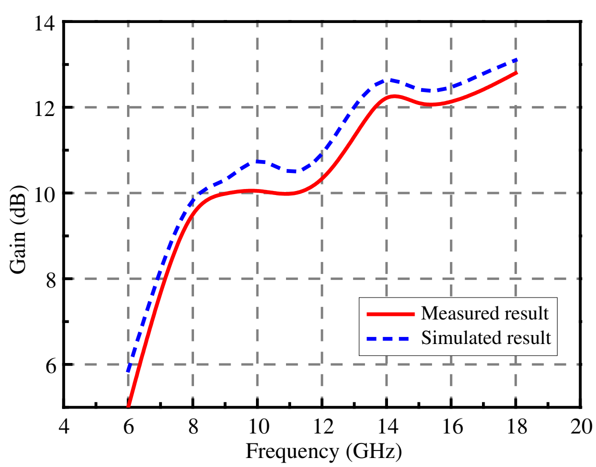

Figure 7. Simulated and measured peak gain results versus frequency of the proposed array of H-plane horn antennas.

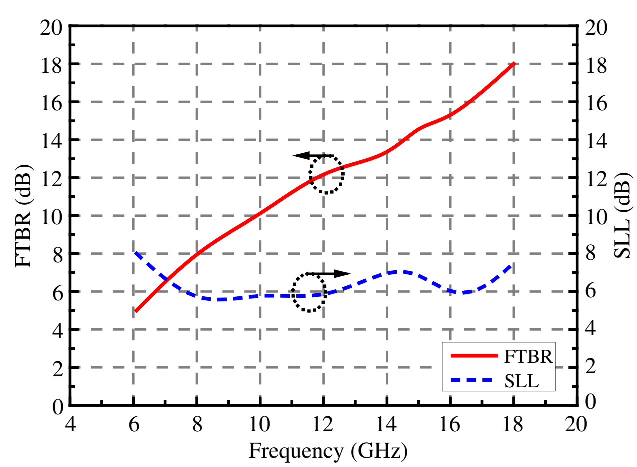

Figure 8. Measured FTBR and SLL versus frequency of the proposed array of H-plane horn antennas.

Table 2. A comparison of bandwidth among low-profile antennas.

Bandwidth (VSWR ≤ 2.5)	Thickness (λ_0 is the wavelength at the center frequency)	Reference
76%	$0.25\lambda_0$	[2]
19%	$0.1\lambda_0$	[3]
13%	$0.24\lambda_0$	[11]
1.8%	$0.23\lambda_0$	[12]
93%	$0.13\lambda_0$	[13]
4%	$0.23\lambda_0$	[15]
1.5%	$0.23\lambda_0$	[16]
122%	$0.22\lambda_0$	[17]
105%	$0.17\lambda_0$	This paper

The design in [17] has a wider bandwidth, though its height is thicker than ours, and it is composed by two layers with complicated structure.

4. CONCLUSION

This paper presents a wideband and low-profile linear array of H-plane horn antennas. The thickness of the array is only $0.16\lambda_0$ at the center frequency, which makes it particularly suitable for some flush-mount applications. In order to construct the linear array in H-plane, the size of the horn aperture in the H-plane is comparable with one free-space wavelength in the operating frequency range. The solution based on removing the side walls of the flare part is introduced to improve the impedance marching which is deteriorated with decreasing aperture size. The elements of the proposed array are fed by a wideband 4-way ridged SIW power divider. The antenna array achieves a wide bandwidth from 5.6 GHz to 18 GHz for VSWR less than 2.5 while retaining acceptable gain values and stable radiation beams over the same frequency range.

REFERENCES

1. Werner, D. H., R. J. Allard, R. A. Martin, and R. Mittra, "A reciprocity approach for calculating radiation patterns of arbitrarily shaped microstrip antennas mounted on circularly cylindrical platforms," *IEEE Trans. Antennas Propag.*, Vol. 51, No. 4, 730–738, Apr. 2003.
2. Mallahzadeh, A. R. and S. Esfandiarpour, "Wideband H-plane horn antenna based on ridge substrated integrated waveguide (RSIW)," *IEEE Antennas Wireless Propag. Lett.*, Vol. 11, 85–88, 2012.
3. Morote, M. E., B. Fuchs, J.-F. Zurcher, and J. R. Mosig, "Novel thin and compact H-plane SIW horn antenna," *IEEE Trans. Antennas Propag.*, Vol. 61, No. 6, 2911–2920, Jun. 2013.
4. Mousavi, P., et al., "A low-cost ultra-low profile phased array system for mobile satellite reception using zero-knowledge beam forming algorithm," *IEEE Trans. Antennas Propag.*, Vol. 56, No. 12, 3667–3679, Dec. 2008.
5. Bayrakter, O. and O. A. Civi, "Circumferential traveling wave slot array on cylinder substrate integrated waveguide (CSIW)," *IEEE Trans. Antennas Propag.*, Vol. 62, No. 7, 3557–3566, Jul. 2014.
6. Azadegan, R., "A Ku-band planar antenna array for mobile satellite TV reception with linear polarization," *IEEE Trans. Antennas Propag.*, Vol. 58, No. 6, 2097–2101, Jun. 2010.

7. Shahabadi, M., D. Busuioc, A. Borji, and S. Safavi-Naeini, "Low-cost, high-efficiency quasi-planar array of waveguide-fed circularly polarized microstrip antennas," *IEEE Trans. Antennas Propag.*, Vol. 53, No. 6, 2036–2043, Jul. 2005.
8. Yang, L., W. Tan, Z. Shen, and W. Wu, "Wide-band widecoverage linear array of four semi-circular sector horns," *IEEE Trans. Antennas Propag.*, Vol. 60, No. 8, 3980–3984, Aug. 2012.
9. Bilgic, M. M. and K. Yegin, "Low profile wideband antenna array with hybrid microstrip and waveguide feed network for Ku band satellite reception systems," *IEEE Trans. Antennas Propag.*, Vol. 62, No. 4, 2258–2263, Apr. 2014.
10. Li, M. J. and K. M. Luk, "A low-profile unidirectional printed antenna for millimeter-wave applications," *IEEE Trans. Antennas Propag.*, Vol. 62, No. 3, 1232–1237, Mar. 2014.
11. Yousefbeiki, M., A. A. Domenech, J. R. Mosig, and C. A. Fernandes, "Ku-band dielectric-loaded SIW horn for vertically-polarized multi-sector antennas," *Proc. 6th Eur. Conf. Antennas and Propagation (EUCAP)*, 2367–2371, Mar. 2012.
12. Wang, H., D.-G. Fang, B. Zhang, and W.-Q. Che, "Dielectric loaded substrate integrated waveguide (SIW) H-plane horn antenna," *IEEE Trans. Antennas Propag.*, Vol. 58, No. 3, 640–647, Mar. 2010.
13. Zhao, Y., Z. Shen, and W. Wu, "Wideband and low-profile H-plane ridged SIW horn antenna mounted on a large conducting plane," *IEEE Trans. Antennas Propag.*, Vol. 62, No. 11, 5895–5900, Nov. 2014.
14. Volakis, J. L., *Antenna Engineering Handbook*, 4th edition, McGraw-Hill, New York, NY, USA, 2007.
15. Tsao, H.-Y., D.-H. Yang, J.-C. Cheng, J. S. Fu, and W.-P. Lin, "W-band SIW H-plane horn antenna development," *4th International High Speed Intelligent Communication Forum (HSIC)*, 1–3, Mar. 2012.
16. Razavi, S. A. and M. H. Neshati, "Low profile H-plane horn antenna based on half mode substrate integrated waveguide technique," *Proc. 20th Iranian Conf. on Electrical Engineering*, 1351–1354, May 15–17, 2012.
17. Chen, Z. and Z. Shen, "Broadband and low-profile H-plane ridged horn antenna," *Proc. IEEE International Sym. on Antennas and Propag. & USNC/URSI National Radio Science Meeting*, 2319–2320, Jul. 19–24, 2015.