# Leaky Wave Fed Substrate Integrated Horn Antenna

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***Abstract*-Linearly flaring horn antennas typically suffer from low aperture efficiency, especially for large apertures. While spline horns can improve the aperture efficiency, this is at the cost of increased and more complex profile. This paper introduces a novel compact horn antenna fed by leaky waves from the horn arms, which presents a good aperture efficiency and geometrical simplicity. The proposed H-plane high gain horn consists of two leaky-wave waveguides. To demonstrate the idea, two leaky-wave waveguides are implemented in the technology of substrate integrated waveguide (SIW). The horn flaring angle is as large as 110° in this example. By combining the two leaky-wave radiation, a linearly phased wave front is formed. As a result, a high antenna gain of 14.3 dBi at 27 GHz is achieved, with the beamwidth of 6° and side-lobe level of -18 dB. There is no constrains on the horn flaring angles and radiation aperture sizes. This compact leaky-wave SIW horn antenna is very promising for the application as high gain antennas and feed.**

## I. Introduction

Horn antennas are one of the most common antennas and feeds. A commonly encountered implementation often is based on flared-out waveguides [1]. With the technology of substrate integrated waveguide (SIW) [2], H-plane horn antennas [3-8] could be implemented in printed circuit boards (PCBs) and integrated with other components. H-plane SIW horn antennas have the constrains of impedance matching from the PCB edge [9], which could be improved by adding printed strips [10], dielectric loadings [11], magneto-electric dipoles [12], and metasurfaces [13]. However, with the flaring of the horn arms, the phase distribution at the horn aperture is not uniform, which reduces the aperture radiation efficiency and antenna gain. Therefore, different types of lenses like dielectric lens [14-15], metallic lens [16-19] are introduced to correct the phase, which will increase the entire antenna geometry. SIW horns are also promising for arrays [11] and phased arrays [20].

Leaky-wave antennas (LWAs) [1] are suitable for high directive communication with simple feedings. SIW LWAs in $TE_{10}$ mode [21], half-$TE_{10}$ mode [22], $TE_{20}$ mode [23] and half $TE_{20}$ mode [24] have been investigated. Because the radiation beams of LWAs steer with frequencies, LWAs are dispersive. By loading compensated dispersive metasurface prism lens, this dispersion could be weakened [25-29], so as to enable LWAs radiating at a specific direction in a wide frequency band.

As shown in Figure 1, this paper proposes a new way to design an SIW horn antenna and validates the method using full-wave simulation. A horn antenna example in SIW technology is discussed with good antenna gain and patterns.

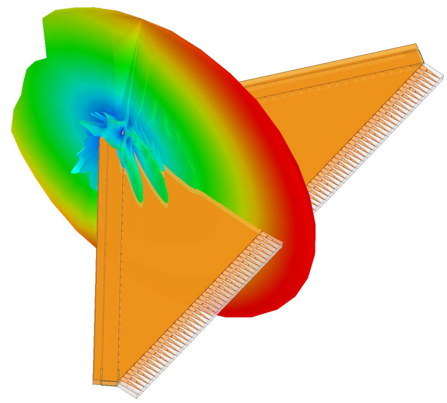


Figure 1. Illustration of the proposed leaky wave fed SIW horn antenna.

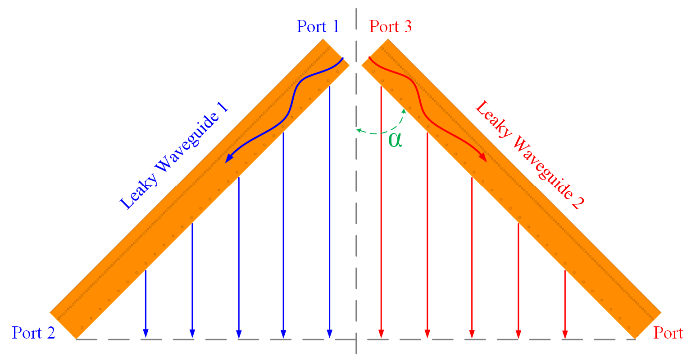


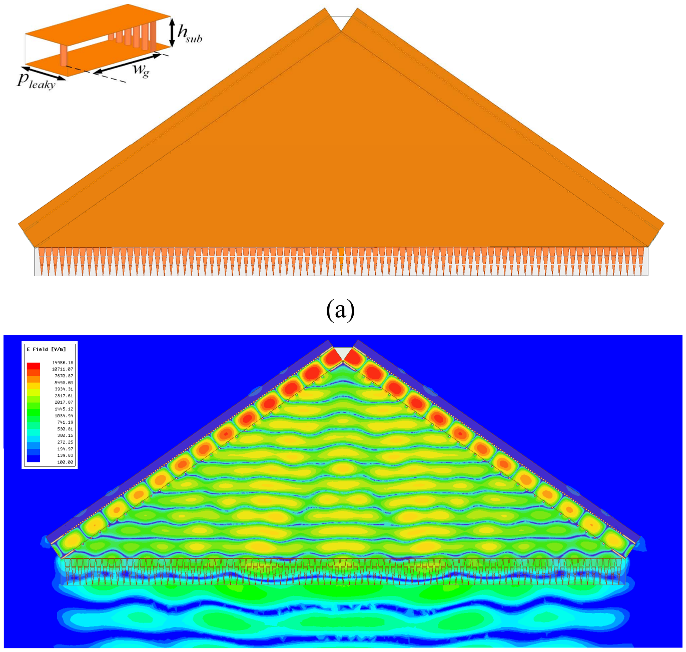

Figure 2. Basic radiation principle of the leaky wave fed SIW horn antenna.

As a first investigation, a 3-dB gain bandwidth of 2 GHz (7%) is obtained in Ka-band.

## II. Antenna Design

### *A. Basic Principle*

In SIW horn antennas the radiating aperture is usually excited by a waveguide from the center. However, in this new SIW horn, the aperture is excited by leaky waveguides, which is also the horn arms, as shown in Figure 2. There is no need of feeding waveguides in the center, reducing the entire antenna size. This new horn is fed from Port 1 and Port 3, with the other two ports Port 2 and Port 4 matched. Same as typically LWAs, the impedance matching is very good wideband. If the radiation beam of leaky waveguide 1 and 2 at the frequency $f_0$ is along the angle α, then the total radiation beams could be synthesized. If the feeding phase at Port 1 and Port 3 is the same, a sum beam will be formed. Because of the leaky-wave characteristics, the leaky waves arriving at the radiation




(a)

(b)

Figure 3. (a) Antenna structure of the proposed leaky wave fed SIW horn, and (b) electric field distribution at 27 GHz.

aperture are co-phase. If the leakage from the waveguide is uniform, then the amplitudes are uniform too. As a result, the total aperture efficiency is high with both uniform field amplitude and phase.

### *B. SIW Horn Example*

As shown in Figure 3(a), two leaky SIWs are designed in a substrate with the permittivity of 3.55 and the thickness of 1.524 mm. The radius of all the metallic vias is 0.15 mm and the distance between adjacent vias for the SIW is 0.5 mm, whereas the distance between adjacent leaky vias ($p_{leaky}$) is 1.0 mm. The waveguide width $w_g$ is 3.5 mm. The length of the leaky SIW is 60 mm and the angle between two leaky SIWs (2α) is 110°. The size of the total radiating aperture is 107 mm × 1.524 mm. In order to match the leaky waves out of the substrate, an array of triangular strips [5] are printed in front of the horn aperture.

Simulated in a full-wave tool, the distribution of the electric fields at 27 GHz is plotted in Figure 3(b), which implies uniform distributions of both phase and amplitude at the horn aperture. With both $S_{11}$ and $S_{33}$ lower than -10 dB, $S_{21}$ and $S_{43}$ are less than -10 dB as plotted in Figure 4. The total antenna efficiency is more than 80% in the band from 26 to 28 GHz.

### *C. Radiation Patterns*

The E-plane and H-plane radiation patterns at the designed frequency 27 GHz are depicted in Figure 5. The half-power beamwidth of the H-plane is 6° with a side-lobe level of -18 dB. Due to the thinness of the substrate, the E-plane beam is as wide as 144°.

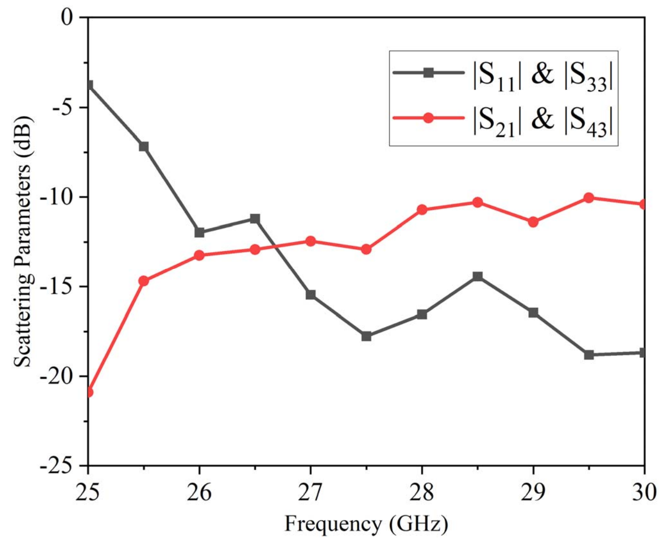



Figure 4. Scattering parameters of the proposed leaky horn antenna.

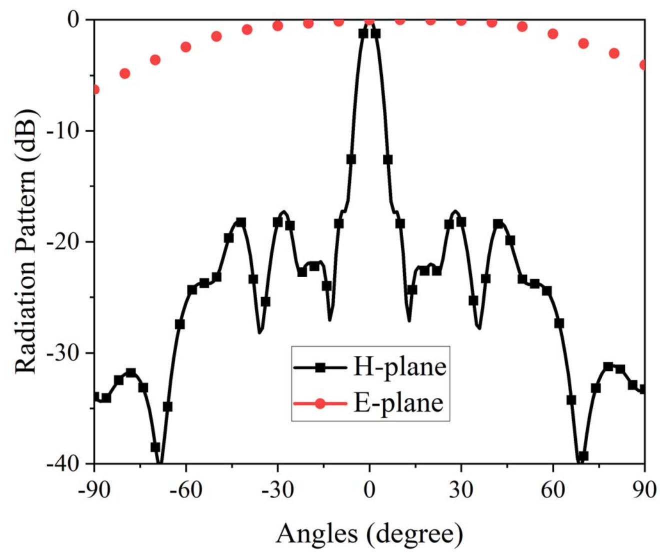



Figure 5. Radiation patterns at 27 GHz on both E- and H- planes.

### *D. Realized Gain*

The realized gain over frequencies is calculated in Figure 6. It indicates that the 3-dB gain covers the frequencies from 26 to 28 GHz, which is more than 7% in fraction. The realized gain approaches the maximum 14.3 dBi at 27 GHz and drops away due to the dispersion of leaky waves. In addition, the cross polarized gain at the main radiation direction is lower than -40 dB, which is more than 50 dB less than the co-polarized gain in the simulation.

## III. Conclusion

This paper describes a novel SIW horn antenna fed from the horn arms. The electromagnetic fields at the horn aperture have uniform phase and amplitude. This horn is especially useful for large aperture and high gain antennas. It has no constrains on the flaring angles. Furthermore, by simply tuning the leakage

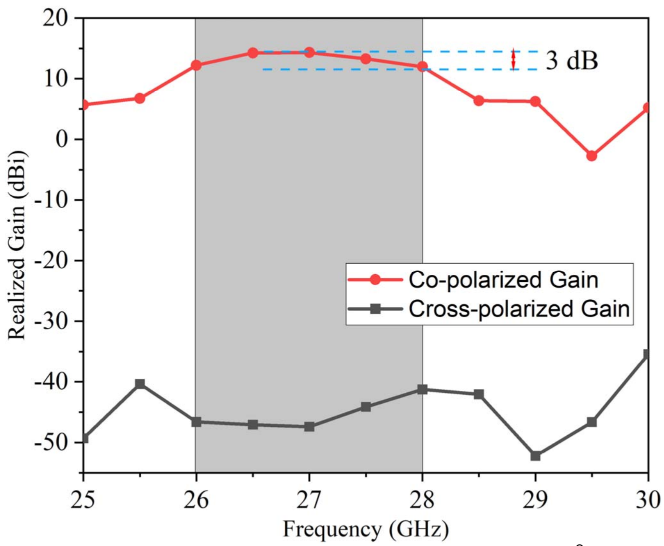


Figure 6. Realized gain at the main radiation direction ($\varphi$=0°).

from the horn arms, the radiation pattern could be easily modified, like low side lobes, which the conventional horns cannot comply. However, due to the dispersion of the leaky horn arms, the main radiation beams are not stable over frequencies, leading to a narrow bandwidth. Future work on the bandwidth enhancement will be taken as integrated dispersive via arrays in the horn as [25].

## REFERENCES


[1] C. Balanis, Modern Antenna Handbook, Hoboken, NJ, USA: Wiley, 2008.

[2] Y. Cassivi and L. Perregrini, “Dispersion characteristics of substrate integrated rectangular waveguide,” *IEEE Microw. Wireless Compon. Lett.*, vol. 12, no. 9, pp. 333–335, Sep. 2002.

[3] Y. Cao, Y. Cai, L. Wang, Z. Qian and L. Zhu, “A review of substrate integrated waveguide end-fire antennas,” in *IEEE Access*, vol. 6, pp. 66243-66253, 2018.

[4] L. Wang, X. Yin, S. Li, H. Zhao, L. Liu and M. Zhang, “Phase corrected substrate integrated waveguide H-plane horn antenna with embedded metal-via arrays,” in *IEEE Trans. Antennas Propag.*, vol. 62, no. 4, pp. 1854-1861, April 2014.

[5] L. Wang, M. Esquius-Morote, H. Qi, X. Yin and J. R. Mosig, “Phase corrected H-plane horn antenna in gap SIW technology,” in *IEEE Trans. Antennas Propag.*, vol. 65, no. 1, pp. 347-353, Jan. 2017.

[6] L. Wang, M. Garcia-Vigueras, M. Alvarez-Folgueiras and J. R. Mosig, “Wideband H-plane dielectric horn antenna,” in *IET Microw. Antennas Propag.*, vol. 11, no. 12, pp. 1695-1701, 22 9 2017.

[7] L. Wang, M. Esquius-Morote, X. Yin and J. R. Mosig, “Gain enhanced H-plane gap SIW horn antenna with phase correction,” *2015 9th Europ. Conf. Antennas Propag.* (EuCAP), Lisbon, 2015, pp. 1-5.

[8] Y. Cai et al., “Design of compact air-vias-perforated SIW horn antenna with partially detached broad walls,” in *IEEE Trans. Antennas Propag.*, vol. 64, no. 6, pp. 2100-2107, June 2016.

[9] L. Wang and C. Schuster, “Investigation of radiated EMI from printed circuit board edges up to 100 GHz by using an effective two-dimensional approach,” *2018 Int. Symp. Electromag. Compatibility (EMC EUROPE)*, Amsterdam, 2018, pp. 473-476.

[10] M. Esquius-Morote, B. Fuchs, J. Zürcher and J. R. Mosig, “A printed transition for matching improvement of SIW horn antennas,” in *IEEE Trans. Antennas Propag.*, vol. 61, no. 4, pp. 1923-1930, April 2013.

[11] H. Wang, D.-G. Fang, B. Zhang and W.-Q. Che, “Dielectric loaded substrate integrated waveguide (SIW) H-plane horn antennas”, in *IEEE Trans. Antennas Propag.*, vol. 58, no. 3, pp. 640-647, Mar. 2010.

[12] J. Wang et al., “Wideband dipole array loaded substrate integrated H-plane horn antenna for millimeter waves,” in *IEEE Trans. Antennas Propag.*, vol. 65, no. 10, pp. 5211-5219, Oct. 2017.

[13] T. Li and Z. N. Chen, “Wideband substrate-integrated waveguide-fed endfire metasurface antenna array,” *IEEE Trans. Antennas Propag.*, vol. 66, no. 12, pp. 7032-7040, 2018.

[14] W. Che, B. Fu, P. Yao, and Y. L. Chow, “Substrate integrated waveguide horn antenna with dielectric lens,” *Microw. Opt. Technol. Lett.*, vol. 49, no. 1, pp. 168-170, 2007.

[15] M. Yousefbeiki et al., “Ku-band dielectric-loaded SIW horn for vertically-polarized multi-sector antennas,” *6th Europ. Conf. Antennas Propag. (EuCAP),* pp. 2367-2371, 2012.

[16] L. Wang, X. Yin and H. Zhao, “A planar feeding technology using phase-and-amplitude-corrected SIW horn and its application,” in *IEEE Antennas Wireless Propag. Lett.*, vol. 14, pp. 147-150, 2015.

[17] L. Wang, X. Yin and H. Zhao, “Quasi-Yagi array loaded thin SIW horn antenna with metal-via-array lens,” *2014 IEEE Antennas Propag. Society Int. Symp. (APSURSI),* Memphis, TN, 2014, pp. 1290-1291.

[18] Q. Chen, X. Yin and L. Wang, “Compact printed log-periodic dipole arrays fed by SIW horn,” *12th Europ. Conf. Antennas Propag. (EuCAP 2018)*, London, 2018, pp. 1-3.

[19] W. Yuan et al., “Glide-symmetric lens antenna in gap waveguide technology,” in *IEEE Trans. Antennas Propag.*, vol. 68, no. 4, pp. 2612-2620, April 2020

[20] J. Zhang et al., “Dual-polarized phased array with end-fire radiation for 5G handset applications,” in *IEEE Trans. Antennas Propag.*, vol. 68, no. 4, pp. 3277-3282, April 2020.

[21] J. Liu, D. R. Jackson and Y. Long, “Substrate integrated waveguide (SIW) leaky-wave antenna with transverse slots,” in *IEEE Trans. Antennas Propag.*, vol. 60, no. 1, pp. 20-29, Jan. 2012.

[22] J. Xu, W. Hong, H. Tang, Z. Kuai and K. Wu, “Half-mode substrate integrated waveguide (HMSIW) leaky-wave antenna for millimeter-wave applications,” *IEEE Antennas Wireless Propag. Lett.*, vol. 7, pp. 85-88, 2008.

[23] F. Xu, K. Wu and X. Zhang, “Periodic leaky-wave antenna for millimeter wave applications based on substrate integrated waveguide,” in *IEEE Trans. Antennas Propag.*, vol. 58, no. 2, pp. 340-347, 2010.

[24] Q. Liao and L. Wang, “Switchable bidirectional/unidirectional LWA array based on half-mode substrate integrated waveguide,” in *IEEE Antennas Wireless Propagat. Lett.*, vol. 19, no. 7, pp. 1261-1265, July 2020.

[25] L. Wang, J. L. Gómez-Tornero and O. Quevedo-Teruel, “Substrate integrated waveguide leaky-wave antenna with wide bandwidth via prism coupling,” in *IEEE Trans. Microw. Theory Techn.*, vol. 66, no. 6, pp. 3110-3118, June 2018.

[26] L. Wang, J. L. Gómez-Tornero and O. Quevedo-Teruel, “Dispersion reduced SIW leaky-wave antenna by loading metasurface prism,” *2018 Int. Workshop Antenna Techn. (iWAT)*, Nanjing, 2018, pp. 1-3.

[27] L. Wang, J. L. Gómez-Tornero, E. Rajo-Iglesias and O. Quevedo-Teruel, “Low-dispersive leaky-wave antenna integrated in groove gap waveguide technology,” in *IEEE Trans. Antennas Propag.,* vol. 66, no. 11, pp. 5727-5736, 2018.

[28] J. Chen et al., “Wideband leaky-wave antennas loaded with gradient metasurface for fixed-beam radiations with customized tilting angles,” in *IEEE Trans. Antennas Propag.*, vol. 68, no. 1, pp. 161-170, Jan. 2020.

[29] O. Zetterstrom et al., “Low-dispersive leaky-wave antennas for mmWave point-to-point high-throughput communications,” in *IEEE Trans. Antennas Propag.*, vol. 68, no. 3, pp. 1322-1331, March 2020.