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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.

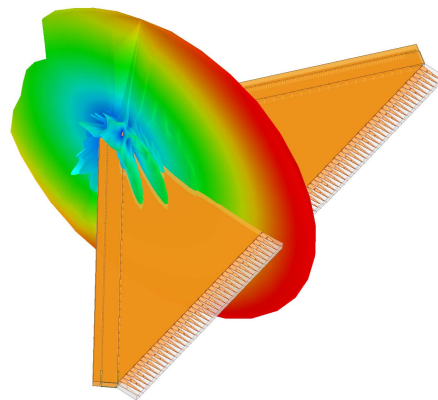


Figure 1. Illustration of the proposed leaky wave fed SIW horn antenna.

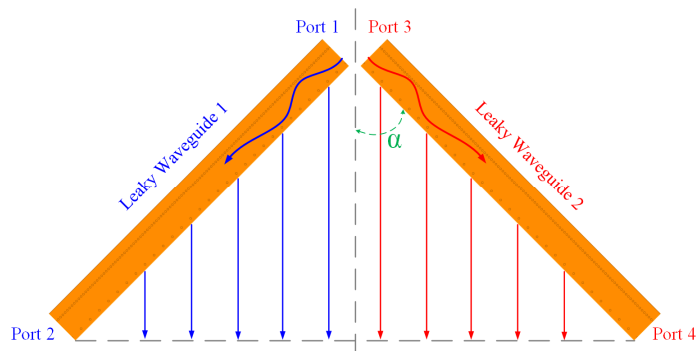


Figure 2. Basic radiation principle of the leaky wave fed SIW horn antenna.

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

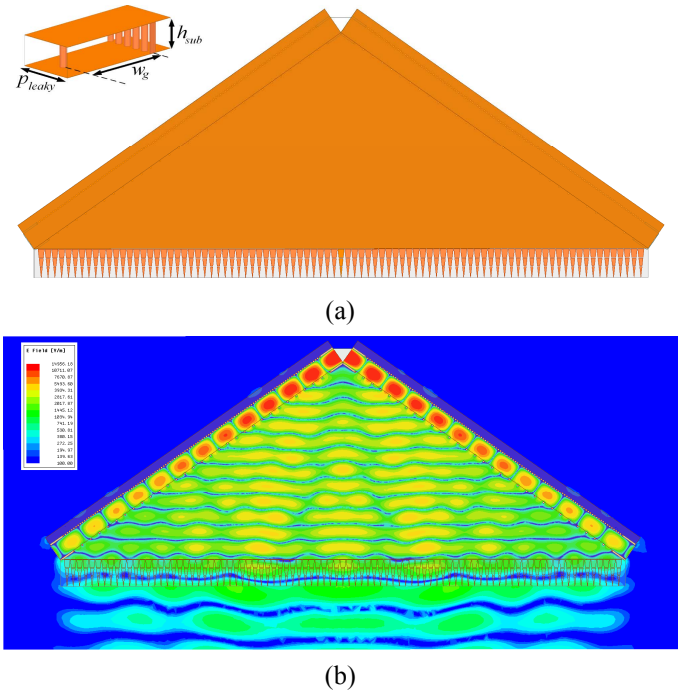


Figure 3. (a) Antenna structure of the proposed leaky wave fed SIW horn, and (b) electric field distribution at 27 GHz.

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 $107 \text{ mm} \times 1.524 \text{ mm}$. 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° .

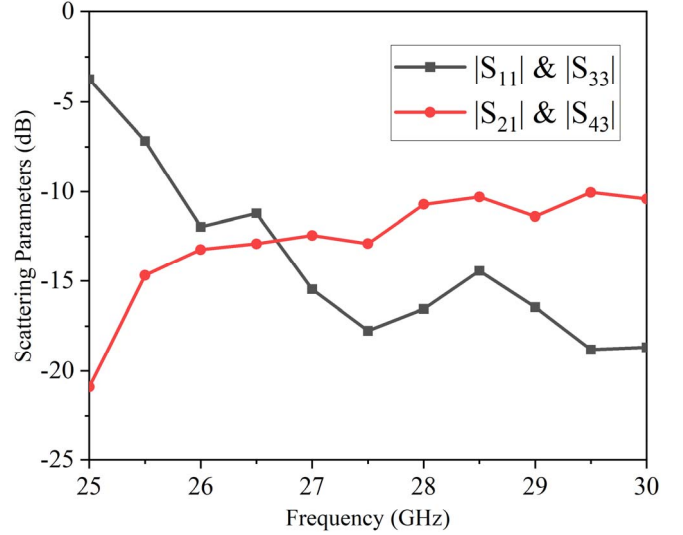


Figure 4. Scattering parameters of the proposed leaky horn antenna.

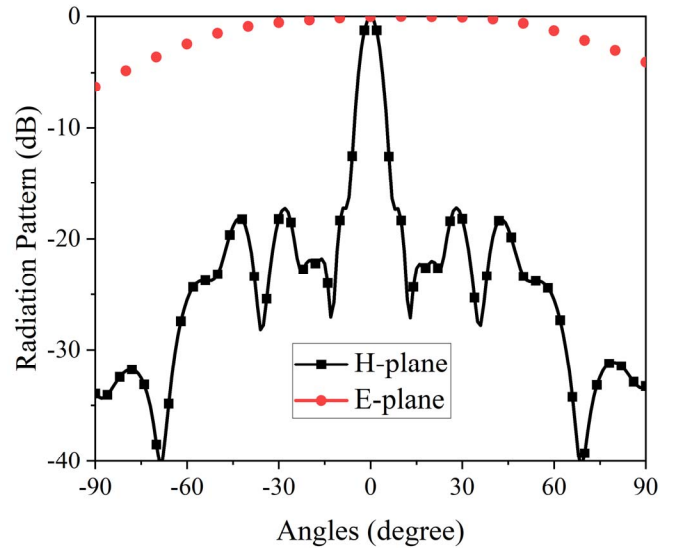


Figure 5. Radiation patterns at 27 GHz on both E- and H- planes.

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 constraints on the flaring angles. Furthermore, by simply tuning the leakage

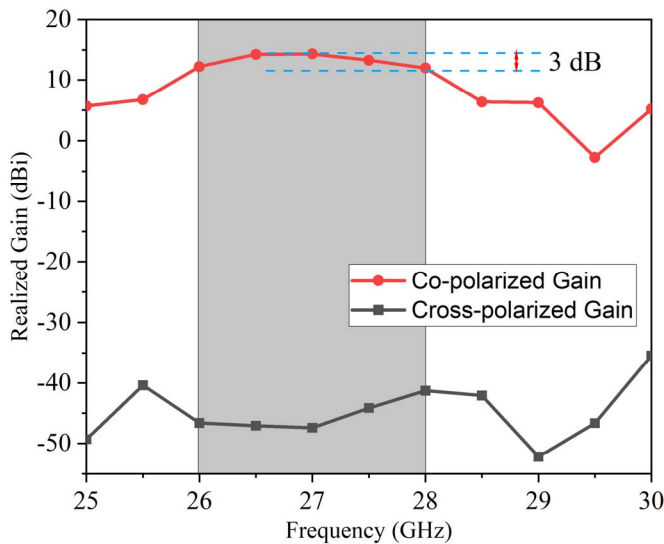


Figure 6. Realized gain at the main radiation direction ($\phi=0^\circ$).

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].

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