Dispersion Reduced SIW Leaky-wave Antenna by Loading Metasurface Prism

Lei Wang
School of Electrical Engineering, Computer Science, and Mathematics
Hamburg University of Technology
21079 Hamburg, Germany
wanglei@ieee.org

José Luis Gómez-Tornero
Department of Communication and Information Technologies
Technical University of Cartagena
Cartagena 30202, Spain
josel.gomez@upct.es

Oscar Quevedo-Teruel
Electromagnetic Engineering Lab of School of Electrical Engineering
KTH Royal Institute of Technology
SE-100 44 Stockholm, Sweden
oscarqt@kth.se

***Abstract*—Leaky-wave antennas (LWAs) are well-known for the high directivity, wide impedance bandwidth, and the beam-scanning performance with frequency. However, in the system that requires high-speed data transfer, wide system band and high directivity, LWAs are struggling with their beam squint effect in the radiation patterns, which limits their applications. In this paper, a dispersive metasurface prism is loaded to a dispersive LWA, reducing the LWA's dispersion, to make the LWA wide band radiating at a specific direction. A substrate integrated waveguide (SIW) LWA is taken to demonstrate the proposed concept with metasurface prism implemented by metallic vias. Full-wave simulation results show that the proposed low-dispersive SIW LWA has the main radiating direction at φ=24°, with half-power beamwidth of 8°, steers only ±0.5° from 33 to 38 GHz.**

Keywords—dispersive lens, leaky-wave antennas (LWAs), metasurface, substrate integrated waveguide (SIW).

I. Introduction

Substrate integrated waveguide leaky-wave antennas (SIW LWAs) offer promising features for millimeter waves wireless applications, for their high directivity and low losses using a single-feeding planar SIW guide [1-3]. As opposed to resonant antennas, their impedance bandwidth is wide due to their travelling-wave radiation mechanism, which is another general advantage of LWAs. However, due to the intrinsic dispersive nature [4], the directive radiated beam is scanned with frequency. This is an important drawback for highly-directive point-to-point broadband millimeter wireless links, since the pattern bandwidth (PBW) is very narrow due to this beam squinting. Anisotropic [5], nonreciprocal [6], and active non-Foster circuits [7], [8] have been proposed to reduce the beam squint of directive LWAs. These solutions are complex since they require biasing signals and expensive materials. One nice solution of a high-gain scanned LWA with wide radiation pattern bandwidth is the leaky lens proposed in [9], [10]. However, it has some important drawbacks. More recently the addition of Huygens passive metasurfaces has been theoretically proposed, in order to reduce the beam squint of general LWAs [11]. The main idea in [11] is that the LWA illuminates the metasurface, which introduces a complementary dispersive transmission response, which corrects for the beam squint of the dispersive LWA illuminator. Clearly, this type of solution is not limited to a non-dispersive slot line like the leaky-lens in [9], since this solution can theoretically be used to correct the beam squint of a dispersive leaky mode. However, no practical demonstration of this has been reported yet, probably due to the complexity to integrate this Huygens metasurface with a practical LWA.

A novel technique to obtain a directive and low dispersive SIW LWA is proposed in this paper, which dispenses from bulky three-dimensional shaped dielectric lenses, and integrates in the same substrate the LWA and a focusing lens with a prism shape. Leakage is obtained by separating the vias of one lateral wall of a SIW as proposed in [12], [13]. This dispersive radiation of the SIW leaky mode is then absorbed by a prism made of vias, which is integrated in the same hosting substrate. The prism has a dispersive response that corrects for the beam squint of the SIW leaky mode.

This work is supported by Alexander von Humboldt foundation.

II. Antenna Analysis

A. Dispersion Diagram Analysis

In Fig. 1, a SIW LWA is analyzed by unit cell, with periodic boundary conditions in the wave propagating direction as shown in left top of the figure. The radius of the metallic vias is 0.15 mm and the space between adjacent SIW vias is 0.5 mm. The width of the SIW (via center to via center) is 3.2 mm. By varying different values from 1.5 mm to 3.0 mm, four dispersion diagram curves are calculated and shown at the left side of lightline in Fig. 1. All these dispersion diagrams show the dispersive behavior of the original leaky-wave antenna. A periodic structure shown at the bottom of the Fig. 1 has been selected to design the dispersive substrate integrated prism. It is a parallel metal-plate loading with an isolated metallic via. Its metallic via has the same radius as the SIW, with the isolated circles of 0.35 mm on both top and bottom plates. Several dispersion diagram curves are also shown at the right side of the lightline in Fig. 1, varying the periodicity from 0.8 mm to 2.0 mm. Fig. 1 shows that these two kinds of dispersive curves

978-1-5386-1851-6/18/$31.00 ©2018 IEEE

are distributed at different sides of the lightline. The curves of the leaky-wave SIW go towards the lightline with the increasing of propagation constant, whereas the curves of the prism tend to be away from the lightline. It means that they feature two opposite dispersive characteristics, such as the curves of (1.5 mm, 0.8 mm), and (2.0 mm, 1.0 mm). Therefore, combining the leaky-wave SIW and the dispersive prism, their dispersive characteristics can be compensated

B. Antenna Design

The parameter pair (2.0 mm, 1.0 mm) mentioned in II.A is taken to design the proposed dispersion reduced SIW LWA, as shown in Fig. 2. A 2.92 mm connector has been used to feed the SIW [15]. The metasurface prism is cut into a triangular shape to make the radiating aperture to be perpendicular to the radiation direction (φ=24°).

Fig. 2 also shows that to have a better matching from the dielectric to free space, two matching strips are added to the radiating aperture [16], for the thickness of the dielectric is 1.524 mm.

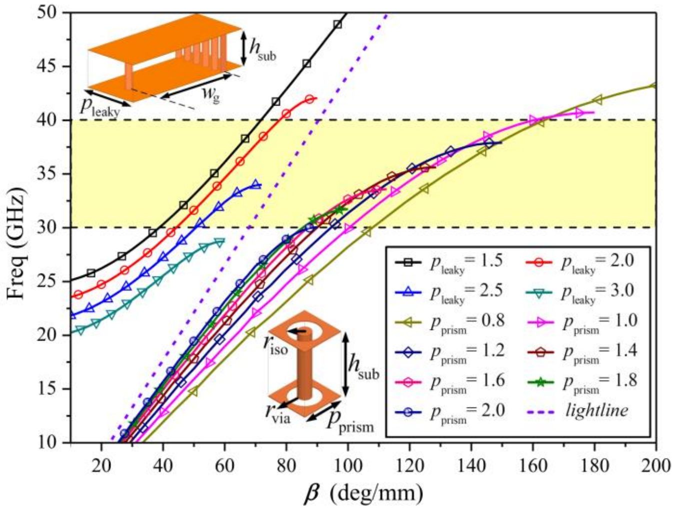


Fig. 1. Dispersion diagram of a number of leaky waveguides in SIW with different periodicities from 1.5 mm to 3.0 mm (left side). Dispersion of pins and with periodicities from 0.8 mm to 2.0 mm (right side).

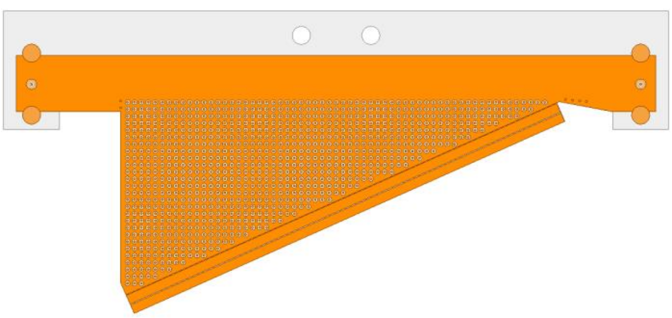
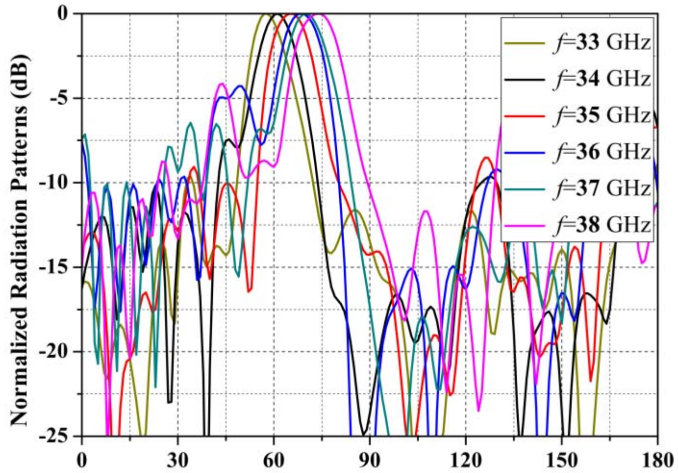
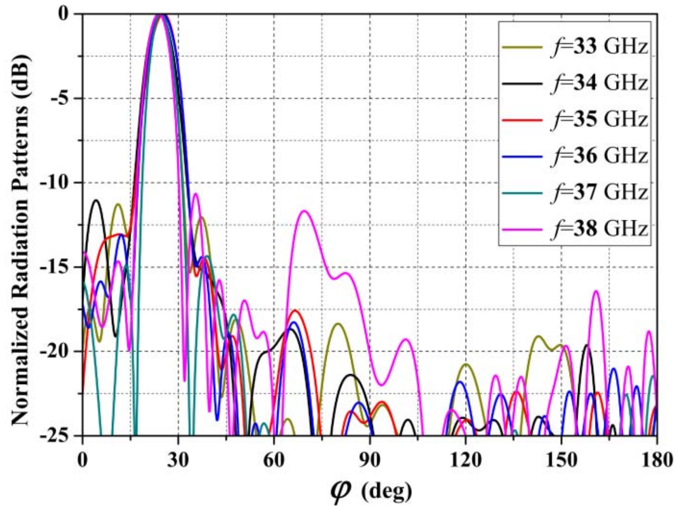


Fig. 2. Full structure of the rpoposed antenna.



(a)



(b)

Fig. 3. Radiation patterns for the antenna including the dispersive prism, without prism (a) and with prism (b) .

III. SIMULATION RESULTS

The complete structure of the proposed SIW LWA is simulated in full-wave simulation tool HFSS. The radiation patterns of the proposed SIW LWA radiate at φ=24° is with only ±0.5° difference from 33 to 38 GHz as shown in Fig. 3. The half-power beamwidth varies from 8.0° to 9.0°. Moreover, the simulated sidelobe levels are all below -10 dB from 33 to 38 GHz. For comparison, one same SIW LWA but without the dispersive prism, which scans from 56° to 74° when frequency varies from 33 to 38 GHz. Thus, the loading prism lens has reduced the dispersion from 18° to less than 1° from 33 38 GHz.

IV. CONCLUSIONS

By loading a dispersive metasurface prism to an SIW LWA, the beam squint effect of the LWA has been overcome for the reduction of the dispersion. The proposed low-dispersive SIW LWA radiates at φ=24 degree is with only

±0.5° difference from 33 to 38 GHz as shown in Fig. 3. The half-power beamwidth varies from 8.0° to 9.0°, and the simulated sidelobe levels are all below -10 dB. The proposed low-dispersive SIW leaky-wave antenna overcomes the conventional problem of squint effect. The proposed method can extend the use of leaky-wave antennas for applications that requiring a wideband radiation directed to a fixed angle.

ACKNOWLEDGMENT

Dr. Lei Wang would like to thank the support from Alexander von Humboldt foundation.

REFERENCES

[1] F. Xu, K. Wu, "Guided-wave and leakage characteristics of substrate integrated waveguide", IEEE Trans. Microw. Theory Tech., vol. 53, no. 1, pp. 66-73, Jan. 2005.

[2] J. Xu, W. Hong, H. Tang, Z. Kuai and K. Wu, "Half-Mode Substrate Integrated Waveguide (HMSIW) Leaky-Wave Antenna for MillimeterWave Applications," IEEE Antennas and Wireless Propag. Lett., vol. 7, pp. 85-88, 2008.

[3] Y. J. Cheng, W. Hong and K. Wu, "Millimeter-Wave Half Mode Substrate Integrated Waveguide Frequency Scanning Antenna With Quadri-Polarization," IEEE Trans. Antennas Propag., vol. 58, no. 6, pp. 1848- 1855, June 2010.

[4] A. A. Oliner and D. R. Jackson, Leaky-wave antennas, in Antenna Engineering Handbook, J. L. Volakis, Ed., 4th ed. New York: Mc-GrawHill, Jun. 2007, ch. 11.

[5] A. Shahvarpour, A. Alvarez-Melcon, and C. Caloz, Bandwidth enhancement and beam squint reduction of leaky modes in a uniaxially anisotropic meta-substrate, in Proc. Antennas Propag. Soc. Int. Symp., pp. 14, Jul. 2010.

[6] A. Porokhnyuk, T. Ueda, Y. Kado, and T. Itoh, "Nonreciprocal metamaterial for non-squinting leaky-wave antenna with enhanced beam steering", in Proc. Antennas Propag. Soc. Int. Symp., pp. 2289 2290, Jul. 2013.

[7] H. Mirzaei and G. V. Eleftheriades, "An active artificial transmission line for squint-free series-fed antenna array applications," in Proc. 41st European Microwave Conf. (EuMC), Manchester, UK, Oct. 2011, pp. 503-506.

[8] H. Mirzaei and G. V. Eleftheriades, "Arbitrary-Angle Squint-Free Beamforming in Series-Fed Antenna Arrays Using Non-Foster Elements Synthesized by Negative-Group-Delay Networks," IEEE Trans. Antennas Propag., vol. 63, no. 5, pp. 1997-2010, May. 2015.

[9] A. Neto, S. Bruni, G. Gerini, and M. Sabbadini, The leaky lens: A broadband fixed-beam leaky-wave antenna, IEEE Trans. Antennas Propag., vol. 53, no. 10, pp. 32403246, Oct. 2005.

[10] A. Neto, "UWB, Non Dispersive Radiation From the Planarly Fed Leaky Lens Antenna Part 1: Theory and Design," IEEE Trans. Antennas Propag., vol. 58, no. 7, pp. 2238-2247, Jul. 2010.

[12] A. Mehdipour, J. W. Wong and G. V. Eleftheriades, "Beam-Squinting Reduction of Leaky-Wave Antennas Using Huygens Metasurfaces," IEEE Trans. Antennas Propag., vol. 63, no. 3, pp. 978-992, Mar. 2015.

[13] D. Deslandes and K.Wu, Substrate integrated waveguide leaky-wave antenna: Concept and design considerations, in Proc. APMC, Suzhou, China, Dec. 2005, pp. 346349.

[14] A. J. Martinez-Ros, J. L. Gomez-Tornero, and G. Goussetis, Planar leaky-wave antenna with flexible control of the complex propagation constant, IEEE Trans. Antennas Propag., vol. 60, no. 3, pp. 1625-1630, Mar. 2012.

[15] 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.

[16] L. Wang, M. Garcia-Vigueras, M. Alvarez-Folgueiras and J. R. Mosig, "Wideband H-plane dielectric horn antenna," in IET Microwaves Antennas Propag., vol. 11, no. 12, pp. 1695-1701, 2017.