High gain leaky wave antenna operating at 0.566 THz

Beaskoetxea, U.; Beruete, M.; Falcone, F.; Etayo, David; Sorolla, M.; Navarro-Cia, Miguel; Zehar, Mokhtar; Blary, Karine; Chahadih, Abdallah; Han, Xiang Lei; Akalin, T.

DOI:
[10.1109/APS.2015.7305440](https://doi.org/10.1109/APS.2015.7305440)

License:
None: All rights reserved

Document Version
Peer reviewed version

Citation for published version (Harvard):
Beaskoetxea, U, Beruete, M, Falcone, F, Etayo, D, Sorolla, M, Navarro-Cia, M, Zehar, M, Blary, K, Chahadih, A, Han, XL & Akalin, T 2015, High gain leaky wave antenna operating at 0.566 THz. in *2015 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*. Institute of Electrical and Electronics Engineers (IEEE), pp. 2101-2102. <https://doi.org/10.1109/APS.2015.7305440>

[Link to publication on Research at Birmingham portal](#)

General rights

Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

- Users may freely distribute the URL that is used to identify this publication.
- Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.
- User may use extracts from the document in line with the concept of 'fair dealing' under the Copyright, Designs and Patents Act 1988 (?)
- Users may not further distribute the material nor use it for the purposes of commercial gain.

Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

Take down policy

While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact UBIRA@lists.bham.ac.uk providing details and we will remove access to the work immediately and investigate.

High Gain Leaky Wave Antenna Operating at 0.566 THz

Unai Beaskoetxea, Miguel
Beruete, Francisco Falcone,
David Etayo and Mario Sorolla
Electric and Electronic Engineering
Department
Universidad Pública de Navarra
Iruña/Pamplona, Spain
unai.beaskoetxea@unavarra.es

Miguel Navarro-Cía
Department of Electrical and
Electronic Engineering
Imperial College London
London, UK
m.navarro@imperial.ac.uk

Mokhtar Zehar, Karine Blary,
Abdallah Chahadih, Xiang-Lei
Han, Tahsin Akalin
IEMN,
Lille University,
Lille, France
Tahsin.Akalin@iemn.univ-lille1.fr

Abstract—Metallic structures consisting of a central $\lambda_0/2$ slot surrounded by straight parallel wedge corrugations present high transmission enhancement for an impinging EM beam, compared to that given by a single central slot with no grooves. Here, a 0.566 THz low profile leaky-wave antenna (LWA) with triangular corrugations is numerically and experimentally analyzed. Negligible differences are observed between triangular and typical square corrugation profiles. A manufactured prototype is also numerically and experimentally studied. LWAs are of high interest in several frequency ranges, including the expanding range of the THz.

I. INTRODUCTION

LWAs [1], [2] are characterized for achieving, despite their low profile, comparable or even higher radiation characteristics compared to larger volume antennas, as horns. In particular, very low profile LWAs can be obtained by using resonant slot on a metallic plate surrounded by corrugations. At first, this radiation enhancement was associated with the Extraordinary Optical Transmission (EOT) resonance, found in the optical range [3]–[9]. As it was proved that the sole EOT plasmonic interpretation was not suitable for the microwave and millimeter range later studied [10], it was complemented by a leaky wave interpretation [1]. Based on this, several prototypes were thoroughly studied [11]–[13]. The main characteristic of the radiation mechanism for these corrugated antennas is the capability of coupling feeding power to a leaky-wave, which propagates along the surface and in-phase re-radiated to the free space because of the periodicity.

With the aim of comparing the behavior arising from the utilization of different corrugation profiles, square and triangular groove profile structures operating at 0.56 THz ($\lambda_0=536\mu\text{m}$) were analyzed. For the triangular case, manufacturing and experimental studies were also done. Research for both antennas, along with the radiation and temporal properties of a THz Bull's-Eye antenna and how radiated pulses are shaped, were published in [14].

Designs are presented in Section I, followed by simulations in Section II and experimental results in Section III. Conclusions in Section IV provide a brief summary of the work.

II. DESIGN

Both designs replicate the periodic straight grooves surrounding a central slot distribution discussed in [11], [12]. The input power is coupled from the input face to the output face through the central aperture, which is approximately half the operating wavelength wide and with height much smaller than the wavelength, by exciting its transversal resonance. The corrugation period is set to approximately λ_0 , so as to achieve broadside radiation. The distance between the slot and the first pair of opposite grooves is such that in-phase radiation is achieved. The latter parameter, as well as the grooves' depth and width, were obtained by means of a fine optimization. A last structure with the measured dimensions of the fabricated one was also numerically analyzed, to study the differences in radiation arising from the design deviations introduced in the manufactured prototype.

III. SIMULATION RESULTS

As stated in Section II, the slot width determines the transversal resonance which couples incident wave to the output interface in the form of a TM_z mode surface-wave, whereas the slot depth (or slab thickness) gives a second resonance, corresponding to the longitudinal resonance, at around $f \sim 0.8\text{THz}$. Fig. 1 shows the radiation performance as a function of angle and frequency for triangular and square corrugations designs. It can be seen that it barely differs for both cases, presenting a maximum gain of approximately 16 dB at $f \sim 0.56\text{ THz}$, +10 dB gain compared to a flat structure.

Triangular grooves structure presents, for the E-plane, a -3dB beamwidth ($\theta_{-3\text{dB}}$) of 5.8 deg, 1 deg narrower than the square grooves case and a side lobe level of 8.6 dB, approximately 1 dB lower compared to the second case.

When designed and fabricated antennas are numerically compared, it can be seen that the latter only shows a slightly reduced directivity for almost all the band and a minor frequency shift of the maximum.

IV. EXPERIMENTAL RESULTS

Transmission enhancement obtained for a flat metallic surface patterned with periodically distributed triangular grooves, inset Fig. 2, was experimentally evaluated by means of a TeraView TPS 3000 Modular Terahertz Instrument. Two experiments were carried out: input face grooves covered with copper film and uncovered grooves, so as to record the

enhancement of the transmission through the slot for an impinging Gaussian beam.

As it was expected for the uncovered grooves case, transmission presented a high increment. Fig. 2 shows transmission normalized to the maximum of the uncovered case, localized at $f = 0.566$ THz.

Fig. 1. Directivity as a function of angle and frequency for triangular (a) and square (b) corrugations designs.

Fig. 2. Normalized transmittance for grooved (brown) and covered (green) structures. Manufactured antenna (inset).

V. CONCLUSIONS

In this work, we have numerically proved that when a slab with a central resonant slot is periodically patterned, a 10 dB gain enhancement is achievable, compared to that given by a flat slab. A directivity around 16 dB is obtained with a narrow beamwidth $\theta_{-3dB} = 7$ deg and a side lobe level less than 10 dB, for both triangular and square corrugations structures, with negligible differences in their behavior. Experimental measurements demonstrate a large increase at 0.566 THz when corrugated and non-corrugated structures were illuminated with a THz Gaussian beam.

Due to their capability of collimating an impinging beam, enhancing thus its gain, these low profile LWAs are of high interest for the THz range, for example, for the development of quantum cascade lasers and other novel THz devices.

ACKNOWLEDGMENT

U. Beaskoetxea was supported by the Public University of Navarre under the Formación de Personal Investigador 2014-1553/2013 contract. M. Beruete was supported by the Spanish Government under the Research Contract Program Ramón y Cajal RYC-2011-08221 and by the European Science Foundation (ESF) for the activity entitled “New Frontiers in Millimetre/Sub-Millimetre Waves Integrated Dielectric Focusing Systems”. M. Navarro-Cía was supported by the Imperial College Junior Research Fellowship. This work was supported in part by the Spanish Government under Grant Consolider Engineering Metamaterials CSD200800066 and Grant TEC2011-28664-C02-01.

REFERENCES

- [1] A. A. Oliner, “Leaky-Wave Antennas,” in *Antenna Engineering Handbook*, R. C. Johnson, Ed. New York: Mc Graw-Hill, 1993.
- [2] L. O. Goldstone and A. A. Oliner, “Leaky-Wave Antennas I: Rectangular Waveguides,” *IRE Trans. Antennas Propag.*, vol. 7, no. 4, 1959.
- [3] T. W. Ebbesen, H. J. Lezec, H. F. Ghaemi, T. Thio, and P. A. Wolff, “Extraordinary optical transmission through sub-wavelength hole arrays,” *Nature*, vol. 391, no. 6668, pp. 667–669, Feb. 1998.
- [4] M. Beruete, P. Rodríguez-Ulibarri, V. Pacheco-Peña, M. Navarro-Cía, and A. E. Serebryannikov, “Frozen mode from hybridized extraordinary transmission and Fabry-Perot resonances,” *Phys. Rev. B*, vol. 87, no. 20, p. 205128, May 2013.
- [5] L. Martín-Moreno, F. J. García-Vidal, H. J. Lezec, K. M. Pellerin, T. Thio, J. B. Pendry, and T. W. Ebbesen, “Theory of extraordinary optical transmission through subwavelength hole arrays,” *Phys. Rev. Lett.*, vol. 86, no. 6, pp. 1114–1117, 2001.
- [6] H. J. Lezec, A. Degiron, E. Devaux, R. A. Linke, L. Martín-Moreno, F. J. García-Vidal, and T. W. Ebbesen, “Beaming light from a subwavelength aperture,” *Science*, vol. 297, no. 5582, pp. 820–822, 2002.
- [7] M. Navarro-Cía, M. Beruete, I. Campillo, and M. Sorolla Aya, “Beamforming by left-handed extraordinary transmission metamaterial bi- and plano-concave lens at millimeter-waves,” *IEEE Trans. Antennas Propag.*, vol. 59, no. 6, pp. 2141–2151, 2011.
- [8] M. Navarro-Cía, M. Beruete, I. Campillo, and M. Sorolla, “Enhanced lens by ϵ and μ near-zero metamaterial boosted by extraordinary optical transmission,” *Phys. Rev. B*, vol. 83, no. 11, p. 115112, Mar. 2011.
- [9] M. Beruete, M. Navarro-Cía, and M. Sorolla, “High numerical aperture and low-loss negative refraction based on the fishnet rich anisotropy,” *Photonics Nanostructures - Fundam. Appl.*, vol. 10, no. 3, pp. 263–270, Jun. 2012.
- [10] M. Beruete, M. Sorolla, I. Campillo, J. S. Dolado, L. Martín-Moreno, J. Bravo-Abad, and F. J. García-Vidal, “Enhanced millimeter wave transmission through quasioptical subwavelength perforated plates,” *IEEE Trans. Antennas Propag.*, vol. 53, no. 6, pp. 1897–1903, 2005.
- [11] M. Beruete, I. Campillo, J. S. Dolado, J. E. Rodríguez-Seco, E. Perea, F. Falcone, and M. Sorolla, “Very Low Profile and Dielectric Loaded Feeder Antenna,” *IEEE Antennas Wirel. Propag. Lett.*, vol. 6, pp. 544–548, 2007.
- [12] M. Beruete, I. Campillo, J. S. Dolado, E. Perea, F. Falcone, and M. Sorolla, “Dual-band low-profile corrugated feeder antenna,” *IEEE Trans. Antennas Propag.*, vol. 54, no. 2, pp. 340–350, 2006.
- [13] M. Beruete, I. Campillo, J. S. Dolado, E. Perea, F. Falcone, and M. Sorolla, “Very Low-Profile ‘Bull’ s-Eye Feeder Antenna,” *IEEE Antennas Wirel. Propag. Lett.*, vol. 4, no. 2, pp. 365–368, 2005.
- [14] M. Beruete, U. Beaskoetxea, M. Zehar, A. Agrawal, S. Liu, K. Blary, A. Chahadih, X. L. Han, M. Navarro-Cía, D. Etayo Salinas, A. Nahata, T. Akalin, M. Sorolla Aya, M. Navarro-Cía, D. E. Salinas, and M. S. Aya, “Terahertz Corrugated and Bull’ s-Eye Antennas,” *IEEE Trans. Terahertz Sci. Technol.*, vol. 3, no. 6, pp. 740–747, 2013.