Multi beam imaging array, based on leaky lens antennas

Citation for published version (APA):

Bruni, S., Neto, A., Gerini, G., & Bekers, D. J. (2007). Multi beam imaging array, based on leaky lens antennas. In *Proceedings of IEEE Antennas and Propagation Society International Symposium, 2007, Honolulu, HI, 9-15 June 2007* (pp. 5567-). Institute of Electrical and Electronics Engineers.
<https://doi.org/10.1109/APS.2007.4396810>

DOI:

[10.1109/APS.2007.4396810](https://doi.org/10.1109/APS.2007.4396810)

Document status and date:

Published: 01/01/2007

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

[Link to publication](#)

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy

If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

MULTI BEAM IMAGING ARRAY BASED ON LEAKY LENS ANTENNAS

S. Bruni, A. Neto, G. Gerini, D. Bekers

TNO - Defence, Security and Safety , Oude Waalsdorperweg 63, 2597 AK, The Hague, THE NETHERLANDS. E-mail : [simona.bruni](mailto:simona.bruni@tno.nl), [andrea.neto](mailto:andrea.neto@tno.nl), [giampiero.gerini](mailto:giampiero.gerini@tno.nl), dave.bekers@tno.nl

ABSTRACT

This paper proposes a novel imaging architecture suited for use in the mm and the sub-mm wave regimes. The structure is composed by a one dimensional array of radiators in order to enhance the image acquisition time with respect to single element detection. Moreover each of the antenna elements composing the array is characterized by a relatively broad band which opens the possibility for the array to be used over multiple frequencies or over a single wide band. Each of the radiators is a Leaky wave slot and all of them radiate in the presence of a unique dielectric lens. A prototype of the array has been designed to operate at relatively low frequencies (18-26 GHz). It has then been manufactured and measured. The performances are extremely promising and provide a hard proof of concept of the feasibility and the advantages of the proposed array architecture.

THE PROBLEM

One of the key parts of a sub-mm wave imaging system is the integrated antenna receiver. Many direct and coherent detection systems use quasi-optical coupling to the incoming radiation field in the form of a combination of a dielectric lens and an antenna integrated with the detector. Very popular detectors like super-conducting vacuum-bridge bolometers or super-conducting hot electron bolometers (HEB) behave almost independently from the frequency, so that the bandwidth of the receiver is mostly determined by the antenna. Typically, twin slot antennas, which are one of the most popular antennas used in sub-mm wave heterodyne receivers, may have 10 -15 % operational bandwidth with good efficiencies [1]. Therefore it is clear that if one can further enlarge the RF bandwidth of a planar antenna, allowing a given frequency range to be covered with fewer mixers, this can result in much simplified instrument designs and significant cost reduction. To pursue this goal a novel type of leaky wave radiation mechanism was presented in [2] which intrinsically supports wide band operation. The basic concept is that a wave propagating at the interface between two homogeneous dielectrics radiates a beam into the denser medium at an angle which largely frequency independent. In [3] the first leaky wave antenna implementing this concept was reported. In a preliminary proof of concept the potential of such leaky lens concepts to realize integrated transmitters or receivers with extremely broadband coverage, high directivity and limited or no dispersion were demonstrated.

However an imaging array is a very interesting solution for those applications (like military or security applications, but also plasma diagnostics) where a fast image acquisition time is an important issue. In fact in all scientific road maps (U.S., Japan, Europe) future imaging systems will also be based on simultaneous multi-pixel acquisition. References [4] and [5] are significant examples where the elliptical lens concept was applied to realize multi pixel imaging. The idea in both papers was the extension to a focal plane array of the same configuration shown in [1]. In the present paper, the design, the scaled model realization, and the demonstration of antenna technology that extends the leaky lens radiation concept introduced in [2] and [3] to an

imaging array are presented. In particular the concept is extended to implement a 7 elements linear imaging array. The array consists of 7 slots (of which only 5 are fed) etched on the focal ground plane of an elliptical lens as the one in [3]. With respect to a standard array solution the novel imaging array presents two characteristic features that render it particularly efficient. In fact the most critical loss factors in imaging arrays are spill over and mutual coupling.

In the case of lenses, the spill-over losses are associated to the rays that are radiated by the sources but impinge on the dielectric air interface in a zone of the lens that does not contribute to focus the beams in the far field. The present array solution is designed in such a way that the field radiated by each slot is reinforced by the fields scattered by the neighboring slots. Thus the field associated to each slot inside the lens is more directive than the single slot pattern would imply. Nevertheless the mutual interference between slots remains significant only at radiation level. The mutual coupling at feed level is very low despite the fact that different beams cross over at about the -2 dB level. A low mutual coupling means very low losses due to power coupled into the matched loads of the neighboring slots. The measured impedance parameters and radiation patterns exhibit good performances over a relatively wide frequency range (about 30 %).

Fig. 1 Four views of the integrated leaky lens slot array.

ARRAY GEOMETRY

The designed structure is shown in Figure 1. The four views allow one to recognize that the array is developed in one dimension only (the y-direction in the figure), while the long slots extend in the x-direction. The dielectric constant of the lens is $\epsilon_r=3.27$. The dimensioning of the lens is divided in the separate design of the two cross sections since the leakage from the slots dominates the radiation pattern in the direction along the axis of the cone while dielectric lens imaging as described in [4], and [5] defines the separation and location of the slots in the y-direction. The length of each slot and the angle of the cone that defines the the dielectric lens are derived once the propagation and attenuation constants of each slot in the presence of the neighboring one is known [6]. In principle each slot is characterized by a different propagation (direction of radiation in the dielectric) and attenuation constant.

Fig. 2 Manufactured lens a) and detailed view of the feeding network with air bridges b)

The reason is that the array is composed of a finite number of slots and the distance between a slot and the end slots impacts the actual propagation constant. However an angle for the lens had to be chosen and the central slot has been taken as reference, so that the radiation arising from it impinges normally onto the dielectric air interface. A detailed picture of the manufactured lens and of the feeding network of the array is shown in Fig. 2. The directivity patterns of the central slot of the array at the central frequency of 23 GHz are shown in Fig.3. They highlight both E and H plane patterns and present the comparisons between calculations and measurements.

Fig.3 H plane (left figure) and E plane (right figure) patterns for the central feed at the central frequency of 23 GHz. Comparisons between measurements and calculations.

Fig. 4 shows the five plots for the co-polarized neighboring beams associated to the 5 active feeds and for the same central frequency of 23 GHz. Even if not reported for the sake of brevity the S_{ii} parameters of the array are below 9 dB over a 20 % bandwidth (18 to 26 GHz), the measurements will be shown during the conference. The matching could be better if the feeding network could have been developed over a larger area rather than being squeezed over the smallest possible area (as visible in Fig 2). However as expected the S_{ij} parameters accounting for the mutual coupling at feed level were lower than 22 dB over the entire investigated bandwidth.

Fig. 4 The plots of the 5 independent beams.

CONCLUSIONS

The leaky lens radiation concept has been proposed as a viable option to realize multi pixel imaging arrays with simultaneous acquisition in one plane. The dielectric lens, the focal plane imaging array and the relevant feeding network have been designed and manufactured to operate from 18 to 26 GHz. Preliminary measurements demonstrate the effectiveness in obtaining useful very closely spaced patterns. The system is efficient thanks to a reinforcing interference between different slots and thanks to the low mutual coupling between the different feeds.

REFERENCES

- [1] D. F. Filippovic, S. S. Gearhart and G. M. Rebeiz, "Double Slot on Extended Hemispherical and Elliptical Silicon Dielectric Lenses", *IEEE Transactions on Microwave Theory Techniques*, Vol. 41, no. 10, October 1993.
- [2] A. Neto, S. Maci, "Green's Function of an Infinite Slot Printed Between Two Homogeneous Dielectrics. Part I: Magnetic Currents and Part II: Space Wave-Leaky Wave Asymptotics " on *IEEE Transactions on Antennas and Propagation*.. Vol. 51 no. 7 July 2003 and Vol. 52, No. 3, March 2004
- [3] A. Neto, S. Bruni, G. Gerini, M. Sabbadini "The Leaky Lens: a Broad Band, Fixed Beam Leaky Wave Antenna" on *IEEE Trans. on Antennas and Propagation Vol.53 no.10, October 2005*
- [4] D. F. Filippovic, G. P. Gauthier, S. Raman and G. M. Rebeiz, "Off axis properties of Silicon and Quartz Dielectric Lens Antennas", *IEEE Transactions on Antennas ad Propagation*, Vol. 45, no. 5, May 1997.
- [5] X.Wu, G.Eleftheriades, T. Emie van Deventer-Perkins, "Design and Characterization of Single and Multiple Beam MM-Wave Circularly Polarized Substrate Lens Antennas for Wireless Communications", *IEEE Transactions on Antennas ad Propagation*, Vol. 49, no. 3, March 2001.
- [6] S. Bruni, A. Neto, S. Maci, G. Gerini, "Analysis of an Array of Long Slots Printed Between Two Dielectric Half-Spaces" submitted to *IEEE Transactions on Antennas and propagation*, also presented at the *IEEE Antennas and Propagation Symposium*, Washington 2005