Dielectric Lens Fed by Coherent Connected-Slot Array as Wideband Reflector Feed

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***Abstract*—A broadband reflector feed is presented, which consists of a dielectric extended hemispherical lens fed by a connected array of leaky-wave slots. The slot elements are coherently combined to generate directive radiation patterns that mostly illuminate the central part of the lens, which is the most efficient. The array is capable of producing secondary patterns with almost constant -10dB beamwitdh over a 4:1 bandwidth. This allows efficient illumination of the reflector over a wide frequency range. Performance is estimated in terms of amplitude taper and phase error losses, yielding efficiency higher than 80% over the entire 4:1 bandwidth.**

Index Terms—Connected array; lens antenna; reflector feed; wideband antenna.

I. INTRODUCTION

Reflector systems with wideband antenna feeds are receiving growing interest for applications such as radio astronomy and space observation [1], [2]. Reflector feeds that can operate efficiently over wide frequency ranges have been previously developed for low-frequency radio telescopes. Some examples are the focal plane array of tapered slot antennas in [3] and the eleven antenna [4]. However, there is currently a need for wideband reflector feeds also at much higher frequencies, for Terahertz (THz) and mm-wave space instruments.

For THz space observation, dielectric lens antenna are typically used, due to their easy integration. However, the typical antenna solutions used as feed of dielectric lenses are efficient only over a narrow band [5]. An improved solution is the leaky-lens antenna recently proposed in [6], which can achieve multi-octave bandwidth. This antenna consists of a leaky-wave slot kept at an electrically small distance from the dielectric lens (Fig. 1(a)), in order to obtain directive radiation inside the dielectric and, consequently, efficient illumination of the lens. The leaky-lens was experimentally proved to be non-dispersive and highly efficient over a wide bandwidth in the microwave [7] and recently also in the THz regime [8].

Although well matched and with stable phase center over a very wide band, the leaky-lens antenna generates radiation patterns that become narrower and more directive when the frequency increases. For this reason, when used as reflector feed over wide bandwidths, this antenna leads to low amplitude taper efficiency. In this work, we aim at improving the illumination efficiency of a single-slot-fed leaky-lens antenna

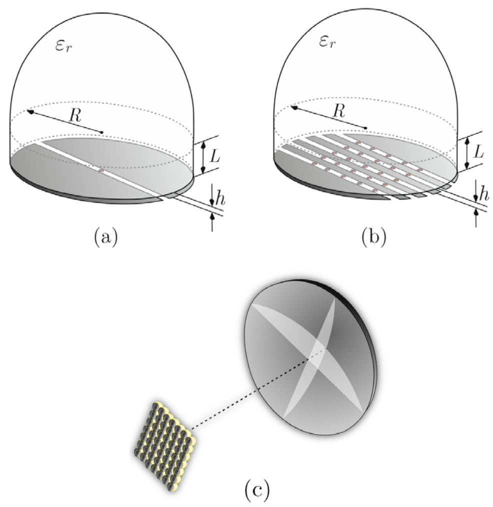

Figure 1. Dielectric lens fed by (a) single leaky-wave slot and (b) connected array of leaky-wave slots. (c) Focal plane array of lenses illuminating a reflector.

by extending the leaky-slot radiation concept to be used in a multi-feed configuration, as shown in Fig. 1(b). To maintain wide bandwidth, the slots are electrically connected so that the array is composed by a finite number of long slots, each excited at a finite number of points. This allows to obtain high mutual coupling, realizing the so called connected-array concept [9]. The array elements are coherently combined, so that they are associated with a single beam outside the lens. To feed the elements coherently, a corporate microstrip feed structure will be designed. Each slot will be fed by aperture coupling with a microstrip terminated with a radial open stub. In order to avoid losses, the feed structure is going to be implemented with transmission lines that are superconductive, i.e., the instrument is working below the gap frequency. Below this frequency the material basically behaves as a perfect conductor and exhibit negligible ohmic losses [10].

In future space missions [1], [2] many of these lenses will be used in the focal plane array of a large reflector, as shown schematically in Fig. 1(c). Therefore, it is important to maintain the illumination as constant as possible at all frequencies within the band of operation.

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II. Radiation Patterns and Efficiency

The radiation patterns outside the lens are calculated by combining a spectral domain approach for the analysis of the array [11] with a physical optics method to include the lens. We consider a silicon lens ($\varepsilon_r = 11.7$) of radius $R = 2.5$ mm and extension length $L/R = 0.35$. The width of the slots is $w = 25$ µm and the distance between the array plane and the dielectric lens is $h = 12.5$ µm. The distance between the slots is 100 µm, as well as the distance between the feeds in each slot. From Fig. 2, It can be noted that the patterns of the isolated elements become narrower when the frequency increases. However, the direction of the maximum remains the same, so that the 10dB beamwidth of the pattern sum remains almost constant with frequency. Oscillations occur at 2 THz because the beams associated with each feed are angularly separated and interfere destructively. Fig. 3 compares the pattern of a lens fed by single slot (Fig. 3(b)) and the ones obtained when the same lens is fed by a 5×5 coherent array of connected slots (Fig. 3(a)). It can be noted that the single slot produces patterns that are frequency dependent and thus not efficient for wideband reflector illumination.

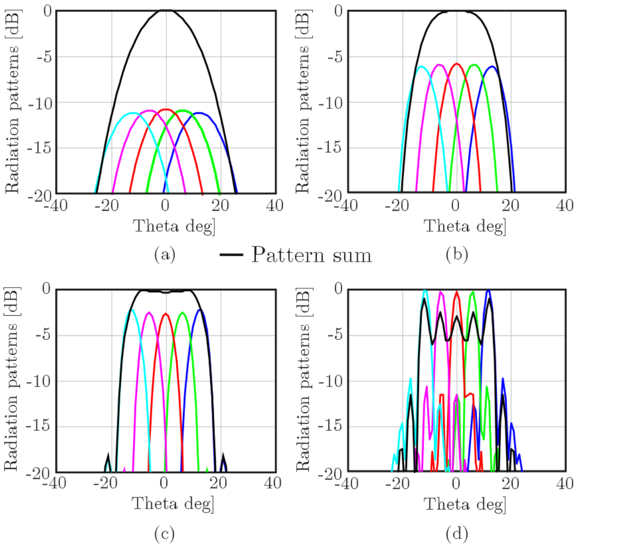

Figure 2. *H*-plane radiation patterns from the lens fed by single elements on- and off-axis and pattern sum when all elements are combined in phase: (a) 0.25 THz, (b) 0.5 THz, (c) 1 THz, (d) 2 THz,.

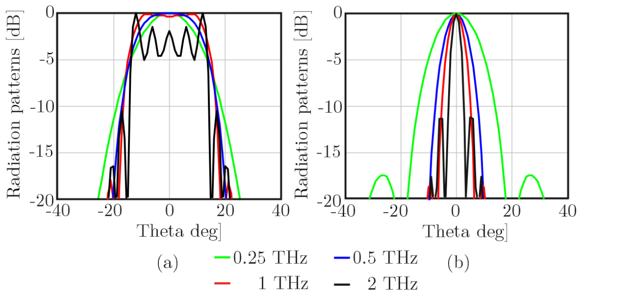

Figure 3. *H*-plane radiation patterns of (a) lens fed by connected array and (b) by single leaky-wave slot.

# elem.	0.25 THz	0.5 THz	1 THz	1.5 THz	2 THz
1	88.6	46.7	34.1	33.9	30.3
3	89.9	66.3	53.9	54.3	46.8
5	**91.0**	**86.6**	**82.8**	77.7	75.4
7	**90.6**	**90.2**	**89.2**	87.0	84.8
9	**90.8**	**92.2**	**92.6**	89.8	87.6
11	90.8	94.4	96.2	93.8	88.8

Table 1. Amplitude taper efficiency (%) versus frequency and number of array elements.

# elem.	0.25 THz	0.5 THz	1 THz	1.5 THz	2 THz
1	99.9	98.9	96.6	99.4	99.9
3	100.0	100.0	99.1	97.3	97.3
5	**100.0**	**99.9**	**97.2**	92.3	92.6
7	**100.0**	**99.7**	**93.6**	83.6	74.1
9	**99.7**	**99.2**	**87.1**	66.5	41.7
11	99.3	97.5	75.8	42.6	11.9

Table 2. Phase taper efficiency (%) versus frequency and number of array elements.

A more quantitative analysis of the performance can be obtained by calculating the amplitude taper loss and the phase error loss, by integration of the pattern in Figs. 2 and 3 over the angle subtended by the reflector. The efficiency is summarized in Table 1 and Table 2, for different frequencies and number of array elements. It can be observed that the amplitude taper efficiency of single slot drops to about 30 % at high frequency, since the reflector is highly under illuminated. Highlighted in the tables are the values pertaining to number of elements between 5 and 9 and bandwidth of 4:1 (0.25 to 1 THz). Within these ranges of parameters, the total efficiency is higher than 80%.

References

[1] DESHIMA. [Online]. Available: http://www.cosmonanoscience.tudelft.nl/?page_id=143

[2] A. Baryshev, J. J. A. Baselmans, A. Freni, G. Gerini, H. Hoevers, A. Iacono, and A. Neto, "Progress in antenna coupled kinetic inductance detectors," *IEEE Terahertz Science Tech.*, vol. 1, no. 1, pp. 112-123, Sep. 2011.

[3] M. V. Ivashina, M. Ng Mou Kehn, P.-S. Kildal, and R. Maaskant, "Decoupling efficiency of a wideband vivaldi focal plane array feeding a reflector antenna," *IEEE Trans. Antennas Propag.*, vol. 57, no. 2, pp. 373-382, Feb. 2009.

[4] R. Olsson, P.-S. Kildal, and S. Weinreb, "The Eleven antenna: A compact low-profile decade bandwidth dual polarized feed for reflector antennas," *IEEE Trans. Antennas Propag.*, vol. 54, no. 2, pp. 368-375, Feb. 2006.

[5] D. F. Filipovic, S. S. Gearhart, and G. M. Rebeiz, "Double-slot antennas on extended hemispherical and elliptical silicon dielectric lenses," *IEEE Trans. Microw. Theory Tech.*, vol. 41, no. 10, pp. 1738-1749, Oct. 1993.

[6] A. Neto, "Planarly fed leaky lens antenna. Part 1: Theory and design," *IEEE Trans. Antennas Propag.*, vol. 58, no. 7, pp. 22382247, Jul. 2010.

[7] A. Neto, S. Monni, and F. Nennie, "Planarly fed leaky lens antenna. Part 2: Demonstrator and measurements," *IEEE Trans. Antennas Propag.*, vol. 58, no. 7, pp. 22482258, Jul. 2010.

[8] A. Neto, J. J. A. Baselmans, "Terahertz prototype of a decade bandwidth leaky-lens antenna: experimental results," *EUCAP 2013*, submitted.

[9] A. Neto and J. J. Lee, "Ultrawide-band properties of long slot arrays," *IEEE Trans. Antennas Propag.*, vol. 54, no. 2, pp. 534-543, Feb. 2006.

[10] Endo, P. van der Werf, R. M. J. Janssen, P. J. de Visser, T. M. Klapwijk, J.J.A. Baselmans, L. Ferrari, A.M. Baryshev, S.J.C. Yates, "Design of an Integrated Filterbank for DESHIMA: On-Chip Submillimeter Imaging Spectrograph Based on Superconducting Resonators", *J. Low Temp. Phys*, vol. 167, issue 3-4, pp. 341-346, 2012.

[11] D. Cavallo and A. Neto, "A connected array of slots supporting broad-band leaky waves," *IEEE Trans. Antennas Prog.*, submitted, 2012.