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Leaky Lens Antenna for Multi-beam Imaging Systems

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***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 (21-26 GHz). It has then been manufactured and measured. The performances are promising and provide a hard proof of concept of the feasibility and the advantages of the proposed array architecture.**

I. Introduction

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.

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 were 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. 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 %).

II. Array Geometry

The designed structure is shown in Fig. 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 ϵ_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

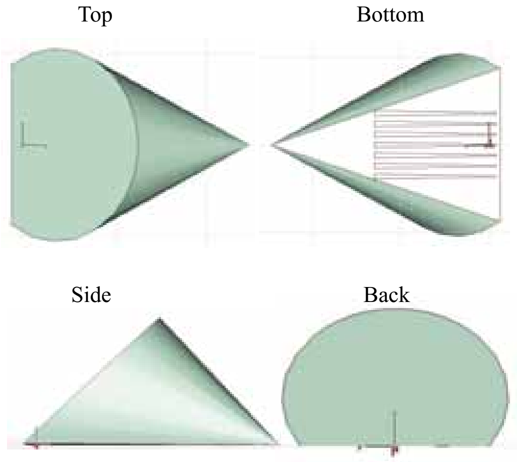
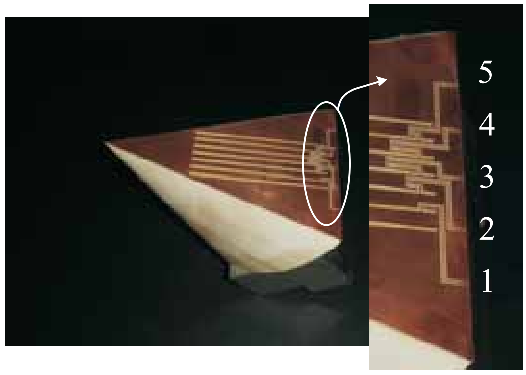


Fig. 1. Four view of the integrated slot array designed to implement the quasi optical portion of the imaging system.



(a)

(b)

Fig. 2. Final prototype with details of the feeding network (a), view of the feeding network with the air bridges (b).

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.

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.

Fig. 3 (a) shows the reflection coefficients S_{ii} of the five ports indicated in the inset of Fig. 2(a). The reflection coefficients S_{ii} of the five ports are below the -8 dB from 21 GHz to 26 GHz (20% bandwidth). The only exception is represented by the feed 4 that presents in the S parameter a bit higher peaks. 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 (b)). The S_{ij} parameters accounting for the mutual coupling at feed level are lower than 19 dB over the entire investigated bandwidth (Fig. 3 (b)).

The directivity patterns of the central slot of the array at the central frequency of 23 GHz are shown in Fig. 4. They highlight both E and H plane patterns and present the comparisons between calculations and measurements. Further measurements of the patterns will be shown at the conference.

III. 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 21 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.

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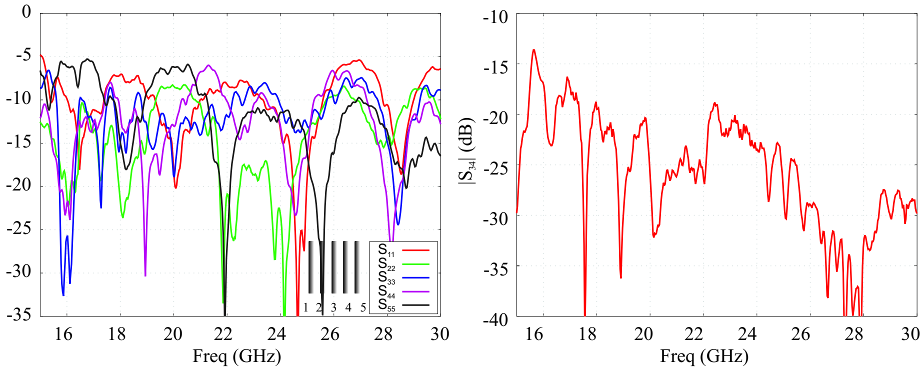
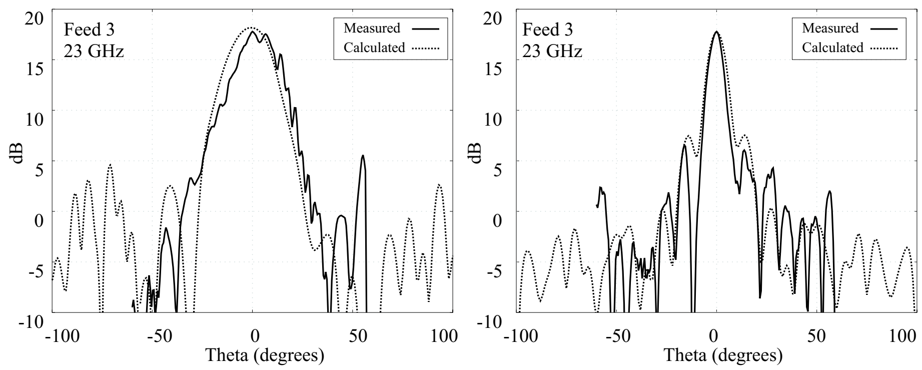


(a) (b)

Fig. 3. Measured S parameters.



(a) (b)

Fig. 4. Measured and calculated radiation patterns for the central slot at 23 GHz.

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