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On the Design of Wide Band Multi-lens Focal Plane Arrays for the TIFUUN Instrument

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***Abstract*— Terahertz Integral Field Unit with Universal Nanotechnology (TIFUUN) is a wideband spectral mapper operating at (sub)-millimeter wavelengths. The instrument is under development for ground-based astronomy and will be deployed to the ASTE telescope in Chile. In this work, the building blocks for TIFUUN's wideband (2:1) mappers are discussed. These components are based on multi-lens focal plane arrays of leaky lens antennas coupled to filter banks based on Microwave Kinetic Inductance Detectors.**

I. INTRODUCTION

A major challenge in millimeter and sub-millimeter astronomy is to map statistically large cosmic volumes with sufficient spectral information to trace the distribution of matter over extremely large timescales. Terahertz Integral Field Unit with Universal Nanotechnology (TIFUUN) is under development to address this challenge. TIFUUN is a wideband imaging spectrometer covering a variety of astronomical surveys. The detectors in TIFUUN are based on leaky lens antennas coupled to Microwave Kinetic Inductance Detector (MKID) based filter banks [1]. These filter banks separate the received wide band signal into different spectral channels, Fig. 1(a).

All of TIFUUN science cases will share a quasi-optical system which guides the sky signal from ASTE telescope through its cabin into the instrument's cryostat. On the other hand, for each science survey, a dedicated multi-lens focal plane array (FPA) is under development. Each of these FPAs is tailored to a specific wideband and/or multi beam requirement. In this work two types of multi-lens focal plane arrays are investigated: i) a plastic based plano-convex hyperbolic lens coupled geometrically to a silicon hyper-hemispherical lens with a FPA of tapered leaky slots, Fig. 1(b); ii) a plastic based plano-convex hyperbolic lens diffractively coupled to a FPA of silicon elliptical leaky lens antennas, Fig. 1(c). In this abstract, the former is referred to as *geometrically coupled design* while the latter is referred to as *diffractively coupled design.* The considered sampling rate for diffractive design is $2\lambda_0 f_{\#}^{hp}$ where λ_0 is the free space wavelength at the central frequency, and $f_{\#}^{hb}$ is the focal length to diameter ratio of the convex side of the hyperbolic lens. In the following sections, the design methodology for each case is described and their capabilities in terms of wide band and wide scanning performance is compared.

II. DESIGN METHODOLOGY

The performance of the considered multi-lens FPAs is estimated in reception mode by resorting to a generalized antenna in reception analysis as described in [2]. In this analysis methodology, an incident plane wave, which represents the shared quasi-optical system above, illuminates the planar side of the hyperbolic lens. The aperture efficiency of the multi-lens quasi-optical system can be evaluated by performing a field matching integral between this incident field propagating downward and the field radiated upwards by the antenna feeder in transmission mode. Both of these fields can be evaluated at an arbitrary equivalent surface between the planar side of the hyperbolic lens and the antenna feeder's ground plane.

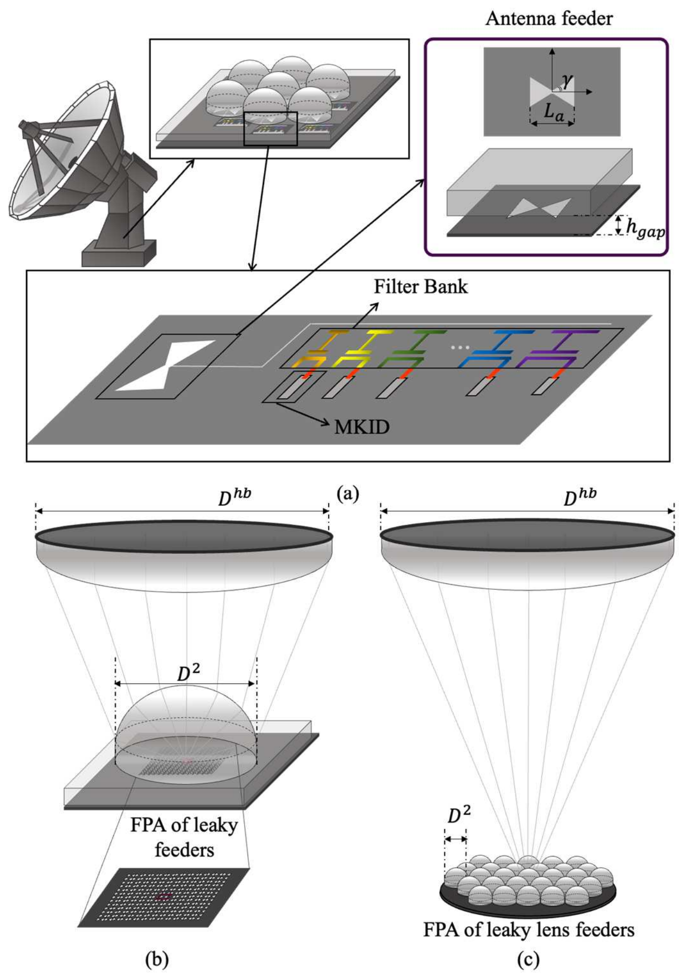

Fig. 1. (a) Schematic representation of TIFUUN instrument consisting of a focal plane array of leaky wave antenna feeders coupled to MKID based filter banks. (b) Geometrically coupled multi-lens FPA. (c) Diffractively coupled multi-lens FPA.

In the case of geometrically coupled FPA, an in-house multi-transmitting surface Geometrical Optics (GO) code based on [3] is developed to propagate the incident plane wave from planar side of the hyperbolic lens to the surface of the hyperbolic lens. The field radiated by the antenna feeder FPA is also evaluated at the same surface. This GO based method is numerically efficient and was previously validated against a time-consuming multi-surface physical optics code with excellent agreement [4].

GO approximation is inaccurate close to the caustic points of the field, i.e. at the focal plane of the hyperbolic lens. As a result, another numerically efficient approach is employed for the case of the diffractively coupled FPA. Coherent Fourier Optics [5] method represents the field at the surroundings of the lens based FPA as a summation of plane waves. The contributions of these plane waves are then summed at each lens surface where the field radiated by their antenna feeder is also evaluated.

The aperture efficiency for broadside and scanning cases are evaluated using the described methodology. The scan loss is defined as the degradation of the aperture efficiency for a scanning case with respect to the broadside one. By using the described analysis in reception method as the kernel for an optimization process, the aperture efficiency and scan loss of the two multi-lens FPAs is optimized.

III. Results

In Fig. 2, the aperture efficiency is shown for broadside and scanning cases of two optimized multi-lens geometries. The optimized parameters for each geometry are given in Table I. In the cases shown here, wide band matching layers are considered on both sides of the plastic hyperbolic lens as well as the silicon lenses. As it can be seen, the geometrically coupled FPA achieves a much wider response over 2:1 bandwidth at broadside direction while achieving a scan loss of about 3dB while scanning up to ± 8 beams (3dB overlapping beams at the center of the frequency band). On the other hand, due to the diffractive coupling between the lens based FPA and the hyperbolic lens, the response of their broadside element is more frequency dependent while achieving a better scanning performance, i.e. about 2.5 dB scan loss for scanning up to ± 12 beams.

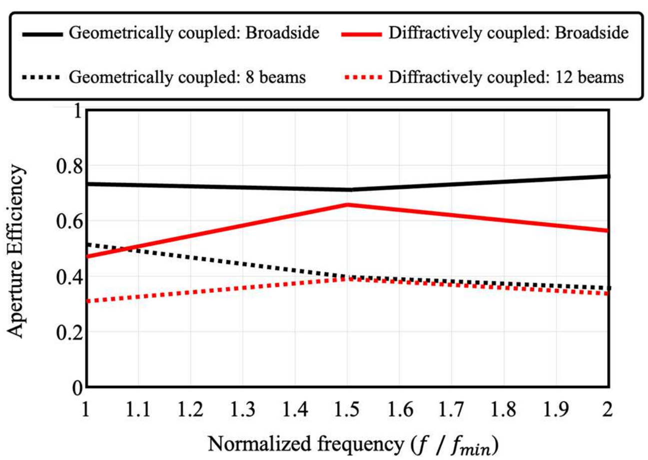

Fig. 2. Aperture efficiency of the optimized geometries for broadside and scanning cases.

Table I. The optimized parameters for the two considered multi-lens FPAs.

	L_a	γ	h_{gap}	D^{hb}	$f_{\#}^{hb}$	D^2
Geo. coupled	$0.5\lambda_0$	40^o	$0.01\lambda_0$	$82\lambda_0$	2.2	$48\lambda_0$
Diff. coupled	$0.4\lambda_0$	35^o	$0.016\lambda_0$	$82\lambda_0$	1.75	$3.5\lambda_0$

In conclusion, each of the two multi-lens FPAs can be employed for a different type of science survey for TIFUUN. The geometrically coupled lens elements achieve a wider frequency response which is more suitable for wide spectral surveys. On the other hand, the diffractively coupled geometry achieves a better scanning performance suited for simultaneous mapping of large cosmic volumes.

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