High Efficiency Submillimeter-wave Imaging Array

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***Abstract*—The period of a focal array is limited by the angular sampling and the *f* number of the system. This fact will limit the efficiency of imaging array systems to around 50%. Recently it been demonstrated that the use of a dielectric layer on top of an array of apertures can improve this efficiency limit. In this paper, we describe a similar structure that improves the efficiency in imaging applications and that it is easy to manufacture due to its compatibility with planar lithographic techniques.**

I. INTRODUCTION

Recently attention has focused on defense and security THz applications since THz signals (at least at the longer wavelengths) can penetrate many garments and provide low resolution images of the body that do not utilize harmful ionizing radiation. A very promising system has recently been realized consisting of a 570-600 GHz chirped FMCW radar imager with a range resolution of $c/2\Delta f<0.5$cm [1]. Now, a full 3D imaging system is operating by using a 40cm reflector and scanning stage. It can image with <1cm radial resolution at 4m and a dynamic range of >70dB at <20 msec/pixel.

Despite significant functional advantages, the difficulties associated with establishing and operating heterodyne instruments in the THz regime are substantial. There is no demonstrated technique for forming large multipixel heterodyne imagers at any wavelength above 100 GHz. This is due to the complexity of having to deal with three widely different signals within the same detector – LO, RF and IF. The few small (≤10 element) heterodyne arrays that have been realized in the submillimeter rely on close packing individual single pixel waveguide receivers with non optimal fill-factors [2]. Several clever millimeter wave array systems have been constructed but all are fairly bulky and expensive [3]. Focal plane direct detection arrays are much easier to realize in this frequency range since there is no LO and only a simple DC output, and there are many viable designs from the late 1980's and 90's for submillimeter-wave array concepts developed for the radio astronomy community [4].

Diffraction limited sampling requires an antenna spacing that cannot be realized with simple horn apertures. More complex antenna elements and geometries are required. As a first step we have been looking at a new geometry for the receiver front end that provides high sampling efficiency with readily fabricated waveguide RF coupling elements in a convenient axial arrangement that allows potential stacking of wafer level components.

In [5] it has been demonstrated that the use of a dielectric layer on top of an array of apertures can improve this efficiency limit. Figure 1 shows the array geometry. The study in [6] stated the limits in terms of mutual coupling and presented embedded patterns with circular symmetry and large beam efficiencies. Such an array should in principle be easy to manufacture at high frequencies due to its compatibility with planar lithographic techniques. In this paper, we describe a similar structure that improves the efficiency in imaging applications. In this case the driven parameter of the design will be the resolution of the system, which is defined as the distance at which the antenna response power is half the peak-power. The main reflector will be an ellipsoid focusing at a certain distance in the near field. A study of the scanning performances of the secondary patterns, including a compensated Gregorian system, is performed using the GRASP software package.

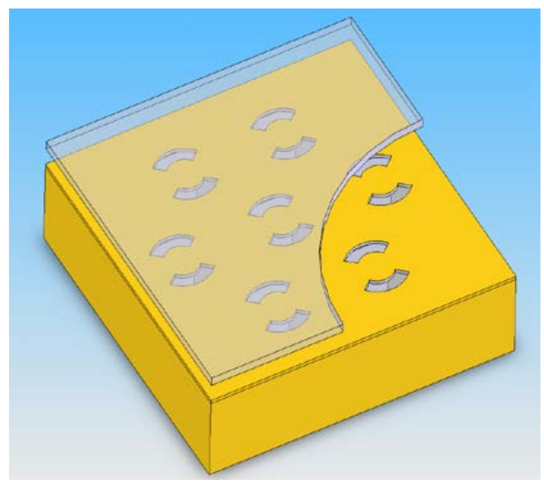

Figure 1: Array composed by waveguides loaded by an iris arranged in a hexagonal grid with a quartz dielectric layer on top

II. ARRAY PROPERTIES

The array design, see Figure 1 and the inset in Fig.2a, uses a single dielectric superlayer of quartz with thickness hd=65μm placed at 126.7μm from a ground plane. The selection of this material is based on the fact that it presents low losses at these frequencies, however it is also birefringent. We chose a Z-cut, which means that the dielectric constant does not change for a field polarized in the transverse plane. Actually, the leaky wave responsible of the enhancement effect will propagate at an angle with respect to Z, so the effective dielectric constant of the quartz will fall between those of the ordinary and extraordinary rays. Following the measurements done in [7], the dielectric constant considered in the simulations has been set to $\varepsilon r=4.452$. The array design has been optimized following the guidelines given in [5]. The period of the array is set to $1.18\lambda_0$ in order to keep the mutual coupling below –20dB. Fig.2 shows the s-parameters and the radiation pattern of the

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central element simulated with CST Microwave Studio.

III. Secondary Patterns

The secondary patters from the focusing optics have been obtained using the Physical Optics software GRASP with the simulated array patterns as input data. An offset system is needed in a real configuration to avoid blockage. The design of a compensated Gregorian system, which reduces cross-polarization, has been performed following the guidelines provided in [8], derived for a parabolic reflector, by matching geometrically the main ray of the parabola (θ0) with the central ray of the ellipse R1, see Fig.3. The second focus of the main ellipse will be placed at wanted focusing distance, Rf, and the ellipse will be rotated by a certain angle α. The validity of this cross polarization compensation will depend on the eccentricity of the main ellipse.

The patterns related to the Gregorian design are shown at the central frequency in Fig. 4(a). The spill-over is 1.99dB and the cross polarization is 45dB below the co-polarized main lobe. Figure 4(b) shows the beam patterns for offset feed elements in the horizontal direction.

The scan loss is shown in Fig. 5(a) as a function of the array elements in the horizontal and the 60deg plane. Each array element corresponds to one scanned beamwidth. Figure 5(b) shows the ratio between the pointing angle of the offset beams and the half power beamwidth. For a full sampling this ratio should be equal to the number of scanned beamwidths for each beam.

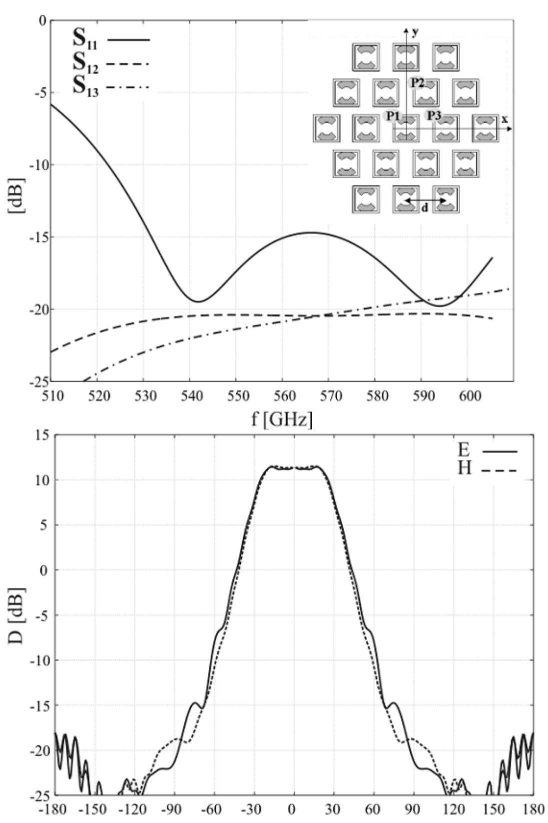

Figure 2: S-parameters and radiation patterns at f=546.8GHz

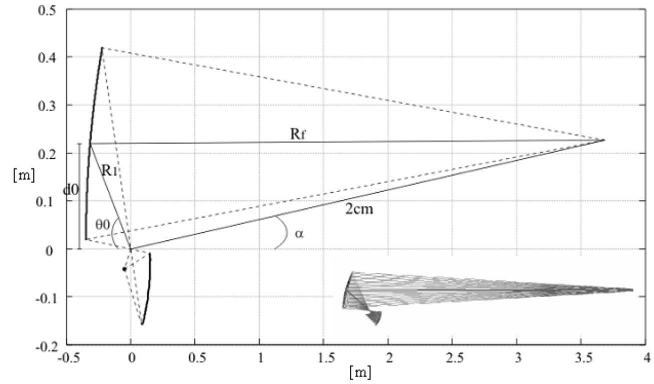

Figure 3: Gregorian system with an ellipsoidal reflector as main aperture

IV. Summary

In the present contribution, an ellipsoidal reflector antenna fed by a leaky wave array has been studied for imaging applications at submillimeter waves. The array geometry is easy to manufacture at these frequencies. The offset ellipsoidal reflector system has been optimized to reduce cross polarization and improve scanning performances. The efficiency of the optical system is better, by 1dB, than a conventional horn array. The design shown in this contribution uses an optical system with an *f* number of 1.1 and presents good scanning performances for 9-10 scanned beamwidths (i.e. an array of 271 elements). However if the application needs a larger number of scanned beams, an optical system with a larger *f* number will be more appropriate. In such case the array design will need a larger dielectric constant layer (or equivalently several low dielectric layers placed at λ/4). This will increase the effective area of the array elements at the cost of reducing the frequency bandwidth.

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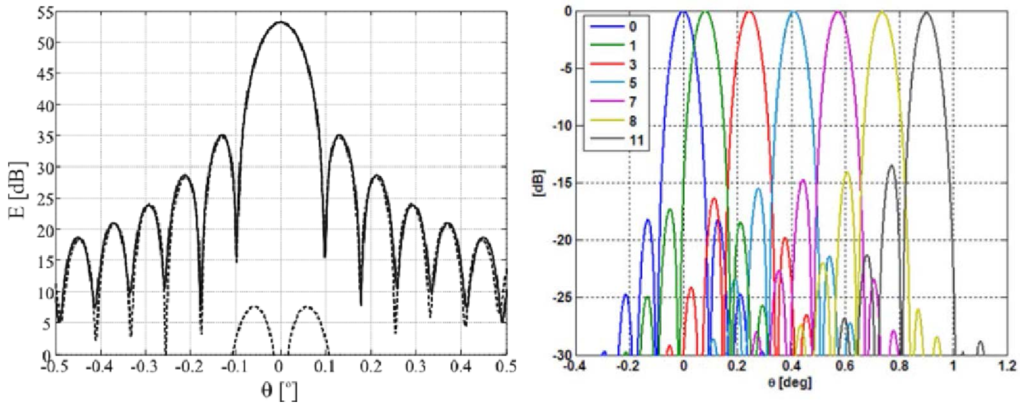

Figure 4: Secondary patterns at 4m for a Gregorian reflector system. (a) Co- and cross-pol patterns for the central element. (b) Co-pol offset patterns. Each color represents a different array element or scanned beamwidth.

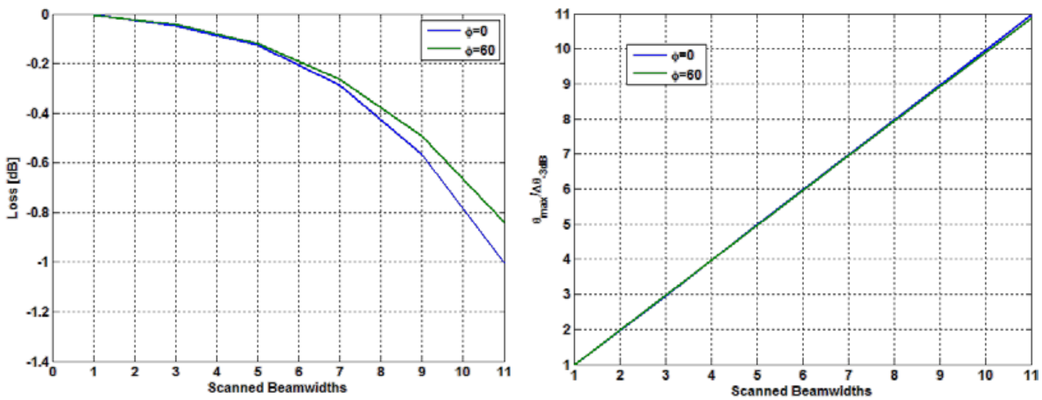

Figure 5: (a) Scan loss and (b) Ratio between the pointing angle and the halfpower beamwidth. The horizontal axis represents the scanned beamwidths of different array elements.

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