Dual Band THz-IR Detector for Radio-Astronomy Applications

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***Abstract*— Dual band THz-IR receivers can be used in application within different fields. For instance, in radio-astronomy, dust emission in the infrared (IR) and submillimeter wave or THz ranges is used for star-formation characterization. This information is normally acquired by different detectors which operate at each of these frequencies; i.e. Terahertz and Infrared. The development of an integrated dual band detector operating at both frequency ranges will be described in this paper. The proposed configuration implements a spiral antenna working at sub-millimeter wave frequencies, which is used as Fresnel lens to focus the IR power (12 µm) into an IR detector. Other applications such security can also benefit from this kind of systems.**

***Index Terms*—dual band detector, Fresnel zones, spiral antenna.**

I. INTRODUCTION

Millimeter wave, sub-millimeter and THz frequency range technologies are experiencing a large development in the last years due to the new applications that are recently emerging. One of the most relevant ones is defense and security. In this field development of novel instruments for systems located at bonder checks or airports, luggage control and guns, explosives and hazardous objects detection and identification, are critical for society security nowadays. Therefore, new and innovative technological developments are essential to implement operational systems.

So far, stand-off detection scanners have been developed for these applications. These scanners take advantage of the peculiarities of electromagnetic waves propagation in this frequency range, e.g. clothes transparency, or vision in low optical visibility conditions. However, the relatively large operational wavelength limits the resolution of these images. Fortunately, if shorter wavelengths are used higher resolution images can be obtained. Therefore, security applications would benefit from the use of a camera system operating at different frequency ranges: THz frequencies would for allow imaging through certain objects and IR frequencies would provide higher resolution. Moreover, by fusioning images taken in different frequency ranges additional information could be extracted, which would help increasing the thread detection rate. An example of this technique is shown in Fig 1, where the sub-millimetre wave information allows imaging the part of a car placed behind a wooden panel.

On the other hand, the radio-astronomy field would also benefit from such a device. For example, the star formation process is characterized by the presence of a huge amount of warm and cold dust, whose emission ranges mainly from infrared to millimeter wavelengths. In order to study the physical conditions in the different stages of the star formation process a detector which could work simultaneously at far-IR and sub-millimeter wavelengths would be very useful. Moreover, such a device could also be used for general space exploration [1-2]

The objective of this work is to study an integrated dual band detector operating at sub-mm and IR frequencies based on the use of a non-ideal Fresnel Zone Plate Lens (FZPL) [3-4]. Similar configurations have been proposed and studied in the IR and visible ranges [4]. However, their use for sub-mm detection is more challenging, due to the larger frequency difference between both bands. Moreover, submillimeter wave detectors are usually built with discrete components, e.g. diodes, which are large in terms of the wavelength. This imposes some constraints in the design, which affect the performance. In this paper, the additional problems of the sub-mm wave antenna design are sorted out by means of the use of the theory of FZPL. The proposed configuration is suitable to operate at both frequency bands; i.e., sub-mm wave and IR with good performances.

Fig. 1: Fusion of an IR and a sub-mm wave image of a car behind a wooden panel.

II. CONFIGURATION DESCRIPTION

The proposed dual band configuration consists of a metallic planar spiral antenna and an IR detector, as it is shown in Fig. 2. In this case, both of them are mounted in a Silicon (Si) substrate, but other substrates can be used. The spiral antenna placed on the top of the Si substrate is designed to operate at sub-millimeter wave frequencies, i.e. will receive the incoming signal around 425GHz [5]. The antenna results from a conversion of an ideal FZPL to a quasi-spiral antenna [6]. The radii of the Fresnel zones used for FZPL design are calculated using the following equation. They depend on the wavelength, the material used as substrate and the focal distance.

$$r_m = \left(m d_0 \frac{\lambda_0}{n}\right)^{1/2}$$

where r_m is the radius of the m-Fresnel Zone, m, the Fresnel Zone index, d_0 is the focal distance, λ_0 is the wavelength at working frequency and n is the refractive index of the substrate, in this case silicon. The circular rings of the Fresnel lens must be transformed into a quasi-spiral in order to act as sub-mm wave antenna. This must be done by connecting adjacent rings, the final results is depicted in Fig. 3.

The Fresnel lens will focus the incoming IR radiation into the IR detector, which is placed at the bottom of the Si substrate (800x800x1000 µm), as depicted in Fig. 2. For this design, the FZPL has been designed to operate in the IR regime at 12 µm (25 THz).

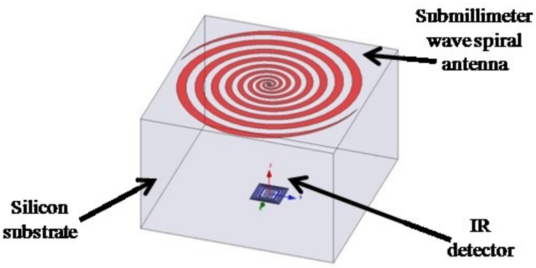

Fig. 2 Schematic of the proposed THz-IR receiver

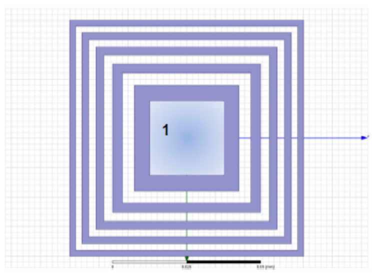

Figure 3: Square Fresnel Zones for the antenna

III. PERFORMANCE

Once the design is done, it is necessary to determine, the real focal distance of the FZPL taking into account the use of square spirals; and the focal gain obtained as a function of the number of Fresnel zones used in the design of the sub-mm wave square spiral antenna. After analyzing the magnitude of the electric field along the silicon substrate with HFSS, it is found that the field focuses at 1000 µm for the case of circular Fresnel zones (see Fig. 4.a). On the other hand, square Fresnel zones (Fig. 4.b) focus the electric field at a shorter distance (800 µm). This result shows an important shifting of the focal distance due to the transformation from circular to square of the Fresnel zones.

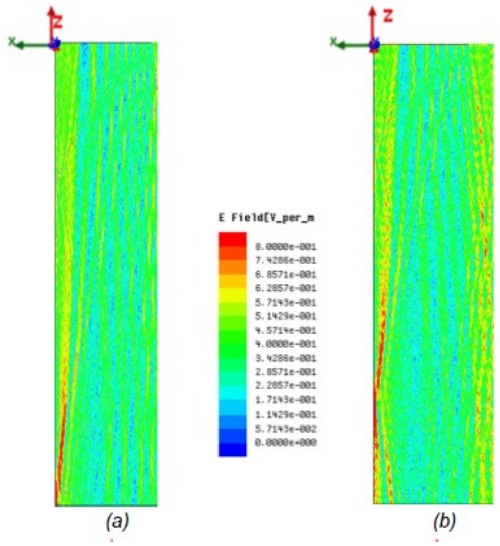

Fig. 4 Comparison of the magnitude of the electric field between (a) 16 circular Fresnel zones and (b) 16 square Fresnel zones.

On the other hand, if the number of Fresnel zones considered increases, the magnitude of the electric field at the focus point is expected to increase as well. For the sake of representation, the ratios between the magnitude of the electric field at the focal point for the cases with and without a FPZL are calculated. This Gain Factor (GF) ratio is defined as:

$$GF = \frac{\textit{Electric Field with FPZL}}{\textit{Electric Field without FPZL}}$$

This Gain Factor at the bottom of the Si substrate (along the x axis for z=800 µm) in shown in Fig. 5. Square and Spiral Fresnel zones are compared in this plot. Higher gain factors are achieved with square spirals. However, integration of the sub-mm wave diode detector is simpler in the square quasi-spiral case. This can be observed in Fig. 6 where the square spiral antenna formed by 8 FZ is depicted. In the center of the antenna is plotted the Schottky diode needed to detect the sub-mm wave radiation. Therefore, the square configuration will be used for the THz antenna.

Using this configuration, the return loss of this square spiral in the THz range has been studied. The impact of the size, i.e. the number of Fresnel zones is shown in Fig. 7.

IV. CONCLUSIONS

The design of a submillimeter wave antenna, operating at 427 GHz, which also acts as Fresnel Zone Plate Lens at IR frequencies (12 µm), has been presented. The sub-mm wave antenna resulted from a transformation of a Fresnel Zone Plate Lens. This device has been designed intended to be used as a front-end for imaging applications which requires THz-IR information; i.e. radio-astronomy or security.

The influence of the number of FZ used to implement the submillimeter wave antenna on the IR power focalization has been studied for the case of linear polarization. As the number of FZ forming the sub-mm wave antenna increases, the gain factor also enlarges. A Gain Factor improvement of 4.5 times has been obtained with the implementation of 16 FZs. Furthermore, the shifting of the focal point due to the square shape of Fresnel Zones used to implement the Fresnel Zone Plate Antenna has also been investigated.

The antenna exhibits reasonable performances operating at sub-mm wave frequencies with a S11 parameter below -5dB (from 424 to 428 GHz) and a directivity of 3.6 dBi (f=427 GHz).

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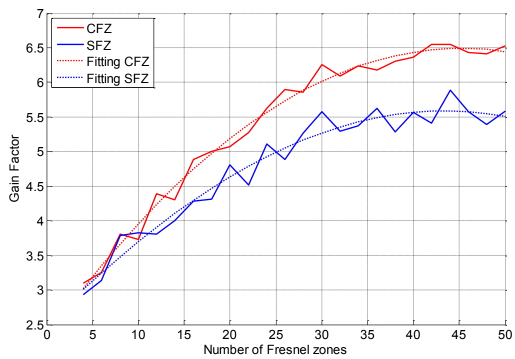

Fig. 5: Gain Factor for each antenna at 800 µm. CFZ is calculated for Circular Fresnel Zones and SFZ for square Fresnel Zones.

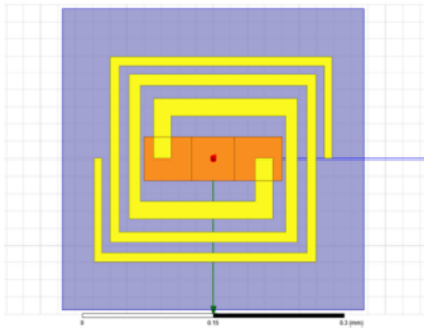

Fig. 6 Sub-millimeter Wave Antenna (yellow) and detector diode (orange). Note that the spiral antenna depicted is formed by 8 FZ.

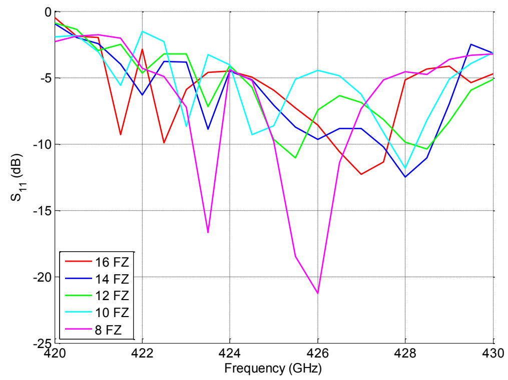

Fig. 7: S11 of the sub-mm wave antenna for different number of Fresnel Zones.

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