Inexpensive Focal Plane Array Detection and Imaging of mm Wave and THz Radiation Using Neon Indicator Lamps

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Abstract

One of the chief bottlenecks towards widespread use of such radiation is detector cost, which can make focal plane arrays prohibitively expensive. We have obtained excellent results using miniature Ne indicator lamps costing about 50 cents each. Other advantages include room temperature operation, electronic ruggedness, and linearity of response which permits heterodyne detection. Images using such detectors in 8X8 arrays are presented with 32X32 pixel resolution. A new 32X32 array board is to be used to obtain higher resolution.

Detection mechanism is primarily enhanced ionization collision rate generated by the incident field which adds to the strong dc bias field.

1. Introduction

Imaging systems in the electromagnetic spectrum between 100 GHz and 10 THz are required for applications in medicine, communications, homeland security, and space technology. This is because there is no known ionization hazard for biological tissue, and atmospheric attenuation of terahertz (THz) radiation is low compared to that of infrared and optical rays. The lack of inexpensive room temperature detectors and FPAs in this spectral region makes it difficult to develop detection and imaging systems, especially real-time ones.

The GDD is a room temperature detector that is used in this study for direct THz radiation detection and imaging. There are several other room temperature THz detectors that are used for direct detection. The most popular detectors are Golay cells, pyroelectric, bolometers and microbolometers, many of which are too slow for video frame rates. All are described in detail in [1]. Furthermore, there are THz cooled detectors which are very expensive [1]. The advantages of GDD are its low cost, its high responsivity, room temperature operation, and its relatively fast response.

A candidate for FPA pixels is miniature neon indicator lamps such as N523 of international light technology (Peabody, MA) which was tested experimentally and found to be a very good THz detector [2]. NEP is on the order of 10^{-9} W/Hz$^{1/2}$, and rise time is on the order of a microsecond. The mechanism of detection in such a Glow Discharge Detector (GDD) involves both enhanced ionization [3-8] and enhanced diffusion current [3, 4, 7, 9-11] caused by the incident terahertz wave. The former increases lamp current, while the latter decreases it.

Recent reports by others indicate GDD sensitivity at 200 GHz [12] is almost as good as that at 100 GHz [2]. Furthermore, imaging experiments in which a GDD is used in a scanning system indicate essentially no difference in image quality from that obtained using a schottky diode detector instead [12]. However, success in developing less expensive real time millimeter wave and terahertz imaging systems depends largely on the ability to develop inexpensive focal plane arrays. This paper focuses on the first focal plane array (FPA) using GDD detectors. Although the concept had been suggested previously [13], this is the first report of imaging results.

There are two configurations to realize an FPA with such lamps. The first is where the THz radiation is incident to the side of the lamp, and the second is where the radiation is incident head-on. Those two configurations are given in Fig 1. In [2], NEP was measured for the side configuration in Fig. 1 (a).

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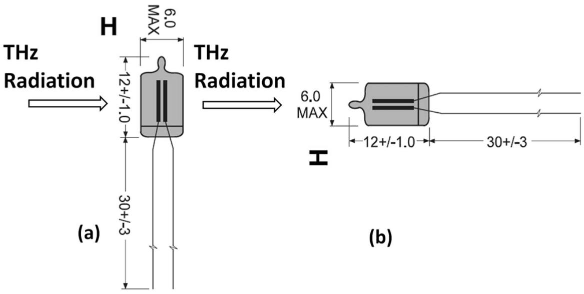

Figure 1: Two configurations of GDD operation (a) side radiation (b) head-on radiation. Dimensions of GDD lamp N523 are in mm.

For relatively long range (far field) imaging the effective pixel size is determined by:

$$d = \frac{\lambda}{D} \cdot f \qquad (1)$$

Where *d* is the diffraction limited pixel diameter (which may be larger than the actual GDD diameter), λ is the THz radiation wavelength, *f* is the focal length of the quasi-optical

system and D is the quasi-optic aperture. Using the head on configuration (see Fig. 1b) determines the diameter of the pixel in the array. Field of view (FOV) of the FPA is given by:

$$FOV = \frac{N\lambda}{D} \qquad (2)$$

where *N* is the number of pixels in the FPA. The resolution of the FPA can be improved by minimizing *FOV* and pixel diameter.

2. Experimental set-up and imaging results

A 100 GHz source was used to illuminate the object in this experimental set-up. The 100 GHz source is based on GaAs multipliers of Virginia Diodes, Inc. (Charlottesville, VA, USA) that multiply a low frequency source of 12.5 GHz 8 times to 100 GHz [14-16]. A 8X8 focal plane array was constructed based on GDD pixel [13].

In order to realize a THz imaging system proper quasi-optic components have to be developed. The quasi-optic design has to decrease the diffraction effects which are very dominant in the THz regime. This requires large aperture optical components. The design of the quasi optical set-up was based on a 500 mm diameter spherical mirror with 1000 mm focal length as imaging mirror. The illumination of the object with collimated THz beam was performed by collimating Off-axis Parabolic Mirror (OPM). The experimental set-up of the imaging system is shown in Fig. 2.

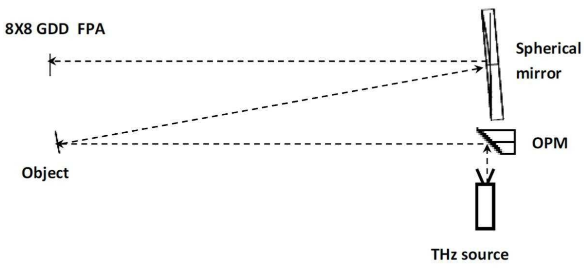

Figure 2: Experimental set-up of the imaging system.

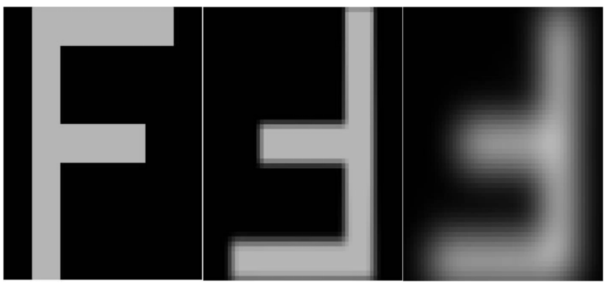

Figure 3: Simulations of obtained “F” shape image in the quasi optic system given in Fig. 2. Left: “F” shape object; middle: Geometrical aberrations; right Diffraction effects.

The design of the quasi optic system was based on geometrical optics principles which states:

$$\frac{1}{f}=\frac{1}{s_1}+\frac{1}{s_2} \tag{3}$$

Where f is the focal length of the imaging objective, s_1 is the distance from the object to the imaging objective, and s_2 is the distance from imaging objective to the FPA. In order to enable imaging on the FPA we had to tilt the off-axis imaging mirror 5 degrees as can be seen in Fig 2. We used ZEMAX optical development software to optimize the system for minimum geometrical aberrations. In order to investigate the diffraction affects in the quasi optical system of Fig 2, a simulation of an “F” shape object was employed using ZEMAX software. The geometrical aberrations and diffraction effects in the obtained “F” shape image are given in Fig. 3.

A metal “F” shape object was placed in the object plane 2m in front of the imaging mirror of the quasi optical system shown in Fig 2. This object was illuminated with a 150 mW collimated 100 GHz beam using the OPM. The 8X8 GDD FPA was placed 1.6m from the imaging mirror to produce 1:0.7 imaging magnification (the size of the FPA is about 70 X 70 mm while the “F” object is 10 X 10 cm and the "F" height is about 7 cm). Fig 4 shows the F shape object and the image obtained in this case.

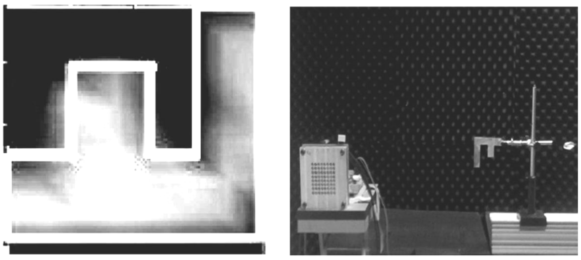

Figure 4: THz image of a metal “F” shape object as was captured by the 8 X 8 GDD FPA (left); and the metal “F” shape object (right).

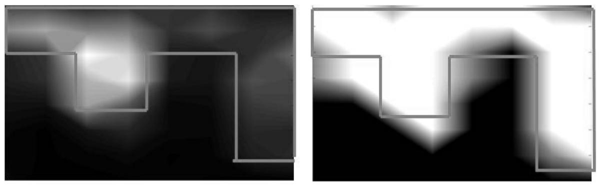

Figure 5: THz images of “F” shape object: before using the correction algorithm (Left); and after using the correction algorithm (right).

The “F” shape of the object is clearly seen in the image of Fig. 4 (with an outline of an ideal “F” shape superimposed over it). The intensity of the “F” image is not uniform due to the nonuniform illumination by the Gaussian beam illuminating the "F", as well as nonuniform GDD pixel response and electrical circuits. This is not unexpected since such devices are manufactured as inexpensive indicator lamps rather than as THz radiation detectors. For lower THz beam intensities the obtained image degradation increases. Since the number of gray levels in THz images is limited, thresholding can be used to limit nonuniformity. Limiting nonuniformity was done using the following DSP algorithm: the readouts of the GDD pixels were divided into 3 levels; each level represents a different region of pixel readout, the 3 levels image is presented using MATLAB surface plot. Fig. 5 demonstrates this correction algorithm when a lower intensity THz beam illuminates the “F” shape object. For lower intensity illumination, the incident nonuniform Gaussian beam illumination is more apparent. From Fig. 5 we can see that after employing the above DSP algorithm the “F” shape image can be observed easily. The blurring of the edges can be explained by diffraction effects and the low resolution of the current GDD array setup. The corrected image of Fig 5 right is in good agreement with the simulation of Fig. 2. It is clear from Fig. 5 that reduced illumination intensity causes pixelization distortion to become more apparent.

2.1 Resolution improvement

In order to improve resolution, we demonstrate operation of 32X32 GDD array by taking 16 different images with the 8X8 array, each at a different location in the image plane as can be seen in Fig. 13. Using the same quasi optic set up with imaging ratio of 2:1 magnification, 32x32 GDD pixel image of the “F” shape object were reconstructed from the sets of 16 images recorded with the 8X8 GDD FPA. Fig. 7 presents the reconstructed image of 32X32 pixels.

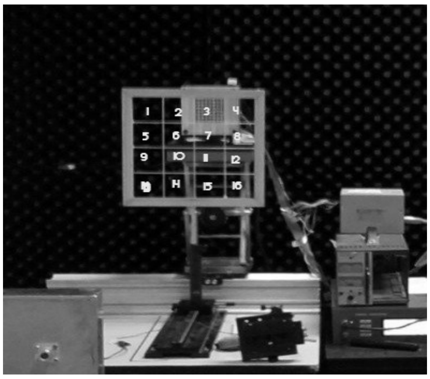

Figure 6: Positions of 8X8 FFA in the 32X32 constructed image.

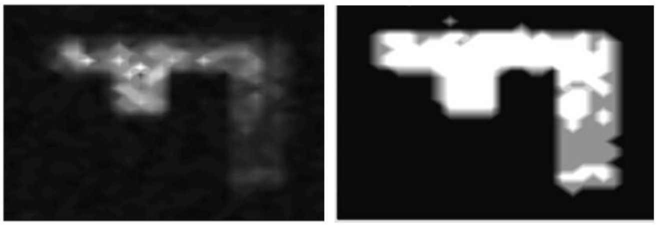

Figure 7: 32X32 reconstructed THz images of “F” shape object: before employing the correction algorithm (Left); and after employing the correction algorithm (right).

3. Conclusion

THz imaging using the 8X8 GDD FPA is presented here, which suggests that use of very inexpensive miniature gas discharge indicator lamps as detectors can greatly reduce the cost of millimeter wave and THz imaging systems while still obtaining good image quality. The experimental results of the “F” shape images are in excellent agreement with simulation results of Fig. 3. The quasi optical design and components prove themselves and minimize the diffraction effects in the images but with their limitations, as can be viewed in Figs. 4, 7. The quality of the 32X32 pixel images obtained using the 8X8 pixel board encourages the development of higher resolution boards such as the 32X32 pixel system presently under construction. Dithering is planned for future systems.

4. References

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