Single Pixel THz Detector for Remote Imaging

B.Kapilevich, Y.Pinhasi, M.Anisimov, R.Arusi, B.Litvak, D.Hardon

Ariel University Center of Samaria, Dept. of Electrical and Electronics Engineering

Ariel, Israel - 40700

ABSTRACT — **High-resolution single-pixel detector operating near 0.33 THz is described. It consists of FMCW transmitter based on multiplying chain (x32) and heterodyne receiver with sub-harmonic mixer. The X-band FMCW synthesizer is employed as a driver of multiplying chain and LO of the mixer. The Gaussian-beam antennas are used in the Rx and Tx channels. The detector was mounted on the scanning platform and can be employed in various homeland security applications where the remote detection of hidden objects both metal and plastics is required.**

***Index Terms* — Image sensors, FMCW radar, millimeter wave imaging, multiplying circuits**

I. INTRODUCTION

Development of homeland security systems allowing remote searching and detecting various danger objects hidden under clothing is important for protection against terrorist's threats. In order to provide personnel screened for undesirable hidden objects as well as concealed weapons in airports, train stations, embassies, and other secure buildings and locations, conventional searching technologies rely almost entirely on metal detectors to scan personnel for concealed weapons and X-ray systems to screen hand carried items. But they are not reliable when it is necessary to detect explosives or other non-metallic weapons. Various types of the sensors and imagers operating in microwave (MW), mm-wave (MMW) and sub-mm wave (Sub-MM) bands have been proposed during the last decade, for example [1-3].

This paper presents our developed high resolution single-pixel detector based on frequency modulated continues wave (FMCW) signal near 0.33 THz. It permits reconstructing both 2D and 3D images using algorithms based on averaged-weighted procedure. In order to improve a spatial resolution the Gaussian-beam horn lens antennas were used in Rx-Tx modules allowing operating for in-door and out-door conditions. Examples of 2D and 3D image reconstructions are reported too.

II. DETECTOR'S CONFIGURATION

The functional diagram of the developed THz detector used in experiments is shown in Fig.1. The HP-8350B sweep signal. Several multiplying stages are used in Rx and Tx channels. In order to drive the sub-harmonic mixer in the Rx-channel, the multiplication is 16 while in the Tx-channel this factor is 32 providing FMCW radiation near 0.33THz oscillator is employed as the source of X-band FMCW with output power about 10mW. Power amplifiers (PA) are also added to both channels in order to optimize multipliers performances. The experimental setup depicted in Fig.2 has been assembled from solid-state components of Virginia Diodes Ltd [4]. The Gaussian-beam antennas (gain = 40dB, beamwidth = 2deg) are used in the Rx and Tx channels. The signal scattered from a target is captured by Rx antenna and after down conversion comes to the processing unit consisting of video-amp and ADC block integrated with Lab View interface.

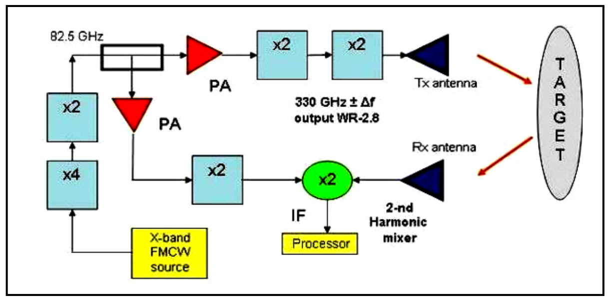

Fig. 1. The functional diagram of the developed THz detector used in experiments.

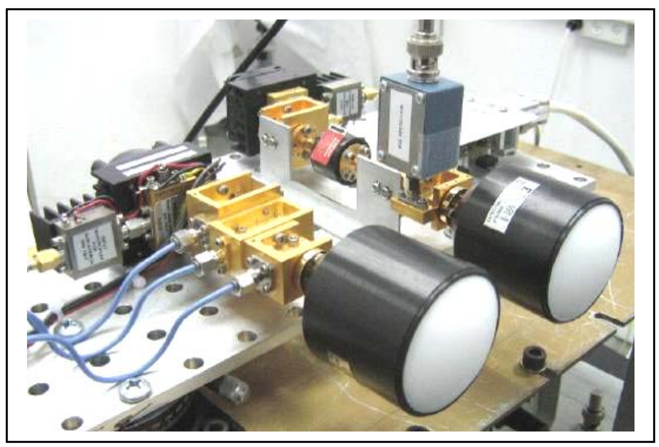

Fig. 2. Photo of the experimental setup used in experiments.

Typical structures of the signal recorded in IF port are shown in Fig.3 before processing as a function of sampling (time) and after processing using FFT procedure as a function of frequency. This record was done for the tested target as a metal plate at the distance equal 1.8m from Rx and Tx antennas using the following setting at the X-band source:

center frequency, f_0=10.15GHz, frequency span ΔF=100MHz, the period of the saw-tooth modulation $T_S = 0.1$s.

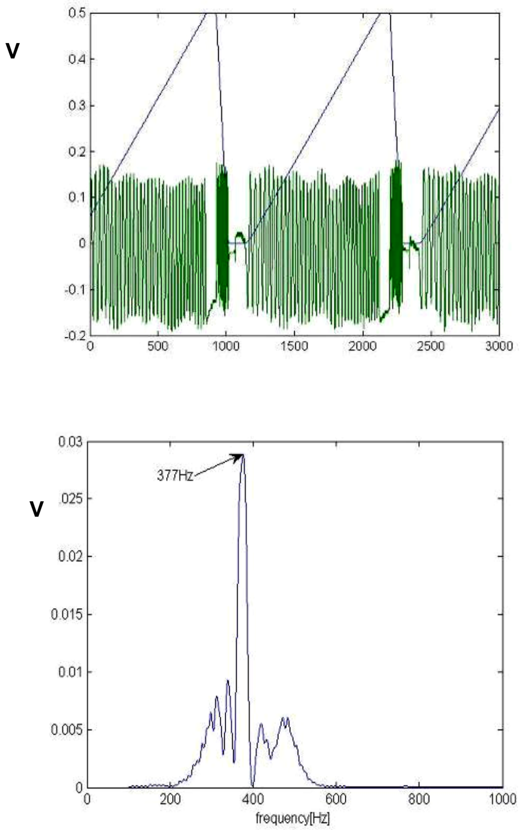

Fig.3. Typical time and frequency domain structures of the signal recorded in the IF port.

III. Estimating Spatial and Range Resolutions

A. Spatial resolution

In order to estimate the spatial resolution of the designed single-pixel detector, the metal disk of 28mm diameter has been installed on absorbing background as shown in the top part of Fig.4. The reconstructed image of this disk at the distance 1.6m is depicted on the same figure for S/N =10dB. The spatial resolution is about 1 deg in such experiment conditions. The spatial resolution can be improved with decreasing S/N but it leads to degrading image quality. So, the trade of must be determined for these parameters.

B. Range resolution

In order to estimate the range resolution of the designed single-pixel detector, the metal plate has been installed in a front of Rx-Tx modules and moved in longitudinal direction. Signals in the IF port have been recorded for different distances in a time domain. Then, they were transformed into a frequency domain using FFT. Finally, the increment of the distance to metal plate L has been determined using expression [5].

$$\Delta L = \frac{c}{2} \cdot \frac{T}{\Delta F \cdot n} \cdot \Delta f \qquad (1)$$

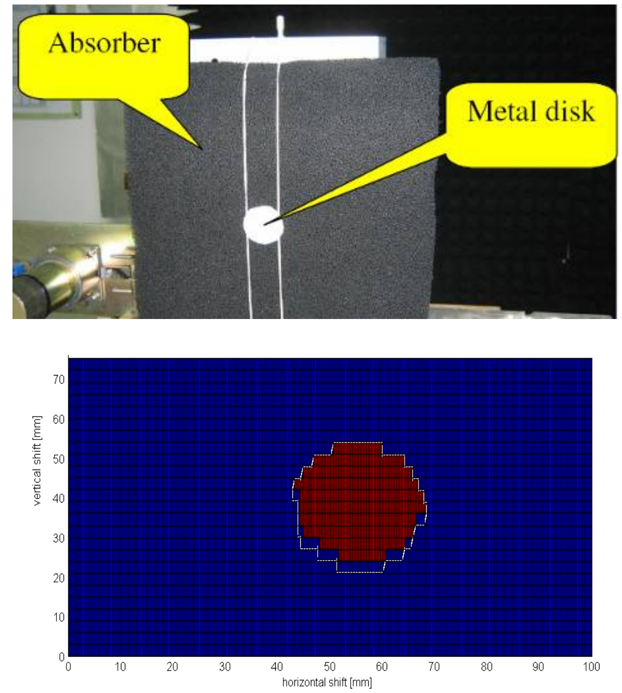

Fig.4. Comparison optical and THz images of metal disk of diameter 28mm and the distance 1.6m.

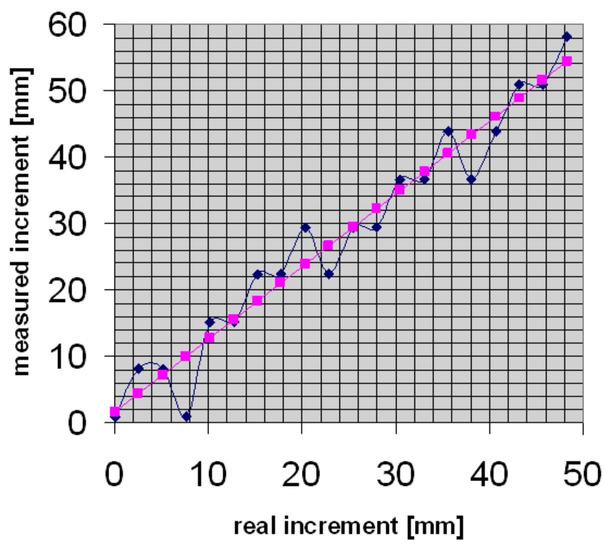

Fig.5. Comparison real and measured increments of distance to the target.

where Δf and ΔF are variation of IF and the frequency span of the X-band synthesizer, n is the multiplying factor (n=32 in our case), T is period of saw-tooth modulation, c is velocity of light.

Theoretically, the increment of distance to the target and its measured value must be the same leading to strait line inclined by 45 degrees as shown in Fig. 5. However, non linearity of FMCW causes deviation from this line. In our case the measured max deviation is 1cm while the standard deviation from linear is 3.6mm.

IV. Examples of Images in 330GHz

A lot of different targets were tested using the developed. single-pixel detector. Some selected results of image reconstruction are given below. The target has been scanned using X-Y positioner. The LabView interface integrated with Matlab has recorded a raw data table of the signal in IF port and stored it for post processing. The total number of pixels within a single picture frame can be varied in the range 500-3000. Fig. 6 shows optical and 330 GHz 2D images of the flat metallic equivalent of gun placed on absorbing background at the distance about 1m. The 3D sub-mm wave image of aluminium disk of diameter d = 6cm placed on metal background at the distance about 1m from antennas is depicted in Fig. 7. Its optical prototype is shown in the same figure at left side. Example of outdoor sub-mm wave image of the 5inch CD-disk is shown in Fig. 8. The experiment was performed at the distance about 8m. General scenery of this experiment is presented in the same figure.

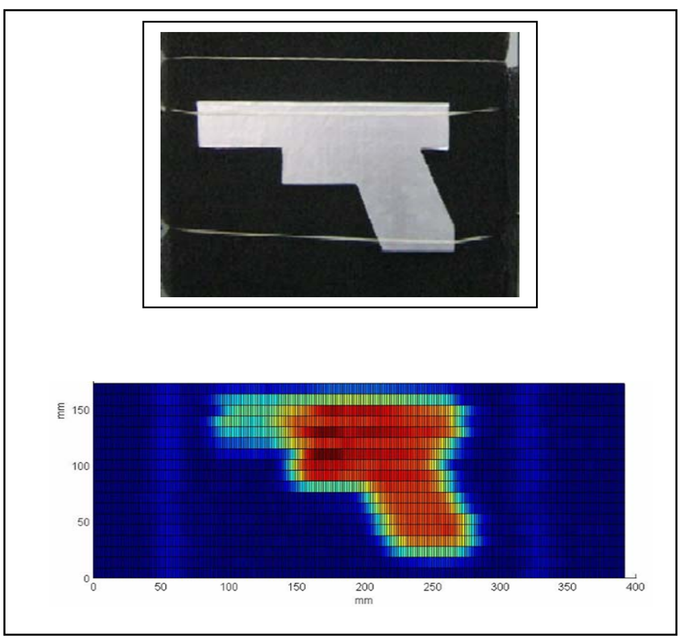

Fig. 6. Optical and 2D images of the flat metal equivalent of gun at 330GHz placed of absorbing background at the distance about 1m.

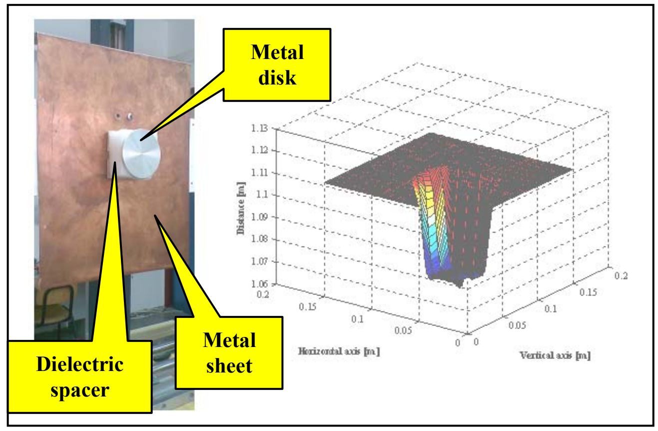

Fig. 7. 3D image of aluminium disk of diameter d = 6cm at 330GHz placed on metal background at the distance about 1m from antennas.

Finally, we have estimated the range limits of the detector developed in outdoor conditions. The metal sheet of size 41x46cm^2 has been installed at the distance about 40m that corresponds to 0.7x0.7 degrees field of view, Fig.9. The shape of the signal recorded in the IF port after its FFT transform scaling to the distance is shown at the same figure.

In order to estimate the real dispersion in determining the distance to targets, we have performed 25 independent tests shown in Fig.10. Standard deviation corresponding to these experiments is 1.3 cm for the distance to the target about 39.4m.

V. Conclusion

Preliminary results of ongoing research and development focused on Sub-MM single-pixel detector operating at 320-340 GHz were presented. A prototype of such a detector based on FMCW radar concept was built up and tested. The entire system operational control has been implemented in LabView while signal processing and image restore have been performed using Matlab. Various tested targets have been studied in order to prove basic concept and to demonstrate ability of the designed detector to operate at the distance up to 40m.

Acknowledgement

The authors wish to acknowledge the assistance of A.Shulsinger in experiments.

References

[1] A.O. Boryssenko, C.Craeye, and D.H.Schaubert, "Ultra-wide band near-field imaging system", *in Proc. IEEE Radar Conference,* pp.402-407, 2007.

[2] B. Kapilevich, B. Litvak, M. Einat, O. Shotman, "Passive mm-wave sensor for in-door and out-door homeland security applications", *In Proc. IEEE Sensor Technologies and Applications, Spain,* pp. 20-23, 2007

[3] K. B. Cooper, R. J. Dengler, G. Chattopadhyay, E. Schlecht, J. Gill, A. Skalare, I. Mehdi, and P. H. Siegel, "A High-Resolution Imaging Radar at 580 GHz", *IEEE Microwave and Wireless Components Letters,* vol. 18, no. 1, pp 64-66, 2008

[4] www.vadiodes.com

[5] I.V.Komarov, S.M.Smolsky, "Fundamentals of Short-Range FM Radar", *Artech House,* 2003.

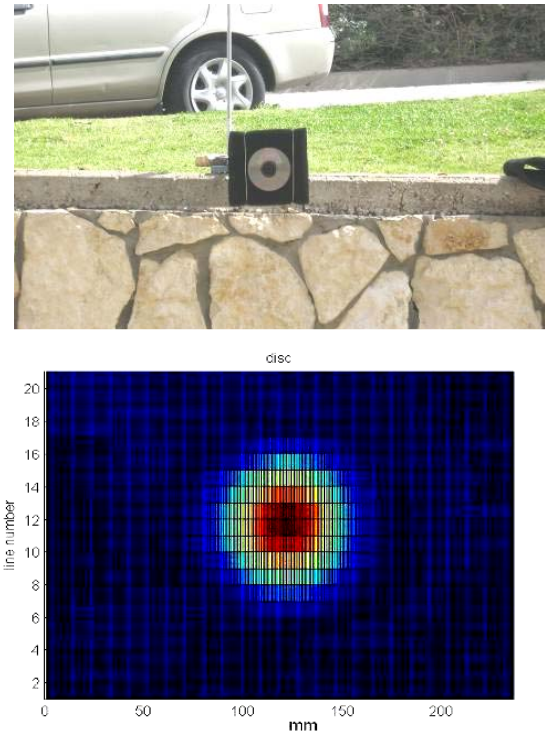

Fig. 8. Outdoor optical and 330GHz images of the 5inch CD-disk at the distance 8m.

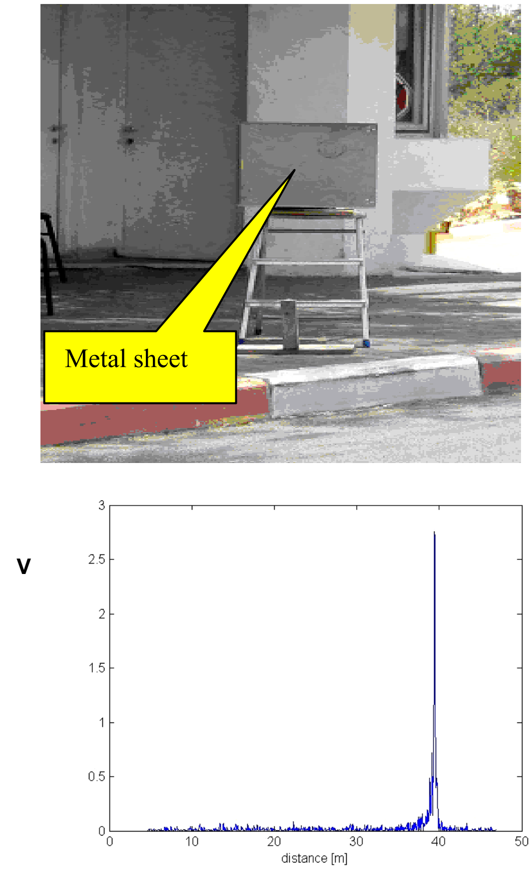

Fig. 9. The tested metal sheet installed at the distance about 40m from the single-pixel 330GHz detector and its IF signal scaled in the distance.

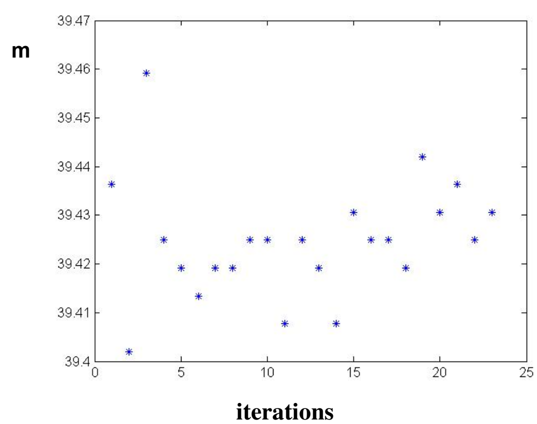

Fig.10. The statistics of range determinations for the target depicted in Fig. 9.