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THZ IMAGING SYSTEM FOR HIDDEN OBJECTS DETECTIONS

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Key words: THz sensor array, bolometer, THz imaging, Hidden objects detection

Abstract: The motivation of the work is to develop a flexible and low cost THz imaging system which can be used for various security applications. The key element is therefore a room temperature operation of THz sensor element capable to be integrated into a sensor array. The selected sensor is antenna-bolometer type which can be fabricated with micro-system and micromachining technologies based on silicon wafer substrate allowing low-cost mass production. These fabrication technologies are available in Laboratory for Microelectronic at Faculty of Electrical Engineering. Additional electronic and signal processing is described in the paper providing THz image. The complete system is described and results of THz images are presented.

THZ vizijski sistem za odkrivanje skritih predmetov

Kjučne besede: Polje THz senzorjev, bolometer, THz vizijski sistem, detekcija skritih predmetov

Izvleček: Cilj dela je razvoj prilagodljivega in cenovno ugodnega THz vizijskega sistema ki se lahko uporablja v številnih aplikacijah, predvsem pa v varnostne namene. Ključni element sistema je delovanje THz senzorskega elementa pri sobni temperaturi in možnost integracije elementa v polje THz senzorjev. Izbrani senzor je tipa antena-bolometer, ki je lahko izdelan s tehnologijo mikrosistemov na osnovi silicija, ki omogoča nizkocenovno masovno proizvodnjo. Takšna tehnologija je na voljo tudi v Laboratoriju za mikroelektroniko na Fakulteti za elektrotehniko. V prispevku je opisan celoten sistem, skupaj z dodatno elektroniko in procesiranjem signalov, ki omogoča izdelavo THz slike. Na koncu so prikazani tudi rezultati slik dobljenih z opisanim sistemom.

1. Introduction

One of the most important benefits of the THz radiation is that its photons have low energies and do not cause harmful photo-ionization in biological matter. The mm Waves are also known for good penetration through different materials, like clothes, paper, plastic, ceramic. /1/ Different materials can also be identified by their specific spectral response in THz region. This makes mm waves very useful in many applications such as industrial process inspection, pharmaceutical product inspection, radar applications, high speed communications, biomedical imaging and security purposes like explosive detection and THz imaging instead of X-ray imagers.

A THz low cost imaging system for hidden objects detection which is capable of detecting a hidden object through multiple layers of different types of clothes is presented. It is capable of producing the image of size up to 32x32 pixels. The image is processed and observed on laptop computer with near real time image refresh rate.

2. THz imaging system design

The concept of a THz vision system is based on the reflected pattern of THz waves from the target. In figure1 the complete system is shown. It consists of a THz continuous wave source emitting at 0,3THz with an output power nominally 1mW. The reflected waves from the target are gathered with a Fresnel type lens with diameter of 250mm. The detector pixel array of 16 detectors positioned in a horizontal line is processed in parallel, while the vertical scanning is processed sequentially to cover the array of 16 x 16. The goal is to obtain a full 256 pixel array. The physical size of the detector array is therefore 27 mm x 27 mm. The signals from the array are processed with a laptop using National instruments USB-6251 Mass Term 16-Bit, 1.25 MS/s M Series Multifunction DAQ and Lab View based software.

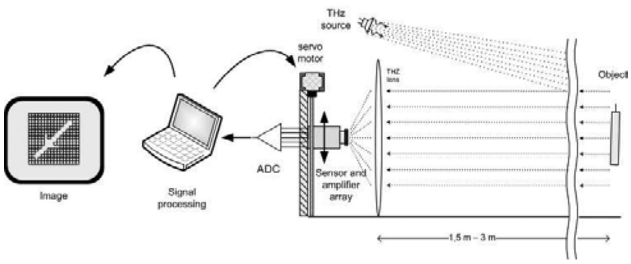

Fig. 1: THz imaging system

2.1. Pixel design

For the THz pixel a bolometer operating at room temperature has been chosen. In the literature the best NEP figures for a bolometer are in the range of hundred of pW$\sqrt{Hz}$. As our target is in 1.5m – 3m away from the THz source and detector, such figures are not acceptable.

A novel antenna and bolometer THz pixel has been developed with a NEP value in the range of 20 – 30 pW$\sqrt{Hz}$. /3/ Such figure is actually extending state of the art for room temperature THz sensors. The bolometer is fabricated on a silicone-dioxide foil with a thickness of 2 µm, the bolometer element is lifted above it with the dimensions of 10um x 1um. The sensitivity figure for such element is close to 100V/W, the bolometer resistance is 300Ω. It has been proved that the noise voltage corresponds to Johnson noise of 300Ω resistor. The bias current of the bolometer is 1mA which increases the operating temperature for about 30 degrees above the ambient temperature. Fig.2 shows the antenna bolometer photog

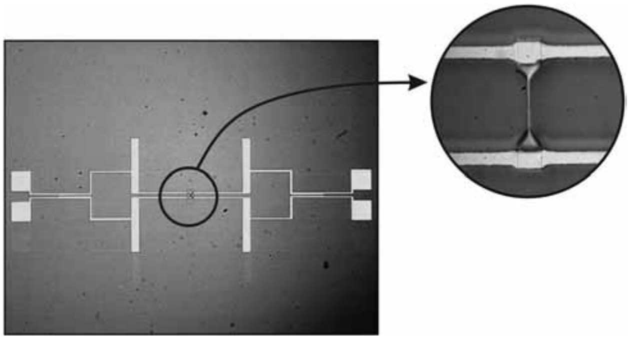

Fig. 2: Photomicrograph of antenna-bolometer

2.2. 4x1 pixel array

An array of 4 x 1 pixel array has been designed and fabricated to provide a building block for larger array. The antenna dimensions are roughly 1mm x 1mm, providing effective area of 1mm^2. The 4X1 pixel array was fabricated in LMFE using its micro system and micromachining facilities. The pitch was selected to be 1,7mm to allow an easy way to join the 4x1 to a larger pixel matrix. Figure 3 shows a test PCB containing the 4x1 pixel array.

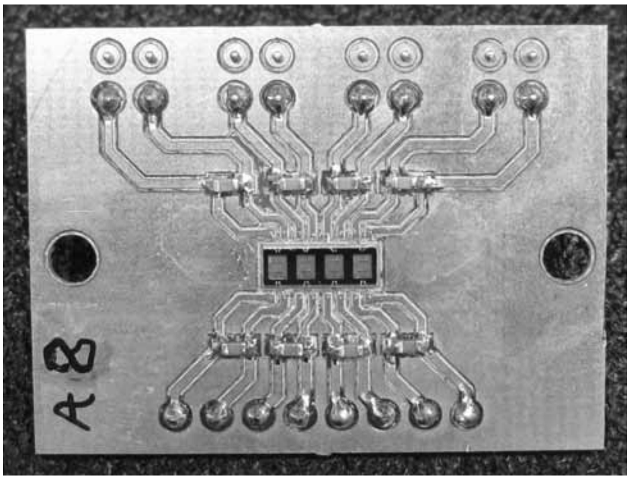

Fig. 3: 4x1 pixel array

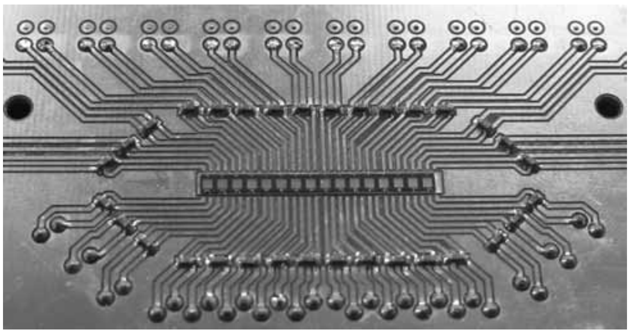

Fig. 4: Linear array of 16 pixels

2.3. 16x1 pixel array

A Linear array of 16 pixels, assembled with four parts of 4 X 1 arrays, together with connection wires and capacitors for ESD protection is shown on Figure 4. To minimize the number of electrical joints, the contacts from bolometers are bonded directly to PCB board which has to be gold-plated to allow gold wire ball bonding.

Figure 5 shows a photo of the final 16 pixel array together with the associated bolometer biasing and amplifying electronics.

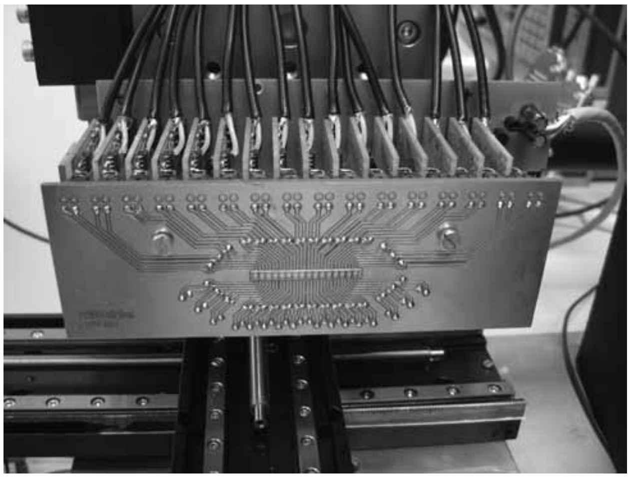

Fig. 5: linear array of 16 pixels with pixel electronic

2.4. Amplifier

The most critical element is LNA (Low noise amplifier) /2/ which should generate lower noise compared to bolometer nose. The measured noise of the amplifier is close to $5nV\sqrt{Hz}$ at 300 Hz which is the chopping frequency of the THz source. The amplifier is AC coupled with the gain transfer bandwidth characteristic shown in figure 7. The LNA Is connected in a close loop configuration with high pass filter to avoid the LNA offset amplification and a low pass filter to suppress high frequency noise. In figure 6 the schematics of complete electronics for one pixel is shown.

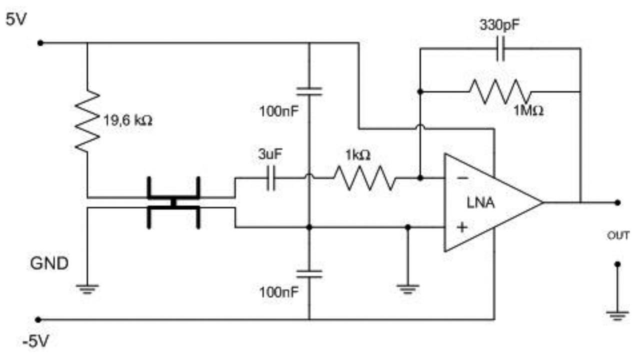

Fig. 6: Complete pixel electronic schematic

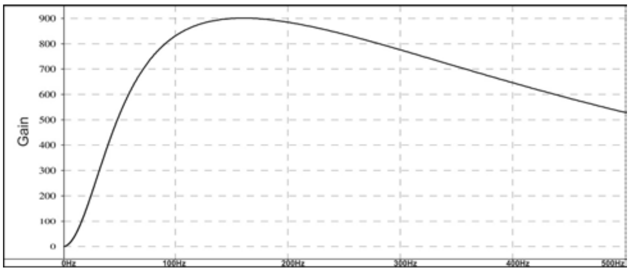

Fig. 7: Gain transfer bandwidth characteristics of amplifier

2.5. Signal Processing

Figure 8 shows a typical signal obtained on the pixel in the case that there is a fair reflected signal. If there is no reflected signal there is almost no 300Hz signal as shown on Figure 9. As seen the signal to noise ratio would need to be improved. This was done by using Fast Fourier Transform (FFT) which gave quite good result as shown in figure 10 and 11.

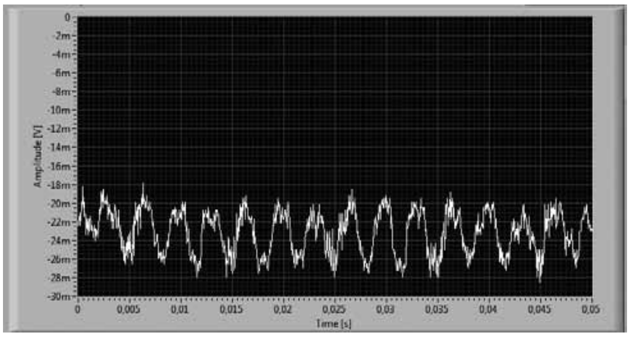

Fig. 8: Pixel signal with good reflection

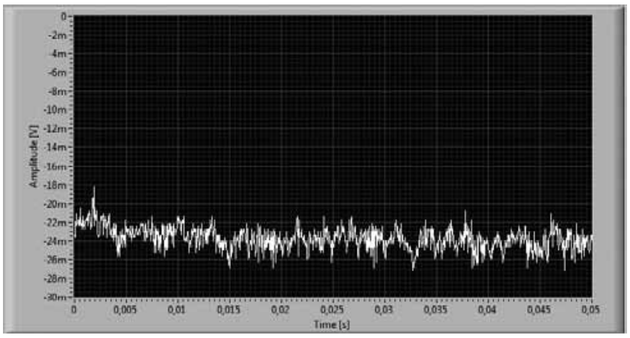

Fig. 9: Pixel signal with poor THz reflection

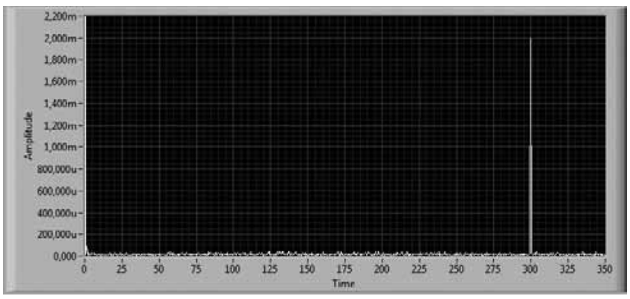

Fig. 10: FFT of reflected signal

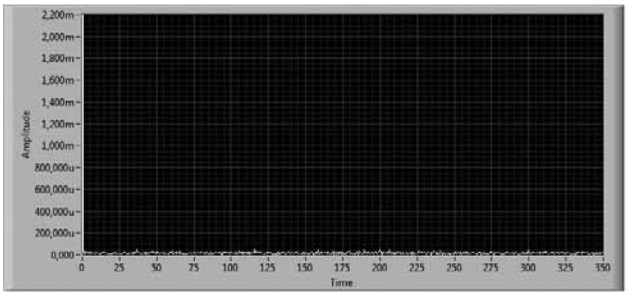

Fig. 11: FFT of signal with poor reflection

2.6. Mechanical scanner

To get a square matrix of 16 x 16 pixels an electro-mechanical micromanipulator is used to move the pixel array of 16 x 1 in vertical direction in 16 steps. To get a symmetrical image, the vertical step must be 1.7mm, which is the same as pixel array pitch. The scanning rate is adjustable by controlling software. The fastest scan rate is 4 seconds for full screen which gives us near real time acquisition of the THz scene. For good signal to noise ratio a longer acquisition time is recommended.

It has been introduced an increase of a pixel array to a size of 32 x 32 with additional electro-mechanical micromanipulator which moves the 16 x 1 array of sensors in horizontal direction for a half of a pixel pitch and scanning in a vertical direction has to be done twice with 32 steps of half of pitch of the pixels

2.7. Image processing

In the described project some effort was invested into the image processing algorithms also. Each pixel is represented as a square in the image. For each square a 300 Hz component from the FFT of the measured signal is represented with 256 shades of grey. Because the difference in signal levels can be very high, compared to 256 levels, two algorithms were implemented. At first all values can be normalized in the way, that the highest value is 255. To present a larger value

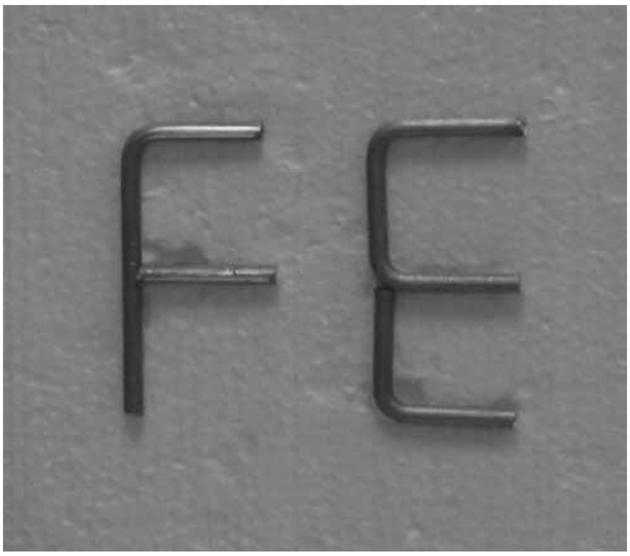

Fig. 12: Optical photo of the target

span, all values can also be exponentiated which provides the same effect as gamma correction in standard video signals

3. Results

The raw image suffers from well known resolution limitation which is governed by the ratio of lens diameter and THz wavelength. In our case the expected resolution was no better than 1mm. An optical photo of the target is shown on figure 12 and its THz image on the figure13. For this image the pixel count was increased to 32 x 32 and only a resolution enhancement was implemented.

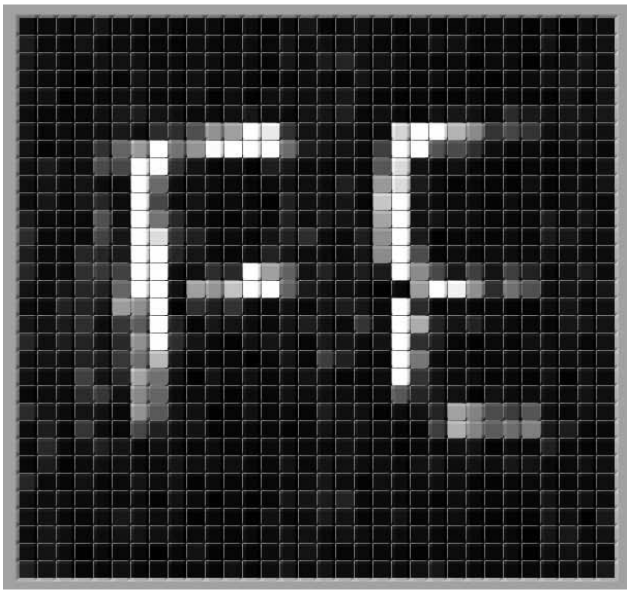

Fig. 13: THz image of the targed

Two layers of clothes are covered over the target as shown on figure 14 and its THz image is shown on figure 15. An additional two layers of T-shirt and a towell are covered over the previous two layers of clothes as seen on figure 16. The THz radiation can penetrate through all these layers, as it can be seen from the figure 17.

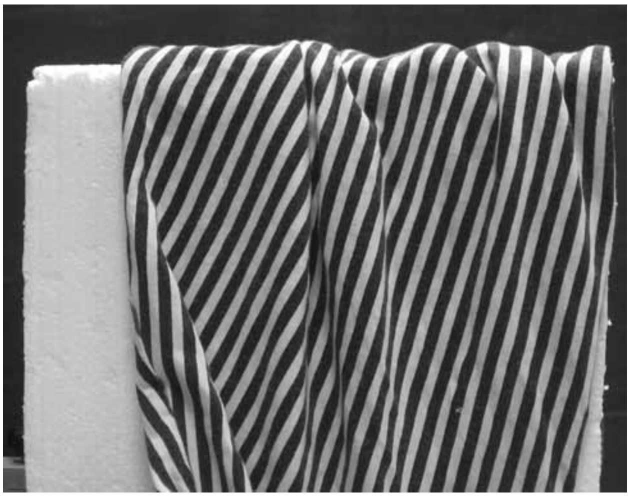

Fig. 14: Optical photo of covered target

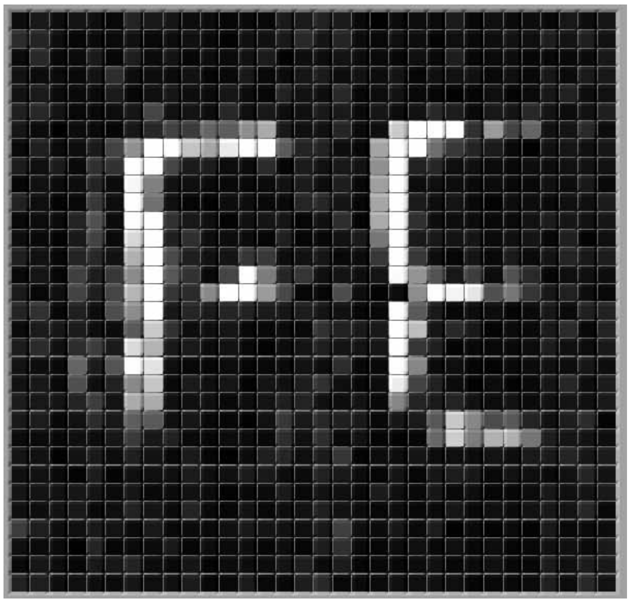

Fig. 15: THz image of covered target

Fig. 16: Optical photo of multiple layer covered target

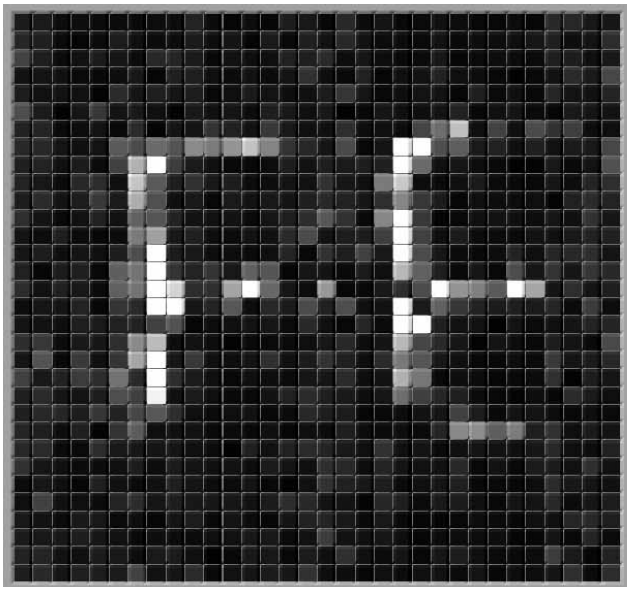

Fig. 17: THz image of multiple layer covered target

4. Conclusions

A low cost THz antenna-bolometer type imaging sensor array of 1x4 and 1x16 has been designed, fabricated and demonstrated at room temperature conditions. A system for near real time imaging has been introduced with capability of producing the image of up to 32x32 pixels. Additional signal processing has been performed on laptop computer and the detection of the target under multiple layers of different clothes has been achieved.

5. Acknowledgements

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6. References

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