Distant Detection of Hidden Objects with a THz Imaging Radar

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Abstract—**Detection of concealed threats at large distances is a key issue in public security. The paper describes a 0.8-THz radar that is capable to indicate hidden objects at a distance of more than 20 meter with a spatial resolution of less than 1 cm. The radar scans the scene with a narrow terahertz beam and uses heterodyne receiver with a hot-electron bolometer mixer. With integration time of 0.3 sec the receiver distinguishes a temperature difference of 2 K at the 20 m distance.**

Index Terms—**Antenna-coupled terahertz detectors, Beam steering, Imaging, Radar.**

I. Introduction

In security applications the terahertz frequency range has several advantages in comparison to millimetre waves. Thermal radiation of the human body becomes sufficiently strong to be detected with modern receiver technologies. Clothing and air are sufficiently transparent and the practically achievable spatial resolution still allows for detection of typical threats at a save distance.

Radar imaging with a resolution of about 1 mm at a distance of 25 m has been realized using a 1.56 THz continuous wave gas-laser transceiver and a heterodyne receiver with an Schottky diode mixer [1]. The authors applied the angular Doppler imaging techniques that requires a precise manipulation of the scanned object and cannot be directly used for security screening.

Passive millimetre wave imagers [2, 3] operating at frequencies up to 250 GHz have been demonstrated for short-range applications. A compact imager [2] using a single Schottky diode mixer at 250 GHz provided a less than 1 cm spatial resolution at a distance of 0.5 m along with the 30 s frame-time required for a 32 x 32 pixel image. For a larger imager [3] utilizing a monolithic microwave integrated receiver at 100 GHz, a frame time of 1 s was achieved for the same number of pixels. The frame time was limited by the maximum allowable acceleration of the scanning 1.2-m mirror. The mirror size defined an angular resolution of » 0.5° that corresponded to a spatial resolution of about 0.6 cm at a distance of 1 m. However, the overall radiometric sensitivity of the imager (» 1 K) and the available contrast limited the acquisition time to about 1 min. Using a similar receiver operated at a frequency of 40 GHz, the same group demonstrated faster imaging with a 12 Hz frame rate at a distance of 5 m. Imaging in the entire 100 GHz to 1000 GHz band was demonstrated [4] with a receiver based on an antenna coupled superconducting microbolometer. The bolometer had a noise equivalent power of 2.6×10-14 W Hz-1/2 that provided a radiometric sensitivity of 125 mK. Although improved sensitivity resulted in images with an excellent contrast, the frame time was limited by the response time of the detector and the scanning approach. The input aperture of the scanner presumably defines the achieved resolution of about 4 cm. At higher frequencies (0.5 – 1.5 THz) a resolution of 1 cm at a distance of 7 m has been achieved with a cryogenic Si-bolometer [5]. Acquisition of a 25x25 pixel image required a few minutes. Both the scanner and the system sensitivity that was restricted by the 15-cm input pupil limited the frame time.

Passive terahertz video-rate imaging at a larger distance needs either a fast detector in combination with a fast scanner or a large detector array. On the other hand, the required radiometric sensitivity can be only achieved with low-temperature detectors, which typically have a relatively large response time. To achieve this sensitivity with a heterodyne receiver, one would have to either enormously increase the bandwidth or use a large integration time. These constraints can be met by the active heterodyne imaging technique. Here we present THz-imaging radar, which was specially designed for indoor security screening.

II. Radar System

The radar (see Fig. 1) consists of a cw transmitter, which illuminates the object, and a heterodyne receiver with a solid-state local oscillator (LO) and a hot-electron bolometer (HEB) mixer. Both the receiver and the transmitter use the same scanning and collimating optics, i.e. the illuminating beam covers only the instantaneous field of view of the receiver. A high-speed conical scanner steers the receiver field of view over the object providing the video-rate imaging. The transmitter utilizes a CO_2/FIR laser system delivering approximately 10 mW single-mode power at 0.8 THz. Similar laser systems [6] were successfully used in heterodyne spectrometers for remote sensing of astronomical objects as well as for limb sounding of the earth atmosphere. The receiver part of our radar system was initially developed for radio astronomy and atmospheric studies [7]. The receiver

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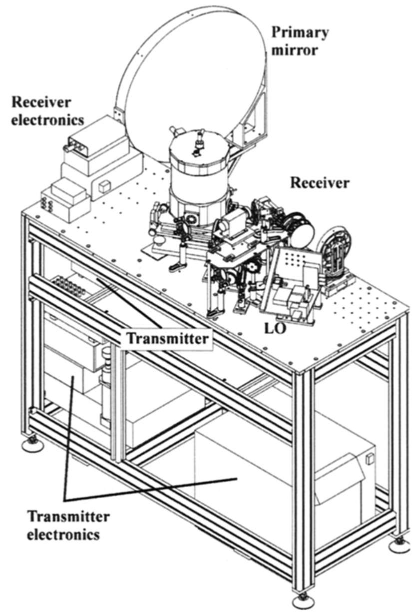

Fig. 1. Mechanical layout of the imaging radar.

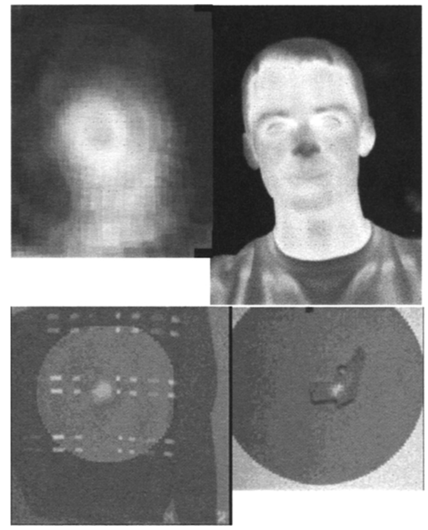

Fig. 2. Upper panel: Passive terahertz image of the human face overlapped with the near-infrared image, which is shown separately on the right side. Lower panel: Active terahertz image of the aluminum dummy gun hidden under the pullover. The terahertz image is superimposed on the video-build of the scene. The circle marks the field of view of the radar. Overlapped terahertz and video images of the non-covered dummy are shown on the right side.

utilises a superconducting HEB mixer that is described elsewhere [8] and a solid state LO made by Virginia Diodes. The LO delivers approximately 100 μW single-mode power around 0.8 THz. For the measurements the total available IF band of 1 GHz centred at 1.5 GHz was used. The receiver had a noise temperature of 4000 K measured with the hot-cold technique at the 20-m distance from the primary mirror.

III. Image Generation

Examples of the images taken at a distance of 18 m are shown in Fig. 2. The upper image was acquired in the passive mode using the heterodyne receiver of the radar. It is overlapped with the image obtained by an infrared video camera. The difference between the spread of the brightness temperature over the human face in the terahertz and near-infrared spectral range is clearly seen. The acquisition time was about ten minutes (1 sec per pixel, 0.3 sec integration time). The lower panel of the Fig. 7 shows the THz image of an aluminium dummy gun hidden under a thick wool pullover. It was taken in the active mode. The total transmitted power (at the output of the gas laser) was less than 10 μW. The radar needed less than 5 sec to obtain the build containing 104 pixels. The image barely allows one to identify the hidden object, however the technique makes it possible to detect the threat. It is worth noting that we could not get any signature of the hidden dummy using the passive heterodyne mode.

IV. Conclusion

We have built and tested the THz imaging radar combining the common mirror-based optics for the transmitted and received beams with the fast scanning mechanism that allows to image with video-rate non-cooperating persons at distances larger than 20 meters. The imaging speed of the radar is presently limited by the sensitivity of the receiver. Further improvement is possible with either a more sensitive receiver or a mixer array.

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