Large Area Terahertz Imaging and Non-Destructive Evaluation Applications

David ZIMDARS, Jeffrey S. WHITE, G. STUK, A.CHERNOVSKY, G. FICHTER, S. WILLIAMSON, Picometrix, Michigan, USA

Abstract: Terahertz (THz) imaging is being adopted for non-destructive evaluation (NDE) applications in aerospace and other government and industrial settings [1-3]. NASA is currently employing THz reflection NDE to examine the space shuttle external tank sprayed on foam insulation (SOFI) for voids and disbonds. Homeland security applications such as the inspection of personnel[2], the detection of concealed explosives[2], biological agents, chemical weapons, flammables, metallic and non-metallic weapons, and other potentially dangerous items are the subject of active investigation. Advancement of many of these application beyond small table top experimentation had been limited by slow imaging speed (tens of minutes or hours), small scan areas (<10 square cm) and in many cases the requirement that the sample itself be mechanically raster scanned. We report the development and applications of a high speed large area time domain terahertz non destructive evaluation imaging system.

1.0 Terahertz Imaging Instrumentation

The Picometrix QA-1000 terahertz imaging setup, as utilized for images shown below, is shown Fig. 1. The system consists of a rack mounted control unit containing a femtosecond laser, fiber launch, 320 ps / 100 Hz optical delay, signal processing, motion control and image analysis computer. A 5 meter fiber-optic and electrical umbilical cord attaches the terahertz transmitters and receivers mounted on an overhead gantry with 1.0 m by 1.0 m scanning range. The fiber optic coupling enables the scanning of the transmitter and receivers, allowing for a stationary object. In reflection, the co-linear transceiver has a 30 cm working distance, bringing the THz pulse to a 2 mm focus. In transmission, a “C” shaped yoke holds the transmitter and receiver above and below the object, respectively. Up to a 30 cm thick objects may be imaged in transmission, with the focusing lenses achieving a similar 2 mm spot. Both the reflection transceiver or transmission “C” yoke can be moved vertically up to 30 cm to achieve the best focus.

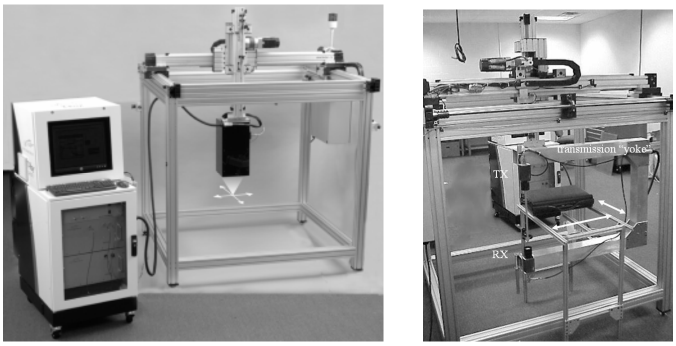

Fig. 1 Large area time domain terahertz non destructive imager (QA1000) with rack mounted laser, high speed optical delay, and control unit.
Left: Reflection configuration with overhead X-Y raster scanner and co-linear reflection transceiver.
Right: Transmission configuration with “yoke” mounted transmitter (TX) and receiver (RX).

2.0 Terahertz Transmission Imaging

Time domain terahertz imaging can been performed in either transmission or reflection. The terahertz pulses emitted from the terahertz transmitter are brought to a focus within the object to be imaged. In transmission imaging, the terahertz pulses pass through the object to be imaged and are re-focused onto the terahertz receiver. In two dimensional imaging, a pixel value is calculated from the terahertz waveform (peak to peak amplitude, delay, spectral power within a range) to assign a pixel value at that point. In a reflection image, the terahertz pulse reflects from surfaces within the object. Terahertz reflection imaging can be used to determine three dimensional structure within the sample[3].

Two sample time domain terahertz transmission images are shown in Fig. 2. The pixel intensity is logarithmically proportional to power integrated from 0.2 to 2 THz, from the Fourier transform of the 320 ps time domain data. The image shows the attenuation of pulses within the object. Both images have 1.5 mm pixel sizes, but are not shown to equivalent scale.

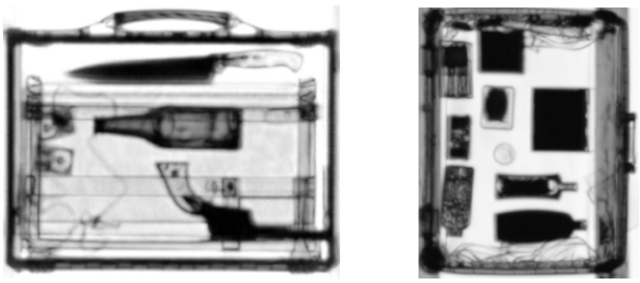

Fig. 2 Transmission terahertz images. Left: Attaché Case.
Right: Suitcase, approx. 30 in. by 20 in, by 13 in.

Pixel acquisition for both images was 66 pixels per second. Raster scan speed was 0.1 m/s in continuous motion. At this rate and resolution, it takes approximately 100 minutes to scan the entire 1 sq. m area of the gantry.

3.0 Co-Linear Terahertz Reflection Imaging

An example of a time domain THz reflection image employing the co-linear (monostatic) transceiver for a homeland security application is shown in Fig. 3. From left to right, the first two images shows the ability of time domain THz to separate layers within an object. The attaché case contains a knife, a pistol, and a block of boron carbide based explosive simulant. The third and fourth image shows the utility of personnel scanning. A knife beneath a jacket, and a metal pistol beneath a jacket are also shown. These items had been placed on the chest of a subject who lay beneath the QA1000, imaging time taking approximately 10 minutes.

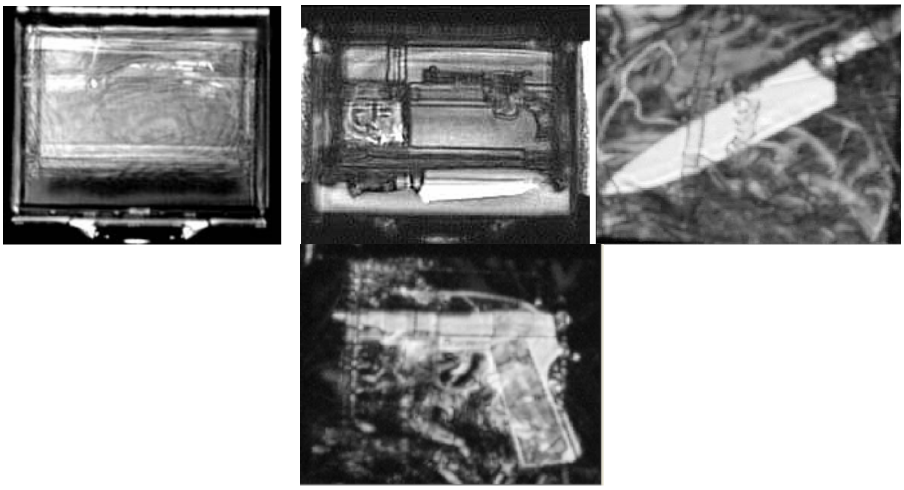

Fig. 3 Reflection terahertz images. From Left: Return from top of case attaché case; return from interior of case showing knife and pistol; knife under jacket; pistol under jacket.

4.0 Terahertz Detection of Voids and Disbonds in Space Shuttle External Tank Foam

The detection of flaws within low-density dielectric materials such as sprayed on foam insulation (SOFI) presents a challenge to conventional non-destructive evaluation (NDE) techniques. The extreme attenuation of sound within foam can severely limit the effective depth of ultrasound, for example. Time domain terahertz reflection imaging has been shown to yield high resolution images promising an exciting new quantitative NDE method for materials such as foam.

We have determined that terahertz pulses can penetrate as much of 20 cm of foam with a maximum frequency of up to 300 GHz (>1 THz for thinner foam). This high frequency, in comparison to microwaves, allows a lateral resolution of less than 2 mm and a depth resolution of <100 microns. Terahertz pulses are shown to scatter from voids with the foam and reflect from disbonds at the foam metal interface.

Disbonds are indicated by a “pre-pulse” reflecting from the air-foam interface above the metal backing. The pre-pulses from a piece of SOFI placed a variable distance (in microns) above a metal backing is shown below. The surface (or fully bonded position) is shown as an estimate because the 75 micron distance represents the foam fully clamped to the plate still exhibiting a pre-pulse, whereas bonded foam exhibits no pre-pulse.

Panels designed to simulate segments of the space shuttle external tank have been constructed to incorporate known voids and disbonds. These panels exhibit a complex three-dimensional surface geometry with a bolt flange (running the circumference of the tank) and structural “stringer” running along the length of the tank. The foam on this structurally complex region of the taken is sprayed on by hand. The operator sprays on the foam, lets it harden, and then mills the surface to the required external shape. The flaws were incorporated by milling voids or disbonds of known sizes in small foam blocks and then spraying on the overlaying standard foam structure. The figure inset shows typical location placements of voids and disbonds.

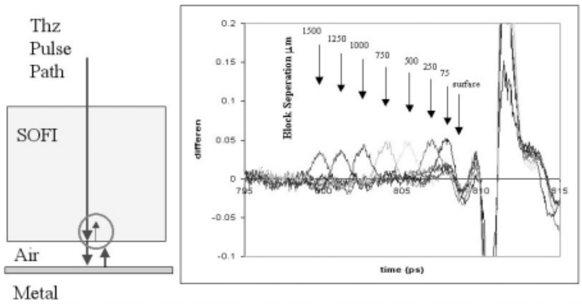

Fig. 4 Terahertz reflection imaging and interaction with space shuttle external tank sprayed on foam insulation. Terahertz pulses are attenuated at higher frequencies by travel through the foam. Traveling through a void will decrease the amount of scattering due to absence of the foam.
A portion of the pulse will be reflected from the surfaces of a void or disbond.
Left: Diagram illustrating pulse path through the foam and the reflection from simulated disbond.
Right: Measured "Pre-pulse" reflecting from air-foam interface as a function of air-metal separation.

The terahertz reflection images of panels with synthetic known flaws are shown in below. Voids appear as bright bubbles with dark rings (small voids are dark), and can be sized as small as 0.25 in.

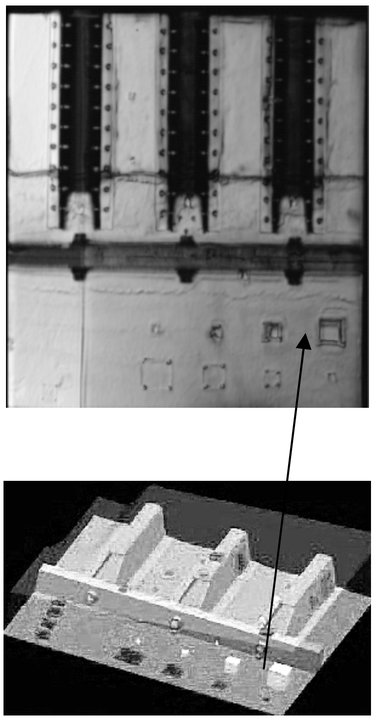

Fig. 5 Terahertz images of space shuttle external tank mock-up panel with programmed synthetic voids and disbonds.
Top: High resolution image of synthetic voids and disbonds.
Bottom: 3D view of programmed location of voids on panel. The 3 structures at top are known as "stringers", the structure from left to right with the 3 bolts is the "flange"

5.0 Acknowledgements

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6.0 References

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