A Solid-State Electronic Millimeter and Terahertz Imaging System

K. Smart[1], J. Du[1], L. Li[1], D. Wang[1], K. Leslie[1], F. Ji[2], X. D. Li[2], and D. Z. Zeng[2]
[1]Commonwealth Scientific and Industrial Research Organisation (CSIRO) Australia
[2] Chengdu Shuguang Optical Fiber Network Co., Ltd, Chengdu, Sichuan, China

***Abstract*— A practical millimeter and terahertz multi-spectral imaging system based on commercially available electronic components is presented. The advantages of its robustness, lower cost design, and the convenience to operate were explored. The system is then used to undertake a study of imaging at millimeter and terahertz wave frequencies with results compared.**

I. INTRODUCTION

Terahertz (THz) radiation designated as 0.3 to 3THz is both non-ionizing and low energy. Many non-conducting materials are transparent to THz radiation including cloth, paper, cardboard, ceramics and most plastic materials. Therefore it is of interest in the fields of security screening, non-destructive testing, metrology and quality assurance.

Imaging at the millimeter (mm), sub-mm wave, and THz regions of the electromagnetic spectrum are of great interest in recent years, especially in the area of security screening due to its unique combined features of penetration and resolution [1-3]. Practical THz measurement systems employ quasi-optical schemes using classical ray-tracing and physical optics propagation. CSIRO has been in recent years developing both mm-wave and THz imaging technologies [2 -4]. The previous imaging systems [2-4] were bulky, complicated, and difficult to operate, which limits its practical application. With a view to progress to a more compact and robust industrial THz imaging system, we investigated, in this work, both the construction of a simpler linearly-aligned lens based multi-spectral imaging system and a study of image quality at the frequencies from millimeter wave 168GHz through to terahertz 0.614THz.

II. IMAGING SYSTEM

Moving to a more compact and practical system, we have firstly made various changes to the hardware components. The very bulky backward wave oscillator (BWO) THz source in previous systems [3, 4] was replaced with a much more compact VDI solid-state 625GHz Amplifier/ Multiplier chain (AMC) source that employs a small programmable economy synthesizer as the RF input power. Another solid-state mm-wave source, Millitech active multiplier, was mounted on the top of the THz source to form a multi-band imaging system. The VDI Schottky diode detectors were used to receive the transmitted or reflected signals from the sample under scanning.

Lenses were used to focus the THz beam onto the sample and then onto the detector for the quasi-optical active imaging system. Precision lens alignment and maintenance of these aligned lenses are important for maximizing the beam signal (or signal-to-noise ratio) thus obtaining the best quality images. The off-axis parabolic mirrors in previous imaging system [3, 4] were replaced with the Plano-convex Teflon PTFE lenses in current system, which has largely simplified the task of lens alignment. The better lens alignment results in more power being coupled to the sample and then through to the detector even though plastic lenses incur some absorption losses in the bulk material that off-axis parabolic mirrors do not. The PTFE lenses are also lower cost at only 10% of the cost of off-axis parabolic mirrors. The optical system was further improved by employing a cage mounting system where all the lenses were linearly aligned to a single axis of the focal points, thus reduce the freedom of individual lens movement. This arrangement simplifies the lens to detector alignment and produces a more robust imaging system. This caged linear system is particularly useful in the case where the system is regularly moved or relocated and needs realignment.

The images were acquired by raster scanning the sample with two linear translation stages moving in the X and Y planes. A lock-in amplifier synchronized with an optical chopper was used to acquire the detector voltage responses, which were processed by a computer to produce an image using an in-house developed LabVIEW program. An area of 5 cm x 5 cm scanned at a typical resolution of 0.5 mm gives an image size of 100 x 100 or 10,000 pixels, which took about 10 minutes to complete. Figure 1 shows a plan view of the combined THz and mmWave imaging system with key components labeled.

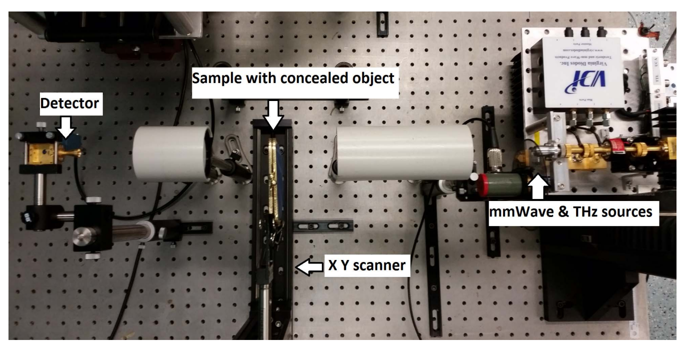

Fig. 1. Plan view of the combined THz and mmWave imaging system. The sample under scan is a purse containing a pair of scissors and the obtained images are shown in Figure 2.

III. RESULTS

The multi-spectral linear quasi-optical system has been applied to study imaging in both the 600GHz and 200GHz bands.

Figure 2 shows the transmission images of a pair of scissors in a purse acquired at a number of different frequencies across the two bands. These images were taken through several layers of fabric and plastic material demonstrating the ability to reveal concealed items through packaging material at these frequencies. This implicates the suitability of our system for security scanning.

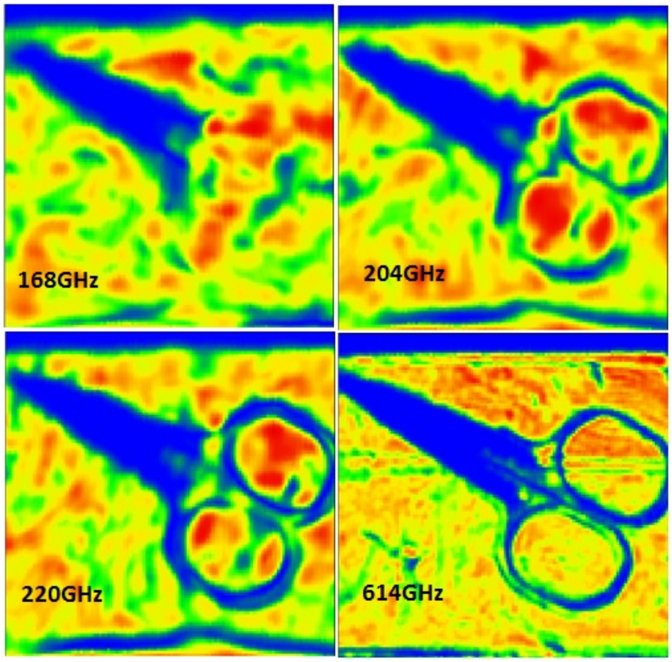

Fig. 2. Imaging of a pair of scissors hidden in a purse at different frequencies between 168-614GHz.

In sub-THz frequency range, the property of transmission through some non-conducting materials becomes more apparent with increasing the frequency, such as the plastic wrapped handles of the scissors shown in Fig. 2 in this experiment. Fig. 2 shows a marked increase in image clarity from 168GHz to 220GHz but the difference from 220GHz to 614GHz whilst clearly visible is more subtle; the difference is primarily resolution which is related to the diffraction-limited focal spot in the centre of the signal beam. The spot size of the THz beam varies in proportion to the wavelength. Thus images formed with higher frequencies show less blurring or better resolution.

IV. Summary

A compact solid-state electronic components based multi-spectral imaging system was developed and applied to investigate the image quality as function of frequency at mm-wave and THz bands. The linearly aligned and rigidly mounted quasi-optical system proved simple and quick to align and robust when relocated. The images demonstrated the unique feature of the sub mm-wave and THz radiation, that is; high transmission through non-conducting materials like cloth and plastics. The image resolution thought the packaging materials improved dramatically beyond 200 GHz. This simple and practical system can potentially be applied to many applications such as security screening and industrial non-destructive testing due to its combined advantages of penetration and resolution.

References

[1] E. N. Grossman and A. J. Miller, "Active millimetre-wave imaging for concealed weapons detection", *Proc. SPIE, Passive Millimeter-Wave Imaging Technology VI and Radar Sensor Technology VII*, **5077**, 62–70 (2003).

[2] M.L. Brothers, G.P. Timms, J.D. Bunton, J.W. Archer, J.Y. Tello, G.C. Rosolen, Y. Li and A.D. Hellicar, "A 190 GHz active millimeter-wave imager", *Proceedings of SPIE - Passive Millimeter-Wave Imaging Technology* X, **6548** pp 6548-04, (2007).

[3] A. D. Hellicar, J. Du, S. M Hanham, L. Li, N. Nikolic, Y. Li, and D. Popescu, "A 600 GHz imaging system for application exploration", *Proc. IRMMW-THz 2009*, vols 1 and 2 Pages: 765-766.

[4] J. Du, A. D. Hellicar, S. Hanham, L. Li, J. C. Macfarlane, K. E. Leslie, and C. P. Foley, "Terahertz and millimetre wave imaging with a broadband Josephson detector working above 77 K", *J Infrared, Millimeter, and Terahertz Waves*, **32** 681–690 (2011).