Terahertz single pixel imaging based on a Nipkow disk

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We describe a terahertz single pixel imaging system based on a Nipkow disk. Nipkow disks have been used for fast scanning imaging systems since the first experimental television was invented in 1926. In our work, a Nipkow disk with 24 scanning lines was used to provide an axial resolution of 2 mm/pixel. By implementing the microscanning technique the axial resolution can be further improved to 0.5 mm/pixel. Imaging of various object masks was demonstrated to show this simple and low cost system is promising for fast and/or real time terahertz imaging applications.

Recently, terahertz imaging systems have been intensively developed due to their wide applications in areas of security [0], non-invasive inspection [2] and medicine [3]. In conventional imaging systems a mechanical scanning method is implemented to obtain 2-D imaging information which limits the imaging acquisition speed [4]. Terahertz imaging systems based on electro-optical sampling and a conventional CCD camera are reported to be able to achieve real time imaging [5-6]. However these systems require high power laser sources in order to obtain a sufficient signal to noise ratio (SNR). Such a high power laser significantly increases both the cost and complexity of the imaging system. Commercial Focal Plane Arrays (FPA) primarily developed for the mid-infrared wavelength range have also been used for terahertz imaging systems. However the detection efficiency of such FPAs is poor in the THz range (typically only 5% absorption is obtained) therefore high power terahertz sources are still needed to overcome the poor detection efficiency. In addition to 2-D multi-pixel arrays, a terahertz single pixel detector can be also used for a fast imaging system. Chan et al. reported a single pixel terahertz imaging system based on compressed sensing (CS) theory [10]. Random masks were used to enable high speed imaging acquisition. A single pixel imaging system based on CS theory is a promising technique for a low cost and fast imaging system, though practical implementation is still limited due to the lack of fast spatial modulators to provide random masks and the complexity of computing processing [11]. In this paper, we describe another approach of single pixel terahertz fast imaging based on a Nipkow disk which is simpler and more cost effective.

The Nipkow disk has been used for imaging systems since the first television was invented in 1926. As shown in Figure 1, the Nipkow disk consists of a series of small apertures with equal diameter. The small apertures are positioned in the form of a single-turn spiral starting from an external radial point of the disk and proceeding to the center of the disk. In the imaging system, the disk is placed at the position of the imaging plane. The disk is partially covered by terahertz opaque material, leaving only a small window as the imaging area. The size of the window is set to make sure that only one aperture is positioned in the imaging area when the disk is rotated. When the disk is rotated, the spirally positioned aperture moves on the image surface in a circular trace. The light transmitted through each aperture is collected and detected by a focusing lens and a single pixel detector. Consequently a 2-D image is obtained by scanning the image line by line with the movable aperture.

The technique is almost 100 years old though it is still used in various modern imaging instruments such as the optical confocal microscope [12]. The Nipkow disk used in our terahertz imaging system is made of aluminium, consisting of a series of 24 apertures with a diameter of 2 mm for scanning the object image, as shown in Figures 1(a) and (b). The apertures are equally spaced in angle over the disk. The distance from the centre of the apertures to the centre of disk is varied with a fixed increment of 2 mm. A second series of apertures is placed along the outer edges of the disk with equal distance. These apertures (5mm in diameter) are used for timing and indicate the break of each scanning line. Among these apertures is a rectangular shaped aperture (10 mm long) which is used to indicate the start time of the image scan. We use a linear coordinate system to describe the position of the image pixels, as shown in Figure 1 (a). For the Nipkow disk with the above geometric parameters, we can obtain a 50 mm x 50 mm imaging area with an axial (Y-axis) resolution of 2 mm/pixel. The resolution along the X-axis is determined by both the acquisition rate of the detector and the rotation speed of the disk, which can potentially be very high. In our work the acquisition rate of the detector is set to be 300 μs and the rotation speed is 2 rps. The maximum resolution along the X-axis is about 0.18 mm/pixel. We manually manipulate the resolution along the X-axis using the control software (Labview 8.6) as 0.5 mm/pixel for the demonstration.

The experimental set up is shown in Figure 2. The terahertz source used in this work is continuous terahertz radiation, of frequency 2.52 THz with a maximum power of 150 mW, generated via a CO_2 pumped methanol vapour laser (*Edinburgh*

Instruments). The beam from the terahertz source is a Gaussian shaped circular spot 15 mm in diameter. A 90^o off-axis parabolic mirror was used to expand the laser beam size to 60 mm in diameter. The Nipkow disk was placed at the position where the whole imaging area is covered by the beam spot. A mask with word patterns was placed 5 mm in front of the Nipkow disk Another 90^o off-axis parabolic mirror was used to collect and focus the transmitted light from the aperture of the Nipkow disk onto the single pixel pyroelectric detector. A mechanical chopper was placed in front of the pyroelectric detector to modulate the THz beam. The signal of the pyroelectric detector was picked up by a lock-in amplifier (*Model 5210 Signal Recovery*) with time constant set at 300 µs. Both the lock-in signal and the timing signal were monitored on a digital oscilloscope. A Labview program was used to acquire data from the oscilloscope, process the raw data and consequently build a 2-D image using the processed data.

First, the intensity profile of the THz beam was imaged by removing the mask and the first parabolic mirror, as shown in Figure 2. The result shows a Gaussian-like imaging profile with beam diameter of 16 mm, which is in good agreement with the beam size measured by the manufacturer. As shown in Figure 2, the image is not slightly blurred due to the low resolution (2 mm/pixel) along the X-axis. There are two methods to improve the resolution of the x-axis. One is to increase the number of apertures thus the number of the scanning lines. Another is to use Multiframe Techniques (MT) based on translational microscanning [13]. In our work, we used the latter as shown in Figure 1(c). For MT, multiple frames of the image are obtained by mechanically shifting the Nipkow disk along the x-axis by a certain distance. Then the obtained multiple frames are interlaced so that a resultant image is obtained with increased resolution, as shown in Figure 3. There is slight distortion of the image in the direction of the Y-axis which is caused by the variable rotation speed. This issue can be solved by using a stepper motor with precise speed control.

In our work, object masks with the word pattern “THZ” were also imaged, as shown in Figure 3. The object masks are made of black aluminum tape on a HDPE plastic plate which is transparent in the terahertz frequency range. The results are shown in Figure 3. The objects were imaged at different axial-resolutions (0.5 mm/pixel, 1 mm/pixel, 2 mm/pixel). The resolution of Y-axis was set at 0.5 mm/pixel for this demonstration. Figures 5(m)-(o) shows the visible image of the objects. Figures 5(d)-(f),(g)-(i) and (j)-(l) show the constructed THz images of the objects at various x-axis resolutions; 0.5 mm/pixel, 1 mm/pixel and 2 mm/pixel respectively. The acquisition time for each single frame is 2 s which can be reduced by increasing the rotation speed and/or decreasing the time constant of the lock-in amplifier.

In this paper, we demonstrated a single pixel imaging system based on a Nipkow disk. Various object masks are imaged using this system. Multiframe Techniques (MT) based on translational microscanning were used to improve the resolution without changing the Nipkow disk itself. Images with a resolution of 0.5 mm/pixel have been obtained with a 2s acquisition time of a single frame. A Nipkow disk provides a simple and low cost solution for terahertz 2-D imaging with a single pixel detector. Faster or even real time imaging is possible using this system with high rotation speed and detection rate of the detector.

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Figure list

Figure 1 (a) Sketch of the Nipkow disk (b) Geometric parameters for our Nipkow disk (b) Resolution improvement by implementing the microscanning technique. The numbers “1”,“2” and 3” represent the imaged pixels for frame 1,2 and 3 respectively.

Figure 2 Experimental set up for the single pixel imaging system based on a Nipkow disk. Section A is the measurement set up for imaging an object mask and section B is the measurement set up for imaging the FIR laser pattern profile.

Figure 3 (a)-(c) Imaging of the FIR laser beam pattern at resolutions of 0.5, 1.0 and 2.0 mm/pixel respectively. (d)-(i) Imaging of an object mask with the word pattern “THZ” at various resolutions (d)-(f): 0.5 mm/pixel (g)-(i):1.0 mm/pixel (j)-(l): 2.0 mm/pixel.

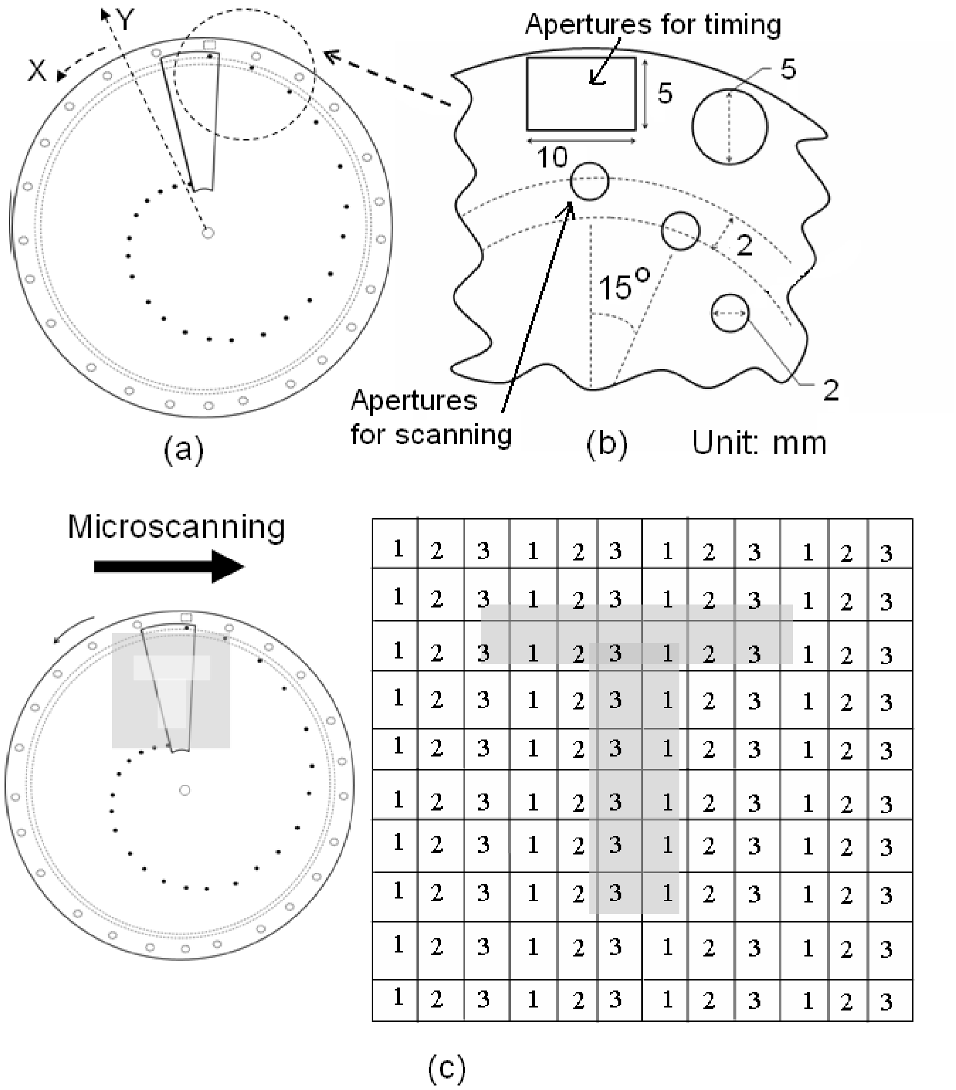


Figure 1 (a) Sketch of Nipkow disk (b) Geometric parameters for Nipkow disk (b) Resolution improvement by using the microscanning technique. The numbers “1”,“2” and 3” represent the imaged pixels for frames 1,2 and 3 respectively.

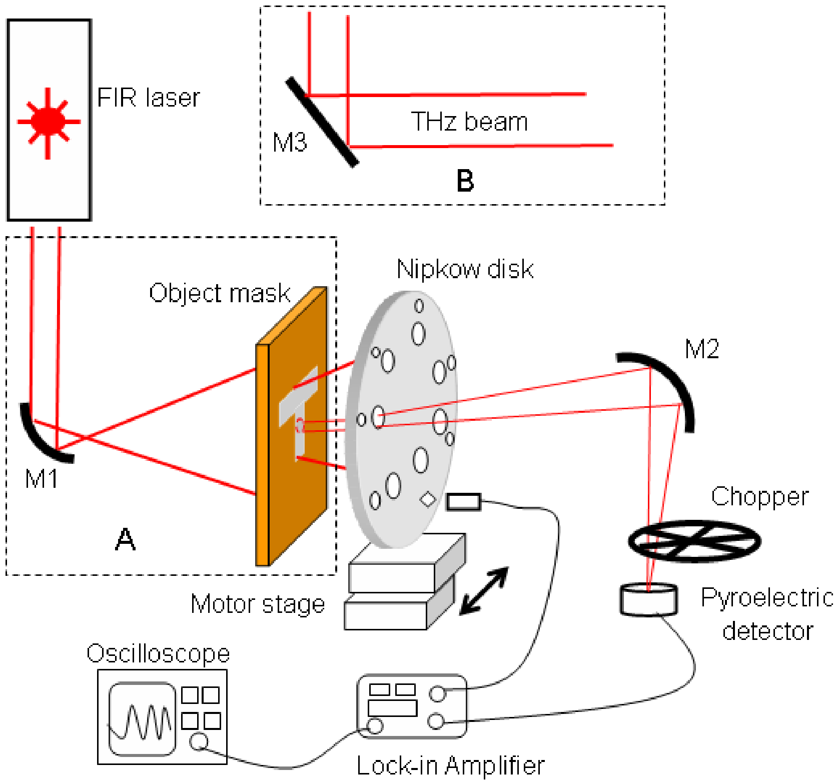
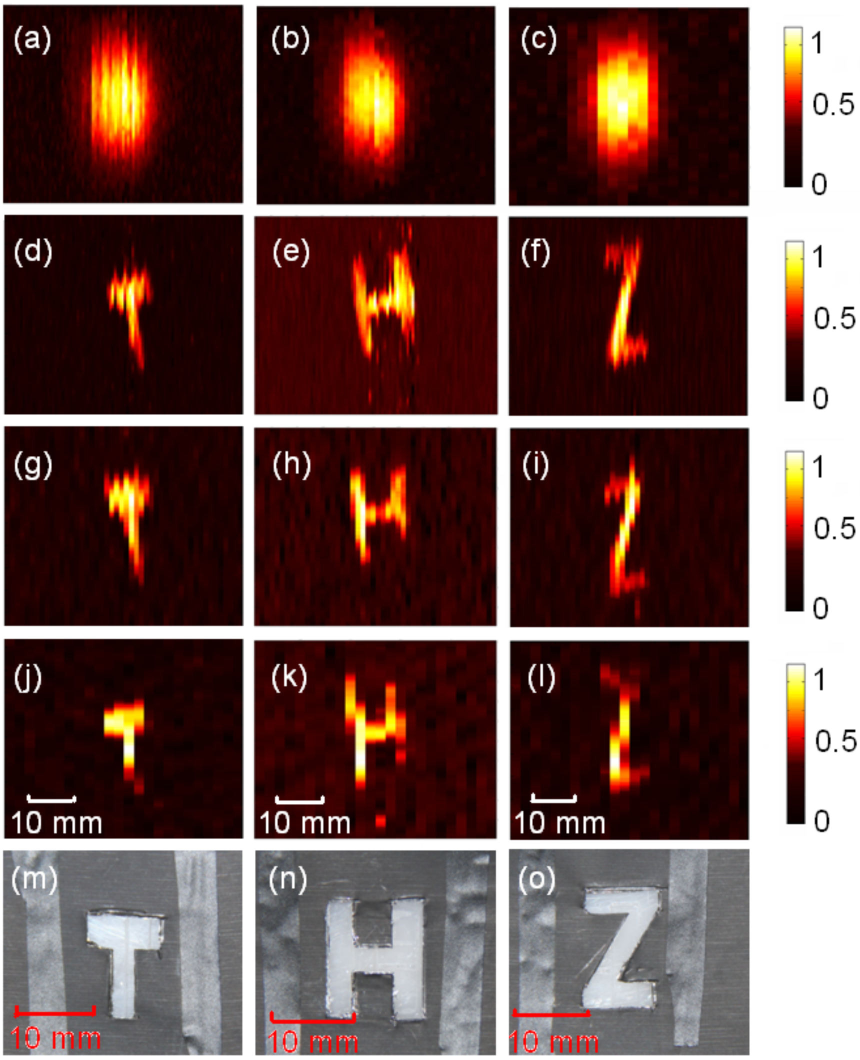


Figure 2 Experimental set up for the single pixel imaging system based on a Nipkow disk. Section A is set up for imaging the object mask and section B is set up for imaging the FIR laser pattern profile.



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