Time-Reversal and Model-Based Imaging in a THz Waveguide

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Abstract: A substantial improvement in the reconstruction of time-reversed THz fields is demonstrated by adapting a waveguide technique from ultrasound imaging. Furthermore, a model based reconstruction method is considered as an alternative to time-reversal THz imaging.

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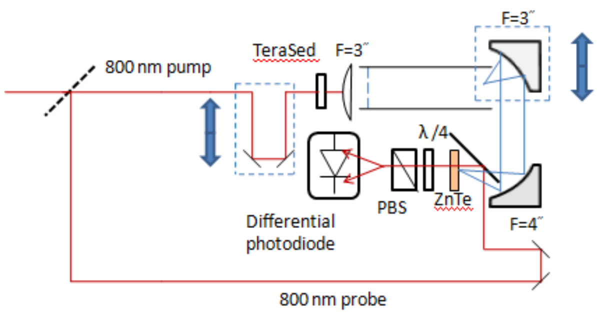
There are several ways of approaching THz imaging including scanning the object directly, performing tomographic reconstruction and by applying the time-reversal method, which we have previously demonstrated, and which is essentially a synthetic aperture technique [1,2]. The main objective of our work is to improve on the time-reversal technique in two ways. First, we adapt the waveguide approach which was pioneered in time-reversal ultrasound imaging to increase the effective numerical aperture of the system [3]. Second, we implement a model-based reconstruction technique which uses the actual impulse response of the THz system to minimize the background clutter and thereby improve the quality of the reconstructed images [4].



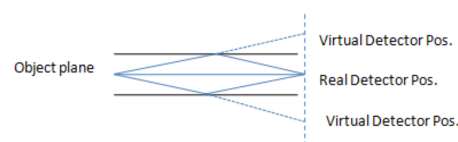


Fig. 1a) The schematic of waveguide THz imaging system 1b) the principle of mirror images as applied to a waveguide

The experimental setup, as given in Fig. 1a), is a typical electro-optic THz imaging system with an additional stage in the pump arm to compensate for the horizontal translation of one of the imaging parabolas. A femtosecond laser pulse is split into a pump and probe pulse by a beam splitter. The pump pulse illuminates a large-area photoconductive emitter (Terased) to generate a nearly single cycle THz pulse. The THz beam is then collimated by a polyethylene lens and then used to image two spectrometer slits with dimensions of 1mm x 8mm and with a spacing of 2.5 mm. The slits are bounded by two 12 inch flat mirrors which act as a waveguide redirecting the largely scattered THz into the numerical aperture of the imaging parabolas. The focal plane of the first parabola is imaged onto the electro-optic (EO) crystal by scanning the first parabola across the exit face of the waveguide whereas the probe pulse is reflected by a pellicle to propagate collinearly through the EO crystal with the THz pulse. The phase of the probe pulse is modulated by the THz electrical field inside the EO crystal via the Pockels effect and the phase change is converted into an intensity modulation and is detected by a nirvana detector. Fig. 1b) clearly illustrates how we effectively increased the numerical aperture of our imaging setup. Theoretically, by the principle of mirror images, each reflected pulse that is detected corresponds to a virtual detector position [3]. Hence, we can double the number of detector positions we have in our synthetic aperture by simply capturing the first set of reflections off the mirrors. Furthermore, the reflected pulses have a higher spatial frequency content than the direct path signals and thus by using a waveguide to redirect them into our numerical aperture we can improve the resolution of our system. Therefore, instead of scanning far off axis to achieve a large numerical aperture, we can use a waveguide to achieve the same numerical aperture with less detector positions provided that we scan longer in time.

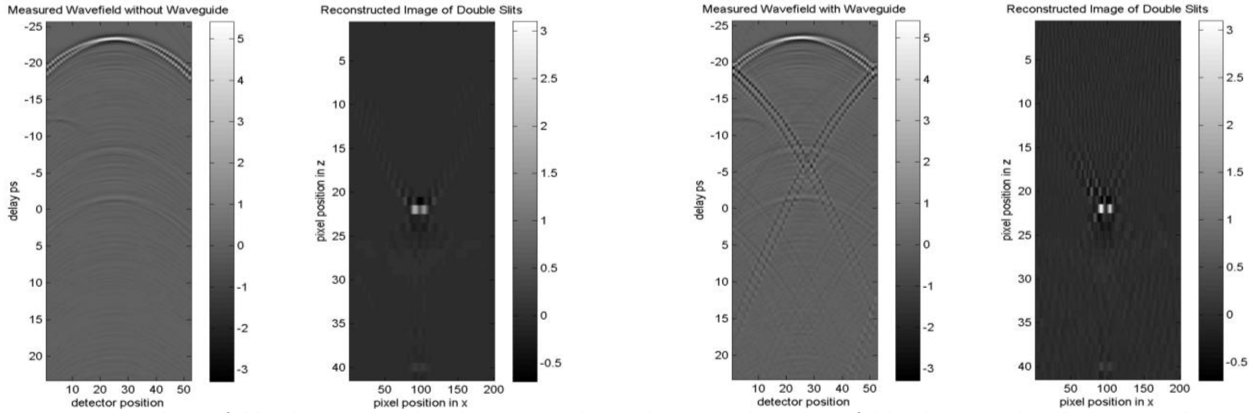


Fig. 2 a) Measured wave field without waveguide and reconstructed image b) measured THz wave field with waveguide and reconstructed image

In our experimental setup, we illuminated a double slit and measured the scattered THz radiation by scanning the parabola horizontally in increments of one millimeter over a range of 52 mm. At each position, the trace was an average of 100 scans. The wave field without the waveguide, as shown in Fig. 2a), was then numerically back propagated in time to reconstruct the object [1]. We then carried out the same experiment with the waveguide in place. The THz wave field plot in Fig. 2b) not only shows the direct path THz but the first reflection off both mirrors as well. We then back propagated in time the direct path and the reflected THz pulses to reconstruct the object in the object plane [1]. The second image is clearly brighter than the first one as a result of better temporal compression. That is the reflected pulses when added coherently to the direct pulses interfere constructively at the maxima while their side lobes destructively interfere with one another. Furthermore, better spatial focusing of the time reversed field has clearly improved the resolution of the second image as compared to the first. The object in Fig. 2a) can hardly be discerned as a double slit where as the reconstruction of the wave field plot in Fig. 2b) clearly shows that the object is indeed a double slit. Furthermore if we take a cross-section of both images and plot the intensity as shown in Fig. 3a) we can clearly see how waveguiding our object can improve both the brightness and the resolution of our imaging setup.

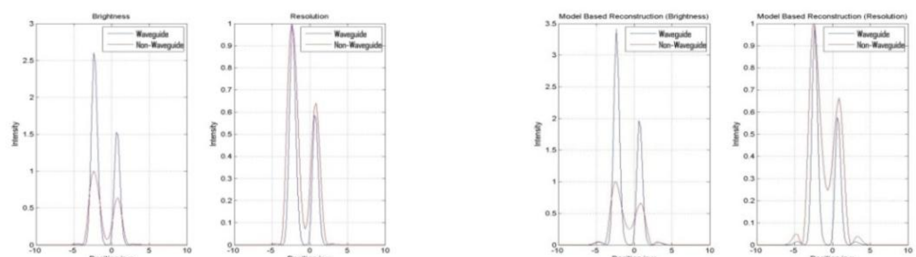


Fig. 3 Cross section of image displaying brightness and resolution for a) time reversal b) model basing imaging

Although the time-reversal process works well in approximating the transfer function of the waveguide, the ringing that is present after the main THz pulse degrades the quality of our images by introducing artifacts. Hence, a model-based reconstruction algorithm is developed to improve the quality of the reconstructed images. The preliminary result in Fig. 3b) shows that model-based imaging which uses the actual impulse response of our THz system can minimize the large ringing in the EO-detected signal and thereby reduce the background clutter in the reconstructed images. We believe that either a model-based matched filter technique or a model-based least-squares image reconstruction method would be more suited than the time-reversal approach for reconstructing quality images [4].

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