Terahertz Holographic Image Reconstruction and Analysis

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Abstract
We report on the reconstruction of terahertz images from digitally recorded holograms. An off-axis lens-less configuration is explored using a test set-up at 0.1THz. A backward propagation algorithm and Gaussian beam mode analysis are used to determine the transmission properties of transparent materials and scattering properties of rough surfaces.

Introduction
The two step-process of image formation by wavefront reconstruction [1] has in the past twenty or so years been adapted into many forms, some requiring two experimental stages for production, while others, through digital means, reduces the need for optical stages by either numerical production or numerical image reconstruction.

In the current climate of research in Terahertz and millimetre wave imaging, holography is an alternative to existing techniques for invasive measurements on organic and non-organic materials [2], [3].

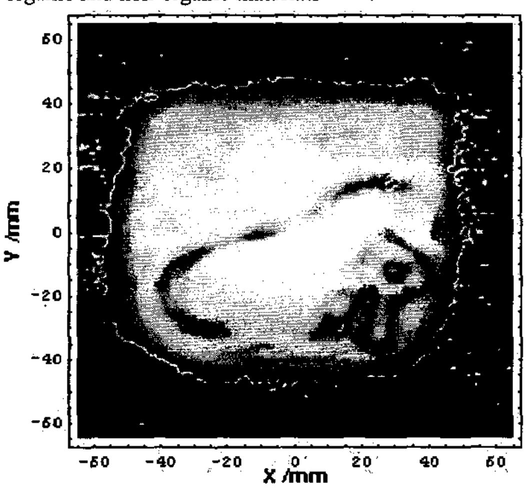

Figure 1 – Near-field image of paper envelope and objects contained within.

Shown in figure 1 is an image illustrating the applicability of millimetre wave radiation to security scanning. An envelope containing an elastic band and an 'R' shaped piece of PTFE was illuminated with a Gaussian 100GHz beam. The elastic band is visible due to its absorption of such radiation (0.8dB mm^{-1}), while the outline of the 'R' is visible due to phase changes caused by the low loss (0.08dB mm^{-1}) material. The above image was captured using a very simple near-field technique, where the object under examination is placed in the focal plane of a collimating lens, which coincides with the plane of a scanning detector. Such a technique is suitable only for imaging through low loss materials. We are currently developing a more general technique, which is based upon holographic methods used at visible wavelengths.

Theory
The theory of holography, or wavefront reconstruction, has been analyzed quite rigorously in many publications [4]. We shall only discuss some of the fundamental elements here. A hologram is the interference pattern generated by the combining of an unknown beam scattered by an object $a(x,y)=\exp[-j\phi(x,y)]$, with an easily replicable reference beam $A(x,y)=\exp[-j\varphi(x,y)]$, whose phase is known. When combined at a given plane, the resulting intensity distribution $T(x,y)$ is found, while ignoring constant responsive factors of the recording medium, to be

$$T(x,y)=|A(x,y)+a(x,y)|^2$$
$$=|A(x,y)|^2+|a(x,y)|^2+2|A(x,y)||a(x,y)|\cos[\varphi(x,y)-\phi(x,y)]$$

Thus we have an expression giving information about the amplitude and phase of the object beam at a certain plane, making it possible to numerically reconstruct, using appropriate diffraction integrals, an image of the scattering object.

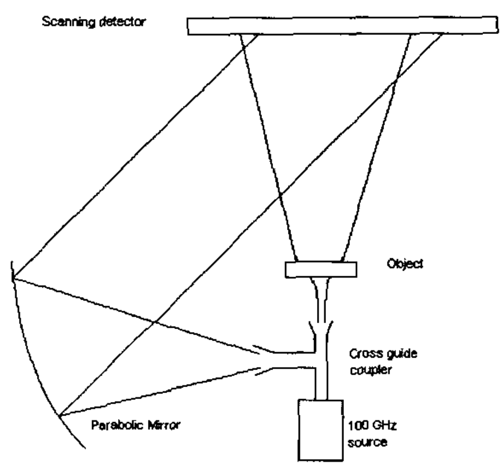

Figure 2 – Schematic diagram of millimetre wave holography arrangement used.

Unlike the arrangement used at visible wavelengths, the action of a beam splitter [5] is achieved by the presence of a cross-guide coupler in the transmitter chain (fig. 2), and through signal attenuators attached to subsequent waveguides, radiation levels in both output beams are adjusted to give the correct ratio between reference and object beams as required in the theory of holography. The creation of two beams at the source, does, however, create difficulties in the geometrical positioning of the object relative to the detector. These problems will be overcome by the manufacture of elliptical mirrors of longer focal lengths tailored to our requirements.

At these preliminary stages of the study, the use of Gaussian beams is not ideal for the illumination of the object aperture, as such an amplitude profile does not illuminate all regions of the object equally. This may be overcome by the use of radiating horns of smaller apertures for the generation of wider beams, but this approach can result in unwanted reflections and interference unless precautions are taken. Our research group has developed methods for the design of phase gratings for the generation of "top-hat" like beams, and such a component would greatly improve the uniformity of the illumination and thus the reconstruction of an object.
While the aspect of holography studied here relies on a numerical image reconstruction, it is also possible to generate physical holograms in binary form using simulated production from simple models of wave front reconstruction. Such holograms have been described as a means for the production of plane waves, and for arbitrary beam steering [6].

Results

Shown in figure 3 is a millimetre wave hologram of an aperture cut from a section of absorbing material using a Gaussian reference beam at an angle of 22° to the plane of the detector.

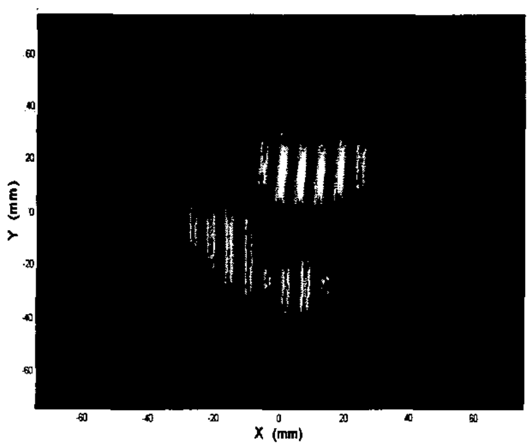

Figure 3 – 100GHz hologram of aperture.

The area of the hologram is $150mm^2$, which, with a wavelength of 3mm thus has quite a low resolution compared to an optical hologram which has a similar size but contains more information.

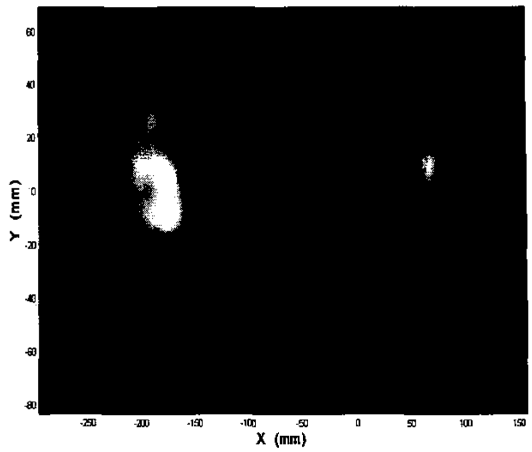

Figure 4 – Reconstruction of hologram in fig. 3

Figure 4 depicts the numerical reconstruction of the above hologram. We calculate the entire intensity distribution at the plane of the object, and find, as expected, that two beams are present. The reference beam is the bright region on the left of the image and its position corresponds to that predicted from the geometry of the holography system. The area seen on the right is the reconstructed image of the test object. Some of the features are difficult to view and we attribute this to the non-uniform illumination by the Gaussian beam.

Conclusion

Off-axis holography has been demonstrated to be a potentially suitable technique for terahertz and millimetre wave imaging. With the manufacture and use of components tailored to our needs for object illumination, image reconstruction is expected to improve considerably as predicted by simulation.

References

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