Applying Energy Absorption Interferometry to THz direct detectors using photomixers

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***Abstract*—The sensitivity and spatial form of the individual optical modes to which a potentially few-moded direct detector is sensitive can be determined by the complex valued coherence matrix from two identical sources as they are scanned through the field of view. We provide experimental verification of this technique using THz photomixers and MKIDs.**

***Keywords*—Energy Absorption Interferometry, photomixer, partial coherence, verification techniques**

I. Introduction

Astronomical imaging and spectroscopy in the THz domain typically involves the study of formation and evolution of planetary, stellar, and galactic systems. Resolution, throughput, and bandwidth requirements for instruments operating at these wavelengths are all key parameters which drive limitations on the size and density of detectors [1, 2]. It is generally the case that these requirements drive the optimum size of detectors to be similar to the wavelengths measured, such that they exhibit a few-moded response to incoming radiation. In such a regime, the detector beam pattern cannot be fully represented by a fully coherent response, as is the case for single-moded detectors. In addition, the system also cannot be fully described using geometric optics and radiative transfer models, such as typically used in the infrared and visible domains. Understanding few-moded power absorbing detectors requires a method to measure the number and relative sensitivities of the natural modes, as well as their spatial forms.

In this work, we applied Energy Absorption Interferometry (EAI) [3], which is a technique by which the coherent properties of any power absorbing structure can be measured, to an end-to-end THz optical system including detectors. In doing so, we demonstrated we were able to recover a complex valued correlation matrix which described sensitivity of the system in terms of individually coherent natural modes.

We introduced two independent source probes in the field of view of an optical system, which while being spatially decoupled, exhibited identical beam profiles, were frequency matched, and the relative phase between the sources could be adjusted. The sources were independently scanned throughout the field of view, and at each pair of positions, the relative phase was varied and an interference fringe was measured. Extracting the phase and amplitude of the fringe allowed us to construct a directly measured representation of the spatial correlation matrix of the complete optical system. Such a matrix could be propagated through the optical system, and decomposed into a weighted set of orthogonal functions which represented the individually coherent optical modes of the system.

II. Theory

Wolf shows that λ_i and ψ_i, which are the eigenvalues and eigenfunctions which describe the natural modes and relative sensitivities of a partially coherent beam, are eigenfunctions and eigenvalues of the following equation [4],

$$\int_D W\,(\mathbf{r}_1,\mathbf{r}_2)\cdot\psi_n(\mathbf{r}_1)d^3\mathbf{r}_1=\lambda_n\psi_n(\mathbf{r}_2),$$

Where $W(\mathbf{r}_1,\mathbf{r}_2,\nu_0)$ is the cross-spectral density of an optical beam evaluated at a single frequency, ν_0, and $\boldsymbol{r_i}$ are position vectors within the domain D,

Withington et al. show that the power coupling of the system to a source is a projection of the cross-spectral density of the detector beam, $\overline{\overline{D}}(\mathbf{r}_1,\ \mathbf{r}_2)$, as well as the cross-spectral density of the source field, $\overline{\overline{E}}(\mathbf{r}_1,\ \mathbf{r}_2)$ evaluated over an arbitrary plane S which forms a cross-section of the beam [3],

$$\langle P\rangle=\iint_{S^2}\overline{\overline{D}}(\mathbf{r}_1,\mathbf{r}_2)\cdot\cdot\,\overline{\overline{E}}(\mathbf{r}_1,\mathbf{r}_2)d^2\mathbf{r}_1d^2\mathbf{r}_2.$$

By illuminating a system under test with two independent monochromatic point sources, the power measured at the detector can be represented by [5],

$$\langle P(\phi)\rangle=D_{m,m}+D_{m',m'}+2\,\left|D_{m,m'}\right|\cos\left(\phi+\theta_{m,m'}\right),$$

Where m,m' are discrete position indices of the two sources, $\left|D_{m,\,m'}\right|$ and $\theta_{m,m'}$ are the amplitude and phase of the discretized version of complex-valued cross-spectral density at coordinates m and m'. If the relative phase difference between the sources, ϕ, can be systematically adjusted, $\left|D_{m,\,m'}\right|$ and $\theta_{m,m'}$ can be measured as the complex amplitude of the resulting fringe. Repeating over all possible pairs of position coordinates with a plane with sufficient sampling and size recreates the full discretized cross-spectral density matrix of the system under test, which we call the detector response function (DRF).

III. Setup

We created two phase-matched, frequency-tunable monochromatic THz source by photomixing two infrared lasers in two identical GaAs photomixers [6]. The two sources are driven with the same pair of lasers, using a 2x2 fiber optic splitter. Phase rotation is applied with fiber stretchers, which modify the differential length between the optical paths [7]. Each source is mounted on a motorized xyz-stage, and the output THz beams are coupled together in free-space with a Mylar beamsplitter.

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IV. Results

The DRF was produced by recording the amplitude and phase of the fringe pattern for each source position pair. The amplitude and phase of the complex DRF is shown in Fig. 1. We limited the source position points to include only a single cut of the focal plane, but at a diagonal between the E- and H- planes such that the cut intersected non-zero regions of both the simulated co- and cross- polarization responses of the system.

Using a technique similar to angular plane wave spectrum (APWS) decomposition and propagation [8], we were able to propagate the measured DRF from an arbitrary measurement plane to an image plane of the system under test. This approach also allowed for spatial filtering of the DRF to limit the impact of detector noise and straylight on the recovery of the natural modes.

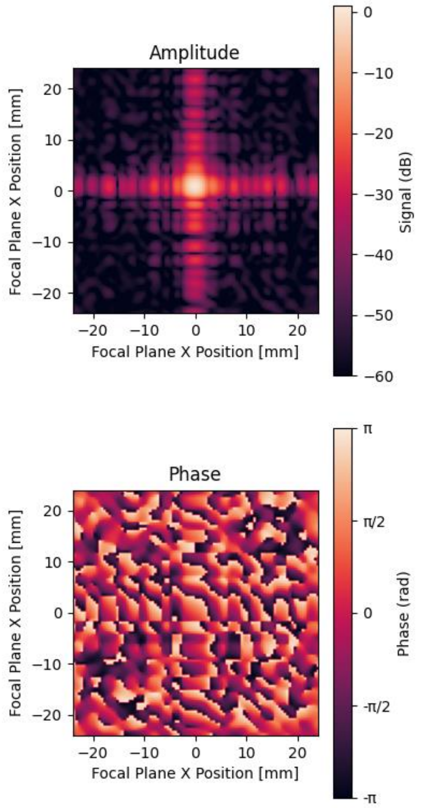

Fig. 1. Amplitude and phase of the complex valued detector response function (DRF) produced by measuring correlations between two point sources over a one-dimensional cut of an instrument beam pattern.

A diagonalization of the DRF matrix, utilizing singular value decomposition (SVD) allowed the extraction of the eigenvalues and eigenvectors, which corresponded to the sensitivity and spatial form of the natural modes (Fig. 2).

The demonstration described in this work proved that this detector could be described as having a single dominant spatial mode and that cross-pol and surface wave stray light can be described as coherent with the main antenna response, at least within measurement accuracy. This would not be expected in a intrinsically multi-moded detector, like a distributed absorber detector. Application of this technique to such detectors will be a topic of future focus, as it has implications for how they couple, particularly for application in wideband instruments such as Herschel/SPIRE and SPICA/SAFARI [9].

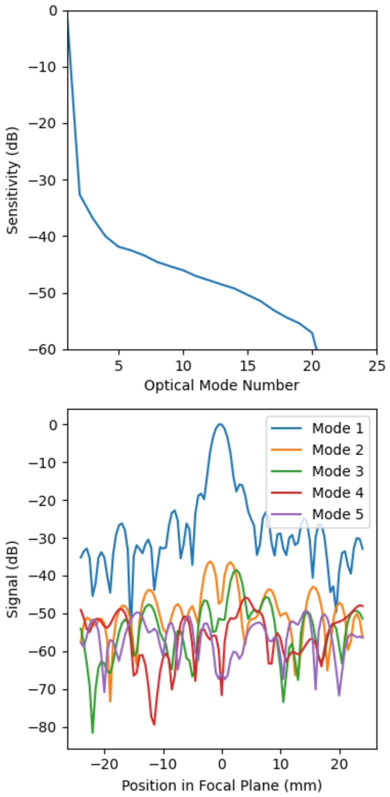

Fig. 2. Extracted sensitivity (top) and spatial form (bottom) of the natural modes extracted from the one-dimensional DRF.

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