Linearity of Terahertz Time-domain Spectrometers.

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***Abstract*— We present a method to quantify the linearity and dynamic range of terahertz detectors and show that terahertz time-domain-spectrometers exhibit a non-linear amplitude response at frequencies below 1.5 THz.**

I. Introduction And Background

Terahertz (THz) time domain spectroscopy (TDS) is widely used to determine absorption and refractive indices of materials in the frequency range 0.1 to 4 THz. Many TDS systems employ biased GaAs emitters combined with electro-optic detection to maximize the system dynamic range, 10^3 to 10^4 in amplitude typically. Electro-optic detection has been studied and shown to be linear [1,2] and the effect of variable dynamic range on spectral measurements analyzed [3]. However, the linearity of THz TDS systems is seldom experimentally verified and no published literature exists. We report measurements quantifying the linearity of two THz TDS measurement systems, using a National Physical Laboratory (NPL) designed calibration device. The NPL linearity kit contains ten equal elements, which can be progressively inserted into a parallel THz beam to provide controlled attenuation steps.

II. Measurement Methodology

The measurement of THz detectors linearity requires a measurement device, which can introduce a constant loss over the operating bandwidth and be varied in additive in steps. Absorbing or scattering materials cannot be used as both loss and scattering are strongly frequency-dependent. Beam splitters, such as wire-grids and pellicles have constant loss over a large bandwidth but are polarisation-dependent, sensitive to angles of incidence, or are vibration sensitive.

The NPL solution is to use a stack of high-resistivity silicon plates, which have negligible absorption over the THz band, but which can produce a nearly frequency-independent Fresnel loss [4]. Since the refractive index of silicon is 3.417 [4], the Fresnel loss is 0.509 in power, 0.299 in amplitude, for each plate inserted into a THz beam. A stack of such plates separated by air gaps will produce additive loss to the power corresponding to the number of plates in the stack. The absorption and refractive index of the plates used in the kit was measured, and was found to agree with Ref 4.

III. Results

The NPL linearity kit was used to characterize two TDS systems, both using biased GaAs emitters and ZnTe electro-optic detection. System 1 used a laser with a 16 fs pulse length and System 2 used a laser with a 60 fs pulse. In both systems the calibration kit was placed within a parallel part of the free space THz beam and the transmitted spectra recorded for up to ten plates, total loss 0.001 in power or 0.03 in amplitude.

Figure 1 and 2 show the spectral amplitudes for the two TDS systems, measured at frequencies from 0.25 to 3.5 THz as a function of the number of linearity kit loss elements placed within the beam. In a linear system, the data points for each frequency should fall on a straight line when plotted on the logarithmic amplitude scale used. At frequencies above 1.5 THz both systems are approximately linear within their dynamic range. However, at lower frequencies there is significant excess loss, especially with the first two plates. The departure from linearity increases at lower frequencies, and is more severe in System 1 than in System 2.

Investigations to determine the causes of the observed non-linearity in TDS are in process and we hope to present a full analysis at the conference. At this stage we believe the overlap of THz and optical beams in the electro-optic detection crystal may be the main contributor. However, it is important to stress that TDS systems should undergo regular amplitude linearity calibration to avoid significant measurement error below 1.5 THz.

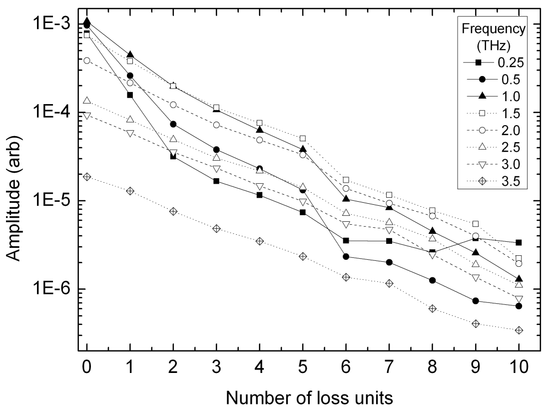

Figure 1: Linearity measurement for TDS system 1.

IV. Conclusion

We have presented a technique to enable linearity and dynamic range calibration over the terahertz band and shown that measurements made using TDS require such calibration to avoid significant measurement error below 1.5 THz. Investigations are continuing to determine the causes of the observed non-linearity in TDS, but we believe the overlap off THz and optical beams in the electro-optic detection crystal may be the main contributor.

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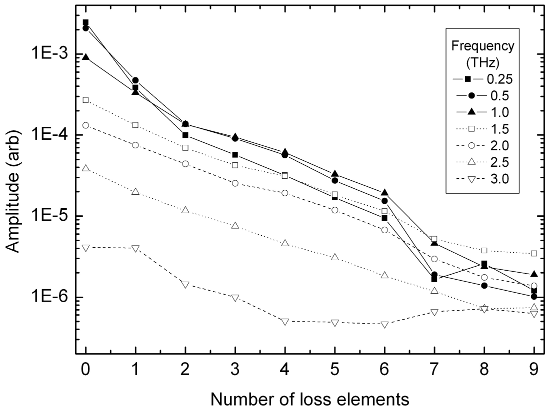

Figure 2: Linearity measurement for TDS system 2.

REFERENCES

[1] N. C. J. van der Valk, T. Wenckebach, P. C. M. Planken, "Full mathematical description of electro-optic detection in optically isotropic crystals", J. Opt. Soc. Am. B/Vol. 21, No. 3/March 2004

[2] Q. Chen, M. Tani, Zhiping Jiang, and X.-C. Zhang, ''Electrooptic transceivers for terahertz-wave applications,'' J. Opt. Soc. Am. B 18, 823–831 (2001).

[3] P. Uhd Jepsen, B. M. Fischer, "Dynamic range in terahertz time-domain transmission and reflection spectroscopy", OPTICS LETTERS, Vol. 30, No. 1 / January 1, 2005

[4] J. Dai, J. Zhang, W. Zhang, D. Grischkowsky, "Terahertz time-domain spectroscopy characterization of the far-infrared absorption and index of refraction of high-resistivity, float-zone silicon", J. Opt. Soc. Am. B 21, Vol 21, No 7/July (2004) 1379-1386

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