Performance Characterization Method of Broadband Terahertz Video Cameras

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Vishal S. Jagtap, Robin Zatta, Janusz Grzyb, and Ullrich R. Pfeiffer
Institute for High-Frequency and Communication Technology, University of Wuppertal, Germany

***Abstract*—Integrated THz systems comprising index matched optical media introduce discontinuities in the propagation path leading to an etaloning effect. The etaloning hinders the absolute accuracy of a measuring instrument thereby limiting its applicability. A methodology using computational notch filtering is implemented here to extract the true performance of a measuring instrument. Specifically, the responsivity and NEP of the portable room temperature 1k-pixel terahertz CMOS camera have been investigated using a continuously tunable broadband spectrally pure terahertz photomixer source. Applying methodology revealed a peak responsivity of 20 MV/W at 822 GHz with a 6-dB bandwidth of 265 GHz and a minimum integrated NEP of 2.9 nW with 1024 frames averaging at 30fps.**

I. Introduction

MILLIMETER–TERAHERTZ waves defined between 100 GHz – 3 THz have shown a tremendous potential in daily-life applications such as high-precision radars, non-destructive testing, materials identification, medical diagnosis, etc.[1]. In integrated THz systems, the index matched optical elements are implemented to improve the radiation coupling as well as the divergence of the radiation in free space. The dimensions of such intermediate media often comparable to the THz radiation wavelengths result in an undesired effect of etaloning (or fringing) due to multiple reflections in a broadband characterization. At strong resonance fields, these fringes can result in large swings between maxima and minima in the spectra masking the true performance of a measuring instrument. A priori knowledge of instrument's accurate spectral and power response is a must to implement it reliably in the investigation of an unknown sample. The physical properties (such as complex refractive index, surface roughness, etc) and chemical composition (by distinct rotational resonance frequencies) of an unknown sample can be extracted from a broadband spectroscopy [2],[3]. This requires absolute power and/or wavelength sensitive measurement capabilities which can be achieved only using a well calibrated and free from etaloning effect instrument.

In optical systems, anti-reflection coatings on the intermediate propagating media are readily available to suppress the etaloning. In THz systems, such coatings are seldom implemented due to significant absorption losses and relatively low available power. Therefore, etaloning effect needs to be treated computationally in a broadband THz measurements. This work presents an experimental-computational methodology to circumvent the problem of systematic unavoidable fringing effect and extract the true performance of a measuring unit. The broadband measuring system characterized here consists of a lens-integrated CMOS terahertz video camera [4] as a detecting unit and a spectrally pure continuously tunable photomixer frequency source between 0.1 THz – 1.3 THz with a resolution of 10 MHz [5]. Note that the CMOS detectors could be replaced by any other direct detector technologies such as microbolometers [6], Schottky diodes, SiGe HBTs, etc.. The methodology can equally be implemented to calibrate terahertz time domain spectrometer. The experiments and applied algorithm are, first, briefly introduced. Following, the extraction of responsivity and NEP characteristics of the camera is discussed.

II. Experiments

As depicted in Fig. 1(a) and 1(b), the camera was placed in two different configurations i.e. in back-to-back position and focal spot. The broadband source was continuously swept in a frequency range of 0.6 THz – 1.32 THz with a step-size of 1 GHz. By varying the longitudinal distance between source and camera, systematic etaloning due to the internal fixed components can be distinguished from those varying due to free space path. The camera is operated in video mode taking 1024 frames per frequency at a rate of 30 fps. The obtained response data were analysed by fast Fourier transformation and repetitive resonances in both set-ups were eliminated by notch filters to reconstruct the etaloning-free response. The same procedure was repeated for relative measurements using an identical receiver photomixer as the emitter mixer.

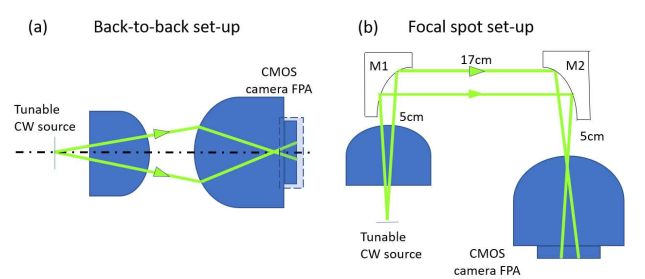

Fig. 1. Schematic of the experimental set-ups: (a) back-to-back and (b) focal spot.

III. Results

The measured response in the back-to-back and focal spot set-up, depicted in Fig. 2(a), exhibited significant etaloning throughout the spectrum. The path losses in the focal spot set-up were approximately 30%. The computational treatment revealed two strong systematic resonance frequencies of 4 GHz

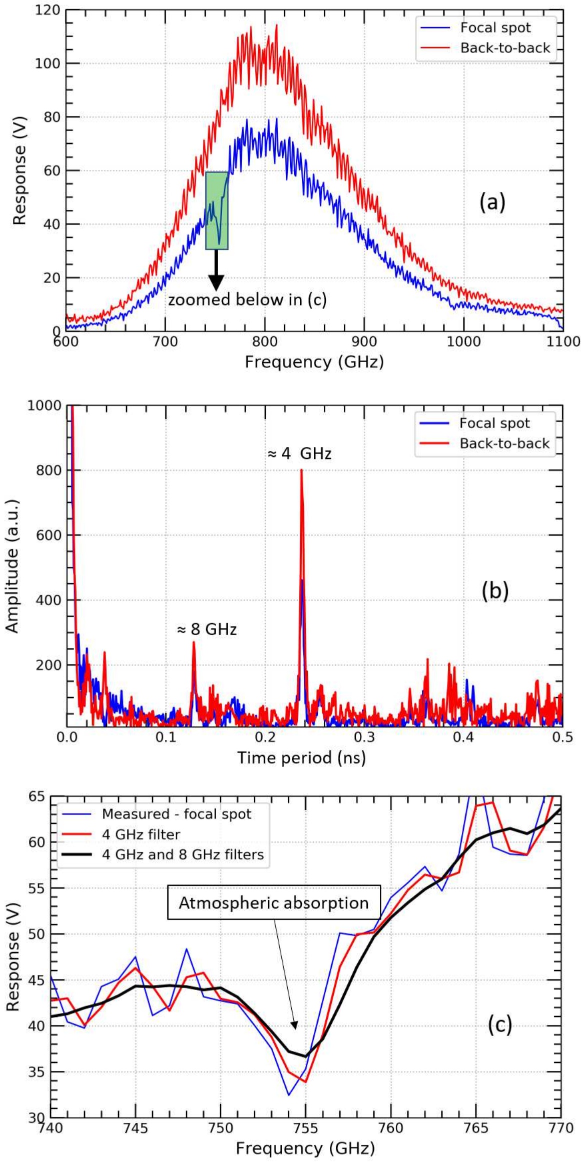

Fig. 2. (a) Measured spectral response, (b) FFT of the response highlighting strong resonances and (c) Improvement of measured response by filtering applied in increasing order of resonances.

and 8 GHz respectively, as can be seen in Fig. 2(b) originating from multiple reflections within the transmitter module. These were confirmed in the relative measurements performed using identical photomixer Tx-Rx instead of the CMOS camera. The fringe-free spectral response was extracted by applying the notch filters at these resonances, as shown in Fig. 2(c). The response could further be improved by measuring with a finer step-size. In this experiment, the frequency step-size was limited to 1 GHz for a scan between 0.1 THz – 1.32 THz due to time constraints.

After obtaining the fringe-free response, the absolute responsivity of the camera was calculated as the ratio of the integrated response over the pixels to the incident source power. The NEP was calculated dividing the measured RMS image noise by the

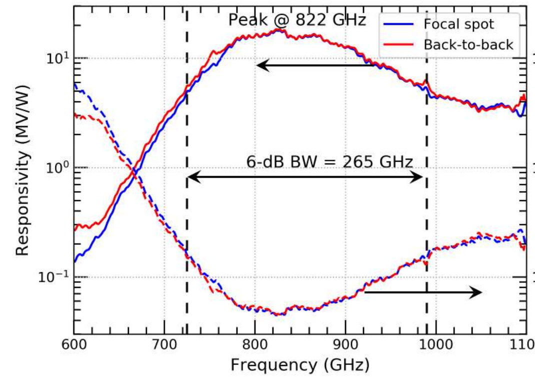

Fig. 3. Responsivity and average NEP of the CMOS terahertz camera after fringes filtering in both configurations.

responsivity [4]. As shown in Fig. 3, the camera shows a peak responsivity of 20 MV/W and an integrated NEP of 2.9 nW averaged over 1024 frames at 822 GHz with a 6-dB bandwidth between 725 GHz – 990 GHz.

IV. Summary

Notch filtering method has been implemented to extract the true performance of a broadband CMOS THz camera using continuously tunable CW photomixer source. The etaloning effect due to multiple reflections occuring within the intermediate propagation paths has been computationally treated. With a high frequency resolution, this method could result in deducing the performance parameters of a system with high accuracy.

Acknowledgement

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