Jerez, B., et al. (2018). Multi-octave spanning, absolute frequency, high resolution THz dual-comb spectrometer based on Electro-Optic Modulators: First spectroscopic measurements. *FTS2018: OSA Fourier Transform Spectroscopy: proceedings of Light, Energy and the Environment 2018 (E2, FTS, HISE, SOLAR, SSL): 5-8 November 2018, Singapore*. OSA Technical Digest (Optical Society of America, 2018), paper JW4A.2, [2] p.

DOI: https://doi.org/10.1364/FTS.2018.JW4A.2

Multi-octave spanning, absolute frequency, high resolution THz dual-comb spectrometer based on Electro-Optic Modulators: First spectroscopic measurements.

B. Jerez, A. Betancur, P. Martín-Mateos, C. de Dios and P. Acedo
Electronics Technology Department, Universidad Carlos III de Madrid, Leganés 28911, Spain
pag@ing.uc3m.es

Abstract: Our first and very recent results on a new approach to obtain compact and practical, multi-octave spanning, absolute frequency and high accuracy THz dual-comb spectrometers based on Electro-Optic modulators (EOMs) are reported. Two different schemes are described and evaluated with the final objective of obtaining a practical solution for THz spectroscopy and other applications in such frequency range.

OCIS codes: (300.6310) Spectroscopy, heterodyne; (300.6190) Spectrometers; (300.6320) Spectroscopy, high-resolution; (120.3930) Metrological instrumentation; (120.6200) Spectrometers and spectroscopic instrumentation

1. Introduction

The development of terahertz dual-comb spectroscopic (THz-DCS) systems is crucial for the achievement of high speed, high-resolution, high-accuracy and broadband spectroscopy needed to effectively make use of the densely distributed rotational and vibrational characteristic transitions of the 0.1-10 THz spectral region [1]. THz dual comb generation has been reported based, for example, on two free-running mode-locked lasers with adaptive resolution [2], or on dual-wavelength mode-locked laser for absolute frequency measurements [3]. Recently, efforts go in the direction of reducing the complexity of the reported architectures to obtain solutions that can be practical for THz spectroscopy and other applications [4].

In this work we present our first and very recent results on a new approach to obtain such a compact and practical, multi-octave spanning, absolute frequency and high accuracy THz dual-comb spectrometer based on Electro-Optic modulators (EOMs) [5]. The schemes proposed rely on our past works on continuous-wave sub-THz photonic generation [6], and EOMs dual-combs in the infrared range [7], and take advantage of the flexibility offered by externally generated Optical Frequency Comb (OFC) Generators using intensity or phase EOMs. Moreover, the use of a common Continuous Wave (CW) source for the probe and local oscillator (LO) combs, and the fact that all the beat-notes are generated from a common RF generator, provide with a superior frequency accuracy and stability and allows, as well, to easily incorporate phase stabilization mechanisms and real-time adaptive interferogram acquisition approaches to increase the Signal-to-Noise Ratio (SNR) [8].

2. Description of the EOM THz dual-comb spectrometers.

We have evaluated two different schemes, both based in EOMs, for our THz dual-comb spectrometer: the first one is based on the use of high-speed photodiodes for THz dual-comb generation and Schottky diodes (or similar devices) for detection (Figure 1.a). The second scheme makes use of Photoconductive Antennas (PCA) for both the generation of the probe THz comb and its detection using a local oscillator (LO) comb, as shown in Figure (1.b).

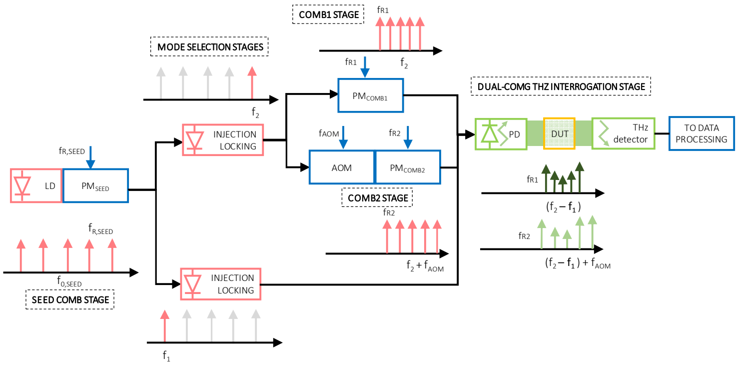

Fig. 1.a EOM THz Dual-comb spectroscopic architecture using high-speed photodiodes and a THz detector (Schottky diode or similar device). The scheme includes a EOM dual comb architecture like the one used in [7] that is mixed with a reference tone (f1) to generate the THz dual-comb using the concept described in [6].

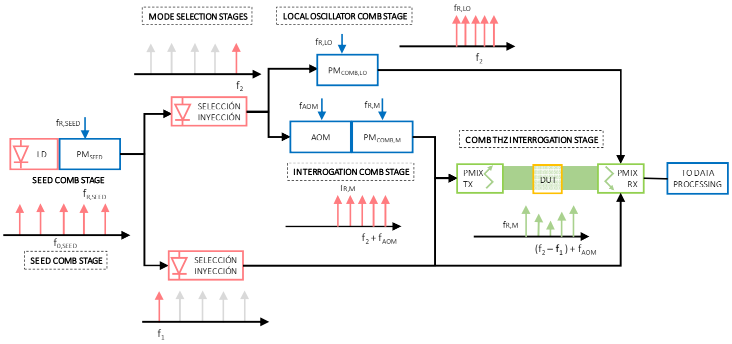

Fig. 1.b EOM THz Dual-comb spectroscopic architecture using Photoconductive Antennas (PCA). In this case the signal comb is generated in the transmission PCA using a EOM comb mixed with the reference tone (f1), and the LO comb is used to pump the receiver PCA.

We can see from Fig. 1.a and Fig.1.b that both schemes are very similar but still present substantial differences. In the first case the signal and LO combs are both generated on the same device and sent through the sample in a dual-comb interrogation architecture. Meanwhile in the second case the LO THz comb is not actually generated but used to drive the PCA in detection and the interrogation is carried out by a single probe comb enabling dispersive sample characterization. Advantages and disadvantages of both schemes are evaluated in terms of sensitivity, phase reconstruction and other parameters.

3. Initial comb characterization.

In Fig. 2 we show our first results using the scheme shown in Fig. 1.b. In this case a frequency range between 100 and 600 GHz is measured with a 500 MHz resolution for a total of 1024 frequency points. The spectrum is interrogated in set of 32 lines, each measurement taking only 80 ms (integration time). Absolute referencing of the generated beat notes allows for total spectrum reconstruction without ambiguities. Again, the flexibility of EOMs dual-combs allows as well for custom and on-line adjustment of the frequency resolution that can be made as small as several kHz (for ultra-high-resolution THz spectroscopy) or as big as several GHz for low-resolution ultra-fast measurements, covering several octaves.

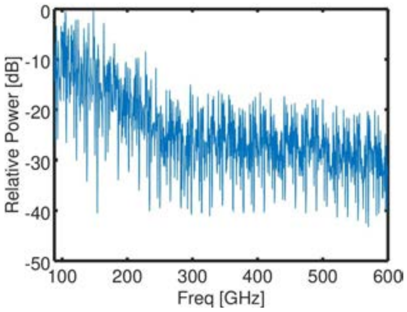

Fig. 2 Multi-octave sub-THz spectrum recovered with the THz-DCS system shown in Fig. 1.b. Frequency resolution is set to 500 MHz for a total of 1024 measurement points spanning from 100 GHz to 600 GHz

4. References

[1] Y. Yang, D. Burghoff, D.J. Hayton, J.-R. Gao, J.L. Reno and Q. Hu, “Terahertz multiheterodyne spectrsocopy using laser frequency combs”, Optica, vol. 3, no. 5, pp. 2334-2536 (2016)

[2] F.S. Vieira, F.C. Cruz, D.F. Plusquellic and S.A. Diddams, “Tunable resolution terahertz dual frequency comb spectrometer”, Opt. Express, vol. 24, no. 26, pp. 30100-30107 (2016)

[3] G. Hu, T. Mizuguchi, X. Zhao, T. Minamikawa, T. Mizuno, Y. Yang, C. Li M. Bai, Z. Zheng and T. Yasui, “Measurement of absolute frequency of continuous-wave terahertz radiation in real time using free-running, dual-wavelength mode-locked, erbium-doped fibre laser”, Scientific Reports, vol. 7 (2017)

[4] G. Hu, T. Mizuguchi, R. Oe1, K. Nitta, X. Zhao, T. Minamikawa, T. Li, Z. Zheng and T. Yasui, “Dual terahertz comb spectroscopy with a single free-running fibre laser” Scientific Reports, vol. 8 (2018)

[5] F. Walla, B. Jerez, P. Martin-Mateos, C. de Dios and P. Acedo, “Absolute-frequency high-resolution real-time terahertz dual-comb spectrometer”. 42nd International Conference of Infrared, Millimeter, and Terahertz Wave, WA4.3 (Cancún, 2017).

[6] A.R. Criado; C. de Dios; E. Prior; G.H: Döhler; S. Preu; S. Malzer; H. Lu; A.C. Gossard; P. Acedo “Continuous Wave Sub-THz Photonic Generation with Ultra-Narrow Linewidth, Ultra-High Resolution, Full Frequency Range Coverage and High Long-Term Frequency Stability” IEEE Trans. on Terahertz Science and Technology, Vol. 3 No 4, pp. 461 - 471 (2013)

[7] P. Martín-Mateos, B. Jerez, P. Acedo “Dual electro-optic optical frequency combs for multiheterodyne molecular dispersion spectroscopy” Optics Express, Vol. 23, Nº 16, pp. 21149-21158 (2015)

[8] P. Martin-Mateos; B. Jerez, P. Largo-Izquierdo, P. Acedo “Frequency accurate coherent electro-optic dual-comb spectroscopy in real-time” Optics Express, Vol. 26, Nº: 8, pp. 9700-9713 (2018)