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Photomixing for Coherent Retrieval of THz Waveforms from a Frequency Multiplier

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Abstract. THz waveforms generated with an electronic frequency multiplier are sampled with a heterodyne detection technique using a LTG-GaAs photomixer and the optical beat of two near-infrared lasers.

1 Introduction

The optical heterodyne conversion (photomixing) is a well-established approach used for bridging the terahertz spectral domain. This technique relies on a photoconductor coupled through a planar antenna (photomixer) with a response time in the sub-ps range. Two cw lasers emitting above the photoconductor bandgap are frequency detuned by a THz gap and irradiates the device. Upon the photomixer is biased, the photocurrent oscillating at the difference frequency drives the antenna and generates THz waves [1]. The photomixer used in this work is an LTG-GaAs photoconductor with a pattern of interdigitated electrodes driven by a spiral self-complementary antenna coupled to a 50-ohm microwave line. It has a quadratic response to the optical fields and an intrinsic non-linear current-voltage dependence. These characteristics have been exploited in direct and heterodyne detection schemes with the photomixer [2]. This contribution demonstrates two asynchronous optical sampling schemes with of the photomixing setup for terahertz pulse measurements.

2 Experimental setup

The THz source used in the experiment (Fig. 1.A) is an electronic frequency multiplier (Millitech AMC-10-R0000) driven by a microwave synthesizer (MW). It multiplies 6 times the MW signal and provides ~2 mW cw signal output in 75-110 GHz range. Terahertz waveforms are generated by pulse-modulating the MW synthesizer with a RF synthesiser (RF_{THz}). The pulse repetition frequency and the THz carrier frequency are phase-referenced to the quartz oscillator. The THz source output is focused on the antenna with a silicon lens mounted against the photomixer chip. The photomixer is driven by two extended-cavity diode lasers (DL1, DL2) emitting around 825 nm operated in a free-running mode. The laser beams are spatially overlapped, frequency shifted with an acousto-optic modulator (AOM) and focused on the photomixer electrodes. Laser beams can be pulse-modulated by switching the AOM with a RF synthesiser (RF_{AOM}) referenced to the quartz oscillator. That allows to have the same time reference for the pulsed operation of the optical and the THz source. Microwave (AC port) and low-frequency (DC port) responses of the photomixer are addressed through a Bias-T and measured with a spectrum analyser (SA) with 50-Ω input impedance.

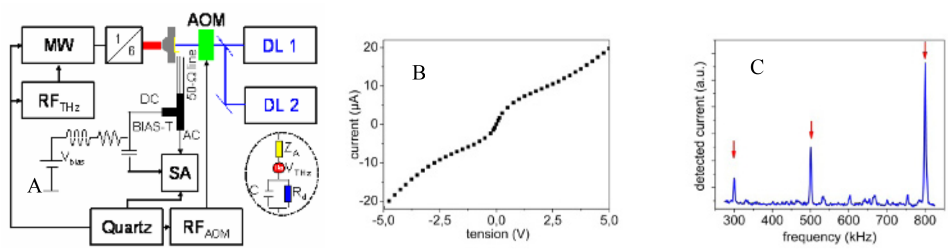

Fig. 1.A. Experimental setup. The photomixer is biased through a RL choke. SA is alternatively coupled on the DC port or capacitively on the AC port. Inset: equivalent model circuit for the detection with the photomixer. R_d dynamic resistance at the bias point under the given optical power, V_{THz} antenna-induced Thévenin voltage, Z_A antenna impedance. Z_A=72-Ω at THz frequencies, it has a complex dependence in the microwave regime and the obvious limit ZA→0 at DC.

Fig. 1.B. Current-voltage dependence of the photomixer under 8 mW optical power.

Fig. 1.C. ASOPS with the pulsed laser source. Optical power 16 mW, bias -18 mV. RBW=3 kHz, sweep time 152.8 ms, 50 video averages

3 Terahertz waveform sampling with laser pulse-modulation

Detection with the photomixer can be described in terms of rectification in the small-signal regime. The THz wave incident on the antenna induces a THz Thévenin voltage in the photomixer circuit, depending on a coupling factor, the THz electric field and the antenna impedance. The rectified current depends on the second-order derivative of the current-voltage characteristic (Fig 1. B). In addition, the THz voltage applied on the optically-modulated conductance of the photomixer allows sampling the terahertz field amplitude with the laser pulses. An asynchronous optical sampling (ASOPS) scheme is demonstrated by pulse-modulating the laser source and the THz source at slight different repetition rates (respectively at 800 kHz and 500 kHz). The frequency-domain dependence of the low-frequency photomixer current (Fig. 1.C) displays the laser pulsed-modulation signal, the THz rectification signal as well as the ASOPS signal at 300 kHz, corresponding to the difference of the pulse-modulation frequencies.

4 Terahertz waveform sampling with pulse-modulation of the optical beat

In the heterodyne detection, the antenna-induced Thévenin voltage is applied on the conductance modulated by the optical beat. That leads to a down-converted signal in the microwave domain. This can be discussed in terms of rectification in the small-signal regime. The optical beat-induced voltage mixes with the antenna-induced voltage through the photomixer’s second-order current-voltage nonlinearity. That yields the heterodyne current carrier at the difference-frequency between the optical beat and the terahertz source. Using a pulsed optical beat and a pulsed THz source leads to multi-frequency heterodyne mixing which adds sidebands to the carrier that are spaced by the pulse modulation frequencies.

THz source operated at 86 GHz is pulse-modulated at 9 MHz. The resulting frequency comb is down-converted to the microwave domain with the optical beat. The current spectrum recorded in the microwave range (Fig 2.A) with the non-modulated optical beat displays sidebands separated by the pulse repetition frequency over ~150 MHz frequency span. Alternatively, the non-modulated THz source is down-converted with an optical beat that is pulse-modulated with the AOM at 2.2 MHz. The current spectrum (Fig. 2.B) displays sidebands separated by the pulse-repetition frequency with ~1 MHz linewidth determined by the spectral purity of the free-running diode lasers. When both THz source and optical beat are pulse-modulated (respectively at 9 MHz and 2.2 MHz) a multi-frequency heterodyne asynchronous optical sampling is demonstrated. Fig. 2.C displays the current spectrum where the most intense spectral features are separated by the pulse-repetition frequency of the THz source. Each spectral feature has a structure shown in the inset with sidebands separated by the AOM pulse-modulation frequency that is similar with spectrum displayed in Fig. 2.B, although the SNR is smaller. In addition, a part of the current spectrum generated in the photomixer by the pulsed optical beat and the pulsed THz source has been recorded at low-frequency (Fig. 2.D). It displays the THz rectification signal at 9 MHz as well as th e multi-heterodyne mixing sidebands respectively at 6.8 MHz and 11.2 MHz.

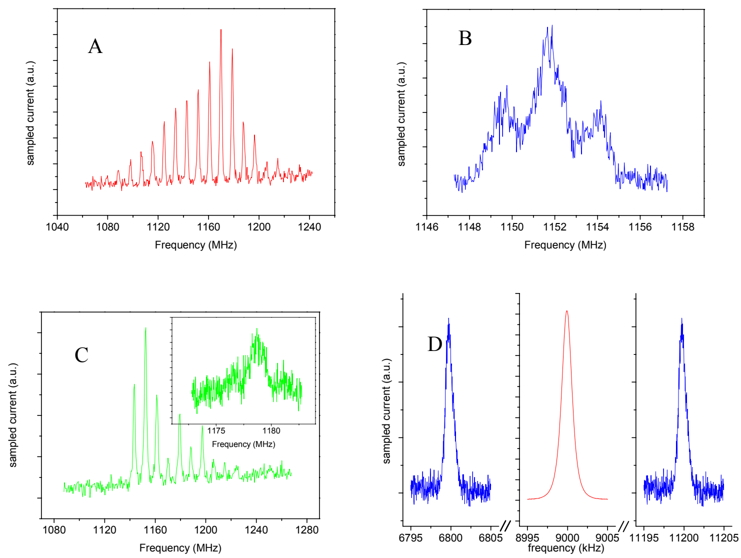

Fig. 2.A. Frequency dependence of the THz comb. Bias 52 mV, combined optical power 16 mW. RBW=1 MHz, sweep time 4 ms, 50 video averages.

Fig. 2.B. Frequency dependence of the optical beat comb. Bias 52 mV, combined optical power 16 mW. RBW=100 kHz, sweep time 5 ms, 50 video averages**.**

Fig. 2.C. ASOPS with the pulsed optical beat. Bias 52 mV, combined optical power 16 mW. RBW=1 MHz, sweep time 4 ms, 50 video averages. Inset: a component of the frequency comb, RBW=100 kHz, sweep time 5 ms, 50 video averages**.**

Fig. 2.D. Low-frequency sampled signals. RBW=1 kHz, sweep time 275 ms, 100 video averages.

5 Conclusion

Asynchronous optical sampling of a pulsed THz electronic frequency multiplier with a photomixer is demonstrated. This approach has the advantage to deliver in a straightforward way THz pulses with carrier frequency and pulse-repetition rate referenced to a frequency standard. The exceptional frequency bandwidth of the photomixer opens the way to characterize with the ASOPS scheme the pulsed operation of electronic multipliers over a broad spectral domain.

References

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