TeraHertz and metrology

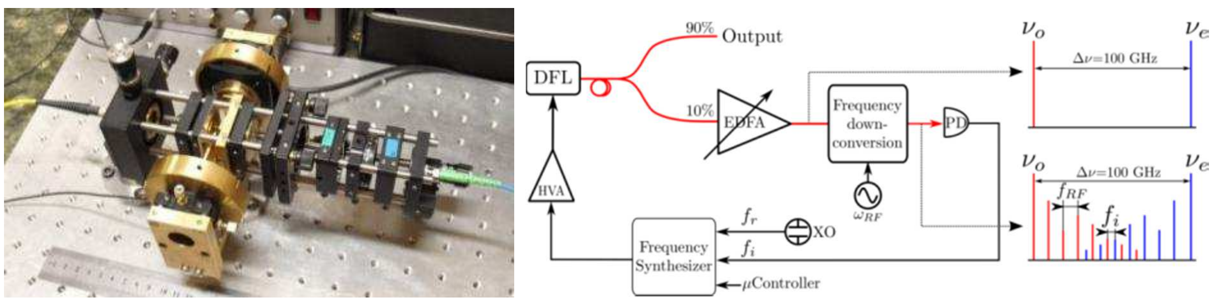
The objective of this research activity is to develop optical means to generate frequency references with high spectral purity in the teraHertz range, with record frequency stability. The applications of such references are high-resolution teraHertz spectroscopy, teraHertz metrology, and heterodyn detection of THz signals at room temperature.

The scientific activities in this domain are closely related to the research carried out in **Laser dynamics**, and correspond to an extrapolation of our work in **Microwave photonics** to the teraHertz range.

Opto-electronic phase lock loop

Within this research, different optical solutions have been designed to realize high-stability oscillators in the microwave and THz range. These techniques are based on the stabilization of the beatnote frequency produced by a dual-freuqency laser cavity, oscillating at the difference frequency between the two optical lines emitted by the laser. Locking this beatnote on an external frequency reference makes it possible to transfer the stability of the latter on the beatnote frequency, although the two optical lines show lower frequency stability.

Within this framework,we have recently demonstrated a new concept of opto-electronic frequency down-conversion based on the generation of an optical frequency comb around each optical carrier. This comb is produced by optical modulation of the beatnote signal. The two interleaved combs produce a signal at an intermediate frequency (in the MHz-GHz range), whose spectrum is a replica of the spectrum around the THz beatnote. When the latter is produced by a dual-frequency laser, the intermediate signal carries the phase noise of the high-frequency beatnote. We have then demonstrated that is was possible to lock the THz beatnote on an external synthesizer, using standard microwave components and low-frequency electronics. This phase locking technique, that we termed OEPLL for Opto-Electronic Phase Lock Loop also provides a continuous tunability of the phase-locked signal, although the phase locking electronics has a fixed frequency [Rol11a].



(a) (b)

Fig. 1 : (a) Photograph of the Er:Yb dual-frequency laser (DFL) at 1,55 µm. (b) Experimental sketch of the OEPLL. (DFL, dual-frequency laser; EDFA, Erbium-doped fiber amplifier; PD, photodiode; HVA, high-voltage amplifier; XO, 10 MHz quartz oscillator). The optical spectrum at the DFL output is sketched on the right, respectively before (upper) and after (lower) the frequency down-conversion process.

This technique has been applied first on a microchip laser, showing a beatnote tunability between 10 to 60 GHz [Rol11b], then to a THz oscillator obtained with a 1.5 µm dual-frequency laser with separated polarization states [Rol11a]. The opto-electronic oscillator realized is today continuously tunable from a few MHz to 380 GHz, with a linewidth under 1 Hz. Extrapolating phase noise spectra allows us to assess that the obtained stability is of the order of the mHz. Frequency down conversion based on four-wave mixing has recently been obtained, enabling efficient OEPLL to be designed with off-the-shelf components only [Rol14a].

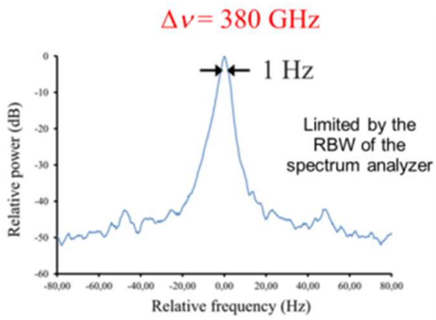
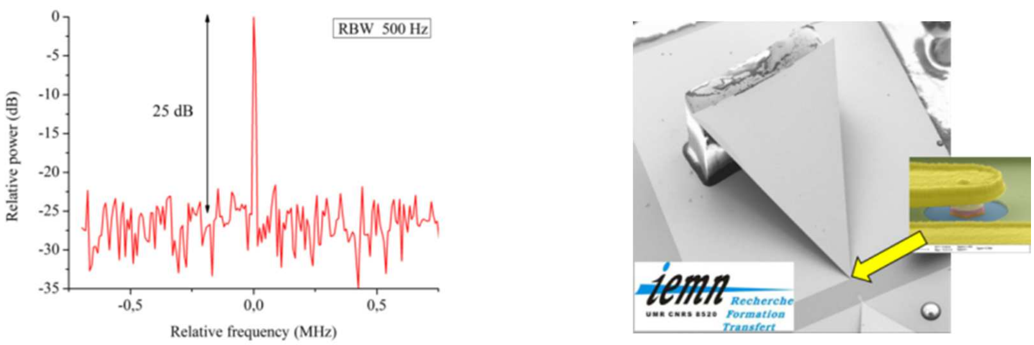


Fig. 2 : Stabilized beatnote spectrum at 380 GHz showing a linewidth below one Hertz (limited by the measurement instrument precision).

In addition, a collaboration with IEMN in Lille has also permitted to use these sources to generate a continuous-wave radiation at 1 THz using UTC photodiodes developed at IEMN, coupled with horn antennas [Rol14b]. The spectral purity obtained enables THz heterodyne detection at room temperature with a signal to noise ratio of about 60 dB at 300 GHz and about 20 dB at 1 THz.



(a) (b)

Fig. 3 : a) UTC photodiode and antenna developed at IEMN of Lille (Photograph IEMN) ; b) A signal-to-noise ratio above 20 dB was obtained on the one teraHertz radiation generated by coupling a dual-frequency laser at 1.55 µm developed at IPR on a UTC photodiode from IEMN.

Selected publications:

[Rol11a] A. Rolland, G. Loas, M. Brunel, L. Frein, M. Vallet, M. Alouini, "Non-linear optoelectronic phase-locked loop for stabilization of opto-millimeter waves: towards a narrow linewidth tunable THz source," Optics Express, 19 (19), 17944-50 (2011).

[Rol11b] A. Rolland, M. Brunel, G. Loas, L. Frein M. Vallet, M. Alouini, "Beat note stabilization of a 10-60 GHz dual-polarization microlaser through optical down conversion," Optics Express 19, 4399-4404 (2011).

[Rol14a] A. Rolland, *et al.*, "Narrow Linewidth Tunable Terahertz Radiation By Photomixing Without Servo-Locking," IEEE Transactions on Terahertz Science and Technology, 4 (2), 260-266 (2014).

[Rol14b] A. Rolland, L. Pouget, M. Brunel, M. Alouini, "Terahertz Optoelectronic Down-Conversion and Phase-Locking Through Four-Wave Mixing," IEEE Photonics Technology Letters, 26, 1944-1947 (2014).

Very low phase noise microwave/THz signal generation on optical carrier at 1.5µm

Design of a compact optical source of millimeter-wave radiation

Continuous THz source by photomixing at 800nm on Titane-Sapphire dual-frequency cavity

Time-domain teraHertz spectroscopy

PhD theses (past / ongoing):

Antoine Rolland, « Oscillateurs ultrastables millimétrique et teraHertz par boucle à verrouillage de phase optoélectronique », 2013

Gwennaël Danion, « Oscillateur micro-onde à teraHertz ultra-stable », 2015

Joachim Boerner, « Theoretical and experimental study of ultrastable solid-state laser delivering millimeter wave and teraHertz signals »

Ayman Hallal, *« Laser impulsionnel à faible gigue »*

Collaboration:

Institut d'Electronique, de Microélectronique et Nanotechnologie – IEMN (Lille)

Laboratoire de Physique des Lasers, Atomes et Molécules – Phlam (Lille)

Thales Research and Technology (Palaiseau)

Observatoire de Nice-Côte d'Azur

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