A COMB-BASED HIGH RESOLUTION THz SPECTROMETER

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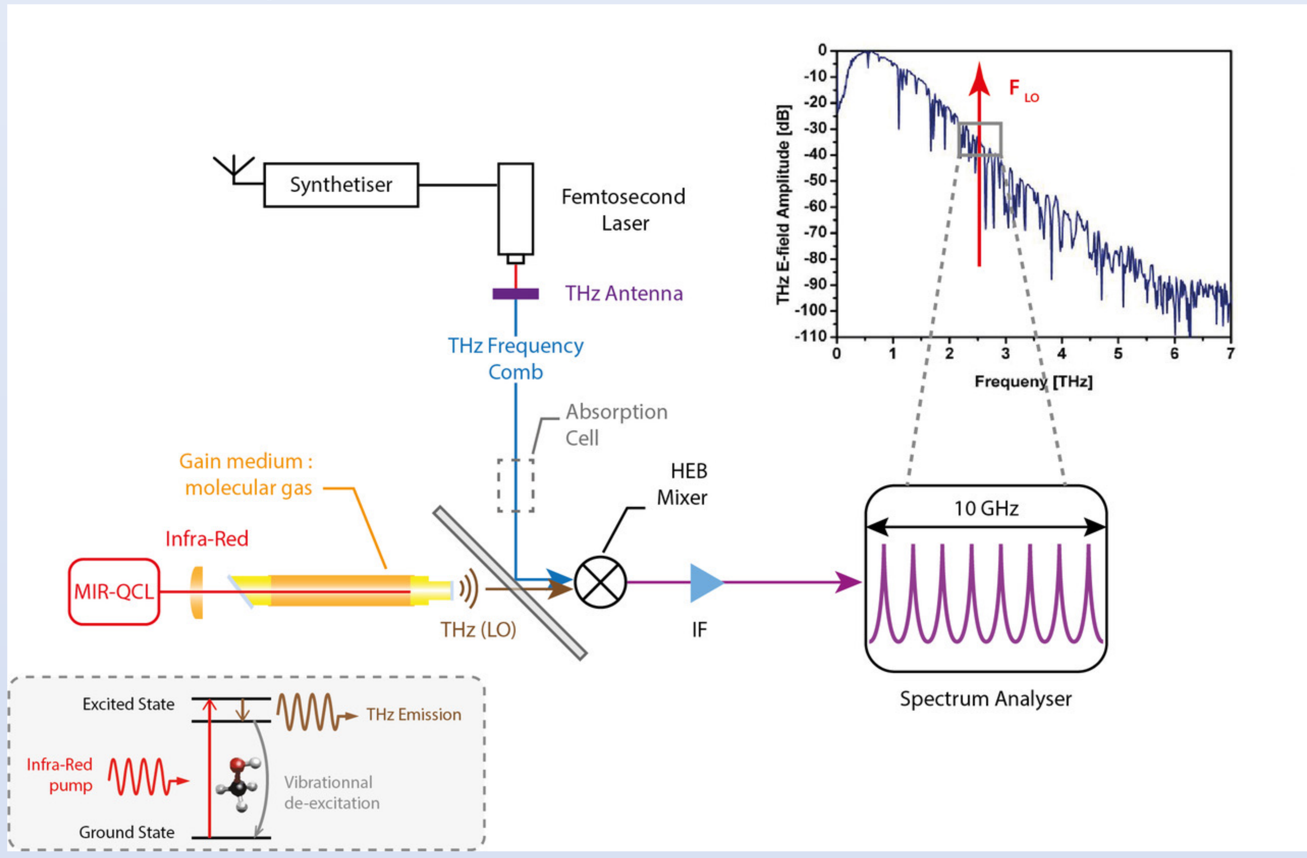
Our project aims to design a unique THz spectrometer with unprecedented capabilities in terms of frequencies accuracy (<50kHz), resolution (<50 kHz) and spectral coverage (1-4 THz) which can provide a unique solution for high resolution spectroscopy

Motivation

The domain of THz waves is less mature than the neighboring spectral bands there is no single spectrometer working on a very wide spectral band and at high resolution

Schematic Overview

- A THz source based on a dedicated frequency comb (FC)
- An absorption cell
- A heterodyne receiver

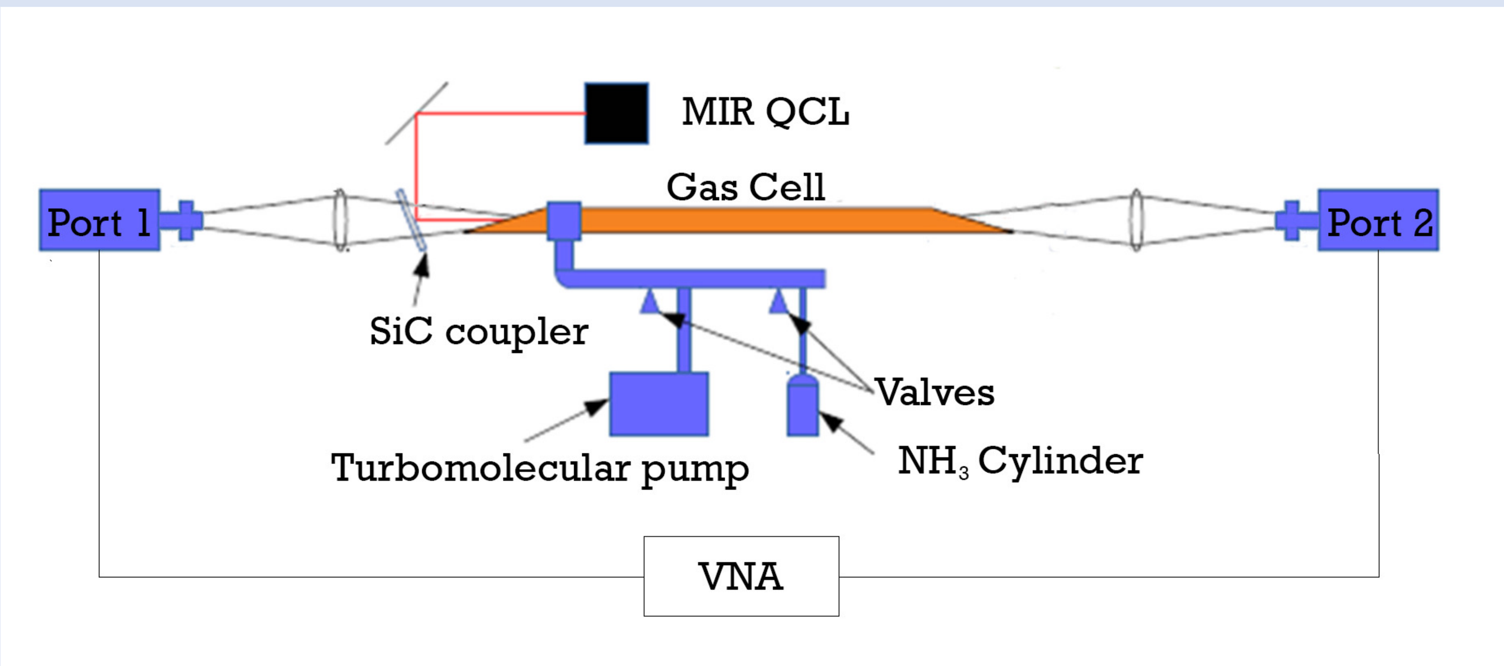


Heterodyne Receiver

The heterodyne receiver will be based on a Hot Electron Bolometer (HEB) used as a mixer and a local oscillator (LO). This LO will be constituted of a molecular laser developed at IEMN[1]. An electrical spectrum analyzer will record the microwave beat frequencies obtained with an instantaneous bandwidth of 5 GHz. The position of this frequency window will be selected by the frequency of the LO. Small changes in the FC repetition rate, will allow to sweep continuously the frequency of each tooth of the FC in order to record the high-resolution spectrum of the sample.

LO Experimental Setup

The LO is a THz molecular laser optically pumped by a mid-infrared (MIR) quantum cascade laser (QCL) based on ammonia (NH_3)[2,3]. In order to design a laser, experimental values of the gain for each transition are needed.



The setup consist of:

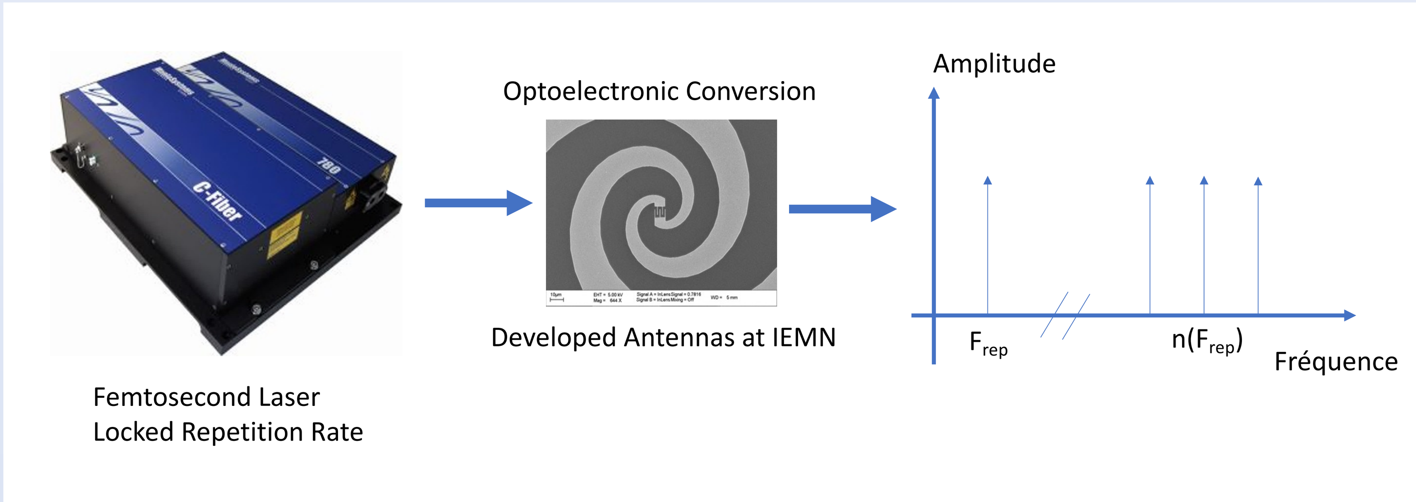
- 750–1100 GHz vector network analyzer (VNA)
- A 46-cm long copper tube is used as a gas cell for NH_3.
- A THz and MIR transparent high resistivity silicon window inclined at the Brewster angle is placed at both ends of the cell to avoid any reflection,

The THz beam from the VNA is superposed to the MIR beam of a QCL tunable from 10 to 10.6 µm.

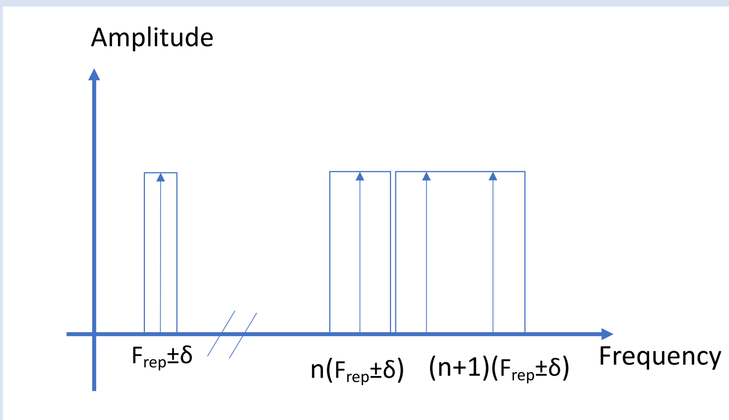
Objectives

- Set up an unrivaled instrument for high-resolution studies in a wide spectral band
- Produce and characterize a THz comb with, if possible, a repetition rate higher than 1 GHz

THz Source



The FC is based on a femtosecond laser that delivers ultrashort optical pulses which are focused onto a photoconductive antenna. The radiated THz beam forms a THz offset-free FC with a periodicity fixed by the repetition rate of the laser. This repetition rate will be tunable and will be referenced onto a "standard" of frequency such as the GPS signal or a rubidium clock. It will allow the discrete frequency positions to be moved in order to obtain a continuous coverage of the 1-4 THz frequency range



$$F_{rep} = 1\ \text{GHz} ;\ 1\ \text{THz} = 1000\ \text{GHz}$$

$$n = \frac{1000\text{GHz}}{1} = 1000$$

$$n(\text{Frep} + \delta) = (n+1)(\text{Frep} - \delta)$$

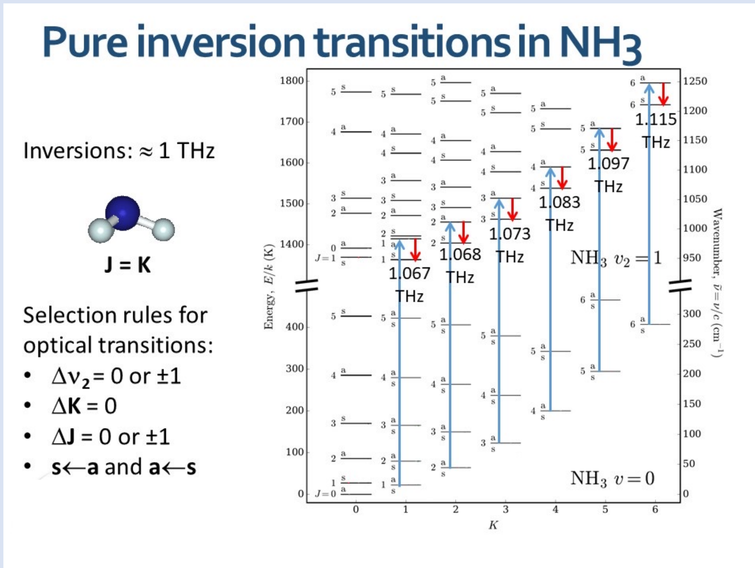
$$n = \frac{F_{rep} - \delta}{2\delta}$$

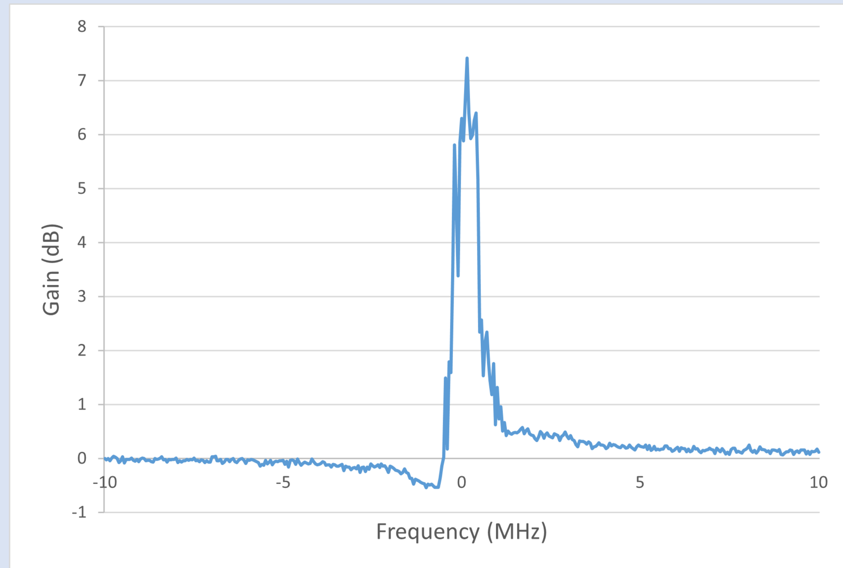
$$\delta = \frac{F_{rep}}{2n+1} = \frac{100\text{MHz}}{2001} \simeq 50\text{KHz}$$

$$F_{rep} \pm \delta = 1\text{GHz} \pm 50\text{KHz}$$

Gain

THz gain measured for the (J=3, K=3) pure inversion transition of NH_3. The spectrum is shifted by 1073049.9 MHz





The gain value is obtained by calculating the ratio between the THz transmission measured with and without the gain medium inside the cell. This figure shows a typical experimental result for the strongest transition, a maximum gain of 7.5 dB is measured for a pump power of 23mW and a pressure of 1.6 µbar.

References:
[1] M.-H. Mammez et al., Adv. Photonics Res. 2022, 2100263.
[2] A. Pagies, G. Ducournau, J.-F. Lampin, APL Photonics 2016,1, 031302.
[3] M. Mičica et al., Opt. Express 2018,26, 21242.