Optical Phase Locked Loop for Quantum Cascade Laser Frequency Combs

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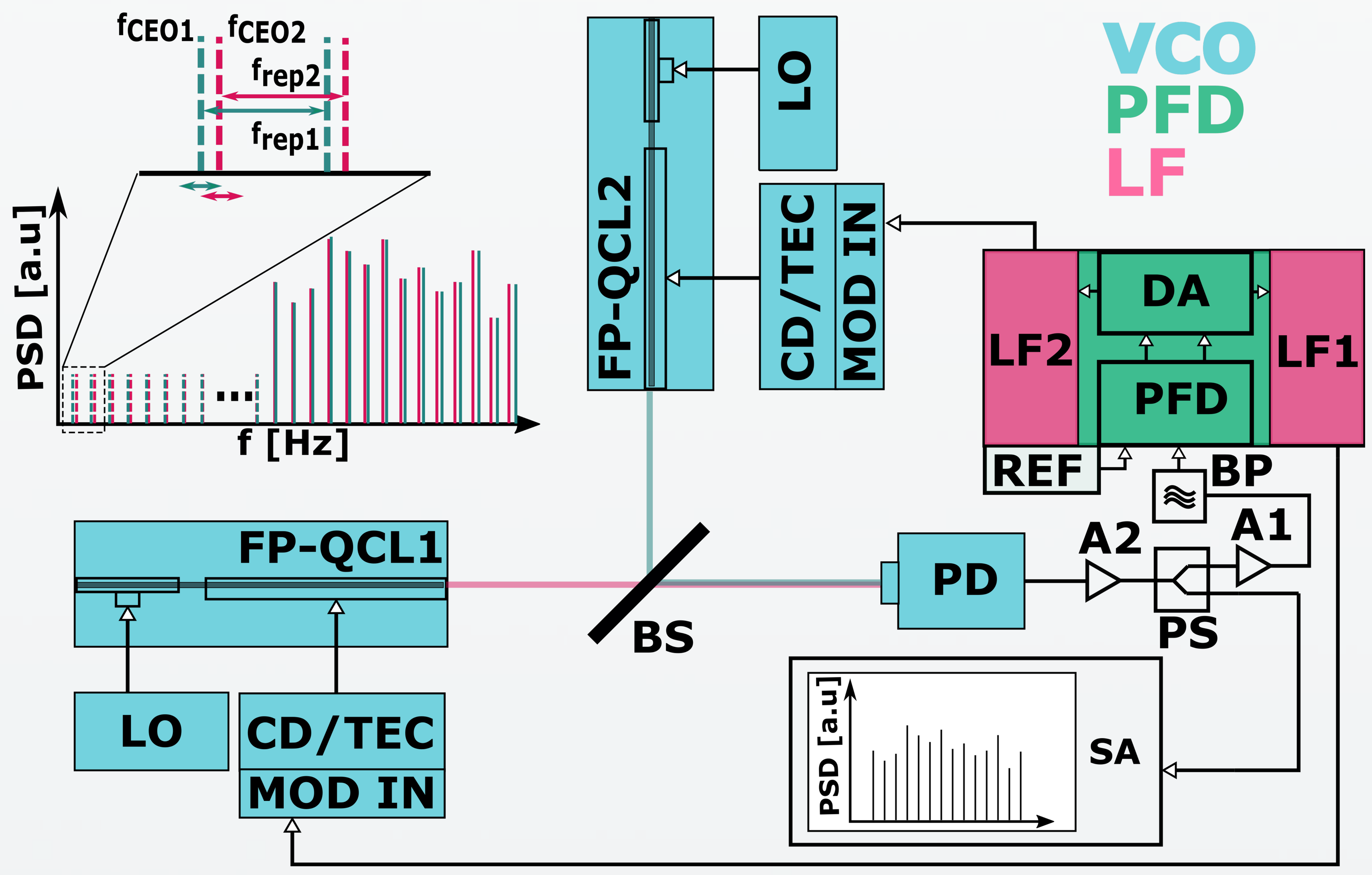
Introduction

The mid-infrared "molecular fingerprint" region ($3\mu m$- $30\mu m$) contains a variety of unique optical absorption features (e.g NH_3,CO_2). Dual comb spectroscopy employing Quantum Cascade Laser (QCL) frequency combs can be applied to investigate such absorption features in the more easily accessible radio-frequency (RF) domain. This can be achieved by superposition of the optical fields of two QCL frequency combs with slightly different repetition frequencies on a single fast photodetector. Conversion of the optical spectra to the RF domain holds great potential for the integration of spectroscopic applications from trace gas analysis to real-time chemical sensing. A challenging factor hindering fast and reproducible measurements is imposed by temperature fluctuations and electronic noise, often leading to highly unstable heterodyne beating signals. We present a reliable phase locking technique based on a dual feedback optical phase locked loop (OPLL) setup as well as a simple theoretical model for loop-filter parameter range prediction.

OPLL Setup



The dual feedback OPLL setup consists of three main parts comparable to a conventional phase-locked-loop setup:

- **Voltage Controlled Oszillator (VCO):** QCL1 and QCL2 superimposed on a 1GHz VIGO photodetector (PD) via a beam-splitter (BS) to produce a beating signal in the RF-domain
- **Phase Frequency Detector (PFD):** Compares one bandpass-filtered beatnote tooth to a stable reference oscillator (REF) producing an error signal proportional to the phase difference
- **Loop Filter (LF):** The phase error signal from the PFD is split up and fed back via two loop filters to the modulation inputs of the current drivers for relative phase locking of the two combs in the optical domain

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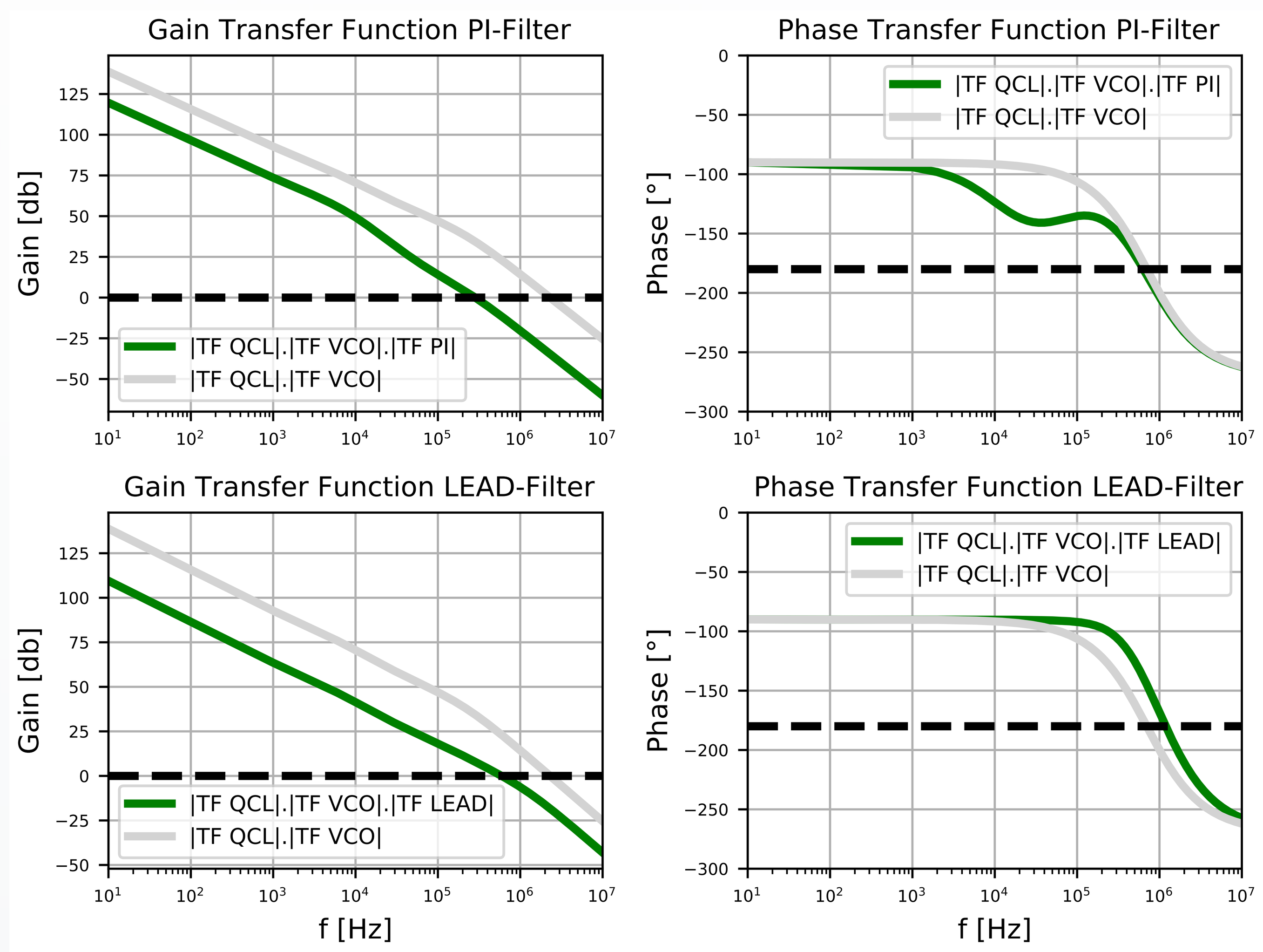
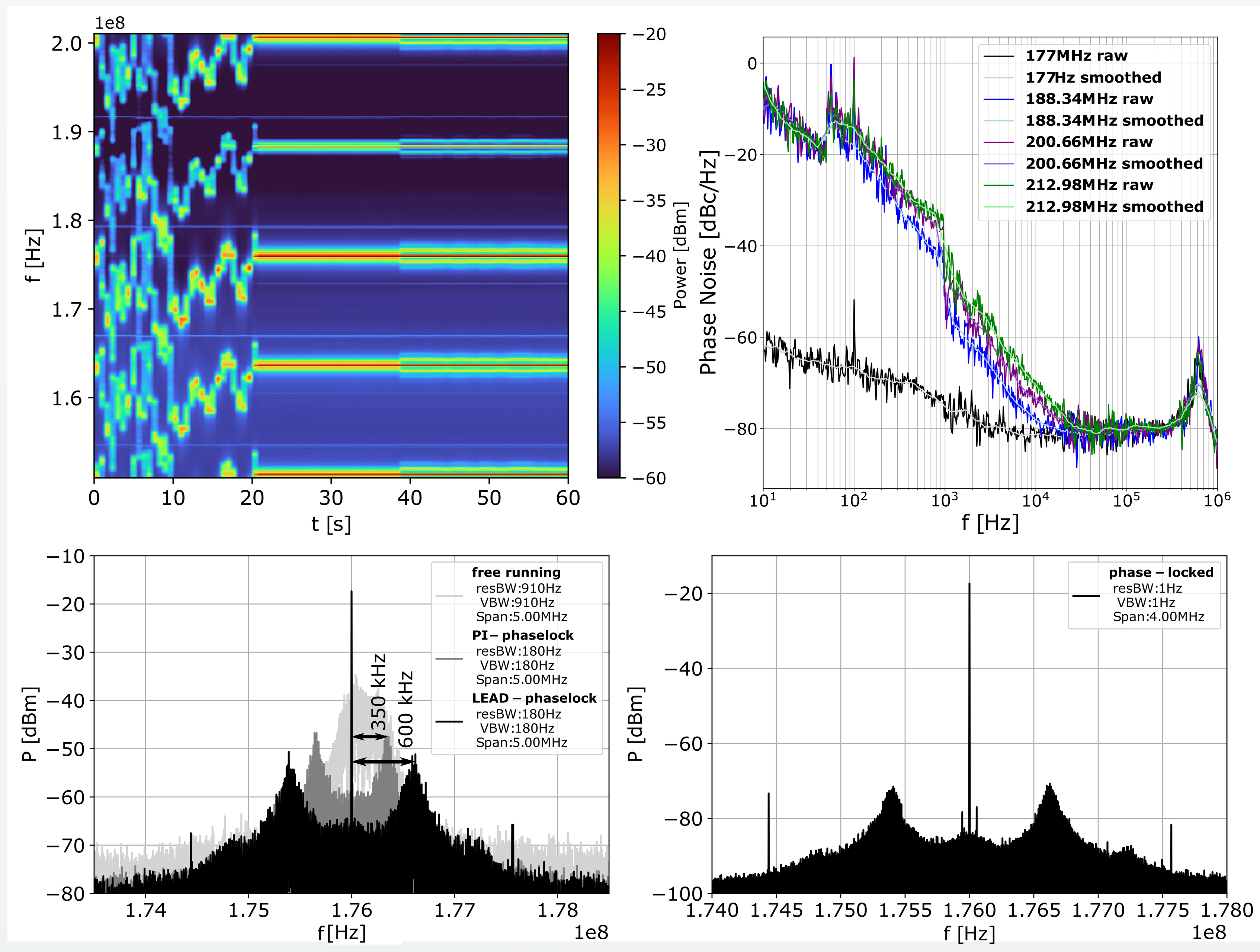
Theoretical Model



- **Required Measurements:** PFD sensitivity (V/rad) and the heterodyne QCL frequency modulation sensitivity (Hz/V)
- **Bode Stability Criterion:**
  Gain Crossover at $0dB$ => Phase > $-180°$
  Phase Crossover at -180° => Gain < $0dB$

Phase Locking Results



Summary

- Phase locking of the QCL frequency comb setup using a dual feeback OPLL
- 600 kHz stable phase locking bandwidth employing theoretical model to predict the loop filter parameter ranges
- Possibility of RF injection-locking for the improvement of phase noise across the entire spectrum