Controlling a Quantum Cascade Laser Frequency Comb with an External Radio Frequency Injection

Audrey Zeng, Advisor: Gerard Wysocki

Department of Electrical and Computer Engineering, Princeton University
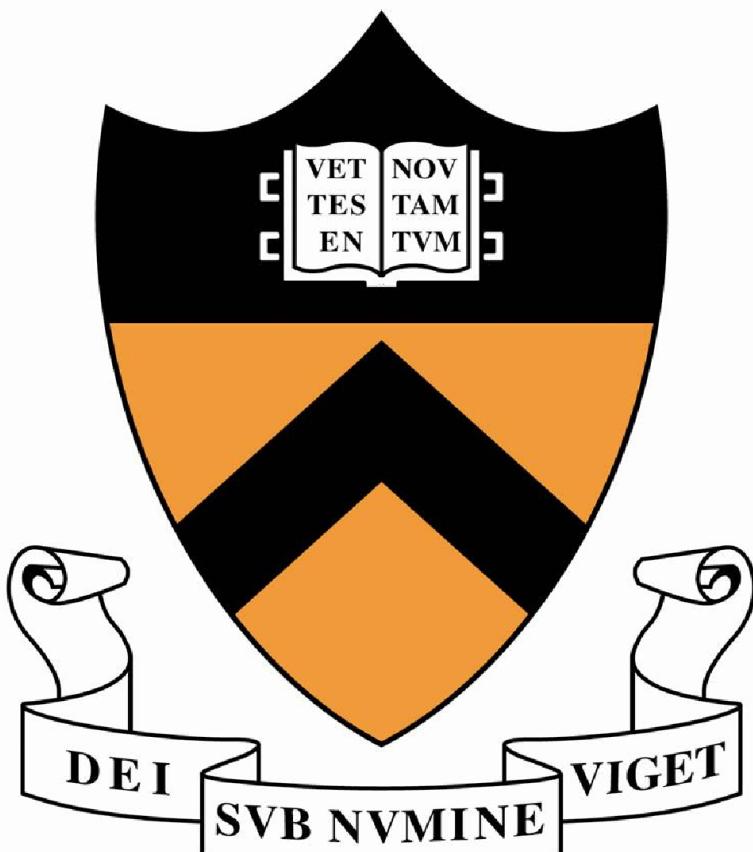
## Quantum Cascade Laser Frequency Combs
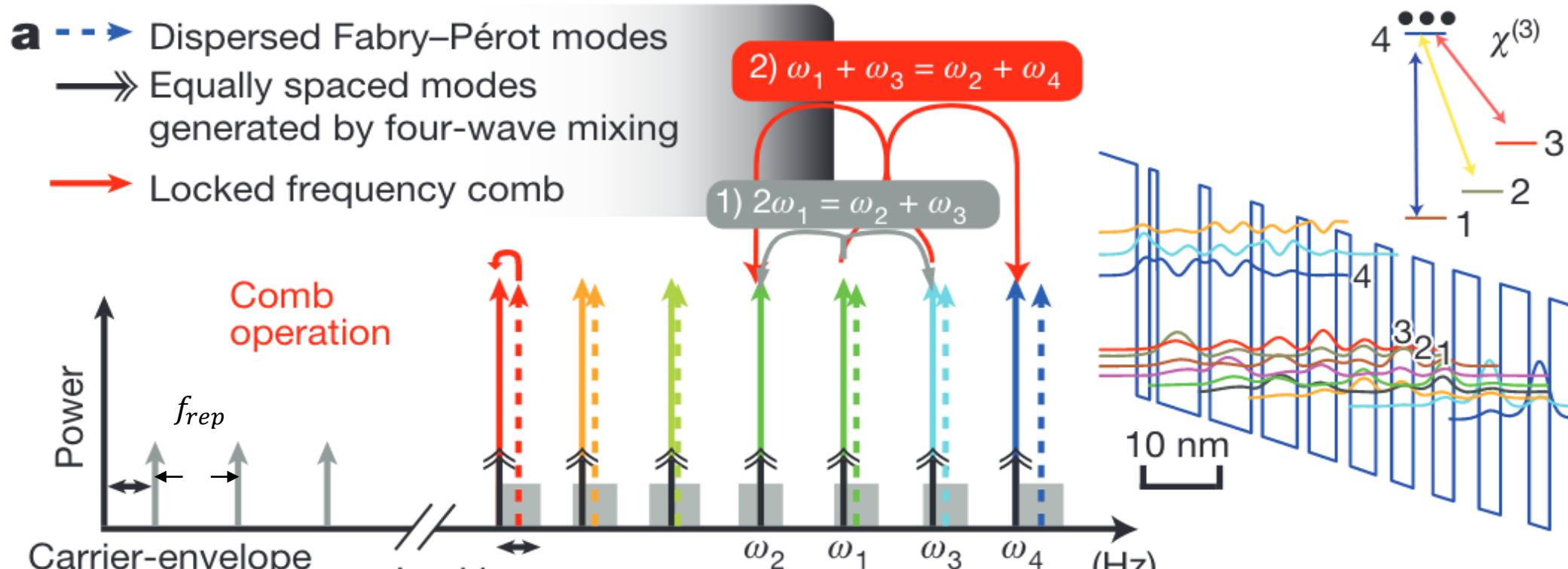
Fig. 1: QCL-FC operation[1]

Advantages:
- Mid-IR operating range
- Self-starting comb generation

Disadvantages:
- f_{ceo} and f_{rep} are hard to reproduce
- Unstable f_{rep} and f_{ceo}

- To characterize the comb, each comb mode frequency can be calculated by $f_{ceo} + nf_{rep}$

Goal: stabilize f_{rep} and f_{ceo} with one external radio frequency (RF) injection

f_{rep} and f_{ceo} effects with RF Injection

- f_{rep} can be locked to an external RF injection at frequency f_{rep}
- f_{ceo} remains unstable

- Greater injection power caused a greater BN shift in one direction:
→ Can we use power/amplitude modulation (AM) to stabilize f_{ceo}?
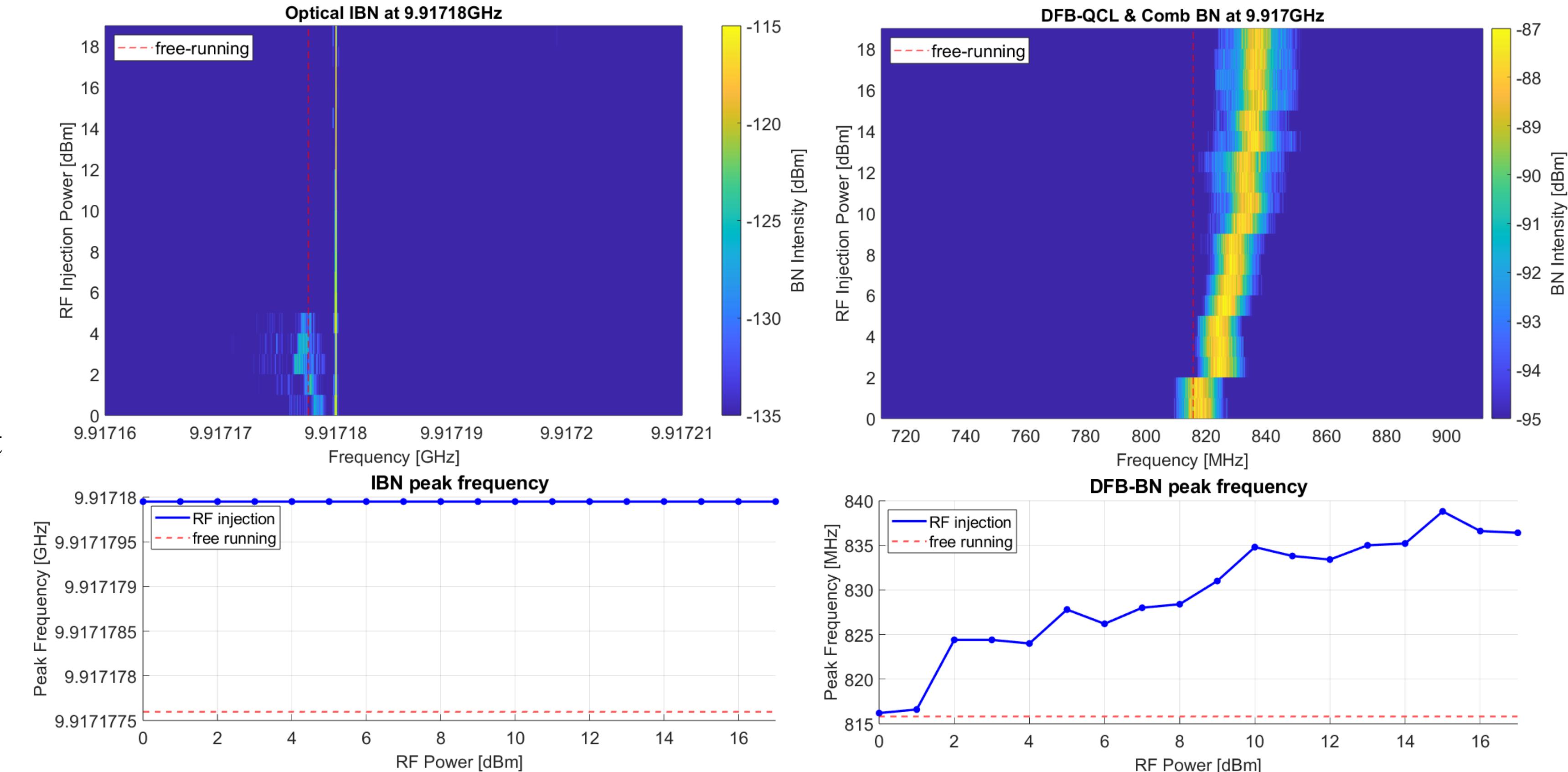
Closed Loop Control

Fig. 3: Feedback Loop Setup and Schematic
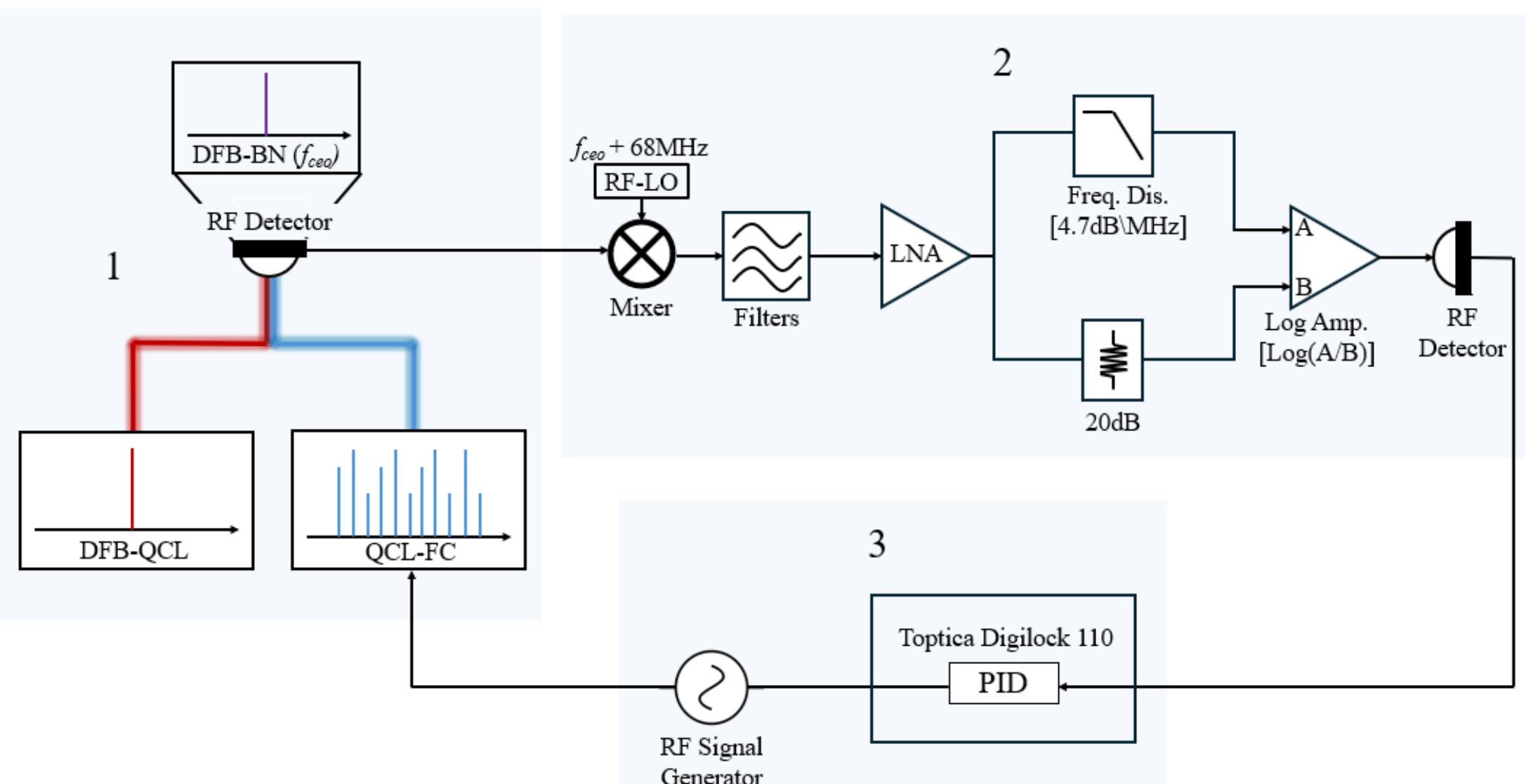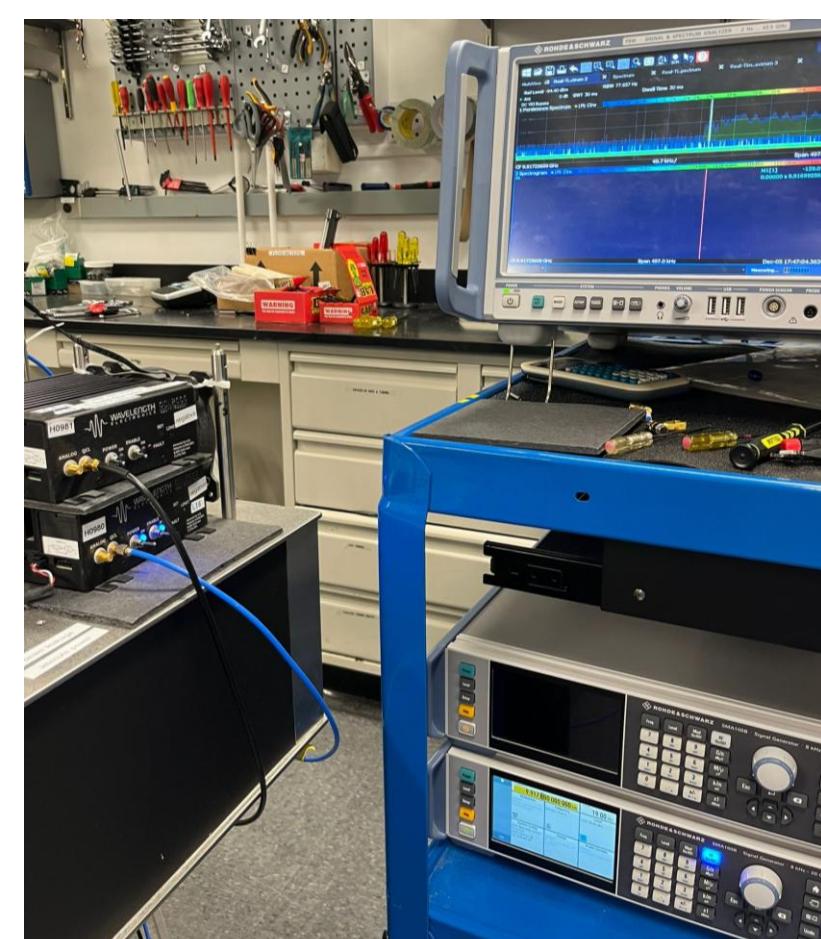
1. The QCL-FC, with injected AM RF signal, and a single-mode DFB-QCL (operating at frequency ~1300 cm^{-1}) beat together and produce a DFB-BN, a proxy signal for f_{ceo}.

2. The DFB-BN signal is mixed with a RF low oscillator (LO) comb at frequency f_{ceo} + 68 MHz, producing a 68MHz signal.
The output is fed through filters and a low noise amplifier (LNA) to increase signal-to-noise ratio. A frequency discriminator converts frequency fluctuation to intensity fluctuation. A log amplifier is used to distinguish between frequency-dependent intensity fluctuations (desired) and power fluctuations.

3. The log amplifier output is sent to a PID controller within a Toptica Digilock 110, which controls AM levels in the RF signal generator to inject into the QCL-FC.

Results: Stabilized f_{ceo}
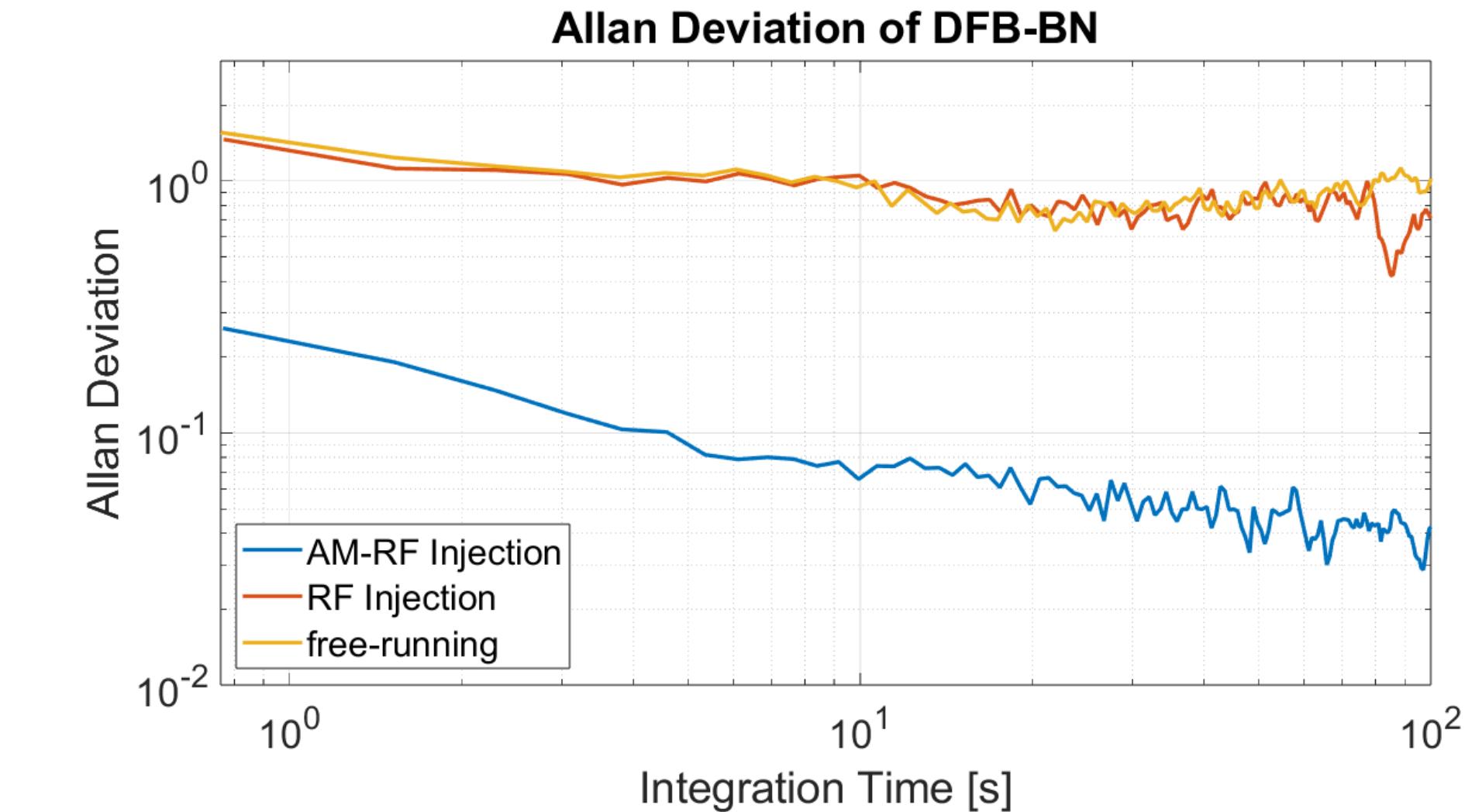
An FPGA-implementation of computational coherent averaging algorithm (CoCoA) was used to acquire data.

The modified Allan deviation of f_{ceo} with an AM-RF injection was significantly lower.

Conclusions, Future Directions

- Demonstrated successful locking of f_{rep} and f_{ceo} using one external RF signal with two parameters: frequency and amplitude modulation

- Possible future direction: compressing the locking scheme to make it field-deployable

Acknowledgements

References

1. Hugi, A., Villares, G., Blaser, S., Liu, H. C. & Faist, J. Mid-infrared frequency comb based on a quantum cascade laser. *Nature* **492**, 229–233 (2012).