Offset Phase-Locked QCL Source for 110-µm Plasma Density Interferometry

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Interferometric line-integrated electron density is a primary real-time diagnostic for fusion plasma control and physics studies. Far-IR probing near 100-µm boosts phase sensitivity, but optically pumped molecular gas lasers are bulky and alignment-intensive, and offer limited electronic agility for long-pulse, multi-chord operation [1], [2].

THz quantum cascade lasers (QCLs) are compact, electrically driven sources spanning ~1–5 THz [3], and microwave-referenced phase locking has been demonstrated in the THz regime [4], [5]. We develop an offset phase-locked pair of CW THz QCLs at 2.7 THz (110 µm) for heterodyne density interferometry. The outputs are combined on a reference detector to generate an IF beat; feedback to one QCL bias phase-locks the beat. We achieve an electronically tunable offset from a few MHz to 1 GHz (898 MHz shown), with ~Hz-level beat linewidth, and long-duration lock, producing stable high SNR I/Q beatnote for continuous phase tracking. The optical platform provides <60 µrad/week pointing stability and continuous days-to-week operation.

This phase-coherent 110-µm source enables compact heterodyne interferometers that reference the locked beat to measure plasma-induced phase shift and can recover line-integrated density. The same architecture can scale to multi-chord and two-color systems and to Faraday/polarimetry extensions for magnetic-field and current-profile measurement.

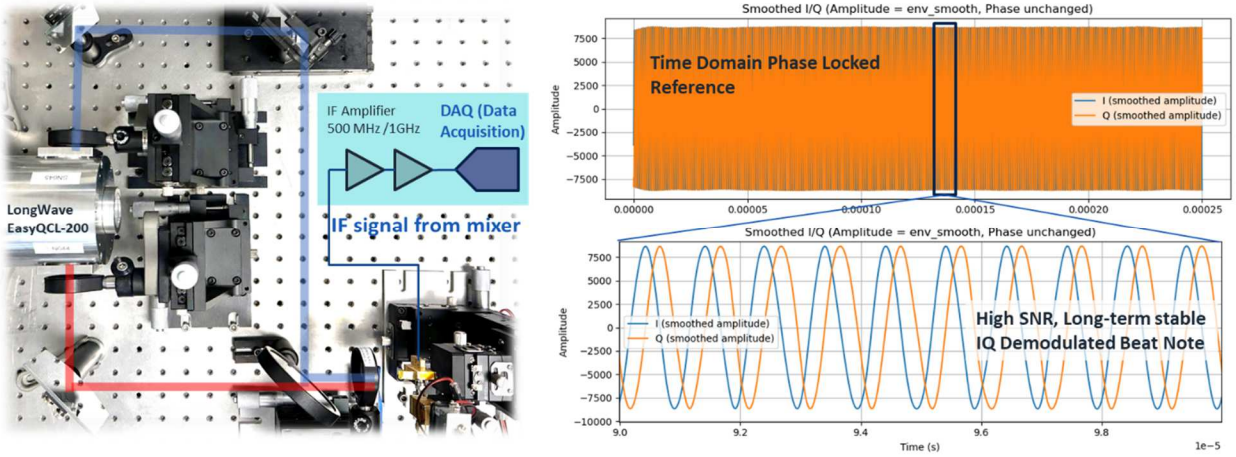

Figure: Dual THz-QCLs at 110-µm (PLL electronics not shown).Offset-phase-locked IQ beat from the mixer.

[1] A. Boboc et al., "JET far-infrared interferometer/polarimeter diagnostic system—40 years of lessons learned," Plasma Phys. Control. Fusion, vol. 66, p. 085011, 2024.

[2] A. Boboc, et al. "Upgrade of the JET far infrared interferometer diagnostic." Review of Scientific Instruments, vol. 83, no. 10, Oct. 2012.

[3] B. S. Williams et al, "Terahertz quantum-cascade lasers," Nature Photonics, vol. 1, pp. 517–525, September 2007.

[4] D. J. Hayton et al., "Phase locking of a 3.4 THz third-order distributed feedback quantum cascade laser using a room-temperature superlattice harmonic mixer," Appl. Phys. Lett., vol. 103, no. 5, p. 051115, 2013.

[5] P. Khosropanah et al., "Phase locking of a 2.7 THz quantum cascade laser to a microwave reference," Opt. Lett., vol. 34, no. 19, pp. 2958–2960, 2009.