National Aeronautics and Space Administration

FY23 Strategic University Research Partnership (SURP)

Injection-locking of THz quantum-cascade laser local oscillators

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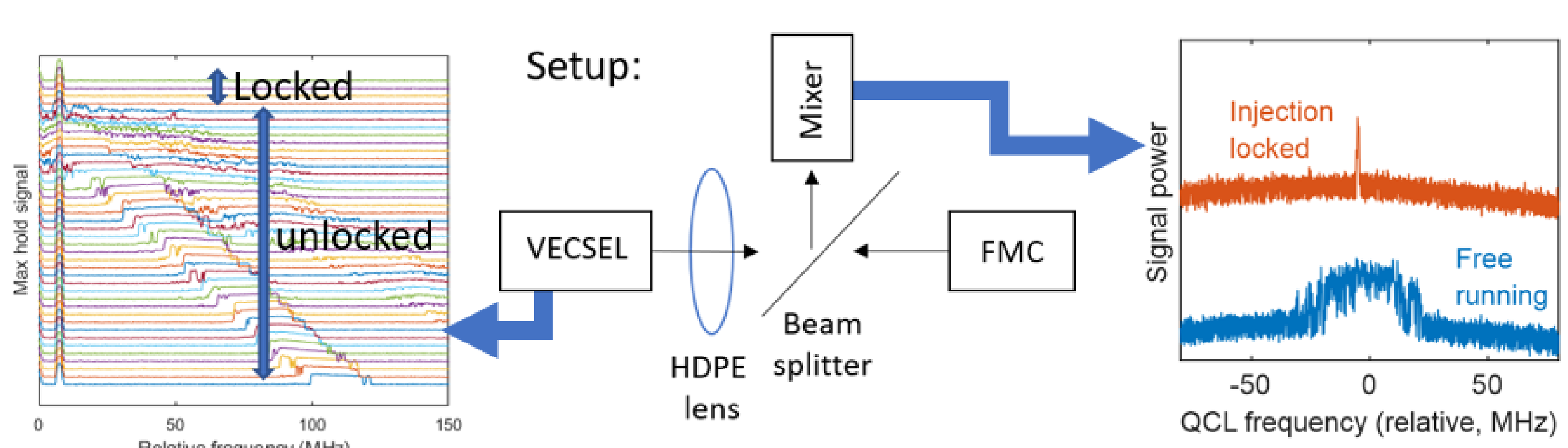
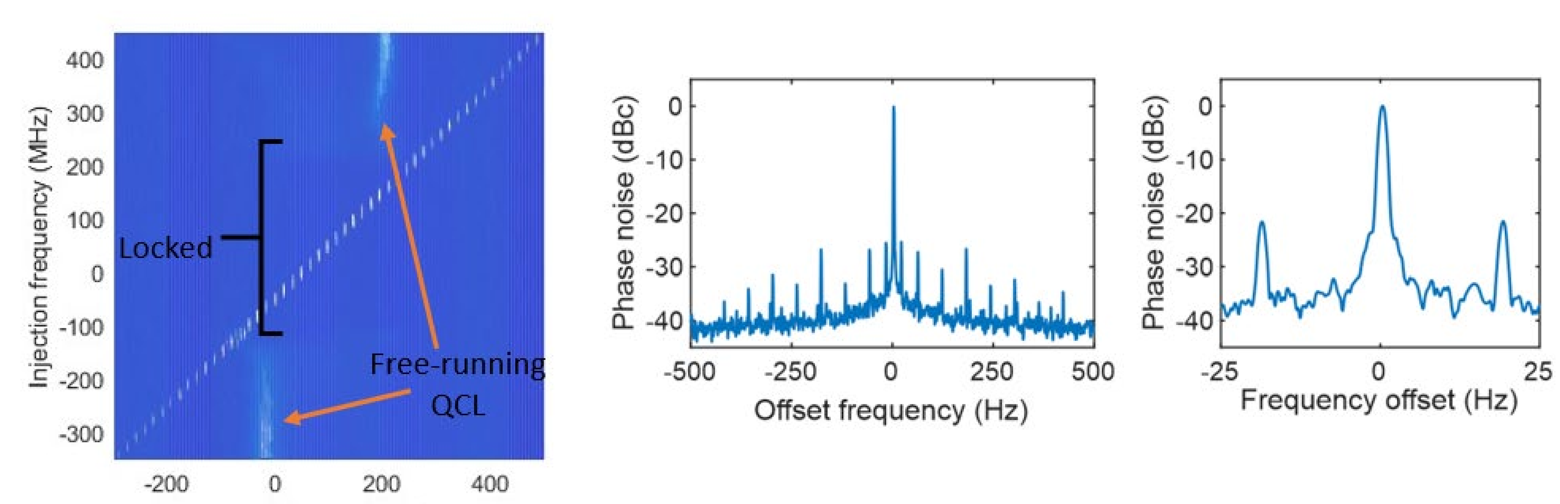
Objectives: The objective of this proposal is to frequency-stabilize a terahertz quantum cascade laser by injection locking: a comparatively weak fundamental or fractional subharmonic terahertz tone generated by an electronic Schottky-diode frequency multiplier chain is coupled to the quantum cascade laser. This will transfer the frequency knowledge and line-width of a low- power, microwatt-power level multiplier output onto that of a high-power output of a quantum cascade laser, which is three orders of magnitude more powerful. This method is superior to other methods of frequency stabilization such as frequency-locking or phase-locking, because it eliminates the need for a secondary THz detector and may result in improved amplitude stability. The lock state may be read directly from the laser device itself, as it is a highly non-linear device. This method will enable quantum cascade lasers to find practical applications as local oscillators, frequency reference tones, and components in terahertz communications.

Background: Quantum cascade lasers operating in the far-infrared and terahertz frequency (150-60 μm or 2-5 THz) range were invented about 20 years ago and have since gained widespread use in the laboratory as powerful and versatile monochromatic sources [see a review by B. S. Williams, Nature Photonics 1, 517-525, 2007]. Prior to their invention, the only sources available in this wavelength range were bulky CO_2 laser-pumped molecular gas lasers and, at the lowest frequency range, microwatt-level sources from Schottky diode-based frequency-multiplied chains. With typical output power of several milliwatts, QCLs have numerous applications including active remote sensing systems, spectroscopy, communications, and as frequency references. In particular, they are especially attractive as local oscillator sources for imaging heterodyne array receivers used for high-resolution spectroscopy in astrophysics. However, unambiguous frequency stability and metrology have proved to be a challenge with these devices.

Approach and Results: We have performed a proof-of-concept experiment with a 2.5 THz QCL where a quantum cascade laser is optically coupled to an electronic terahertz source and a small portion of the laser's output is coupled to a harmonic mixer for monitoring. We demonstrated injection locking of a quantum cascade laser, with a full-width locking range of about 400 MHz and a pull range of >800 MHz (full-width). Demonstrated line widths replicates that of the master source very closely, indicating coherence between the master and slave sources and that the laser does not add significant phase noise. We have also demonstrated the utility of using the quantum cascade laser itself for lock detection. The microwave output of the quantum cascade laser shows a peak t the difference frequency between the injection tone and free-running laser. When locking occurs, the spectrum (and noise) is abruptly minimized as no difference frequency signal is generated under this condition. Recent work has involved developing 4.7 THz QCLs to demonstrate injection locking there and developing a suitable architecture for subharmonic injection locking, e.g., injection locking a 2.7 THz laser using a 0.9 THz source. We are presently setting up a full receiver demonstration at 2.7 THz using a superconducting receiver.



Center: A simplified diagram of the injection locking experiment. The QCL ("VECSEL") is optically coupled to a master reference ("FMC"), and a portion of the output from the QCL is monitored using a harmonic mixer ("Mixer"). Right: The output from the harmonic mixer is used to monitor the lock condition. Left: the output from the QCL can also be used to monitor the lock state as the mixing signal decreases and the difference frequency approaches zero.



Left: Output from the harmonic mixer monitoring the QCL as the master reference is stepped in frequency (diagonal steps). The locking range is ~400 MHz. Outside the locking range the output from the free-running QCL is visible as well as the amplified signal from the master reference. Center: Phase noise of the locked QCL. Numerous sidebands are caused by electronic noise (mostly line) in the master reference; Right: at the limit of our measurement the QCL line demonstrates a Hz-level linewidth.

Significance/Benefits to JPL and NASA: The quantum cascade laser device fills a technology gap at JPL for a high-power THz source needed to implement future instruments. The work here to demonstrate injection-locking will address key technical aspect of practically operating this source by providing frequency metrology and stabilization. The quantum cascade laser is now a viable complete solution for a high-power continuous-wave source throughout the 2-5 THz frequency range. Apart from the urgent need for local oscillators for high-resolution spectroscopy, there are other applications including in-situ scanning spectroscopy, communications, and radar. In the near term we expect to demonstrate a QCL-based LO system in a suborbital mission.

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Clearance Number: CL#23-5756
Poster Number: RPC-061

Publications:

Christopher A. Curwen, Anthony D. Kim, Boris S. Karasik, Jonathan H. Kawamura, and Benjamin S. Williams, "Optical injection locking of a THz quantum-cascade VECSEL with an electronic source," Opt. Lett. 48, 3809-3812 (2023) https://doi.org/10.1364/OL.492182

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