National Aeronautics and Space Administration

Injection-locking of THz quantum-cascade laser local oscillators

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Strategic Focus Area: Direct/Coherent Detectors and Arrays

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 stablility of a low-power, microwatt-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 detector. 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: The first year of the project is dedicated for the initial proof-of-concept experiment with a 2.7 THz QCL. Very simply, 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 (Figure 1). Preliminary data show that we have 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; see Figure 2). Demonstrated line widths are sufficient for high-resolution spectroscopy by a large margin. Spectrally, the phase noise 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 at the difference frequency between the injection tone and free-running laser. When locking occurs, the spectrum (and noise) is abrupty minimized as no difference frequency signal is generated under this condition.

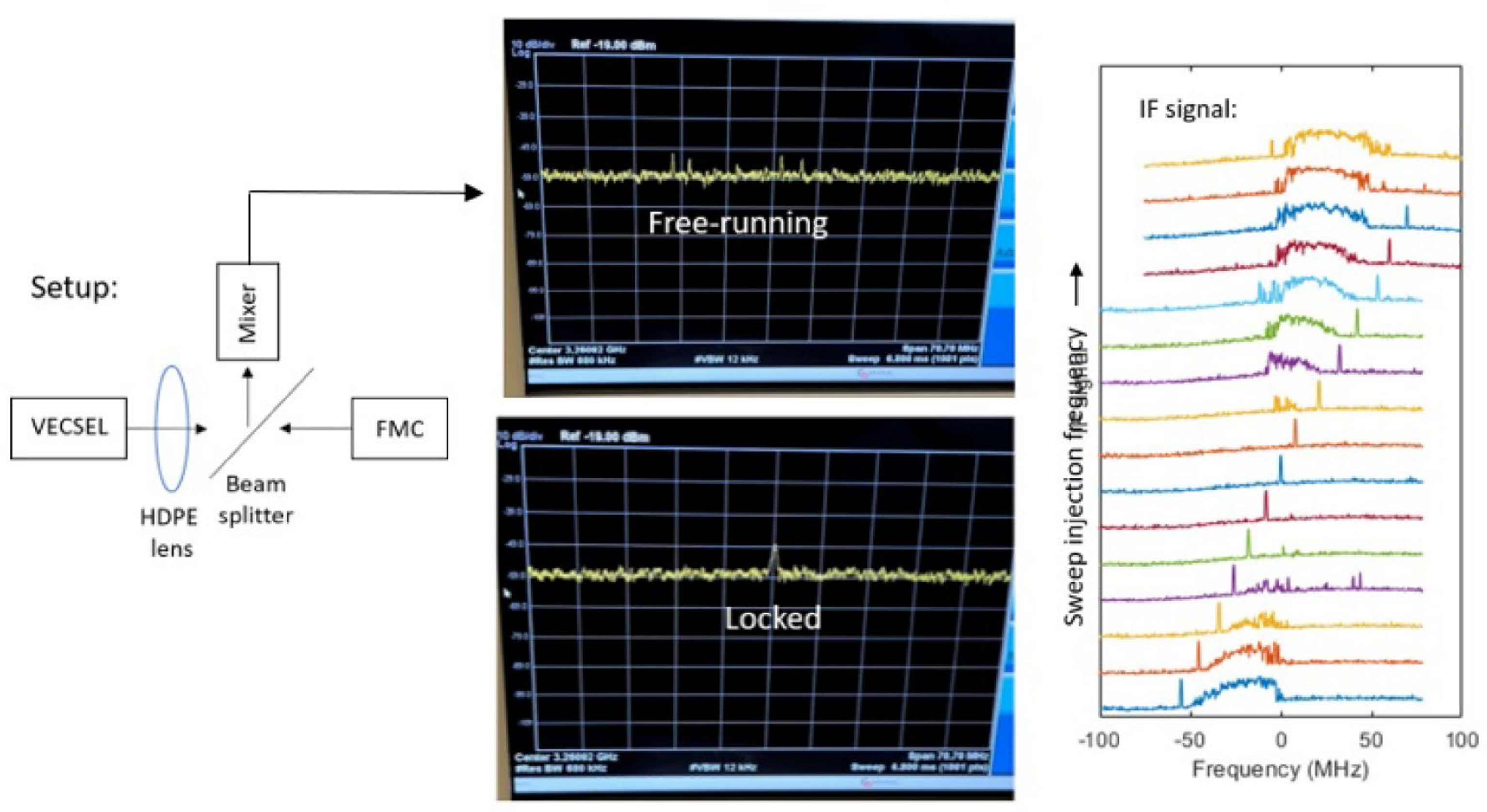

Figure 1. Figure (left) shows a block diagram of the setup. (middle) Photos of a single scan of the spectrum analyzer when the QCL is free-running vs injection locked. (right) Recorded IF power as the injection frequency is swept. Full locking only occurs when the injected signal is well aligned with the free-running QCL frequency.

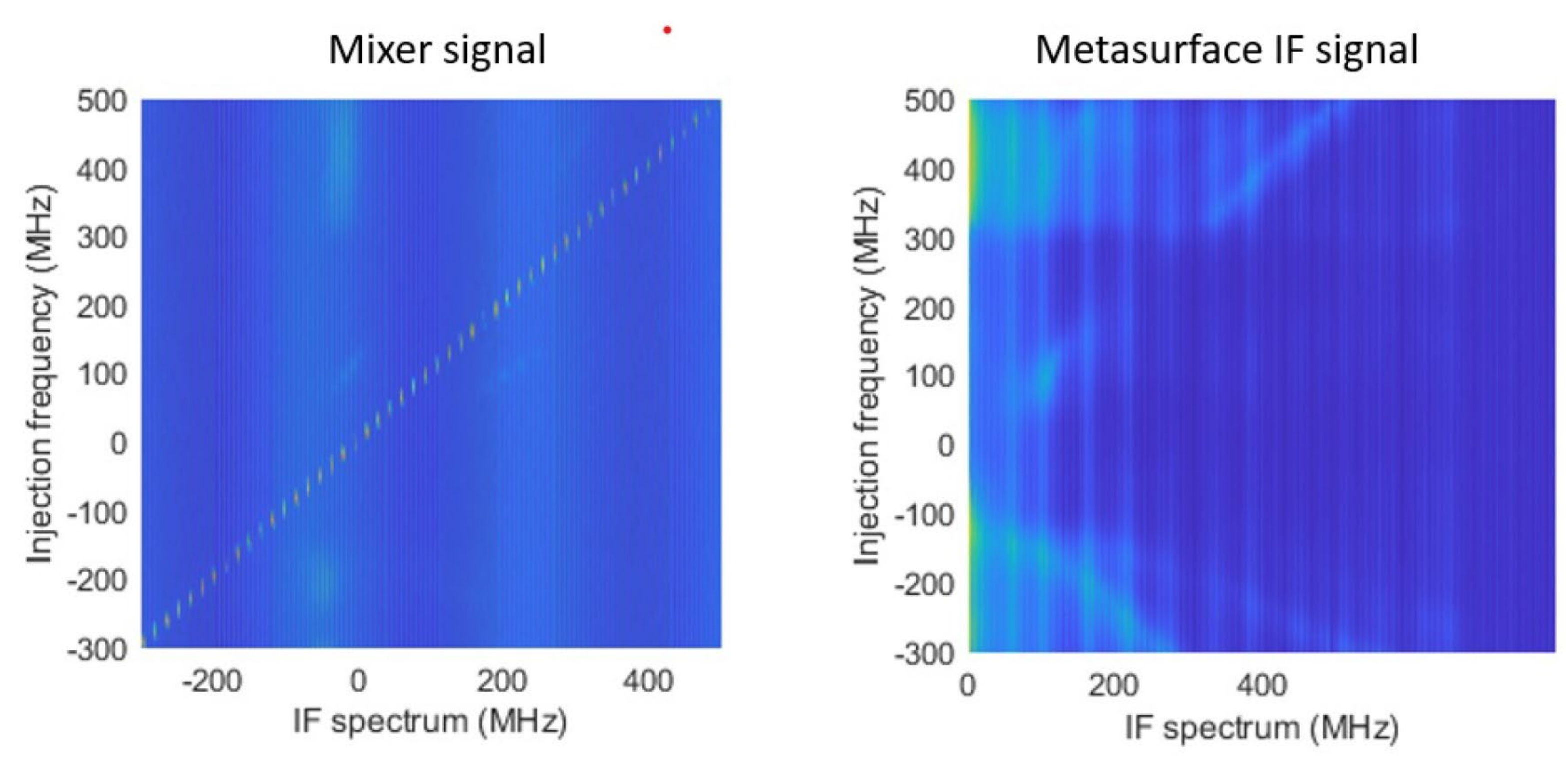

Figure 2. Signal detected by a harmonic mixer (left) and the quantum cascade laser (right) as the injection frequency is stepped away from the average free running frequency of the laser. The steps in the left figure show that injection locking "pulls" the laser across much of the 800 MHz range, but both figure clearly delineate the locking range of about 400 MHz where only one component is seen (left) and the IF signal is depleted (right).

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.

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