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Low noise RF optical signal synthesis using an optical phase locking of hybrid integrated lasers

Optically assisted RF carrier generation offers promising solutions for producing and distributing high-quality radio-frequency signals in 5G and 6G networks. One solution is the heterodyne optical phase-locked loop (OPLL) which stabilizes the relative phase and frequency difference between two lasers. When locked, the beat note replicates the RF reference phase noise within the OPLL bandwidth and follows the intrinsic beat note noise outside it. Thus, maximizing bandwidth and using low phase noise lasers are essential. Under these conditions, self-injection locking (SIL) of semiconductor DFB lasers combined with actuators enables rapidly tunable, low phase noise lasers.

The SIL lasers from DEEPLIGHT rely on a high-quality factor Si_3N_4 ring resonator with a free spectral range of 1.5 GHz. An AlN MEMS structure deposited on the resonator applies stress that shifts its resonance frequencies, enabling linear laser tunability [1]. We characterized the follower laser's frequency response, observing a modulation coefficient of 2.5 MHz/V with a cutoff frequency around 500 kHz, and a resonance near 1 MHz. Both leader and follower lasers have an optical phase noise as low as -115 dBc/Hz at 1 MHz offset. This makes this laser architecture ideal for PLL.

The OPLL setup is shown in Fig. 1(a). The combined optical fields from the leader and follower lasers are detected by a high-speed photodetector generating a RF beat signal at their frequency difference. This beat note is amplified, downconverted to produce a baseband error signal, filtered by a PID controller before closing the PLL on the follower laser MEMS actuator. The beat note phase noise is finally measured with a R&S FSWP-26 signal source analyzer. Two measurements were performed at different beat note frequencies, namely 7 GHz and 15 GHz (see Fig 1(b) and (c)), and compared to a model. As expected, the open-loop phase noise corresponds to the sum of the individual phase noise of the two lasers. The phase noise in closed loop remains lower than -95 dBc/Hz over the full spectrum. Apart from experimental parasitic noise, results are well predicted by our model. The natural phase of the laser allows for reaching better performances than previously reported work with optimized compact design [2] except in the region where OPLL is limited by MEMS resonances. New architectures are under study to increase the beat note frequency, while keeping on working with lower frequency references.

References

[1] A. S. Voloshin et al., *Optica*, vol. 12 (2025), pp. 1442–1451.

[2] K. Balakier et al., *IEEE J. Select. Topics Quantum Electron.*, vol. 24 (2018), no. 1, pp. 1–12, Jan.

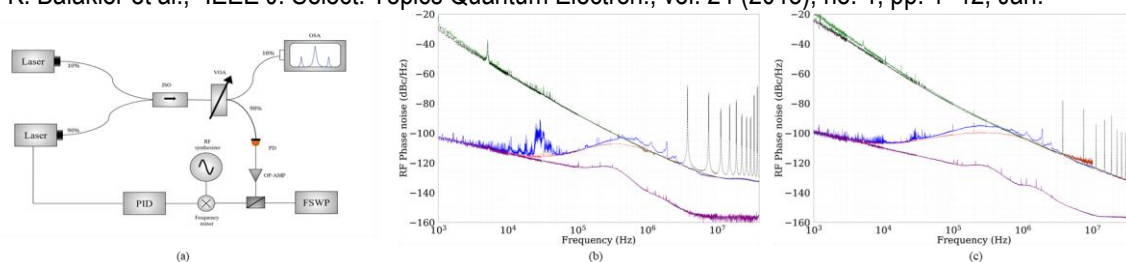


Figure 1 : (a) schematic diagram of a heterodyne optical phase locked loop. (b) (resp. (c)) Phase noise spectra of the phase locked heterodyne signal at 7 GHz (resp. 15 GHz). Green: open-loop beat note phase noise. Red: Sum of the optical phase noise of both lasers. Blue: closed loop beat note phase noise. Light blue: Simulated closed-loop phase noise. Purple: RF reference phase noise.