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► **To cite this version:**

Aurélien Thorette, Peppino Primiani, Marco Romanelli, Mehdi Alouini, Frederic van Dijk, et al.. Self-stabilization of the beat-note of monolithic DFB lasers for microwave signal generation. International Symposium on Physics and Applications of Laser Dynamics 2017 (IS-PALD 2017), Nov 2017, Paris, France. hal-01708260

**HAL Id: hal-01708260**

**<https://hal.science/hal-01708260v1>**

Submitted on 13 Feb 2018

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# Self-stabilization of the beat-note of monolithic DFB lasers for microwave signal generation.

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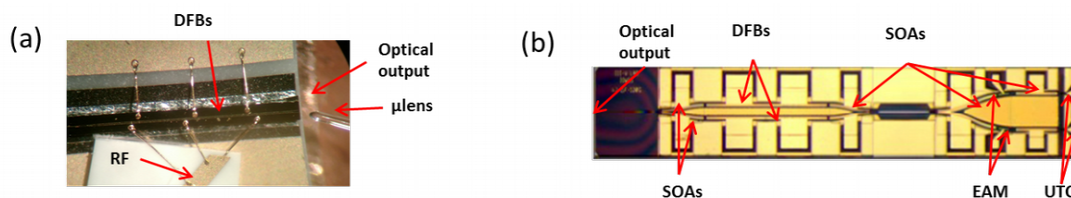
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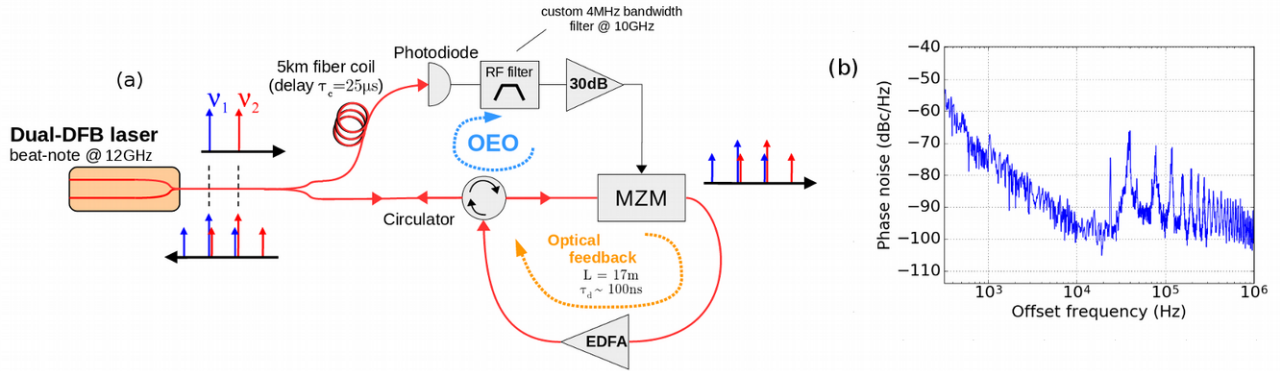
**Abstract** We report an opto-RF source based on the beating between two integrated DFB lasers, and discuss several schemes for self-stabilization (i.e. without an external reference oscillator) of the output beat-note. These schemes are based on a hybrid opto-electronic feedback loop, combining optical cross-injection locking and delayed optoelectronic feedback. We demonstrate the generation of a dual-frequency output signal with a good spectral purity. This stabilization mechanism has also been integrated on a single chip as a standalone opto-RF generator, showing good performances up to 20 GHz. Such a scheme should be scalable up to 100GHz.

At high frequencies, RF signals become harder to generate and to carry by electronic means, and optical solutions are often considered. Such so-called opto-RF signals can be generated by various schemes, for instance using an opto-electronic oscillator (OEO), and then carried over long distances through conventional fiber links. However, as the RF signal is embedded in sidebands around the optical carrier, it is sensitive to chromatic dispersion along the fiber link, which can lead to a dramatic reduction of the modulation depth. Alternatively, if the signal is generated by a heterodyne method, i.e. by mixing two optical frequencies, it will feature almost 100% modulation depth and be insensitive to dispersion. This can be done by using the beat-note between two laser sources, which also allows for a more convenient and wider tuning range of the RF frequency. As a drawback, the frequency difference between the two lasers has to be stabilized. Here we present a hybrid stabilization method, which merges passive optical injection locking and an opto-electronic loop based on an optical delay line. This scheme benefits of standard phase stabilization methods used in OEO technology. This setup can be further integrated into a semiconductor photonic device.



**Figure 1:** Two samples of monolithic dual DFB lasers used as heterodyne source. (a) 2 DFB lasers coupled to a microlensed fiber. (b) PIC containing 2 DFBs, semiconductor optical amplifiers, electroabsorption modulators, and UTC photodiodes.

Instead of using two separate lasers, we consider a specially-designed photonic integrated circuit (PIC) that contains two quantum dash InGaAsP DFB lasers, whose outputs are coupled (as shown on Fig. 1). Other elements, such as amplifiers, modulators and photodiodes can be added on our PICs, allowing for a great versatility [1]. Having the two lasers to share the same wafer allows them to experience correlated thermal and acoustic noises, so that their output beat-note does not drift significantly. By tuning the bias current of one of the lasers, RF frequencies up to 100GHz can be obtained [2].



**Figure 2:** (a) Generic principle of the optoelectronic oscillator, with a frequency-shifted feedback loop (orange) and an optoelectronic delay line (light blue). (b) Power spectral density of the RF phase. Here, the carrier frequency is set to 12 GHz.

This dual-DFB chip is then subjected to a frequency-shifted optical feedback (FSF). The optical feedback loop contains an amplitude modulator, driven by a delayed and filtered version of the RF output signal delivered by a photodiode. As shown on Fig. 2, this setup contains two different delays, a short and a long one (a fiber coil) and each of them helps filtering out phase fluctuations of the signal. Each laser experiences self-feedback, but also cross-feedback from the other one. In general, depending on the parameter values the system can display many dynamical regimes. Under the right conditions, it is possible to obtain self-stabilization of the frequency difference. For instance, in Fig. 2b, with a 12GHz beat-note, a phase noise of  $-65\text{dBc/Hz}$  has been measured for a 100Hz offset from the carrier [3]. Spurious peaks that can be seen in the phase noise spectrum are due to the long delay line, and are typical of OEO operation. These can be reduced when using a RF interferometer, made with two fiber coils of different lengths and two photodiodes. We have experimentally confirmed this is also true in our hybrid setup.

This proof-of-concept setup can be transposed to a more compact one, using an integrated on-chip electro-absorption modulator, which allows using shorter feedback loops. This is shown on Fig. 1(b), where residual reflections on the photodiodes have been used as a way to induce frequency-shifted feedback. With an additional external OEO loop of a few meters, frequency locking in the range 15-20GHz has been obtained with very encouraging performances, i.e. phase noise level at 10kHz from carrier that are similar to the setup of Fig. 2.

In conclusion, we have shown a proof-of-concept of a self-stabilized heterodyne opto-RF source, based on optical frequency-shifted feedback and an OEO-like opto-electronic loop. This injection-based stabilization mechanism proves to be effective to enhance phase noise quality of the generated RF signal. We are also moving towards an integration on a single compact chip, as we have shown this can be done while still maintaining good performances. Theoretical work and numerical simulations aimed at a better comprehension of the laser dynamics in this frequency-shifted feedback configuration are also in progress and will be shortly discussed.

## References

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