

## Opto-electronic oscillator based on hybrid feedback loop for single-side band operation

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Opto-electronic oscillators (OEO) are important building blocks in microwave photonics systems, allowing to obtain low-phase noise optically-carried radiofrequency signals. We have recently demonstrated an OEO scheme based on a monolithic dual-frequency source [1], whose beatnote is self-stabilized using frequency-shifted optical feedback and a delay line [2]. The main interest of such a setup is that it allows the generation of single-sideband signals, which are thus insensitive to dispersion fading when propagating in optical fibers. The scheme presented in [2] offered good short-term performances, however could be affected by undesired mode-hopping due to both the resonant modes of the optical feedback loop, and to those of the optoelectronic loop including the delay line. In the present work, we discuss significant improvements in the performances of the OEO, namely the complete suppression of mode-hopping, and a significant reduction of the spurs in the phase noise spectrum [3].

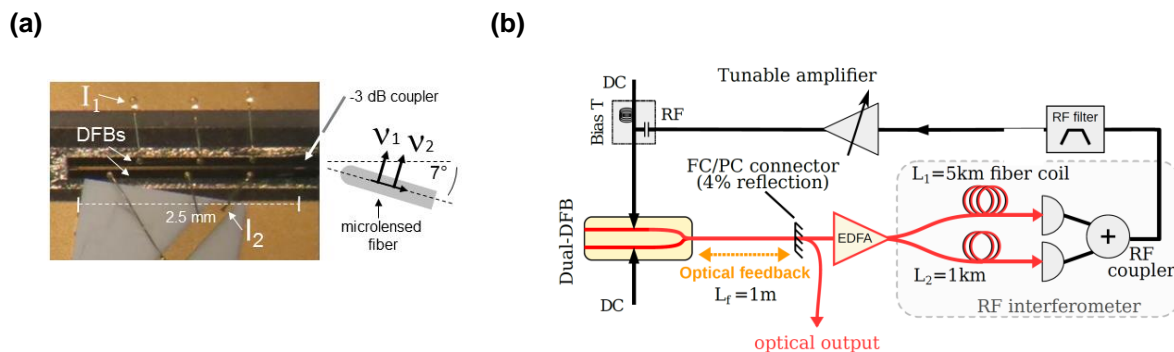


Figure 1. (a) Monolithic dual DFB laser: the two lasers are independently pumped by currents  $I_1$  and  $I_2$ . Both lasers are coupled into an AR-coated micro-lensed optical fiber. (b) Scheme of the hybrid OEO. See text for details.

The optical source consists in two 2.5 mm long InGaAsP DFB lasers grown on the same wafer and emitting at 1.5  $\mu\text{m}$  (See Fig. 1(a)). The mean frequency difference can be controlled by the two pump currents  $I_1$  and  $I_2$  leading to a beatnote  $\Delta\nu$  (here set at around 10 GHz). Additionally, the pump current of one laser can be modulated with a RF signal by a bias tee. The modulation bandwidth of the laser has been measured to be about 14 GHz at  $-3$  dB cut-off frequency. The output beam is then injected into a 1-m-long fiber connected to a FC/PC connector, leading to a 4% optical feedback. The rest of the signal goes through a RF interferometer made of two fibers of different lengths. The RF signals are recombined by a directional RF coupler. The resulting signal is then filtered by an 80 MHz bandpass filter centred at 10 GHz, amplified and fed back into the bias tee. It generates small modulation sidebands. Owing to the optical feedback, these modulation sidebands lead to mutual optical injection between the two lasers, which causes their optical phases to lock, thus stabilizing the beating frequency. A typical optical spectrum is reported on Fig. 2(a). The three main peaks correspond to the emissions at  $\lambda_1$  and  $\lambda_2$ , and to one modulation sideband (the other sideband being coincident with  $\lambda_1$ ). Note that, with respect to [2], in order to reduce the length of the optical feedback loop, we have resorted to direct current modulation. One may argue that this spoils the single-sideband character of the signal, but Fig. 2(a) demonstrates that the third optical frequency seen in the spectrum is 15 dB

below the main frequencies; a straightforward calculation shows that, in the worst case (i.e. destructive interference between the  $\lambda_1 - \lambda_2$  beating and the  $\lambda_2 - \lambda_3$  beating), this can reduce the amplitude of the RF signal by only 1.6 dB. So the source is, in practice, almost ideally single-sideband.

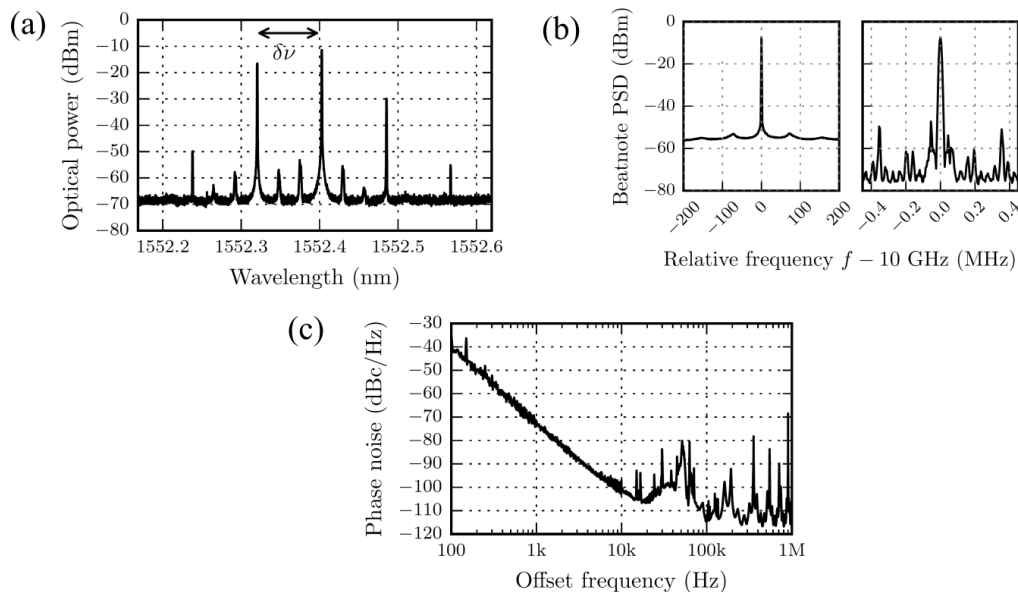


Figure 2. (a) Optical spectrum. (b) RF spectrum for two different spans. (c) Phase noise of RF beat note.

As shown on Fig. 2(b), a look at the electrical spectrum of  $\Delta\nu$  shows a 40 dB rejection between the carrier and the surrounding spurs. Indeed, the RF interferometer leads to suppression, by destructive interference, of the spurs at kHz frequencies that are due to the fiber loops before the photodiodes (right panel of Fig. 2(b)). The left panel of Fig. 2(b) shows the RF spectrum on a larger span. The short optical feedback loop results in broadly spaced external cavity modes, that are efficiently suppressed using a standard RF filter (on the contrary, longer loops require custom filters with high quality factors). As a result, mode hops are completely absent and under our laboratory conditions, the beat note remains stabilised for hours. Finally, a good phase noise performances are also obtained (Fig. 2(c)) [3].

The ability to shorten the optical feedback path opens interesting perspectives towards an integrated self-stabilized heterodyne oscillator, as shown by promising work done in this direction [4].

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## References

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