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Photonic RF oscillator based on monolithic DFB lasers with frequency-shifted feedback

L. Wang, M. Romanelli, F. Van Dijk, and M. Vallet

A photonic oscillator, locked to a master RF synthesizer, was built by using monolithic dual-wavelength DFB semiconductor lasers submitted to a frequency-shifted optical feedback. A [3;15] GHz tuning range is reported, with a phase noise level lower than -70 dB rad^2/Hz at 10 Hz from the carrier, instrument-limited.

Introduction: The potentialities of optical heterodyning for photonic oscillators are now firmly established [1], the optically-carried microwave being provided by the beat note between two laser modes. Active phase locking to a RF local oscillator (LO), by means of analogue [2] or digital [3] phase-locked loops (PLL), have been shown to transfer the spectral purity of the LO to the beatnote. However, such architectures inherently need a way to electronically tune the frequency difference. Conversely, optical injection locking schemes are free from electronics and it has been recently proved that dual-frequency Er^{3+} -doped lasers can be locked to an external LO by using frequency-shifted optical feedback [4]. However, the use of Bragg cell for single-sideband modulation limits the RF frequency below the GHz range and optical injection in rare-earth lasers presents small locking range. As semiconductors are well known to be sensitive to injection with a large locking range [5], the aim of this letter is to propose to use DFB lasers submitted to an intensity modulated optical feedback by using an electro-optic modulator (EOM), in order to benefit from both the simplicity of the injection locking scheme and the bandwidth (BW) of EOMs.

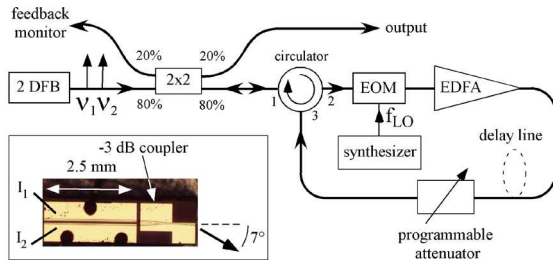


Fig. 1 Schematic of the setup (see text for details).

Experimental Setup: The optical source at $1.55 \mu\text{m}$ is similar to the one described in [6]. It consists of two 2.5 mm-long DFB semiconductor lasers grown on the same wafer (see inset of Fig. 1). The lasers are electrically pumped by two current sources, so that both frequencies ν_1 and ν_2 can be tuned independently using the bias currents I_1 and I_2 . The two output beams are coupled by a -3 dB coupler providing a 7° angled output to reduce back reflections, followed by a lens fiber. The 26m long feedback loop contains a Mach-Zehnder intensity modulator (EOM, BW = 10 GHz) driven by a synthesizer which provides a frequency reference f_{LO} . Next, an Erbium doped fiber amplifier (EDFA, 30 dB gain) and a programmable attenuator (from 0 dB to -60 dB) allow controlling the feedback power. An optical circulator closes the loop. The power sent back to the DFBs is monitored from one output of a 80/20 coupler. The other output provides the useful output beam, whose beatnote is analyzed

by an InGaAs photodiode (40 GHz BW) followed by an electrical spectrum analyzer.

Results: The typical power coupled into the fiber is 1mW. In the free running regime, the frequency difference $\Delta\nu = \nu_1 - \nu_2$ is finely tunable from 0.3 up to 15 GHz by sweeping the bias current of one DFB section from 230 mA to 440 mA, while the other is biased at a constant current of 200 mA. It is important to note that $\Delta\nu$ is much more stable than ν_1 and ν_2 , since the two lasers share the same temperature fluctuations on the chip. The -3 dB linewidth of the beatnote is 630 kHz for typical bias currents that are respectively 320 mA and 194 mA, as shown in Fig. 2(a).

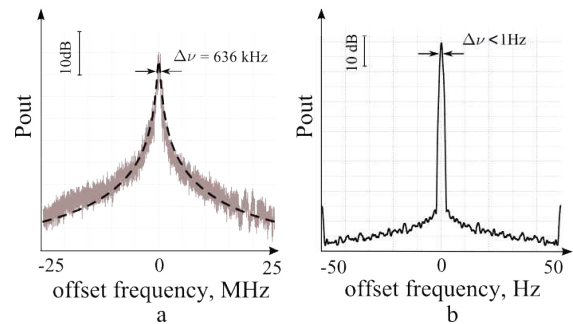


Fig. 2 Beatnote RF spectra. Solid line: measured data. Dashed line: Lorentzian fit. (a) Free running, RBW: 30 kHz, span: 50 MHz. (b) With feedback, RBW: 1Hz, span: 100Hz.

With the optical feedback loop, if the reinjected light is sufficient, the beatnote locks to the external synthesizer. In this case, the -3 dB linewidth of the beat note is equal to 1Hz, instrument limited (see Fig. 2(b)). Furthermore, the laser remains stable, locked for several hours. When locked, the beatnote can be tuned from 3 GHz to 10 GHz. The lower boundary is set by the relaxation oscillation frequency that are known to destabilize injection locking [5], and the upper one is fixed by the BW of the electronic amplifier for the EOM. In the experiments below, we choose the frequency of the beatnote at 7.3 GHz.

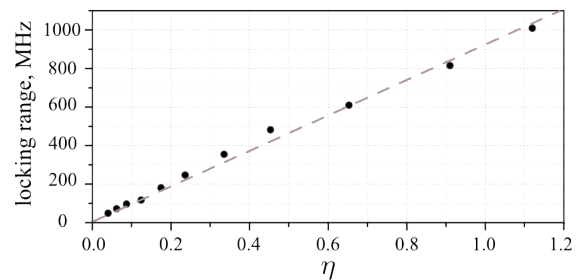


Fig. 3 Measured locking range with different feedback levels. Dots: measured data. Dashed line: linear fit.

Fig.3 reports the locking range as a function of the feedback level η . The latter is defined as the ratio of the amplitude of feedback optical field with respect to the laser output optical field. We observe that when the feedback level goes from 0.02 to 1.2, the locking range increases linearly, as in master-slave injection locking. Moreover, a locking range

as large as 1 GHz can be demonstrated. For low feedback levels, the locking range is typically of several tens of MHz. The modulation depth of the EOM was independently measured to be equal to 80%. At variance with experiments using frequency-shifters [4], a certain amount of self-injection is unavoidable in our setup, and the frequency ν_2 is not injected only by $\nu_1 + f_{LO}$. However, our experiment shows that, at least in the explored range of parameters, self-injection does not seem to play an important role.

To characterize the spectral purity of the photonic oscillator, we have measured the phase noise spectrum in the locking regime. As shown in Fig. 4, it coincides with the noise floor of the detection at low frequency, showing that our oscillator has a better stability than the available measurement apparatus. The phase noise is thus lower than -70 dBc/Hz at 10 Hz from the carrier. To check the sensitivity of the locking to spurious delay, we inserted a delay line (700m, $\tau = 3.5\mu\text{s}$) in the feedback loop, as shown on Fig. 1, and could hardly measure a difference between these two cases.

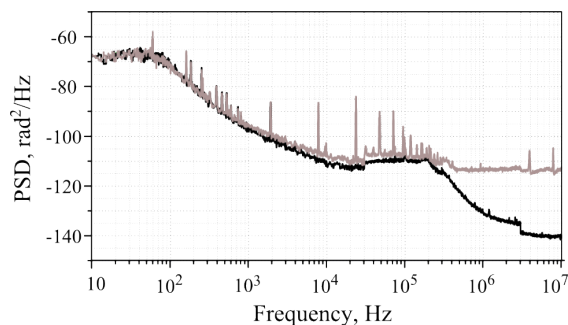


Fig. 4 Measured phase noise spectra. Black: noise floor, red: without delay line, blue: with delay line

Conclusion:

We have demonstrated a photonic oscillator based on monolithic DFB semiconductor lasers, driven by a master RF synthesizer. The oscillator is stable, finely tuneable, and displays a large locking range and a low phase noise level. Further improvements could now be investigated. Modeling using rate-equations as in [7] may lead to a global comprehension of the dynamics and possibly the observation of new regimes. Then, our scheme could be extended to microwave frequencies [8], by using side-bands generated by in-loop dual-drive EOMs.

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