

# Low phase noise microwave generation from a direct-modulation optoelectronic oscillator (DM-OEO)

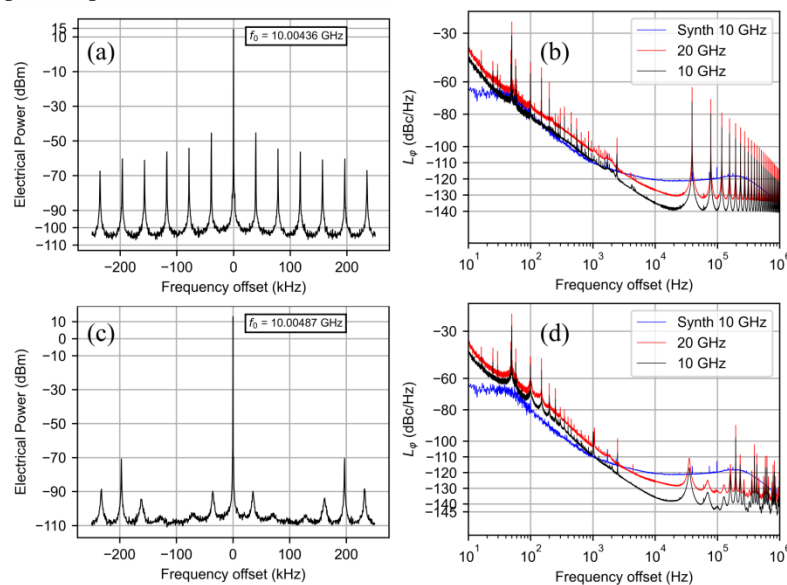
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Optoelectronic oscillators (OEO) have become of paramount importance for the generation of high spectral purity, (optically-carried) microwave signals. The most widespread architecture uses a Mach-Zehnder Modulator as the generator of the RF modulation [1]. Direct modulation of the injection current of a semi-conductor laser, arguably the simplest possible OEO [2], has been comparatively much less explored [3].

In the present contribution, we demonstrate a direct-modulation OEO with performances comparable to the standard external-modulation architecture, while reducing the system size and complexity.

In a first experiment we use a single loop architecture with a 5 km fibre spool. The laser is a commercial telecom 1.5  $\mu\text{m}$  DFB laser designed for direct modulation. Its emitted power is detected by a PIN photodiode after propagation in the fibre. The photocurrent is then amplified and filtered by a high quality factor bandpass filter centred at 10 GHz, before being fed back to the pump current. A part of the signal fed back to the laser is extracted using a RF power splitter.



**Fig. 1** (a,c) RF spectrum of the oscillator output for the single loop (a) and dual-loop (b) cases. (b,d) Phase noise for the single loop (b) and dual-loop (d) cases, for the 10 GHz signal and for the 2<sup>nd</sup> harmonic at 20 GHz. For comparison, the phase noise of a low-noise RF synthesizer (Rohde & Schwarz SMF100A) is shown.

Stable RF oscillation at 10 GHz is observed, with a rejection ratio of 60 dB and no mode hops (Fig. 1 (a)). We measure a phase noise of -135dBc/Hz at 10 kHz from the carrier, and a noise floor of -140 dBc/Hz (Fig. 1 (b)). A dual-loop architecture, using two fibre spools of different lengths (5 and 6 km) and two photodetectors in order to obtain a RF interferometer, improves some figures of the OEO: the rejection ratio of non-oscillating modes is  $> 80$  dB (Fig. 1(c)), and the suppression of the phase noise of the closest-to-the-carrier spur is  $> 40$  dB (Fig. 1 (d)) compared to the single-loop case. Thanks to the nonlinearity of the detection and amplification, a 20 GHz signal of -5 dBm power is also available at the output of the oscillator, with a slight increase of the phase noise due to reduced power and frequency multiplication (Fig. 1(b, d)). To the best of our knowledge, these figures represent the state-of-the-art of DM-OEOs. The architecture based on direct modulation is thus a valuable alternative, promising in particular for monolithic integration in photonic chips [4].

## References

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