Phase Noise Performance of Double-Loop Optoelectronic Microwave Oscillators

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In applications such as radar, time-frequency metrology and lightwave technology, microwaves with exceptional purity are needed. Optoelectronic oscillators (OEOs) are useful for these applications because they can convert continuous light energy into stable and spectrally pure microwave signals[1–3]. In such systems, the purity of microwave signal is achieved thanks to an optical fiber delay-line inserted into the feedback loop. The role of the delay is to store the energy providing a quality factor equal to $Q = 2\pi f_m T$, where f_m is the microwave frequency and T the delay induced by the optical fiber. A convenient way to evaluate the purity in systems is to measure its phase noise spectrum, which is directly connected to the oscillator performance. The main advantage of the OEO is its capability to generate ultra-stable, spectrally pure microwaves with frequencies as large as 75 GHz, and with a phase noise lower than −160 dBc/Hz at 10 kHz[4]. Later, these studies were complemented with a nonlinear and stochastic dynamics approach which enabled to investigate theoretically the stability properties of OEOs, and also to predict phase noise performance[5–7].

Theoretical studies predict that the use of a long delay line plays a key role in improving the phase noise performance. However, in the single loop configuration, the possibility of using long delays is limited because the delay is also responsible to the appearance of very strong parasite ring-cavity peaks, which appear at the integer multiples of the round-trip frequency $\Omega_T = 2\pi/T$. Thus, the increase of delay line reduces the region of low phase noise because of these ring-cavity peaks.

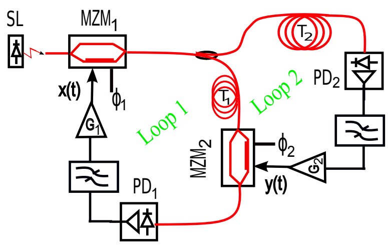

FIG. 1. Setup

Here, we consider a double-loop optoelectronic delay system in which the output of one of the loops is used to modulate the other (Fig. 1). A semiconductor laser (SL) injects light into a Mach-Zehnder (MZM_1). One part of the optical output is delayed by T_2 , detected by photodiode PD_2, fed to a narrow-band filter with a central frequency Ω_0 and bandwidth $\Delta\Omega_2$, amplified, and used to modulate MZM_2. The other part is delayed by T_1, optically fed to MZM_2, detected by PD_1, filtered by an RF filter of central frequency Ω_0 and bandwidth $\Delta\Omega_1$, amplified and finally fed to the MZM_1 RF electrode to close the loop. Proceeding as in ref.[5], the system can be described by the dimensionless amplifier outputs $x(t)$ and $y(t)$

$$x + \frac{1}{\Delta\Omega_1}\frac{dx}{dt} + \frac{\Omega_0^2}{\Delta\Omega_1}u_1 =$$
$$= \frac{G_1}{4}\Big[F(x_{T_1},\phi_1) + F(y,\phi_2) + F(x_{T_1},\phi_1)F(y,\phi_2) + 1\Big],$$
$$y + \frac{1}{\Delta\Omega_2}\frac{dy}{dt} + \frac{\Omega_0^2}{\Delta\Omega_2}u_2 = \frac{G_2}{2}[F(x_{T_2},\phi_1) + 1]$$

where $x_{t_0} = x(t - t_0)$, $F(x,\phi) = \cos[2x(t) + 2\phi]$, $du_1/dt = x(t)$, $du_2/dt = y(t)$ and G_1 and G_2 are the overall loop gains.

We derive an amplitude equation to investigate the stability properties and study the noise performance. We show that by carefully setting the parameters of the second loop, a significant improvement of performance can be achieved comparatively to the single-loop configuration, as the detrimental effect of the multiplicative phase noise can be reduced up to about 18 dB close to the carrier, while delay-induced spurious peaks can be strongly damped.

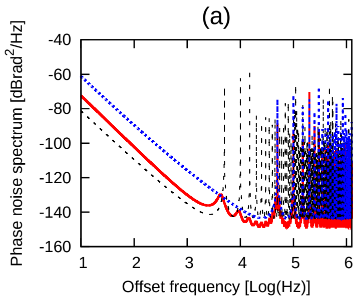

FIG. 2. Phase noise spectrum of a single loop OEO with $T = 20\ \mu$s (dotted line) and with $T = 200\ \mu$s (dashed line) and of a double loop OEO (solid line) ($\phi_1 = \phi_2 = 0.5$, $T_1 = 20\ \mu$s, $T_2 = 200\ \mu$s, $G_1 = 2.0$ and $G_2 = 0.5$)

[1] X.S. Yao and L. Maleki, *Electron. Lett.*, **30**, 1525 (1994).
[2] X.S. Yao and L. Maleki, *J. Opt. Soc. Am. B* **13**, 1725, (1996).
[3] X.S. Yao and L. Maleki, *IEEE J. Quantum Electron.* **32**, 1141 (1996).
[4] See www.oewaves.com.
[5] Y.K. Chembo, L. Larger, H. Tavernier, R. Bendoula, E. Rubiola, and P. Colet, *Opt. Lett.*, **32**, 2571 (2007).
[6] Y.K. Chembo, L. Larger, P. Colet, *IEEE J. Quantum Electron.* **44** 858 (2008).
[7] Y.K. Chembo, K. Volyanskiy, L. Larger, E. Rubiola, and P. Colet, *IEEE J. Quantum Electron.*, **45**, 178 (2009).