Semiconductor Laser Optical Phase Lock Loops

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What is a Phase Lock Loop?

- A PLL is a control system that generates an output signal whose phase is related to the phase of an input signal

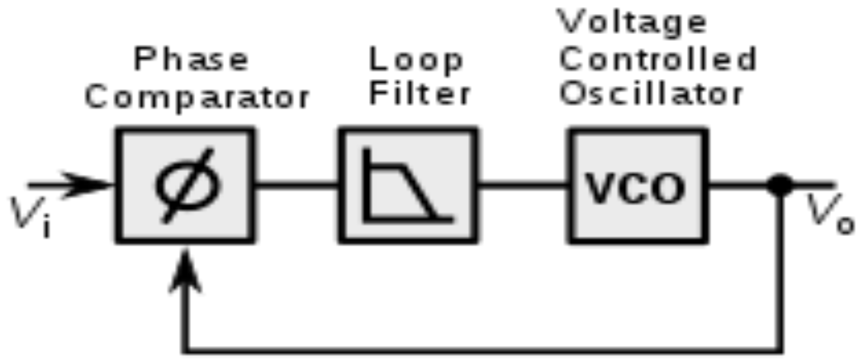


Fig 1: Simple analog phase locked loop

- Key elements: Phase comparator, voltage controlled oscillator
- Applications: Clock Generation, Wireless communication systems

Source: Wikipedia

Semiconductor Laser Optical Phase Lock Loops - Overview

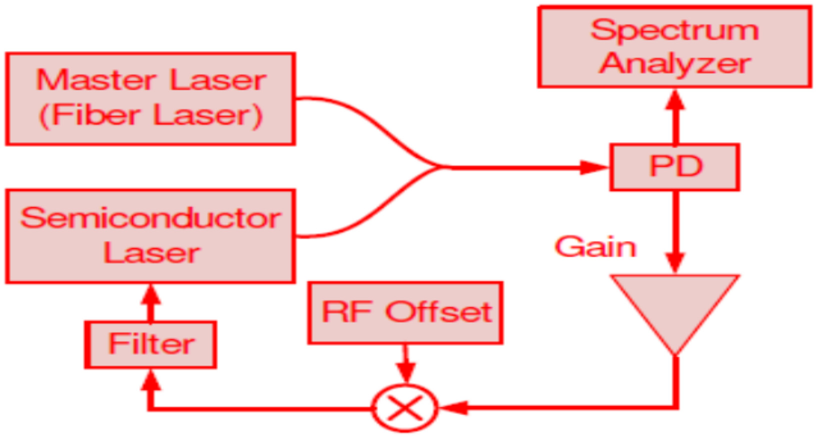


Fig 2: Semiconductor Laser Optical Phase Lock Loops

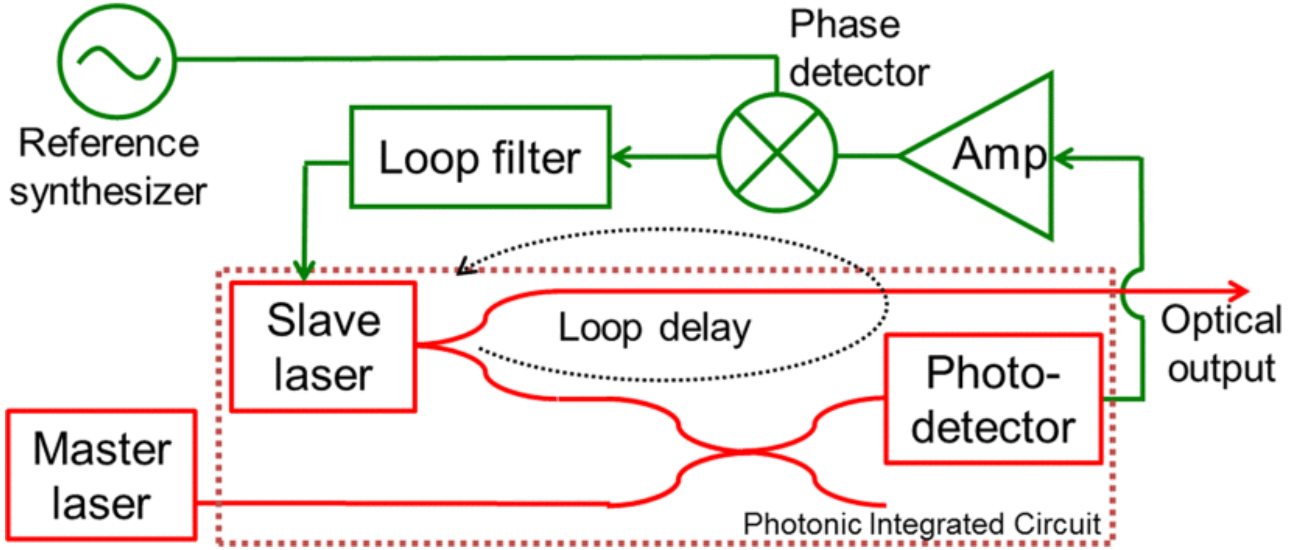
PLL Building Blocks	
Electronic PLL	Semiconductor Laser Optical PLL (OPLL)
Phase Detector (Mixer)	Photodetector
Voltage Controlled Oscillator (VCO)	Semiconductor Laser (Current Controlled Oscillator)

Source: A. Yariv, Opt. Lett. 30, pp2191, 2006

Phase locking of commercial SCLs

- Demand for solutions to control the large free running linewidth (0.1 to 50 MHz) of semiconductor diode lasers.
- Dependence of broad linewidth with strong temperature and current dependence of the emission frequency (typically 10 GHz/K and 1 GHz/mA, respectively)
- Special control techniques to stabilise laser emission frequency and reduce the phase noise, which improves receiver sensitivity
- Phase stabilisation of an independent laser source by phase locking technique of OPLL

- Master Laser- Side-band of a modulated laser or a line from an optical frequency comb
- Slave Laser- laser to be phase synchronised and must have good static spectral properties such as wavelength tuneability and a narrow linewidth
- Loop filter is to improve the dynamics of the loop
- Loop delay presents a fundamental limitation on the loop bandwidth



Principle

- Free-running SCL has an output $a_s \cos(\omega_s t + \phi_s t)$
- The master laser output is $a_m \cos(\omega_m t + \phi_m t)$

The detected photocurrent is

$$i_{PD}(t) = \rho \left(a_m^2 + a_s^2 + 2a_s a_m \cos\left[(\omega_m - \omega_s)\, t + (\phi_m(t) - \phi_s(t))\right]\right),$$

where ρ is the responsivity of the PD.

Photodetector gain is $K_{pD} = 2\rho\langle a_s a_m\rangle$,

where $\langle\cdot\rangle$ denotes the average value

- The detected photocurrent is mixed down with a radio frequency (RF) signal, whose output $a_{RF} \sin[\omega_{RF}^t + \phi_{RF}(t)]$

- The choice of trigonometric functions ensures a mixer output of the form

$$i_M(t) = \pm K_M K_{PD} a_{RF} \sin\left[(\omega_m - \omega_s \pm \omega_{RF})\, t + (\phi_m(t) - \phi_s(t) \pm \phi_{RF}(t))\right].$$

- This mixer output is amplified with gain Kamp, filtered and fed into the SCL, acts as a current-controlled oscillator whose frequency shift is proportional to the input current,

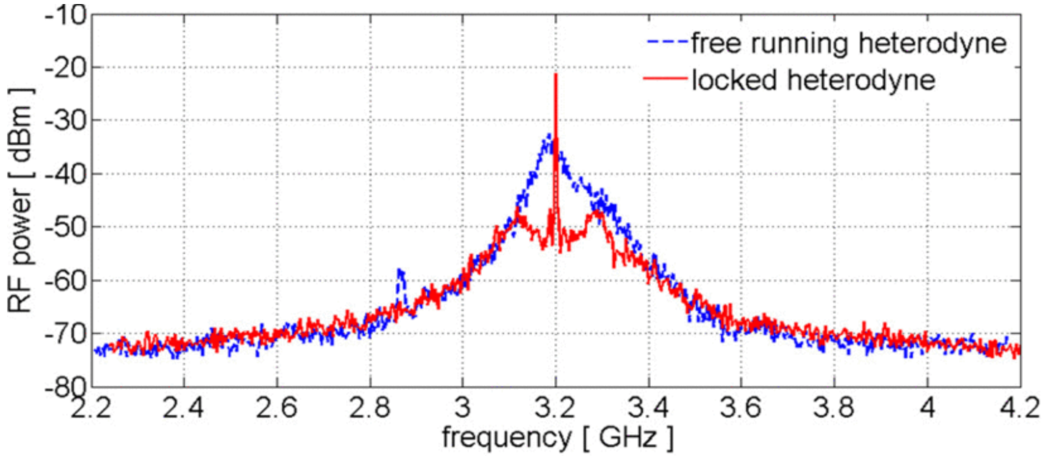
$$\delta\omega_s = k_s i_s(t) = -k_s k_{amp^{i_M}}(t)$$

- Frequency shift of SCL is

$$\delta\omega_s = -K_{dc} \sin\left[(\omega_m - \omega_s \pm \omega_{RF})\, t + (\phi_m(t) - \phi_s(t) \pm \phi_{RF}(t))\right].$$

OPLL Performance

- The peaks are maximum frequency at which the phase of the SL can be controlled that the phase-error between the ML and SL is reduced.
- The spectral purity of the heterodyne signal evaluated by phase noise power spectral density (PSD) or by the phase-error variance
- PSD is calculated by spectrum analyser or a dedicated phase noise measurement instrument
- Phase-error variance is obtained by integrating the phase noise PSD over a specified frequency range
- A variance of 0.03 rad , measured over the offset frequency range from 1 GHz to 10 GHz, is often used as a target value as it corresponds to a phase-error standard deviation of 10°



Source: "Integrated Semiconductor Laser Optical Phase Lock Loops" Katarzyna Bałakier, IEEE, 1500122 (2017)

Integration on InP

- Introduction of photonic integrated circuits (PICs) with optical components integrated onto a single chip
- Optical path delay reduced to tens of picoseconds and total delay to a few nanoseconds
- InP- PIC consisting of sampled-grating DBR (SG-DBR) lasers, semiconductor opticalamplifiers(SOAs), phase modulators, balanced photodetectors, and MMI couplers/splitters

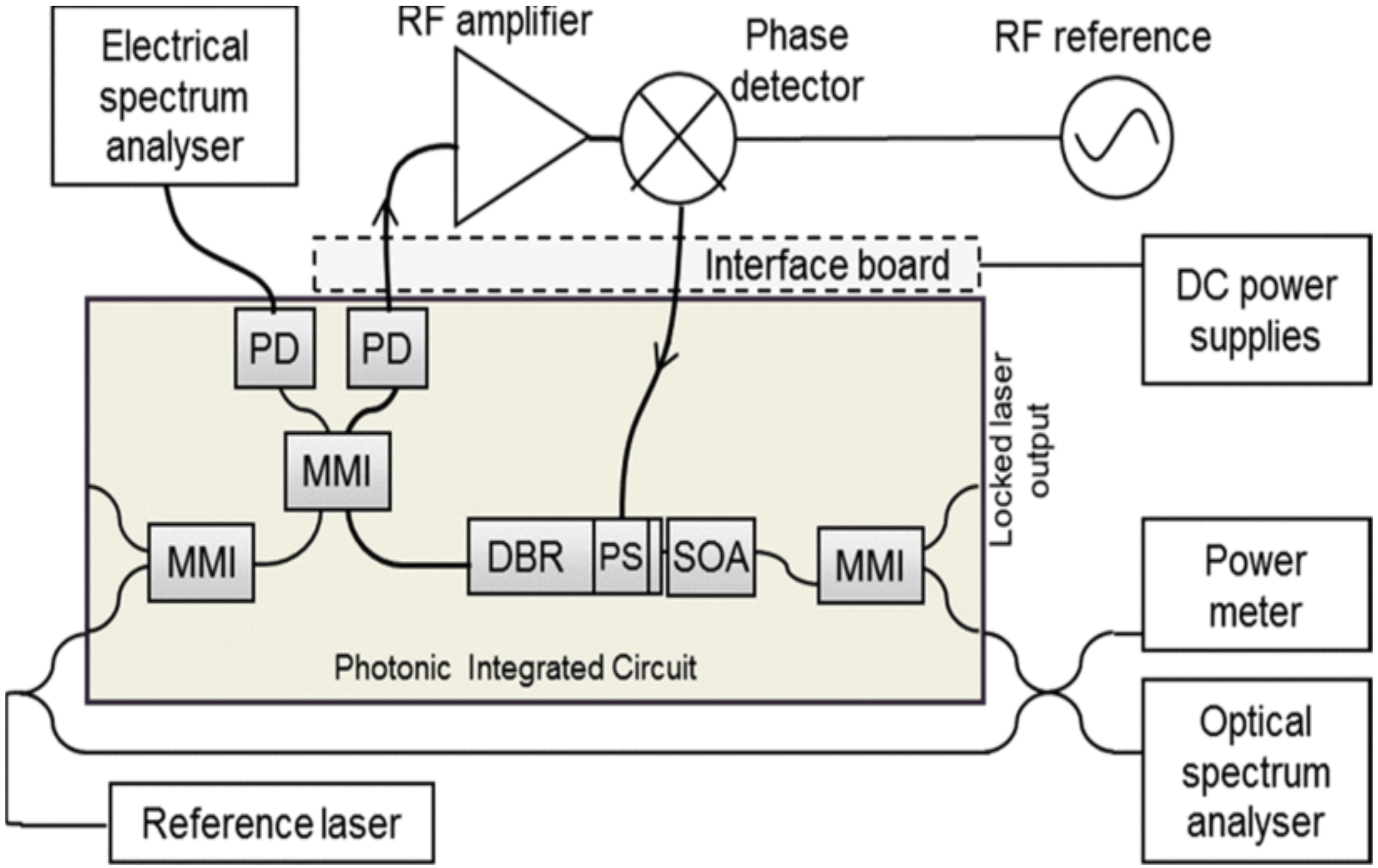


Fig 5: Schematic diagram of the optical phase lock loop assembly

Source: "Integrated Semiconductor Laser Optical Phase Lock Loops" Katarzyna Bałakier, IEEE, 1500122 (2017)

References

- Katarzyna Balakier, Lalitha Ponnampalam, "Integrated Semiconductor Laser Optical Phase Lock ", IEEE J. Quantum Electronics, 2017
- R. W. P. Drever, J. L. HallF. V. Kowalski, J. Hough, “Laser phase and frequency stabilization using an optical resonator” Applied Physics B, June 1993, Volume 31
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