Theoretical analysis of forward and backward optical injection locking configurations in semiconductor Fabry-Perot and DFB lasers

Injection locking properties of laser were originally derived from the studies performed in the field of electrical and microwaves oscillators and especially from Adler’s works on vacuum tube oscillator circuit. Consequently, the equation commonly used for optical injection locking, often referred as the Lang’s equation [1], doesn’t take into account specific parameters of the laser’s structure, nor the sense of the injection compared to the output field observation sense.

Using a transmission line and Green’s function approach [2] with electromagnetic boundaries conditions taking into account field injection through each side, we have derived, for the first time to our knowledge, theoretical general equations for the laser field of a Fabry-Perot and a DFB laser submitted to coherent optical injection by output side facet (backward) or opposite side facet (forward). These equations take into account spatial hole burning and gain compression, but fundamental results of this paper are already existing in low power Fabry-Perot laser.

Firstly, this equation gives the rigorous expression of the coupling constant of the external field, for each side of injection; for DFB laser, this constant is expressed in function of a complex equivalent round trip time.

The static locking equation shows the influence of the laser structure on the phase locking condition. We pointed out the existence of a “phase trap” regime of locking for large forward injection, characterized by an enlargement of the locking band and an ultra-stabilization of the phase of the slave laser on the master.

The calculation of the external coupling constants for DFB lasers with an anti-reflection coated facet is performed and establishes that these lasers are generally more sensible to injection locking than standard cleaved facet Fabry-Perot laser for normalized grating coupling factor less than two. For injection through the anti-reflection coating used as output facet, the external coupling factor is considerably reduced, with normalized grating coupling factor greater than four and with a high reflectivity coated opposite side facet.

Finally, we derive locked slave laser intensity and phase noise spectral equations. They show that output fields of each facet don’t exhibit the same noise. The usual noise equations [3] (corresponding to backward injection) result in a second order low pass filter behavior for the master phase noise power spectral density transfer to locked slave laser. However, for the forward sense, i.e. for injection through the opposite facet to the output, the phase noise equation involves not only the master phase noise but also its first derivative, thanks to the fact that the injected field is added to the cavity wave at the half of its round trip time. Consequently, in forward configuration, the phase noise spectral components of the master laser field can be transferred even for large Fourier frequencies, resulting in a higher cross-correlation between slave laser and master laser. This effect appears to be stronger in Fabry-Perot laser than in anti-reflection coated single facet DFB laser.