Influence of spontaneous emission noise on the dynamics of an external cavity semiconductor laser

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Introduction
Pumped close to threshold and subject to a moderate amount of optical feedback, laser diodes operate in the low-frequency fluctuation regime (LFF) [1]: their output measured by a slow detector exhibits sudden drops, followed by progressive recoveries until the next drop. The time interval between drops is aperiodic but lasts up to several µs.

Numerous studies have shown that spontaneous emission noise has a tremendous importance on the statistical distributions of the LFF drops [3-5].

Martinez Avila and coworkers [6] have recently investigated the LFF in a laser diode. They have obtained a good agreement between their experiments and their numerical simulations based on purely deterministic equations, thus neglecting spontaneous emission noise.

Using the same parameters but taking spontaneous emission noise into account, I investigate numerically its influence on the LFF statistics. I not only observe that their experimental results can be numerically reproduced with a realistic noise level but also, and more importantly, the statistics remain almost unaffected for their estimation of the laser parameters.

Equations
The behavior of a laser diode subject to optical feedback (see Fig. 1) is predicted by the Lang-Kobayashi equations [2]. Taking spontaneous emission noise into account, these equations are

\[ \frac{dE}{dt} = \frac{1 + i \alpha}{2} \left[ G_{\text{ext}}(N - N_{\text{s}}) - \frac{1}{\tau_p} \right] E + \kappa \omega_0 \tau \exp(-i \omega_0 \tau) + F_{\text{L}}(t) \]

\[ \frac{dN}{dt} = \frac{I}{\varepsilon} - \frac{G_{\text{ext}}(N - N_{\text{s}})}{1 + \varepsilon |E|^2} |E|^2. \]

\( E(t) \): slowly varying complex electric field
\( N(t) \): electron-hole pair number

\( G_{\text{ext}} \) and \( \varepsilon \): gain coefficient and saturation
\( \alpha \): linewidth enhancement factor
\( \tau_p \) and \( \tau_z \): photon and carrier lifetimes
\( \kappa, \tau, \omega_0, \tau \): feedback rate, delay and phase
\( F_{\text{L}}(t) \): Langevin noise force

\(<F_{\text{L}}(t)F_{\text{L}}(t')> = R_{\text{sp}} \delta(t-t') \) where \( R_{\text{sp}} \) is the spontaneous emission rate.

\( \delta(t-t') \) is the Dirac delta function.

Numerical results
Time trace of the laser output. It has been averaged to account for the finite bandwidth of a slow detector. LFF drops are clearly visible.

Mean time interval between successive drops as a function of the injection current and for different rates of the spontaneous emission.

Normalized standard deviation of the time between drops as a function of the injection current and for different spontaneous emission rates.

Conclusion
Using the same parameter values than in Ref. [6], my numerical simulations reveal that the mean time between successive intensity drops and its normalized standard deviation are barely modified when spontaneous emission noise is taken into account. This contrasts with the results of many numerical studies.