Analysis of Transmission Performance Enhancement with Injection-Locked Semiconductor Lasers

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It is well known that directly modulated semiconductor lasers have significant amounts of frequency chirping during modulation and this limits the performance of long-distance high speed fiber-optic communication systems [1]. One of the methods that can overcome this limitation is using injection-locked semiconductor lasers. Injection-locked semiconductor lasers can offer reduced chirping [2] and larger modulation bandwidth [3-4] with the proper adjustment of injection parameters such as injection ratio and frequency detuning. In this paper, the large signal characteristics of injection-locked semiconductor lasers and their performances in optical transmission systems are analyzed in detail. The rate equations for a single-mode semiconductor laser under optical injection [5] are numerically solved for the NRZ modulation format at the bit rate of 2.5 Gbps. The configuration used for the simulation is illustrated in Fig.1. The laser parameters are obtained from [1], where the linewidth enhancement factor of 5 is used. The emitting power of the slave laser (SL) is maintained at about 3 mW for on state and 1 mW for off state, regardless of the injected optical power.

The transient responses of the lasers are shown in Fig. 2 for (a) free-running (no injection) and (b) injection-locked (Δf = -10.6 GHz) lasers. The injected optical power is -6 dB, defined as the ratio of the injected power to SL's intracavity power at off state. The amount of frequency detuning (Δf) is selected so that the resulting BER is optimal at the given injected power. The bit sequence used for simulation is {1, 0, 1, 1, 1, 0, 0, 0}. Also shown in Fig. 2 are the transient changes in lasing frequency. It is clearly shown that injection locking provides a significant amount of chirp reduction.

The influence of chirp reduction on transmission performance can be illustrated with eye diagrams shown in Fig. 3. The eye diagrams are obtained with randomly generated 2^7 bits. In contrast to free-running lasers, not much eye closure is observed for injection-locked lasers even after 100 km transmission of the fiber. It can be noted from the figure that the initial eye opening for the injection-locked lasers is somewhat smaller than that of the free-running laser. This results from the higher relaxation oscillation (RO) frequency for injection-locked lasers. We find that the RO frequency increases with the injected power.

The influence of injection locking on transmission Bit Error Rate (BER) is shown in Fig. 4. The truncated pulse train, Gaussian approximation method [1] is used for BER calculation. For 100 km of the fiber, the increase of the external optical injection helps improving the BER. This is mainly attributed to the reduced chirp by injection locking.

The dependence of the receiver sensitivity at 10^{-9} BER on the fiber length is examined in Fig. 5. The BERs for free-running and weakly injection-locked lasers are strongly influenced by the chirping and dispersion penalties of 2.0 dBm for free-running and 1.6 dBm for –33 dB injection-locked lasers are observed. Strongly injection-locked lasers, however, have much reduced chirping and have only 0.3 dBm dispersion penalty for –6 dB injection.

In summary, we performed large-signal analyses of directly modulated semiconductor lasers under optical injection, and demonstrated that the injection locking reduces chirping and improves transmission performances.

References :

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[3] T. B. Simpson and J. M. Liu, IEEE *Photon. Technol. Lett.*, vol. 9, no. 10, pp. 1322-1324, 1997
[4] X. J. Meng et al., IEEE *Photon Technol. Lett.*, vol. 10, no. 11, pp. 1620-1622, 1998
[5] O. Lidoyne et al., IEEE J. *Quantum. Electron.*, vol. 27. no. 3, pp. 344-350, 1991

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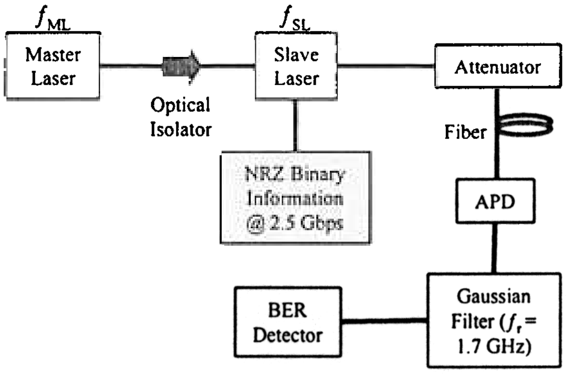
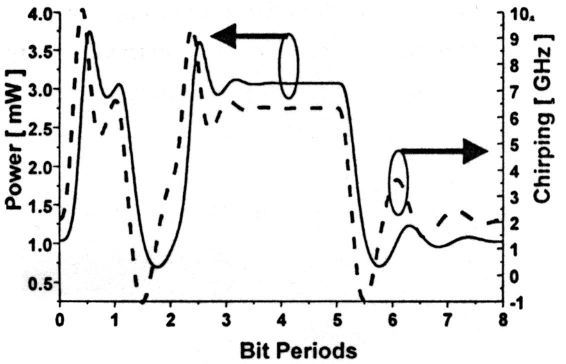
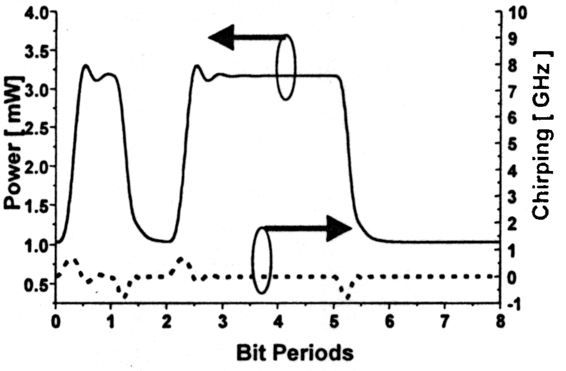


Fig. 1 System configuration for simulation. The frequency detuning, Δf, is defined as f_{ML}-f_{SL}, and f_r the cutoff frequency.

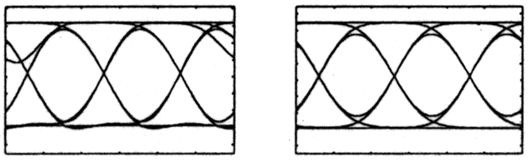


(a) free-running



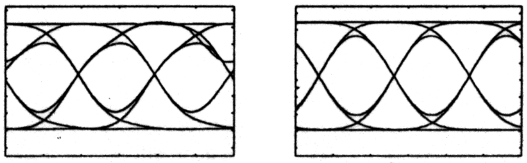
(b) injection-locking

Figure 2. Transient solutions of the rate equations for (a) free-running, and (b) injection-locked (-6 dB) lasers. The solid lines represent optical power, and dotted lines the frequency chirping



(a) Free-running after 0 km

(b) Injection-locking after 0 km



(c) Free-running after100 km

(d) Injection-locking after 100 km

Figure 3. Eye diagrams at 0 km (top) and 100 km (bottom) fiber.

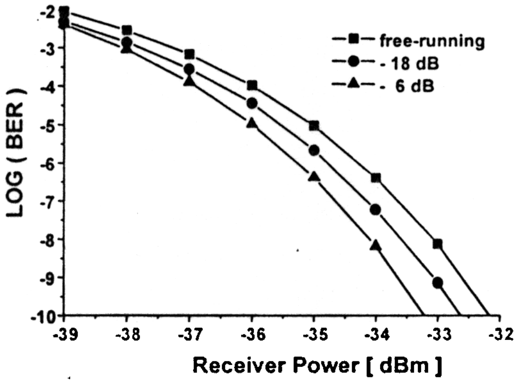


Figure 4. BER versus received optical power after 100 km fiber. The SL's emitting power is 1.03 mW and 3.08 mW at off- and on- state respectively.

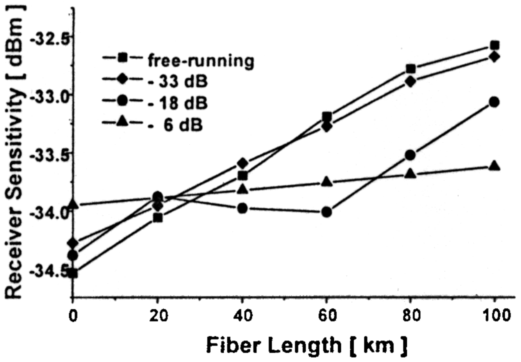


Figure 5. Receiver sensitivity versus fiber length.