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Reduction of Fiber Dispersion-Induced Third-Order Intermodulation Distortion with Injection-Locked Distributed Feedback Lasers

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The third-order intermodulation distortion (IMD3) in fiber optic link increases over transmission through dispersive fiber. We experimentally investigate dispersion-induced IMD3 variation in fiber optic link and show that IMD3 can be reduced and made less dependent on dispersive fiber transmission length by using injection-locked distributed feedback laser diodes.
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KEYWORDS: semiconductor laser nonlinearity, intermodulation distortion, fiber dispersion, optical injection locking, subcarrier multiplexed fiber optic link

Subcarrier multiplexed (SCM) fiber optic systems have many applications such as wireless local loops, cable television distributions and fiber-radio systems. The direct modulation of semiconductor lasers is a simple and low-cost approach for transmitting RF-range subcarriers. However, semiconductor laser nonlinearities and fiber chromatic dispersion cause harmonic and intermodulation distortions, and these can severely degrade overall system performance.[1,2] Although third-order intermodulation distortion (IMD3) is much smaller than second-order harmonic (2HD) and sum term intermodulation distortion (IMD2), the overall system performance is mainly affected by IMD3 in systems where 2HD and IMD2 frequencies lie outside the frequency band of interest.[3] Hence, it is crucial to suppress the IMD3.

To reduce nonlinear distortions in semiconductor lasers, several methods have been proposed, such as electrooptical feedback and feed-forward compensation.[4,5] Moreover, Meng *et al.* have reported that laser distortion can be significantly suppressed by injection locking. Light from an external master laser (ML) is used to lock the signal transmitting slave laser (SL).[6] This technique can increase the laser relaxation oscillation frequency, which can cause the intrinsic nonlinear distortion suppression in directly modulated semiconductor lasers. However, to author's knowledge, the IMD3 variation of the injection-locked semiconductor laser over dispersive fiber transmission has not been studied for the analog fiber-optic applications.

In this letter, we report the experimental observation of the IMD3 variation of the injection-locked distributed feedback laser diode (DFB-LD) over fiber transmission. We show that the fiber dispersion-induced IMD3 of the free-running DFB-LD increases during fiber transmission because of the combined effect of laser source nonlinearities and fiber chromatic dispersion, and it can be greatly reduced and made less dependent on fiber transmission length by employing the injection locking technique.

Figure 1 shows the experimental setup for measuring IMD3 dependence on dispersive fiber length for the free-running and injection-locked semiconductor lasers. An external-cavity tunable light source is used as master laser (ML). For slave laser (SL), a commercially available, unisolated DFB-LD (Samsung SDL-24) is used. For generating subcarriers, SL is directly modulated by a two-tone RF signal ($f_1 = 2.6$ GHz, $f_2 = 2.7$ GHz) and, consequently, third-order intermodulation products (IMP3) at $2f_1 - f_2$ (= 2.5 GHz) and $2f_2 - f_1$ (= 2.8 GHz) are produced. The standard single-mode fiber is used in the experiment. In both free-running and injection-locked cases, the SL is biased at 15 mA ($\cong 1.9 \times I_{\mathrm{th}}$) and modulated by a two-tone RF signal whose power level before Bias-T is −6 dBm. To achieve the stable injection-locked state, the incident ML lasing frequency is set at about 10 GHz lower than the free-running SL lasing frequency. The injection ratio is set at −5 dB. It is defined as $P_{\mathrm{inj}}/P_{\mathrm{out}}$, where P_{inj} is the injected optical power from the ML into the SL and P_{out} is the free-running output power of SL.

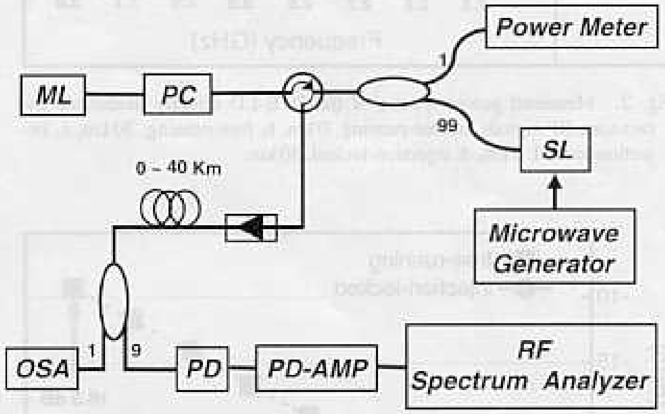

Fig. 1. Experimental Setup. ML: external-cavity tunable laser diode, SL: DFB-LD, PC: polarization controller, OSA: optical spectrum analyzer, PD: photodetector, PD-AMP : PD pre-amplifier.

Figure 2 shows the measured RF spectra at the fundamental and IMP3 frequencies in the free-running (Figs. 2(a) and 2(b)) and injection-locked states (Figs. 2(c) and 2(d)) at 0 Km and 30 Km fiber transmission. IMD3 is defined here as the ratio of the power at IMP3 frequency (= 2.8 GHz) to the power at the fundamental modulating frequency (= 2.7 GHz). IMD3 for the free-running state is −21.5 dBc at 0 Km and increases to −14.0 dBc at 30 Km. The RF power reduction at the fundamental frequency after 30 Km transmission is due to the intrinsic fiber loss, but the RF power at IMP3 frequency is not as much reduced, resulting in 7.5 dB increase in IMD3. For the injection-locked state, IMD3 is −27.17 dBc at 0 Km and −26.0 dBc at 30 Km. The IMD3 increases only by 1.17 dB after the transmission. These results show that injection locking helps in suppressing the laser nonlinearity as can be seen from the reduced IMD3 by 5.67 dB at 0 Km, and also reduces the fiber dispersion-induced IMD3 by 12.0 dB as can be seen

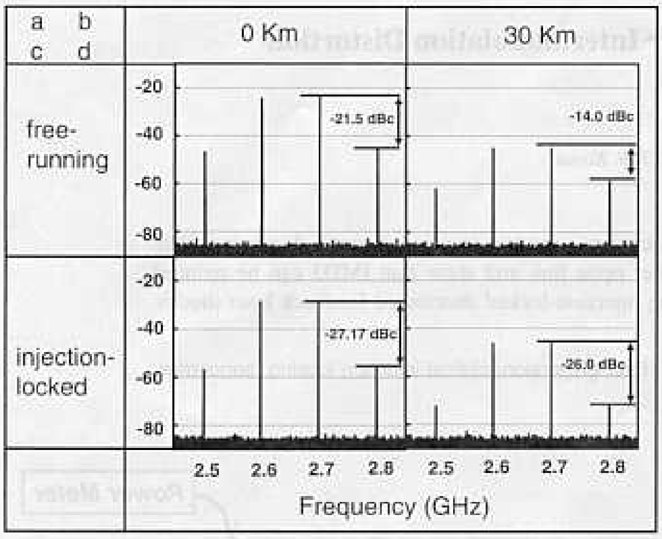

Fig. 2. Measured power spectra of the DFB-LD directly modulated by two-tone RF signals. a. free-running, 0 km, b. free-running, 30 km, c. injection-locked, 0 km, d. injection-locked, 30 km.

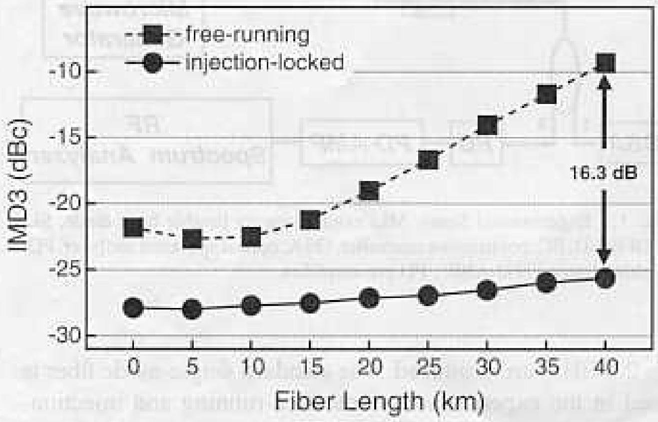

Fig. 3. Measured IMD3 against fiber transmission length for free-running and injection-locked cases.

from the much smaller increase in IMD3 after transmission.

The reduction of the dispersion-induced IMD3 for the injection-locked laser can be explained as follows. When the semiconductor laser is directly modulated by RF signals, it produces the broad optical spectrum including the combination of various harmonic and intermodulation products mainly due to the laser frequency chirp. During the dispersive fiber transmission, these harmonic and intermodulation products can be affected by the fiber chromatic dispersion, depending on the modulation frequency and fiber length,[1] which leads to IMD3 increase as shown in our experiments. That is, the broad optical spectrum is susceptible to the fiber chromatic dispersion effect, resulting in the dispersion-induced distortion. On the contrary, the injection-locked semiconductor lasers have the reduced frequency chirp and thus, when directly modulated by RF signals, produces the rather narrow optical spectrum including the smaller number of harmonic and intermodulation products. Consequently, it is less affected by the fiber chromatic dispersion, and the fiber dispersion-induced IMD3 of the injection-locked DFB-LD does not increase much as shown in Fig. 2.

Figure 3 shows the measured IMD3 at various transmission lengths. For the free-running state, IMD3 does not change much up to 10 Km and, we believe, this is related to the "self-steepening" interaction of the fiber dispersion with the frequency chirp.[7] After then, IMD3 starts to increase and reaches −9.31 dBc at 40 Km resulting in 12 dB increase compared to 0 Km. On the contrary, for the injection-locked state, the slight increase of IMD3 can be observed in the overall transmission length under measurement. The IMD3 degradation after 40 Km fiber transmission is 1.55 dB.

We have experimentally shown that the fiber-dispersion-induced IMD3 increases for the directly modulated DFB-LD over dispersive fiber transmission and that it can be suppressed by injection-locking the DFB-LD. IMD3s for free-running semiconductor lasers are degraded due to the combined effect of the semiconductor laser nonlinearities and fiber dispersion. But, in the injection-locked case, the laser frequency chirp is suppressed, and the influence of fiber dispersion on IMD3 is much reduced. In our experiments, IMD3 variation was bounded within about 1.5 dB by using injection-locked DFB-LD and 16.3 dB reduction in IMD3 is achieved for 40 Km transmission.

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