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Dependence of Semiconductor Laser Intermodulation Distortions on Fiber Length and its Reduction by Optical Injection Locking

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Abstract

We experimentally investigate the dependence of semiconductor laser intermodulation distortions (IMDs) on fiber transmission length. IMDs in fiber optic link are degraded over transmission through dispersive fiber. We show that IMDs can be reduced and made less dependent on fiber transmission length by using injection-locked DFB and Fabry-Perot (FP) semiconductor lasers.

1. Introduction

Subcarrier multiplexed (SCM) fiber optic systems with direct laser intensity modulation have many applications such as wireless local loop, cable television distributions and fiber-radio systems. The direct modulation of semiconductor laser is a simple, low-cost approach for transmitting RF-range subcarriers. However, the nonlinear distortions due to semiconductor laser non-linearities and fiber dispersion can severely degrade overall system performance [1].

Hence, it is needed to suppress semiconductor laser nonlinearities and also to reduce IMD dependence on fiber length. As one method for suppressing non-linearities of semiconductor lasers, optical injection locking of semiconductor lasers has been widely investigated and found very effective [2, 3]. The optical injection locking scheme requires two light sources - master laser (ML) and slave laser (SL). The light from ML is injected into SL and SL's output is locked to ML. Two major parameters for the injection locking are frequency detuning - frequency difference between ML and SL - and injection power ratio. If the injection locking conditions are satisfied, improvements in laser dynamics such as relaxation oscillation frequency increase and frequency chirp reduction can be achieved [4, 5].

When optical signals produced by a directly-modulated semiconductor laser are sent over fiber, their third-order intermodulation distortions (IMD3) can be degraded because of the fiber dispersion. There has been not much investigation on this issue and we report results of our experimental investigation on the dependence IMD3 degradation on fiber length. In addition, we demonstrate that IMD3 dependence on fiber length can be much reduced by using injection-locked semiconductor lasers.

2. Experimental setup

Fig. 1 shows the experimental setup for measuring IMD3 dependence on fiber length for free-running and injection-locked semiconductor lasers. For injection-

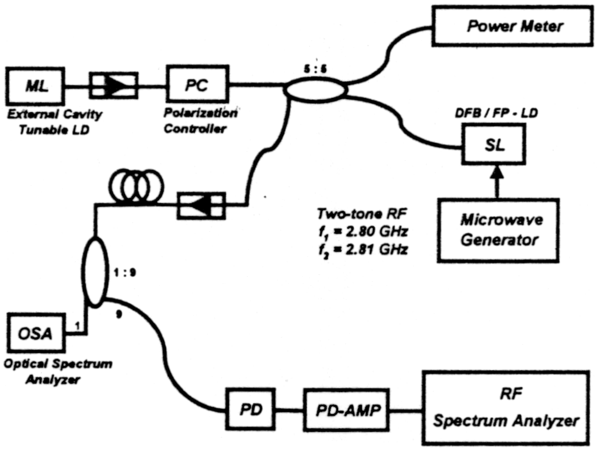

Fig. 1. Experimental Setup

locking, the external-cavity tunable light source is used for ML. For SL, a commercially available, fiber-coupled, isolator-free DFB (Samsung SDL-24) and FP (Samsung SFL-24, Δλ= ~0.84nm) lasers are used. Optical isolators with >50dB isolation are used to prevent light coupling from SL to ML and protect the SL against backreflected light as shown in the figure. For generating subcarriers, SL is directly modulated by two–tone RF signals (f1= 2.80GHz, f2=2.81GHz) and, consequently, third-order intermodulation products (IMP3) at 2f1-f2 (=2.79GHz) and 2f2-f1 (=2.82GHz) are generated. Standard single-mode fiber with different length from 5 to 40 km is used in the experiment.

3. Results

I. DFB – LD

For both free-running and injection-locked states, SL (DFB-LD) is biased at 15mA (≅1.9Ith) and directly modulated by two-tone RF signals. The power level of both RF signals before Bias-T is kept at -0.8dBm. To achieve the stable injection-locked state, the frequency offset between ML and SL was set at 4.1GHz, where stable locking range about 5GHz, and the injection ratio at about –6dB. Received RF powers at the fundamental (f2=2.81GHz) and IMP3 (2f2-f1=2.82GHz) frequencies are measured while the fiber length is varied in the increment of 5 km up to 40km. In this condition, the IMD3 dependence on fiber length for both free-running and injection-locked states is investigated.

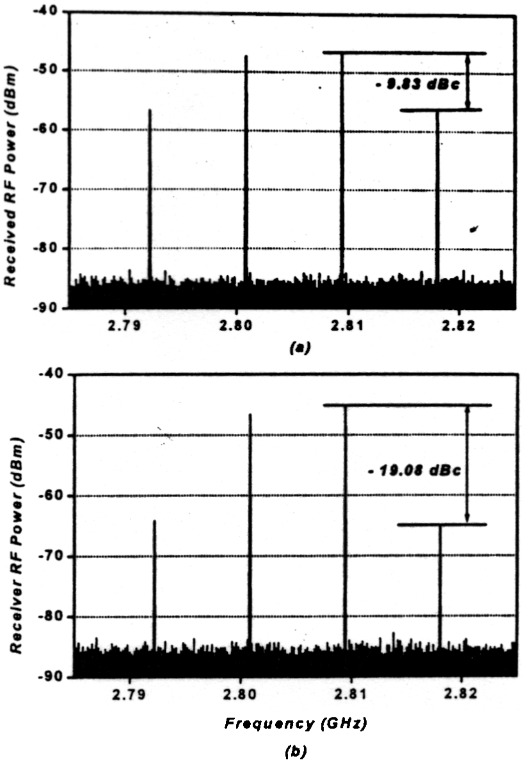

Fig 2. **Measured power spectra of the DFB-LD directly modulated by two-tone RF signals after 30km transmission for (a) free-running and (b) injection-locked state.**

Fig. 2 shows an example of the measured RF spectrum at the fundamental and IMP3 frequencies in the free-running and injection-locked state after 30Km transmission. IMD3 for the free-running state is –9.83 dBc (Fig. 2(a)) and IMD3 for the injection-locked state (Fig. 2(b)) is –19.08 dBc where IMD3 is defined as the ratio of the power at IMP3 frequency to the power at the fundamental frequency. About 9.25dB reduction in IMD3 is achieved by optical injection locking.

In Fig. 3(a), the received RF powers at the fundamental and IMP3 frequencies are plotted for the free-running and injection-locked state at various fiber lengths. Overall, the received RF powers at both fundamental and IMP3 frequencies decrease with increasing fiber length and this is due to the fiber loss and dispersion. However, this reduction is smaller for the injection-locked state. IMD3 dependence on fiber length is shown in Fig. 3(b). In the free-running state, IMD3 is –20.1dBc back-to-back and –6.58dBc at 40km transmission, which shows IMD3 degradation of 13.52dB after 40km transmission. In the injection-locked state, IMD3 is –23.97dBc back-to-back and –18.81dBc at 40km transmission. The IMD3 degradation is only 5.16dB in the injection-locked state and its variation is maintained within about 5dB for the entire transmission length. Compared to the free-running state, the injection-locked state has 12.23dB reduction in IMD3 for 40km fiber transmission.

II. FP – LD

FP-LD is used as SL instead of DFB-LD in order

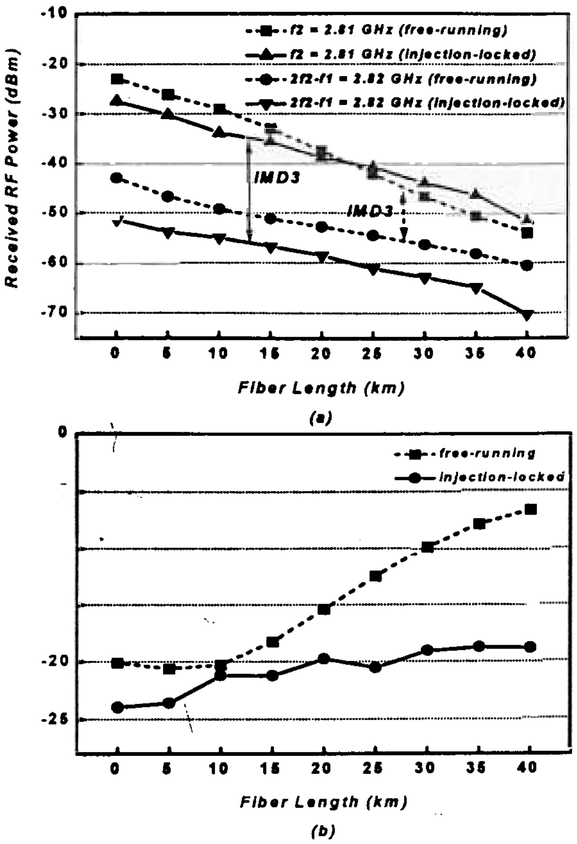

Fig. 3. (a) Received RF power at f2 and 2f2-f1 (b) IMD3 when DFB-LD is used as SL.

to investigate the IMD3 dependence of FP-LD on fiber length. SL is again biased at 15mA (≅3.3Ith) and directly modulated by two-tone RF signals at f1=2.81GHz and f2=2.82GHz. The power level of both RF signals before Bias-T are kept at –0.8dBm. In order to achieve injection locking, one injection target mode among FP-LD's multi-modes is chosen and ML is tuned within the locking bandwidth. In this experiment, we chose a side-mode located at the shorter wavelength side from the peak mode so that the larger injection locking bandwidth can be utilized [6]. Since the optical power of the injection-locked FP mode is much smaller compared to that of DFB-LD's fundamental mode, the injection locking bandwidth is much larger for FP-LD than DFB-LD. Hence, injection locking of FP-LD can be achieved more easily than DFB-LD. The injection ratio between ML and FP-LD target mode is about –0.45dB and the stable locking range is about 30GHz.

Fig. 4 shows an example of the measured RF spectra at the fundamental and IMP3 frequencies for the free-running and injection-locked states after 20km transmission. Fig. 4(a) shows IMD3 of –5.7dBc in the free-running state. The RF spectrum of the injection-locked state in Fig. 4(b) shows IMD3 of –24.21dBc. 18.51 dB reduction in IMD3 is achieved with injection-locked FP-LD. In Fig. 5(a), the received RF powers at the fundamental and IMP3 frequencies are plotted for the free-running and injection-locked states. In the free-running state, the received RF powers at the fundamental and IMP3 frequencies show a significant fluctuation, while the received RF powers of free-running DFB-LD decrease monotonously. The fluctuation shown by the free-running state is related to the modal dispersion of FP-LD [7]. Fig. 5(b) shows that IMD3 variation for injection-locked FP-LD is bounded within about 5dB for the entire transmission

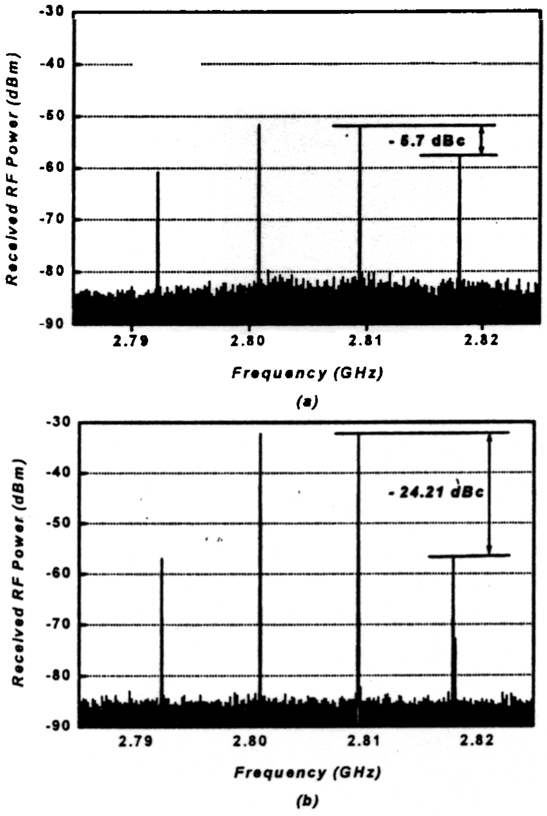

Fig 4. Measured power spectra of the FP-LD directly modulated by two-tone RF signals after 20km transmission for (a) free-running and (b) injection-locked state.

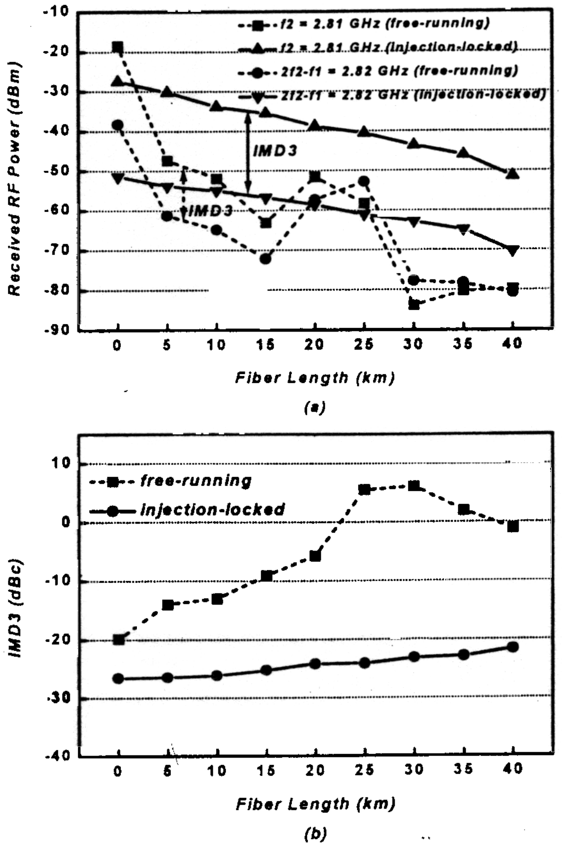

Fig. 5. (a) Received RF power at f2 and 2f2-f1
(b) IMD3 when FP-LD is used as SL.

range, which is quite comparable with that of the injection-locked DFB-LD.

4. Conclusions

We have experimentally shown the dependence of IMD3 of directly modulated DFB- and FP-LD on fiber length and that IMD3 can be reduced by optical injection locking of both DFB- and FP-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, semiconductor laser nonlinearities are suppressed, and the influence of fiber dispersion is much reduced. In our experiments, 12.23 dB reduction in IMD3 for DFB-LD and 20.55 dB reduction for FP-LD can be achieved with injection locking, and IMD3 variation was bounded within ~5dB for up to 40km transmission. In addition, the injection-locked FP-LD shows almost the same IMD characteristics as the injection-locked DFB-LD.

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