Suppression of Intermodulation Distortion in DFB Lasers by External Optical Injection Locking

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Sub-carrier-multiplexed (SCM) fiber optic systems are very attractive for local access networks, fiber radios, and cable television distribution. Direct modulation of semiconductor lasers is a simple, low-cost approach for the SCM systems. However, its performance is often limited by the nonlinear distortion of semiconductor lasers. The nonlinear distortion increases significantly as the carrier frequency approaches the relaxation oscillation frequency of the laser due to the coupling between photons and electrons in the laser cavity [1-2]. Recently, it has been theoretically shown that the laser nonlinearity can be considerably reduced by optical injection locking [3]. Previously, we have shown that injection locking is very effective in suppressing the second harmonic distortion [4]. In most applications, however, the effect of the third-order intermodulation distortion is more important.

In this paper, we report on the first experimental observation of the reduction of the third-order intermodulation distortion in directly modulated semiconductor distributed feedback (DFB) lasers under strong injection locking.

The experimental setup is shown in Fig. 1. The master laser is a commercial external-cavity tunable laser diode (ECT-LD) at 1.55 μm. The laser linewidth is less than 200 kHz. The CW light from the ECT-LD is injected into the slave laser through an optical isolator. The slave laser is a 1.55-μm single-longitudinal mode DFB laser diode with a threshold current I_{th} of 23 mA. A polarization controller is employed to adjust the polarization of the injected light. Two microwave subcarriers with frequencies f_1 and f_2 from signal generators are combined to modulate the DFB laser directly through a bias-T. The optical signal is detected and amplified by a 15-GHz lightwave converter (HP 11982A) with responsivitiy of 300 V/W for 50Ω load. The output is connected to a microwave spectrum analyzer for measuring the third-order intermodulation distortion (IMD3), which is defined as the power ratio of the third-order intermodulation wave at $2f_2-f_1$ ($f_2 = f_1 + \delta f$) to the fundamental wave.

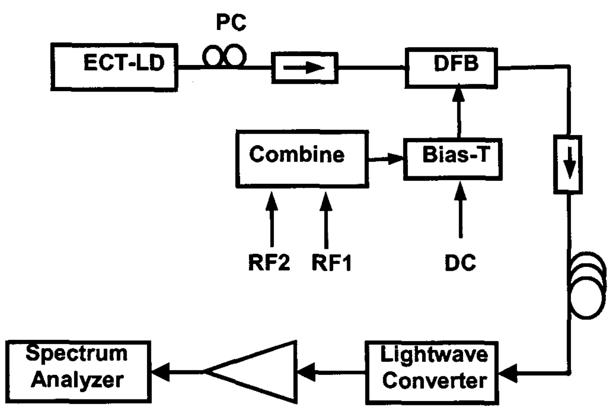

Fig. 1 The experimental setup.

In our experiments, the slave laser is biased at 40 mA ($\cong 1.75 I_{th}$) and the received optical power at the receiver end is –7 dBm. The relaxation oscillation frequency of the free-running laser under this bias condition is 4.1 GHz. The DFB laser is then injection locked to the master laser. The injection ratio and detuning frequency are set at –8 dB and –15 GHz, respectively, which are located in the middle of the stable locking range. Under injection locking, the relaxation oscillation frequency is dramatically increased to 13.6 GHz. The increase in relaxation oscillation frequency suggests that intrinsic nonlinear distortion can be suppressed in the high frequency range close to the relaxation oscillation frequency of the free-running laser [2]. Figure 2(a) shows the measured power spectrum of the free-running laser modulated by a two-tone microwave signal. The power levels of both subcarriers before the Bias-T are kept at 2 dBm. The f_1 and δf are 2.0 GHz and 0.1 GHz, respectively. The IMD3 is measured to be –23.3 dBc. In contrast, Figure 2(b) shows the corresponding power spectrum of the DFB laser under injection locking. The IMD3 has been dramatically reduced to –38.1 dBc.

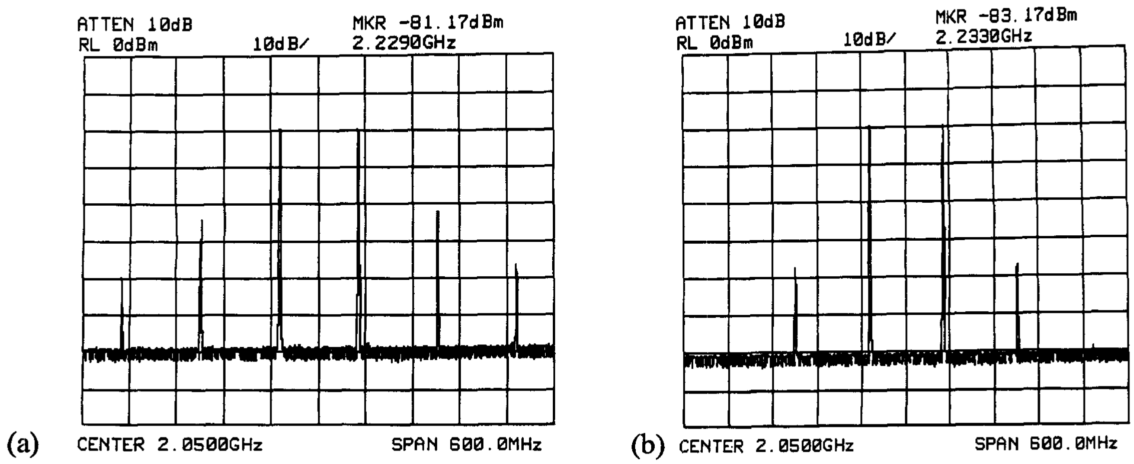

Fig. 2. Power spectra of the DFB laser modulated by a two-tone microwave signal at f_1 = 2.0 GHz and f_2 = 2.1 GHz for (a) free-running and (b) injection-locked laser.

Figure 3 shows the measured third-order intermodulation distortion with and without external optical injection versus the modulation frequency. The injection parameters are the same as those used in Fig. 2(b). With injection locking, the third-order intermodulation distortion is suppressed by nearly 15 dB from 1.4 to 3.0 GHz. Figure 4 shows the RF output power of the fundamental wave and the third-order intermodulation waves with and without injection locking versus the RF input power. Again, the f_1 and δf are 2.0 GHz and 0.1 GHz, respectively. With optical injection locking, the spurious-free dynamic range (SFDR) has been improved from 95 dB·Hz$^{2/3}$ to 100 dB·Hz$^{2/3}$.

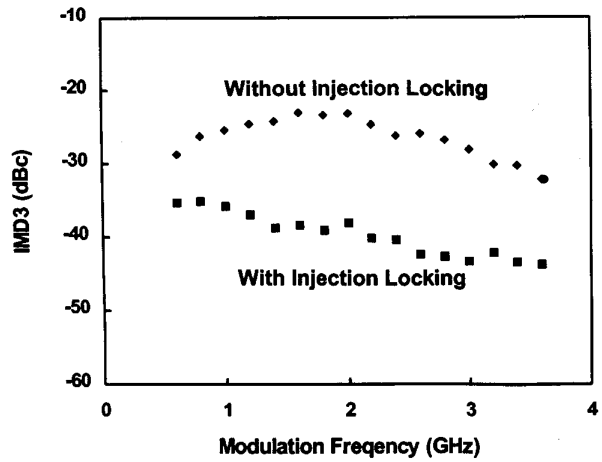

Fig.3. Third-order intermodulation distortion versus modulation frequency.

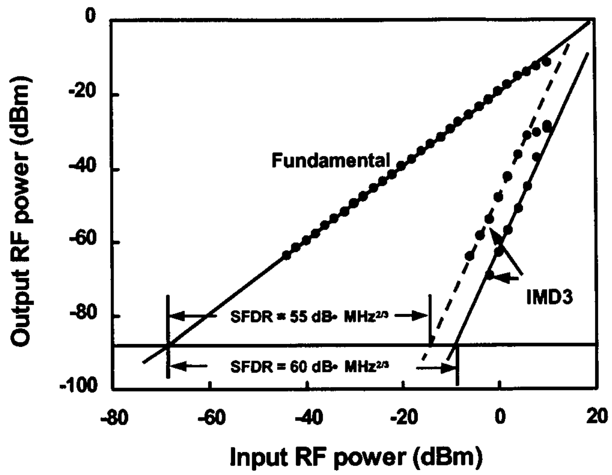

Fig. 4. The spurious-free dynamic range (SFDR) of the link with directly modulated DFB laser with (dashed line) and without (solid line) optical injection locking.

In conclusion, we have experimentally demonstrated that optical injection locking is very effective in suppressing the intermodulation distortion in directly modulated semiconductor lasers. Nearly 15 dB reduction in third-order intermodulation distortion has been observed from 1.4 to 3.0 GHz. This technique is very useful for high performance sub-carrier multiplexed fiber optic systems with subcarrier frequencies of several GHz. This work is supported by ONR MURI on RF Photonics.

References:

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