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반도체 레이저의 비선형성 분석

Analysis and Suppression of Dynamic Nonlinear Distortions in Semiconductor Laser Diodes

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There is a strong need for analog optical communication systems(1). In these systems, one of the key elements that determine the total system performance is optical source linearity. Direct modulation of semiconductor laser diodes is the simplest and most economical solution but linearity of the laser diode is often not sufficient for many applications. This is especially the case for next generation mobile systems, which require much higher carrier frequencies. Consequently, it is of significant importance to understand the causes for nonlinearity in laser diodes and to come up with ways of suppressing it. In this paper, we present an accurate method for analyzing signal distortions due to laser diode nonlinearity. In addition, we investigate the injection locking technique that can be used for suppressing laser diode nonlinearity.

Intrinsic dynamic nonlinearity in a laser diode is caused by the interaction between carriers and photons in laser cavity. This can be analyzed based on the rate equations(2).

$$\begin{aligned} \frac{dS(t)}{dt} &= \Gamma g_0 \frac{N-N_0}{1+\varepsilon S(t)} S(t) - \frac{S(t)}{\tau_p} + \frac{\Gamma\beta}{\tau_n} N(t) \\ \frac{dN(t)}{dt} &= \frac{I(t)}{qV} - \frac{N(t)}{\tau_{(n)}} - g_0 \frac{N-N_0}{1+\varepsilon S(t)} S(t) \\ \frac{d\phi(t)}{dt} &= \frac{\alpha}{2}[\Gamma g_0 (N(t)-N_t) - \frac{1}{\tau_p}] \end{aligned} \tag{1}$$

For the nonlinear distortion analysis, we used the perturbation method in which a sinusoidal input current of small magnitude with modulation frequency is assumed, and output photon density and carrier density have their harmonic responses varying around the mean values.

For analyzing second harmonic distortions after fiber transmission, the E-field can be expressed as shown below in Eq. (2) that fully considers laser diode dynamics. Values for both magnitude and phase indices can be obtained from the perturbation analysis. In order to model the influence of fiber dispersion, the fiber transfer function $H(f)= e^{j\cdot\pi\cdot\lambda^2\cdot D\cdot L\cdot f^2}$ is used.

$$\begin{aligned} E(t,z=0) \cong\ & P_0{}^{1/2}(1+ m_{IM1}\cos(\omega t+\phi_{IM1}) + m_{IM2}\cos(2\omega t+\phi_{IM2}))^{1/2} \\ & \cdot \exp(i\cdot m_{FM1}\sin(\omega t+\phi_{FM1}) + i\cdot m_{FM2}\sin(2\omega t+\phi_{FM2})) \end{aligned} \tag{2}$$

Experiments are performed in order to verify the accuracy of our model for a fixed link length (40km) with varying modulation frequencies and at a fixed modulation frequency (4GHz) for varying fiber lengths. Fig. 1 shows measured fundamental signals and second harmonic distortions. Calculated results with our model are shown in solid lines. Good agreement with the measured results can be seen. For comparison, calculated results with previously reported models are shown in dashed(3) and dotted lines (4) respectively.

It has been reported that injection-locked laser diodes have significantly reduced dynamic nonlinear distortions(5), (6). Optical injection locking occurs when external light from Maser Laser (ML) is injected into Slave Laser (SL) and then, the SL characteristics are controlled by the ML. For injection locking, the frequency difference between ML and SL and injection power ratio are important parameters. When locking occurs, the relaxation oscillation frequency of the SL increases. Since the nonlinear distortions are more pronounced as the modulation frequency approaches the relaxation oscillation frequency, the injection-locked laser with the increased relaxation oscillation frequency suffers less from nonlinear distortions. However, the amount of distortion suppression can be influenced by the locking conditions such as injection wavelength. Our investigation is aimed at understanding this dependence and determining the optimal locking condition.

In order to determine the dependence of distortion suppression on injection wavelength, the amounts of IMD2 (second order intermodulation distortion) suppression are measured at various injection wavelengths that are within the stable locking range. The SL is modulated with 2.8 GHz and 2.9 GHz RF signals, and the modulation power is adjusted to the free-running (no optical injection) modulation power. Fig. 2 shows the experimental results.

To investigate this result, the laser frequency responses according to the optical injection wavelengths are simulated. With the perturbation method, the frequency responses after light injection are calculated [5]. At small frequency detuning, the relaxation oscillation frequency increases very much with small damping. However, at large frequency detuning, the relaxation oscillation frequency does not increase much. Instead, damping is very large. Such frequency [illegible] changes influence the IMD2 suppression and we believe that the fundamental signal power level change is [illegible] important factor. Then, to investigate the [illegible] [illegible] ects is change [illegible] distortion suppression, the IMD2 suppression simulation considering these ef[illegible] IMD2 also done. When the fundamental signal power is adjusted as was done in the experiment, the detailed suppression characteristics are good agreement with the experimental results. All the [illegible] procedures and the simulation results will be presented at the meeting.

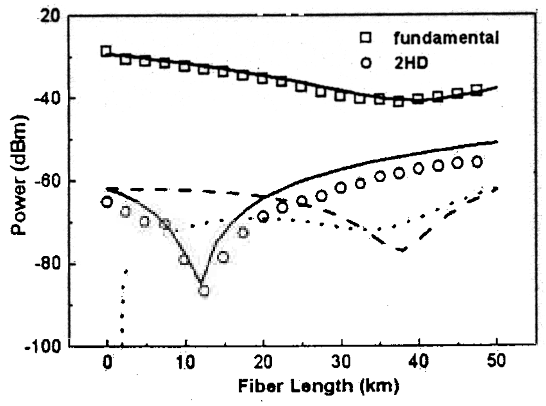

Fig. 1 Fundamental signal and 2nd harmonic distortion

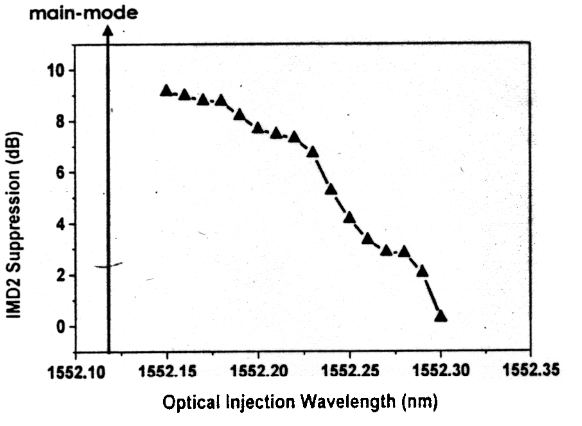

Fig. 2 IMD2 suppression according to the injection wavelength

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