Application Note:

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Maintaining the Extinction Ratio of Optical Transmitters Using K-Factor* Control

*Patent Pending[1]

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Maintaining the Extinction Ratio of Optical Transmitters Using K-Factor[1] Control

1 Overview

It is critical to maintain constant optical output for laser diodes addressing high speed, fiber optic transmitter applications. Establishing a proper laser bias current is necessary to minimize laser turn-on/turn-off delay and relaxation oscillation. Appropriate laser biasing also limits the sensitivity penalty of optical receivers introduced by inadequate extinction ratio ($r_e = P_1 / P_0$). A well-controlled laser modulation current (corresponding to P1) ensures that the channel optical-power budget is met without exceeding the optical-receiver-overload level. For some low-cost lasers, optimized performances can only be achieved within a tight bias and modulation range.

Figure 1 shows the driving current and optical output behavior of a typical laser diode. Notice that the laser threshold increases and the slope efficiency decreases as the operating temperature goes up. Therefore, the driver needs to provide an increased amount of bias current and modulation current to maintain a constant laser emission.

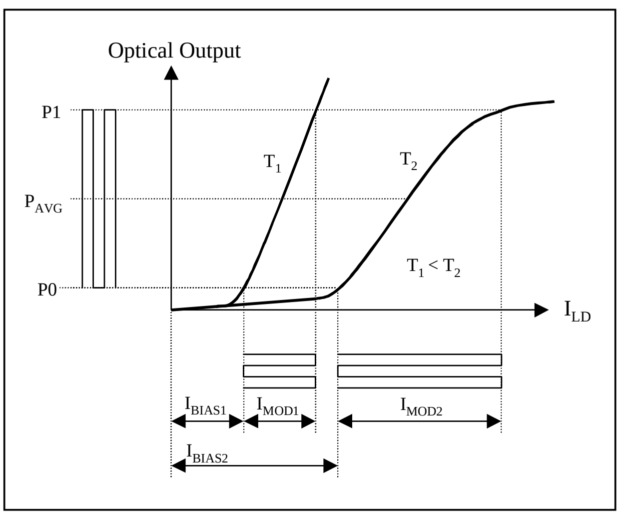

Figure 1. Laser behavior changes over temperature

One way to compensate for the laser behavior change in both threshold and slope efficiency over temperature is based on an automatic power control (APC) loop and a temperature sensor. The driver sets the laser modulation current (I_{MOD}) to a pre-programmed value according to the operating temperature. The APC loop determines the bias current based on the monitor diode photocurrent, which is proportional to the average optical power (P_{AVG}). This approach requires part-to-part adjustment, and provides loose control accuracy of the modulation current.

An alternative approach is to use an automatic modulation control (AMC) loop, together with an APC loop[2]. The average laser slope efficiency is predicted by detecting the incremental slope of the laser diode at P0 or P1. This is accomplished by applying a low-frequency tone to the laser current within the monitor diode bandwidth. However the incremental slope at P0 or P1 does not necessarily follow the average slope efficiency change over temperature and operating range.

This application note presents a new solution, using K-factor[1] compensation to maintain laser extinction ratio by changing the modulation current in proportion to the bias current when closing the APC loop. The concept is discussed and experimental results are presented. This approach has been implemented in the MAX3863 2.7Gbps laser driver with modulation compensation[3, 4].

2 K-Factor Compensation

The following equation shows the relationship between the laser modulation current and the threshold current over temperature. It is found that this approximation is valid for most semiconductor laser diodes:

$$\rho \approx \frac{1}{A + B \cdot I_{th}} \quad (1)$$

where $\rho = \dfrac{P1 - P0}{I_{MOD}}$ is the average laser slope efficiency over P0 and P1, I_{th} is the laser threshold, and A and B are laser specific constants obtained from sloop-efficiency measurements. The laser driver is designed to deliver a modulation current, containing a component that is proportional to the threshold current by a factor of K, as shown in equation 2:

$$I_{MOD} = I_{MODS} + K \cdot I_{th} \quad (2)$$

I_{MODS} is a constant current. K and I_{MODS} are defined by the following conditions:

$$I_{MODS} = 2 \cdot P_{AVG} \cdot \frac{r_e'-1}{r_e'+1} \cdot A \quad (3)$$

$$K = 2 \cdot P_{AVG} \cdot \frac{r_e'-1}{r_e'+1} \cdot B \quad (4)$$

where r_e' is the desired extinction ratio and P_{AVG} is the desired average optical power maintained by an APC loop. The logic "1" level P1 and logic "0" level P0 are:

$$P1 = P_{AVG} + \frac{1}{2} \cdot \rho \cdot I_{MOD} \quad (5)$$

$$P0 = P_{AVG} - \frac{1}{2} \cdot \rho \cdot I_{MOD} \quad (6)$$

The actual extinction ratio (r_e) of the optical signal will then be adjusted and maintained to the desired level:

$$r_e = \frac{P1}{P0} = \frac{P_{AVG} + \frac{1}{2} \cdot \rho \cdot I_{MOD}}{P_{AVG} - \frac{1}{2} \cdot \rho \cdot I_{MOD}} = r_e' \quad (7)$$

Constants A and B should be selected to take into account the variation of average laser slope efficiency over the operating temperature range.

3 Example

Figure 2 and Figure 3 show the threshold current and average slope efficiency change over temperature for the laser diode used in this experiment. It is noticed that the laser threshold varies from 23mA to 57mA for a temperature change from -40°C and +85°C. The measured average slope efficiency is between 0.013 and 0.019 over the same temperature range. It is found that the average slope efficiency follows equation (1) well when A = 33.7 and B = 0.75. The calculated slope efficiency is presented in Figure 3.

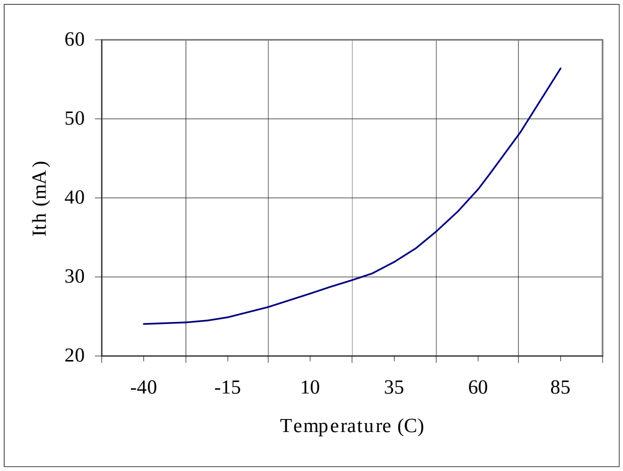

Figure 2. Laser threshold change over temperature

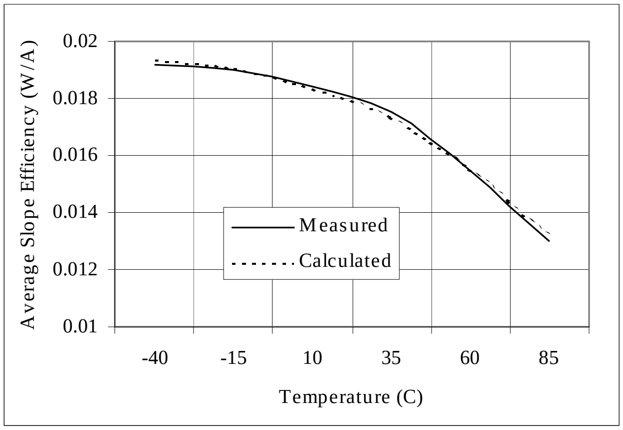

Figure 3. Laser average slope efficiency change over temperature (P_{AVG} = -4dBm): from measurement and from calculation

For a desired extinction ratio r_e' = 8.0 (9dB) and average power P_{AVG} = 0.4mW (-4dBm), the compensation factor K and the constant portion of the modulation current I_{MODS} are determined from equations (3) and (4):

$$K = 2 \cdot P_{AVG} \cdot \frac{r_e'-1}{r_e'+1} \cdot B = 0.47 \quad (8)$$

$$I_{MODS} = 2 \cdot P_{AVG} \cdot \frac{r_e'-1}{r_e'+1} \cdot A = 21\,(mA) \quad (9)$$

An optical transmitter was built to drive the laser diode mentioned above using the MAX3863. The average optical output was maintained to -4dBm by an APC loop. When the compensation circuit was disabled, the extinction ratio dropped from 10.8dB to 5.3dB (5.5dB change), using a constant modulation current of 36mA and varying the operating temperature from -40°C and +85°C. When the compensation circuit was enabled with the compensation factor K set to 0.47, the extinction ratio was maintained between 8.5dB and 9.2dB (0.7dB change), as shown in Figure 4. This change in extinction ratio limits the peak-to-peak optical signal variation to less than 0.19dB.

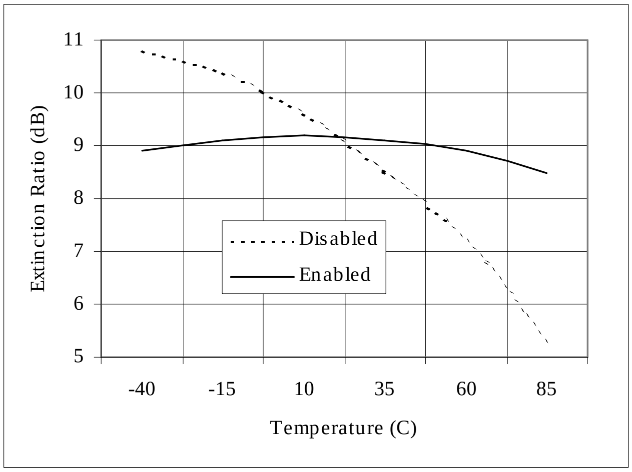

Figure 4. Measured extinction ratio vs. temperature with compensation disabled and enabled

4 Summary

This application note introduces a new approach to maintaining the extinction ratio of optical transmitters using K-factor[1] control. The theory and test results demonstrate that the extinction ratio is well maintained over a wide temperature range. This approach takes advantage of setting the average slope efficiency and avoids errors in deducing the average slope efficiency based on the information obtained only from the P1 or P0 point. K-factor control has proven to be a cost-effective solution for high-performance optical transmitters.

References

1. "Controlling Modulation and Bias of Laser Drivers", US Patent #6,859,473.

2. Data Sheet: "MAX3865: 2.5Gbps Laser Driver with Automatic Modulation Control." - Maxim Integrated Products, October 2001.

3. Data Sheet: "MAX3863: 2.7Gbps Laser Driver with Modulation Compensation." - Maxim Integrated Products, January 2002.

4. Reference Design: "2.5Gbps SFF Transmitter." – HFRD 02.0, Maxim Integrated Products. Document may also be obtained by calling Customer Applications hot line at 503-547-2400.).