Application Note:

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Maintaining Average Power and Extinction Ratio, Part 2

MAX3863 Laser Driver and DS1847 Digital Resistor

MAXIM High-Frequency/Fiber Communications Group

Maxim Integrated Products

Maintaining Average Power and Extinction Ratio, Part 2

MAX3863 Laser Driver and DS1847 Digital Resistor

1 Overview

Variations in the temperature dependent variables of lasers can have a significant effect on the performance of an optical module. In modules where the laser temperature is not held constant, compensation must be applied in order to obtain reliable and constant operation (reference 1).

Key optical transmitter parameters affecting the performance of an optical system include extinction ratio and average power. In part one (reference 1) of this application note series, the temperature dependencies of the extinction ratio and average power were measured with three lasers.

Using the data obtained from the measurements in part 1, methods to maintain extinction ratio and average power constant will be demonstrated in this application note, using the MAX3863 laser driver and DS1847 digital variable resistor. Calculated and measured values will be given to illustrate the results. Although the numbers presented are directly relevant only for the particular lasers and board design used for the measurements, the methods can be applied to other devices to obtain similar results.

2 Average power

In part 1 of this application note series, the average power of the three lasers was seen to exhibit part-to-part and temperature-related variations. The MAX3863 APC loop dramatically reduces the temperature-related variations, but the part-to-part variations must also be compensated. Setting the lasers to have the same photodiode current does not assure that they will have the same average power. Due to offsets associated with threshold current and laser-to-monitor transfer, the photodiode current must be set (using R_{APCSET}), for each individual laser during the module calibration process (reference 1).

Connecting a digital resistor to R_{APCSET} provides a simple calibration method for the average power (references 2 and 5). By removing the offsets from the average power data obtained in part 1, only 0.7dBm part-to-part plus temperature-related variation in average power for the three lasers would be expected (Figure 1).

Given that the average power variation using the APC loop is less than 1dBm after calibration, no other compensation will be applied. If tighter margins are desired, digital variable resistors can be used to minimize deviation in the average power over temperature using methods similar to those that will be demonstrated for maintaining extinction ratio. The remainder of this document will focus on methods to maintain extinction ratio using the features associated with the MAX3863 and the DS1847.

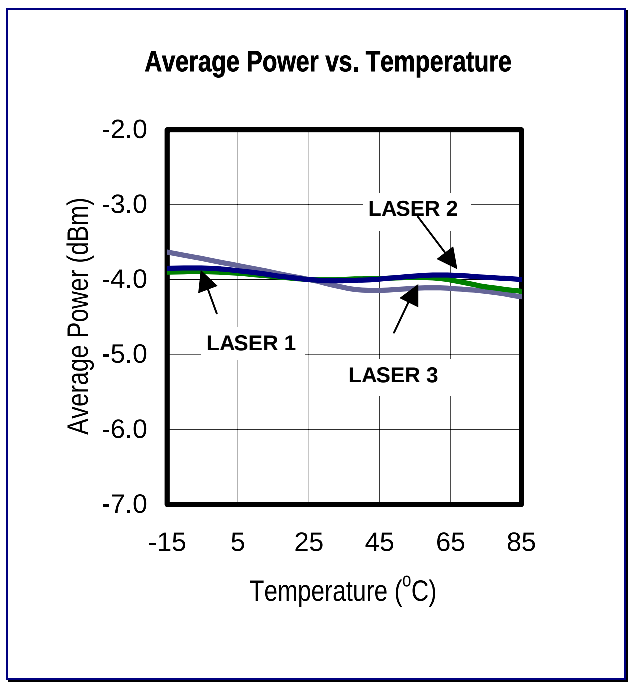

Figure 1: Average Power vs. Temperature

3 K-Factor* Compensation

The MAX3863 uses a compensation factor (K) to increase the modulation current in proportion to the bias current. As the bias current is increased by the APC loop (to maintain average power), a portion of the bias current increase is added to the set modulation current (reference 5). Therefore, the total modulation current (I_{MOD}) is equal to the set modulation current (I_{MODS} - which is determined by R_{MODSET}), plus K times the bias current (I_{BIAS}).

$$K = \frac{\Delta I_{MOD}}{\Delta I_{BIAS}}$$

$$I_{MOD} = I_{MODS} + K \cdot I_{BIAS}$$

Since the modulation current increases as the bias current increases, the extinction ratio will be compensated over temperature and the life of the laser. K-factor compensation works well but is not a perfect solution since the relation between the bias current change and slope efficiency change is not always the same. For most applications the extinction ratio will dip slightly at extreme high and low temperatures.

Using the values for bias current, average power, and slope efficiency obtained in part 1, the extinction ratio for various K values was calculated. Figure 2 shows the extinction ratio over temperature for laser one given various K-factor compensation values. A summary for all three lasers is shown in Table 1.

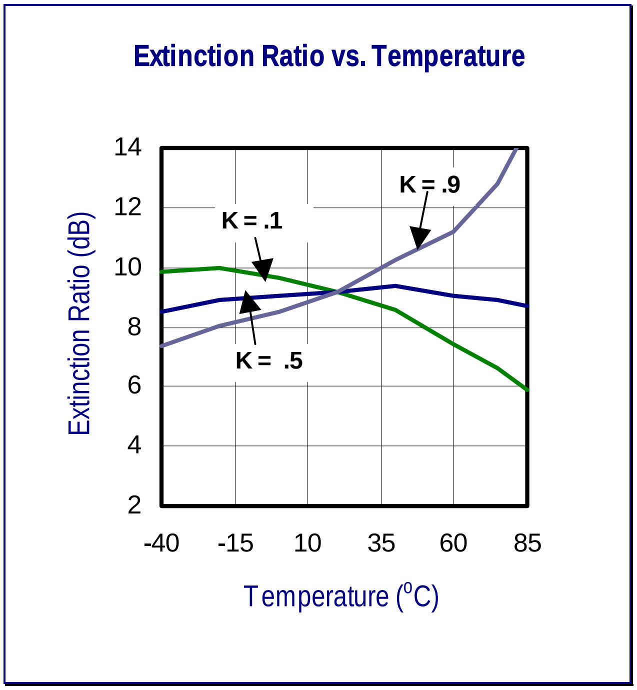

Figure 2: Extinction Ratio vs. Temperature with various K

Table 1. Extinction Ratio Variation vs. K Factor

		K = .3	K = .473	K = .6
LASER 1	MAX r_e(dB)	9.43	9.29	9.62
	MIN r_e(dB)	7.64	8.56	8.18
	DIFF r_e(dB)	1.79	0.73	1.44
LASER 2	MAX r_e(dB)	9.61	9.24	9.47
	MIN r_e(dB)	7.52	8.53	8.48
	DIFF r_e(dB)	2.09	0.71	0.99
LASER 3	MAX r_e(dB)	9.25	9.20	9.68
	MIN r_e(dB)	7.73	8.50	8.15
	DIFF r_e(dB)	1.52	0.70	1.53
Overall Variation (dB):		2.09	0.79	1.53

By choosing the K value correctly, the total extinction ratio variation can be estimated to be less than 1dB. K = 0.473 was found to be the optimum value for the three lasers, giving a calculated overall variation of only 0.79dB for the three lasers (Figure 3).

* Patent Pending

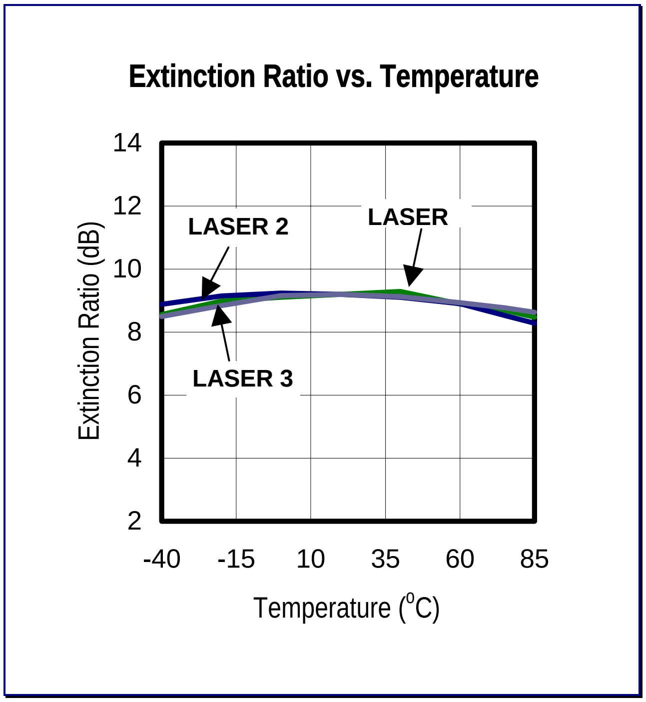

Figure 3: Extinction Ratio vs. Temperature, K = 0.473

Finding the optimal K-factor compensation was accomplished by first calculating the K factor for each individual laser that minimized the overall extinction ratio variation over temperature (Table 2). The average K-factor value for the three lasers was then used as the optimal value. In practice slightly larger variation in extinction ratio due to variations in the K-factor gain and resistor temperature coefficient values would be expected. The values are presented as estimations.

Table 2. Extinction Ratio Variation vs. Optimal K Factor

LASER 1 K = 0.46	MAX r_e(dB)	9.27
	MIN r_e(dB)	8.60
	DIFF r_e(dB)	0.67
LASER 1 K = 0.51	MAX r_e(dB)	9.20
	MIN r_e(dB)	8.76
	DIFF r_e(dB)	0.44
LASER 2 K = 0.45	MAX r_e(dB)	9.20
	MIN r_e(dB)	8.57
	DIFF r_e(dB)	0.63
Average K Value:		0.473

4 Digital Resistor Compensation

Digital variable resistors can also be used to maintain extinction ratio. Digital resistor implementations have the disadvantage of being open loop, but offer the possibility of maintaining extinction ratio within tighter margins. The DS1847, for example, features a temperature-controlled look-up table. Resistor values as a function of temperature are stored in non-volatile memory with a new memory location allocated for every 2°C temperature increment in the –40°C to +95°C temperature range. Using an on-chip temperature sensor, the resistor settings are automatically adjusted as the temperature changes (reference 6). Minimizing extinction-ratio variation is limited due to the horizontal temperature resolution and the vertical resistance resolution of the digital resistor.

The extinction ratio will generally decrease with increased temperature. Ideally, when the extinction ratio has reached a minimum value at a given temperature, the digital resistor would decrease the resistance as seen by the MODSET pin of the laser driver. The decrease in resistance would cause an increase in modulation current (reference 5). Since the change in resistance is a discrete step, the extinction ratio would jump to a new value corresponding to the new modulation current setting. The extinction ratio variation cannot be made less than the change in extinction ratio created by a one-bit change in the digital resistor's setting (Figure 4).

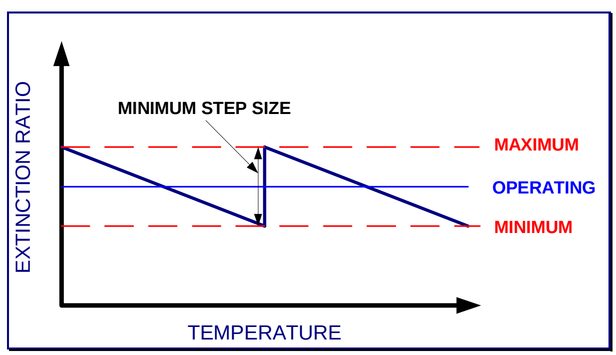

Figure 4: Minimum Step Size

Digital resistors commonly contain either 10kΩ or 50kΩ resistors (or some combination of the two). Each of the resistors has 256 positions to which the resistor can be set. The minimum resistive step size (R_{LSB}) is thus estimated as (10kΩ/256) = 39Ω or (50kΩ/256) = 195Ω. Note that this is an estimation since the maximum resistance – minimum resistance of a digital resistor is slightly less than its rated resistance (references 6 and 7)

A typical extinction ratio step size is calculated by first finding the resistance required for a given modulation current. Using the following equation from the MAX3863 data sheet, it is determined that R_{MODSET} = 8kΩ for 30mA of modulation current.

$$I_{MODS} = 200 \cdot \left(\frac{1.2V}{R_{MODSET}} \right)$$

A typical modulation current step size is then calculated as the change in modulation current for a given change in resistance. Using the equation below, a negative 39Ω resistive step equates to a 0.15mA increase in modulation current and a negative 195Ω resistive step equates to a 0.75mA increase in modulation current.

$$\Delta I_{MODS} = 200 \cdot 1.2V \cdot \left(\frac{1}{R_{MODSET} - R_{LSB}} - \frac{1}{R_{MODSET}} \right)$$

Using the data obtained in part one, the average change in extinction ratio vs. average change in modulation current (I_{MOD}) for the three lasers was calculated (Figure 5). At room temperature, a 0.15mA increase in modulation current would generate approximately 0.1dB of variation in extinction ratio, while a 0.75mA increase would produce about a 0.4dB difference. The vertical extinction-ratio resolution using the digital resistor is therefore about 0.1dB for a 10kΩ resistor and 0.4dB for a 50kΩ resistor.

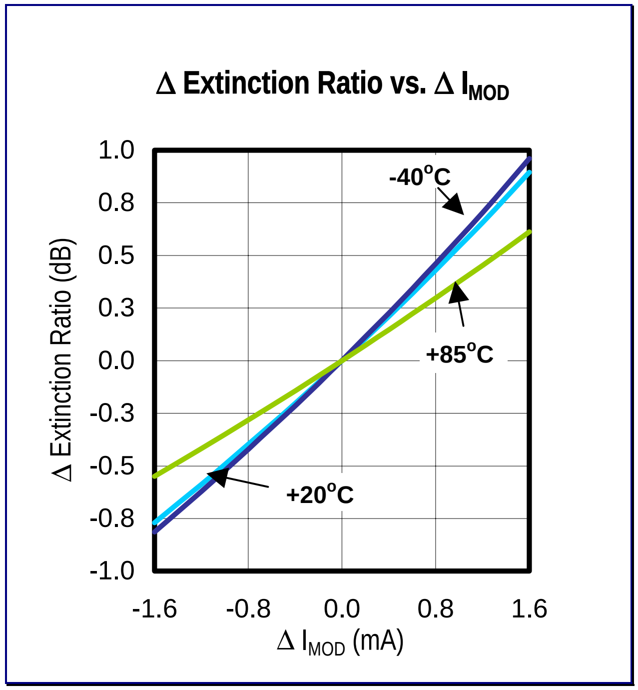

Figure 5: Change in Extinction Ratio vs. Change in Modulation

In order to get a better understanding of how well the extinction ratio can be maintained the horizontal resolution of the digital resistor must also be explored. The resistor settings can only be changed in 2°C steps. As the temperature increases, the slope of the extinction-ratio curve increases (Figure 6).

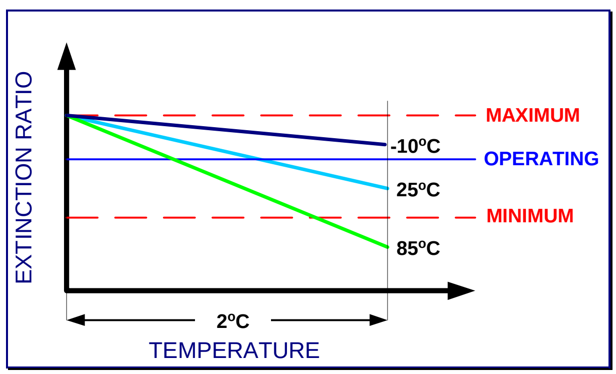

Figure 6: Extinction Ratio Slope

From 75°C to 85°C, the uncompensated extinction ratio was seen to change an average of 0.16dB per 2°C change in temperature (Table 3). Since the extinction ratio can drop below the minimum before the digital resistor is able to compensate, the smallest variation attainable with the 10kΩ digital resistor would be approximately 0.16dB.

Table 3. Average Extinction-Ratio Slope for various K factors

Temp Range	Avg. Slope (dB/°C) K=0	Avg. Slope (dB/°C) K=0.3	Avg. Slope (dB/°C) K=0.473
-40°C to –20°C	.00	-.01	-.02
-20°C to 0°C	.04	.00	-.01
0°C to 20°C	.04	.01	.00
20°C to 40°C	.04	.01	.00
40°C to 60°C	.06	.03	.01
60°C to 75°C	.07	.03	.02
75°C to 85°C	.08	.04	.02

5 Combined Compensation

By minimizing the average slope of the extinction ratio the accuracy of the digital resistor compensation can be improved (Table 3). Combining the K-factor and digital-resistor compensation methods, variations in extinction ratio could be minimized even further. The average slope of the extinction ratio can be made smaller by using K-factor compensation, and then the digital potentiometer can flatten out the overall response. Using a K factor of 0.473 combined with a digital resistor could lead to extinction-ratio variation as low as 0.1dB over the entire temperature range.

6 Example

Using the calculations as a guide, an SFF transmitter board was used to show measured results using the compensation methods as explained above. In addition, three other SFF boards were built and measured in order to show typical part-to-part variations. High Frequency Reference Design 2.0: *2.5Gbps Small Form Factor (SFF) Transmitter* (HFRD-02.0) was used to demonstrate the compensation methods of the MAX3863 laser driver and DS1847 digital resistor (reference 2).

A 50kΩ digital resistor of the DS1847 and a K-factor compensation of approximately 0.3 were used to adjust and offset the modulation current. The K factor was chosen to provide about half the compensation and to help reduce the slope of extinction-ratio variation (Table 3). The digital potentiometer was then used to provide additional modulation-current compensation. Average power was maintained using the APC loop of the MAX3863. A digital resistor was also connected to the APC loop setting resistor and was used to correct for vertical offsets in average power due to variations in photodiode current.

The first of the four boards was set to have an average power of –4dBm and an extinction ratio of 9.2dB at 25°C using the digital resistors. Using one calibration point is useful for offsetting the part-to-part variation in the laser, the laser driver, digital potentiometer and passive external components (references 5,6, and 7). The extinction ratio was then measured as the ambient temperature was changed from -40°C to +85°C. All measurements were made using an OC-48, 2^{23}-1 PRBS pattern.

For the first test, only the K-factor compensation was active. As seen in Figure 7, the extinction ratio varied by approximately 1.8dB which is consistent with the calculations in Table 1.

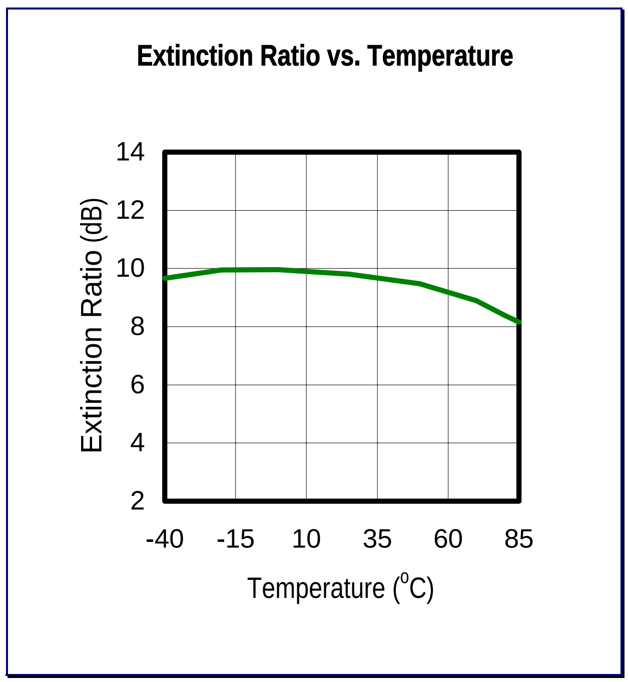

Figure 7: Extinction Ratio vs. Temperature, K ~ 0.3

Next, the settings of the digital resistor that controls the modulation current were adjusted using multiple calibration points to provide additional modulation compensation. The extinction ratio was then measured again in 5°C increments (to reduce measurement times). This time, the measured variation was only 0.25dB (Figure 8) over the entire temperature range. Since the extinction ratio was not measured every 2°C, the results are slightly lower than the estimated value of 0.4dB when using a 50kΩ digital resistor.

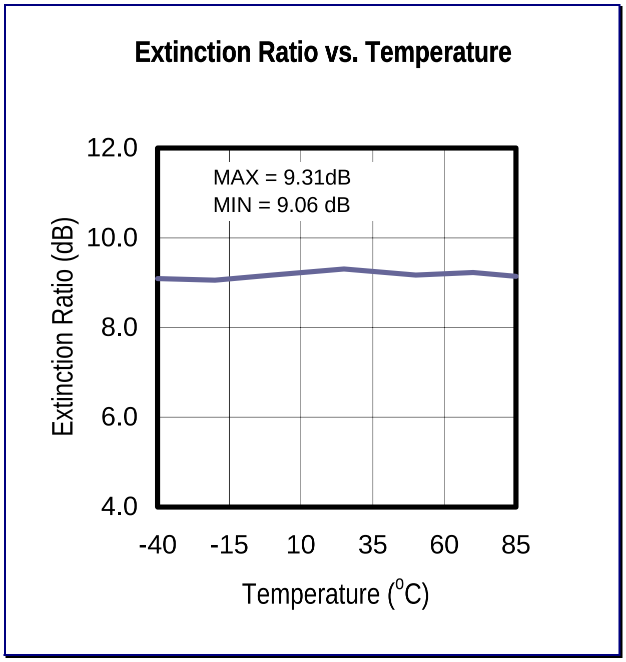

Figure 8: Extinction Ratio vs. Temperature, K ~ 0.3 and Digital Look-Up Table.

Obtaining results with 0.25dB variation is excellent, but detailed information about each individual laser and multiple calibration points are needed. Ideally, a manufacturer that produces large quantities would like to use only one calibration point (room temperature) and one curve in the digital look-up table. While this speeds up production and reduces cost, larger variations in extinction ratio would be expected.

To illustrate this point, three additional SFF boards were built and tested. Using the data obtained in Part 1 of this series, the average modulation current curve required to maintain extinction ratio was implemented with the MAX3863 and DS1847. The same K value (approximately 0.3) and digital pot settings were used for all three boards. Each of the SFF boards was calibrated at room temperature to set the average power to –4dBm. The digital resistor curve implemented in each of the three boards is shown in Figure 9. During calibration, the digital resistive curve for the modulation current was vertically offset to obtain an operating extinction ratio of 9dB for each of the SFF boards. The resulting modulation currents are shown in Figure 10.

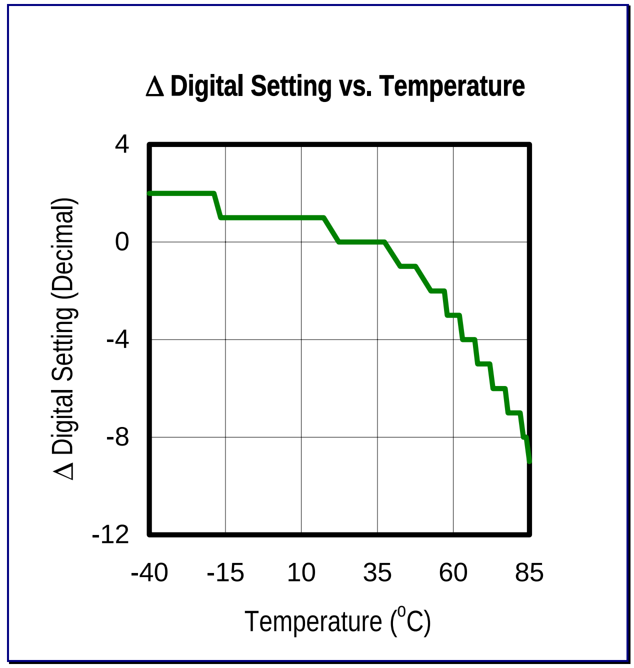

Figure 9: Change in Digital Setting vs. Temperature

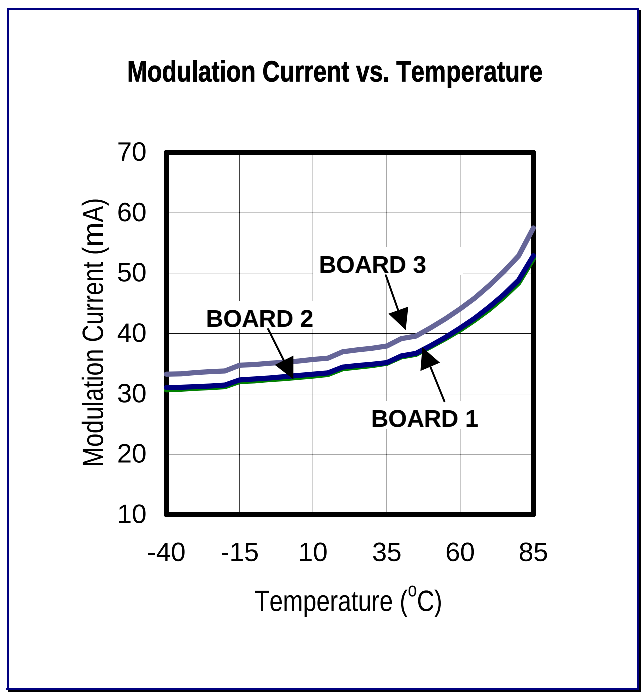

Figure 10: Modulation Current vs. Temperature

The extinction ratio for each of the boards was then measured in 5 °C increments. Figure 11 and Table 4 show a larger variation in extinction ratio than that previously measured on a single SFF board, but the

0.65dB variation is still acceptable given the many part-to-part variations and the single-point calibration method that was used. Using a 10kΩ digital resistor, a different K factor and more calibration points would improve these results.

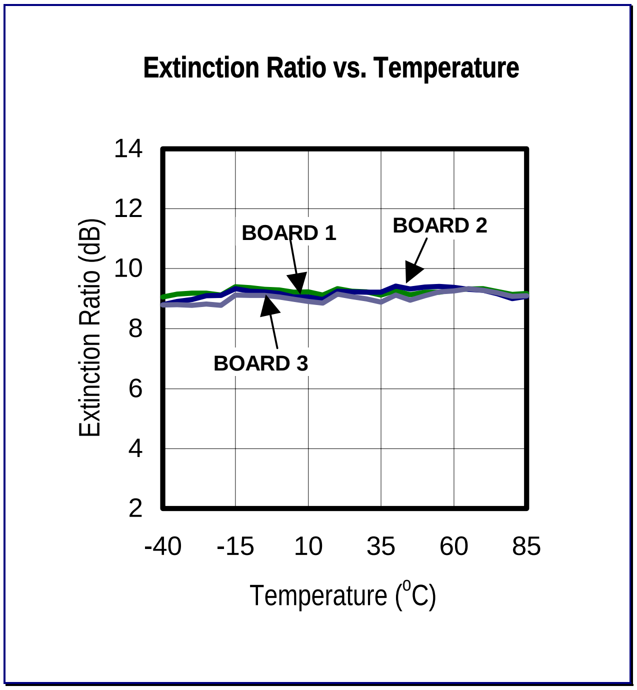

Figure 11: Extinction Ratio vs. Temperature (Three Boards)

Table 4: Overall Extinction Ratio Variation

BOARD 1	**MAX r_e(dB)**	**9.33**
	MIN r_e(dB)	**8.77**
	DIFF r_e(dB)	**0.56**
BOARD 2	**MAX r_e(dB)**	**9.42**
	MIN r_e(dB)	**8.80**
	DIFF r_e(dB)	**0.62**
BOARD 3	**MAX r_e(dB)**	**9.39**
	MIN r_e(dB)	**9.05**
	DIFF r_e(dB)	**0.34**
Overall Variation (dB):		**0.65**

7 Conclusion

The temperature dependant variables in an optical module can cause large variations in the extinction ratio and average power. Using the previously described methods and the MAX3863 and the DS1847, variations of these parameters can be minimized.

Using the K factor (MAX3863) alone allows for easy setups (single resistor) and good compensation using a closed loop. The digital resistor (DS1847) has the disadvantage of being open loop, but better temperature compensation is possible. Part-to-part calibration at the production level is also simplified with the digital resistor.

Combining the K factor and the digital resistor produce a system that provides excellent temperature compensation and easy part-to-part calibration.

8 References:

1. Application Note: "Maintaining Average Power and Extinction Ratio, Part 1" – HFAN-2.3.1, Maxim Integrated Products, May 2002.

2. Reference Design: "2.5Gbps SFF Transmitter." – HFRD 02.0, Maxim Integrated Products. (Document available on Maxim's web site in Q302. May also be obtained by calling Fiber/HF Communications Customer Applications hot line at 503-547-2400.)

3. Application Note: "Interfacing Maxim Laser Drivers with Laser Diodes." – HFAN 02.0, Maxim Integrated Products, May 2000.

4. Application Note: "Extinction Ratio and Power Penalty." – HFAN 02.2.0, Maxim Integrated Products, May 2001.

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

6. Data Sheet: "DS1847: Dual Temperature-Controlled NV Variable Resistor." - Maxim Integrated Products, February 2002.

7. Application Note: "Interfacing Digitally Controlled Pots and Resistors to Laser Drivers." – App Note 166, Maxim Integrated Products, January 2002.