

Application Note

Modulator Bias and Transmitter Power Control using LiNbO₃ Modulators with Integrated Monitor Photodiodes

Introduction

When designing high-performance transmitters for optical communications at 2.5 and 10 Gb/s, the modulated output power, P_{mod} , is typically monitored and controlled. This is especially true in amplified dense wavelength division multiplexing (DWDM) and long reach applications. In amplified long haul applications, there is a concatenation of erbium doped fiber amplifiers (EDFAs). Each EDFA has variable gain across the transmission band, which causes variable power at the receiver for the individual channels. In current systems, the receiver power can vary by more than 10 dB. By controlling the P_{mod} of the transmitter, the variation in receiver power of the system can be controlled. This is typically done by adjusting the P_{mod} of the individual channels by up to 13 dB.

In long reach applications, which do not have concatenated EDFAs, the receiver power variation is typically less than 3 dB. However, it is still important to be able to adjust, monitor, and control the transmit power. JDS Uniphase has been manufacturing LiNbO₃ modulators with integrated photodiodes for bias control of the modulator for many years. Recently we developed a new integrated photodiode, which has performance characteristics that enable power control to less than ± 0.5 dB. With time division multiplexing, this same photodiode can be used to provide bias control. A picture of our new small form factor (SFF) 10 Gb/s modulator with an enhanced performance monitoring photodiode is shown in Figure 1. The photodiode anode and cathode are connected to the pins labeled A and C, respectively.



Figure 1

These small form factor modulators are available in either 0 α chirp or $\pm 0.7 \alpha$ chirp. They are called X5 and Z5, respectively. The X5 has a bit error rate receiver penalty of < 1 dB when operating in a dispersion environment of $\pm 1,200$ ps/nm. The Z5 modulator has a bit error rate receiver penalty of < 2 dB in a dispersion environment of $-1,600$ ps/nm. These modulators are being used in both long reach and long haul applications.

Description

Typical long haul transmitter designs consist of a distributed feedback (DFB) laser, a LiNbO₃ modulator, a variable optical attenuator (VOA), and a tap coupler, with a power-monitoring photodiode connected to the tap fiber. In this configuration, the VOA is used to adjust P_{mod} and the photodiode is used to provide feedback in a control loop. In this application, a VOA is usually required to achieve the P_{mod} dynamic range requirements. A typical block diagram for a long haul DWDM transmitter is shown in Figure 2.

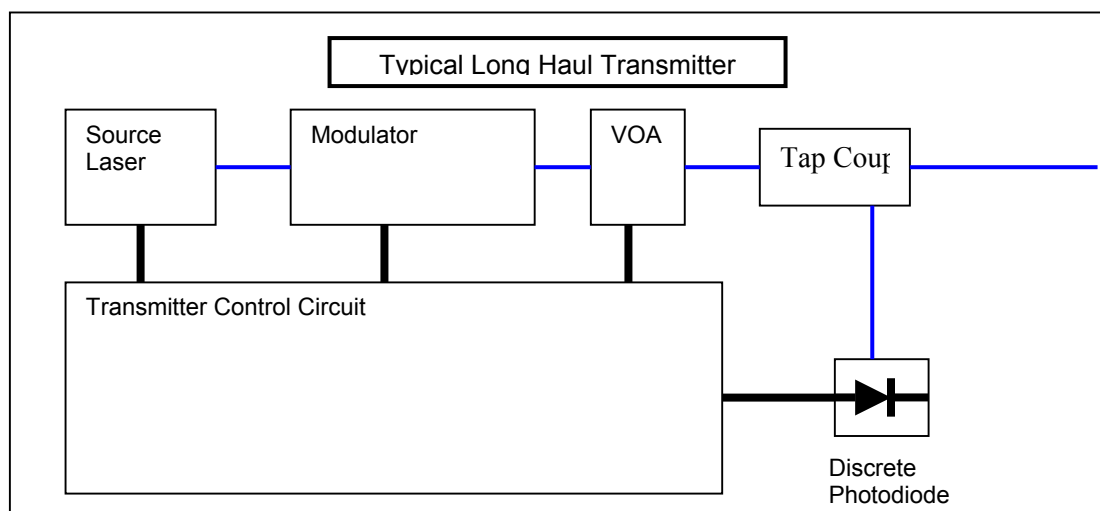


Figure 2

Typical long reach transmitter designs consist of a DFB laser, a LiNbO₃ modulator, and a tap coupler, with a power-monitoring photodiode connected to the tap fiber. In this configuration, the injection current of the laser is adjusted for P_{mod} control and the photodiode is used to provide feedback in a control loop. The dynamic range of control is limited to approximately 3 dB by the source laser, because laser characteristics such as the side-mode suppression ratio, linewidth, relative intensity noise, and field reliability are affected by injection current to the laser. In both the long haul and long reach applications, the typical requirement is that P_{mod} be controlled to < 1 dB variation over the operational case temperature and life.

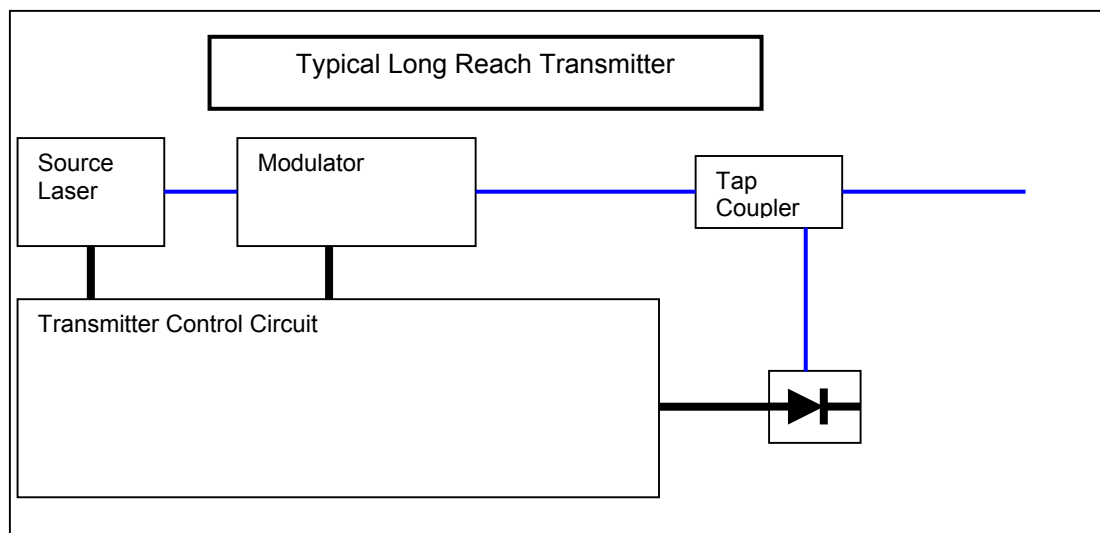


Figure 3

Performance Characteristics

The most important performance characteristics to consider when assessing modulators with integrated photodiodes for transmitter power and modulator bias control are the relationship between the photodiode signal and the output power, and how this relationship varies as a function of signal wavelength and case temperature. This relationship is herein defined as the monitor photodiode **responsivity** or **R**. It is very similar to the tracking error of a power-monitoring photodiode in a laser package. The unamplified photodiode signal is current and the modulated output power is in watts. The variation in correlation between the photodiode signal and the power in the fiber is defined as the **change in responsivity** or ΔR . By knowing the ΔR characteristics of the power-monitoring photodiode, assessment of its ability to measure and track fiber launch power can be made.

R and ΔR as a Function of Laser Frequency

Figure 4 shows the responsivity of the integrated monitor photodiode as a function of laser frequency across both the L and C bands. There is a linear variation of R with respect to laser frequency. There are two dominant effects that cause this linear dependence. The first effect is the change in the intrinsic responsivity of the photodiode versus wavelength or channel frequency, and the second is a change in the waveguide-to-photodiode coupling coefficient versus wavelength. The total change in responsivity from 186.5 to 196.5 THz laser frequency is about 9 mA/W. The change across one band is approximately 4 mA/W. The average responsivity for the five devices shown in Figure 4 is approximately 33 mA / W. In an application where the transmitter modulated output power is set to 3 dBm or 2 mW, the unamplified average photodiode current is 66 μ A.

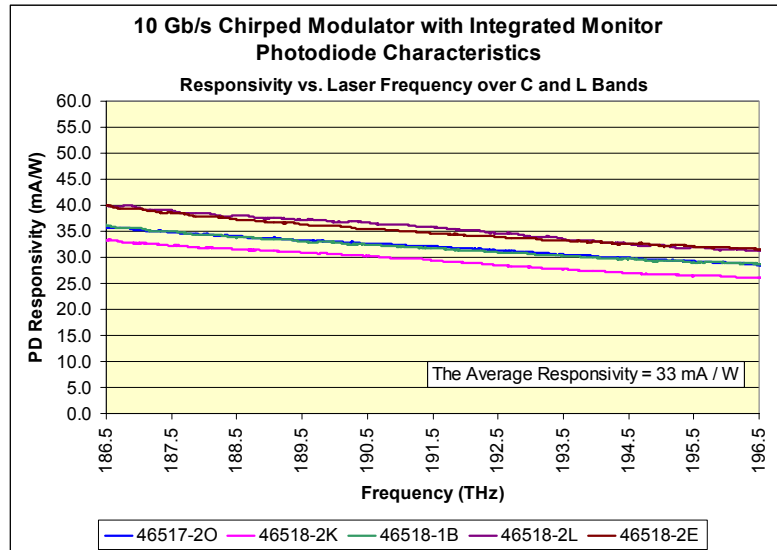


Figure 4

Inspection of Figure 5 shows approximately 0.5 dB change in responsivity across the L and C bands. For applications using either a fixed-wavelength laser or a tunable laser, the actual responsivity of a channel or channels can be calibrated. If responsivity calibration is performed, the responsivity variation with wavelength does not add significantly to the power monitoring tolerance budget.

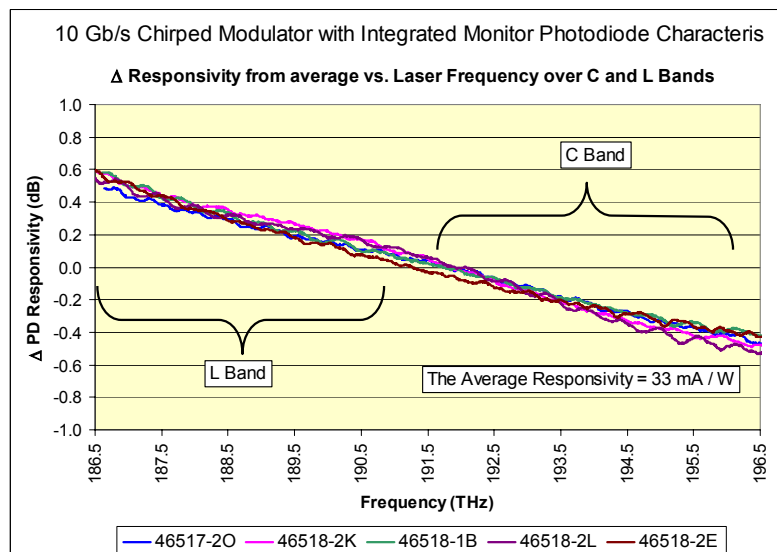


Figure 5

R and ΔR as a Function of Temperature

Another important parameter to consider is the variation in responsivity with respect to case temperature. Since the responsivity is the relationship between the photodiode signal and the fiber output power of the modulator, the dominant thermal effects are the change in the waveguide-to-photodiode coupling coefficient and the change in the insertion loss between the waveguide and the output pigtail. The dominant change in the insertion loss mechanism is the change in insertion loss of the fiber pigtail. The budget for this effect is a change in insertion loss over temperature of < 0.25 dB. This is a common characteristic of modulators.

In Figure 6, the variation in P_{mod} is shown as a function of ambient temperature through a thermal ramp between 0 and 65 °C. P_{mod} in units of dBm is shown on the primary Y axis, the ambient temperature ramp is shown on the secondary Y axis and time is shown on the X axis. The actual case temperature of the device is approximately 5 °C above ambient temperature. So the case temperature range is from 5 to 70 °C. This data was taken on an integrated tunable laser modulator (TLM), which uses the enhanced monitor photodiode for power stabilization, an X5 modulator and the same fiber optic pigtail as a small form factor discrete modulator. Thus, R and ΔR behavior is very similar to that of the discrete X5 and Z5 modulators. This data was taken while running the TLM in constant power mode. The variation in P_{mod} as a function of ambient temperature includes the changes in responsivity of the enhanced monitor photodiode, and the control electronics thermal variability. The output current of the monitor photodiode is amplified, and the amplifier gain is set to approximately 24K.

P_{mod} for this channel frequency was calibrated to be 5 dBm. The change in P_{mod} over this temperature range is less than ± 0.2 dB.

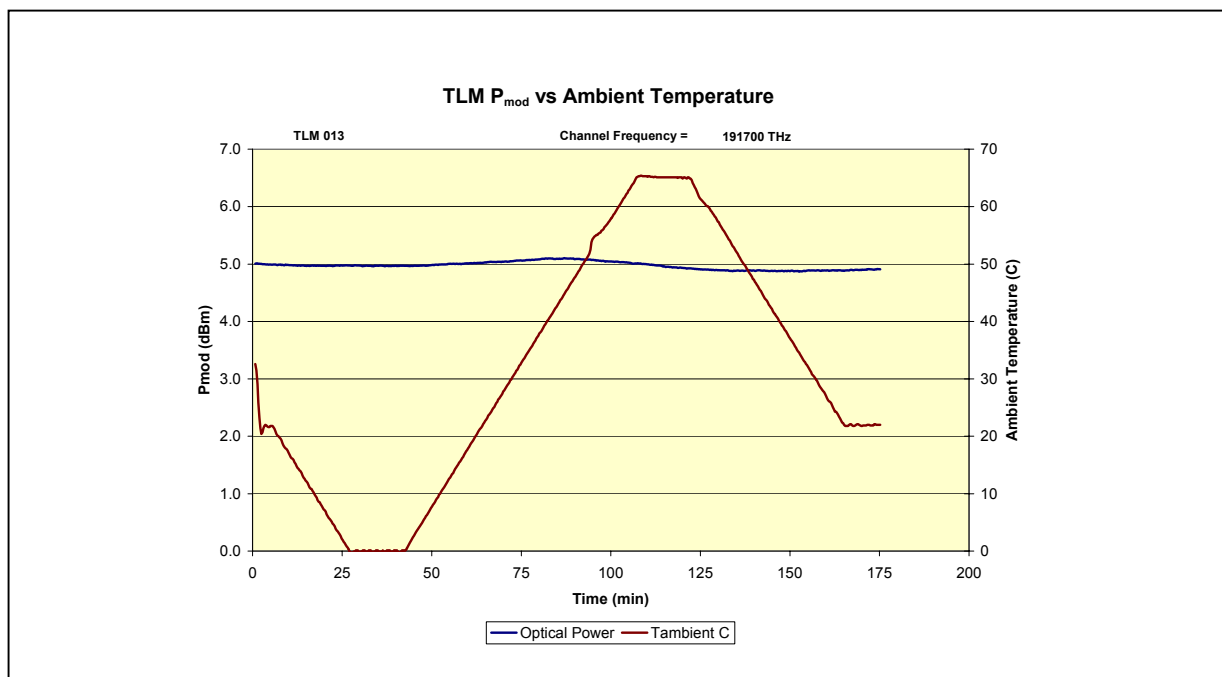


Figure 6

Figure 7 shows how the amplified monitor photodiode signal changes over temperature on the same device shown in Figure 6. Plotted on the primary Y axis are both the amplified monitor photodiode signal in V/mW, since the amplifier output converts current to voltage, and the change in responsivity (ΔR) in dB. The temperature profile is shown on the secondary Y axis and time is on the X axis. ΔR of the monitor photodiode gives a good idea how well P_{mod} can be controlled in a closed loop as a function of ambient temperature. The variability of ΔR from the average value is $< \pm 0.2$ dB. If the case temperature range is extended to -5 to 75 °C, the typical variation in responsivity is ± 0.3 dB with a maximum variation of ± 0.5 dB.

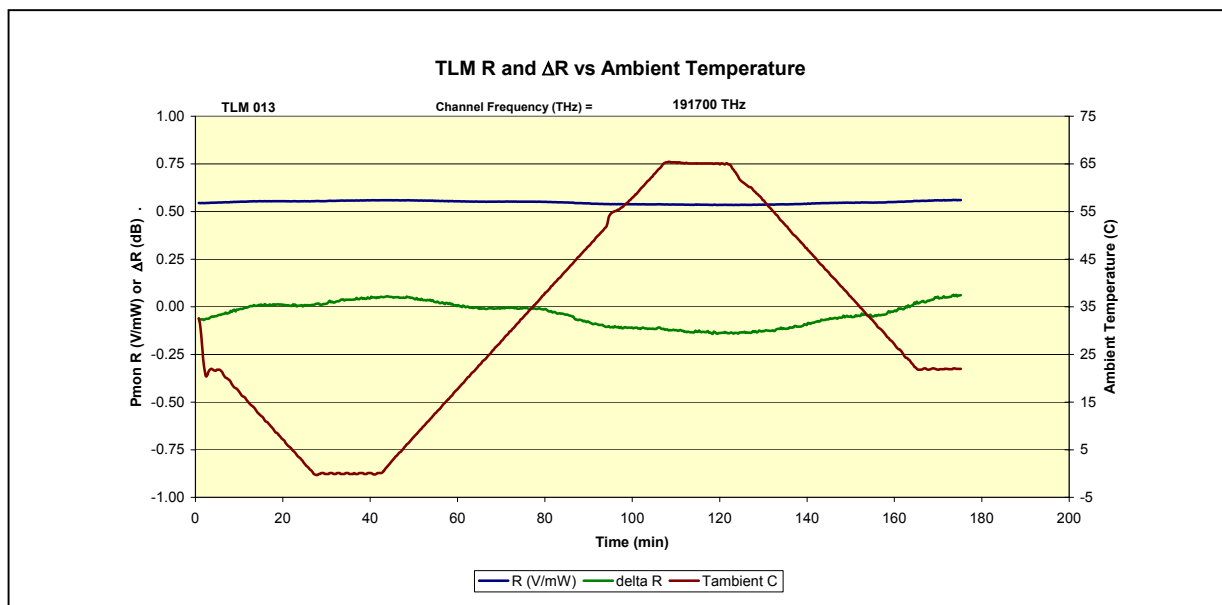


Figure 7

Responsivity Tolerance Budget

The tolerance budget for responsivity of the power-monitoring photodiode is shown in Table 1. The typical values—including temperature, aging, and laser frequency—give a total variation in the responsivity of ± 0.50 dB. When the responsivity of the modulator with an integrated photodiode is calibrated for the laser frequency, the typical variation will be ± 0.30 dB. The maximum variation of responsivity over life and operational case temperature with laser frequency calibration is ± 0.65 dB.

Characteristic	Symbol	Min.	Typical	Max.	Units
Responsivity	R	6	25	40	mA / W
ΔR vs. temperature	$\Delta R(T)$	-0.40	± 0.20	0.40	dB
ΔR vs. BOL	$\Delta R(t)$	-0.25	± 0.10	0.25	dB
ΔR vs. laser frequency	$\Delta R(\nu)$	-0.40	± 0.20	0.40	dB

Table 1

Applications in Long Reach and Long Haul Transmitter Applications

Figure 8 shows the block diagram of either a long reach or long haul transmitter using JDS Uniphase's small form factor modulator package with an integrated, enhanced performance monitor photodiode. For long reach applications, this eliminates the need for a discrete tap coupler, power monitor photodiode, and fusion splice. Using a standard DFB laser, P_{mod} can be set over approximately 3 dB of dynamic range.

For long haul applications, the VOA can be integrated with the LiNbO₃ modulator having the power-monitoring photodiode after the VOA. Alternatively, the VOA can be integrated into the laser package, increasing the dynamic range of the CW laser power. This eliminates the need for 3 fusion splices as well as a discrete VOA, tap coupler, and monitor photodiode.

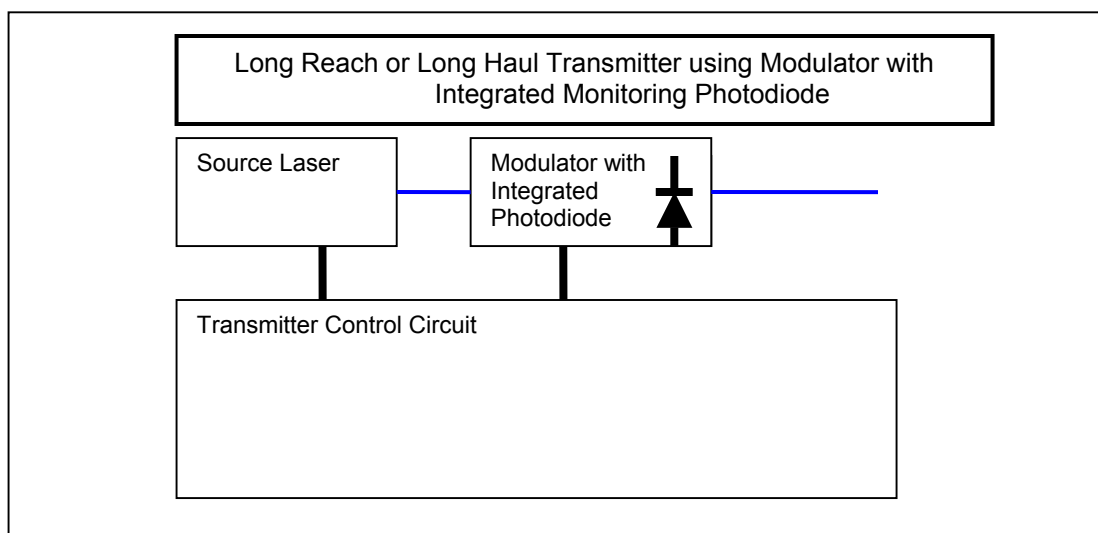


Figure 8

For both of these applications, using JDS Uniphase's small form factor modulator package with an integrated, enhanced performance monitor photodiode helps to reduce cost, due to the reduction in the number of optical components required. There is also a reduction in the labor required to build a transmitter since there are fewer parts that need to be tested and fusion-spliced together. The module uses a time division multiplexing of the photodiode to perform both bias control and power monitoring.

Conclusion

The enhanced performance characteristics of the integrated photodiode in the X5 and Z5 small form factor modulators enable them to be used for both bias and power control. In typical applications, where the channel frequency is constant and the rack is temperature-controlled, modulated output power can be controlled to $< \pm 0.2$ dB using the photodiode. Power stabilization of $< \pm 0.65$ dB can be achieved over a case temperature range of -5 to 75 °C and 20 years of service life. In both long reach metro and long haul applications this reduces cost by eliminating components and assembly labor for transmitters.

Author

Timothy C. Munks, JDS Uniphase Applications Engineering Manager, August 27, 2004



North America toll free: 1-800-498-JDSU (5378)
Worldwide: +800-5378-JDSU
www.jdsu.com

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