11.1 Gbit/s Pluggable Small Form Factor DWDM Optical Transceiver Module

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We have developed an SFP+ (Enhanced Small Form Factor Pluggable) optical transceiver module for 11.1 Gbit/s DWDM (dense wavelength division multiplexing) application, which can cover up to 100 km reach over standard single-mode fiber. We have also successfully reduced its total power dissipation to less than 1.5 W by utilizing a newly developed laser diode chip. This world's smallest and power-saving DWDM SFP+ optical transceiver will contribute to the downsizing of high density optical transmission equipment.

Keywords: SFP+, DWDM, 11.1 Gbit/s, long haul, low power dissipation

1. Introduction

In recent years, the demand for data traffic of trunk lines has significantly increased and high performance transmission equipment using high bit-rate or WDM (wavelength division multiplexing) technologies have been introduced to the market to catch up with the demand. The SFP+ (Enhanced Small Form Factor Pluggable) is one of the most popular form factors used in 10 Gbit/s transmission equipment and can be hot-plugged into a host board of the equipment. The SFP+ is 30% smaller than the conventional XFP (10 Gbit/s Small Form Factor Pluggable), enabling an increased number of transceivers to be installed into transmission equipment. However, in these ways, the performance of the factor can be limited by its thermal condition. Therefore, a power saving function is required for the SFP+ to overcome the limit.

We have successfully developed and produced an SFP+ DWDM (dense wavelength division multiplexing) optical transceiver that meets these requirements and operates at 11.1 Gbit/s at 70˚C for transmission over up to 100 km (1600 ps/nm chromatic dispersion).

In this paper, we report on the design and the optical performance of the newly developed SFP+ DWDM transceiver that has reduced the power dissipation to less than 1.5 W, which meets the MSA regulation[1] Power Level II at an operating temperature of 70˚C.

2. Architecture

2-1 Specification

The appearance and the main specifications of the developed SFP+ DWDM transceiver are shown in **Photo 1** and **Table 1**, respectively. Operating temperature of this SFP+ DWDM transceiver ranges from 0˚C to 70˚C and maximum power dissipation is 1.5 W. The EDC (electro dispersion compensator) installed outside the module enables transmission at up to 11.1 Gbit/s over 100 km, which corresponds with 0 to 1,600 ps/nm chromatic dispersion. The

Photo 1. The picture of SFP+

Table 1. Specifications of SFP+ DWDM transceiver

Items			Specified Values
Operation Case temperature			0˚C to 70˚C
Mechanical dimensions			L56.5, W13.8, H8.6 mm
Electrical interface			20Pin connector
Signaling speed			9.95 to 11.1 Gbit/s
Transmitter	E/O technology		EML
	Wavelength		1,530 to 1,565nm
	Wavelength stability		±100pm
	Optical average power		-1 to 3 dBm
	Extinction ratio		> 9 dB
Receiver	O/E technology		APD
	Sensitivity	10.3 Gbit/s	< -23 dBm (0 ps/nm, 1E-12) < -20 dBm (1,600 ps/nm, 1E-12)
		11.1 Gbit/s	< -27 dBm (0 ps/nm, 1E-3) < -24 dBm (1,300 ps/nm, 1E-3)
	Required OSNR	10.3 Gbit/s	< 24 dB / 0.1 nm (0 ps/nm, 1E-12) < 27 dB / 0.1nm (1,600 ps/nm, 1E-12)
		11.1 Gbit/s	< 15 dB/ 0.1nm (0 ps/nm, 1E-3) < 16 dB/ 0.1nm (1,100 ps/nm, 1E-3)
	Overload		> -7 dBm
Supply voltage			3.3 V (±5%)
Power dissipation			< 1.5 W

DWDM optical transceiver must be adjusted to the wavelength grid defined at ITU-T (International Telecommunication Union Telecommunication Standardization Sector). The wavelength of an LD (laser diode) is determined by the temperature. The wavelength needs to be tuned to the wavelength grid defined by ITU-T(2) by adjusting the TLD (temperature of the LD) using a TEC (thermoelectric cooler).

The more the difference between the case temperature (Tcase) and the TLD is, the more power dissipation of the TEC is necessary to keep the LD at a certain temperature. As a result, the power dissipation of the SFP+ DWDM transceiver becomes the largest at the upper limit of the operating temperature (Tcase) is 70˚C. In general, the wavelength of the TDM (time division multiplexing) optical transceiver module doesn't need to be adjusted. Therefore, the TLD can be set at the highest and the power dissipation decreases. The TLD of the DWDM optical transceiver should be set at a temperature between 40˚C and 50˚C depending on the wavelength of the LD. The decrease in the TLD from 50˚C to 40˚C increases power dissipation by 0.2 W at a maximum when Tcase is 70˚C. In general, it is more difficult to suppress the power dissipation of the DWDM optical transceiver than that of the TDM optical transceiver. However, to satisfy the market demand, we targeted the power dissipation of less than 1.5 W at Tcase 70˚C.

SFP+ DWDM transceiver can be classified into two categories by the design of the receiver. One is the linear interface, which converts an optical signal into an electrical signal and outputs it. Another is the limiting interface, which outputs an electrical signal in a certain amplitude by saturating it. The limiting I/F can be used at the same host board of the transmission equipment as the conventional SFP+ DWDM transceiver. On the other hand, the linear I/F need to be assembled with the EDC on the host board side. In this paper, we present the linear I/F SFP+ DWDM transceiver with the EDC to improve transmission performance.

Figure 1 shows the basic architecture and the interconnection between each functional block in the linear I/F and **Fig. 2** shows those of the limiting I/F. The transceiver consists of a transmitter, a receiver, and a control system block. The following sections describe the details of each block.

2-2 Transmitter

The transmitter block, as shown in **Fig. 1 and 2**, consists of four sub-blocks: (i) TOSA (transmitter optical subassembly) as the E/O converter, (ii) ACC (automatic current control) circuit to control the injection current of the CW-LD inside the TOSA, (iii) ATC (automatic temperature control) loop to control the laser temperature assembled on the TEC (thermoelectric cooler) inside the TOSA, and (iv) LDD (laser diode driver) to drive the EA (electroabsorption) modulator.

Photo 2 shows the in-house TOSA assembled in the SFP+ DWDM transceiver, which is developed to cover 11.1 Gbit/s signaling speed over 100 km reach. The EML (electro-absorption modulator integrated laser diode) chip and the TEC unit are assembled in the TOSA, and the operating temperature of the EML chip is controlled by the TEC.

2-3 Receiver

The receiver block, as shown in the **Fig. 1 and 2**, consists of two sub-blocks: (i) ROSA (receiver optical sub-assembly) as the O/E converter and (ii) APD (avalanche photodiode) bias control loop to adjust the bias voltage inside the ROSA.

Photo 3 shows the in-house ROSA assembled in the SFP+ DWDM transceiver. The InGaAs APD chip and the TIA (transimpedance amplifier) chip are assembled in the

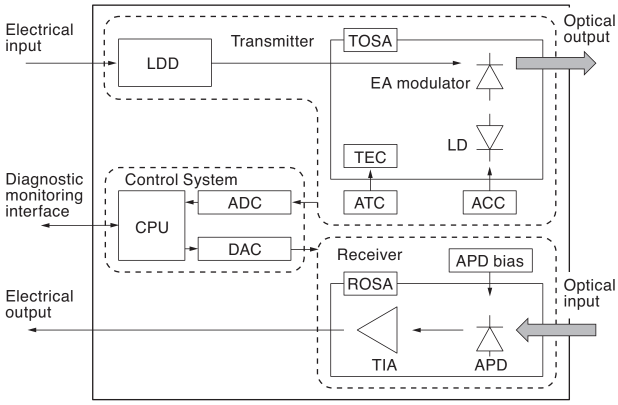


Fig. 1. Block diagram of SFP+ Transceiver (Linear I/F)

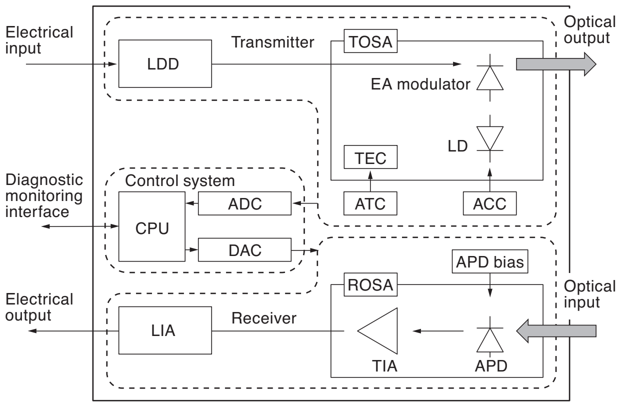


Fig. 2. Block diagram of SFP+ Transceiver (Limiting I/F)

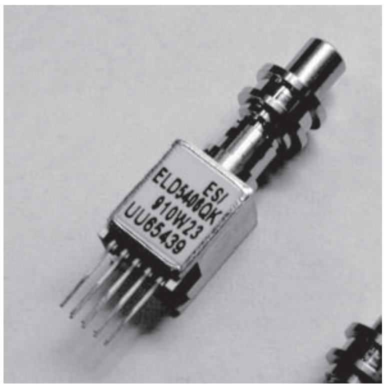


Photo 2. The picture of TOSA

ROSA, and the APD chip's bias voltage is optimized by the APD bias control loop.

At the linear I/F, the EDC improves the receiver sensitivity by compensating the distortion of the electrical signal sent from the ROSA. For this purpose, an AGC (auto gain control) type TIA is used to linearly convert an optical signal to an electrical signal.

At the limiting I/F, the TIA amplifies the voltage to drive the CDR (clock data recovery) in the host board. But the output voltage of the TIA is not large enough to drive it. The limiting amplifier is used to amplify the voltage in order to drive the CDR.

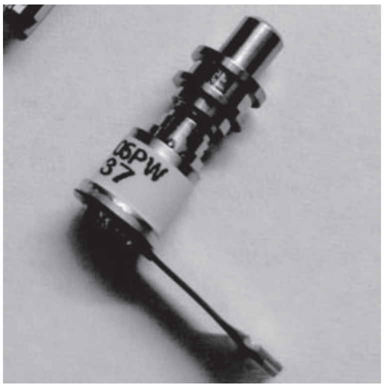


Photo 3. The picture of ROSA

2-4 Control system

Figure 3 shows the detailed architecture of the control system block in the SFP+ DWDM transceiver. This block consists of three sub-blocks: (i) ADC (analog-digital converter) block to monitor the operating status of the SFP+ DWDM transceiver including case temperature, (ii) DAC (digital-analog converter) block to control the key parameters such as the EA modulation voltage, and (iii) CPU (central processing unit) to manage the SFP+ DWDM transceiver's whole system including the 2-wire diagnostic monitoring interface. Using information on the SFP+ DWDM transceiver, such as the serial ID and the digital 2-wire interface, the host board can read the management diagnostics and control certain functions.

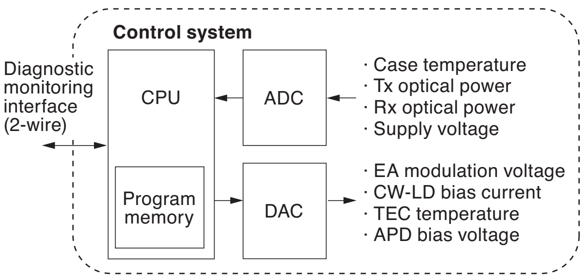


Fig. 3. Detail of SFP+ DWDM transceiver control system

3. Low Power Dissipation Design

3-1 Conventional design

Figure 4 shows the temperature dependency of the SFP+ DWDM transceiver's power dissipation using the conventional design. Here, 0, 35 and 70˚C values are based on the estimation for the initial design. The temperature dependence of the power dissipation is dominated by that of TEC and its ATC control circuit. At a higher case temperature, the TEC operates as a cooler and its forward current increases. At a lower case temperature, the TEC operates as a heater and its backward current increases. Power dissipation of the TEC at Tcase = 70˚C was estimated to account for 1/3 of the total power dissipation. The temperature range of the conventional LD was limited between 35 and 45˚C due to the degradation of the transmission performance. If the optical transceiver operates at Tcase = 70˚C, the difference between the Tcase and the TLD becomes 35˚C at a maximum. Compared with the room temperature (Tcase = 35˚C) operation, the power dissipation increases by 0.65 W. As a result, the total power dissipation at Tcase = 70˚C is 1.75 W, which is larger than the target of 1.5 W. Besides the TEC related part, there is still room to decrease the power dissipation of the conventional design SFP+ DWDM transceiver. The next section describes approaches taken by the new design.

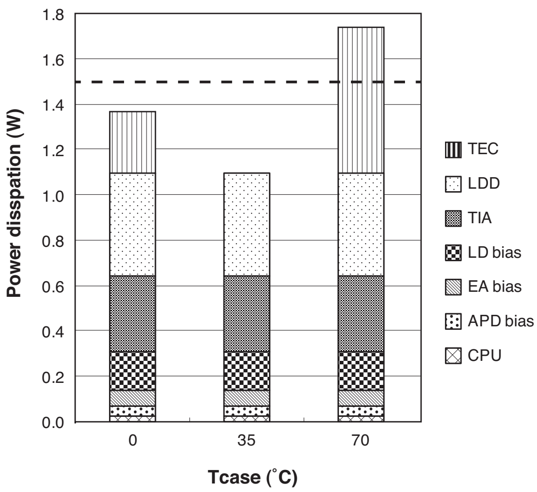


Fig. 4. Power dissipation of conventional design (estimation)

3-2 New design

In order to achieve low power dissipation, following three new technologies were adopted to the new SFP+ DWDM transceiver.

(1) High temperature operating LD chip

The TEC power dissipation was reduced by 0.07 W at Tcase = 70˚C. With the innovated LD, we succeeded in increasing the temperature range of the LD from the 35-45˚C range to the 40-to 50˚C range without any performance degradation.

(2) High efficiency TEC driver circuit

The TEC power dissipation was reduced by 0.1 W at Tcase = 70˚C. With an innovated discrete TEC driver circuit, we successfully achieved a high efficiency at Tcase = 70˚C, where power dissipation is highest. The efficiency is higher than that of commercially available TEC driver ICs.

(3) Optimized LDD and TIA supply voltage

LDD and TIA power dissipation was reduced by 0.09 W at Tcase = 70˚C. We assembled a low voltage stable power supply and optimized the applied voltage to the LDD and the TIA.

Figure 5 shows an estimation of power dissipation after these new technologies are adopted. The estimation shows that the new design reduces power dissipation by 0.26 W at the TEC and LD control circuits, which are the major sources of power dissipation with the conventional technology.

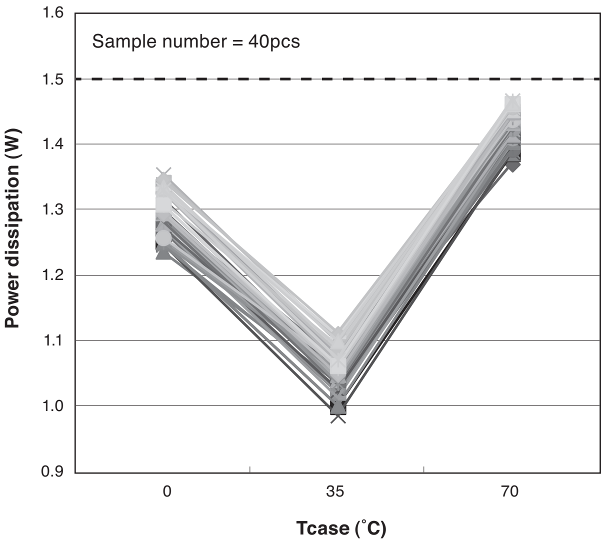


Fig. 6. Power dissipation of the SFP+ DWDM transceiver

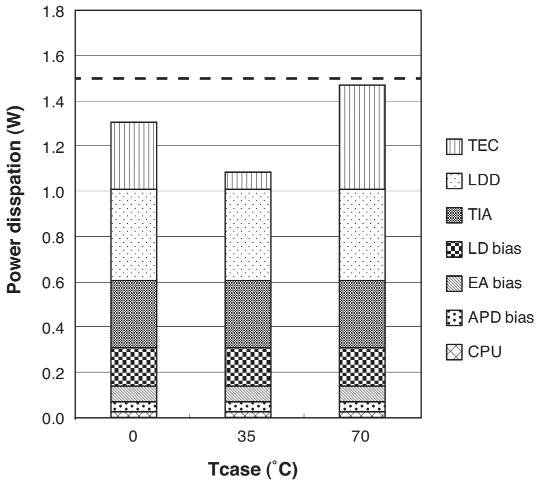


Fig. 5. Power dissipation of new design (estimation)

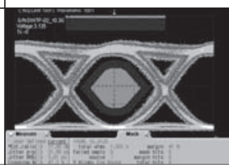
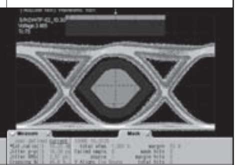
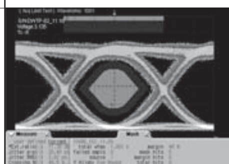
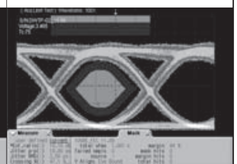
	-5˚C	75˚C
10.3Gbit/s		
Pulse mask margin	41%	53%
11.1Gbit/s		
Pulse mask margine	40%	44%

Fig. 7. Transmit eye diagram (PRBS31)

4. Evaluation Results

4-1 Power dissipation

Figure 6 shows the measured temperature dependence of power dissipation with the new design. The power dissipation is about 1.15 W and 1.47 W at Tcase = 35˚C and 70˚C, respectively, both of which meet the target of 1.5 W. Note that those values are similar to the estimation.

4-2 Optical waveform

Figure 7 shows transmit eye diagrams before transmission at 10.3 Gbit/s and 11.1 Gbit/s at -5˚C and 75˚C. Our SFP+ DWDM transceiver satisfied the 10G Ethernet mask regulation with a margin of more than 40%.

4-3 Wavelength stability

Figure 8 shows the measured temperature dependence of the wavelength variation of the new design.

Values are normalized to that of 35˚C. We suppose that our products are used for the 100 GHz (800 pm) grid

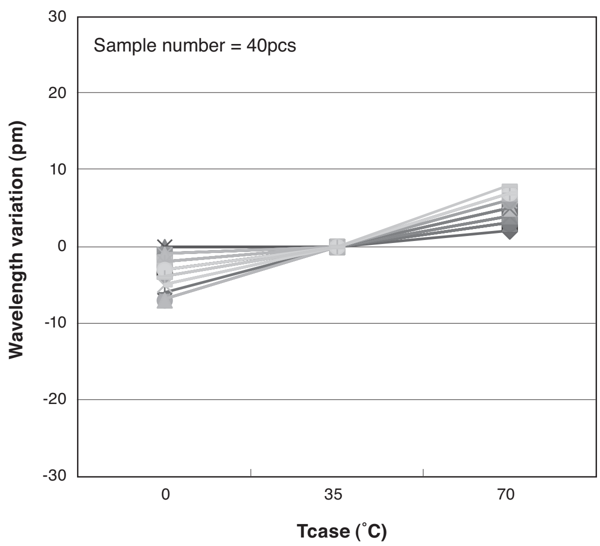


Fig. 8. Wavelength variation of new design

DWDM application.

The stable operation within ±10 pm has been observed at the operating temperature. This is realized by keeping the TLD at the operating temperature using the TEC and suppressing the wavelength temperature dependency of the LD.

4-4 Receiver sensitivity

A mux (multiplexer) and a demux (demultiplexer) are used at the DWDM transmission equipment to transmit multiple wavelengths with a single optical fiber. In general, the mux and demux have large insertion loss. To transmit signals over a long distance of more than 100 km, an optical amplifier is installed between the transmitter and the receiver. The optical amplifier generates the ASE (amplified spontaneous emission) noise. The receiver sensitivity decreases if the ASE noise level is high. To measure the ASE noise level, the OSNR (optical signal noise ratio) is used. The tolerance against the OSNR is required of the optical transceiver. The receiver sensitivity of this product was measured with the measurement system shown in **Fig. 9**.

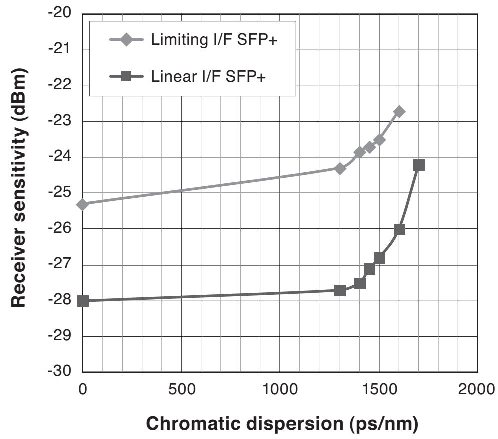


Fig. 10. Receiver sensitivity comparison (10.3Gbit/s, 35°C, PRBS31)

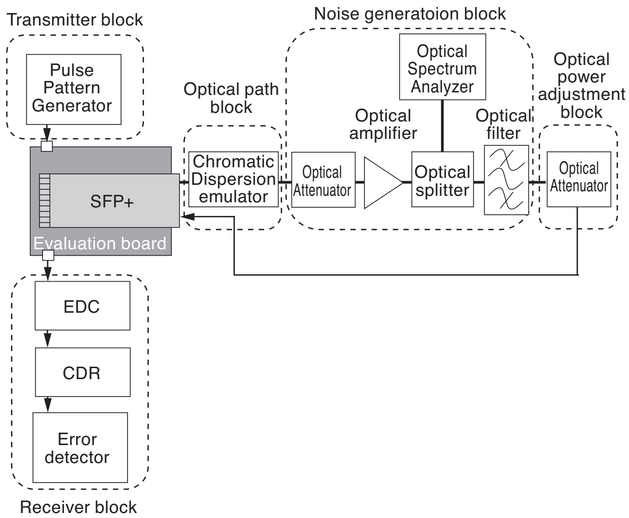


Fig. 9. Measurement system

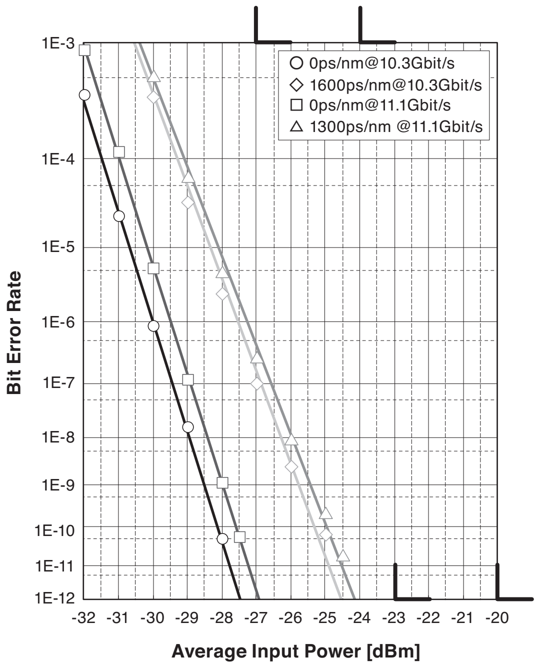


Fig. 11. Receiver sensitivity (35°C, RPBS31)

In this measurement system, a chromatic dispersion emulator is used instead of optical fiber because of its low insertion loss. The noise generation block determines the OSNR. The electrical output signals go through the EDC and the CDR. Then, the BER (bit error rate) is measured at the error detector.

Figure 10 shows the transmission performance of the limiting I/F and the linear I/F of the SFP+ DWDM transceiver. The receiver sensitivity of the linear I/F was improved by about 3 dB compared with that of the limiting I/F by using the EDC at 1600 ps/nm transmission.

Figure 11 shows the 10.3 Gbit/s and 11.1 Gbit/s BER (bit error rate) plots of the receiver sensitivity measured at 35°C. Regarding the sensitivities of the back to back and the after transmission at 10.3 Gbit/s, there are margins of more than 3 dB, in comparison to the target specifications of -23 dBm and -20dBm, respectively (see **Table 1**).

Also at 11.1 Gbit/s, the sensitivities of the back to back and the after transmission have margins of more than 3 dB, in comparison to the target specifications of -27 dBm and -24 dBm, respectively (see **Table 1**). To improve the OSNR tolerance, adjusting the bias voltage of the EA modulator is effective. **Figure 12** shows the EA modulator bias voltage dependence of the optical wave form at the OSNR of 24 dB/0.1 nm and 1,600 ps/nm dispersion. The waveform of the bias voltage of -0.41 V applied to the EA modulator has a larger opening at 1,600 ps/nm dispersion. The error detector can easily detect the signal level 1 and the signal level 0 if the eye opening of the waveform is large. Consequently, the receiver sensitivity improves.

On the other hand, however, the performance of the

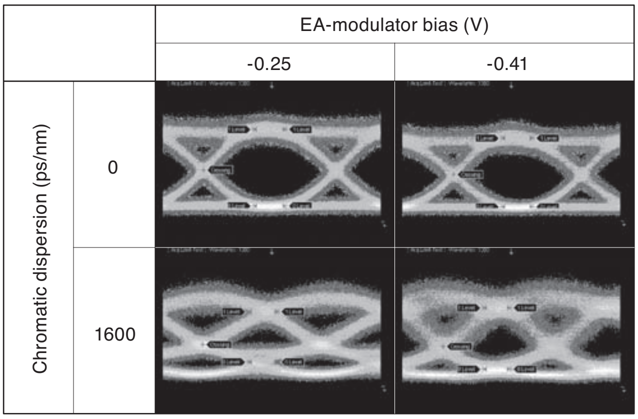


Fig. 12. Transmit eye diagram comparison (PRBS31)

pulse mask margin at the back to back degrades. There is a tradeoff relationship between the OSNR tolerance and the pulse mask margin. Therefore, we optimized the bias voltage of the EA modulator. **Figure 13** shows the BER plots of the OSNR tolerance measured at Tcase = 35˚C. Regarding the OSNRs of the back to back and the after transmission at 10.3 Gbit/s, there are margins of more than 3 dB, in comparison with the target specifications of 24 dB/0.1 nm and 27 dB/0.1 nm, respectively (see **Table 1**). Also at 11.1 Gbit/s, the OSNR tolerances of the back to back and the after transmission have margins of more than 3 dB, in comparison to the target specifications of 15 dB/0.1 nm and 16 dB/0.1 nm, respectively (see **Table 1**).

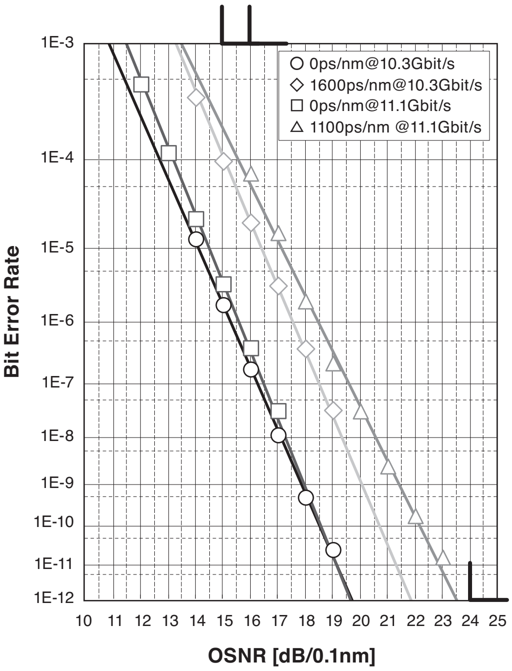


Fig. 13. OSNR tolerance (35˚C, RPBS31)

5. Conclusion

We have successfully developed an SFP+ DWDM optical transceiver module that supports a long link distance of up to 100 km at 11.1 Gbit/s, and reduced its power dissipation to less than 1.5 W at 0 to 70˚C. In order to achieve these new features, we adopted innovative low power dissipation components and improved the circuit efficiency. Those features will contribute to the downsizing and the cost reduction of transmission equipment. We believe that the low power dissipation and small form factor will play a key role in building a low-carbon economy, and hope that this development will make a contribution.

References

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(2) ITU-T G.694.1, "Spectral grids for WDM applications: DWDM frequency grid" (June 13, 2002)

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