Optical Receiver Module with Integrated 8-ch Optical De-multiplexer for 400 Gbit/s Transceivers

Masanobu KAWAMURA*, Kazuaki MII, Kenichi NAKAYAMA, Hiroyasu OOMORI, Fumihiro NAKAJIMA, and Hiroshi HARA

With the growth of cloud services that require high-speed communication, CFP4 and QSFP28 optical transceivers have been commonly used for 100 Gbit/s transmission. Along with an increase in the market need for higher-speed transmission beyond 100 Gbit/s, the Institute of Electrical and Electronics Engineers (IEEE) published 400GBASE-FR8/LR8 as the next-generation communication standards, and the CFP Multi-Source Agreement (MSA) defined the CFP8 form factor of an optical transceiver to support 400 Gbit/s interfaces. Against this backdrop, we have developed a new optical receiver module for 400GBASE-FR8/LR8 CFP8. Using the conventional design for 100 Gbit/s, the module has an integrated 8-ch optical de-multiplexer. This paper describes the module structure, optical characteristics, and sensitivity in 26.56 Gbaud PAM4 signal transmission.

Keywords: optical receiver module, 400G, optical de-multiplexer, CFP8

1. Introduction

In recent years, video and music streaming services drawing on cloud technology have been rising in popularity along with improvements in the functionality of smartphones and other mobile devices. These services require high-speed and large-capacity communication capabilities in not only wireless networks between user devices and base stations, but also optical networks connecting with wireless ones. Consequently, as a component of optical networks, optical transceiver modules must be smaller and faster.

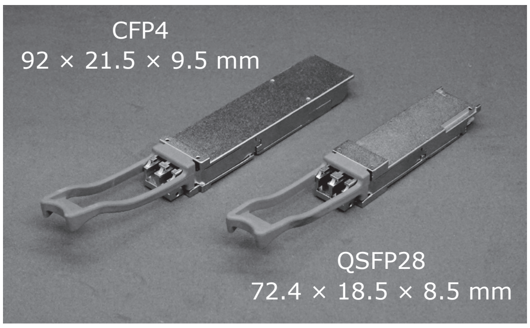

Fig. 1. 100 Gbit/s optical transceivers

Currently, while optical transceivers, such as CFP4*1 and QSFP28*2 shown in Fig. 1 that support a data rate of 100 Gbit/s and are compliant with Multi-Source Agreement (MSA)*3 are widely used, the Institute of Electrical and Electronics Engineers (IEEE) is working on the standardization of 400 GbE as a next-generation communication standard. In 2015, IEEE 802.3bs[1] specified a wavelength-division multiplexing system using eight parallel wavelengths and 4-level pulse amplitude modulation (PAM4)*4 encoding that was compliant with LAN-WDM*5 for distances of 2 to 10 km. In 2017, CFP MSA newly defined CFP8 optical transceivers for 400 Gbit/s. As such, expectations are high for 400 Gbit/s optical transceivers.

Sumitomo Electric Industries, Ltd. developed a 100 Gbit/s optical receiver module with an integrated 4-ch optical de-multiplexer[2],[3] and a 200 Gbit/s optical receiver module with an integrated 4-ch optical de-multiplexer[4] for QSFP28. By integrating de-multiplexing capabilities for 8 wavelengths in a package, we have developed a 400 Gbit/s optical receiver module with n integrated 8-ch optical de-multiplexer for CFP8, which has a low insertion loss level comparable to our previous products.

2. Structure of Optical Receiver Module with Integrated 8-ch Optical De-Multiplexer

Figure 2 shows the external appearance of the optical receiver module with an integrated 8-ch optical de-multiplexer. The package size of the newly developed optical receiver module is 22.3 mm × 12.0 mm × 5.3 mm, which can be built into CFP8. This module's design concept is similar to that of the conventional 100 Gbit/s optical receiver module with an integrated 4-ch optical de-multiplexer, ensuring high compatibility with the existing mass

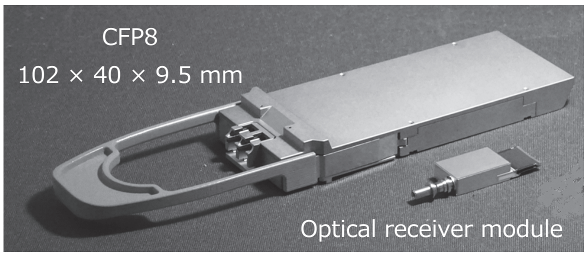

Fig. 2. 400 Gbit/s optical transceiver and optical receiver module

production line.

The internal structure of the optical receiver module is illustrated in Fig. 3. Wavelength-division multiplexed optical input signals are converted to a collimated beam by an optical lens, are de-multiplexed into 8-wavelength optical signals by a 1:8 optical de-multiplexer in the package, undergo a change in optical axis by a mirror toward the package bottom, and are subsequently focused on the photodiode (PD) by a lens array. The 1:8 optical de-multiplexer is made up of two 1:4 optical de-multiplexers designed for different wavelengths, a short-pass filter (SPF), and mirrors, as seen in Fig. 4. An optical signal incident on the 1:8 optical de-multiplexer is de-multiplexed by an SPF into a group of four shorter wavelengths (1273.55–1286.66 nm) and another group of four longer wavelengths (1295.56–1309.14 nm). These wavelength groups are led to enter their respectively compatible 1:4 optical de-multiplexers. A 1:4 optical de-multiplexer is made up of band-pass filters (BPFs) opposed to mirrors. Each lane only passes the optical signal of the corresponding wavelength and reflects optical signals of other wavelengths. This action is repeated to de-multiplex wavelength-division multiplexed optical signals.

To achieve a data rate of over 50 Gbit/s, the 400GbE standard specified in IEEE 802.3bs adopted a modulation method that uses 4-level pulse amplitude modulation (PAM4) signals instead of conventional non-return-to-zero (NRZ) signals. Eight PAM4-encoded optical signals are converted to electrical signals by a PD, amplified by a transimpedance amplifier (TIA), and output from the optical receiver module via the high-frequency transmission lines of the flexible printed circuits.

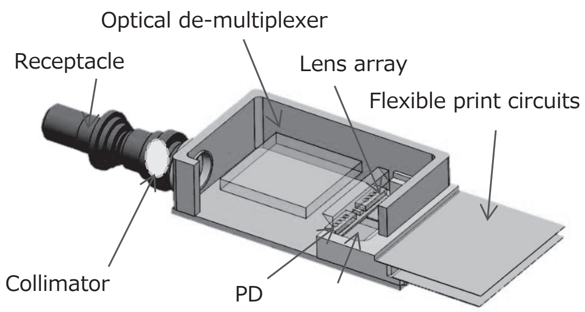

Fig. 3. Structure of optical receiver module

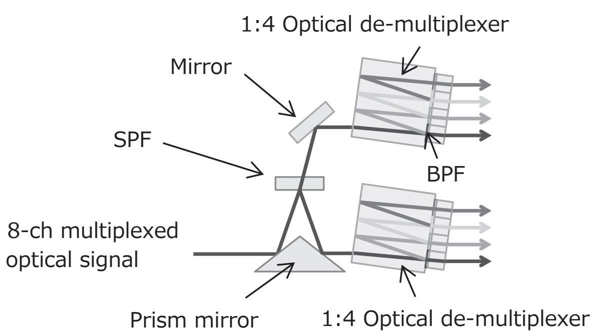

Fig. 4. Structure of 1:8 optical de-multiplexer

3. Target Specification

Table 1 shows the target specifications, which are 400GBASE-FR8/LR8 specified in IEEE 802.3bs.

Table 1. Target Specifications

Parameter		400GBASE-FR8	400GBASE-LR8
Symbol rate		26.5625 Gbaud	
Modulation method		PAM4	
Center wavelength	Lane0	1273.55 nm	
	Lane1	1277.89 nm	
	Lane2	1282.26 nm	
	Lane3	1286.66 nm	
	Lane4	1295.56 nm	
	Lane5	1300.05 nm	
	Lane6	1304.58 nm	
	Lane7	1309.14 nm	
Overload (OMA)		< 5.7 dBm	
Minimum sensitivity (OMA)		> -5.3 dBm	> -7.1 dBm
Return Loss		> 26 dB	

4. Optical Receiver Module Characteristics

4-1 Optical characteristics

Figure 5 graphs the responsivity spectrum of the optical receiver module with an integrated 8-ch optical de-multiplexer. Table 2 shows the responsivity, isolation, and return loss of each lane.

IEEE 802.3bs specifies eight wavelengths, consisting of four shorter wavelengths and four longer wavelengths with an unused wavelength between these wavelength groups. The low-loss 1:8 optical de-multiplexer incorporating a newly designed SPF exhibits favorable characteristics in all lanes, being not higher than 1 dB in insertion loss, not lower than 25 dB in isolation, and not lower than 26 dB in return loss.

Figure 6 shows the temperature dependence of responsivity and isolation. Responsivity variation is within ±0.1 dB in a package temperature range of −20°C to +90°C. Isolation variation is ±1 dB in the same range, indicating stable characteristics.

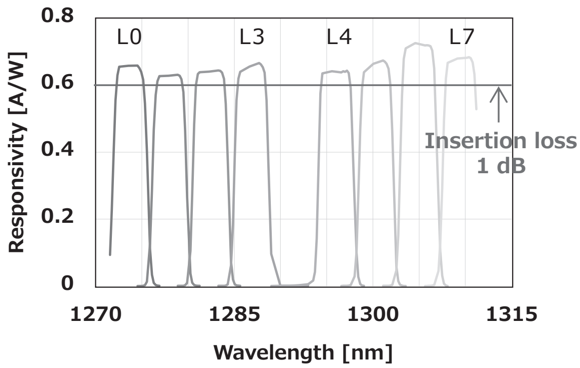

Fig. 5. Responsivity spectrum

Table 2. Optical Specifications

Parameter	Responsivity [A/W]	Isolation [dB]		Return Loss [dB]
Lane0	0.658	Long	27.7	43.4
Lane1	0.628	Short	31.7	38.8
		Long	29.2	
Lane2	0.641	Short	28.6	40.7
		Long	28.4	
Lane3	0.655	Short	28.6	40.0
Lane4	0.642	Long	29.3	38.9
Lane5	0.664	Short	29.9	40.7
		Long	30.3	
Lane6	0.726	Short	29.8	40.5
		Long	30.1	
Lane7	0.680	Short	30.7	42.3

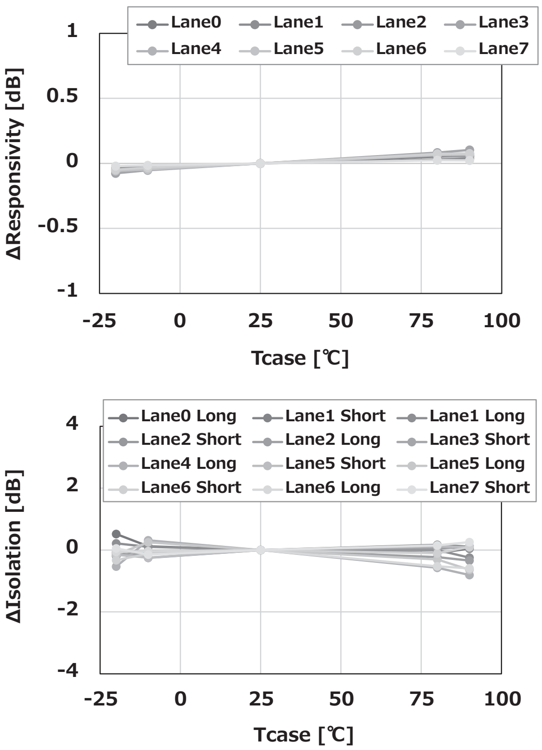

Fig. 6. Temperature dependence of optical characteristics

4-2 RF characteristics

To achieve high-speed transmission, the high-frequency transmission line in the package used for the optical receiver module with an integrated 8-ch optical de-multiplexer is optimized so that lanes have minimum differences in characteristics and reduced mutual crosstalk between lanes. For frequency characteristics, the −3 dB bandwidth is not less than 20 GHz, as shown in Fig. 7. Moreover, lane-to-lane variation is small, ensuring consistent characteristics.

4-3 Crosstalk characteristics

Using a light wave component analyzer, optical signals of specified wavelengths were input to lanes other than lane 6 (lanes 0, 1, 2, 3, 4, 5, and 7). Figure 8 shows the frequency characteristics of the electrical output from lane 6.

The adjacent lanes (lanes 5 and 7) affected lane 6 more than did other lanes. However, the crosstalk was not more than −30 dB at 25 GHz. Accordingly, the effect of crosstalk is minimal.

4-4 Minimum sensitivity

Figure 9 shows bit error rate characteristics exhibited when a PAM4-encoded optical signal was input at a symbol

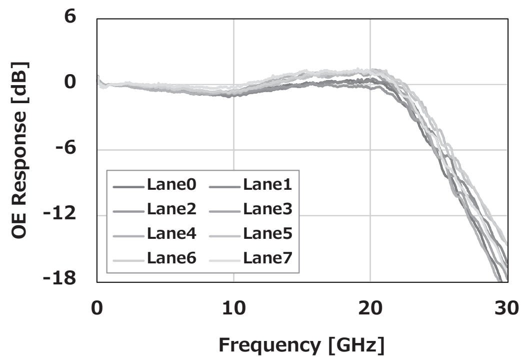

Fig. 7. Frequency characteristics

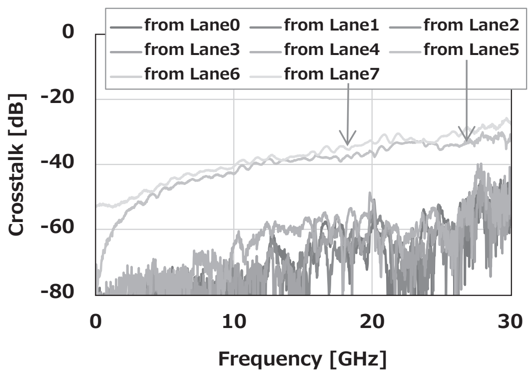

Fig. 8. Crosstalk characteristics

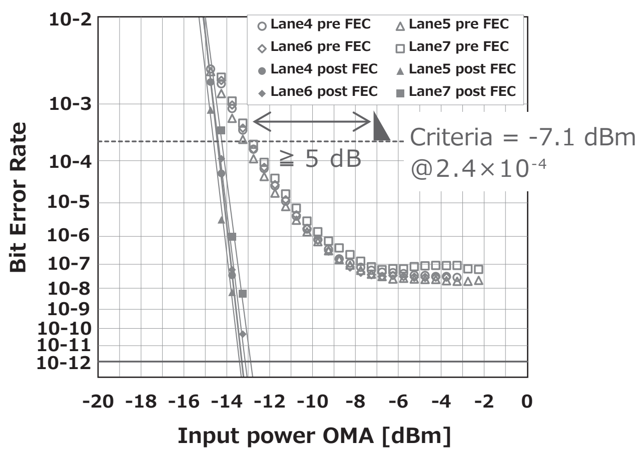

Fig. 9. Bit error rate

rate of 26.56 Gbaud (PRBS2^{31}-1). Before forward error correction, the minimum sensitivity was −13 dBm (bit error rate = 2.4×10^{-4}). Even after forward error correction, the minimum sensitivity was −13 dBm (bit error rate = 1×10^{-12}). These favorable characteristics meet the specifications for both 400GBASE-FR8 and 400GBASE-LR8.

5. Conclusion

We have developed an optical receiver module with integrated 8-ch optical de-multiplexer that can be built into next-generation 400 Gbit/s optical CFP8 transceivers. The integration of de-multiplexing capabilities for eight wavelengths in a package has been effective for achieving a low insertion loss of 1 dB or less, which is a comparable level to our previous products. For the bit error rate characteristics exhibited when inputting a PAM4-encoded optical signal at a symbol rate of 26.56 Gbaud (PRBS2^{31}-1), the receiver module exhibited a minimum sensitivity of −13 dBm (bit error rate = 2.4×10^{-4}) before forward error correction and also −13 dBm (bit error rate = 1×10^{-12}) even after forward error correction. These characteristics indicate that the receiver module can be used for stable 400 Gbit/s transmissions.

Technical Terms

＊1 CFP/CFP4/CFP8: C form-factor pluggable: An industrial standard for 100–400 Gbit/s transceivers. CFP8 is designed to achieve a data rate of 400 Gbit/s by combining 50 Gbit/s optical signals in 8 lanes.

＊2 QSFP28: Quad small form-factor pluggable: An industrial standard for 100–400 Gbit/s transceivers. QSFP28 is designed to achieve a data rate of 100 Gbit/s by combining 25 Gbit/s optical signals in 4 lanes.

＊3 MSA: Multi-source agreement: A common standard for parts specifications developed by module suppliers.

＊4 PAM4 modulation mode: Four-level pulse amplitude modulation: An encoding technique that enables information transmission of 2 bits per symbol.

＊5 LAN-WDM: A wavelength-division multiplexing technique. LAN-WDM multiplexes signals at 800 GHz spacing.

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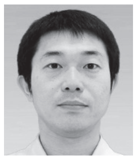
Contributors The lead author is indicated by an asterisk (＊).

M. KAWAMURA＊
• Assistant Manager, Transmission Devices Laboratory

K. MII
• Assistant Manager, Transmission Devices Laboratory

K. NAKAYAMA
• Transmission Devices Laboratory

H. OOMORI
• Assistant General Manager, Transmission Devices Laboratory



F. NAKAJIMA
• Ph.D (Doctor of Science)
Sumitomo Electric Device Innovations, Inc.

H. HARA
• Group Manager, Transmission Devices Laboratory