

Compact Receiver Module with Integrated Optical De-multiplexer for 40 Gbit/s and 100 Gbit/s

Masanobu KAWAMURA*, Fumihiro NAKAJIMA, Hiroyasu OOMORI, Hiroshi HARA and Atsushi YASAKI

The authors have successfully developed new compact optical receiver modules with integrated optical De-multiplexer for 40GBASE-ER4 QSFP+ and 100GBASE-LR4 CFP4. These compact optical receiver modules achieved excellent wavelength specification and sensitivity. By applying the basic structure of the compact optical receiver module for 40GBASE-LR4 QSFP+, the newly developed modules are in the same form as the predecessor. The development of compact optical receiver modules are essential for QSFP+ and CFP4, which are compact optical transceivers, to realize 40 Gbit/s and 100 Gbit/s transmission, respectively. This paper describes the design and representative specification of the new modules.

Keywords: optical receiver module, optical De-multiplexer, 40GBASE-ER4, 100GBASE-LR4, CFP4

1. Introduction

With the diffusion of communication devices, such as smart phones, that require high-speed and large-capacity communication, optical network equipment, such as switches and routers constituting the optical communication network, requires high-speed and large-capacity communication too. The miniaturization and high-speed communication is very important, in the optical transceiver mounted on the optical network equipment and optical transmitter/receiver modules which are main component of the optical transceiver.

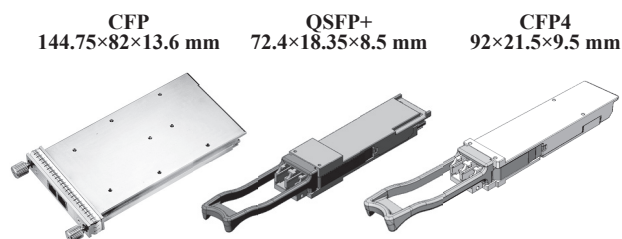


Fig. 1. External view and size of optical transceivers

Figure 1 shows the external view and size of optical transceivers. Currently, a CFP (100G Form-factor Pluggable) optical transceiver specified by Multi Source Agreement (MSA) for 40 Gbit/s and 100 Gbit/s is popular. However, the CFP is larger than conventional compact optical transceiver for 10 Gbit/s. For increase of the optical network equipment capacity, a more compact optical transceiver, such as 4 times higher density mounting is possible; a Quad Small Form-factor Pluggable Plus (QSFP+) and a CFP4 specified by MSA, are desired.

We developed a compact optical receiver module with integrated optical De-multiplexer for 40GBASE-LR4

QSFP+ in 2012^{(1),(2)}. By applying the basic structure of the optical receiver module for 40GBASE-LR4 QSFP+, we have successfully developed new compact optical receiver modules for 40GBASE-ER4 QSFP+⁽³⁾ and 100GBASE-LR4 CFP4^{(4),(5)}, which are the same as the predecessor form.

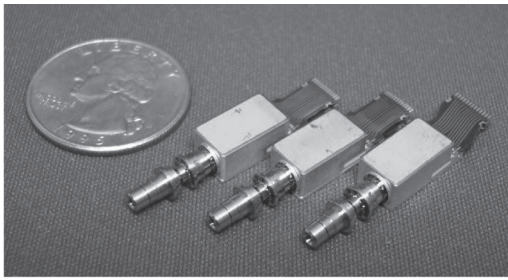
2. Structure of Compact Optical Receiver Module with Integrated Optical De-multiplexer

Figure 2 (a) shows the external view of compact optical receiver modules with integrated optical De-multiplexer. The new developed compact optical receiver modules for 40GBASE-ER4 QSFP+ and 100GBASE-LR4 CFP4 have the same package size 15.4 × 6.7 × 5.3 mm as the compact optical receiver modules for 40GBASE-LR4 QSFP+ developed in 2012.

Figure 2 (b) shows the structure of a compact optical receiver module with integrated optical De-multiplexer. An optical De-multiplexer, a mirror, a micro lens array, a transimpedance amplifier (TIA) and photodiodes (PDs) are mounted in the module package. A light from optical fiber is collimated by a lens mounted outside the module package. Subsequently, the collimated beam is divided into four wavelength beams by an optical De-multiplexer. Four wavelength collimated beams are changed to an optical axis to the package bottom by a mirror, and then they are focused on the PDs by the micro lens array.

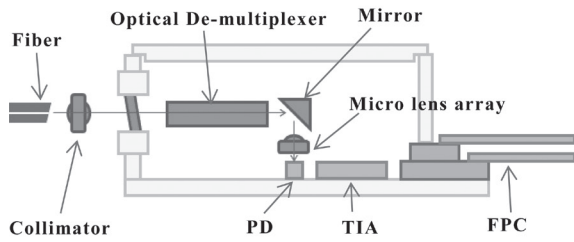
Figure 2 (c) shows the structure of an optical De-multiplexer.

An optical De-multiplexer consists of a mirror and four band pass filters (BPFs) that have a characteristic of selectively transmitting the beams to each lane, depending on the corresponding wavelength. The electrical signals, subjected to photoelectric conversion at the PDs, are amplified by the TIA, and they are output through the high-frequency transmission line of the

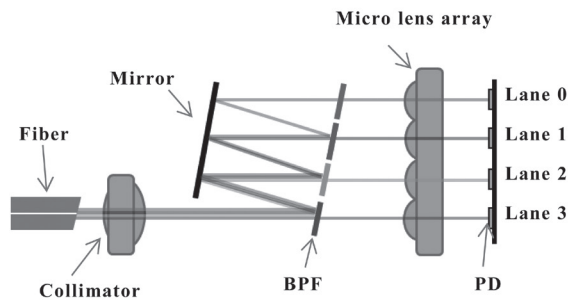


Left: Receiver module for 40GBASE-LR4 QSFP+
Center: Receiver module for 40GBASE-ER4 QSFP+
Right: Receiver module for 100GBASE-LR4 CFP4

(a) External view



(b) Structure



(c) Optical layout

Fig. 2. Compact optical receiver module with integrated optical De-multiplexer

package and the flexible printed circuits (FPC). To realize the receiver modules, which have low insertion loss and broadband, we have optimized the design of the high-frequency transmission line of the package and the FPC. Furthermore, we have designed all high-frequency transmission lines on the same plane as the PDs and the TIA.

3. Specification

Table 1 shows the target specifications, i.e. the 40GBASE-ER4 and 100GBASE-LR4—both are specifications of IEEE802.3ba—and the Optical-channel Transport Unit 3 (OTU3) and Optical-channel Transport Unit 4 (OTU4)—both specifications of ITU-T G695.

The wavelength specification of 40GBASE-ER4 / OTU3 is defined in the same CWDM (1271, 1291, 1311, 1331 nm \pm 6.5 nm) as the 40GBASE-LR4. In contrast, the receiver

sensitivity (OMA, optical modulation amplitude) specification is required to be -19 dBm, which is smaller than that of 40GBASE-LR4. We adopted four avalanche photodiodes with monolithic lens to realize high-sensitivity.

The wavelength specification of 100GBASE-LR4 / OTU4 is defined as the LAN-WDM (1295.56 nm, 1300.05 nm, 1304.58 nm, 1309.14 nm). Furthermore, the data rate specification is defined as 25.78125 Gbit/s (100GBASE-LR4) and 27.95249 Gbit/s (OTU4), which is a higher data rate than that of 40GBASE-LR4. We have developed a new optical De-multiplexer for LAN-WDM, new broadband PD with monolithic lens for 28 Gbit/s and a new package for 28 Gbit/s that has optimized high-frequency transmission.

Table 1. Specifications

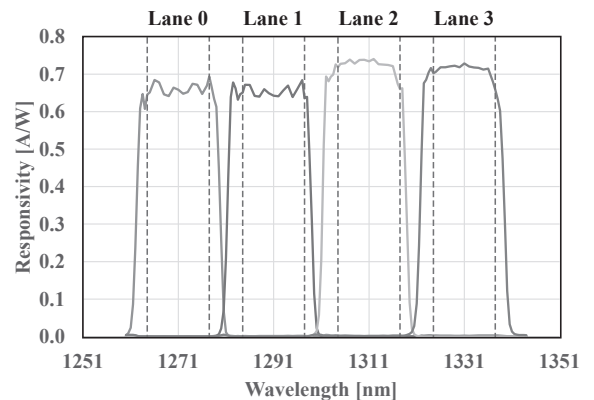
Parameter	40GBASE-ER4	OTU3	100GBASE-LR4	OTU4	unit
Data rate	10.3125	10.7546	25.78125	27.95249	Gbit/s
Wavelength	Lane 0	1271 \pm 6.5	1294.53 - 1296.59		nm
	Lane 1	1291 \pm 6.5	1299.02 - 1301.09		nm
	Lane 2	1311 \pm 6.5	1303.54 - 1305.63		nm
	Lane 3	1311 \pm 6.5	1308.09 - 1310.19		nm
Overload (OMA)	> -4	> -4*	> 4.5	-	dBm
Overload (Average)	-	-	-	> 4	dBm
Sensitivity (OMA)	< -19	< -19*	< -8.6	-	dBm
Sensitivity (Average)	-	-	-	< -10.3	dBm

*The ITU-T G.695 OTU3 does not define the specification of optical receiver module for transmission distance 40 km Specification. Accordingly, we describe the same specifications as the 40GBASE-ER4 as target specifications.

4. Optical Receiver for 40GBASE-ER4/OTU3

4-1 Optical characteristics

Figure 3 shows wavelength characteristics of the new receiver at multiplication factor = 1, room tempera-



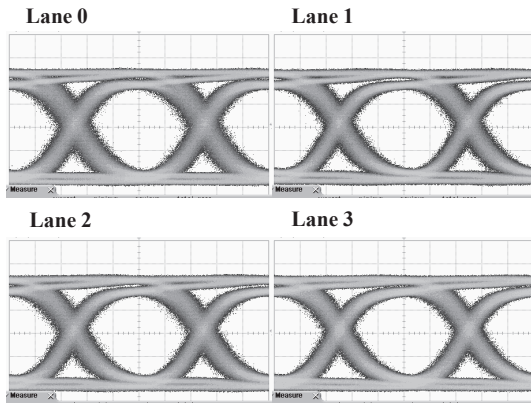
Tc = RT, Multiplication factor = 1, Pin = -10 dBm

Fig. 3. Responsivity spectrum

ture and $P_{in} = -10$ dBm. The focus position of the micro lens array is optimized to avalanche PDs with monolithic lens, the responsivity is more than 0.64 A/W at all lanes.

4-2 Receiver characteristics

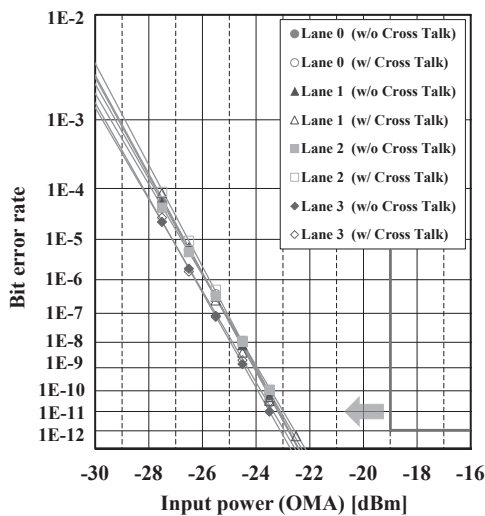
Figure 4 shows electrical waveforms at 10.7546 Gbit/s (OTU3), room temperature and $P_{in} = -22$ dBm.



$T_c = RT, 10.7546$ Gbit/s (OTU3), $P_{in} = -22$ dBm

Fig. 4. Electrical waveforms

The electrical waveforms are good eye pattern at all lanes. **Figure 5** shows bit error rate curves including the influence of the cross talk. To evaluate the influence of the cross talk, the optical input power of the measured lane was adjusted to be 7.5 dB smaller than that of the other lanes. With or without cross talk, minimum sensitivity (OMA) is less than -22.5 dBm. The



$T_c = RT, 10.7546$ Gbit/s (OTU3), $\Delta P_{xtalk} = +7.5$ dB

Fig. 5. Bit error rate curves

obtained value proves that the receiver has a wider margin to the specification. The receiver operates error-free at -4 dBm of the overload specification.

4-3 Temperature dependency of sensitivity

Figure 6 shows the temperature dependency of sensitivity at the case temperature from -10°C to 90°C at 10.7546 Gbit/s (OTU3). The receiver has the margin of 2.9 dB to the sensitivity specification with the influence of temperature dependency.

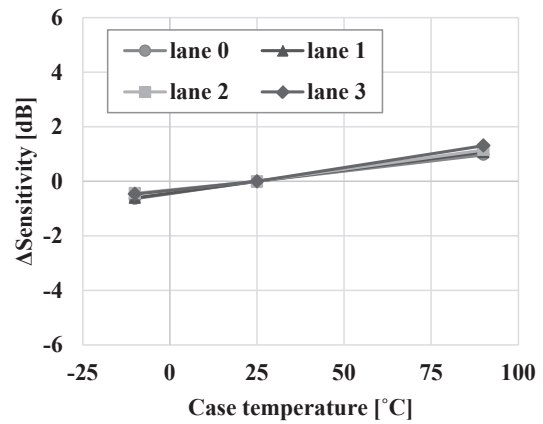


Fig. 6. Temperature dependency of sensitivity

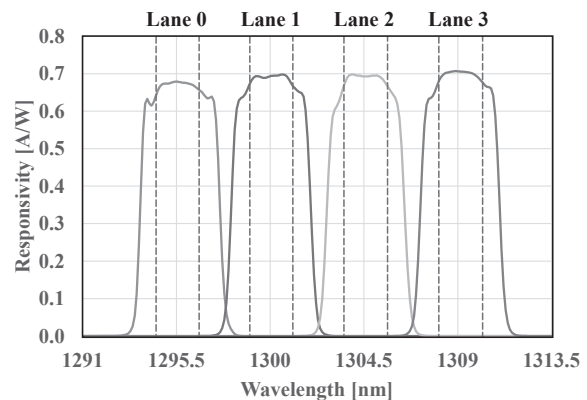
5. Optical Receiver for 100GBASE-LR4/OTU4

5-1 Optical characteristics

Figure 7 shows wavelength characteristics of the new receiver at room temperature and $P_{in} = +1$ dBm. The focus position of the micro lens array is optimized to the PD with monolithic lens, thereby obtaining the responsivity of more than 0.64 A/W at all lanes.

5-2 RF characteristics

We have optimized anew the package design to realize a higher data rate. Although the pin-pitch of the



$T_c = RT, P_{in} = +1$ dBm

Fig. 7. Responsivity spectrum

TIA does not correspond with the package and the FPC, we have designed the equal length of the outside lane and inside lane of the package. **Figure 8** shows RF characteristics of the new package, which has a low insertion loss.

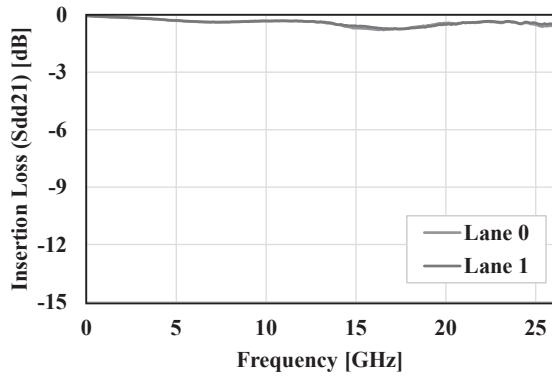
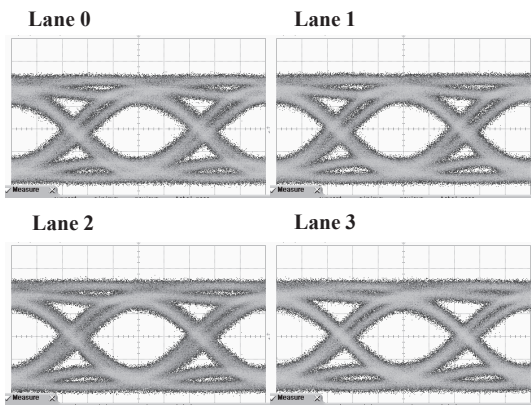


Fig. 8. Insertion loss

5-3 Receiver characteristics

Figure 9 shows electrical waveforms at 27.95249 Gbit/s (OTU4), room temperature and Pin = -12 dBm. The electrical waveforms are good eye pattern at all lanes.



Tc = RT, 27.95249 Gbit/s (OTU4), Pin = -12 dBm

Fig. 9. Electrical waveforms

Figure 10 shows bit error rate curves included the influence of the cross talk.

To evaluate the influence of the cross talk, the optical input power of the measured lane was adjusted to be 6 dB smaller than that of the other lanes. With or without cross talk, minimum sensitivity (average) is less than -12.6 dBm, the receiver has a wider margin to the

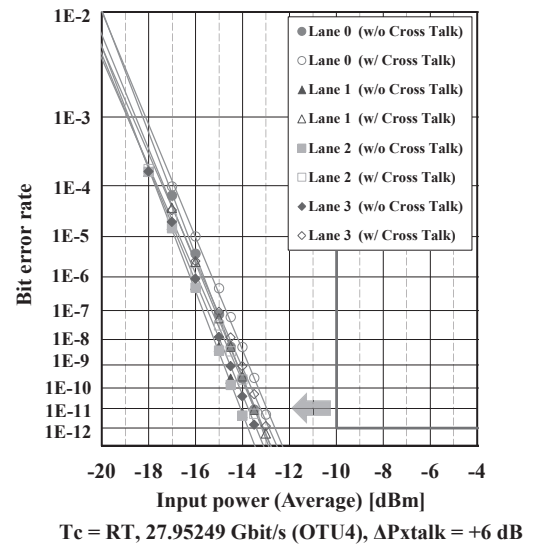


Fig. 10. Bit error rate curves

specification. The receiver operates error-free at 4dBm of the overload specification.

5-4 Temperature dependency of sensitivity

Figure 11 shows the temperature dependency of sensitivity at case temperature from -10°C to 90°C at 27.95249 Gbit/s (OTU4). The receiver has the margin of 2.2 dB to the sensitivity specification with the influence of temperature dependency.

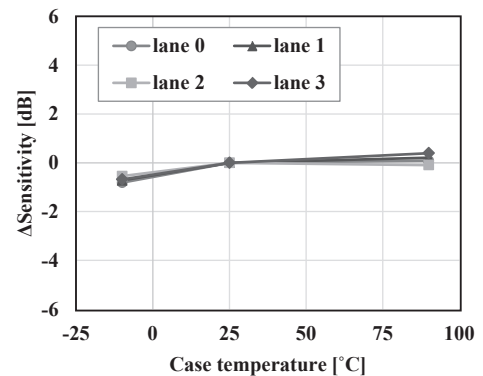


Fig. 11. Temperature dependency of sensitivity

6. Conclusion

We have developed new compact optical receiver modules for 40GBASE-ER4 QSFP+ and 100GBASE-LR4 CFP4. These new receivers are compliant with the 40GBASE-ER4/OTU3 and 100GBASE-LR/OTU4 specifications, and show excellent performance. The receiver for 40GBASE-ER4 QSFP+ has a responsivity of more than 0.64 A/W at multiplication factor = 1 and a

minimum sensitivity (OMA) of less than -22.5 dB at 10.7546 Gbit/s (OTU3).

The receiver for 100GBASE-LR4/OTU4 has a responsivity of more than 0.64 A/W and a minimum sensitivity (average) of less than -12.6 dB at 27.95249 Gbit/s (OTU4). We continue to work on the development of the receiver modules to be mounted in other compact optical transceivers for 100 Gbit/s.

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

M. KAWAMURA*

- Assistant Manager, Transmission Devices R&D Laboratories



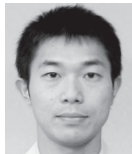
F. NAKAJIMA

- Ph.D. degree in engineering
Assistant Manager, Transmission Devices R&D Laboratories



H. OOMORI

- Assistant General Manager, Transmission Devices R&D Laboratories



H. HARA

- Group Manager, Transmission Devices R&D Laboratories



A. YASAKI

- Group Manager, Sumitomo Electric Device Innovations, Inc.

