Development of Small Receiver Module with Integrated Optical Demultiplexer

Kazushige OKI*, Masanobu KAWAMURA, Fumihiro NAKAJIMA, Michio SUZUKI, Hiroshi HARA and Yasushi FUJIMURA

The authors have successfully developed a small receiver module with an integrated optical demultiplexer. The module is compliant with the 40GBASE-LR4/OTU3 specifications and sufficiently small (7 mm) to be mounted in a QSFP+ (Quad Small Form-factor Pluggable plus) next generation 40 GE optical transceiver. The optical demultiplexer uses thin film band pass filters to divide a multiplexed optical signal into 4 demultiplexed optical signals, thereby realizing low optical insertion loss and low temperature dependency. The unique optical alignment system that consists of the optical demultiplexer, a PD array, a collimating sleeve and a micro lens array enables the downsizing of the receiver module. The module demonstrates excellent performance at the specified temperature range (-10 to 95 deg. C) and supply voltage (3.0 to 3.6 V). The low loss optical design realizes a high receive sensitivity of -17 dBm, providing a wide margin to the IEEE requirement of -11.5 dBm (OMA) and the OTU3 requirement of -10.8dBm.

Keywords: 40GBASE-LR4, OTU3, demultiplexer, ROSA, QSFP+

1. Introduction

In order to match the increase of data network traffic, the optical network equipment, such as routers and switches with much larger capacity, has been required. The downsizing and high transmission of an optical transceiver that is one of the key parts of such equipment is very important.

Conventional 10 GE optical transceivers, such as XFP (10 Gigabit Small Form Factor Pluggable) and SFP+ (Small Form-Factor Pluggable Plus) specified by MSA (Multi Source Agreement, a common specification for the pluggable optical transceiver), convert a single electrical signal to a single optical signal and vice versa. In order to increase the transmission volume, the demand for a 40 GE optical transceiver that has an optical multiplexer/demultiplexer of 4 x 10 GE is increasing rapidly. Although we have already produced a 40GE-CFP (100G Form-factor Pluggable) optical transceiver, it is much larger than the conventional 10 GE optical transceivers, and a 40 GE optical transceiver as small as the conventional 10 GE is desired for high density mounting.

We have successfully developed a small optical receiver module with an integrated optical demultiplexer. The receiver module is compliant with the 40GBASE-LR4/OTU3 (Optical- channel Transport Unit 3) specifications and sufficiently small to be mounted in a QSFP+ (Quad Small Form-factor Pluggable Plus) optical transceiver that is as small as the XFP. The demultiplexer uses thin film band pass filters to realize low optical insertion loss and low temperature dependency. The unique optical alignment system enables the downsizing of the receiver module. This paper describes the basic structure and the basic characteristics of the receiver module.

2. Development Target and Specification

Figure 1 shows optical network equipment that consists of several line cards where 4 CFP optical transceivers

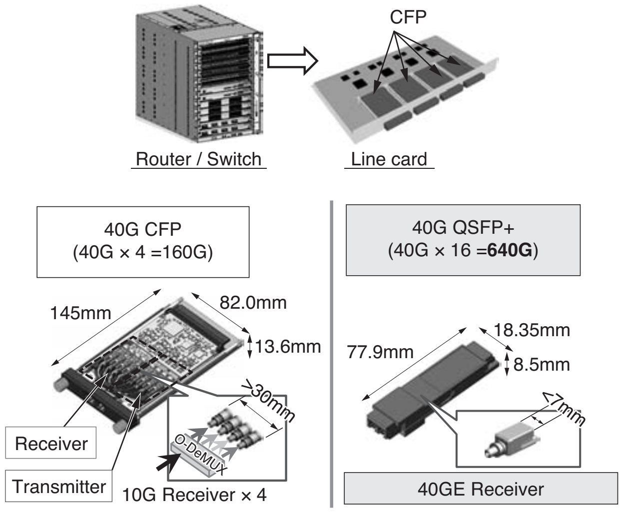


Fig. 1. Comparing of variable spaces for mounting a receiver module in an optical transceiver

are mounted horizontally. Reduction in the width of the optical transceiver is the key to the increase of the transmission volume of the optical network equipment. The optical network equipment with QSFP+, which is about one quarter of the CFP in width, can transmit data about 4 times larger than that with the CFP. As the required width of the receiver module for the QSFP+ is estimated to be less than 7 mm, the discrete type that consists of four receiver modules connected to a demultiplexer by optical fibers and is used in the CFP is impossible to be mounted in the QSFP+. Therefore, the integration of the 4 x 10 GE optical receiver modules with the optical demultiplexer is the key to downsizing.

Table 1 shows the 40GBASE-LR4 specification in IEEE802.3ba and the OTU3 specification in ITU-T G695. A multiplexed optical signal that includes 4 wavelength signals (i.e. 1271, 1291, 1311, 1331 nm) should be demulti-

Table 1. Specifications of the receiver module

Parameter		Spec.		Unit
		40GBASE-LR4	OTU3	
Speed		10.3	10.8	Gbit/s
Wavelength	L0	1271±6.5		nm
	L1	1291±6.5		nm
	L2	1311±6.5		nm
	L3	1331±6.5		nm
Overload (OMA)		>3.5		dBm
Difference in launch power between any two lanes (OMA)		<7.5	<5.5	dB
Receive sensitivity (OMA)		<-11.5		dBm
Average receive senitivity			<-10.8	dBm
Receiver reflectance		>26	>26	dB

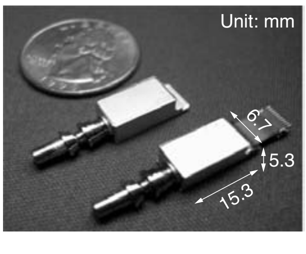
plexed in the receiver module. Required receive sensitivity (OMA, optical modulation amplitude) by the IEEE is -11.5 dBm under the condition that the optical input power of one lane is 7.5 dB smaller than the other lanes. Required overload (OMA) by the IEEE is 3.5 dBm. Required receive sensitivity by the OTU3 is less than -10.8 dBm. Required receiver reflectance is more than 26 dBm.

3. Structure of the Small Receiver Module with Integrated Optical Demultiplexer

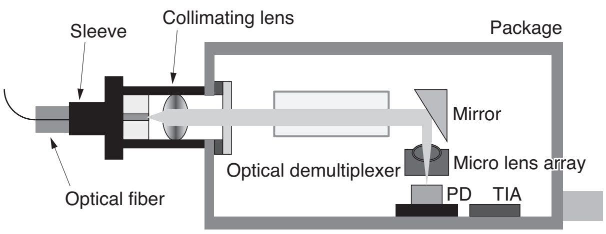
3-1 Overall structure

Figures 2 (a) and (b) show the external view and the cross section of the small receiver module with an integrated optical demultiplexer, respectively. The upper part of **Fig. 2 (a)** shows the module without the FPC, which is described later, and the under part of **Fig. 2 (a)** shows that with the FPC. The module package contains an optical demultiplexer, a micro lens array, a photo diode array, a transimpedance amplifier (TIA) and so on, and is aligned with a sleeve and a collimating lens for CWDM (1271, 1291, 1311, 1331 nm +/- 6.5 nm) optical signals from an optical fiber to be input into the demultiplexer. The PD (photo diode)-array is the top illuminated type whose diameter is ø 50 μm. The demultiplexed optical signals are focused on the PD-array by the micro lens array.

To place many electrical line pads that have the transmission lines for 4 lanes in the module package of 7 mm or less in width, the pads for RF lines and for DC lines are double-decked on the rear end of the package. All the pads are connected to the pads of the transceiver PCB by FPCs to obtain the package size of 15.3 mm x 6.7 mm x 5.3 mm to be mounted in QSFP+.



(a) External view

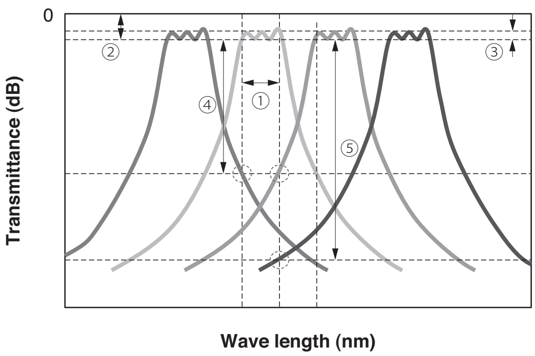


(b) Cross section

Fig. 2. Small receiver module with integrated optical demultiplexer

3-2 Optical demultiplexer

The required characteristic parameter of the optical demultiplexer is shown in **Fig 3**. In addition to these characteristics, the temperature dependency and the size determine the overall performance of the demultiplexer. There are several methods to demultiplex an optical signal from an optical fiber, such as those using a thin film band pass filter, planer lightwave circuit (PLC), optical directional coupler, and grating. In this development, we adopted thin film band pass filters to the optical demultiplxer in consideration of the size, optical insertion loss, isolation for each lane, and temperature dependency.



① Pass band width
② Insertion loss
③ Pass band ripple
④ Adjacent channel isolation
⑤ Non-Adjacent channel isolation

Fig. 3. Characteristics of an optical demultiplxer

3-3 Optical design / characteristics

Figure 4 shows the optical system of this small receiver module with the integrated optical demultiplexer. The collimating lens transforms a diffusion beam from a fiber stub connected to an optical fiber into a collimated beam. The

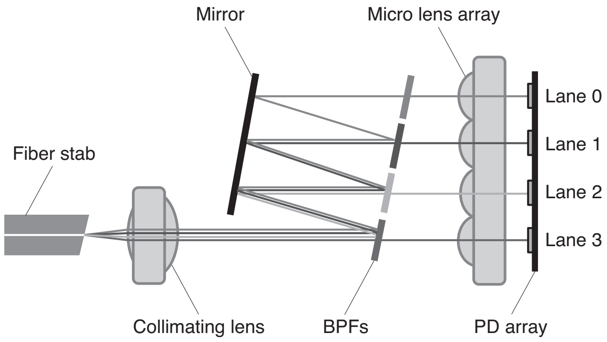


Fig. 4. Optical system of the optical receiver module

optical demultiplexer consists of a mirror and 4 band pass filters (BPFs) which have a characteristic of selectively transmitting the beams to each lane depending on the corresponding wavelength. The First BPF demultiplexes Lane 3 (1331 nm) from a multiplexed collimated beam, and reflects the others, i.e. Lane 0 (1271 nm), Lane 1 (1291 nm) and Lane 2 (1311 nm). Then, the beam is reflected by the mirror again and Lane 2 (1311 nm) is separated by the second BPF. By repeating this, the 4 multiplexed beams are demultiplexed.

As shown in **Fig. 4**, the optical path lengths from Lane 0 to Lane 3 are different from each other. As the diffusion of collimated beam used in such a small size optical system cannot be ignored, the distance between the fiber stub and the collimating lens should be adequately controlled to minimize the variation of beam diameters on each micro lens. As the pass band of the BPF shifts depending on the incident angle of a beam and the optical path length of the last demultiplexed Lane 0 (1271 nm) is longer, the angle and orientation of the collimated beam and the BPFs are significantly important in order to obtain the intended demutiplexing characteristic. Therefore, the BPFs and the mirror are aligned in a predetermined position as a sub-assembly (optical demultiplexer) to obtain desired demultiplexing characteristics. The demultiplexed collimated beams are condensed into the micro lens array, and then into the PD array that is aligned to the micro lens array in advance.

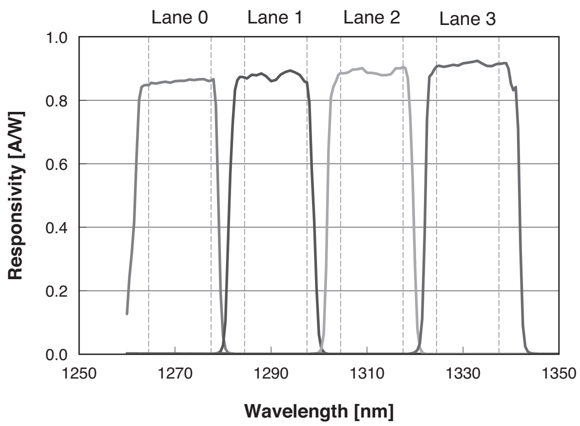


Fig. 5. Responsivity spectrum

Figure 5 shows the responsivity spectrum of the small receiver module with an integrated optical demultiplexer. The desired characteristic is obtained as the prescribed wavelength is demultiplexed at each lane and a high responsivity of more than 0.8 A/W is measured. **Table 2** shows the optical characteristics. We have achieved low insertion loss of less than 0.5 dB and high adjacent isolation of more than 27 dB. We also obtained optical reflection loss of 33 dB, which satisfies the specifications.

Table 2. Optical characteristics

Paramter	Lane	Spec.	Wavle length		
			-6.5nm	Center	+6.5nm
Responsivity [A/W]	Lane 0	> 0.7	0.85	0.86	0.86
	Lane 1		0.87	0.86	0.86
	Lane 2		0.89	0.89	0.91
	Lane 3		0.91	0.92	0.91
Insertion loss [dB]	Lane 0	< 1.0	0.38		
	Lane 1		0.46		
	Lane 2		0.40		
	Lane 3		0.32		
Ripple [dB]	Lane 0	< 0.5	0.07		
	Lane 1		0.20		
	Lane 2		0.15		
	Lane 3		0.11		
Adjacent channel isolation [dB]	Lane 0	> 25	–	–	29.6
	Lane 1		27.8	–	31.4
	Lane 2		29.2	–	32.4
	Lane 3		29.3	–	–

3-4 RF design and evaluation results

As the transmission lines for 4 lanes need to be designed in a narrow width of less than 7 mm in the module package, the degradation of receive sensitivity due to a cross talk between each lane is one of the essential issues. Our original design of the transmission line reduces the insertion loss and electrical cross talk as shown in **Fig. 6**, and **Fig. 7**.

Figure 8 shows the bit error rate (BER) characteristic of the receiver module. A 40 GE CFP is used as an optical source whose extinction ratio is 5.5 dB. Receive sensitivity is less than -17 dBm at BER = 10^{-12} for both 40GEBASE-LR4 and OTU3. The receive sensitivity is less than -16.4 dBm and its deviation is less than 1 dB at a specified temperature range (-10 to 95 deg. C) and a supplied voltage range (3.0 to 3.6 V) as shown in **Fig. 9**. To verify the influence of the cross talk, the BER is evaluated under the condition that the optical input power of the measured lane is 7 dB smaller than that of the other lanes. The cross talk penalty at each lane is less than 0.2 dB as shown in **Fig. 10**. The overload is 3.7 dB m (OMA), which meets the 40GBASE-

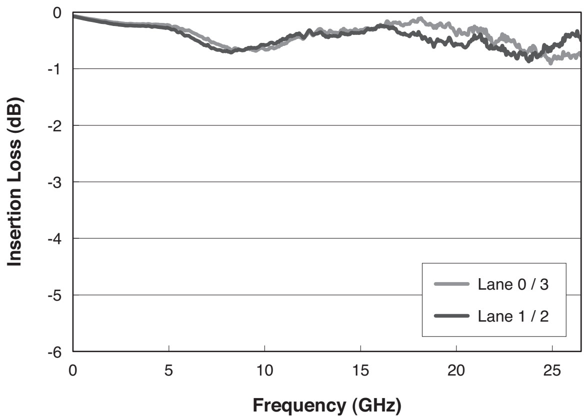


Fig. 6. Insertion loss

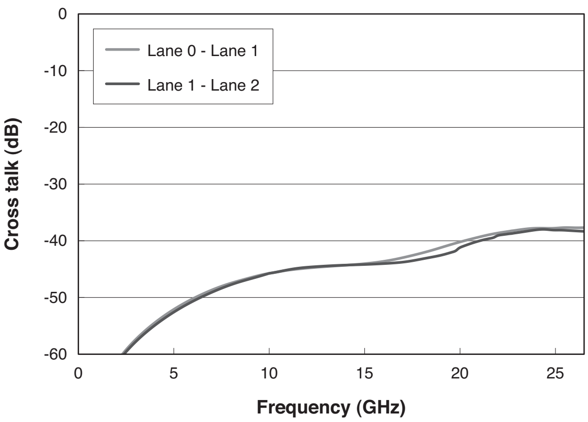
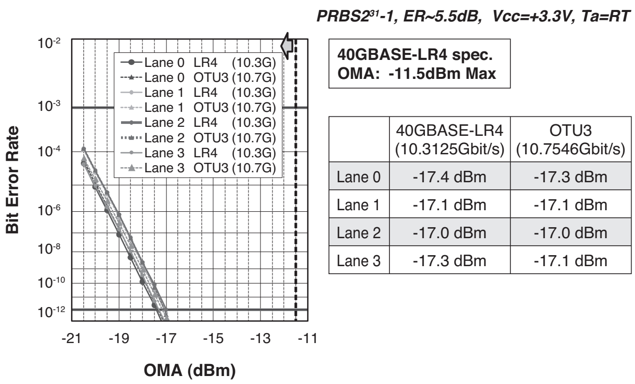


Fig. 7. Electrical cross talk



	40GBASE-LR4 (10.3125Gbit/s)	OTU3 (10.7546Gbit/s)
Lane 0	-17.4 dBm	-17.3 dBm
Lane 1	-17.1 dBm	-17.1 dBm
Lane 2	-17.0 dBm	-17.0 dBm
Lane 3	-17.3 dBm	-17.1 dBm

Fig. 8. Bit error rate curve

LR4 specification. **Figure 11** shows electrical waveforms at 3.3 V and 25 deg. C. As described above, the receiver module provides a wide margin to the IEEE requirement of -11.5 dBm (OMA) and the OTU3 requirement of -10.8 dBm.

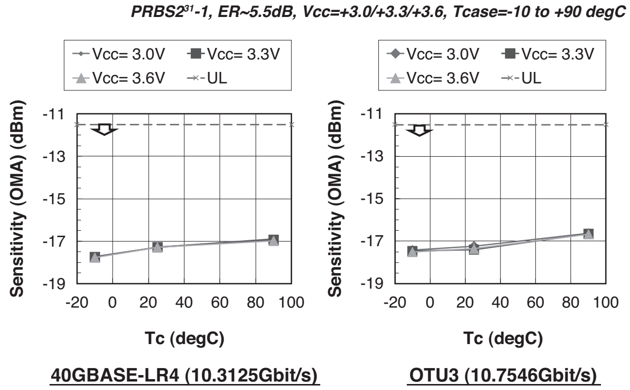
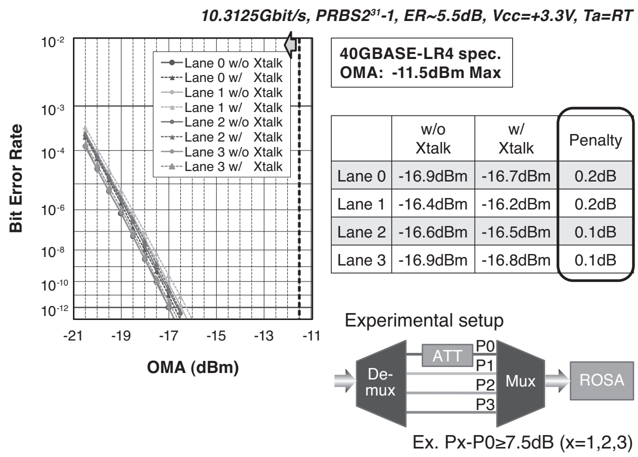


Fig. 9. Temperature dependency of receive sensitivity



	w/o Xtalk	w/ Xtalk	Penalty
Lane 0	-16.9dBm	-16.7dBm	0.2dB
Lane 1	-16.4dBm	-16.2dBm	0.2dB
Lane 2	-16.6dBm	-16.5dBm	0.1dB
Lane 3	-16.9dBm	-16.8dBm	0.1dB

Fig. 10. Cross talk penalty

4. Conclusion

We have developed a small receiver module with an integrated optical demultiplexer to mount it in a QSFP+. The module is compliant with the 40GBASE-LR4/OTU3 specifications. Its unique optical alignment system and the optimized package designs enable the downsizing of the module. The Receive sensitivity is less than -17 dBm @ BER = 10^{-12}, providing a wide margin to the IEEE/OTU3 specifications. We continue to work on the development of high-speed receiver modules to be mounted in CFP2, CFP4 and other 100 GE optical transceivers for which the standardization has been promoted.

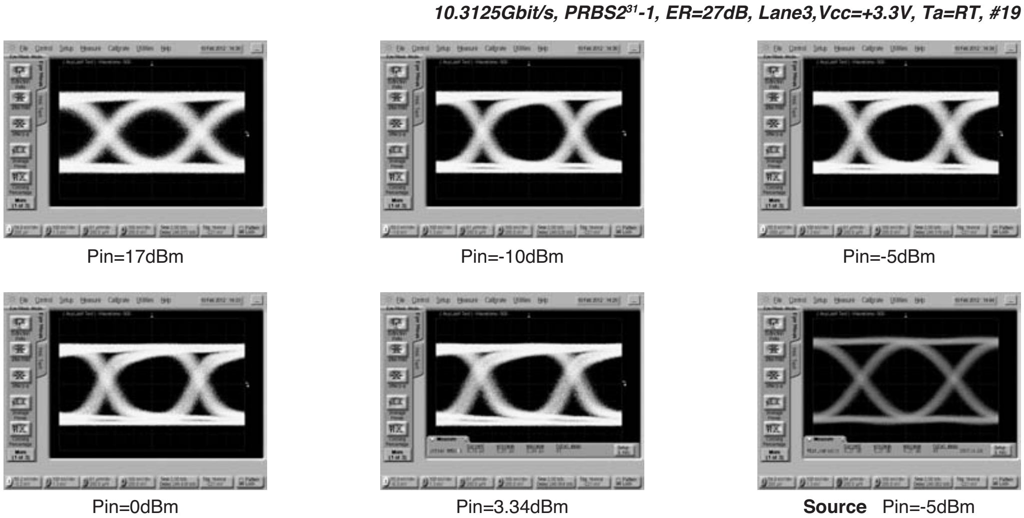


Fig. 11. Electrical waveforms

References

(1) Eiji Tsumura et.al., "Development of 43/112 Gbit/s Optical Transceiver Modules," SEI Technical Review, No.75, Oct. 2012

(2) "SFF-8436 Specification for QSFP+ 10 Gbps 4X PLUGGABLE TRANSCEIVER" Rev 4.3, July 7, 2012 (ftp://ftp.seagate.com/pub/sff/SFF-8436.PDF)

(3) Kazushige Oki et.al., "Development of 40GBASE-LR4 receiver module with an integrated optical demultiplexer for QSFP+" IEICE General Conference, B-10-115, Mar. 2012

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

K. OKI*
- Assistant Manager, Transmission Devices R&D Laboratories

M. KAWAMURA
- Transmission Devices R&D Laboratories

F. NAKAJIMA
- Ph.D. degree in engineering
  Transmission Devices R&D Laboratories

M. SUZUKI
- Transmission Devices R&D Laboratories

H. HARA
- Group Manager, Transmission Devices R&D Laboratories

Y. FUJIMURA
- Group Manager, Transmission Devices R&D Laboratories