Compact Optical Transceiver “CFP4” for 100 Gbit/s Network Systems

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One of the keys to enhancing optical networking capacity is increasing the number of optical transceivers on a network card. A new compact optical transceiver called “CFP4” has been developed for 100 Gbit/s systems. Because of a compact integrated optical transmitter and receiver, the size of the transceiver is less than 1/6th in comparison with the conventional 100 Gbit/s CFP transceiver. Its power consumption is less than 5.3 W at any operating case temperature by leveraging the multi-channel shunt-driving technique. The small size and low power consumption contribute to the expansion of the transmission capacity of the network card.
The transceiver complies with IEEE (Institute of Electrical and Electronic Engineers) standards and CFP MSA (Centum gigabit Form factor Pluggable Multi-Source Agreement) specifications. The CFP4 transceiver supports the same management interface as the CFP transceiver, thus making it possible to reuse existing firmware. Additionally, the CFP4 transceiver newly implements in-service firmware upgrading. This paper describes the superior optical and electrical properties of the transceiver as well as some of the design features.

Keywords: optical transceiver, 100GBASE-LR4, CFP4

1. Introduction

Data communication services based on the widely-used high performance mobile devices have been sophisticated and diversified recently. These services require increasing the data rate and enhancing the capacity of optical transmission equipment in the network systems. One of the important functions of optical transmission equipment is to transform electrical data streams to optical data signals and vice versa. Since optical transceivers built in the equipment play this role, the targets of the transceiver development can be translated from the aforementioned demands for the apparatus.

The transceiver needs to speed up its data rate as the equipment is required. Given that increasing the number of transceivers on a network card makes it possible to expand the optical networking capacity, downsizing is another target for optical transceiver development.

Centum gigabit Form factor Pluggable (CFP) has a 100 Gbit/s interface, which is the fastest data rate in all commercial pluggable optical transceiver form factors.[1] However, it has a large package of 144.75 x 82 x 13.6 mm and this limits the number of transceivers plugged in a network card by four. The large package of CFP blocks to enlarge the transmission capacity in 100 Gbit/s network systems.

Recently, a miniaturized optical multiplexer or de-multiplexer, which is an indispensable part of the 100 Gbit/s optical transmission system, and a compact optical transmitter[2],[3]/receiver[4],[5] module, which integrates the optical multiplexer/de-multiplexer, have been reported. These modules enable the development of a small 100 Gbit/s optical transceiver.

In general, pluggable transceiver suppliers constitute a group that specifies the mechanical form factor, electrical interface, and control/management functions. Centum gigabit Form factor Pluggable Multi-Source Agreement (CFP MSA), an organization for 100 Gbit/s optical transceiver standardization, published a specification for a new 100 Gbit/s transceiver called “CFP4” in August 2014.[6] CFP4 is smaller than CFP in outer shape though having the same functions and performance as CFP in terms of optical and control/management interfaces. CFP4 hardware specification premised to adopt the high speed electrical interface on 25.78 Gbit/s discussed at the Institute of Electrical and Electronic Engineers (IEEE) in parallel. This interface facilitates reducing the size by 1/6th owing to decreasing the number of high speed electrical data lines from 40 in CFP to 16 in CFP4.

This paper describes a newly developed CFP4 optical transceiver for a 100 Gbit/s single mode fiber networking system incorporating an in-house compact optical transmitter and receiver module. The transceiver shows less than a quarter power consumption of CFP and contributes to expanding the optical networking capacity without any increase in power consumption.

2. CFP4 Transceiver Design and Specifications

This section introduces the specifications of the newly developed CFP4 transceiver and the international standards that the transceiver complies with. The block diagram and the detail of the design to meet these specifications and standards are described as well as a brand-new function the conventional transceivers have not supported.

2-1 Specifications

An optical transceiver specifications are generally classified into two categories: the specifications for optical and electrical data communication interfaces and the specifications for the mechanical and the control/management interfaces. The former complies with 100GBASE-LR4,(7) ratified in June 2010, and Chip-to-module 100 Gb/s four-lane Attachment Unit Interface,(8) ratified in March 2015. The latter adheres to CFP MSA CFP4 Hardware Specification(6) and CFP MSA Management Interface Specification.(9)

Table 1 shows the target specifications of the CFP4 transceiver. The values in optical transmitter/receiver and high-speed data input/output characteristics are specified in each channel.

Table 1. CFP4 Optical Transceiver Specifications

		Min.	Max.	Unit
Operating temperature		-5	70	°C
Supply voltage		3.135	3.465	V
Power consumption			6	W
Optical transmitter & receiver characteristics				
Output wavelength	$\lambda 0$	1294.53	1296.59	nm
	$\lambda 1$	1299.02	1301.09	nm
	$\lambda 2$	1303.54	1305.63	nm
	$\lambda 3$	1308.09	1310.19	nm
Optical power in OMA		-1.3	4.5	dBm
Extinction ratio		4.0		dB
Signal speed		25.78		Gbit/s
Eye mask		100GBASE-LR4 compliant		
Receiver sensitivity in OMA			-8.6	dBm
Overload in OMA		4.5		dBm
High speed data input & output characteristics				
Signal speed		25.78		Gbit/s
Eye width		0.57		UI
Eye height		229		mV
Outer shape				
Size	length	92.0		mm
	width	21.5		mm
	height	9.5		mm
Optical connector		LC (SMF)		

2-2 Functions and configurations

Photo 1 pictures our CFP4 transceiver and Fig. 1 shows its block diagram. Four channel electrical data streams coming from the network card are recovered by the clock and data recovery IC, and then they are converted into optical four channel signals in the optical transmitter module. Conversely, the optical receiver module transforms four channel optical signals incoming from the optical fiber network to four channel electrical data streams, and then the clock and data recover IC reshapes them.

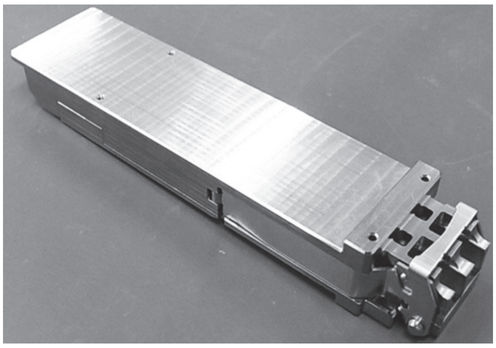

Photo 1. External view of CFP4 optical transceiver

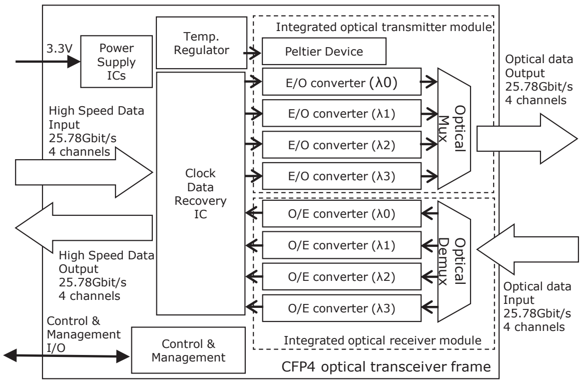

Fig. 1. Block diagram of CFP4 optical transceiver

The optical transmitter module consists of four electrical/optical (E/O) converters, the Peltier device and the optical multiplexer. The Peltier device is controlled by the temperature regulator. Similarly, the optical receiver module integrates four optical/electrical (O/E) converters and the optical de-multiplexer. The power supply ICs generate the voltage that the clock and data recovery IC and the ICs inside the optical modules need. In addition, the control and management IC is built into the transceiver to control and monitor all functions inside the transceiver and to report its status to the IC populated on the host board.

The output wavelength of the laser diode used in the E/O converter shows large dependence on its temperature. To meet the strict specification on the output wavelength range as shown in Table 1, the very fine control on laser diode temperature using the Peltier device is required.

Laser diode driving technique is a key factor to reduce the power consumption of the Peltier device and its controlling circuitry. In our CFP4 transceiver design, a quadrupled 25.78 Gbit/s multi-channel laser driver IC has been newly developed and mounted on the E/O convertors inside the optical transmitter module. This driver IC(11) is based on the shunt-driving technique that has been already introduced in the QSFP+*1 transceiver development,(10) with the bitrate increased from 10 Gbit/s to 25.78 Gbit/s for each channel.

The firmware of the control and management IC built into the transceiver was installed before factory shipment. The firmware determines the operation of the IC, but sometimes it is necessary to upgrade it to enrich its functions. In the case of the conventional transceiver such as CFP, the transceiver needs to be unplugged from the network card because revising the firmware is only performed with the dedicated fixture. Hence, it is inevitable to stop the data traffic.

To avoid the inconvenience in the firmware upgrading process, the CFP4 transceiver newly supports the firmware upgrade without any traffic shut-down by defining the protocol between the control IC on the network card and the control/management IC in the transceiver.

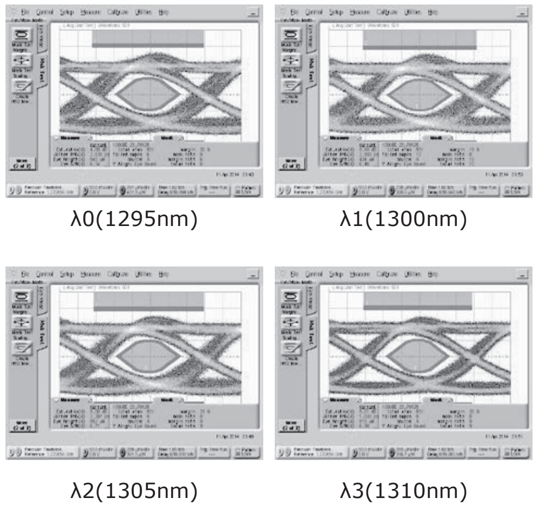

Fig. 3. Optical output waveforms

3. Characteristics

This section presents several characteristics of the CFP4 transceiver.

3-1 Power consumption

Figure 2 shows the temperature dependence of power consumption of the CFP4 transceiver. The temperature regulator controls the Peltier device so that it heats up the laser diode at low case temperature and it cools down at high case temperature. Therefore, the power consumption hits the bottom at room temperature. As shown in the graph, the power consumption of the transceiver is less than 5.3 W, which is below the target specification of 6 W with enough margin.

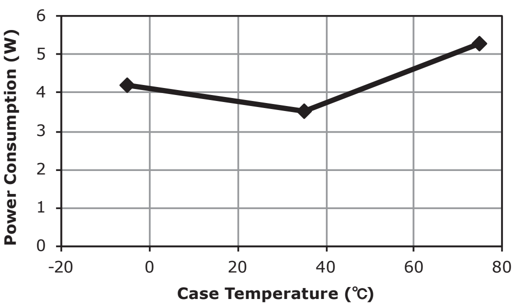

Fig. 2. Case temperature dependence of power consumption

3-2 Characteristics of optical transmitter and receiver

One of the important characteristics on the optical transmitter function is the output optical waveform. Figure 3 shows the waveforms from the all channels. The extinction ratio of each channel was set to be 5 dB. A parameter to evaluate the quality of the waveform is called mask margin, which is how much margin the waveform has relative to the IEEE standard hexagonal eye mask. As shown in this figure, more than 18% of mask margin was observed for each channel.

Receiver sensitivity is the most important parameter to qualify the optical receiver performance. It is defined by the input optical power that the transceiver shows the bit error ratio less than 10^{-12}.

Bit error rate curves for all channels are shown in Fig. 4. The input optical power of the measured channel was adjusted to 6.0 dB lower than that of the other channels so that they caused optical crosstalk to the measured channel. As shown in the figure, all channels showed the minimum sensitivity of less than -10.6 dB, although there was channel-to-channel variation. Given that the specification of the minimum sensitivity is -8.6 dBm based on IEEE standards, the transceiver has more than 2.0 dB margin.

In general, the mask margin of the optical output waveform degrades proportional to added noise or

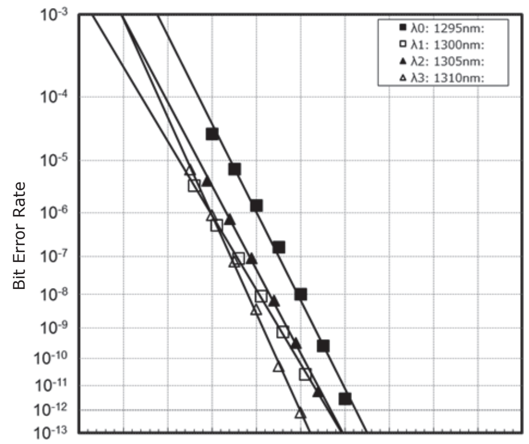

Fig. 4. Bit error rate curves

distortion of the transmitting signal. Likewise, the deterioration in receiver sensitivity depends on how much noise is added on the signal that the clock and data recovery IC receives. According to the block diagram of the CFP4 transceiver, there are eight pairs of transmission lines in between the clock and data recovery IC and the optical transmitter or receiver module. Considering the size of the CFP4 transceiver package, the high speed data lines have to be packed into the tiny space. Large mask margin and low sensitivity are attributable to the transceiver design that well suppresses the cross talk between any two transmission lines.

3-3 High speed data interface characteristics

Figure 5 provides the waveform output from the high speed data interface of the CFP4 transceiver. The quality of this waveform was measured by time width and amplitude of the eye opening area. As shown in the figure, measured time width and amplitude were 0.66 UI*[2] and 365 mV, respectively. These values are large enough compared to those specified in "Chip-to-module 100 Gb/s four-lane Attachment Unit Interface": 0.57 UI and 228 mV.

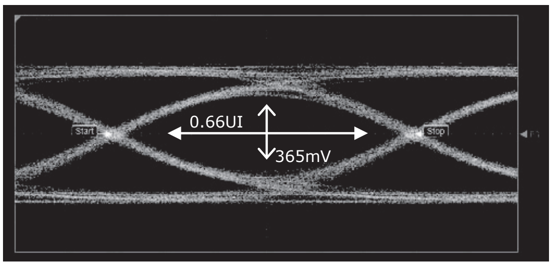

Fig. 5. Eye diagram of electrical output data from CFP4 optical transceiver

The jitter*[3] tolerance test results for all channels of the input high speed data interface are depicted in Fig. 6. Since the jitter tolerance was to be measured with the worst case scenario in terms of the eye opening area of the input data signal, its time width and amplitude were adjusted to be 0.46 UI and 82 mV, respectively. All the channels, except the measured one, were directly connected to the CFP4 transceiver output in order to cause the electrical crosstalk to the channel under test. As shown in the plotted data, large jitter tolerance was observed in the wide frequency range from 10 kHz to 250 MHz for all channels. These results endorse that the high speed data signal lines on the host board in which the CFP4 transceiver is plugged are easy to trace.

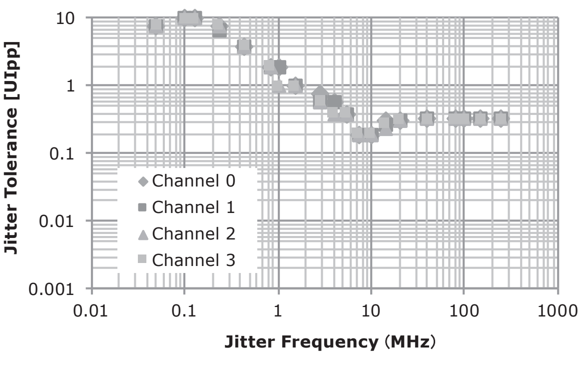

Fig. 6. Jitter tolerance of CFP4 optical transceiver

4. Conclusion

The 100 Gbit/s CFP4 transceiver that complies with IEEE standards and MSA specifications has been developed. The power consumption is less than 6 W at 75 degC case temperature, and its optical interface and high speed data interface show excellent performance. The CFP4 transceiver facilitates increasing the capacity of 100 Gbit/s optical network cards because it is smaller in size and lower in power consumption compared with the conventional CFP transceiver.

Technical Terms

∗1 QSFP+: Quad Small Form factor Pluggable Plus. One of the multi-source agreement for 40 Gbit/s optical transceiver.

∗2 UI: Unit Interval. 1 UI means the time width of 1 bit. For the case of 25.78 Gbit/s, 1 UI is equal to 38.79 ps.

∗3 Jitter: The deviation of the pulse rising or falling edge from the nominal position is called jitter. A clock and data recovery circuit extracts a clock component from an incoming data signal, but it is unable to extract clock when the jitter gets larger and to keep error-free operation in the retiming circuit. Jitter tolerance is defined by the maximum allowed jitter at a specific error rate. Jitter tolerance is measured in units of UI pp (UI peak-to-peak).

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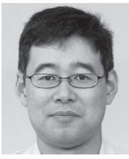

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