Compact Optical Transmitter Module with Integrated Optical Multiplexer for 100 Gbit/s

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High-speed and small-sized transceivers are strongly required to support the rapidly growing internet traffic. The CFP (100G form-factor pluggable) using four-wavelength LAN-WDM (wavelength division multiplexing) is now widely used. To increase the transmission capacity of a line card, CFP4, a very small transceiver, has been standardized. To support this trend, we have developed a 100Gbit/s compact optical transmitter module for CFP4 and integrated a compact low-loss optical multiplexer, a quad-channel laser diode driver, and four laser diodes. The module achieves clear eye openings at low power consumption. This paper describes the design and basic characteristics of the module.

Keywords: optical transmitter module, optical multiplexer, CFP4, 100GBASE-LR4

1. Introduction

With the dissemination of smartphones and tablet PCs, as well as the spread of cloud services, the communication volume has dramatically increased. In response to the surge in demand for fast and small optical transceivers, 100 Gbit/s optical transceivers, such as the CFP,*1 have been commercialized. To increase the transceiver port density and expand the transmission capacity per line card, the CFP4,*1 which is an optical transceiver approximately one-sixth the size of a CFP, has been standardized. We have developed a small four-wavelength integrated optical transmitter module[(2),(3)] that can be mounted on a CFP4. We describe its electrical and optical design, the major technology for realizing the required performance.

2. Issues of Optical Transmitter Modules

Figure 1 shows the structures of CFP and CFP4 optical transceivers. The optical transmitting section of a CFP transceiver consists of four optical transmitter modules and an optical multiplexer, which are connected with optical fibers. On the other hand, a CFP4 transceiver is required to have a total width of 21.5 mm or less (1/4 of a CFP) to achieve the downsizing. The allowable width of an individual optical transmitter and optical receiver is 7 mm or less. Therefore, the optical transmitter module must integrate the functions of a CFP optical transmitting section into a single package so that the width does not exceed 7 mm.

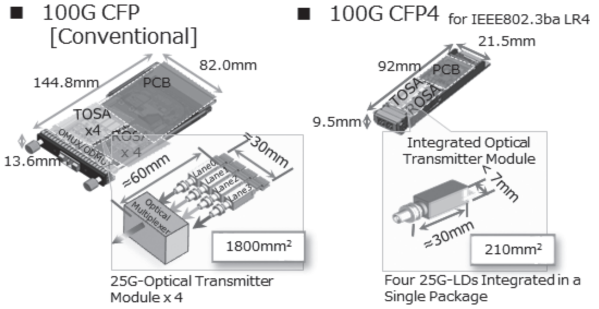


Fig. 1. CFP, CFP4, and the Optical Transmitter Modules Inside

3. Development Targets

Table 1 lists the required specifications of the optical transmitting section stipulated in IEEE802.3ba 100GBASE-LR4.[(1)]

The 100GBASE-LR4 standard specified the wavelength set of LAN-WDM for optical signals with center wavelengths spaced at very narrow intervals of 4.5 nm. The standard also specifies the difference in optical power between the lanes as well as the optical power of each wavelength lane. All wavelength lanes of an optical transmitter module must satisfy these requirements.

According to the specifications in Table 1, the target specifications of the four-wavelength integrated

Table 1. IEEE Required Specifications (for an Optical Transmitting Section)

Item		Minimum	Maximum	Unit
Transmission Distance		2m – 10 km		-
Transmission Speed		25.78125		Gbit/s
Optical Wavelength	Lane 0	1294.53	1296.59	nm
	Lane 1	1299.02	1301.09	nm
	Lane 2	1303.54	1305.63	nm
	Lane 3	1308.09	1310.19	nm
Average Optical Power		-4.3	4.5	dBm
Difference in Optical Power between Lanes		-	5	dB
Extinction Ratio		4	-	dB

optical transmitter module were defined as listed in Table 2. Assuming that the output power of the laser diode (LD) chip is +10 dBm, and considering enough margin for the module assembling process of production, the maximum allowable optical coupling loss of the optical transmitter module was calculated to be 7.3 dB. For high-speed modulation performance at a transmission speed of 25 Gbit/s, a pulse mask margin (PMM) of 10% or more was required. The power consumption is 1.5 W or less within the range of –5 to 75°C to achieve the power consumption of 6.0 W or less for the CFP4.

Table 2. Target Specifications of the Optical Transmitter Module

Item	Target Specifications
Package Size	A width of 7.0 mm or less
Optical Coupling Loss	7.3 dB or less
Mask Margin (PMM)	10% or more
Power Consumption	1.5 W or less

4. Design of Compact Optical Transmitter Module

4-1 Electrical and optical design

Figure 2 is a schematic diagram of the optical transmitter module. To shrink the width of the package, a small laminated ceramic package is used. The flexible printed circuit (FPC), which provides electric connections with printed circuit board of the optical transceiver, employs a two-stage design with one for high-frequency signals and the other for DC signals from the viewpoints of improving high-frequency performance. A package width of 6.7 mm was achieved by developing the high-density packaging design and the high-precision assembling technology that enable 4 LDs and optical multiplexer of four wavelengths to be installed in a minimum space. A local connector (LC) receptacle of a single mode fiber (SMF) is used for the optical output port.

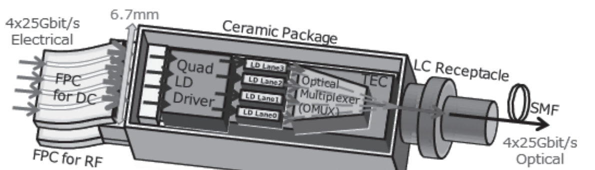


Fig. 2. Structural Drawing of the Optical Transmitter Module

The CFP uses an optical transmitter module[6] that has an electro-absorption (EA) modulator integrated distributed feedback (DFB) laser with high quality optical waveform. However, the power consumption is approximately 2 W per module and a total of approximately 8 W for four wavelengths. Therefore, it is impossible to achieve the target of 1.5 W or less. We used our newly developed high-speed direct-modulation DFB-LDs,[5] with shunt-driving technology to reduce power consumption.

Figure 3 shows the concept of shunt driving using our developed LD driver IC.[4] Shunt driving achieves lower power consumption compared to a widely-using differential driving LD driver IC, because it eliminates an output termination that consumes an excess current for LD modulation. The estimated power consumption under the operating conditions with LDs and an LD driver IC is as small as 160 mW per channel, and it is highly possible to achieve power consumption of 1.5 W or less for the entire optical transmitter module.

Since this LD driver IC can be mounted near LDs, lower RF signal loss and better optical waveform are expected.

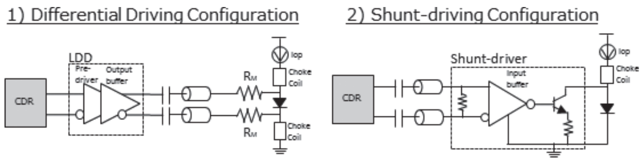


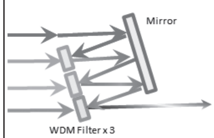
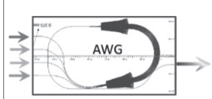
Fig. 3. Schematic Diagram of Differential Driving and Shunt-driving

4-2 Optical multiplexer

Table 3 describes the technology of optical multiplexers. There are two technologies used for optical multiplexing. One is the optical waveguide method that combines lights by letting them enter and travel through a waveguide, and the other is the spatial multiplexing method that combines lights in a free space using thin-film filters.

The advantage of the optical waveguide method is its easy assembling process, because the optical system itself can be treated as a single component that functions as a multiplexer. However, the component has a

Table 3. Optical Multiplexing Technology Benchmarks

Method	Spatial Multiplexing	Optical Waveguide
Structure		
Insertion Loss	0.5 dB - 1.0 dB	3.5 dB - 5.0 dB
Optical Multiplexing Loss	3.0 dB - 5.0 dB	6.0 dB - 8.0 dB
Size	Width: 4.5 mm	Width: 4.5 mm
Assembling Technology	Filter mounting + lens alignment	Lens alignment

large optical transmission loss. Even the arranged-waveguide grating (AWG) method with relatively lower loss has an optical loss of approximately 4 dB. Considering the coupling efficiency of the lens optic for coupling LD output lights to the SMF, it is difficult to attain the target optical loss of 7.3 dB.

The spatial multiplexing method consists of several optical thin-film filters. The optical transmission loss of a single filter is as small as 0.3 dB or less. Even in a multi-filter configuration, it is possible to achieve an insertion loss of 1.5 dB or less. With consideration given to the optical coupling efficiency of the lens optic, it is possible to realize an optical multiplexer with an optical loss of 7.3 dB or less. This is why we chose a spatial multiplexing optical multiplexer. However, to obtain a low optical loss with this method, it is necessary to mount several filters with high precision. By carefully selecting an adhesive and optimizing the curing conditions and mounting method, we succeeded in developing new high-precision resin assembling technology that reduces an error in mounting position to 1.0 µm or less and in the mounting angle to ±0.2° or less, which are one-third of the conventional technology.

A widely used spatial multiplexing optical multiplexer consists of three WDM filters*2 and a mirror as shown in Table 3. Since the LAN-WDM standard specifies a narrow wavelength interval of 4.5 nm, the WDM filters of this optical multiplexer need to have specially designed steep wavelength transmission characteristics. We made use of the polarization of LDs and designed an optical multiplexing method that combines four wavelengths with two WDM filters and a polarized wave selection filter. This multiplexing method reduces the number of WDM filters, as indicated in Fig. 4, so that the steepness of the wavelength transmission characteristics of the WDM filter can be reduced by a factor of two, which facilitates filter design and enables a low optical loss.

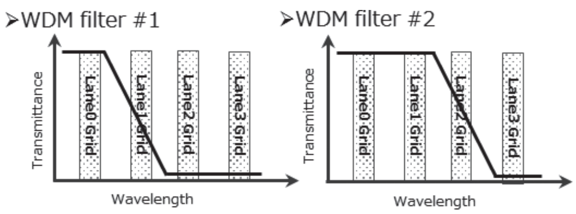


Fig. 4. Wavelength Transmission Characteristics of Two WDM Filters

Figure 5 is a schematic diagram of our optical multiplexer. The four different wavelength lights from the LDs are converted into parallel collimated beams with a lens and enter the optical multiplexer. The optical beams in Lane 0 and Lane 2 are combined with WDM Filter #1, and travel through the polarization filter as the original P-polarized light. The optical beams in Lane 1 and Lane 3 are similarly combined with WDM Filter #2, then converted from P-polarized light to S-polarized light with a half-wave plate. Finally, the polarized wave selection filter combines the beams in Lanes 0 to 3.

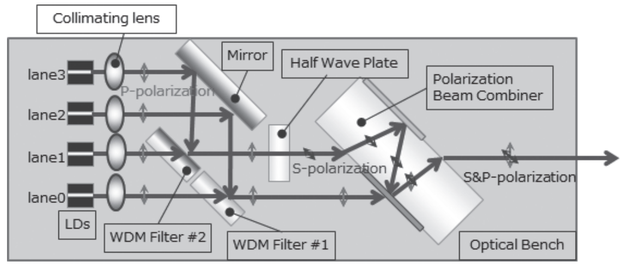


Fig. 5. Schematic Diagram of an Optical Multiplexer

4-3 Design of Optical Coupling System

Figure 6 shows schematic diagrams of a common two-lens optic and the three-lens optic used in our optical transmitter module, with a comparison of assembling tolerances. An optical module using two-lens optics is generally assembled by laser welding with sub-micron precision, and the severe assembling tolerances are not the major issues. However, the component consists of lenses and metal holders, which requires a large mounting area when laser welding method is used. Our module is designed to mount bare lenses with resin to achieve the width of 7 mm or less. We have newly developed high-precision resin assembling technology that reduces an error to ±1 µm or less. However, it is still difficult to attain the mounting precision required for a two-lens optic. To cope with this issue, we used a three-lens optic that introduces an adjustment lens as the second lens. This optical design enables resin mounting of the lenses while maintaining a high optical coupling efficiency and allowing five-fold greater assembling tolerances.

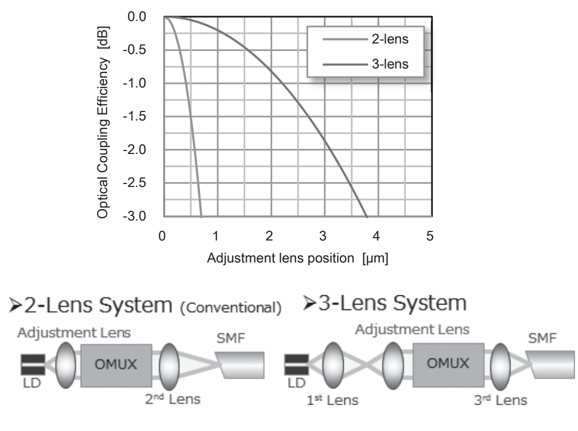


Fig. 6. Schematic Diagram of the 3-Lens System and Assembling Tolerances of the Adjustment Lens

5. Characteristics of Compact Transmitter Module

5-1 Dimension of compact transmitter module

Figure 7 shows a four-wavelength integrated compact optical transmitter module we have developed. The Package is 5.3 mm in height, 6.7 mm in width, and 21.3 mm in length, and can be mounted in the CFP4 transceiver.

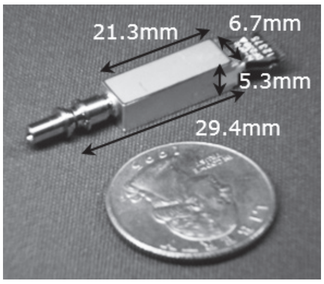
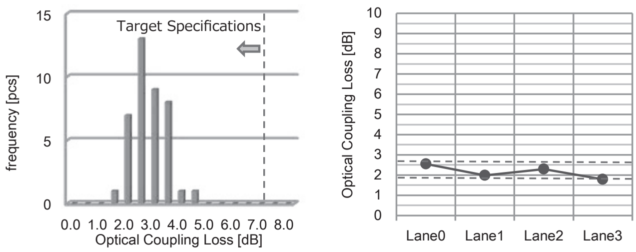


Fig. 7. 100Gbit/s compact optical transmitter module for CFP4

5-2 Optical coupling loss

Figure 8 indicates the measured optical coupling loss and the difference in optical power between the lanes. With the introduction of an originally designed spatial multiplexing optical multiplexer and the three-lens optic, a low optical coupling loss of 4.2 dB or less (with an average of 2.5 dB) is achieved, which is sufficiently lower than the target performance of 7.3 dB. In addition, the difference in optical power between the lanes is 1.0 dB or less. This is also lower than the target.



(a) (b)

Fig. 8. (a) Optical Coupling Loss Distribution,
(b) Optical Output Difference between Lanes

5-3 High-frequency response

Figure 9 shows the frequency response characteristics. The frequency response is very flat with a 3 dB bandwidth of approximately 20 GHz, which is sufficient for modulations at 25 Gbit/s.

Figure 10 shows the eye pattern under 25Gbit/s modulation. Very clear eye openings are confirmed for lanes with pulse mask margin of 10% or more.

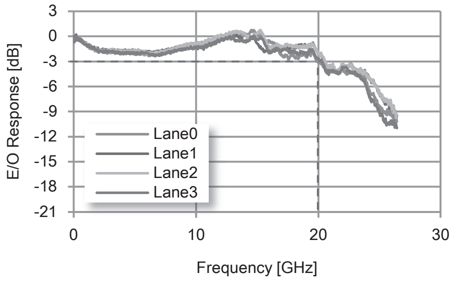


Fig. 9. Frequency Response of the Optical Transmitter Module

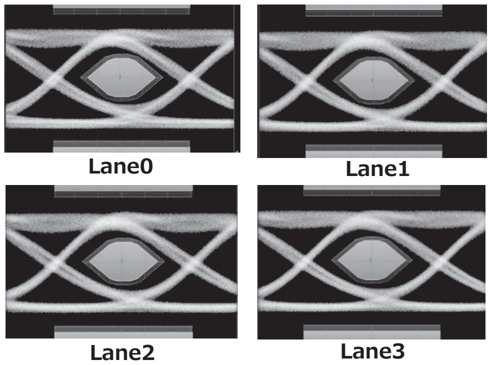


Fig. 10. Optical Waveform at 25 Gbit/s

5-4 Temperature dependence of optical output

Figure 11 shows the temperature dependence of the optical output. Although the optic is complex with several optical components, the application of the newly developed resin assembling technology achieved extremely low optical output fluctuations of ±0.5 dB or less across the entire range of operating temperatures and in all lanes.

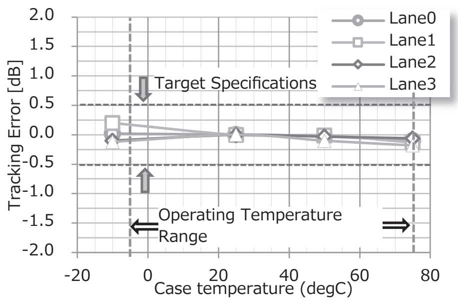


Fig. 11. Thermal Dependence of Optical Output

5-5 Power consumption

Figure 12 shows a typical dependence of power consumption on the case temperature of the optical transmitter module. With the introduction of newly

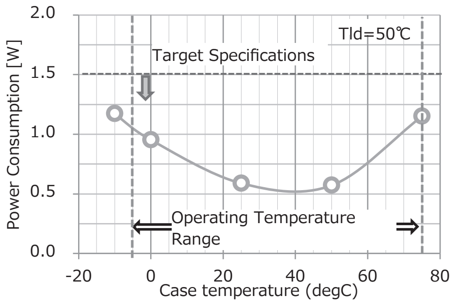


Fig. 12. Temperature Dependence of Power Consumption

developed DFB-LDs and a shunt-driving LD driver IC, a good result was obtained for power consumption, which is sufficiently lower than the target of 1.5 W across the entire temperature range.

6. Conclusion

We have developed a four-wavelength integrated compact optical transmitter module that can be mounted in the CFP4 transceiver.

The extremely low optical coupling loss of typical 2.5 dB is realized by adopting an original optical multiplexer and the newly developed high-precision/high-density assembling technology.

By using internally produced direct modulation DFB-LDs and a shunt-driving driver IC, the measured power consumption is lower than the target of 1.5 W in the temperature range from -10 to 75 degC, and the clear optical eye opening under 25 Gbit/s is also confirmed for each lane.

We will continue the development of new optical modules by utilizing the technology we have developed to meet the market demands for further miniaturization and speed enhancement.

Technical Terms

∗1 CFP, CFP2, and CFP4: CFP, or 100G form-factor pluggable, is a factory standard optical transceiver for 100 Gbit/s.

∗2 WDM filter: A wavelength selection filter, which is an optical filter with a thin film that transmits only light of certain wavelengths.

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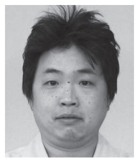

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