XFP Transceivers for Long-distance Transmission

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Abstract

The 10-Gbit/s-class optical transceivers for the backbone of optical access network systems are required to be compact, easy to maintain, and cost effective. To meet these requirements, we are focusing on the XFP (10-Gbit/s small-form-factor pluggable) transceiver because it has the most cost-effective packaging structure among 10-Gbit/s-class transceivers. In this paper, we discuss technical issues in developing high-performance XFP transceivers and describe some new technologies we have introduced to reduce power consumption and extend transmission distance. Experimental results show that our XFPs are suitable for both 40-km transmission and wavelength division multiplexing transmission systems.

1. Introduction

The development of cost-effective optical transceivers has accelerated the spread of broadband optical access services. The data rates of ONU (optical network unit) transceivers are increasing rapidly and have reached 1.25 Gbit/s. This has led to demands for more transmission capacity in optical access networks. Optical transceivers operating at 10 Gbit/s are promising candidates for providing high-capacity backbone networks for optical access services. To improve the transmission capacity of the access networks cost-effectively, we need to develop compact and cost-effective 10-Gbit/s optical transceivers.

Several 10-Gbit/s optical transceivers have been designed to comply with various multisource agreements (MSAs) reached by industry leaders. Some of them are listed in **Table 1**. The 300-pin MSA optical transceivers are the ones most commonly used in the 10-Gbit/s applications. However, their large size, relatively high power consumption, and high production cost are problems. In addition, they are connected to printed circuit boards (PCBs) by a multipin connector and screws, which makes it impossible to attach and release PCBs quickly.

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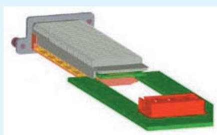
XENPAK transceivers conform to the 10 Gigabit Ethernet (10 GbE) standard and feature a compact package with a volume about one third that of the 300-pin MSA. They eliminate the optical fiber pigtail, and the package has optical connector receptacles on one side and card-edge electrical connectors on the opposite side for simple push-pull replacement. These transceivers are therefore called pluggable. Though they offer a very convenient packaging design, they exploit only the XAUI (10-GbE attachment unit interface) electrical interface, which is reserved for 10-GbE local area network (LAN) applications. This means that these transceivers cannot be applied to conventional networks that use an SONET/SDH (synchronous optical network, synchronous digital hierarchy) electrical signal interface.

The XFP (10-Gbit/s small-form-factor pluggable) arose from a recent MSA that specifies a compact 10-Gbit/s transceiver. The XFP's packaging volume is about one-tenth that of the 300-pin MSA. The electrical signal interface of the XFP is called XFI (10 Gigabit serial electrical interface). XFI does not need serializer and deserializer integrated circuits, which have relatively large dies and consume a lot of power, so the XFP has the most compact package and the smallest power consumption among the 10-Gbit/s optical transceivers. In addition, XFI can be applied to both 10-GbE and SONET/SDH systems. Like XENPAK, the XFP transceiver has an optical con-

Table 1. 10-Gbit/s MSA optical transceivers.

Appearance and size	Electrical interface	Transmission distance
 100 mm 300-pin MSA	OIF-SFI-4 (622 Mbit/s × 16)	300 m to 80 km
 40 mm XENPAK	XAUI (3.125 Gbit/s × 4)	300 m to 80 km
 20 mm XFP	XFI (10 Gbit/s × 1)	300 m to 10 km

OIF: Optical Internetworking Forum

nector receptacle interface and card-edge electrical connectors for easy maintenance. The XFP transceiver has the most convenient physical, optical, and electrical interfaces and is expected to be cost effective and have low power consumption. In this study, we focused on the development of a high-performance XFP transceiver that can be applied to long-distance and wavelength division multiplexing (WDM) transmission [1], [2].

2. High-performance XFP transceivers

2.1 Technical issues

According to MSA specifications, the transmitter in the XFP should include a directly modulated distributed feedback laser diode (DFB-LD) as a transmitter without a thermo-electric cooler (TEC). This DFB-LD transmitter has a specially designed package called a transmitter optical sub-assembly (TOSA) (**Fig. 1(a)**). Though this DFB-LD TOSA is a cost-effective transmitter, its application field is restricted to short-reach transmission of less than 10 km. This

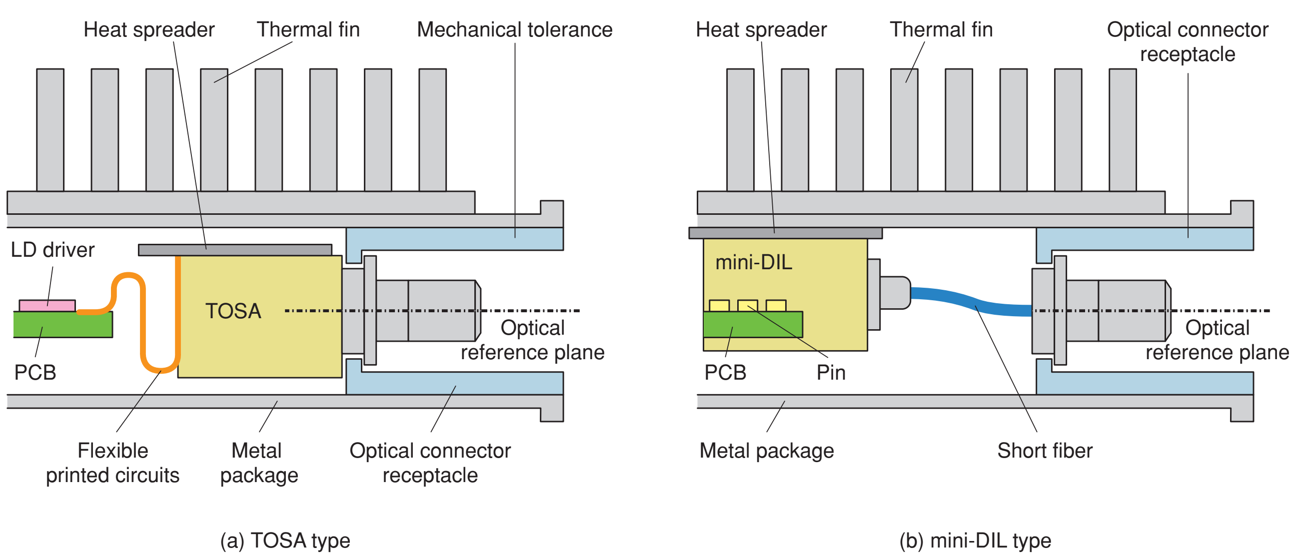


Fig. 1. Schematic outlines of the transmitter portions of XFPs.

restriction is imposed by wavelength variations caused by the modulation current injection and by changes in chip temperature. To extend the transmission distance, we must first stabilize the laser emission wavelength. This can be accomplished by incorporating a TEC to stabilize the laser chip temperature and by using an electroabsorption (EA) modulator integrated DFB-LD to eliminate the need for modulation current injection.

To accommodate the TEC, the optical transmitter package must be enlarged. In addition, some electronic circuits for temperature control must be mounted on the transceiver's PCB and these circuits increase the power consumption. The increase in transmitter package size and addition of electronic circuits lead to a high-density assembly, which generates considerable heat and raises the temperature inside the package. To avoid the TEC running out of control, careful attention should be paid to achieving good internal thermal conductivity for the transceiver package because an uncontrollable TEC sometimes causes catastrophic damage to the transmitter. Therefore, these conflicting technical issues, namely combining high-density assembly and high thermal conductivity, need to be resolved in order to make high-performance XFP transceivers.

2.2 Transceiver structure

It might seem that a high-performance XFP transceiver could be easily developed by giving the TOSA a TEC and an EA modulator integrated DFB-LD (EA-DFB-LD). However, the problem of how to improve the thermal conductivity would still remain. The solution would seem to be to have the heat spreader of the TOSA make contact with the thermal fin of the XFP transceiver. However, as shown in Fig. 1(a), this is impossible because the Z-axis position of the TOSA depends on the optical connector receptacle and has some uncertainty due to the mechanical tolerances of the receptacle and metal packages.

We have developed a transmitter module that contains a TEC, EA-DFB-LD, and EA driver IC and uses a short fiber instead of the TOSA. We call this transmitter module the mini-DIL, which stands for "miniature dual in line" [1]. Its position in the transceiver is shown in **Fig. 1(b)**. The flexibility of the short fiber enables the heat spreader of the mini-DIL transmitter to make contact with the thermal fin of the XFP transceiver. This rigid thermal contact is expected to provide excellent thermal conduction between the mini-DIL transmitter and the XFP transceiver package.

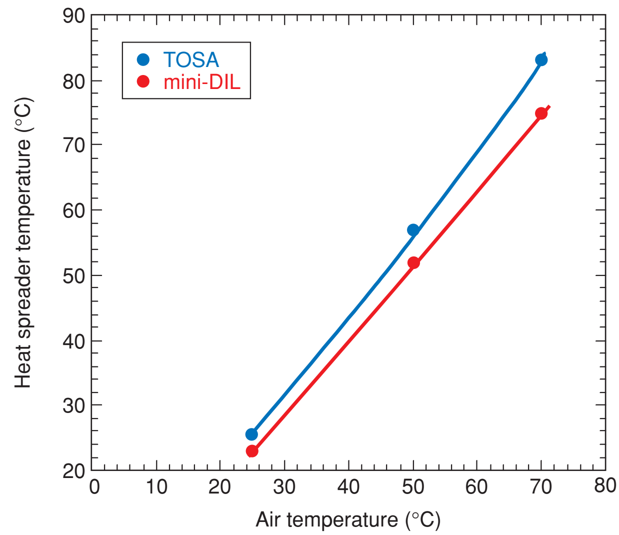


Fig. 2. Calculated heat spreader temperatures of TOSA and mini-DIL in XFP.

We estimated the improvement in thermal conductivity by computer simulation. The simulation conditions were electrical power of 4 W uniformly consumed by the PCB of the XFP, air flow rate of 1.5 m/s and air temperature ranging from 25 to 70°C. We calculated the heat spreader temperatures of a TOSA and the mini-DIL (**Fig. 2**). We found that the heat spreader of the TOSA reached about 85°C at an air temperature of 70°C, while that of the mini-DIL reached only 75°C. This excellent thermal conductivity of the mini-DIL transmitter allowed us to mount the electronic circuits with high density.

2.3 Transceiver characteristics

Optical eye diagrams of the XFP transceiver with the mini-DIL transmitter for a 10.7-Gbit/s NRZ-PRBS (non-return-to-zero pseudo-random bit stream) 2^{23}-1 data stream measured at case temperatures (Tcase) of 25 and 75°C in back-to-back transmission and after 40-km transmission are shown in **Fig. 3**. The back-to-back transmission eye diagrams have a margin of more than 25% for the ITU-T G.709 eye-mask and the eye openings are wide enough for long-distance transmission (Fig. 3(a) and (c)). Even after 40-km transmission, the eye openings were good (Fig. 3(b) and (d)).

Receiver sensitivities measured after 40-km transmission by using the loop-back configuration were –18.6 dBm at 25°C and –17.6 dBm at 75°C. This excellent thermal conductivity of the mini-DIL transmitter resulted in the power consumption of the XFP

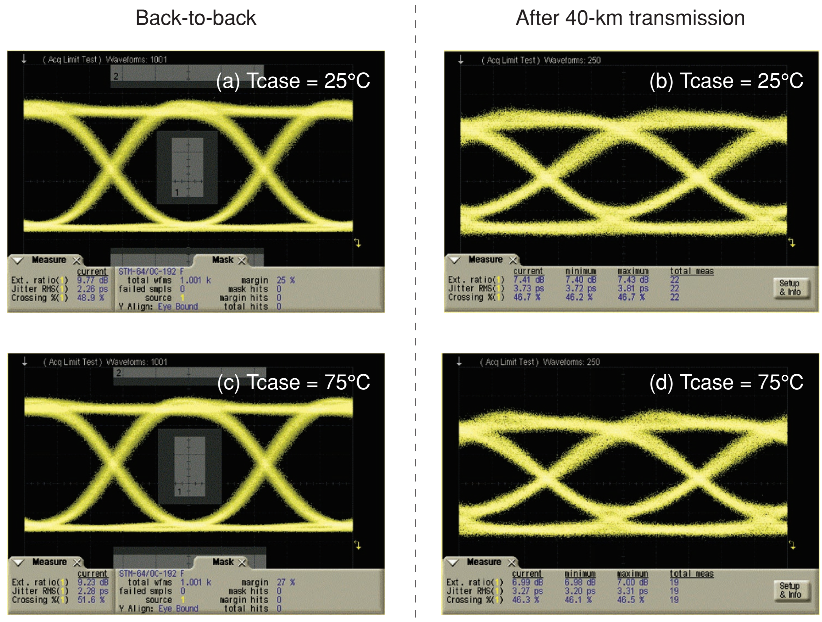


Fig. 3. Eye diagrams for 10.7 Gbit/s NRZ-PRBS 2^{31}-1.

Table 2. Characteristics of our XFP transceivers.

		Developed XFP		ITU-T G691 S-64.2b	10-GbE ER/EW
		Tcase = 25°C	Tcase = 75°C		
Bit rate		9.95 to 11.1 Gbit/s		9.95 Gbit/s	9.95 to 10.3 Gbit/s
Transmission distance		>40 km		>40 km	>40 km
Tx	Average output power	+1 to 0 dBm		–1 to +2 dBm	–4.7 to +4.0 dBm
	Mask margin	25%	25%	—	—
	Extinction ratio	>10 dB	>10 dB	>8.2 dB	>3.0 dB
	Cross point	50±5%	50±5%	—	—
Rx	Receiver sensitivity	–18.6 dBm	–17.6 dBm	<–14 dBm	<–15.8 dBm
	Power penalty (800 ps/km/nm)	0.8 dB	1.2 dB	—	—

Tx: transmitter
Rx: receiver

transceiver being 2.4 W at 25°C and 3.2 W at 75°C. These values meet the MSA's power consumption specification (less than 3.5 W). In addition, the variation in emission wavelength due to changes in air temperature between 0 and 75°C was less than 0.1 nm, which is sufficient for dense WDM systems with 100-GHz inter-channel spacing [2].

The main characteristics of the developed XFP transceivers are summarized in **Table 2** in comparison with the typical ITU-T G.691 telecommunication specifications and LAN specifications for 10-GbE ER/EW*. This table shows that our XFP transceivers have sufficient performance for both telecommunications and LAN applications.

3. Conclusion

We have successfully developed high-performance XFP transceivers for 40-km transmission and dense WDM systems. These XFPs use a compact optical

* In the 10-GbE interface nomenclature, E stands for extra long wavelength (1550 nm), R stands for 64B/66B coding (LAN PHY), and W stands for 64B/66B + "simplified" SONET encapsulation (WAN PHY) wavelengths (PHY: physical layer; WAN: wide area network).

transmitter module called the mini-DIL that provides high thermal conductivity between the optical transmitter module and the thermal fins of the XFP. We intend to improve this XFP to extend its transmission distance to 80 km.

References

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