Development of Small Optical Transceiver for 10G-EPON

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As the amount of Internet traffic increases every year, expectation is growing for 10 Gigabit Ethernet passive optical network (10G-EPON) technology that enables high-speed data transmission. For a smooth replacement of the currently-used GE-PON, 10G-EPON needs to support a maximum loss budget of 29 dB and to coexist with GE-PON in the same optical network. In addition, reduction in capital and operating expenditures is required. To meet these demands, optical transceivers can be a key component. The authors have developed small pluggable optical transceivers for 10G-EPON systems and confirmed their efficiency and power-saving operation.

Keywords: FTTH, 10G-EPON, optical transceiver, OLT, ONU

1. Introduction

The number of broadband access subscribers in Japan reached 37.7 million at the end of 2011. In particular, 58% of the subscribers (i.e., 21.89 million subscribers) are using Fiber-to-the-Home (FTTH) service and the number of FTTH subscribers is still growing (see **Fig.1**)[(1)]. Most FTTH services in Japan use Gigabit Ethernet Passive Optical Network (GE-PON), which was standardized by the Institute of Electrical and Electronics Engineers (IEEE) 802.3ah Working Group in June 2004.

However, a rapid growth in Internet traffic resulting from increasing video distribution services, offload traffic of wireless network, and cloud computing services will bring a lack of bandwidth of GE-PON systems in the future. Therefore, 10 Gb/s Ethernet Passive Optical Network (10G-EPON), which can provide 10 times higher bandwidth than GE-PON, is expected as a next generation system.

Standardization work of 10G-EPON was initiated by IEEE802.3 in March 2006 and finalized in September 2009. Since then, many research and development institutions have worked on the development of the 10G-EPON system and it is now ready for commercial deployment.

Optical transceivers are key components to support the 10G-EPON system, determining the optical transmission performance of the system. Taking this into account, the authors have developed small and pluggable optical transceivers for 10G-EPON systems and successfully demonstrated the maximum loss budget of 29 dB at low power consumption.

2. 10G-EPON System

2-1 Requirements

The FTTH service using GE-PON systems has been deployed on a large scale in Japan. Since the construction of new optical distribution networks needs significant investment, 10G-EPON systems need to work on the existing network, which means that the systems must support the

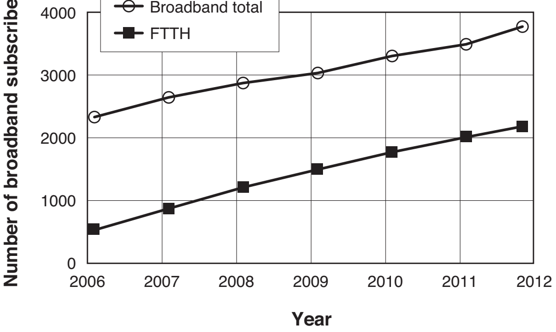


Fig. 1. Number of broadband subscribers

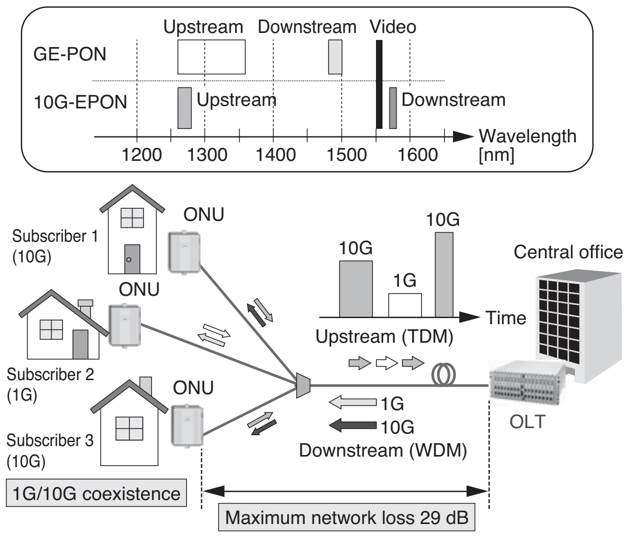


Fig. 2. 10G-EPON system and wavelength allocation

existing network with a maximum loss budget of 29 dB. In addition, to achieve a smooth migration from GE-PON to 10G-EPON, the 10G-EPON system needs to coexist with the GE-PON system on the same optical distribution network (see **Fig. 2**).

2-2 Standards

At the standardization work by IEEE 802.3av[(2)], the aforementioned requirements for 10G-EPON were taken into account. As a result, two high power budget classes were defined: the PRX30 for the asymmetric system and the PR30 for the symmetric system. The specifications of these classes are outlined in **Table 1**. To meet the maximum loss budget of 29 dB, three element technologies have been introduced, i.e. optical transmitter with enhanced output power, optical receiver with higher sensitivity, and digital receiver circuit using the Forward Error Correction (FEC) technology.

The specifications for the upstream of the asymmetric PRX30 system (1 Gb/s) are based on the specifications of the GE-PON system in Japan (i.e., the loss budget is 29 dB).

In addition, the wavelength for the 10G-EPON system was allocated as shown in **Fig. 2** in order to enable coexistence with GE-PON. On the other hand, there were some issues on the interconnection between telecom operators and vendors because the IEEE 802.3av standard only covers the transmission specifications (PHY layer[*1] and MAC layer[*2]) and does not cover any higher layers.

Therefore, IEEE P1904.1 Working Group was established for the purpose of interoperability improvement on the system level. It is expected to complete the standardization by February 2013[(3)]. This standard is called Service Interoperability in Ethernet Passive Optical Networks (SIEPON).

Due to the growing social awareness of the need for power saving in recent years, it has been discussed how to realize the power-saving features of optical network units (ONUs), the total of whose power consumption accounts for a large percentage of that in the PON system[(4)].

Furthermore, a study group in IEEE 802.3, called "Extended EPON," started considering the standardization of the PMD layer with loss budgets of 29 dB or more in July 2011. The study group became a task force of IEEE 802.3bk in March 2012. This activity aims to meet the demand for an increased split ratio, which enables a single line terminal equipment to accommodate more subscribers to reduce capital expenditures.

Table 1. 10G-EPON standard

Parameter		Downstream	Upstream		Unit
		PR30/PRX30	PR30	PRX30	
Line rate		10.3125	10.3125	1.25	GBd
Wavelength		1575～1580	1260～1280	1260～1360	nm
Maximum reach		≧20	≧20	≧20	km
Maximum channel insertion loss		29	29	29	dB
Tx	Average launch power	2～5 *	4～9 **	0.62～5.62 **	dBm
	Extinction ratio	≧6	≧6	≧6	dB
	TDP	≦1.5	≦3.0	≦1.4	dB
Rx	Bit error rate	$\leqq 10^{-3}$	$\leqq 10^{-3}$	$\leqq 10^{-12}$	—
	Average receive power	-10～-28.5	-6～-28	-9.38～-29.78	dBm

* Extinction ratio 9dB ** Extinction ratio 6dB

3. 10G-EPON Optical Transceiver

Figure 3 shows the evolution of our 10G-EPON optical transceivers. The first transceiver consists of several discrete optical sub-assemblies (OSAs), 10G transmitter, 1G transmitter, and 10G/1G receiver, and therefore, it was large. We integrated those OSAs into one single Bi-Directional optical sub-assembly called Bi-D. This small Bi-D enables the downsizing of optical transceivers. Integration and power reduction of 10G drivers and receiver ICs also play important roles in downsizing.

Recently, the hot-pluggable function that enables the exchange of transceivers while systems are operating is strongly required. We developed a 10 Gigabit Small Form Factor Pluggable (XFP)[(5)] transceiver for optical line terminals (OLTs) and an enhanced Small Form Factor Pluggable (SFP+)[(6)] transceiver for ONUs. XFP and SFP+ are industry standard form factors that have the hot-pluggable function.

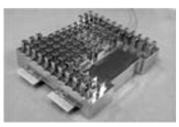
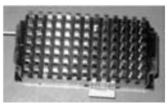
		CY2009	CY2010	This work
OLT	Outline			 XFP
	Size (cc) Optical I/F Function	52 Pigtail	34 Pigtail	13 Receptacle Pluggable
ONU	Outline			 SFP+
	Size (cc) Optical I/F Function	36 Pigtail	25 Receptacle Sleep	7 Receptacle Sleep

Fig. 3. Downsizing of 10G-EPON optical transceiver

3-1 The configuration and characteristics of OLT optical transceiver

OLT optical transceivers need to transmit 1Gb/s signals on the 1490 nm band and 10Gb/s signals on the 1577 nm band simultaneously to allow the 10G-EPON system to share the same optical distribution network (ODN) with the GE-PON system.

In addition, OLT optical receivers need to receive both 1Gb/s signals on the 1310 nm band and 10Gb/s signals on the 1270 nm band because an upstream signal contains 1G burst signals from GE-PON ONUs and 10G burst signals from 10G-EPON ONUs. **Figure 4** shows the configuration of an OLT optical transceiver and the Bi-D which is called a triplexer.

(1) Transmitter

At the 10G transmitter section, an electro absorption modulator which integrated a distributed feedback (DFB) laser (EML) and an EML driver IC modulates transmitting signal on the 1577 nm band. The EML operates under electrically controlled temperature conditions by a thermoelectric cooler. We use AC coupling between the EML and the driver IC for low voltage operation and low power consumption.

The 1G transmitter section includes a DFB laser whose wavelength is 1490 nm without temperature control. Both 10Gb/s downstream signals on the 1577 nm band and 1Gb/s downstream signals on the 1490 nm band are wavelengths multiplexed and transmitted through a wavelength divider which divides upstream signals and downstream signals.

Figure 5 shows optical eye diagrams of 10G optical output and 1G optical output. Regarding 10G optical output, we set output power and the extinction ratio on +4 dBm and 10 dB, respectively, over the operation temperature range. Regarding 1G optical output, we set output power and extinction ratio on +5 dBm and 11 dB, respectively, over the operation temperature range.

(2) Receiver

Upstream burst signals are divided from downstream signals through a wavelength divider, converted to current signals by an avalanche photo diode (APD), and amplified as voltage signals by a trans-impedance amplifier (TIA). The TIA is a dual-rate amplifier IC that can receive both 1Gb/s and 10Gb/s burst signals. The TIA has a function to switch its receiver bandwidth between 1G and 10G signals.

Figures 6 and 7 show receiver output waveforms and bit error curves. Here, following the application of -6 dBm of loud signals, 1G or 10G weak signals are applied without guard time. Each burst signal consists of 400 ns synchro-

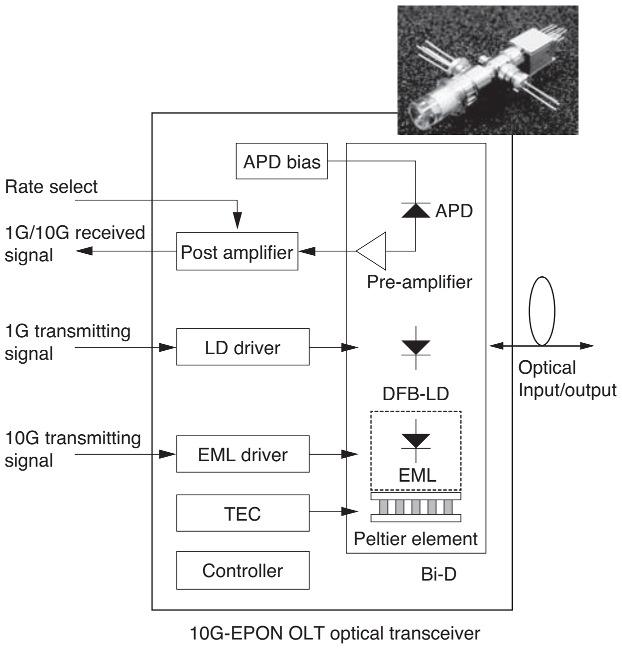


Fig. 4. Block diagram of OLT optical transceiver

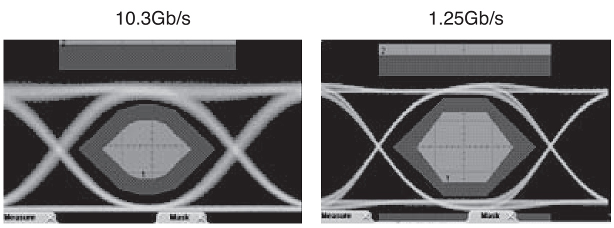


Fig. 5. Optical eye diagrams

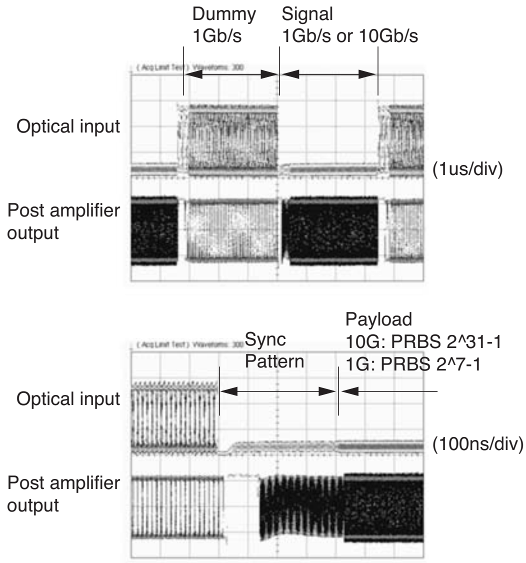


Fig. 6. Burst received signal

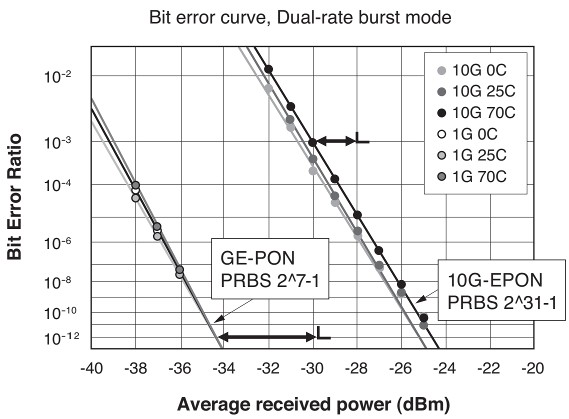


Fig. 7. Burst receiver performance

nization pattern and 3 us payload. For the convenience of the measurement, the loud signals and 1G weak signals are modulated at 1.29 Gb/s, which is divided down from 10.3 Gb/s. In this condition, the sensitivity is about -30 dBm for the 10G weak signals and about -34 dBm for the 1G weak signals. They meet the IEEE PR-30 specification with enough margin.

3-2 The configuration and characteristics of ONU optical transceiver

Figure 8 shows the block diagram of our 10G symmetric ONU transceiver. Video signals on the 1550 nm band and 1G downstream on the 1490 nm band are blocked by filters in a Bi-D. Only 10G downstream signals on the 1577 nm pass through the filters. Then, they are separated from 10G upstream signals of the 1270 nm band and received by an APD.

(1) Transmitter

A DFB laser diode oscillating at the 1270 nm band is directly modulated by an LD driver which supports burst mode operation. To avoid the collisions of upstream signals from ONUs, the transmission timings are controlled and the signals are transmitted in a burst mode. To maintain the extinction ratio and 10Gb/s modulation stability, the bias current (Ib) and modulation current (Imod) of the LD need to be controlled accurately according to temperature changes.

Generally, there are two methods for controlling the laser currents. One is temperature feed-forward control, in which ambient temperature is monitored and Ib and Imod values are applied based on the calibration data stored in a memory device. The other is temperature feed-back automatic power control (APC), in which optical output power is monitored during burst transmissions and Ib and Imod are controlled to keep output power constant. For our ONU transceiver, we combined both methods and succeeded in compensating aging degradation of the LD and responding to fast burst. In addition, we were able to avoid excessive emissions of the LD by applying Ib ahead of Imod until the LD emissions became stable when burst transmission started.

Figure 9 shows a burst transmission waveform and eye diagram of the optical transmitter. We achieved the burst-on time of 65 ns and burst-off time of 8 ns. Also, the optical power of +7 dBm, the extinction ratio of 7.5 dB, and the mask margin of 30% are achieved over the operation temperature range.

(2) Power saving function

In order to reduce power consumption of ONU, power saving protocol is defined in SIEPON so that the transmitting or receiving function of ONU goes into a sleep mode when data traffic is low. There are two kinds of sleep mode: Tx sleep mode where the Tx circuit is shut down and TRx sleep mode where both the Tx and Rx circuits are shut down. **Figure 10** and **Table 2** show sleep response waveform and power consumption in a sleep mode, respectively. Power consumption is reduced to nearly 40% in the Tx sleep mode and nearly 20 to 30% in the TRx sleep mode.

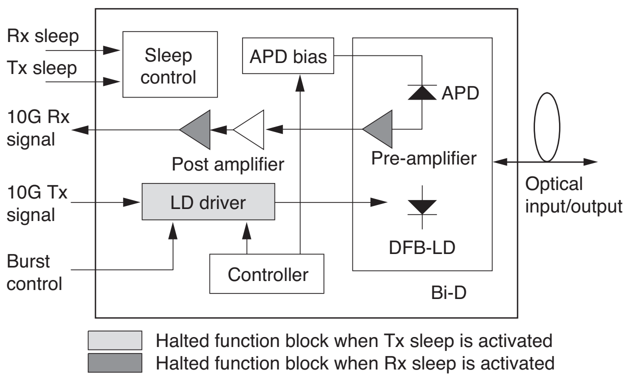


Fig. 8. Block diagram of ONU optical transceiver

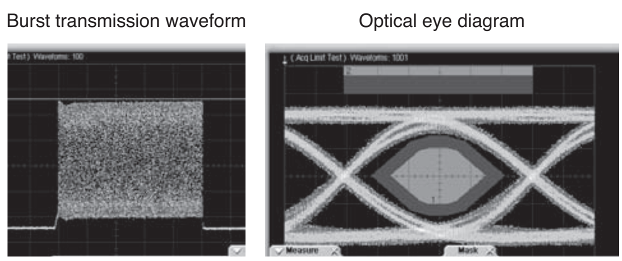


Fig. 9. Burst optical output waveform at T case 35 deg. C

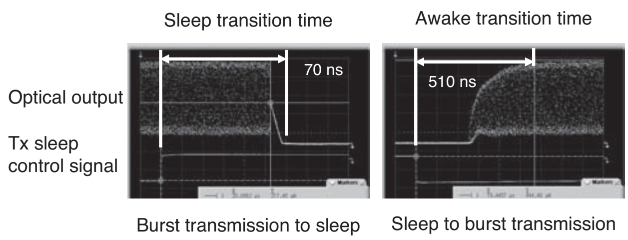


Fig. 10. Sleep response of ONU optical transceiver

Table 2. Power consumption of ONU optical transceiver in sleep mode

	Normal operation (Continuous Tx output)	Normal operation (No Tx output)	Tx sleep	TRx sleep
Power consumption (Tc 35C)	1.1W	0.9W	0.5W	0.3W
Power consumption (Tc 70C)	1.3W	1.0W	0.5W	0.3W

(3) Receiver characteristics

Figure 11 shows the bit error curve of an ONU receiver which uses our new optical transceiver and communication

LSI with re-timing and FEC functions. The bit error ratio is calculated from the frame error ratio. In this measurement, the data traffic in use is 900 Mbit/s Ethernet Frame, which has a random pattern in payload. We confirmed that both 2R and 3R optical receivers can meet IEEE 802.3av PR30 specification with enough margin.

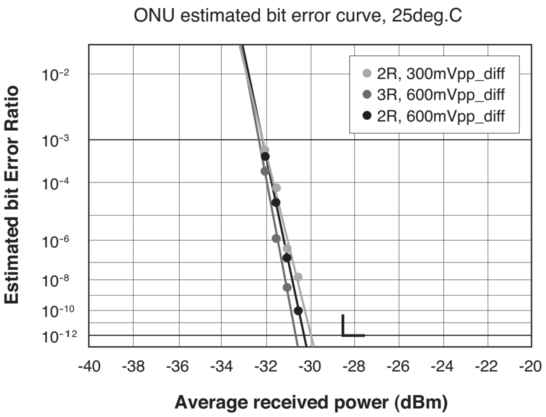


Fig. 11. Receiver performance of ONU (With FEC)

4. Conclusion

We have developed small and pluggable optical transceivers: an OLT optical transceiver that employs an XFP form factor and an ONU optical transceiver that employs an SFP form factor, both of which are optimized for the 10G-EPON symmetrical application. We confirmed superior performances of these optical transceivers to IEEE 802.3av PR30 standards. In particular, we demonstrated that significant power savings can be realized by implementing a sleep function.

· Ethernet is a Trademark of XEROX Corporation.

Technical Terms

*1 PHY (Physical) layer: The lowest layer of an OSI reference model that specifies hierarchical structure of a communication function. Physical specifications encoding of transmission paths and other items are defined in this layer.

*2 Media Access Control (MAC) layer: A sublayer of the second (Datalink) layer of an OSI reference model. Frame format, frame transmission/reception process and other items are defined in this layer.

References

(1) The press material of Ministry of Internal Affairs and Communications, Japan "The publication of quarterly data about the number of contracts and the share of the telecommunications services," the end of 2011
(2) IEEE 802.3av, http://www.ieee802.org/3/av/
(3) IEEE 1904.1, http://www.ieee1904.org/1/
(4) Daido et al. "The development of the communication LSI for 10G-EPON," SEI Technical Review vol.180, 2012, pp.43-48
(5) SFF Committee, "INF-8077i 10 Gigabit Small Form Factor Pluggable Module," Revision 4.5, August 2005
(6) SFF Committee, SFF-8431 Specifications for Enhanced Small Form Factor Pluggable Module SFP+, Revision 4.1, July (2009)

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