High-sensitivity and Low-cost Optical Transceiver for Passive Optical Network Systems

Makoto Nakamura†, Jun Endo, Yohtaro Umeda, and Yuji Akatsu

Abstract

We have developed a burst-mode optical transceiver for gigabit-per-second-class passive optical network (PON) systems using receiver integrated circuits (ICs) that exhibit high sensitivity with a low-cost PIN-photodiode (positive-intrinsic-negative photodiode (PIN-PD)). This transceiver enables us to construct a low-cost PON system with high quality.

1. Introduction

Passive optical network (PON) systems have recently been introduced into fiber-to-the-home access systems. In constructing optical line terminals (OLTs) and optical network units (ONUs) for gigabit-class PON systems, the challenge is to achieve high performance at low cost. In such PON systems, burst-mode optical transceivers are essential components. They are constructed by integrating transceiver-circuit, optical-device, and module technologies [1], [2]. The configuration of a typical optical transceiver is shown in **Fig. 1**. The optical module is based on an optical sub-assembly (OSA). The transmitter and receiver modules are called TOSA and ROSA, respectively. A TOSA contains a semiconductor laser diode (LD), while a ROSA contains a photodiode (PD), optical lens, preamplifier, and passive electrical parts.

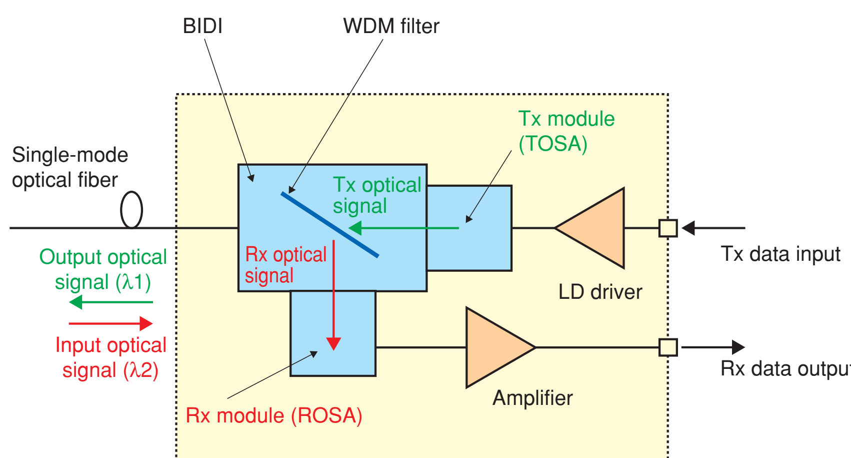

Fig. 1. Configuration of a transceiver.

In a PON system, one optical fiber is used for bidirectional transmission to reduce the network cost by using optical wavelength division multiplexing (WDM). For bidirectional transmission, a WDM filter is used: it lets transmitted optical signals pass through and reflects received optical signals, as shown in Fig. 1. The optical bidirectional (BIDI) module is composed of a TOSA, a ROSA, and a WDM filter. An LD driver integrated circuit (IC) and an amplifier IC for the transceiver are directly mounted on the electrical substrate of the transceiver, and the BIDI module and the electrical substrate with these ICs are assembled on a chassis. The module chassis should comply with various industry standards, and a smaller size is preferred. However, a

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small chassis will lead to more heat generation, which degrades the transceiver's performance.

To achieve further progress in gigabit-per-second-class PON access systems, we must construct a small high-performance optical transceiver module that is inexpensive. Moreover, the optical transceiver module used in the OLTs requires a quick response [3], [4]. To meet these requirements, we have developed an optical transceiver module for gigabit-per-second-class PON systems [5]. To achieve high performance at low cost, we used various optical-module, electrical-circuit, substrate-mounting, and case-assembly techniques. In particular, we used our developed receiver ICs [6]-[8], which exhibit high sensitivity, and an inexpensive PIN-photodiode (positive-intrinsic-negative photodiode (PIN-PD)). This transceiver enables us to construct a low-cost PON system with high quality.

2. Transceiver configuration

Block diagrams of our optical transmitter and receiver for the OLT are shown in **Fig. 2**.

2.1 Transmitter configuration

The transmitter (**Fig. 2(a)**) mainly consists of an LD and its driver circuit with an automatic optical power control (APC) circuit [5].

Fabry-Pérot LDs (FP-LDs) and distributed feedback LDs (DFB-LDs) are widely used in optical transmission systems. FP-LDs are inexpensive and commonly used in ONUs. On the other hand, the LD of the OLT should provide a narrower wavelength for the optical signal than that of the ONU. The standardized allocation of optical wavelengths in a PON system is shown in **Fig. 3**. To achieve this accuracy for the OLT transmitter, we used a DFB-LD, which can provide a narrow optical wavelength spectrum.

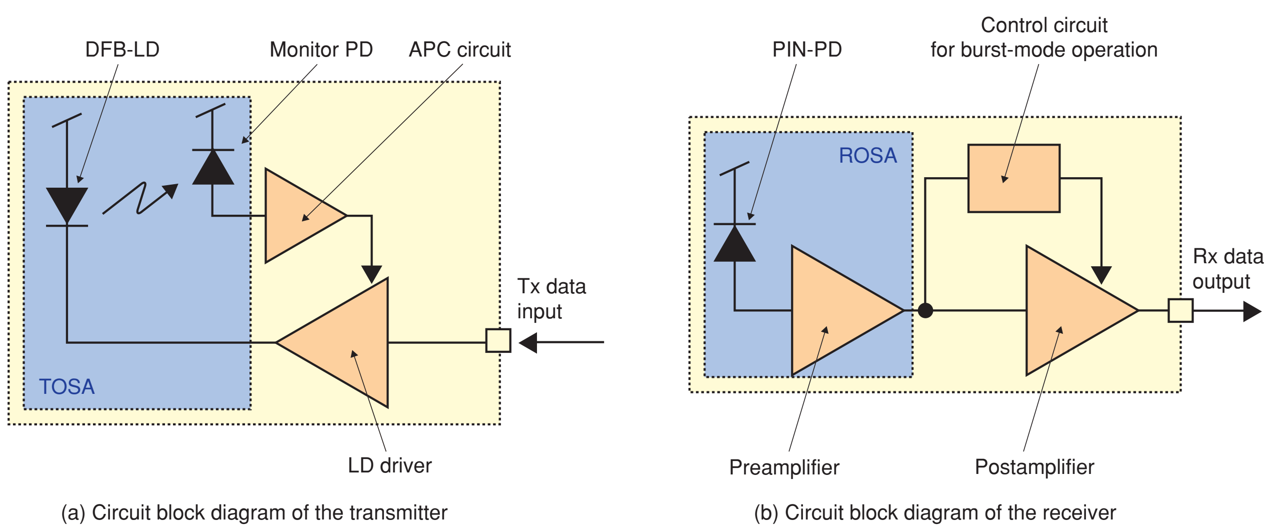

Fig. 2. Block configuration of the transceiver.

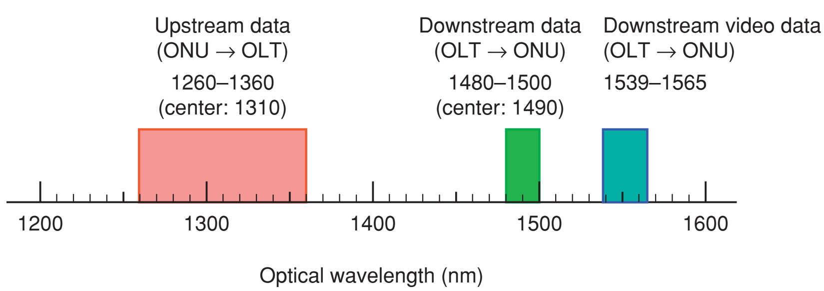

Fig. 3. Optical wavelength allocation in a PON system.

Although DFB-LDs are more expensive than FP-LDs, the cost is mitigated because several subscribers can share one OLT.

The LD driver circuit can use either a single-ended-signal driver or a differential-signal driver. A differential-signal driver has a complicated circuit, although it can improve optical output waveforms in high-speed operation. A single-ended-signal driver offers a simple circuit configuration with fewer external parts, and the mounting process is simple. Considering these technical points, we chose to use a single-ended LD driver configuration. The output of the LD driver circuit is directly connected to the cathode of the LD, and the driver circuit acts as a sink for the LD current. The APC circuit works to stabilize the optical output power, which is affected by temperature deviations or device aging. In APC operation, a monitor PD detects the optical signal power and controls the LD drive current to keep the optical output at a constant power.

2.2 Receiver configuration

The receiver (**Fig. 2(b)**) consists of a PD, which converts a received optical signal to an electrical current signal, and amplifiers. The amplifiers reshape input signals degraded by long-distance transmission. The amplifier circuit consists of a preamplifier and a postamplifier. The preamplifier converts a current signal to a voltage signal and amplifies the converted signal. The postamplifier equalizes the output signal of the preamplifier to an amplitude level suitable for input to the following digital circuit. The PD and preamplifier are assembled in a ROSA module because the preamplifier is very sensitive to mounting conditions. The ROSA module makes it easy to handle the optical module and better performance is obtained.

To obtain high sensitivity, an avalanche photodiode (APD), which has a multiplication function, is commonly used in the receiver in the OLT of gigabit-per-second-class PON systems. However, since APDs are still quite expensive, we used a common PIN-PD and our developed preamplifier IC [6], [7]. A conventional preamplifier with a PIN-PD cannot obtain sufficient sensitivity for a PON system; however, our developed IC, which has very-low-noise performance, provides the same receiver sensitivity as preamplifier ICs using an APD.

In addition, the amplifier ICs have an automatic control circuit that can stabilize operating conditions and respond to input data quickly. An ordinary receiver amplifier can only receive continuous data with a constant amplitude. Moreover, the receiver in the OLT must be able to receive burst-mode optical signals with different power levels for each data packet. To meet these requirements, we developed advanced circuit techniques that make possible both a high-speed response and high sensitivity. The receiver ICs are explained in detail in the previous paper in this issue [8].

3. Characteristics of the OLT optical transceiver

Using the transmitter and receiver techniques described above, we developed a burst-mode optical transceiver module.

3.1 Transceiver module

A photograph of the developed OLT transceiver module is shown in **Fig. 4**. To miniaturize the transceiver module, we used a small-form-factor pluggable (SFP) chassis, which can be attached to and detached from an electrical substrate. It contains a BIDI optical module with metal-can-type TOSA and ROSA, an LD driver IC, and a postamplifier IC, as shown in Fig. 1. The module was designed to effectively dissipate heat because a small chassis usually has trouble dissipating heat and this degrades the performance. We also devised a way to isolate the transmitter signal from the receiver signal because the amplitudes of these signals are completely different when the module receives a small signal. To reduce the cost, we mounted the LD driver IC and postamplifier IC in a molded plastic package. The power supply voltage of the module is +3.3 V, and its power consumption is 1.1 W.

3.2 Transmitter performance

An optical waveform transmitted at 25°C is shown

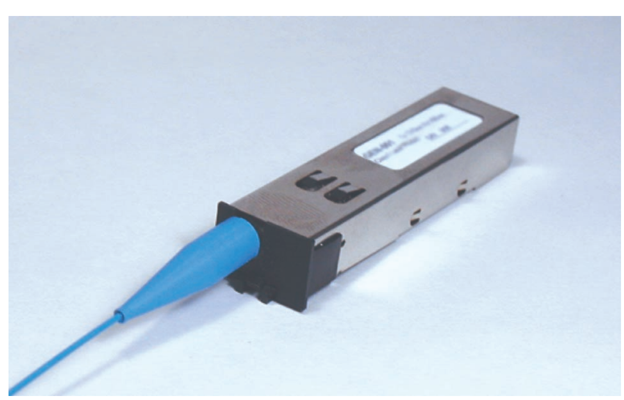

Fig. 4. Optical transceiver module for the OLT.

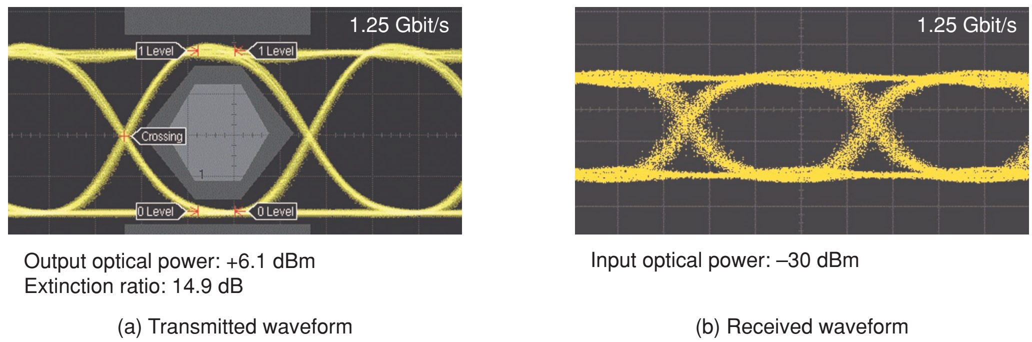

Fig. 5. Waveforms of the OLT transceiver.

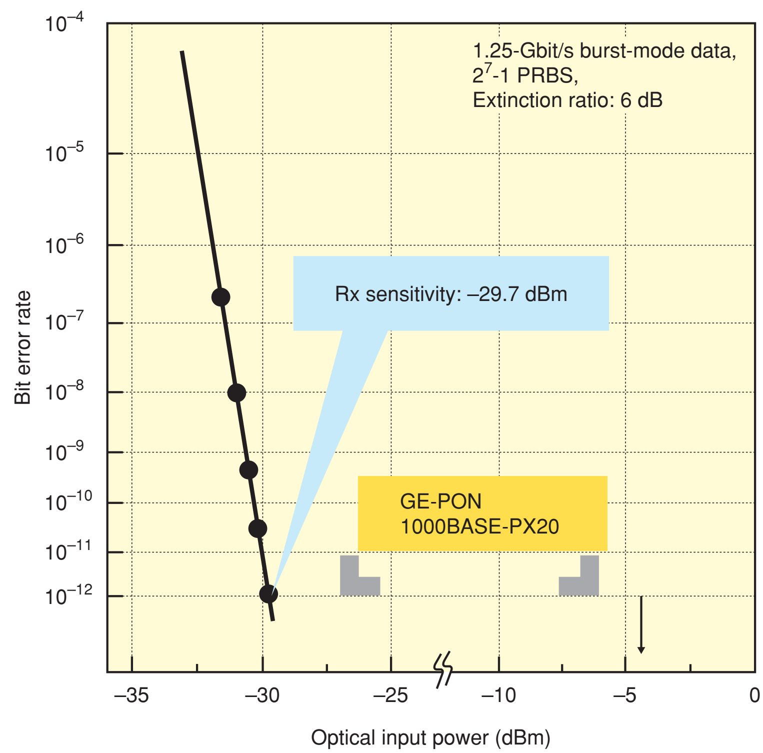

Fig. 6. Bit error rate of the OLT transceiver.

in **Fig. 5(a)**. The optical output power was +6.1 dBm and the optical extinction ratio was 14.9 dB in the optical power waveform with a 4th-order Bessel filter. The data rate was 1.25 Gbit/s and the optical wavelength was 1.49 µm. The matching impedance between the electrical input of the TOSA and the output of the LD driver IC was 25 Ω. This was the optimal value considering the parasitic capacitance, resistance, and inductance of the IC and the mounting board. As a result, we obtained a good waveform that fully filled the mask pattern specified in IEEE802.3ah.

3.3 Receiver performance

A received waveform at 25°C and the results of bit error rate (BER) measurement are shown in **Figs. 5(b)** and **6**, respectively. These characteristics were measured at an input-signal rate of 1.25 Gbit/s using a data pattern of a 2^7-1 pseudo-random bit sequence (PRBS) and an input optical wavelength of 1.31 µm.

Table 1. Characteristics of the transceiver module.

Characteristics	Spec. (IEEE802.3ah)	Developed module
Transmitter performance (downstream)		
Optical wavelength	1.49 µm	1.49 µm
Extinction ratio	> 6 dB	> 10 dB
Output optical power (av.) min.	> 2 dBm	> 5 dBm
Receiver performance (upstream)		
Optical wavelength	1.31 µm	1.31 µm
Sensitivity	< –27 dBm	–29.7 dBm
Optical input overload	> –6 dBm	–4.5 dBm
Settling time	< 400 ns	< 16 ns
Transceiver module		
Power supply voltage	—	+3.3 V
Electrical input/output Interface	—	LVPECL

In this measurement, the data consisted of two data packets, and each data packet had preamble data, which is used for settling the receiver conditions. To evaluate the burst-mode transmission, we used data packets with different signal powers. One had a fixed power of –5 dBm, and the power of the other was changed from –32 to –5 dBm. The sensitivity of the receiver in burst-mode operation was –29.7 dBm at a BER of 10^{-12} with an optical extinction ratio of 6 dB. The results include the penalty due to the temperature change from 0 to 70°C and simultaneous operation with a transmitter. On the other hand, the input overload, the maximum permissible input optical intensity, was –4.5 dBm. The developed module also exhibited a quick response time of less than 16 ns for burst-mode data, which is a sufficiently fast response for gigabit-per-second burst signals.

3.4 Performance summary

The performance of the developed optical transceiver module is summarized in **Table 1**. The transceiver module meets the specifications of IEEE802.3ah 1000BASE-PX20 [1], which is the standard for Gigabit Ethernet PON (GE-PON) systems. The module provides optical power of more than +5 dBm. The maximum available output power is +9 dBm. The power supply voltage for the module is +3.3 V, and the electrical input and output (I/O) signal interface is low-voltage positive emitter-coupled logic (LVPECL).

4. Conclusion

We have developed a burst-mode optical transceiver for gigabit-per-second-class PON systems. The use of various optical and electrical module techniques along with our developed receiver ICs enabled us to obtain high performance with an inexpensive PIN-PD. The transceiver is built on a small SFP chassis. It achieved a sensitivity of –29.7 dBm and an output optical power of more than +5 dBm. This optical transceiver will enable us to decrease the cost of gigabit-per-second-class PON systems.

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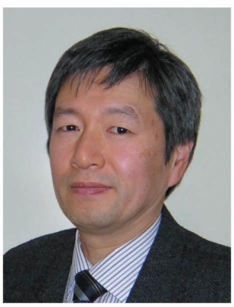

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