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High sensitivity APD burst-mode receiver for 10 Gbit/s TDM-PON system

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Abstract: In order to replace existing TDM-PON (TDM-Passive Optical Network) systems by new PON (10G-PON) systems providing 10 Gbit/s access in a flexible manner, it is necessary to realize loss budgets that are not less than those of existing PON systems. In this paper, we propose a new 10 Gbit/s APD burst-mode receiver, which attains the sensitivity of −24.8 dBm and the dynamic range of 17.8 dB. When forward error correction (FEC) is employed, the corresponding values are −29.8 dBm and 22.8 dB; the resulting loss budget of 29 dB satisfies the requirement for new PON systems.

Keywords: 10 Gbit/s burst-mode receiver, APD, 10GEPON

Classification: Photonics devices, circuits, and systems

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1 Introduction

PON yields cost-effective optical access systems because the fiber network and central office equipment are shared by many lines. Recently in Japan, the IEEE 802.3ah Gigabit Ethernet PON (GE-PON) system which provides the transmission rate of 1.25 Gbit/s, has been spreading and is already being used by several million subscribers [1, 2]. In North America, the Gigabit-capable PON (G-PON) system (complies with ITU-T recommendation G.984 and provides transmission rates of up to 2.4 Gbit/s), has been rapidly introduced [3]. The next generation access systems, currently at the research stage, are now one of the hot topics, particularly 10 Gbit/s TDM-PON systems, and they have already been discussed in IEEE and FSAN [4, 5].

When we consider system upgrades, it is important for new systems to be able to use the optical distribution network (ODN) composed of optical fibers and power splitters already laid. Higher bit-rate systems usually required higher receiver sensitivity. Furthermore, in TDM-PON systems, the upstream optical signals are generally burst signals with different intensities because the distances between the optical line terminal (OLT) and each optical network unit (ONU) differ. This means that the OLT burst-mode receiver faces several technical difficulties compared to continuous-mode ones. They are high sensitivity performance with wide dynamic range and high-speed response. Several reports described 10 Gbit/s burst-mode technologies. Ref. [6] reported high sensitivity, however the attributes of dynamic range and instantaneous response are not enough because the receiver uses continuous-mode components. Ref. [7], on the other hand, used burst-mode components to achieve high performance in terms of dynamic range and instantaneous response. Especially, that firstly reported successful demonstration of instantaneous response less than 175 ns at the bit-rate of 10.3 Gbit/s.

In this paper, we propose an OLT receiver composed of an APD followed by the burst-mode components previously reported in Ref. [7] and show the experimental result that fully satisfies the 29 dB loss budget required when using existing networks. First, the receiver characteristics and overhead size required by a 10GEPON system are shown, and then the instantaneous responsivity, sensitivity, and dynamic range of the 10 Gbit/s APD burst-mode receiver are evaluated. Finally, the validity of our 10 Gbit/s burst-mode receiver is described.

2 10G-PON physical layer specifications

Table I shows the upstream physical layer overhead parameters and receiver specifications targeted in this work. Although drafts of the 10GEPON system are under consideration by IEEE 802.3av, we set the targets with reference to Ref. [6, 7] and the specifications in existing PON systems. As the first step,

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in order to maintain transmission efficiency, we have to make the overhead size small. However, the guard time is restricted by the ON/OFF switching time of the transmitting LD, and the preamble length is restricted by the response time of the receiver circuit. In this research, therefore, we set the same overhead size determined in Ref. [7] as the target. On the other hand, the 10GEPON system requires a loss budget of 29 dB and a dynamic range of more than 20 dB. The receiver sensitivity of around −27 dBm is considered to realize these requirements assuming the use of FEC.

Table I. Upstream physical layer overhead parameters and receiver specifications

	This work	Ref. [6]	Ref. [7]	IEEE 802.3ah
Detector	APD	APD	PIN	PIN/APD
Bit rate [Gbit/s]	10.3	10.3	10.3	1.25
Guard time [ns]	99.3	100000	99.3	1024
Preamble [ns]	75	1312	75	800
Sensitivity [dBm] @ BER $=10^{-12}$	***−27 with FEC (target)***	−27.3 with FEC	−18.0	−27
Dynamic range [dB]	***20 with FEC (target)***	N.A.	16.5	20

Note: Dynamic range is defined as the difference between receiver overload and sensitivity.

3 Experimental setup and results

Fig. 1 (a) shows the experimental setup. Each ONU used a 1.3 μm direct modulated DFB-LD, and its output could exceed +3 dBm; extinction ratios were 7.8 dB (ONU1) and 10.9 dB (ONU2). The transmission timing of each ONU was controlled via the enable signals from the timing generator, which was synchronized to the PPG. Burst signal sequences with different intensities were created by the variable attenuators (V-ATT) at the output of each ONU. Fig. 1 (b) shows the burst frame format evaluated in this work. The payload of a strong burst signal consisted of PRBS $2^7 - 1$, while that of a weak burst signal consisted of PRBS $2^{23} - 1$. The purpose of using bursts with different PRBS is to distinguish them at the error detector (ED). These burst signals were separated by 99.3 ns guard time and 75 ns preamble (continuous "101010" signal) as overhead. We evaluated the bit error rate (BER) characteristics of the burst signal payloads. In this work, we fixed the maximum input of the strong burst signal to −7.0 dBm.

Fig. 2 (a) shows the waveforms of optical input and limiting amplifier (LIM) output. The strong burst input and weak burst input were −7.0 dBm and −24.8 dBm, respectively, and the multiplication factor, M, was 8.7. Although the reset signal which switched TIA gain was observed to create a small effect between the burst signals, each optical input was clearly regenerated during burst overhead time. These results show that our 10 Gbit/s APD burst-mode receiver satisfied the target overhead time requirement.

Fig. 2 (b) shows the BER performance of the 10 Gbit/s APD burst-mode

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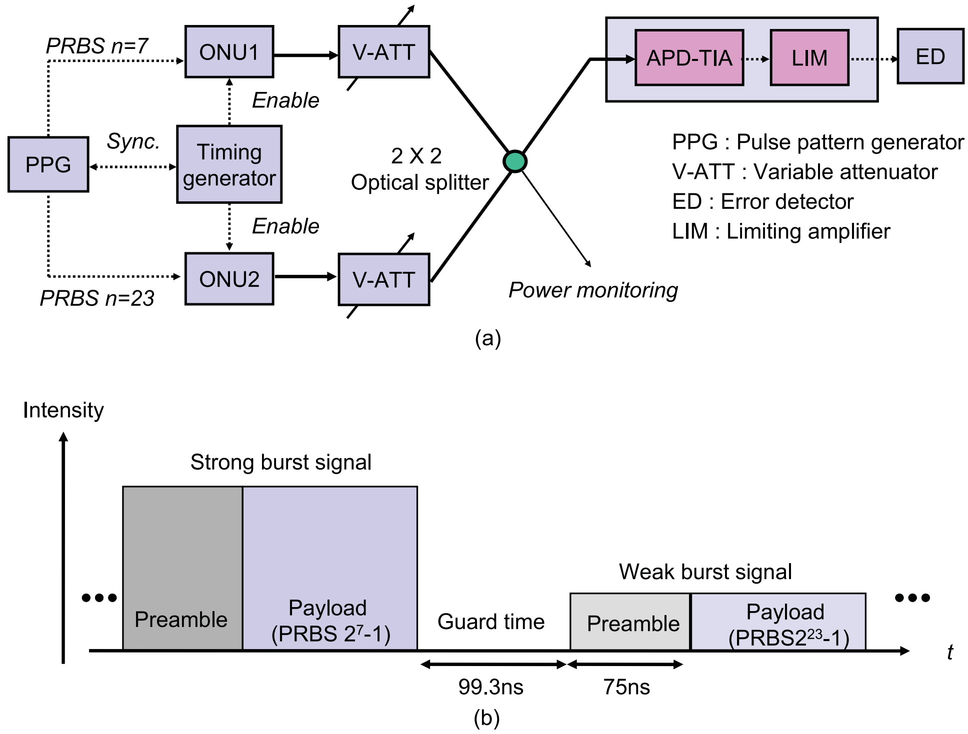

Fig. 1. (a) Experimental setup, (b) Upstream burst frame format.

receiver. In an APD receiver, receiver sensitivity is generally improved by raising multiplication factor, M, when thermal noise is dominant. However, when the M is too large, the excessive noise unique to APDs becomes larger than the thermal noise. As a result, receiver sensitivity is not improved by raising M. Moreover excessively large M degrades receiver overload because the preamplifier after APD is saturated due to the large current injected from the APD; as a result, the dynamic range becomes narrow in many cases. In this experiment, we changed the M from 1.2 to 14.6 and obtained the minimum receiver sensitivity of -24.8 dBm and the maximum dynamic range of more than 17.8 dB when $M = 8.7$. Note that we did not evaluate receiver overload precisely because of the fixed maximum input of the strong burst signal.

In IEEE802.3av, though details remain undecided, it is promising to use an error correcting code. We considered the application of RS (Reed-Solomon) (255, 239) code to our receiver since this code is widely used in current optical communications systems and has sufficient coding gain to improve the BER from 10^{-4} to 10^{-12}. The results suggest that we can attain the high sensitivity of -29.8 dBm and the wide dynamic range of 22.8 dB. These results also satisfy the loss budget of 29 dB required by the 10GEPON system. Thus our 10 Gbit/s APD burst-mode receiver can be used in 10GEPON systems.

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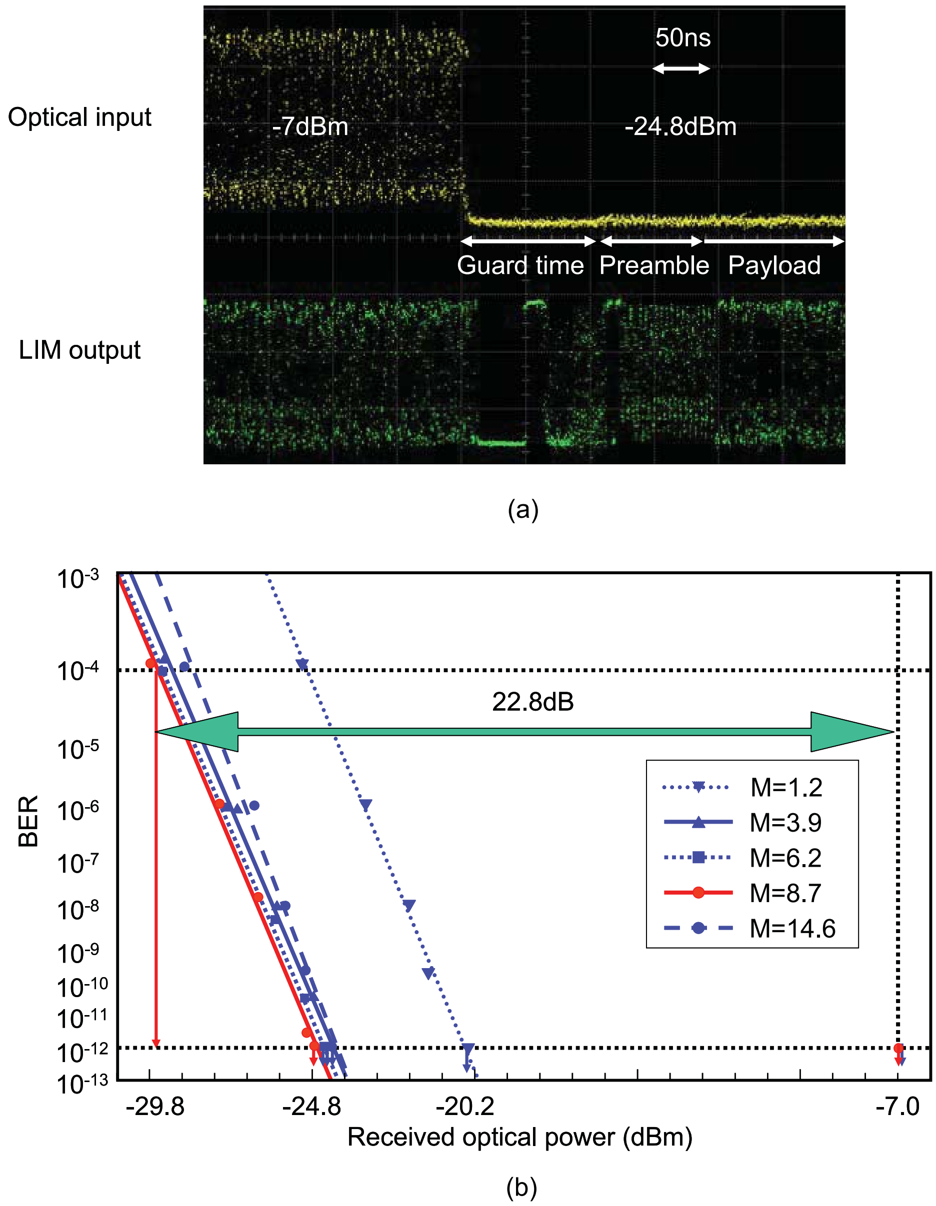

Fig. 2. (a) Optical input and limiting amplifier output waveforms, (b) BER performance of 10 Gbit/s APD burst-mode receiver.

4 Conclusion

We introduced a 10 Gbit/s APD burst-mode receiver that can realize the 10G-PON system. Measured results confirmed that the receiver sensitivity of −24.8 dBm and the dynamic range of 17.8 dB are achieved when the APD multiplication factor, M, is 8.7. Those results suggest that the sensitivity of −29.8 dBm and the dynamic range of 22.8 dB can be achieved by using the error correcting code RS (255, 239), and that the receiver can satisfy the loss budget of 29 dB required by the 10GEPON system.

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