Compact 2.5 Gb/s Burst-Mode Receiver with Optimum APD Gain for XG-PON1 and GPON Applications

Jongdeog Kim, Quan Le, Munseob Lee, Hark Yoo, Dong-Soo Lee, and Chang-Soo Park

ABSTRACT—This letter presents a compact 2.5 Gb/s burst-mode receiver using the first reported monolithic amplifier IC developed with 0.25 μm SiGe BiCMOS technology. With optimum avalanche photodiode gain, the receiver module can obtain a fast response, high sensitivity and wide dynamic range, satisfying the overhead timing and various power specifications for a 2.5 Gb/s next-generation passive optical network (PON), as well as a legacy 1.25 Gb/s PON in the upstream.

Keywords—Burst-mode receiver, monolithic amplifier IC, GPON, XG-PON1.

I. Introduction

Gigabit-class passive optical networks (PONs) such as Gigabit-capable PON (GPON) and Ethernet PON (EPON) are being widely deployed as an economical solution for attractive triple-play services. With the continuously increasing bandwidth demand for future broadband services, standardization efforts toward a next-generation PON (NG-PON) are actively in progress for 10-Gigabit-class PONs, 10G-EPON by the IEEE 802.3av Task Force [1] and 10-Gigabit-capable PON (XG-PON) by the Full Service Access Network (FSAN) NG-PON Task Group [2].

To realize the 10-Gigabit-class PONs, one of the key components for higher speed upstream transmission is the burst-mode receiver (BM-Rx) in the optical line termination (OLT). Some BM-Rxs for 10G-EPON have recently been actively studied and reported [3], [4], but a BM-Rx for XG-PON has not yet been reported. This is because the standardization has just recently been discussed, and more importantly, XG-PON has inherited the timing specification of GPON, which is much stricter than that of EPON, making it difficult to realize a BM-Rx for a higher data rate. Therefore, among the NG-PON approaches currently discussed in FSAN, XG-PON1 for 2.5 Gb/s upstream and 10 Gb/s downstream data rates is considered the most promising solution for a post-PON because of the practical benefits of its technical and economical feasibility, as compared with XG-PON2 for 10 Gb/s symmetric data rates in the upstream and downstream.

We present a compact 2.5 Gb/s BM-Rx with the first reported monolithic amplifier IC and an avalanche photodiode (APD) to satisfy both the XG-PON1 and GPON standards. This BM-Rx module with an external reset obtains a fast response for the specified mandatory overhead time with a minimum guard time in ITU-T G.984.2. It has high sensitivity and wide loud/soft ratio for various classes of power budgets required in XG-PON1 and GPON.

II. Configurations of the Burst-Mode Receiver

1. Target Specification

The recommended burst mode overhead times for 1.25 Gb/s and 2.5 Gb/s upstream data rates in ITU-T G.984.2 [5] are a minimum guard time of 25.7 ns and a suggested preamble time of 51.4 ns with a suggested delimiter of 20 bits. A state-of-the-

Manuscript received May 26, 2009; revised July 7, 2009; accepted July 22, 2009.
Jongdeog Kim (phone: +82 62 970 6914, email: jd03@etri.re.kr), Quan Le (email: quanle@etri.re.kr), Munseob Lee (email: mslee21@etri.re.kr), Hark Yoo (email: harkyoo@etri.re.kr), and Dong-Soo Lee (email: d-soolee@etri.re.kr) are with the Research Strategy Laboratory, ETRI, Gwangju, Rep. of Korea.
Chang-Soo Park (email: csp@gist.ac.kr) is with the Department of Information & Communication, GIST, Gwangju, Rep. of Korea.
doi:10.4218/etrij.09.0209.0227

Table 1. Target specification and result for OLT receiver.

Items	Bit-rate (Gb/s)	Sensitivity w/o FEC (dBm)	Overload (dBm)	Dynamic range (dB)	References
XG-PON1	2.488	-26 to -30	-5 to -11	21	FSAN meeting
This work	2.488	-33	-10	23	Back-to-back burst cond.
GPON	1.244	-29	-8/-12	21	G.984.2
This work	1.244	-33.5	-8	25.5	Back-to-back burst cond.

art 1.25 Gb/s clock-data recovery (CDR) chip in the current GPON market requires a maximum of 13 bits to lock, and no CDR chip for 2.5 Gb/s GPON is commercially available at this time. Therefore, we use a conservative estimate of a minimum 44-bit locking time for a 2.5 Gb/s GPON CDR, which results in 64 bits, equaling 25.7 ns of settling time as in our design target. The overhead time specification for XG-PON1 is considered for the 2.5 Gb/s upstream parameters in G.984.2 as a base, although modifying this for easier implementation and possible compatibility with other standardizations may be discussed in the next FSAN meeting.

Table 1 shows the target power specifications of an OLT receiver for both XG-PON1 and GPON, along with the results achieved in this work. The specifications for XG-PON1 have been taken from the summaries of the last FSAN NG-PON meeting in May 2009 [2]. The different power specifications of an OLT receiver for a 2.5 Gb/s XG-PON1 upstream have been suggested to be agreed upon later, as summarized in Table 1. For OLT receiver power for a 1.25 Gb/s upstream, a minimum sensitivity of -29 dBm without forward error correction (FEC) and a minimum overload of -8 dBm are specified for Class C with the highest optical path loss of 30 dB in G.984.2.

2. Receiver Design and Fabrication

The 2.5 Gb/s BM-Rx IC was designed for a trans-impedance amplifier (TIA) and limiting amplifier (LA) combined in a single chip [6] as shown in Fig. 1. The TIA part consists of a TIA-core with a feedback variable resister (Rf), a trigger block for automatic gain control (AGC), a single-to-differential converter (S2D), and an on-chip bias generator (Vbias). The LA part includes an LA with auto-offset compensation (AOC), a squelch block (SQ), and a buffer block (BUF) with CML output matched to 50 Ω. The TIA-core converts and amplifies the current signal from the photodiode to single-ended voltage signal, which is converted to the differential by the S2D and further amplified by limiting the AOC to a fixed amplitude. An

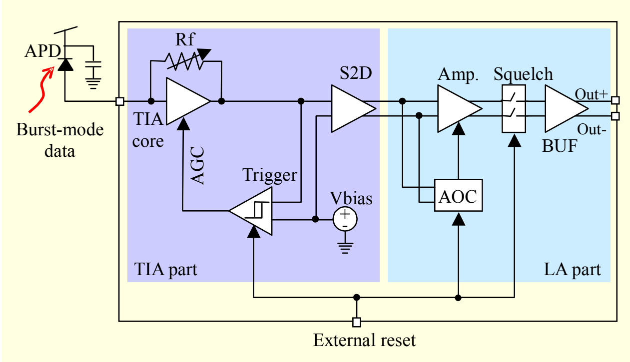

Fig. 1. Circuit block diagram of a burst-mode receiver.

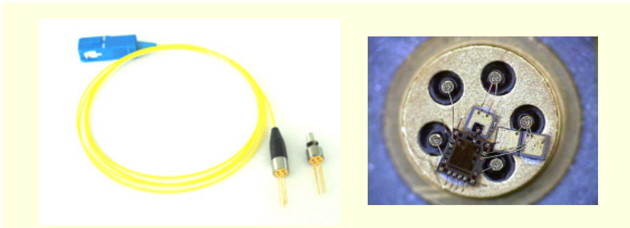

Fig. 2. Photograph of a burst-mode receiver module.

on-chip bias circuit generates the bias voltage for the S2D. The trigger also uses this bias voltage as a reference to quickly switch the TIA to a lower gain at the beginning of a burst using a digitized AGC signal when the input signal is strong, thereby extending the dynamic range [7]. The trigger and AOC are initialized by an external reset signal during the guard time before each burst to allow for a fast response and high loud/soft ratio. An SQ circuit is used to release the settled preamble output after the AOC process, which is helpful for correct phase alignment during the CDR locking time.

The receiver IC was fabricated using 0.25 μm SiGe BiCMOS technologies. The chip size is 1.0 mm × 1.2 mm, which is suitable for a conventional TO-Can package. The 2.5 Gb/s BM-Rx module was built using the cheapest commercially available APD in a 6-pin TO-46 package for a cost effective receiver as shown in Fig. 2.

III. Performance of the Burst-Mode Receiver

The bit error rate (BER) and output waveform of the BM-Rx module were evaluated in an experimental setup with two GPON optical network terminals (ONTs) set at extremely different input powers at the receiver end. The power dissipation of the BM-Rx IC was less than 135 mW with a supply voltage of 3.3 V.

Figure 3 shows the output waveforms of the receiver at 2.5 and 1.25 Gb/s. The overhead times of a burst data packet were set to a guard length of 25.7 ns and a preamble length of 51.4 ns, including a 20 bit delimiter. The waveform shows a

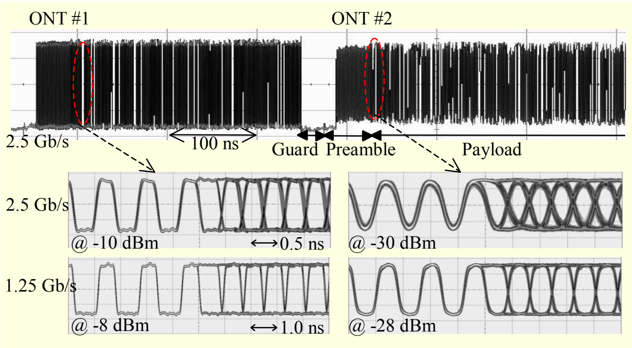

Fig. 3. Waveform and eye patterns at 2.5 Gb/s and 1.25 Gb/s.

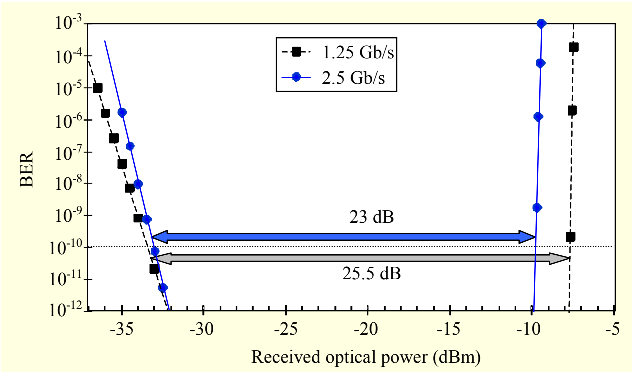

Fig. 4. BER performance for 2.5 Gb/s and 1.25 Gb/s at a fixed APD gain for minimum sensitivity.

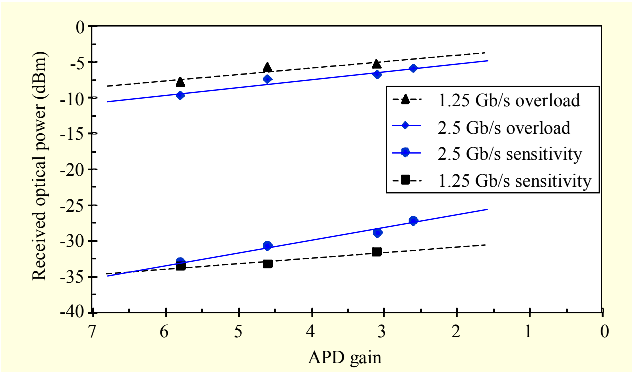

Fig. 5. BER performance versus APD gain.

fast settling time of less than 20 ns for both data rates, when the TIA gain is changed by the different powers of the burst inputs.

The BER characteristics of the BM-Rx module shown in Fig. 4 were measured using a fixed APD gain of 5.8 for minimum sensitivity at room temperature. For the 2.5 Gb/s data rate, the back-to-back sensitivity and overload were -33 dBm and -10 dBm, respectively, resulting in a dynamic range of over 23 dB. For the 1.25 Gb/s data rate, the sensitivity and overload were -33.5 dBm and -8 dBm giving a dynamic range of about 25.5 dB. The sensitivities were measured using various input power levels for one ONT, and the input power of the other ONT was maintained within an overload range for the worst case. Sensitivity and overload were evaluated at a BER of 10^{-10} for all burst-mode data with a payload of PRBS 2^{31}–1.

To optimize the range of APD gain in satisfying the power specifications for a 2.5 Gb/s NG-PON and legacy 1.25 Gb/s GPON, we also evaluated the sensitivities and overloads with the decreased APD gain to the marginal boundary for no BER error as shown in Fig. 5. For a 2.5 Gb/s data rate, a 3 dB improvement in overload requires about 5 dB of sensitivity penalty, which means 2 dB of penalty in the dynamic range as well. Otherwise, for 1.25 Gb/s, a 2 dB higher overload is obtained with about 2 dB of sensitivity penalty, which means no penalty in the dynamic range. Based on the measurement, this OLT receiver at a 2.5 Gb/s data rate can work for a wide dynamic range of 23 dB from -30 dBm to -8 dBm with a moderate APD gain, or for a dynamic range of 21 dB from -27 dBm to -6 dBm, with the lowest APD gain. These characteristics of an OLT receiver with optimum APD gain are very useful in extending the overload coverage with lower sensitivity penalty in applications for various optical path losses, that is, the different classes of power budgets specified in PON standards.

IV. Conclusion

We have developed and demonstrated a new 2.5 Gb/s BM-Rx module with a monolithic receiver IC and an APD in a conventional TO-Can package. The module shows a fast response time that exceeds the overhead timing specification of GPON. This receiver uses the optimum APD gain and can realize high sensitivities and overloads with a wide dynamic range to meet the various power specifications from class B to class C++. Our developed BM-Rx will contribute to the next-generation XG-PON1 which is currently being proposed for standardization, as well as to the current GPON.

References

[1] IEEE 802.3av Task Force, http://www.ieee802.org/3/av/.

[2] FSAN NG-PON Task Group, http://www.fsanweb.org/ ngpon.asp.

[3] K. Hara et al., “1.25/10.3 Gbit/s Dual-Rate Burst-Mode Receiver,” *Electron. Lett.*, vol. 44, no. 14, July 2008, pp. 869 -870.

[4] S. Nishihara et al., “10.3 Gbit/s Burst-Mode PIN-TIA Module with High Sensitivity, Wide Dynamic Range and Quick Response,” *Electron. Lett.*, vol. 44, no. 3, Jan. 2008, pp. 222-223.

[5] ITU-T Std. G.984.2, Gigabit-Capable Passive Optical Networks (GPON), ITU-T, Mar. 2003.

[6] Q. Le et al., “2.5Gb/s GPON Single-Chip Burst-Mode Receiver,” *Proc. ECOC*, vol. 5, Sept. 2008, p. 119-120.

[7] M. Nakamura et al., “1.25-Gb/s Burst-Mode Receiver ICs with Quick Response for PON Systems,” *IEEE J. Solid-State Circuits*, vol. 40, no. 12, Dec. 2005, pp. 2680-2688.