Extended-loss-budget pluggable transceiver for 10G/1G compatible PON with N:1 redundant OLT protection

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Abstract: We develop the first OLT-pluggable extended-loss-budget transceiver necessary for 10G/1G compatible PON with N:1 redundant OLT protection. This paper newly define the requirement of the OLT transceiver supporting protection by assuming an additional loss of redundant function. The average output power of 6.95/8.35 dBm and minimum receiver sensitivity of \(-32.02/34.53\) dBm for 10G/1G are attained, respectively. Experiments also confirm 40-km-SMF transmission with no dispersion penalties. It achieves the 36.02/35.53-dB loss budget as 10G/1G OLT transceiver, where ONU transceiver’s specification is based on 10GBASE-PR40/1000BASE-PX40, successfully meeting required loss budget for N:1 redundant OLT protection.

Keywords: optical communication, PON, OLT transceiver, redundant OLT protection

Classification: Transmission Systems and Transmission Equipment for Communications

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1 Introduction

The explosive growth in internet data traffic has been driving the demand for high capacity and cost-effective optical access networks, resulting in the commercial development of the 10-Gbps-class passive optical access network (PON), that is, the 10G-EPON system standardized in IEEE802.3av [1]. It is essential to consider cost-effectiveness and compatibility with legacy GE-PON systems [2] because the optical line terminal (OLT) must accommodate both 10G optical network units (ONUs) and 1G ONUs on the same PON branch at the initial stage of adoption. In addition, recently emerging PON applications such as mobile backhaul and business subscribers have raised the importance of optical access network reliability [3], and protection schemes have been discussed and standardized [4, 5]. Redundant OLT protection is attractive because it can also reduce total system operating expense (OPEX) owing to its automatic and fast switching to the redundant OLT transceiver.

In terms of realizing its redundant OLT architecture, it is necessary to define the specification of OLT transceiver for protection by assuming an additional loss imposed by protection components, which must meet its requirement. However, the loss-budget requirement of redundant-protection-based PON architecture has not been adequately examined, and no argument has addressed this problem up to this point.

In this paper, we develop an extended-loss-budget optical transceiver pluggable to current OLTs for a 10G/1G compatible PON with redundant OLT protection; its wavelength-division multiplexing (WDM) filters are thinned sufficiently to minimize its insertion loss and thus maximize output power and improve receiver sensitivity. An internal booster semiconductor optical amplifier (SOA) is set at only the 10G transmitter to reduce overall volume and permit the realization of a truly compact pluggable package.

2 Required loss budget for PON with redundant OLT protection

This chapter describes the loss budget needed to realize the 10G/1G compatible PON with redundant OLT protection by summarizing the loss of each component such as optical fiber line, optical coupler and optical switch (OSW).

Four types of PON protection topologies are standardized in Ref. [4], whereas Ref. [5] develops type B and N:1 protection schemes using N:1 OSW. “Type B with N:1” in Ref. [5] is an example of PON with redundant OLT protection, which we think is one of the best approaches because of its low cost and OPEX. Its architecture is schematically illustrated in Fig. 1, where optical subscriber unit (OSU) for protection is linked to working OSU via OSW and optical coupler. The protection system, composed of optical coupler and OSW, causes additional loss.
between OLT and ONUs, which must be considered when estimating required loss budgets. IEEE standards allow 29/26 dB channel insertion loss between OLT and ONUs for an optical link based on 10G/GE-PON respectively [1, 2], so a 10G/1G compatible PON system must work with optical link losses of at least 29 dB. The maximum insertion loss of N:1 OSW and that of \( \times 2 \times 2 \) optical coupler are specified as 1.5 dB in [6] and 3.6 dB in [7], respectively, so the additional insertion loss of the protection system is assumed here to be 5.1 dB. Accordingly, channel optical link loss is increased from 29 dB to 34.1 dB. The extended EPON, which was standardized in 2013, provides 10GBASE-PR40 and 1000BASE-PX40 [8], but neither has a budget sufficient for the PON with redundant OLT protection described above. In Ref. [9], of 10.3-Gbps PON with 37.6-dB loss budget is developed based on SOA-embedded OLT, but none of the components were assembled in any package. Furthermore, an optical band-pass filter (OBPF) with pass bandwidth of 4.2 nm is inserted after the preamplifier SOA, making 1G signal reception impossible because GE-PON system allows upstream lasers to operate in the 100 nm wavelength range [2].

To meet the loss-budget requirement described above, we introduce here the OLT-pluggable extended-budget optical transceiver. An inset located in the right side of Fig. 1 illustrates its functional configuration. 10G transmitter (10G-Tx) and 1G transmitter (1G-Tx) are multiplexed by WDM filter\#1, and WDM filter\#2 is inserted to de-multiplex the received upstream signal. Each WDM filter is thinned sufficiently to minimize their insertion losses, which yields high output optical power and improved minimum receiver sensitivity. 1G-Tx is composed of laser diode (LD) and external modulator (EM), and booster SOA is set only in the 10G-Tx for the purpose of reducing the entire volume so that all components can be assembled in the compact package pluggable to the current OLTs. Received signal is input into an avalanche photodiode (APD), and its output is amplified by a trans-impedance amplifier (TIA).

### 3 Experimental evaluations

Experimental procedure for transmitter evaluation is as follows. Pulse pattern generator (PPG) output bipolar electrical signals with electrical power of 500 mVpp. 10.3125-Gbps signal of \( 2^{31} \) pseudorandom binary sequence (PRBS31) was used for 10G tests while 1.25-Gbps signal of PRBS7 was used for 1G tests. Modulated...
signal propagated through standard single-mode fiber (SMF) and input into ONU receiver after passing an optical variable attenuator (ATT). SMF lengths were 0, 20, 40 and 80 km, and received optical power at ONU is changed by tuning ATT level. Received optical signal is converted into an electrical signal and input to error detector (EDT) for bit-error ratio (BER) measurement. Eye diagrams captured at each bitrate are shown in Figs. 2 (a) and (b). They confirm the extinction ratios of 7.82/10.87 dB, and average output power of 6.95/8.35 dBm for 10G/1G transmitter, respectively. Figure 2 (c) shows measured BER performance of the transmitter. Even after 40-km-SMF transmission, no dispersion penalties are observed at the point of $BER = 10^{-3}$ for 10G signal and at $BER = 10^{-12}$ for 1G signal.

![Fig. 2. Transmitter evaluation. (a) 10G Eye diagram. (b) 1G Eye diagram. (c) Transmitter BER performance](image)

Similarly, receiver test is as follows. The each output of 10G and 1G ONUs are coupled after each ATT and input to the transceiver, so the EDT could measure BER. The bitrates, extinction ratios, wavelengths of ONU transmitters of 10G/1G were 10.312 Gbps of PRBS31/1.25 Gbps of PRBS7, 6.5/9.0 dB and 1270/1310 nm. The detailed frame configurations of this burst-mode test are depicted in Figs. 3 (a) and (b), where the length of preamble data, dummy data and guard time are described. Figure 3 (c) shows the results of the receiver sensitivity evaluation. At the point of $BER = 10^{-3}$ received optical power of the 10G signal was $-32.02$ dBm, and at the point of $BER = 10^{-12}$ that of the 1G signal was $-34.53$ dBm, resulting in the minimum receiver sensitivity of $-32.02/-34.53$ dBm for 10G/1G, respectively.

10GBASE-PR40 and 1000BASE-PX40, which we assume as specifications of ONU transceiver, define ONU minimum-launch-powers of $+6/+2$ dBm and maximum receiver sensitivities of $-29.5/-30$ dBm. These means 36.45/38.35-dB available power budgets for 10G/1G downlink and 38.02/36.53 dB for 10G/1G uplink, respectively. They also define maximum transmitter and dispersion penalties as 2/1 dB for 10G/1G uplink; our evaluations confirm the transceiver has zero dispersion penalty at the transmitter. Consequently, these results validate the 36.02/35.53-dB
loss budgets for 10G/1G optical links, successfully meeting loss-budget requirements of 34.1 dB we summarized for the redundant OLT protection PON in the previous chapter.

4 Conclusion

This paper defined the loss budget needed to realize the 10G/1G compatible PON with redundant OLT protection by summarizing the loss of each component, and we developed the extended-loss-budget pluggable optical transceiver to meet its loss-budget requirement. All components such as EM, SOA and APD are assembled in a compact package pluggable to existing commercial OLTs, and internal WDM filters are thinned enough to minimize their insertion loss and thus maximize output power and improve receiver sensitivity. As for 10G performance, our transceiver attained average output power of 6.95 dBm and extinction ratio of 7.82 dB; its receiver sensitivity at $BER = 10^{-3}$ is −32.02 dBm. Similarly, 1G average output power is 8.35 dBm, and receiver sensitivity is −34.53 dBm at $BER = 10^{-12}$. The loss budget of 36.02/35.53 dB are attained for 10G/1G optical link, respectively, where ONU specifications are assumed as 10GBASE-PR40 and 1000BASE-PX40. These values achieve the OLT transceiver requirements we defined for 10G/1G compatible PON with N:1 redundant OLT protection.