40-km Reach Symmetric 40-Gbit/s $\lambda$-tunable WDM/TDM-PON Using Synchronized Gain-Clamping SOA

Katsuhisa Taguchi(1), Hirotaka Nakamura(1), Kota Asaka(1), Takayuki Mizuno(2), Yasuaki Hashizume(2), Takashi Yamada(2), Mikitaka Itu(2), Hiroshi Takahashi(2), Shunji Kimura(1), and Naoto Yoshimoto(1)

(1) NTT Access Network Service Systems Laboratories, NTT Corporation, 1-1 Hikari-no-oka, Yokosuka-shi, Kanagawa, 239-0847, Japan
(2) NTT Photonics Laboratories, NTT Corporation, 3-1 Morinosato Wakamiya, Atsugi-shi, Kanagawa, 243-0198, Japan

taguchi.katsuhisa@lab.ntt.co.jp

Abstract: We propose a high power $\lambda$-tunable burst-mode transmitter with an output of over +10 dBm using a synchronized gain-clamping booster SOA, and demonstrate a 40-dB loss budget and 40-km reach symmetric 40-Gbit/s $\lambda$-tunable WDM/TDM-PON.

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1. Introduction

Recently, time division multiplexing (TDM)-based high speed optical access system of 10G-EPON and XG-PON has been developed, and some field trials were reported[1, 2]. Moreover, the discussion of the next generation optical access networks (NGOA) operating at over 10Gbit/s has started [3]. For the flexible NGOA, we must consider the high scalability of the system configuration as regards the total bandwidth, the number of accommodated users, and the transmission distance, the smooth migration from existing PON systems, and the low power consumption in order to reduce the OPEX. To satisfy these requirements, $\lambda$-tunable WDM/TDM-PON is a promising candidate and its wavelength ($\lambda$)-tunability can allow us to realize a photonic aggregation function; a high split ratio, a long reach, an incremental upgrade of the total bandwidth and a flexible load balancing according to users’ demand [4]. To construct $\lambda$-tunable WDM/TDM-PON more cost effectively, it is important to improve the loss budget, and a booster amplification technique is easy to increase the launched power at the transceiver. In particular, semiconductor optical amplifiers (SOAs) are attractive device for WDM/TDM-PONs because of their wide gain bandwidth, smaller size, and low power consumption. However, the pattern effect is a serious problem in the booster SOA because the SOA has to handle a strong signal. We have already proposed a simple technique of the synchronized gain-clamping (SGC) light injection SOA for optically-amplified 1-Gbit/s class PONs [5].

In this paper, we propose a high power $\lambda$-tunable burst-mode transmitter (B-Tx) that achieves an output of over +10 dBm without waveform distortion by using a SGC booster SOA. We demonstrate a 40-dB loss budget and 40-km reach symmetric 40-Gbit/s $\lambda$-tunable WDM/TDM-PON for flexible photonic aggregation networks.

2. Proposed high output power $\lambda$-tunable B-Tx for $\lambda$-tunable WDM/TDM PON

Figure 1 (a) shows a configuration of our 40-Gbit/s $\lambda$-tunable WDM/TDM-PON. The OLT consists of LCs that output downstream signals and receive upstream signals, a dynamic wavelength bandwidth allocation (DWBA) controller, and a photonic aggregator using a 4 x M cyclic arrayed waveguide grating (AWG) that connect 4-LCs to M-PON branches (M-PBs). Each LC has a $\lambda$-tunable Tx (4$\lambda$) and a burst-mode receiver (B-Rx). The optical network unit (ONU) has a $\lambda$-tunable B-Tx and a B-Rx. The $\lambda$-tunable Tx in the LC and the ONU output the downstream signal and upstream signal while switching its output wavelength according to instructions from the DWBA controller, respectively.

![Fig. 1 Configuration of (a) 40-Gbit/s $\lambda$-tunable WDM/TDM-PON, and (b) our proposed high output power $\lambda$-tunable B-Tx.](image-url)
Figure 1 (b) shows the configuration of our proposed high output power λ-tunable B-Tx using an SGC booster SOA. It consists of an LD array, an SGC Tx, a WDM filter, a 3 dB coupler, an SOA, a switch (SW), and a SW and LD driver controller. These wavelengths are same as those used for 40GbE and the optical components are available. When the λ-tunable B-Tx outputs the upstream signal with changing its wavelengths, the SGC Tx is modulated with the inverted bit pattern of the upstream signal bit pattern. The upstream signal is output by the LD array and the SGC light are multiplexed by the 3 dB coupler. The inset in Fig.1 (b) shows the principle of pattern effect suppression. The total average input power into the SOA remains almost constant so that SGC light suppress the pattern effect for the λ-tunable and burst signal amplification in the SOA. The amplified signal is launched into the transmission line.

3. Design of high output power λ-tunable B-Tx
To construct the proposed B-Tx cost effectively, the wavelength allocation of the upstream signal and the SGC light is important. We select the four wavelengths for the upstream signals on the CWDM grid, 1271 (λ1), 1291 (λ2), 1311 (λ3), and 1331 (λ4) nm, because these wavelengths are same as those used for 40GbE and the optical components are available. Moreover, the SGC light wavelength should be selected that doesn’t affect the upstream transmission performance. The wavelength of the SGC light is required to be selected so that the SOA can amplify the upstream signal against the four wavelengths with suppressing the pattern effect in the SOA and the SGC light doesn’t affect the upstream signal. To confirm the effectiveness of the pattern effect suppression, we investigated the SGC light wavelength dependence on the pattern suppression effect. The saturation output power and the gain peak of the used SOA at a driving current of 300 mA are 12.8 dBm and 1280 nm, respectively. Figure 2 (a) shows the measured output power and the extinction ratio of all the signal wavelengths by changing the SGC light wavelength between 1260 and 1340 nm. The output power of each signal wavelength is obtained over +10 dB at each SGC light wavelength. In addition, the extinction ratios of all the signal wavelengths are improved at an SGC light wavelength of around 1300 nm. Figure 2 (b)-(d) shows measured eye diagrams at a signal wavelength of 1271 nm. With regard to the eye diagram, Fig. 2 (c) exhibits significant degradation compared with Fig. 2 (b) owing to the pattern effect generation. On the other hand, Fig 2 (d) shows that the pattern effect is greatly suppressed owing to SGC light injection at 1302 nm. 1302 nm is suitable as the wavelength of the SGC light as shown in Fig.2 (a), because the SGC light at 1302 nm can realize the pattern effect suppression and doesn’t affect the upstream signal.

4. Experiment
Figure 3 shows the experimental setup we used to confirm the feasibility of the 40 km reach 40-Gbit/s λ-tunable WDM/TDM-PON. The experimental setup consisted of our proposed high output power λ-tunable B-Txs, a 4 x 4 cyclic AWG router, and a burst-mode Rx [6], respectively. Each PON branch includes a power splitter and 40-km transmission optical fiber line. The cyclic AWG router shown in Fig.3 (b) and (c) can multiplex/demultiplex 20-nm and 200-GHz-spaced signals in the 1300 and 1570 nm bands, respectively. The wavelengths for the downstream signals are 1575.4, 1577.0, 1578.7, and 1580.4 nm with a 200-GHz spacing. Moreover, the insertion loss of both stream are less than 7 dB at all wavelengths.

Figure 4 (a) shows the waveforms of 10.3125 Gbit/s upstream optical signals output from cyclic AWG port 1. The strong signal is dummy signal at λ3 from ONU2-1, and the weak signal is adjusted -30 dBm of bit error rate (BER) measured signal at λ1 from ONU1-1. The transmitted burst pattern consist of a block of 397-ns preambles, a 1589-ns payload with 2^21-1 PRBS, and a 99-ns end of burst. Figure 4 (b) shows output from the B-Rx. The weak and
strong signals are adjusted to the same level by the burst-mode limiting amplifier (LA) in the B-Rx. As shown in Fig. 4 (c), the $\lambda$ switching time for $\lambda_3$ to $\lambda_1$ is less than 30 ns.

Figure 4 (d) shows the BER characteristics of 1271 nm signal. Here, forward error correction (FEC) is assumed to achieve error free operation at a BER of $10^{-3}$. The receiver sensitivity of B-Rx at BER of $10^{-3}$ was -30.0 dBm at all signal wavelengths. Without the SGC light injection, the power penalty is observed 5.8 dB at $\lambda_1$ owing to the pattern effect. The highest and lowest received sensitivity of our proposal are -31.0 dBm and -29.8 dBm through 40-km SMF at 1271 nm and 1311 nm, respectively. As shown in Fig. 4 (e), our proposal system could achieve over 40-dB loss budget at all four signal wavelengths.

Fig.3 (a) Experimental setup of BER measurement. Cyclic AWG characteristics of (b) upstream signal at 1300 nm, and (d) downstream signal at 1570 nm.

Fig.4 Waveform of (a) optical signal input to B-Rx, and (b) electrical signal output from B-Tx. (c) electrical signal of wavelength switching from $\lambda_3$ to $\lambda_1$. (d) BER characteristics. (e) Measured loss budget.

5. Conclusion
We proposed a $\lambda$-tunable high output power B-Tx to improve the upstream loss budget of a 40-Gbit/s $\lambda$-tunable WDM/TDM-PON. The proposal suppressed the pattern effect and greatly improved the output power without the waveform distortion. The 40-km reach 40-Gbit/s WDM/TDM-PON was demonstrated with over 40 dB loss budget.

6. Reference