Optical Burst and Transient Equalizer for 10Gb/s Amplified WDM-PON

Y. Liu, C. W. Chow*, C. H. Kwok, H. K. Tsang and Chinlon Lin

Department of Electronic Engineering, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong.
Email: yliu@ee.cuhk.edu.hk

* Present Address: Photonic Systems Group, Tyndall National Institute and Department of Physics, University College Cork, Ireland

Abstract: We propose and demonstrate an optical-burst-and-transient-equalizer (OBTE) on silicon-on-insulator (SOI) to provide a compact and low-cost solution to compensate gain-transient, gain-spectrum-tilt and to equalize the upstream packets amplitude in EDFA-amplified WDM-PON.

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1. Introduction

WDM-PONs are currently under intensive study as possible candidates for the next-generation of high-bandwidth (~10Gb/s) optical access networks due to their cost-effective user-shared facilities. To offer more cost-insensitive services, system designers are needed to improve the system budget by providing long reach and high split ratio. Using optical amplifiers, such as EDFA, can increase the system budget significantly. But there are issues in the implementation of amplified WDM-PONs. In the upstream traffic, where the signal is bursty [1], EDFA gain transient and gain spectrum tilting will make the optical bursts exceed the dynamic range of receivers and cause power penalty. Although gain tilt may be compensated by EDFA gain-clamping [2], individual channel equalization is more favorable to compensate complicated gain spectrum tilting produced by cascaded EDFAs and simulated Raman scattering (SRS). On the other hand, the different lengths of optical fiber between the central office (CO) and various optical network units (ONUs) generate differences in path loss. This means although each ONU generates optical signals are at same strength, the power levels will vary when they reach the CO (Fig. 1). Burst-mode receiver (Rx) may improve the detection of optical bursts with different amplitude, but speed at > 1.25Gb/s is not mature at present [3].

Here we propose and demonstrate an optical burst and transient equalizer (OBTE), which can be monolithically integrated on silicon-on-insulator (SOI) platform to provide compact and low cost solution to equalize power fluctuation. In section 3, we show that the OBTE can effectively remove the gain transient and compensate gain spectrum tilt in EDFA-amplified WDM-PON. 15dB Rx sensitivity improvement at 10Gb/s bit-error rate (BER) measurement of 10^-9 was achieved. In section 4, we show that it can equalize the amplitude of the bursty upstream packets to greatly enhance the dynamic range of the Rx.

2. Architecture

The proposed architecture of the OBTE is shown in Fig. 2. At the CO, optical bursts from different WDM-PONs are wavelength demultiplexed by a 40-channels, 100GHz channel spacing (3-dB bandwidth 50GHz) arrayed-waveguide grating (AWG) on SOI. Each wavelength demultiplexed channel is detected by an in-line channel power monitor (ICPM) [4], which is based on helium ion implanted silicon waveguides to detect below-bandgap wavelengths (C-band). The ICPM provides the same function as a waveguide tap coupler and a hybrid-integrated photodiode, without tapping out optical power to realize in-line power monitoring. By using different implantation doses and annealing durations, we can obtain different responsivities of the ICPM [4]. The ICPM then provides electrical control signal to a control circuit, which is connected to an electrical variable optical attenuator (EVOA), which equalizes the amplitude of the upstream signal by adjusting its optical attenuation using current injection [5].
control circuit consists of an RF amplifier to amplify the electrical signal for driving the EVOA and a threshold decision module to equalize the transient with the rest of the optical signal. As the typical gain saturation and recovery times of EDFA fall between tens and hundreds of μs [6, 7], a slow speed control circuit can be used.

3. EDFA Gain Transient and Spectrum Tilt Compensation

In this section, three separate experiments were performed to evaluate the OBTE when operated in one, two and multiple wavelength channels. Firstly, a single wavelength channel gain transient compensation was performed. A 10kHz optical square pulse, with extinction ratio (ER) of 10dB, experienced gain transients after being amplified by an EFDA as shown in Fig. 3 (degraded curve). The distorted signal was then passed through the ICPM for transient detection. The responsivity of the ICPM prepared by using implantation dose of $1 \times 10^{12}$ cm$^{-2}$ followed by annealing at 200°C for 45mins was 64mA/W. The speed of the ICPM is 20MHz. The electrical signal from the ICPM was fed to the control circuit, which then provides a feed-forward signal to the EVOA for transient suppression. The EVOA can provide attenuation of about 40dB with 50mA applied current. Fig. 3 shows that the transient can be efficiently suppressed from 8dB to 0.8dB. Fig. 4 shows the photocurrent generated by ICPM at different DC biases to detect different packet lengths of 10Gb/s optical packet, showing that it can generate sufficient photocurrent even when the packet is short (50bits). We then numerically analyze (VPI Transmission Maker v6.5) the improvement in $Q$ of different upstream packet lengths when subjected to EDFA gain transient (Fig. 5), showing that the OBTE can significantly improve the dynamic range of Rx. Where $Q=20\log\left(\frac{\mu_1-\mu_0}{\delta_1+\delta_0}\right)$, $\mu_1$, $\mu_0$ are the mean of one and zero respectively; and $\delta_1$, $\delta_0$ are standard deviation of one and zero respectively.

Secondly, we experimentally determine the Rx sensitivity improvement of compensated upstream 10Gb/s signal, which is affected by cross gain modulation (XGM) produced by optical burst in neighboring wavelength channel sharing the same EDFA (Fig. 1). The experiment consisted of launching a 10kHz optical square pulses ($\lambda_0$) of ER = 10dB and a 10Gb/s NRZ signal, PRBS of $2^{31}-1$ ($\lambda_1$), into an EDFA via a 3dB fiber coupler. At the output of the EDFA, the two channels were then launched into the OBTE. BER measurements were performed as shown in Fig. 6. For the uncompensated signal, power fluctuation was observed in the $\lambda_1$ channel generated by the neighboring $\lambda_0$ channel, as shown in the eye-diagram [inset (a) of Fig. 6], and an error-floor was observed. 15dB Rx sensitivity improvement was observed without error-floor in the compensated case by OBTE. The Rx sensitivity improvement is due to the removal of the power fluctuations as shown in inset (b) of Fig. 6.
Finally, we experimentally evaluated the compensation of multiple channels and complicated gain-tilt compensation when one of the channels is dropped, by using four EDFA-amplified channels at wavelengths of 1548.4nm, 1550.9nm, 1553.4nm and 1555.7nm. Fig. 7(a) shows the optical spectrum (resolution 0.01nm) of the four wavelength channels with nearly equal amplitude after being amplified by an EDFA. When the 1548.4 nm wavelength channel was dropped, the three surviving channels experienced gain tilt as shown in Fig. 7(b). Fig. 7(c) shows the optical spectrum of the three surviving channels which were individually equalized in amplitude by different EVOAs. The experimental results also suggest that the OBTE can compensate more complicated gain slope, which may be generated in cascaded EDFAs or SRS.

4. Upstream Optical Packet Equalization

In this section, we characterize the power equalization property of the OBTE. The upstream optical packets will have different amplitude when they reach the CO from different ONUs (Fig. 1). We numerically analyze the 10Gb/s upstream packet (300bits and 100bits) improvement by the power equalization of OBTE at different packet amplitude ratios. Since we want to specifically characterize the power equalization property of the OBTE, we remove the EDFA in this study. Fig. 8 shows that the OBTE can effectively equalize the upstream packet amplitude even at short packet length (300bits) and high packet amplitude ratio of 11.

5. Conclusion

We propose and demonstrate an OBTE that can compensate gain-transient and gain-spectrum-tilt in EDFA-amplified WDM-PON, in order to improve the dynamic range of Rx. 15dB receiver sensitivity improvement at 10Gb/s BER measurement of 10^-9 was achieved in the compensated channel. It can also equalize the upstream packets amplitude even at high packet amplitude ratio of 11. It can be monolithically integrated on SOI platform to provide compact and low cost solution.

References