OOK and DPSK Signal Noise in All-Optical Regeneration based on Saturation of FWM

Nor Shahida Mohd Shah[1,*], Masayuki Matsumoto[2]

[1]Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia, Parit Raja 86400, Batu Pahat, Johor MALAYSIA.
[2]Graduate School of Engineering,
Osaka University, 2–1 Yamada-oka, Suita, Osaka 565–0871, JAPAN.

Abstract: Signal noise suppressed and accumulated in all-optical regeneration based on saturation of FWM in a highly nonlinear fiber is investigated. Two modulation formats, on-off keying (OOK) and differential phase-shift keying (DPSK), were used in this study. Input signal OSNR was 20 dB/0.1nm. Mark and space level noise were evaluated by measuring signal threshold value. The regenerator suppressed mark level noise of both OOK and DPSK signals. However, noise at space level was amplified, which degraded OOK signal performance.

Keywords: Differential phase-shift keying, four-wave mixing, nonlinear optics, on-off keying, optical signal processing

1. Introduction

Progressive development in optical transmission technologies allows the growth of transmission speed and capacity. As the optical transmission system moves toward higher bit rates and more advanced technologies evolve, signal degradation becomes more dominant. Regeneration can refine the degraded signal and improve transmission performance. Conventionally, electrical repeaters are used for optical signal regenerations, which need optical-to-electrical and electrical-to-optical signal conversions. All-optical regenerator is an alternative to electrical repeater, which can work ultrafast and less complicated.

All-optical signal regeneration relies on optical nonlinearity to reshape optical signals. Silica-based highly nonlinear fiber (HNLF), which has a long interaction length and high confinement in the waveguide structure, is an attractive nonlinear medium for high bit rate all-optical signal processing [1]. Various types of nonlinear effects can be used for fiber-based signal regeneration, such as self-phase modulation (SPM) [2], cross-phase modulation (XPM) [3], four-wave mixing (FWM), and stimulated Raman scattering (SRS) [4].

Regeneration based on saturation of FWM in nonlinear fiber, where the input and output signal wavelengths are same, has been studied for on-off keying (OOK) [5] and advanced modulation format signals [6-8]. The regeneration based on saturation of FWM is attracting because of many advantages, such as signal wavelength is unchanged; signal is amplified; and phase information is preserved [1]. Multi-format signal regeneration using saturation of FWM is also being investigated [9].

In our study of simultaneous regeneration of OOK and differential phase shift keying (DPSK) signals based on saturation of FWM, OOK signal performance did not improve much after regeneration when input signal was degraded by amplified spontaneous emission (ASE) noise, even though mark level noise was greatly suppressed [10]. Theoretically reason for this is because of amplification of space level ASE noise during the regeneration as the regenerator is also an amplifier.

In this paper, we experimentally study noise suppression and addition in the regeneration based on saturation of FWM for OOK and DPSK signals. We investigate the regeneration performance when using continuous wave (CW) pump, as in [10], and pulsed pump. Signal performance is investigated by measuring BER versus threshold voltage.

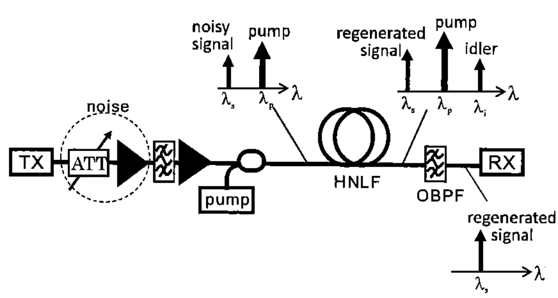

Fig. 1 Schematic diagram of regeneration based on saturation of FWM.

2. Regeneration Based on Saturation of FWM

Fig. 1 shows schematic diagram of the regeneration based on saturation of FWM. The configuration is the same as parametric amplifier, which consist of a pump, a HNLF, and an optical bandpass filter (OBPF). The pump and signals are injected to the HNLF, where FWM occurs. When the signal input power is small, the signal is amplified and an idler is generated. At a certain signal input power, the signal output power saturates, which is caused by change in power flow direction due to the power dependence of phase-matching condition. Because the FWM is an ultrafast process, the saturation of FWM is also very fast and can basically be used for amplitude regeneration by which bit-by-bit fluctuations in the signal amplitude are suppressed.

In our experiment, at transmitter (TX), signal pulses are generated from a 10-GHz mode-locked semiconductor laser diode at a center wavelength of 1558 nm. Then, the signal is modulated in OOK or DPSK format with 1024 bits data. Optical signal-to-noise ratio (OSNR) is degraded to 20 dB/0.1nm by being passed through an attenuator and an amplifier. The spectrum of the input signals is narrowed by an OBPF, resulting in a temporal pulse width of 6 ps.

In the regenerator, after being amplified, the signal is inserted into a highly nonlinear fiber (HNLF) together with a pump through a polarizer. In this study, we compare two types of pump, CW pump and 10-GHz pulsed pump. The pulsed pump is synchronized with signal to reduce zero level noise within signal pulses. The wavelength and the power of the pump are 1561 nm and 30 mW, respectively. The pump is phase-modulated by a 1-GHz RF tone to increase the stimulated Brillouin scattering (SBS) threshold. The HNLF has a zero-dispersion wavelength of 1556 nm, a dispersion slope of 0.026 $ps/nm^2/km$, nonlinearity of ~14 /W/km, loss of 0.78 dB/km, and a length of 1.5 km. After the HNLF, the signal is extracted using an OBPF. Direct detection is used at the receiver (RX). For DPSK signal demodulation, a delay interferometer and a balanced detector are used.

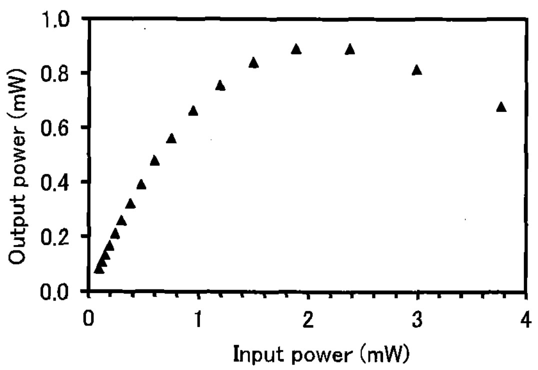

Fig. 2 Power transfer function of unmodulated signal pulses.

Fig. 2 shows average output power versus average input power of the regenerator for a 10-GHz unmodulated pulse train when CW pump is used. It is shown that the output power increases linearly for small input signal. Then, the output power saturates when the input signal power is around 2 mW. Amplitude fluctuation can be suppressed when input signal power is around the saturation regime.

3. Results and Discussion

In order to see noise suppression and accumulation, we measure bit error rate (BER) versus decision threshold voltage of the received signal, also known as BER-V testing, and compare the result with the result without regenerator.

Fig. 3 shows BER versus threshold voltage for OOK signal. It shows that the regenerator improves mark level noise (shows by the right lines), but, degrades space level noise of the signal (shows by the left lines). The improvement on mark level by the regenerator is due to suppression of noise by saturation. While, the degradation on space level is due to amplification of ASE noise by the optical parametric amplifier based regenerator. Space level noise when regenerated with pulsed pump degrades less than when regenerated with CW pump due to suppression of inter-pulse noise. Another way to suppress space level noise is by using a suitable saturable absorber [11].

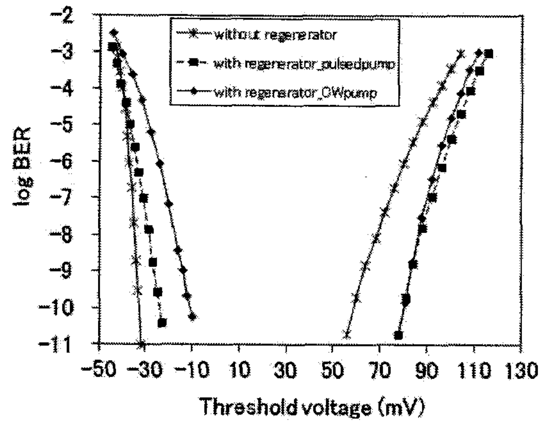

Fig. 3 BER evolutions vs threshold voltage of OOK signal when input OSNR is 20 dB/0.1nm.

Fig. 4 shows BER versus decision threshold voltage for DPSK signal. The regenerator worsens DPSK signal a bit. This is due to generation of nonlinear phase noise and broadening of signal spectrum inside the HNLF in the regenerator. The improvement of DPSK signal by this type of regeneration is not direct and cannot be seen in this measurement result, as the regenerator does not directly suppress phase noise. This regeneration suppresses amplitude noise [10], so that build-up of nonlinear phase noise, which is generated by the amplitude to phase noise, can be eliminated. Improvement of DPSK signal by this regeneration has been shown in [10], when the regenerated signal was launched into a transmission fiber.

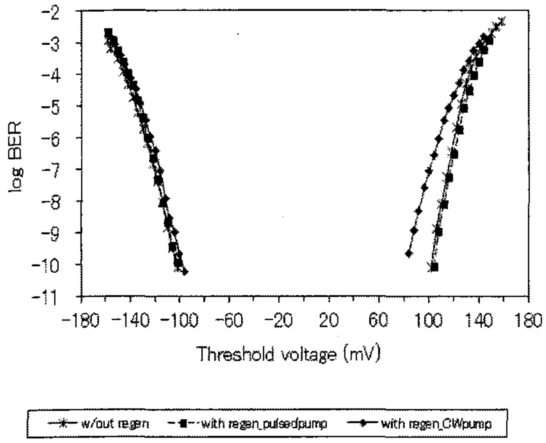

Fig. 4 BER evolutions vs threshold voltage of DPSK signal when input OSNR is 20 dB/0.1nm.

4. Summary

All-optical regeneration based on saturation of FWM has been studied using BER-V measurement. Suppression and accumulation of noise on mark and space level can be seen clearly for OOK signal as expected. However, for DPSK signal, phase data is degraded a bit by this regeneration. DPSK signal improvement by this regeneration can be observed after transmission [10]. The results obtained in this study are useful in the study of simultaneous OOK and DPSK signal regeneration.

References

[1] Matsumoto, M. Fiber-based all-optical signal regeneration. *IEEE J. Sel. Top. Quant. Electron.*, Rapid Post, (2011), pp. 1-15.

[2] Mamyshev, P.V. All-optical data regeneration based on self-phase modulation effect. *Proc. Eur. Conf. Opt. Commun. (ECOC)*, (1998), pp. 475-476.

[3] Jinno, M. and Abe, M. All-optical regenerator based on nonlinear fibre Sagnac Interferometer. *Electron. Lett.*, Volume 28, (1992), pp. 1350-1352.

[4] Dahan, D., Alizon, R., Bilenca, A., and Eisenstein, G. Optical noise reduction in inter-band Raman mediated wavelength conversion. *Electron. Lett.*, Volume 39, (2003), pp. 307-309.

[5] Inoue, K. Optical level equalisation based on gain saturation in fiber optical parametric amplifier. *Electron. Lett.*, Volume 36, (2000), pp. 1016-1017.

[6] Peucheret, C., Lorenzen, M., Seoane, J., Noordegraaf, D., Nielsen, C.V., Grüner-Nielsen, L., and Rottwitt, K. Amplitude regeneration of RZ-DPSK signals in single pump fiber-optic parametric amplifiers. *IEEE Photon. Technol. Lett.*, Volume 21, (2009), pp. 872-874.

[7] Matsumoto, M. and Kamio, T. Nonlinear phase noise reduction of DQPSK signals by a phase-preserving amplitude limiter using four-wave mixing in fiber. *IEEE J. Sel. Top. Quant. Electron.*, Volume 14, (2008), pp. 610-615.

[8] Mohd Shah, N.S., Sato, M. and Matsumoto, M. Adaptive delay control for time-interleaved multi-channel amplitude limiter based on saturation of four-wave mixing in a fiber. *Opt. Express*, Volume 19, (2011), pp. 21246-21257.

[9] Mohd Shah, N.S., Yang, D., and Matsumoto, M. Amplitude limiting of time-interleave-multiplexed OOK and DPSK signals based on four-wave mixing in a fiber. *Proc. Photon. Global Conf. 2010*, Singapore, Paper 2-3A-6 (2010), pp. 1-3.

[10] Mohd Shah, N.S., Furutani, A., Yang, D., and Matsumoto, M. Amplitude-noise reduction of time-interleave-multiplexed OOK and DPSK signals based on four-wave mixing in fiber. *Jurnal Teknologi - Special Edition (Optoelectronics & Optical Communication),* Volume 55, (2011), pp. 177-187.

[11] Rouvillain, D., Seguineau, F., Pierre, L., Brindel, P., Choumane, H., Aubin, G., Oudar, J.L., and Leclerc, O. 40 Gbit/s optical 2R regenerator based on passive saturable absorber for WDM long-haul transmissions. *Proc. OFC*, Paper FD11, (2002).