# A Novel OCDMA Thresholder Based on Nonlinear Polarization Rotation

Xuezhi Hong, Changjian Guo, Ying Gao , and Sailing He
Center for Optical and Electromagnetic Research, Joint Laboratory of Optical Communications
Zhejiang University
Hangzhou 310058, China
hongxuezhi@coer.zju.edu.cn

*Abstract*—**A novel low-power and cost-effective OCDMA thresholder based on nonlinear polarization rotation (NPR) is proposed. The excellent performance and feasibility of the NPR thresholder are experimentally demonstrated in our 2.5 Gb/s ultrashort pulse OCDMA system.**

***Keywords- OCDMA; MAI; Thresholder; Nonlinear fiber optics***

## I. INTRODUCTION

Optical Code Division Multiple Access (OCDMA) is one of the enabling techniques of the next generation optical network due to its high capacity, asynchronous access and optical layer security features. The BER performance and maximum number of simultaneous users of an OCDMA system are primarily limited by the multiple access interference (MAI) [1].

Besides the development of various coding techniques, efforts have been made on hardware techniques to eliminate or reduce the MAI. One choice is the optical time gating [2], which shows good performance. However, its requirement for optical clock recovery and timing coordination makes the receiver more complicated. An alternative choice is the optical thresholder, which allows asynchronous operation. Different technologies, including nonlinear gain and phase changes in semiconductor optical amplifier (SOA), second harmonic generation (SHG) in periodically poled lithium niobate (PPLN) [3] and super continuing (SC) generation in dispersion-flattened fiber (DFF) [4], have been used for optical thresholding.

In this paper, we propose a novel low-power OCDMA thresholder based on nonlinear polarization rotation (NPR) which uses commercial low-cost elements including a Faraday rotation mirror (FRM) and a highly nonlinear fiber (HNLF). The experiment of a 2-user 2.5 Gb/s ultrashort pulse OCDMA system with this NPR thresholder is successfully demonstrated.

## II. PROPOSED NONLINEAR POLARIZATION ROTATION THRESHOLDER

Intensity-dependent polarization rotation happens when strong optical fields pass through nonlinear medium [5]. All-optical intensity discrimination using birefringent fibers has been investigated [6,7]. A FRM configuration with a twisted fiber is reported in [7]. However, the conclusions in [7] are under quasi continue wave condition. Besides, the twisted fiber employed in [7] is not commercial available which puts obstacle for direct applications.

Fig.1 depicts the structure of our proposed OCDMA thresholder based on nonlinear polarization rotation. A highly nonlinear fiber is employed as the nonlinear medium for its high nonlinear coefficient. The input light pulse from the SSFBG decoder is amplified by a tunable EDFA before entering a variable attenuator (VOA1). The forward propagating light from the VOA2 is reflected back by the FRM.

The linear and nonlinear phase delay between the fast and slow axis components after the HNLF, which are induced by the linear and nonlinear birefringence respectively, can be

$$\begin{aligned} \Delta\phi_L &= (n_y - n_x)\beta L \\ \Delta\phi_{NL} &= -(1/3)\gamma PL\cos(2\alpha_2) \end{aligned} \tag{1}$$

expressed as follows [8]:

and the output light power $I_{out}$ can be calculated using (2):

$$I_{\text{out}} = (1/2)(1-\alpha)^2 P\cos^2\alpha_1 \sin^2(2\alpha_2)\left[1-\cos\left(\Delta\phi_{NL}\right)\right] \tag{2}$$

where P is the input light power; α is the attenuation rate of the VOA2; β=2π/λ is the propagation constant; $n_x$ and $n_y$ are the linear birefringence coefficients; L=500m is the length of HNLF; $\gamma=10\text{W}^{-1}\text{km}^{-1}$ is the nonlinear coefficient of the HNLF; $\alpha_1$ is the angle between the polarization direction of input

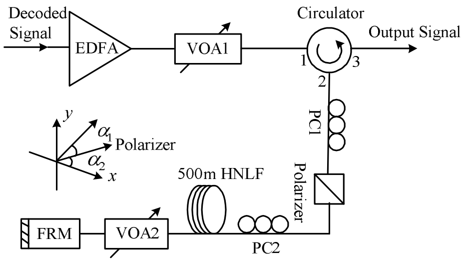

Figure 1. Proposed nonlinear polarization rotation thresholder

978-1-4244-4412-0/09/$25.00 ©2009 IEEE

signal and the polarization direction of the polarizer; $\alpha_2$ is the angle between the polarization direction of the polarizer and the fast axis of HNLF. The $\alpha_1$ and $\alpha_2$ can be adjusted by the polarization controllers PC1 and PC2.

The polarized light undergoes birefringence in the HNLF. When the input power intensity is low, only linear birefringence is present. A 90-degree polarization change induced by the FRM interchanges the fast axis component and slow axis component of the incident light. Therefore, the linear phase delay between the two components will be automatically compensated after backward propagation. The polarization direction of the backward propagating light after PC2 will be perpendicular to that of the polarizer. Thus there will be no output after the polarizer (predicted by (2)). However, when the input power intensity is high, additional nonlinear birefringence will be induced in forward propagation, while the backward propagating light will not suffer from nonlinear birefringence due to the attenuation caused by the VOA2. Hence, an ellipse polarization rotation will accumulate because of the uncompensated nonlinear phase delay. In this case, the output power will increase nonlinearly with the input power in the HNLF (see (2)). Through carefully adjusting PC1 and PC2, the optimum output signal can be obtained.

## III. Experiment of the 2-user 2.5 Gb/s OCDMA System with the NPR Thresholder

Fig. 2 shows the experiment setup of our 2-user 2.5 Gb/s OCDMA system implementing nonlinear polarization rotation thresholder. In the experiment, a mode locked fiber laser with pulse width of about 1.76 ps and repetition rate of 9.953 GHz is employed as the light source. The optical pulse train is first down converted to 2.488 GHz, and then modulated by $2^{23}$-1 pseudorandom bit sequence (PRBS). The amplified signal is equally split into two arms and encoded via two different super structured fiber Bragg gratings (SSFBG). The encoded signals are then combined and fed into 60km SMF. At the receiver side, the signal is amplified and decoded before entering the NPR thresholder.

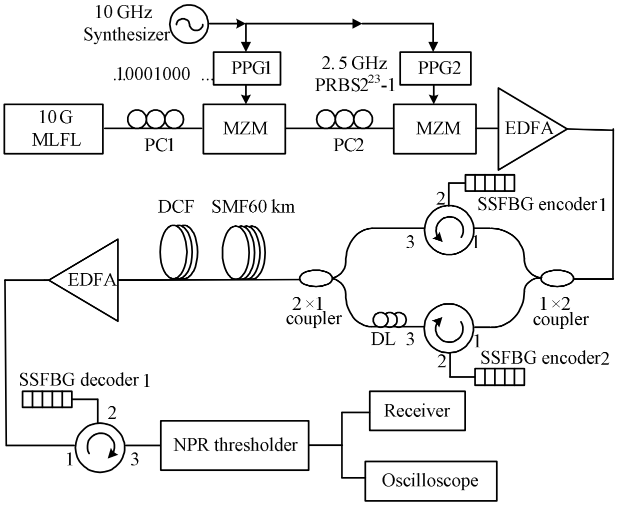

Figure 2. Experiment setup of a 2-user 2.5 Gb/s OCDMA system using NPR thresholder

We finely adjust the PCs and the gain of the EDFA in the thresholder to get a clear eye on the oscilloscope. The VOA2 is set to 5 dB in the measurement. Fig. 3 (a) shows the eye open factor of the output pulse versus the input light power of the HNLF. Fig. 3 (b) shows the eye diagrams of the output with different input powers of the HNLF. As is shown in Fig. 3 (b), the eye open factor is primarily determined by the amplitude fluctuation of the "1" bits in the decoded signal. The fluctuation will be suppressed or aggravated depending on the gain of the EDFA in the thresholder. This can be explained by the cosine-like relationship between P and $I_{out}$ in Eq. (2). The distortion of the pulse in high-power input cases may also be attributed to the other nonlinear effects, such as self-phase and cross-phase modulation. An optimum eye open factor of 0.94 is obtained at only 10.16 dBm input, as shown in Fig. 3 (a).

Fig. 4 shows the measured BER results. Fig. 5 shows the eye diagram before (up) and after (down) the NPR thresholder. A sensitivity improvement of about 2.35 dB is observed at a BER=10e-9 after 60km transmission when the NPR

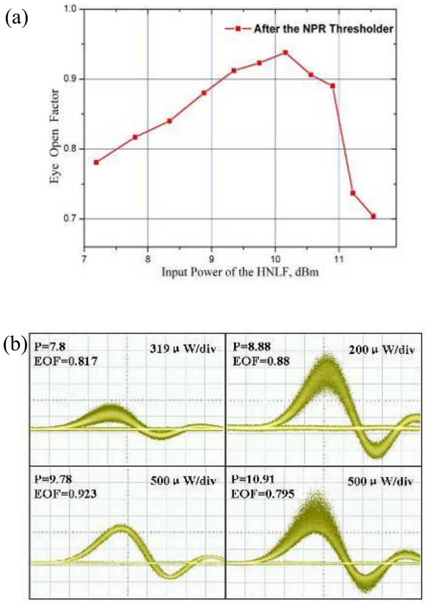

Figure 3. (a) Eye open factor (EOF) and (b) eye diagrams of the output pulse with different input powers (P, dBm) of the HNLF.

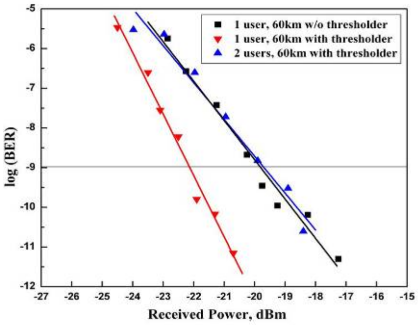

Figure 4. BER performance of the 2.5 Gb/s OCDMA system with/without the NPR thresholder.

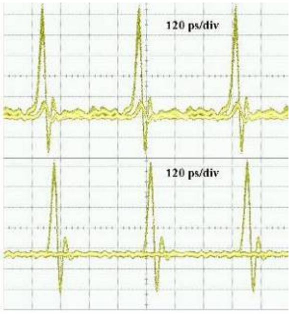

Figure 5. Eye diagram of input / output before/after the NPR Thresholder.

thresholder is used. A power penalty of about 2.44 dB at a BER=10e-9 is observed for two users compared with a single user case.

## IV. CONCLUSIONS

We have proposed a novel low-power OCDMA thresholder based on nonlinear polarization rotation. The feasibility of the NPR thresholder is experimentally demonstrated in a 2-user 2.5 Gb/s OCDMA system. We have also investigated the performance of the NPR thresholder output with different input powers. The experimental results show that this NPR thresholder offers a cost-effective solution in reducing the MAI in ultrashort pulse OCDMA systems.

## ACKNOWLEDGMENT

The author would like to thank Zhangwei Yu for her work on the fabrication of the SSFBGs and fruitful discussion.

## REFERENCES

[1] C. F. Lam, "To spread or not to spread-the myths of optical CDMA," Optical Fiber Communication Conference, OSA Technical Digest Series, paper TuV6, 2001.

[2] S. Etemad, et.al., "Optical-CDMA incorporating phase coding of coherent frequency bins: concept, simulation, experiment," Optical Fiber Communication Conference, OSA Technical Digest, paper FG5, 2004.

[3] I. Glesk, B. C. WANG, Lei Xu, V. Baby, P. R. PRUCNAL, "Ultra-fast all-optical switching in optical networks", Progress in optics, vol. 45, pp. 53-117, 2003.

[4] Hamanaka T., Xu Wang, Naoya Wada, Nishiki, A. ,Kitayama K., "Ten-user truly asynchronous gigabit OCDMA transmission experiment with a 511-chip SSFBG en/decoder," Lightwave Technology, vol. 24, no. 1, pp. 95-102, Jan. 2006.

[5] P. D. Maker and R. W. Terhune, "Study of optical effects due to an induced polarization third order in the electric field strength," Physical Review vol. 137, A801-A818, Feb. 1965.

[6] Rh Stolen, A Ashkin, J Botineau, "Intensity discrimination of optical pulses with birefringent fibers," Opt. Lett., vol. 7, no.10, pp. 512-514, Oct. 1982.

[7] T. Tanemura and K. Kikuchi, "Observation of elliptical polarization rotation in a long twisted fiber," Opt. Lett. vol. 31, pp. 882-884, April 2006.

[8] Li Yuhua, Lou Caiyun, Wu Jian, Wu Boyu, Gao Yizhi, "Novel method to simultaneously compress pulses and suppress supermode noise in actively mode-locked fiber ring laser," Photonics Technology Letters, vol. 10, no. 9, pp. 1250-1252, Sep. 1998.