

Nonlinear Optical Thresholding in a 4-Channel OCDMA System via Two-Photon Absorption

K. J. Dexter, D. A. Reid and L. P. Barry

Research Institute for Networks and Communications Engineering, Dublin City University, Dublin 9, Ireland.
karl.dexter@eeng.dcu.ie

P. Petropoulos and D. J. Richardson

Optoelectronics Research Centre, University of Southampton, Southampton, United Kingdom.
pp@orc.soton.ac.uk

Abstract: We demonstrate the use of a Two-Photon Absorption based detector in an OCDMA system. This detector provides a significant performance improvement over standard linear detection.

©2008 Optical Society of America

OCIS codes: (060.4510) Optical communications; (190.7110) Ultrafast nonlinear optics

1. Introduction

As demand for bandwidth continues to grow with the increase in internet usage, online gaming, internet telephony and other bandwidth intensive applications, optical networks continue to move closer to the end consumer through deployments such as Fibre-To-The-Home (FTTH). While current multiplexing techniques such as Wavelength Division Multiplexing (WDM) and Optical Time Division Multiplexing (OTDM) are ideally suited to long haul networks, these techniques require precise wavelength stabilisation techniques and strict synchronisation between users respectively [1], providing a limit on their overall flexibility and scalability. Optical Code Division Multiple Access (OCDMA) is an alternative multiplexing technique for access networks that can provide all optical processing, asynchronous transmission, soft capacity on demand and quality of service control [2].

While a number of techniques for encoding/decoding the OCDMA signals have been experimentally demonstrated [3-6, 10], nearly all techniques suffer from the phenomenon of Multiple Access Interference (MAI). MAI is generated when cross-correlation noise generated from the improper decoding of an optical signal is incident on an optical receiver. This noise increases with the number of users transmitting data across the network, limiting the overall system performance. A number of techniques have been proposed for MAI suppression [7-11] however many of these methods require varying lengths of fibre, are polarization dependent, can introduce signal distortion or require a synchronized clock pulse and an additional nonlinear element. In this paper we demonstrate how the nonlinear optical-to-electrical conversion process of Two-Photon Absorption can be used for simultaneous optical thresholding and detection at the operating bit rate, in an OCDMA system.

2. Two-Photon Absorption Based Optical Thresholder and Detector

TPA is a nonlinear optical-to-electrical conversion process where two photons are absorbed in the generation of a single electron-hole pair [12]. As a result, the photocurrent generated is proportional to the square of the optical intensity of the light falling on the detector. Therefore the nonlinear response of a TPA based device is dependent on the peak power of an optical pulse. This peak power dependency allows a TPA device discriminate between correctly decoded pulses (high peak powers) and MAI (low peak powers) resulting in optical thresholding of an OCDMA signal. In this paper, we present a four-channel OCDMA system employing simultaneous optical thresholding and detection using a TPA based device. The TPA device used was a commercially available 1.3 μm FP laser.

The TPA detector was characterised by measuring the photocurrent generated as a function of incident optical peak power when 2 ps optical pulses at a repetition rate of 100 MHz were incident on the detector. This result is shown in Fig. 1 (a). From the graph it can be seen that at low incident powers, the detector operates in a linear region indicated by the response having a slope of one. However, at a peak power of ~ 1 W (200 μW average power), the response starts to become nonlinear, characterised by the slope moving towards a value of two.

3. Experimental Setup

The four-channel OCDMA system used to test the TPA based detector is shown in Fig. 1 (b). The optical pulse source used was an Electro-Absorption Modulator (EAM) based pulse carver which generated a train of 25 ps optical pulses at 10 GHz. The wavelength of the pulses was 1559.22 nm in order to match the operational wavelength of the encoders.

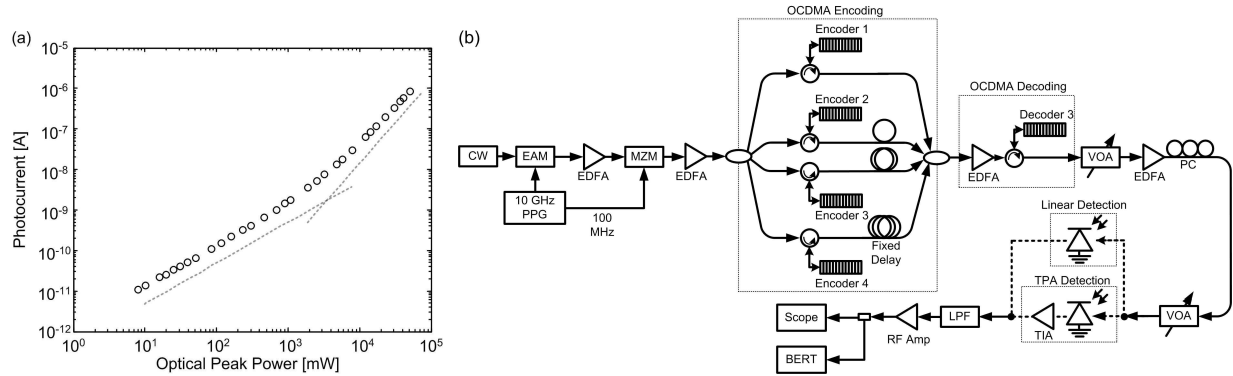


Fig. 1. (a) Plot of photocurrent as a function of incident optical peak power for the TPA detector at 100 MHz. The dashed lines represent slopes of 1:1 and 2:1 from left to right respectively (b) Experimental setup of a four-channel OCDMA system using a TPA based detector.

The 10 GHz optical pulses were then gated down to 100 MHz and data-modulated with a Pseudorandom Bit Sequence (PRBS) using a Mach-Zender Modulator (MZM). This data signal was amplified before being split using a one-to-four optical coupler. Each path from the coupler is reflected off a Fibre Bragg Grating (FBG) encoder which is used to apply the optical code corresponding to that particular channel. The FBG encoders apply 31-chip, 40 Gchip/s quaternary phase-shift keyed codes to the pulses [10]. The encoded channels passed through varying lengths of SMF fibre to ensure the data signals are uncorrelated and not mutually coherent while roughly overlapping in the time domain providing the worst case scenario in terms of MAI. The aggregate signal was amplified using an EDFA before being reflected off an FBG decoder that is matched to one of the codes used during the encoding process. A Variable Optical Attenuator (VOA) was used to vary the power that entered the optical receiver. The optical receiver itself consisted of an additional EDFA, a polarisation controller, a VOA and either a standard linear photodetector or a TPA based detector. The VOA in the receiver was used to ensure that the power falling on either detector remained constant. Due to the inefficiency of the TPA process, additional electrical amplification was required after the TPA detector. This electrical amplifier limits the bandwidth of the TPA detector to roughly 70 MHz while a low pass filter was used to ensure that the linear detector had a bandwidth of 117 MHz. The resultant electrical eye diagrams and Bit Error Rate (BER) curves were recorded using a Digital Communications Analyser (DCA) and BER tester respectively.

4. Experimental Results

Fig. 2 shows the BER curves as a function of incident average power for encoder 3 using both linear and TPA detection methods. It can be seen that error free performance (1×10^{-9}) can be achieved using a standard linear detector with a single channel (channel 3) transmitting and with an additional interfering channel, albeit with a 3.5 dB power penalty. The electrical eye diagrams for these two cases are shown in Fig. 3 (a) and (b) respectively. Fig. 3 (b) shows that the addition of a second channel degrades the eye opening due to MAI and the fact that detection is performed at the channel data rate rather than the chip rate similar to [9]. Error free performance is achieved due to the fact that the eye opening to the left is the intended data signal to be retrieved. With the addition of the third channel, the eye is closed further (Fig. 3 (c)). The measured eye diagram is multi-levelled due to the different combinations of 1's and 0's for each channel. As a result not all eye openings represent correct detection of the desired channel. Fig 2 shows that the system with 3 channels has an error floor of 1×10^{-3} . The addition of the fourth channel completely closes the eye diagram (Fig. 3 (d)). No BER data could be obtained for this four channel case.

Fig. 2 also shows the BER curves obtained using the TPA detector. It can be seen that error free performance can be achieved for the single and two channel cases with a power penalty of ~ 3 dB. Fig. 3 (f) shows the eye diagram for the two channel system. It can be seen that the interfering channel is suppressed by the TPA detector. For the three and four channels situations, the best BER achieved was $\sim 5 \times 10^{-8}$ and 6×10^{-6} respectively. However

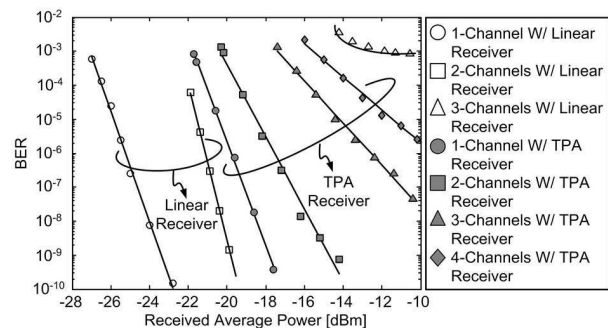


Fig. 2 Plot of the BER curves as a function of received average power for encoder 3 as each OCDMA channel to the system.

it is believed that this is due to generated optical pulses having an OSNR of 18 dB prior to transmission and noise added in the electrical amplifier after the TPA detector. Fig. 3 (g) and (h) show the eye diagrams for the three and four channel cases. Again it can be seen that the MAI from the interfering channels is suppressed by the TPA detector. The overall power penalty associated with the transition from a single channel system to a four channel system is ~ 9 dB at 1×10^{-5} . It should be noted that in the BER versus received power curves the optical power measured is for all channels, thus in a four channel system if all channels have the same average power then there is an inherent 9 dB power penalty incurred between the single channel and four channel case (with an ideal optical threshold). This result demonstrates the significant performance improvement that can be achieved using the TPA based threshold/detector operating at the data bit rate in an OCDMA system.

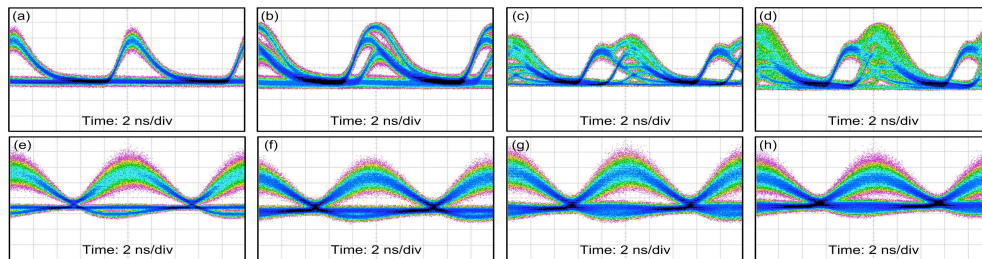


Fig. 3 (a-d) Electrical eye diagrams using linear detection for one-four transmitting channels respectively (e-h) Electrical eye diagrams using TPA detection for one-four transmitting channels respectively.

5. Conclusions

This paper has shown the use of the nonlinear optical-to-electrical conversion process of TPA in a semiconductor device as a method for simultaneous optical thresholding and detection in an OCDMA system. It was shown that the performance of the OCDMA system using a linear detector was severely degraded when more than two channels were transmitting due to MAI. However, by using a TPA based detector operating at the channel bit rate, the system performance was improved significantly with an error rate lower than 1×10^{-5} achievable with a four channel OCDMA system. As a result, TPA is ideally suited as a simultaneous optical thresholder and detector in an OCDMA system.

Acknowledgements

This research was enabled by the Higher Education Authority Program for Research in Third Level Institutions (2007-2011) via the INSPIRE programme and was supported by the Science Foundation Ireland Research Frontiers Programme ENE012.

References

- [1] N. Wada and K. Kitayama, "A 10 Gb/s Optical Code Division Multiplexing using 8-Chip Optical Bipolar Code and Coherent Detection," *IEEE J. Lightw. Technol.* **24**, 1758-1765 (1999).
- [2] X. Wang and K. Kitayama, "Analysis of Beat Noise in Coherent and Incoherent Time-Spreading OCDMA," *IEEE J. Lightw. Technol.* **22**, 2226-2235 (2004).
- [3] P. R. Prucnal, M. A. Santoro and T. R. Fan, "Spread Spectrum Fibre-Optic Local Area Network using Optical Processing," *IEEE J. Lightw. Technol.* **4**, 547-554 (1986).
- [4] E. Park, A. J. Mendez and E. M. Garmire, "Temporal/Spatial Optical CDMA Networks: Design, Demonstration and Comparison with Temporal Networks," *IEEE Photon. Technol. Lett.* **4**, 1160-1162 (1992).
- [5] D. Zaccarin and M. Kavegard, "An Optical CDMA System based on Spectral Amplitude Encoding of an LED," *IEEE Photon. Technol. Lett.* **5**, 479-482 (1993).
- [6] L. Tancevski and I. Andonovic, "Wavelength Hopping/Time Spreading Code Division Multiple Access Systems," *IEEE Electron. Lett.* **30**, 1388-1390 (1994).
- [7] J. H. Lee *et al.* "Reduction of Interchannel Interference Noise in a Two-Channel Grating-Based OCDMA System using a Nonlinear Optical Loop Mirror," *IEEE Photon. Technol. Lett.* **13**, 529-531 (2001).
- [8] I. Glesk, P. R. Prucnal, and I. Andonovic, "Incoherent Ultrafast OCDMA Receiver Design with 2 ps All-Optical Time Gate to Suppress Multiple-Access Interference," *IEEE J. Sel. Top. Quantum Electron.* **14**, 861-867 (2008).
- [9] Z. Jiang *et al.* "Four-User, 2.5-Gb/s, Spectrally Coded OCDMA System Demonstration using Low-Power Nonlinear Processing," *IEEE J. Lightw. Technol.* **23**, 143-158 (2005).
- [10] C. Tian *et al.* "A 16-Channel Reconfigurable OCDMA/WDM System using Continuous Phase-Shifted SSFBGs," *IEEE J. Sel. Top. Quantum Electron.* **13**, 1480-1486 (2007).
- [11] P. J. Maguire *et al.* "Reduction of Multiple Access Interference in a DS-OCDMA System via Two-Photon Absorption," *OFC paper OWV6* (2007).
- [12] H. Folliot *et al.*, "Two-Photon-Induced Photoconductivity Enhancement in Semiconductor Microcavities: A Theoretical Investigation," *JOSA B* **19**, 2396-2402 (2002).