Reduction of Multiple Access Interference in OCDMA Systems Using a Semiconductor Based TPA Device

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ABSTRACT
The authors present a simulation model and results for a four user OCDMA system operating at an overall data rate of 4 Gb/s (4 x 1 Gb/s). The work presents the novel use of a nonlinear detector based on TPA for simultaneous thresholding and detection in an OCDMA system. The detection of the decoded optical signal is also performed using a linear (PIN) detector separately. It is demonstrated that the use of the nonlinear detector can improve the power penalty associated with the transition from a single user system to a four user system by approximately 8.5 dB in comparison to the same system using a linear detector. These results are in good agreement with experimental results already taken.

Keywords: optical code division multiple access, two-photon absorption, nonlinear detection, optical thresholder.

1. INTRODUCTION

New multiple-access schemes for local access networks are required to meet the growing demand for high-speed and high-capacity communications, allowing simultaneous network access to each user over the same transmission medium. The current multiplexing schemes used in optical networks are wavelength division multiplexing (WDM) and optical time division multiplexing (OTDM). These formats however, require precision wavelength-stabilisation techniques and strict synchronisation between users which reduces network flexibility and scalability [1]. An alternative multiplexing format for local access networks is optical code division multiplexing (OCDM). Advantages of optical code division multiple access (OCDMA) schemes are that they allow multiple users share the same bandwidth simultaneously while providing soft capacity on demand and greater network flexibility [2].

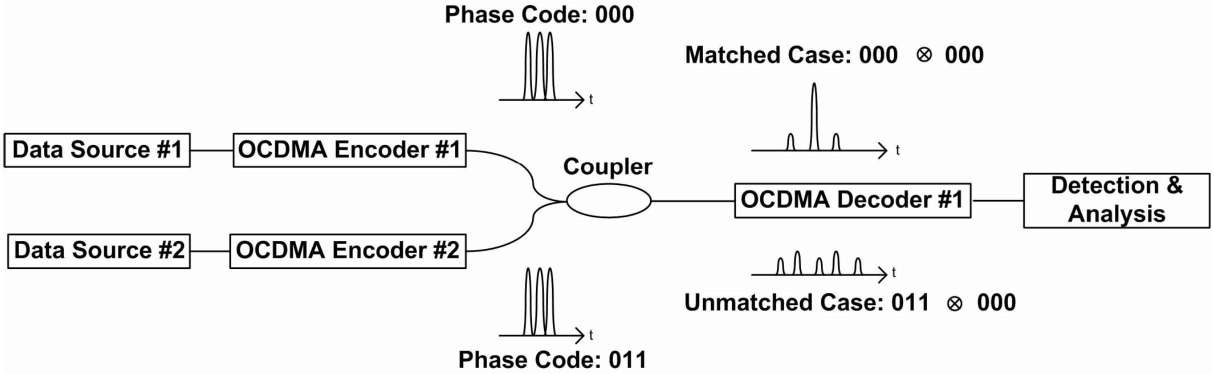

Figure 1. Diagram of a two channel OCDMA system with a single decoder.

In an OCDMA system, such as the one shown in Figure 1, each user is assigned a unique signature code. These codes are impressed upon the incoming data, with all user data then multiplexed on the same fibre. The codes used are designed to be as mutually noninterfering as possible. The desired receiver can then retrieve data sent from a specific user by correlating (matched filtering) the incoming signal with a stored version of the desired code. This creates an auto-correlation peak as seen for the matched case in Figure 1. Data sent by other users forms a cross- correlation peak (unmatched case), known as multiple access interference (MAI).

As the number of users increases, the MAI also increases, severely limiting the performance of the system. This can be overcome by increasing the length of the signature code used. However, this requires an ultra-fast pulse source in order to generate the codes needed for relatively high bit rates. Alternatively, nonlinear thresholding can be used to suppress MAI while allowing properly decoded pulses through. Examples of such nonlinear thresholding devices are nonlinear optical loop mirrors (NOLM) and periodically poled lithium niobate (PPLN) fibres [3, 4]. In this paper, we present a semiconductor based nonlinear thresholder and detector based on two-photon absorption (TPA) for use in an OCDMA system. Our results show an improvement of 8.5 dB for such a device in comparison to a standard linear detector.

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1.1 TWO-PHOTON ABSORPTION

Two-photon absorption (TPA) is a nonlinear optical-to-electrical conversion process where two photons are absorbed in the generation of a single electron-hole pair. A single photon, with energy Eph, incident on the TPA device does not have sufficient energy to generate an electron-hole pair as the device bandgap is greater than Eph but less than 2Eph. However, the simultaneous absorption of two photons results in the generation of a single electron-hole pair. As a result, the photocurrent generated is proportional to the square of the intensity falling on the detector, with the TPA process being peak-power dependent [5]. It is this nonlinear response that allows the TPA device to discriminate between the correctly decoded pulses from the decoder and the MAI present from other users, as the intensity of correctly decoded pulses is much larger than that of the MAI. TPA devices have already been shown to be suitable for optical sampling, demultiplexing and for use in autocorrelators [6, 7]. This paper presents simulation results for an OCDMA system using a commercially available 1.3 µm InGaAsP laser diode as the TPA device. This TPA device allows for simultaneous thresholding and detection from a single device for a given channel therefore reducing the system cost and complexity.

2. SIMULATION SET UP

With this simulation model, the performance improvement in a four user OCDMA system using a TPA detector in comparison to a standard linear PIN detector was investigated. The simulation model used is shown in Fig. 2. Each user generated a continuous train of optical pulses with a pulse duration of 2 ps at a repetition rate of 1 GHz at 1550 nm. The train of pulses were data-modulated with separate pseudorandom bit sequences of length 2^7- 1, to create the transmitted data. The data sequences were encoded with eight chip bipolar phase codes, with a chip separation of 5 ps. The phase codes used are based on an eight element Walsh matrix. While all the codes in the matrix are ideally orthogonal, a comparison of the size of the cross-correlation peaks for each code with respect to the others was preformed in order to find four codes that produced the least amount of MAI. This was done by measuring the auto-correlation peak for a particular code, and then measuring the cross-correlation peaks generated by the remaining user codes individually. This process yielded four codes that produced clearly distinguishable auto- and cross-correlation peaks.

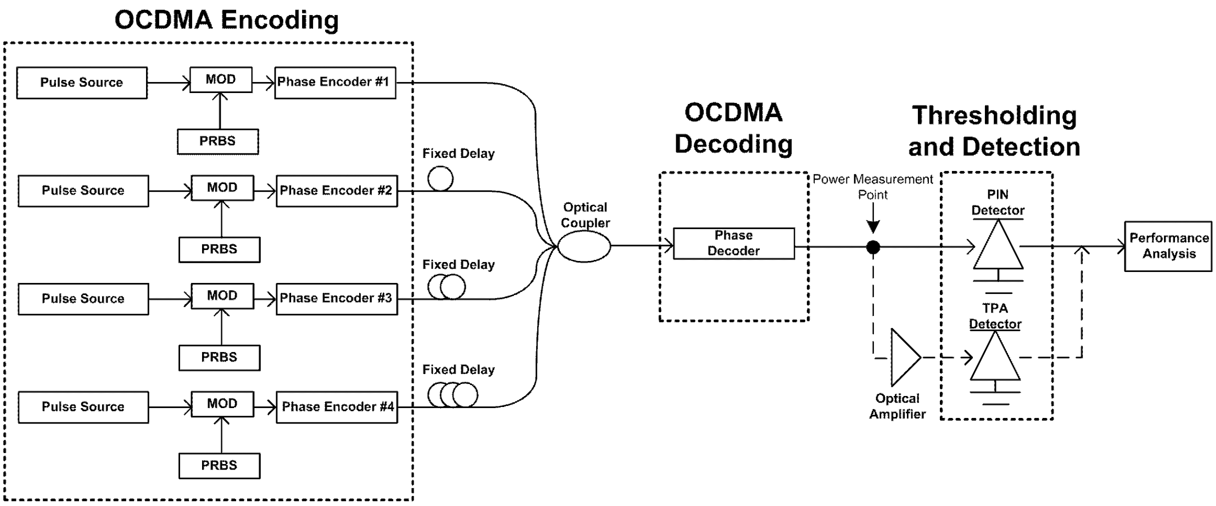


Figure 2. Four user OCDMA simulation model to demonstrate reduction of MAI interference with the use of a TPA based detector.

The encoded data from each user then passes through a fixed fibre delay line before being combined together using a passive fibre coupler. These fixed delays prevented the generated data from coherently interfering and producing beat noise [8]. The data generated by the four users was delayed by 150 ps with respect to the previous user. The combined data passed through the phase decoder which is a matched filter for one of the user codes. An auto-correlation peak was generated for a single matching code while MAI was generated for the remaining unmatched codes. The resultant optical signal was then incident on the detector (PIN or TPA) with a bandwidth of 700 MHz.

The PIN detector used in the model had a responsivity of 1 A/W. A theoretical investigation into TPA is given in [5] which forms the basis of the TPA model in the simulation. The TPA device used had a bandgap of 0.954 eV, with the single photon absorption (SPA) coefficient set to 0.01 cm-1 and a TPA coefficient of $2{\cdot}10^9$ m/W. The overall length of the device is 600 µm. To overcome the inefficiency of the TPA process, an optical amplifier is inserted just before the TPA detector with a gain of 28 dB. The average power incident on each detector is measured at the point shown in Figure 2. After detection of the optical signal, the performance of the system is then analysed by comparing the electrical outputs for the linear and nonlinear detectors separately.

3. SIMULATION RESULTS

To prove the nonlinear response of the TPA model used in the simulation, a photocurrent measurement as a function of varying incident peak power was performed. From the results shown in Figure 3, it can be seen that there is a square dependence of the photocurrent on the incident optical intensity. This square dependence is characterised by the graph having a slope of two, indicating the TPA process. It can be seen that the dynamic range of the TPA region is limited at lower energies by residual SPA and total absorption at higher energies. These regions are linear and are characterised by a slope of one.

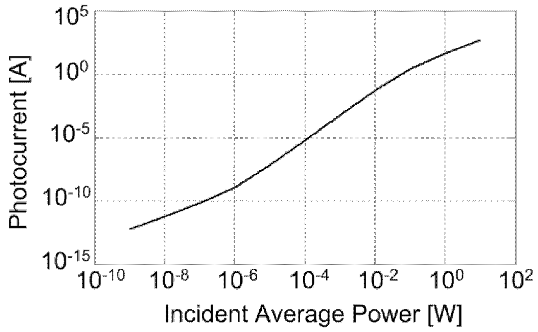


Figure 3. Plot of photocurrent as a function of incident optical power for the TPA detector.

In order to analyse the performance improvements of the OCDMA system using a TPA detector, bit error rate (BER) plots and eye diagrams were generated for the linear and nonlinear detectors separately. The phase decoder in the model was matched to the user code that showed the worst performance in terms of MAI generated by additional users, which in this simulation was user four. The power penalties associated with the addition of interfering users was measured at a BER of 10^{-9}. Figure 4*a* shows the BER versus received power plots generated for the worst performing decoder phase code, as each additional user is added onto the system using the linear detector. It can be seen that moving from a single transmitting user to a two user system incurs a power penalty of 2.9 dB. Again, this is due to the interfering users code generating a cross-correlation peak (MAI) as it passes through the decoder, resulting in the generation of errors at the detector. The power penalty associated with the transition from two to three users is a further 1.8 dB, increasing the overall penalty to 4.7 dB in comparison to a single user system. The addition of the fourth user further increases the power penalty by 6.5 dB over the three user system. Therefore the total power penalty incurred as a result of moving from a single user to a four user system is 11.2 dB.

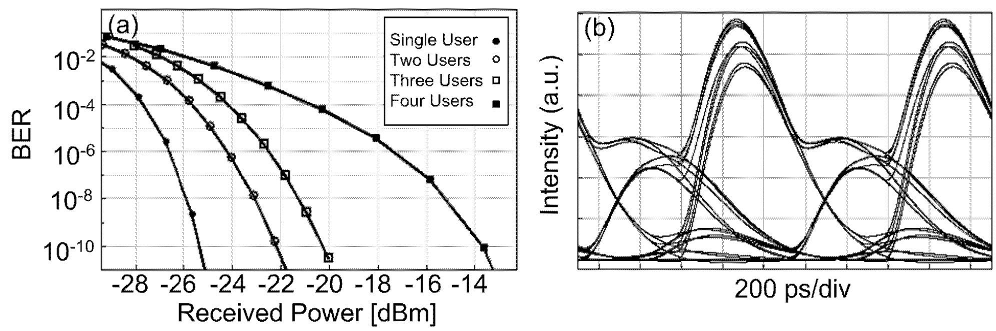
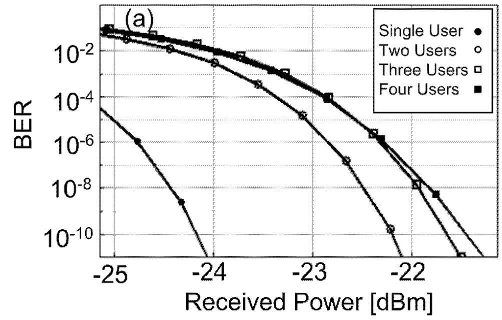


Figure 4. (a) BER plot for OCDMA system using a PIN detector; (b) Eye diagram for four user OCDMA system using PIN detector.

Figure 4*b* shows the eye diagram obtained for the four user system after linear detection. It can be seen that the MAI present results in a large side lobe adjacent to the main pulse, which significantly degrades performance.

Figure 5*a* shows the BER graph for the OCDMA system using the TPA detector for the same users as per the linear detection scheme already described. As in the case for the system using linear detection, the BER plots were obtained as each additional user was added individually. It can be seen that the power penalty incurred as a result of adding a second user is 2 dB. This is an improvement of 0.9 dB over the linear detection system. The addition of the third user results in a further penalty of 0.5 dB, bringing the overall penalty to 2.5 dB. Again, compared to the three user system with linear detection, the TPA detector gives an improvement of 2.2 dB. Adding the fourth user to the system increases the power penalty by 0.2 dB, bringing the total power penalty associated with moving from a single user to a four user system to 2.7 dB. This is an overall improvement of 8.5 dB when compared with the linear detector.



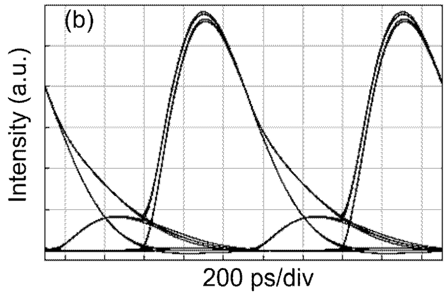


Figure 5. (a) BER plot for OCDMA system using a TPA detector; (b) Eye diagram for four user OCDMA system using TPA detector.

Figure 5*b* shows the eye diagram generated for the four user system after nonlinear detection. In contrast to Figure 4*b* it can be seen that the side lobes caused by the MAI have been significantly reduced by the TPA process. Noise at the top and bottom of the eye opening has also been suppressed, hence improving system performance when additional users are added to the system.

4. CONCLUSIONS

This paper presented a simulation model of a four user OCDMA system employing a semiconductor based TPA device that acts as a simultaneous optical thresholder and detector. It has been shown that for the worst performing decoder, the TPA detector suppressed a large amount of MAI generated by the interfering users on the system. This suppression leads to an improvement in the power penalty associated with the transition from a single user to a four user system of 8.5 dB when compared to the same results using a linear detector. These results are in good agreement with recent experimental results shown in [9]. As a result, TPA is ideally suited for simultaneous optical thresholding and detection in OCDMA systems.

5. REFERENCES

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