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Multiple access interference rejection in OCDMA using a two-photon absorption based semiconductor device

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ABSTRACT

An experimental demonstration of a two-channel OCDMA system with detection performed using standard linear detection or a TPA-based nonlinear detector is presented. These results show an improvement in the extinction ratio of the decoded signal by ~5 dB using TPA detection. A simulation model of the TPA detector used during the experiments was created and used in a four-channel OCDMA system simulation using both linear and nonlinear detection methods. The simulation results show that error-free performance is achievable for a 4-user system using the nonlinear TPA detector while the OCDMA system employing linear detection is severely limited by the effects of noise generated by adjacent optical channels (multiple access interference).

1. Introduction

Optical code division multiple access (OCDMA) is emerging as an attractive multiplexing technique for future last mile fibre optic networks such as local area networks (LAN's) and fibre to the home (FTTH) [1]. While current multiplexing techniques such as wavelength division multiplexing (WDM) and optical time division multiplexing (OTDM) are ideally suited to long-haul networks, their requirements of high precision wavelength-stabilization techniques and strict synchronization control limit their overall flexibility and scalability [2]. In comparison, OCDMA provides several unique advantages for implementation in a LAN environment such as all optical processing, asynchronous transmission, soft capacity on demand and quality of service control [3].

While a number of different methods for encoding and decoding optical signals have been presented in OCDMA literature [4–9], each coding technique suffers 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 proportionally with the number of users transmitting data across the network, limiting the overall system performance. Optical time gating and optical thresholding have been suggested in order to suppress MAI [10–13], thereby maximizing system performance. However, the methods described in the literature require a synchronized clock pulse at the receiver and/or varying lengths of fibre, increasing the complexity of the receiver and making the time gate/thresholder susceptible to environmental conditions.

The optical nonlinearity of two-photon absorption (TPA) has also been discussed for the purpose of optical thresholding [14,15]. In [14] the TPA process in a GaAs waveguide detector is used to experimentally show the pulsewidth dependence of the photocurrent from the detector using spectrally coded optical pulses, while in [15] a purely statistical treatment is applied to a spectrally-phase-encoded OCDMA system using a TPA receiver. While these papers look favourably on the use of TPA for optical thresholding, neither present any experimental results for an OCDMA system employing a TPA-based detector while the simulation models use device specifications which are not based on actual measured parameters of a TPA detector.

In this paper, an experimental demonstration of a simple two-channel OCDMA system using the nonlinear TPA process found in a commercially available 1.3 μm FP laser is presented. The experimental results clearly show the ability of the TPA detector, bandwidth-limited to the data rate of the optical signal, to suppress the interference generated by the second channel. From these results a simulation model of a TPA detector was created using the parameters and response characteristics of the device used, allowing a realistic 4-channel simulation of an OCDMA system to be analyzed. The performance improvement gained from the use of a

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TPA-based detector in comparison to a standard linear detector is demonstrated.

2. Two-photon absorption (TPA) device characterisation

TPA is a nonlinear optical-to-electrical conversion process present in semiconductor devices where two photons are absorbed simultaneously, producing a single electron–hole pair. As a result, the TPA photocurrent generated is proportional to the square of the incident optical power falling on the detector [16]. It is this square response that allows a TPA device to be used as an optical thresholder.

The TPA device for operation at 1550 nm that was investigated in these experiments was a commercially available 1.3 μm FP laser with a detection bandwidth of 1 GHz and a load of 50 Ω. This device was characterized in terms of the average photocurrent generated as a function of incident peak power using a femtosecond laser pulse source generating pulses at a repetition rate of 100 MHz with pulsewidths of 5 ps at a wavelength of 1550 nm. The resultant plot of average TPA photocurrent as a function of input peak power is shown in Fig. 1, for both experimental characterization data (○), and for the TPA model (–) described later in the simulation section. In addition, Fig. 1 shows two lines with slopes of 1 and 2, respectively. By using these lines are a reference, it can be clearly see that the TPA detector starts to exhibit a nonlinear (slope of 2) response at incident peak powers greater than 5 W.

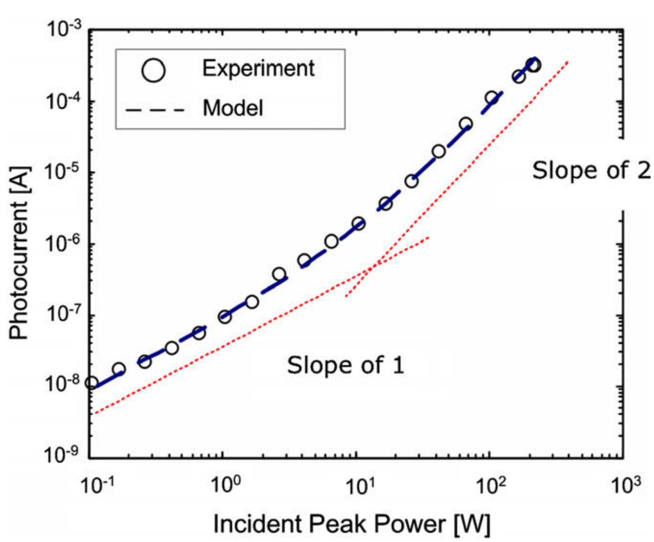

Fig. 1. Plot of average TPA photocurrent generated as a function of incident peak power.

3. Experimental setup and results

To determine the feasibility of a TPA-based optical thresholder and detector in an OCDMA system, a simple two-channel back-to-back OCDMA system was investigated (see Fig. 2) [17]. Optical pulses with durations of 28 ps were generated at repetition rate of 10 GHz at a wavelength of 1561 nm. The corresponding pulse train was gated down to 155 MHz and encoded with a PRBS data signal before being split by a 50:50 optical coupler. The first arm of the OCDMA encoding stage consists of a 150 m reel of SMF, and EDFA, an optical circulator and the optical encoder. The SMF was used to ensure that the two copies of the signal that propagate through the first and second arms of the encoding stage are uncorrelated and are not coherently interfering when recombined. The encoding/decoding process was achieved using super-structured fibre bragg gratings (SSFBG's), with the SSFBG encoders applying two 31-chip, 40 Gchip/s quaternary phase shift keyed codes. The second arm of the encoding stage consists of an optical delay line (ODL), EDFA, optical circulator and a second slightly different SSFBG for channel 2. The ODL allows the relative timing between the two codes to be adjusted at the output of the transmitter. The two encoded signals were then combined before entering the decoding stage. The decoder stage used in the experiment consisted of an EDFA and a single SSFBG, with the SSFBG designed to match that which is used to encode data for channel 1. Once decoded, the signal then entered the detection and analysis stage which is shown in more detail in Fig. 3.

The analysis and detection stage consists of two detection subsystems (a nonlinear thresholder and detector, and a linear detector) and a system performance analysis section which consisted of a digital communications analyzer (DCA) which allowed the production of optical eye diagrams. The output of the optical decoder enters an inline power meter/attenuator which allowed the average power of the optical signal to be constantly monitored. The nonlinear thresholding and detection sub-system consisted of an EDFA, polarization controller, a 1.3 μm laser diode (InGaAsP, bandwidth ∼1 GHz) acting as a TPA detector and a low noise RF amplifier.

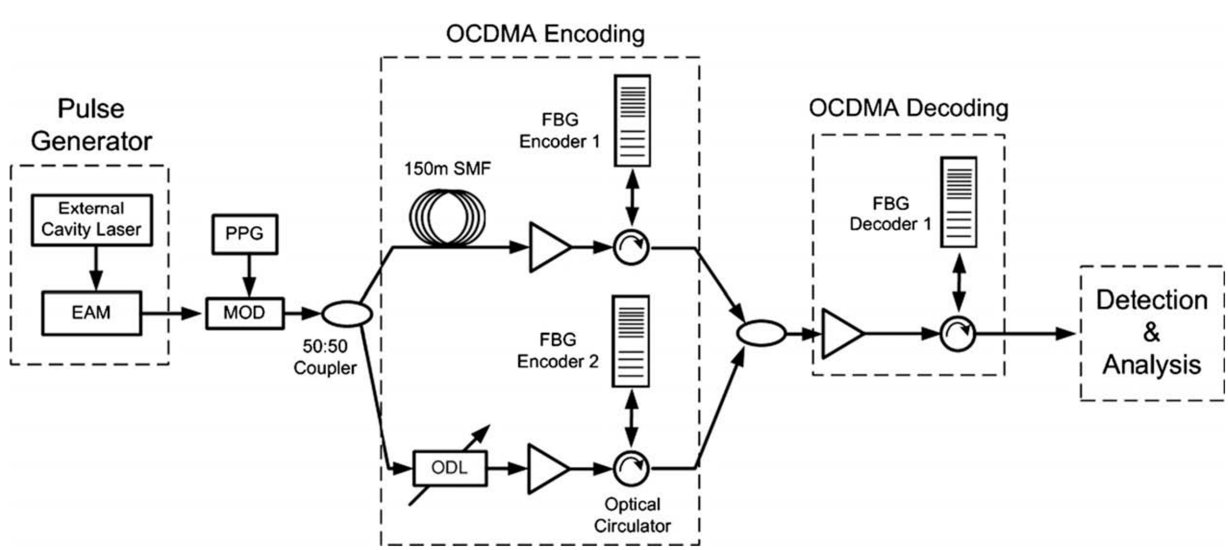

Fig. 2. Experimental setup for an OCDMA system compromising of two encoders and one decoder.