Experimental assessment of the gating functionality of a TOAD operating at 1310 nm in high speed OTDM systems

R.J.W.Jonker, R.C.Schimmel and H. de Waardt

Eindhoven University of Technology, Faculty of Electrical Engineering, Electro-Optical Communications, P.O. Box 513, 5600 MB Eindhoven, The Netherlands (e-mail: R.J.W.Jonker@tue.nl)

In this paper, an experimental analysis of the gating characteristics of the TOAD for different granularities (tributary bitrates) of an OTDM stream is presented. This study is based on the evaluation of the time-domain response (i.e. the switching window) and Contrast Ratio (CR) measurements of the dropped tributary and the residual (through) signal. The minimum obtainable switch window is approximately 6 ps for the TOAD under investigation and allows deployment in a 160 Gbit/s environment. Applying a TOAD in an OTDM add/drop node is possible with optical granularities up to 2.5 Gbit/s. Application as an OTDM demultiplexer is possible at higher granularities (10 Gbit/s) at the expense of reduced CR of the dropped tributary.

Introduction

In high capacity systems, based on Optical Time Division Multiplexing (OTDM), a key function at the receiver or OTDM add/drop node, is the demultiplexing/dropping of a sub-channel (tributary). The total capacity C (# bit/s) of this single wavelength Return-to-Zero (RZ) transmission system is limited by the pulsewidth of the RZ clock signal. In general, the maximum obtainable bitrate in the optical domain is beyond the capability of the current state of the art electrically driven intensity modulators. Therefore, a combination of Electrical and Optical time division multiplexing (ETDM and OTDM, see Fig. 1) has to be applied to deploy single wavelength systems beyond 40 Gbit/s [1].
At the receiver end or at an OTDM add/drop node, an optical switch is used to demultiplex or drop a single OTDM tributary. A Terahertz Optical Asymmetrical Demultiplexer (TOAD) is a Sagnac interferometer build around a Semiconductor Optical Amplifier (SOA), which can perform this switch function [2]. In this paper, we focus on the gating characteristics of a TOAD in a high speed OTDM environment. The width of the TOAD's switching window limits the maximum bitrate of the OTDM stream, since it determines a single time-slot in the TDM system. However, due to the slow recovery of an SOA, the performance of the TOAD is also dependent on the probe pulse repetition rate, i.e. the granularity (tributary bitrate) of the OTDM system.
In the experimental assessment, the electrical granularity b is fixed at 622 Mbit/s (see Fig. 1) and n electrical tributaries (n = 1,2,4,8 and 16) are multiplexed, which corresponds to 622 Mbit/s up to 10 Gbit/s respectively. Therefore, the bitrate of an optical tributary (granularity) of the TOAD equals b x n, corresponding to 622 Mbit/s up to 10 Gbit/s, which means that a 160 Gbit/s OTDM system (C = 160 Gbit/s) will be interpreted as a 256x622 Mbit/s (m = 256, b x n = 622 Mbit/s) or as a 16x10 Gbit/s (m = 16, b x n = 10 Gbit/s) respectively (see Fig. 1).

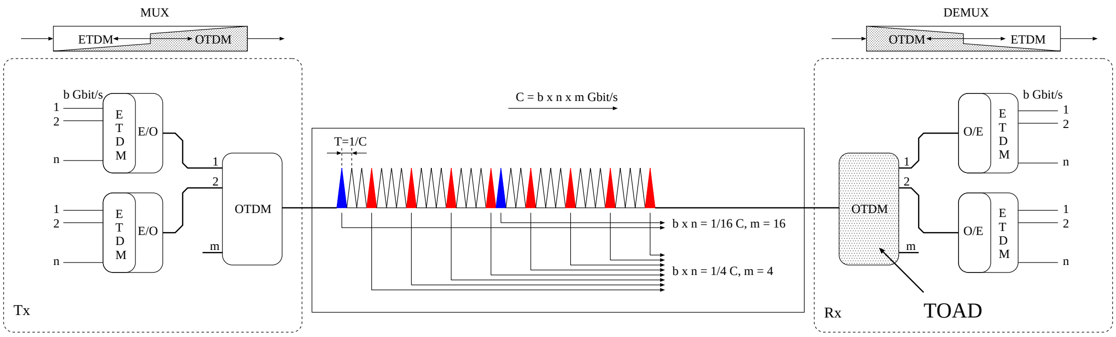

Figure 1: Schematic overview of point-to-point transmission system using Optical and Electrical Time Domain Multiplexing with transmission capacity $C = b$ x n x m, with b ETDM granularity, n number of electrical tributaries of ETDM signal and m number of optical tributaries of OTDM signal (O/E optical-to-electrical conversion)

Experimental Setup

The experimental configuration is shown in Fig.2A. The TOAD is build around a 1.31 μm SOA (Philips MQW CQF882), which is placed slightly outside the loop centre ($\Delta\tau$) by means of a tuneable optical delay. The polarisation beam splitter allows the probe signal to enter the TOAD as a probe pulse orthogonally polarised with respect to the data signal. To measure the envelope and the contrast ratio (see Fig.2B) of the switch window, a continuous wave signal is gated with the probe pulses. This continuous wave signal entering the TOAD, is divided into a clock-wise (cw) and a counter clock-wise (ccw) component, by means of a 50/50 coupler. The orthogonally polarised probe pulse saturates the SOA, changing the refractive index and propagation constant. Hence, the cw- and ccw-component encounter a different delay which results in a phase shift. If the phase shift equals π, which results in destructive interference at the 50/50 coupler, the data signal will be directed to the output port of the TOAD [2]. To block the probe signal, which is also present at both output ports of the switch, a 1 nm bandpass filter is used (see Fig.2A).

In all experiments, the wavelength of the (continuous wave) data signal is fixed at 1300 nm with an optical power of -10 dBm. The probe signal is generated by an optical pulse source which provides soliton shaped optical pulses with a pulsewidth of approximately 5 ps (FWHM) at 1314 nm. The probe switch energy E is kept constant at 0.2 pJ, which is an experimentally determined optimum for the setup.

Results and Discussion

The described setup (Fig.2A) is used to analyse the switching characteristics of the TOAD (Fig.2C). Since a continueous wave signal is used at the data input, applying probe pulses will reveal information about envelope and contrast ratio of the switch at the drop and through port simultaneously. These characteristics ultimately determine the performance of the TOAD in an high speed OTDM system, since the convolution of the OTDM bit stream and the envelope results in the dropping/demultiplexing of a single tributary and also determines the quality of the remaining signal at the through port.

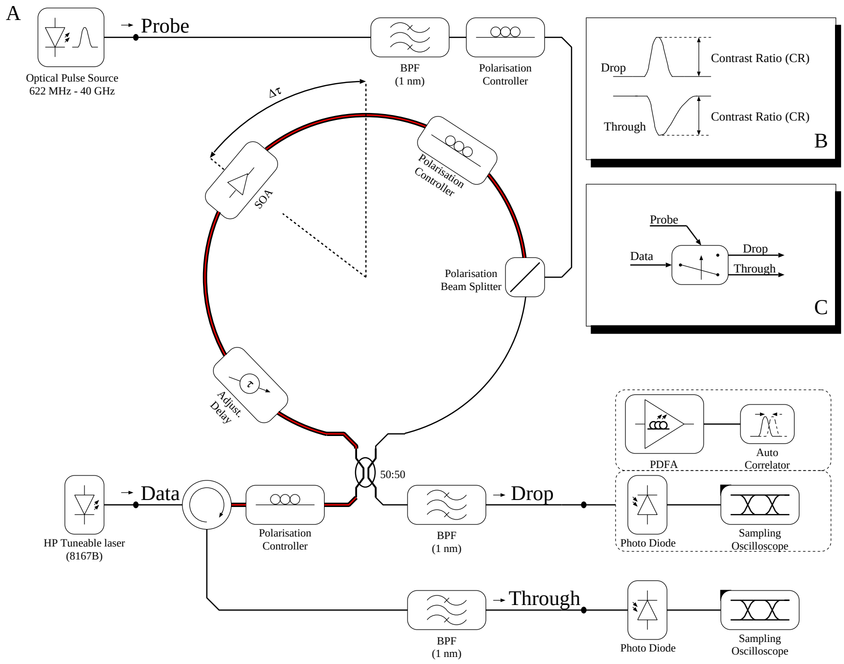

Figure 2: A) Experimental setup for performance assessment of a Terahertz Optical Asymmetrical Demultiplexer (TOAD) (BPF Band Pass Filter, SOA Semiconductor Optical Amplifier, PDFA Praseodymium Doped Fibre Amplifier). B) TOAD output signals envelope. C) Functional block representation of TOAD.

The switch window is determined, among other things, by the position of the SOA with respect to the loop centre and the rise time of the probe pulse and the time response of the SOA [2]. In the experiments $\Delta\tau$, which determines the position of the SOA in the loop and hence the width of switch window, is kept constant to yield a switch window of approximately 10 ps, estimated from the autocorrelation trace (not shown). The low sensitivity of the autocorrelator used, necessitates amplification of the signal at the drop port, carrying the switch window information (Fig.2A). A Praseodymium Doped Fibre Amplifier (PDFA) is used to boost this signal to the desired power level, without distorting the waveform[3]. The minimum obtainable switch window of the setup, estimated from the autocorrelation trace (not shown) is approximately 6 ps (FWHM). This allows the setup to be used in an 160 Gbit/s OTDM environment.

Fig. 3a shows the oscilloscope traces for different granularities, at the drop port of the switch for the continueous wave input signal. Note that the time response is limited by the electrical bandwidth of both photodiode and sampling oscilloscope. From the graph it becomes clear that the CR at the drop port reduces as the bitrate of the tributaries increases. For rates up to 2.5 Gbit/s the performance is optimal. Increasing the granularity up to 5 and 10 Gbit/s further reduces the contrast of the switch. Bitrates above 10 Gbit/s (not shown in Fig. 3a) result in further degraded performance, which prohibits practical application of the switch in a OTDM add/drop node. However, these granularities can still be applied in a TOAD based demultiplexer, albeit with a reduced CR.

The time response of the through channel in depicted in Fig. 3b. From the graph can be concluded that at higher granularities ($\geq$ 2.5 Gbit/s) the SOA does not recover from saturation induced by the probe pulses. The switch contrast increases for decreasing gran-

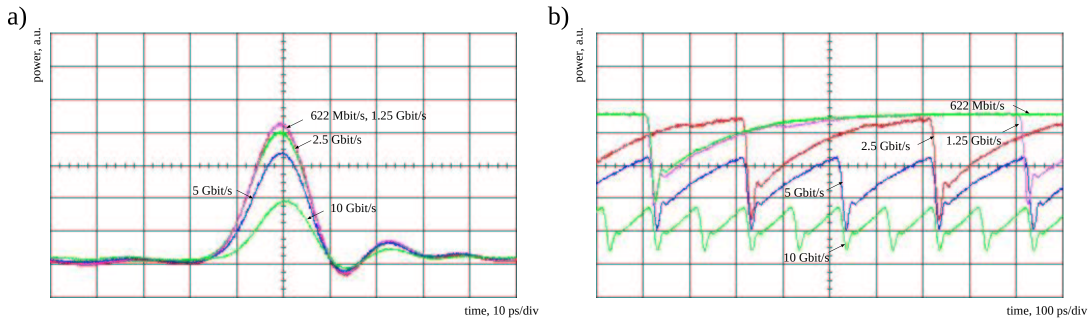

Figure 3: Switch characteristics of the drop (a) and through (b) channel for different optical granularities.

ularities and at 1.25 Gbit/s (and lower rates) the SOA recovers completely.
To avoid crosstalk in an OTDM add/drop node, clearing or suppression of a tributary is important since any residual optical power in a TDM time slot can not be filtered out at the receiver end. Therefore, the application of this TOAD configuration in an add/drop node is limited to granularities up to 2.5 Gbit/s.

Conclusions

A Terahertz Optical Asymmetrical Demultiplexer (TOAD) is capable of demultiplexing a high speed OTDM stream. The performance of the gating is dependent on the granularity used, where granularities up to 2.5 Gbit/s, have a better performance than 5 and 10 Gbit/s. For a TOAD, used in an add/drop configuration, the clearing of the dropped TDM time slot in the through channel is important, since any residual power in this time slot will lead to crosstalk penalties. The contrast ratio or the suppression of the dropped time slot is also dependent on the granularity used and improves significantly at granularities lower than 5 Gbit/s. The TOAD analysed indicates capability to demultiplex/drop a single tributary from a 160 Gbit/s OTDM stream, based on the minimum switching window of 6 ps, and has a optimal performance for granularities of 2.5 Gbit/s or less. Operating the TOAD as a demultiplexer at 10 Gbit/s (and higher granularities) is possible at the expense of a reduction in switch contrast, due to the incomplete relaxation of the SOA in the TOAD.

Acknowledgment

Part of this work was carried out within the framework of the B4-RETINA project.

References

[1] T. Koonen and H. de Waardt et al.,”A very high capacity optical fibre network for large scale antenna constellations: the RETINA project”, in *Proc. of the 6th European Conference on Networks and Optical Communications (NOC2001), Adastral Park, Ipswich*, 2001, pp. 165-172

[2] J. P. Sokoloff and P. R. Prucnal et al., ”A terahertz optical asymmetric demultiplexer (TOAD)”,*IEEE Photonics Technology Letters*, vol. 5, no. 7, July 1993, pp. 787-790

[3] R.C. Schimmel and R.J.W. Jonker et al., ”Experimental assessment of 1.3 um telecommunication system incorporating a Praseodymium Doped Fibre Amplifier (PDFA)”, *Proc. of 5th international conference on application of photonic technology (ICAPT2002), Quebec, Canada*, June 2002