Terahertz Optical Asymmetric Demultiplexer Switch with a Symmetrical Switching Window

Hoa Le-Minh, Zabih Ghassemlooy, Wai Pang Ng., and Razali Ngah
Optical Communications Research Group, School of Engineering and Technology
Northumbria University, Newcastle upon Tyne, NE1 8ST, United Kingdom
Phone: +44 (0)191 227 4902, Fax: +44 (0)191 227 3684
Emails:{h.le-minh, fary.ghassemlooy, wai-pang.ng, razali.ngah}@unn.ac.uk

Abstract

The paper presents a novel symmetrical and narrow switching window for a terahertz optical asymmetrical demultiplexer (TOAD) switch. This is achieved by saturating the semiconductor optical amplifier (SOA), located within the TOAD loop, from both directions. So that, both clockwise (CW) and counter-clockwise (CCW) data components will experience the same fast saturation effect when propagating through the SOA. Simulation results show that a symmetrical switching window with fast rising and falling times is obtained regardless of the SOA length.

1. Introduction

For future ultra-high speed photonic network based on optical time division multiplexing (OTDM), optical switches are one of the essential components. There are a number of approaches to implement the optical switches such as nonlinear optical loop mirror (NOLM) [1], terahertz optical asymmetric demultiplexer (TOAD) [2], ultrafast nonlinear interferometer (UNI) [3],[4] and symmetrical Mach-Zehnder (SMZ) [5],[6]. The advantages of TOAD switches are low switching energy, a simple structure and identical propagation paths for signals within a short length fibre loop. The width of the switching window is determined by the offset of SOA from the central point of the loop. The major limitations of TOAD switches are the finite length of fibre loop and the SOA. The loop length, which sets the switching window, is only critical at lower data rates where a longer length of fibre loop is required. However, at higher data rates where the switching window width is only a few picoseconds, the loop length is rather short. The second limitation is due to the counter-propagation of the control pulse with the CW (or CCW) data pulses within the SOA, which results in an asymmetrical window profile. TOAD with asymmetrical switching window profile results in an increased crosstalk and reduced switching speed [7]. To overcome this deficiency, optical switch based on two cascaded TOADs has been reported [8]. In this paper, we propose a novel method of generating a symmetric and narrow switching window profile for a single TOAD switch by saturating the SOA from both directions using two identical control pulses.

2. TOAD switch with single control pulse

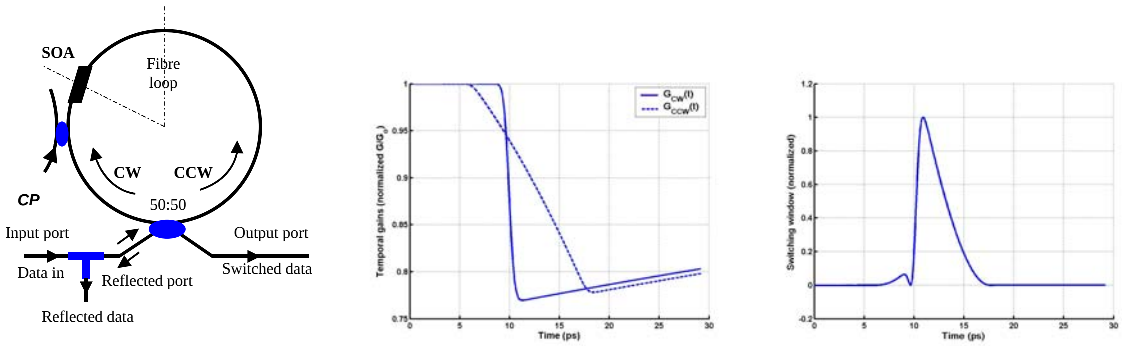
The TOAD switching window profile is defined by the characteristics of the gain and phase profiles of the CW and CCW components propagating within the loop. In a switch, data entering the input port of TOAD are split at a 50:50 input coupler into two CW and CCW components, see in Fig. 1(a). With no control pulse, CW and CCW components propagating within the loop will experience the same unsaturated amplifier gain G_0, recombine at the input coupler and emerge from the reflected port. Introducing a control pulse (CP) via a second coupler in CW direction will change the optical properties of the SOA, and as a result, the CW and CCW components will experience different gain saturation profiles (known as co-propagation and counter-propagation effects). Therefore when recombined at the input coupler, data will exit from the output port, thus switching of a particular channel or packet. An expression for the TOAD switching window is given by [9]

$$G_{TOAD}(t) = 0.25\left[G_{CW}(t) + G_{CCW}(t) - 2\left[G_{CW}(t)G_{CCW}(t)\right]^{0.5}\cos\Delta\phi(t)\right], \qquad (1)$$

where $\Delta\phi(t)$ is the phase difference between the CW and CCW components.

In order to study the effects of control pulses propagations within the SOA, the SOA is modelled as a number of small segments. Thus the gain and phase modulations on the passing signals are the accumulation of responses of all the segments [7,10].

For switching a particular channel or a complete packet, the CW and CCW components must have different phase characteristics before arriving at the input coupler. Therefore when recombined, data will emerge from the output port. To achieve this, the CP enters the SOA after the switching-target CW component but before the switching-target CCW component, and fully saturates the SOA. The CW component entering the SOA well before the CP will experience G_0. However, the next CW component entering the SOA after the CP will experiences a full-longitude saturated gain G_{SAT} of the SOA, see $G_{CW}(t)$ profile in Fig. 1(b). The transition time from G_0 to G_{SAT} is mainly determined by the width of the CP. On the other hand, CCW component entering the SOA following the CP will experience partial-longitude saturated gains (at different values) of SOA. The partial gain is mainly determined by the locations of both the CP and CCW components within the SOA, which results in a reduced slow gain response as shown in Fig. 1(b). The CCW component experience fully saturated gain once the CP has exited the SOA. The slower response of $G_{CCW}(t)$, which lasts in $2T_{SOA}$ [11], contributes to the longer slope of the switching window, see Fig. 1(c). For such switch, it has been shown that asymmetrical triangle-shape switching window results in an increased crosstalk due to non-target channels [7]. For zero crosstalk, the TOAD should ideally have a perfect square-shaped switching window exactly covering the target channel. This can only be achieved if the SOA is considered as a point element and the control pulse has an impulse characteristic, which is not a practical solution. Here we introduce a novel scheme for saturating the SOA in order to achieve symmetrical switching window.

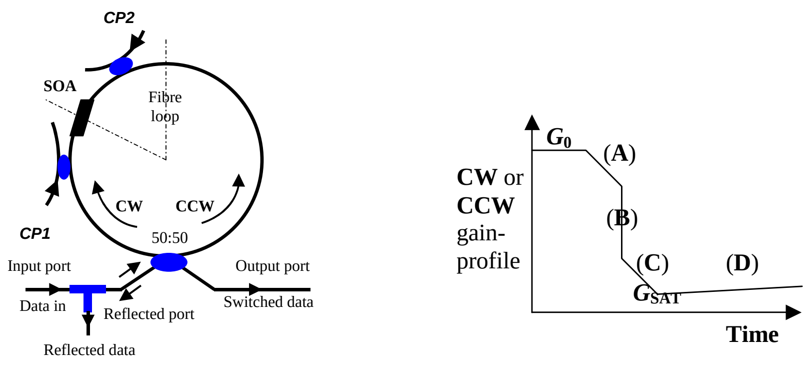


(a) (b) (c)

Fig. 1: (a) TOAD with single control pulse, T_{asym} = 2ps (b) gain profiles and (c) asymmetrical switching window

3. TOAD switch with dual control pulses

As shown in Fig. 2(a) the SOA is simultaneously excited from both directions by two identical control pulses. In the absence of the CP, CW and CCW components will experience the same SOA gain G_0, and therefore resulting in no switching as outlined in section 2.



(a) (b)

Fig. 2: (a) dual excitation TOAD switch (b) Theoretical gain profiles $G_{CW}(t)$ or $G_{CCW}(t)$

With the CPs applied via couplers into the SOA after and before the switching target CW and CCW components, respectively, the CW and CCW components will experience different gain and phase properties of the SOA as outlined below:

(a) With the CPs located at the first and last segments of the SOA, CW and CCW components residing within the SOA are subjected to the gain and phase changes of the SOA induced by only the counter-propagating

CP2 (CCW direction) and CP1 (CW direction), respectively. The $G_{CW}(t)$ and $G_{CCW}(t)$, within the period of T_{SOA} in this case, display identical slow responses as shown in the region **A** in Fig. 2(b).

(b) With the CPs now located at the last and first segments after propagating within the SOA, CW component (of T_{SOA} period in length) following CP1 propagating through SOA will experience gain saturation due to CP1, as shown in region **B** with steep transition in Fig. 2(b). However, due to counter propagating CP2, the SOA is further saturated to a new level, but with slow response, as shown in region **C** in Fig. 2(b).

(c) When both CPs having exited the SOA, the gain recovery process backs to its initial value of G_0. Therefore any new CW and CCW components arriving at the SOA will experience the recovery gain characteristics as shown in region **D** Fig. 2(b).

The gain profile for CCW component should also be identical to that of CW component with steep region **B**. Therefore the resultant switching window should display a symmetrical profile, as outlined in the following section.

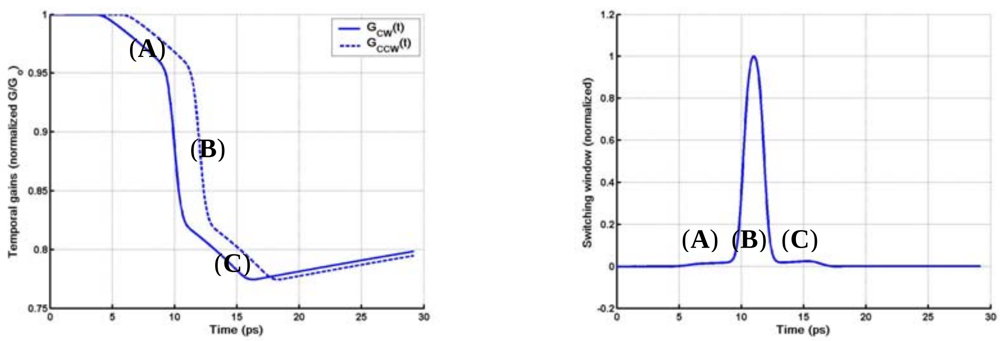
4. Simulation Results

The TOAD switch, excited by two identical control pulses, is simulated using MATLAB®. The obtained gain profiles are substituted into the equation (1) to obtain the switching window. The simulation work is based on the previous work reported in [9]. The main simulation parameters used are shown in Table I.

Parameters	**Values**
SOA length	500 μm
SOA recovery time	100 ps
SOA confinement factor	0.3
SOA transparent carrier density	10^{24} m^{-3}
SOA linewidth enhancement	4
SOA active area	$3x10^{-13}$ m^2
SOA differential gain	$2x10^{-20}$ m^2
Number of SOA segments	100
Control pulse width (FWHM)	1 ps
Single control peak power (P_{CP})	1 W
Dual control peak power (P_{CP1}= P_{CP2})	0.5 W per CP
T_{asym}	2 ps

Table I: Main simulation parameters

The normalized $G_{CW}(t)$ and $G_{CCW}(t)$ shown in Fig. 3(a) display identical profiles with three distinct regions as in Fig. 2(b). The resultant switching window profile shown in Fig. 3(b), is symmetrical and with a full width half magnitude of 2ps equal to the temporal separations between $G_{CW}(t)$ and $G_{CCW}(t)$ in Fig. 3(a). Notice that the base of the switching window is not completely flat. This is due to the slow slopes of regions **A** and **C** in Fig. 3(a).



(a) (b)

Fig. 3: Simulation result for TOAD switch using dual control pulses with P_{CP1} = P_{CP1} = 0.5W, T_{asym} = 2ps (a) the gain profiles and (b) the corresponding symmetrical switching window

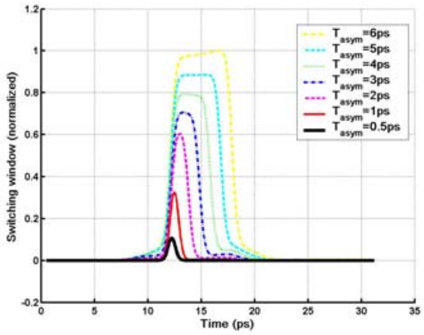


Fig. 4: Switching window profiles for different values of T_{asym}

We further investigated the switching window profiles using the same parameters in Table 1 except for different T_{asym} values. As shown in Fig. 4, increasing T_{asym} will increase the switching window height (amplitude) and its width. This is because $G_{CW}(t)$ and $G_{CCW}(t)$ for all values of T_{asym} are the same but differ only in the temporal separations. The slopes **A** and **C** of gain profiles (as in Fig. 3(a)) will determine the flatness of the switching window since these regions will appear inside the switching interval when T_{asym} is large. Therefore changing the power will certainly affect switching window profile and this is currently being investigated

5. Conclusions

A new scheme for saturating SOA within a TOAD switch has been proposed and simulated. The results obtained for the gain profiles and switching window show a narrow and symmetrical profile compared with the traditional single control TOAD switch. It is shown that the switching window profiles depend on the control pluses power, which is currently be studied.

6. Acknowledgements

The authors would like to thank Northumbria University for sponsoring this research. Thank is also due to Dr. Graham Swift (Sheffield Hallam University) for the helpful discussions.

References

[1] N. J. Doran, and D. Wood, “Nonlinear optical loop mirror”, Optics Letters, 13 (1), pp.56-58, Jan. 1998.
[2] J. P. Sokoloff, P. R. Prucnal, I. Glesk, and M. Kane, “a Terahertz optical asymmetric demultiplexer (TOAD)”, IEEE Photon. Technol. Lett., 5 (7), pp.787-790, 1993.
[3] N. S. Patel, K. L. Hall, and K. A. Raushenbach, “40 Gbits cascadable all-optical logic with an ultrafast nonlinear interferometer”, Opt. Lett., 21, pp. 1466-1468, 1996.
[4] S. A. Hamilton, B. S. Robinson, T. E. Murphy, S. J. Savage, and E. P. Ippen, "100 Gb/s Optical time-division multiplexed networks", J. Light. Techno., 20 (12), pp. 2086-2100, Dec. 2002
[5] S. Nakamura , K. Tajima, and Y. Sugimoto, “Experimental investigation on high-speed switching characteristics of a novel symmetric mach Zehnfer all optical switch”, Appl. Phys. Lett., 65, pp. 283-285, 1994.
[6] R. Ngah, and Z. Ghassemlooy, “Simulation of simultaneous all optical clock extraction and demultiplexing for OTDM packet signal using SMZ switches”, European NOC2004, Eindhoven, pp. 437-442, Jun. 2004
[7] C. Y. Cheung, “Noise and Crosstalk analysis of All-optical Time Division Demultiplexers”, PhD thesis, 2001
[8] B. C. Wang, V. Baby, W. Tong, L. Xu, M. Friedman, R. J. Runster, I. Glesk, and P. Prucnal, “A novel fast optical switch based on two cascaded Terahertz Optical Asymmetric Demultiplexers (TOAD)”, Opt. Express, 10 (1), pp.15-23, Jan. 2002.
[9] M. Eiselt, W. Pieper, and H. G. Weber, “SLALOM: semiconductor laser amplifier in a loop mirror”, J. Light. Tech., 13(10), pp. 2099-2110, 1995.
[10] G. Swift, “Modelling of an Optical Time Division Demultiplexer”, PhD thesis, 1997
[11] G. Swift, Z. Ghassemlooy, A. K. Ray, and J. R. Travis, “Modelling of semiconductor laser amplifier for the terahertz optical asymmetric demultiplexer”, IEE Proc.-Circuits Dev. Syst., 145 (2), pp. 61-65, Apr. 1998.