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Design of SOA based Uni in Dual Rail Switching Mode using a Cascaded Optical Delay Interferometer

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***Abstract*—The prospect of increasing by a factor of two the data speed of the semiconductor optical amplifier based ultrafast nonlinear interferometer in dual rail switching mode by means of cascaded optical delay interferometer is scrutinized and represented by means of the numerical simulation. Based on the respective analysis it has been found that such extension may not possible without employing this passive element for any selection of crucial parameters but the SOA carrier lifetime for which the requirements are yet very stringent. If, although the time delay introduced by the optical delay interferometer is approximated to almost** 1/3rd **of the bit period, then the outcome of the Boolean XOR operation can be improved for a particular range of parameter values which is in turn selected to be more relaxed than is feasible when the ODI is not being used. The ODI allows both error-free and patterns free performance at the output of the interferometric structure designated as ultrafast XOR gate. In this manner, this scheme can offer a substitute solution for extending the operating rate of this logic module and developing its victimization as a basic building unit in the revolutionary all-optical circuits and subsystems.**

***Index Terms*— SOA, UNI, dual rail switching mode, ODI.**

I. Introduction

Optical circuits may be considered to be a fundamental stepping stone of the optical transmission system. The demand for bandwidth may correspond to play a challenging role in optical telecommunication networks. The semiconductor optical amplifier based ultrafast nonlinear interferometer is a significant type of switch for executing, only with the help of light the processing tasks required towards a higher degree of transparency without the problematic optoelectronic conversions and associated bottleneck in fore coming photonic networks[1]. it is considered as the best candidate material as it has high compactness, flexibility, stability and so on.[2]In this view, it has also been recognized to be the fundamental building block for many different node functionalities.[3]It is mandatory to satisfy the needs of the increasing bandwidth demand in broadband lightwave networks, it has become clear that the working rate of UNI XOR should comply with the current trend. The intense research efforts have been made including the use of double UNI configuration and then the combination with so-called TURBO SWITCH as well as of a modified version of standard switching [4].
These schemes have managed to achieve faster XOR operation and they are characterized by a significant degree of technical complexity in terms of the excessive SOA and consequent filters required with the associated performance limitations while the adjustment of the corresponding setups as well as the process of logically

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forming the XOR output is rather tricky. It would be preferable if this issue could be addressed in a more affordable way and a practically efficient alternative relies on placing an optical delay interferometer (ODI) in series with the considered gate. [5]However the potential of this combination has been explained for the case of the SOA based mach Zehnder interferometer but not for the UNI where the strain imposed on the SOA gain dynamics in dual rail switching mode is inherently heavier due to its single arm geometry and accordingly the employment of the ODI to confront is expected to be more demanding.

There has been no periodical study of its capability for speed and performance development until now, but the theoretical work focused only on its logical outcome. hence there exists a lag in knowledge and in order to fill it the ODI technique is applied to the traditional UNI whose competence to be structured like the full pattern – operated XOR gate has been recently predicted. This is attained by means of numerical simulation focused at scrutinizing the impact of the critical parameters of operation on the Q factor, which is in turn to be analysed and it is considered to be an ultimate performance criterion and extracting specific rules for their selection in order to improve this metric and improve the design of the whole setup. In this wise, the contribution of the ODI in doubling the rate of bitwise switching from our aforementioned work is assessed. As it will be shown this is possible only if this passive element is cascaded at the output of the interferometric module since then there is simultaneous there is a probability for each critical parameter that allows this to happen. The theoretical confirmation of this fact can tend to the adaptation of the optical delay interferometer a more feasible and direct solution for upgrading the data rate of the all-optical XOR gate implemented with the SOA based UNI to match that of the modern networks.

II. Technical concept

In brief, the switching deals with the main idea of polarization discrimination; a combination of a polarization controller (PC), a polarization beam splitter (PBS) and a polarization maintaining fiber (PMF) is used to inject a clock pulse (CLK-black colored) and categorize it into corresponding delayed copies of Tdelay. By synchronizing a control (CTRL-gray-colored) pulse (A) with the fast and a control pulse (B) with the slow one a nonlinear phase shift can be induced between them through the manifestation of cross-phase modulation in the SOA. At the back end of the setup, these components are combined using the same set of passive elements and the amount of the differential phase they have acquired, which determines to switch. As a result if both controls are 'on' or 'off', which is equivalent to a logical '1' or '0', respectively, then we get nothing at port O1, on the other case if either of them is 'on' then a pulse is obtained at the same exit. In this manner Boolean XOR is executed between the binary content of the two control data streams and the outcome is delivered on the clock, which is transferred to the output. The consequent interpreted procedure can significantly produce the correct XOR truth table. Practically, although the SOA cannot respond timely in the changes of its dynamical state when driven by intense data signals that bring it into deep saturation, as it happens for the XOR case because of its corresponding intrinsic slow gain recovery time.Hence, as a result of this situation, the XOR function cannot be realized with bitwise logical correctness and high quality when the interval between successive excitation pulses is shortened since the alternating marks and spaces distort the profile of the logical outcome. This is visible in the sketched pulse train that emerges from output O1, where the '1 suffers from peak fluctuations because of pattern effect whilst the amplitude of the '0' is noticeable, thereby impairing the unambiguous distinction between the 'on' and 'off' levels and increase the probability of making errors. The degradation or extinction of the performance can be overcome by launching the resultant pulse train into an ODI, which is constructed by connecting two 3 dB couplers with a length difference between the upper and lower arms that is equivalent to a relative time delay, Dt. The prime key for doing this relies on properly exploiting the valuable information that is contained in the phase of the switched signal and converting the change of this quantity to an amplitude modulation of the opposite magnitude to that without the ODI. This can be achieved by the crosswise subtraction of an offset copy of the switched signal from itself using the ODI. In this manner and analogously to the difference between the corresponding temporally displaced phases predicted in the below figures (top) at an arbitrary time interval creates a window (Fig. 2 (bottom)) of duration smaller than the target repetition period in this paper in an respective manner. Therefore,as a result the perspective derived pulses acquire a shape determined solely by their relative delay in the ODI and not by the slower SOA gain recovery whose contribution is effectively masked, which affects their quality favorably. Eventually when the phase difference is zero (closed window), which happens for the '0' output pulses whose phase content is small, the output of the ODI becomes null and these bits are extinguished, as desired. If on the other hand, the produced pulses are '1' the phase excursions induced by them are arranged to lie within this window and around the same average level. This is in fact done by making through the adjustment of Dt the originally switched signal to interfere with its lagging counterpart more destructively or more constructively, thereby causing the higher ‘1's to be clamped and the lower ones to be comparatively enhanced so that the variations in their peaks are balanced. The concept can also be explained clearly and briefly in the frequency domain by noting that the origin of the problem from this standpoint is actually the uneven spectral shift in the leading edge of the switched ‘1's to the low-frequency region. This can be seen in Fig. 3, where the instantaneous frequency deviation, or chirp, which has been calculated from the variation per time increment of the phase response [11] given by Eq. (7) in is plotted for an indicative XOR result. From its evolution it can be observed that if the fluctuations in the red chirp components were compensated and the blue chirp components in the trailing edge, which remain closer to the position of the input carrier frequency and are nearly uniform, were not impaired while the ‘0' components were fully suppressed then a far better performance than with the UNI alone could be achieved at ultrafast rates.

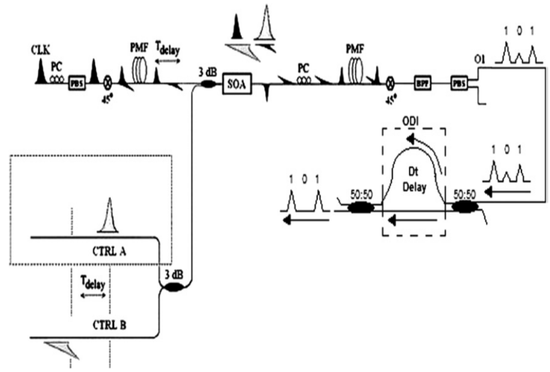

Fig 1. Setup of SOA based UNI and ODI

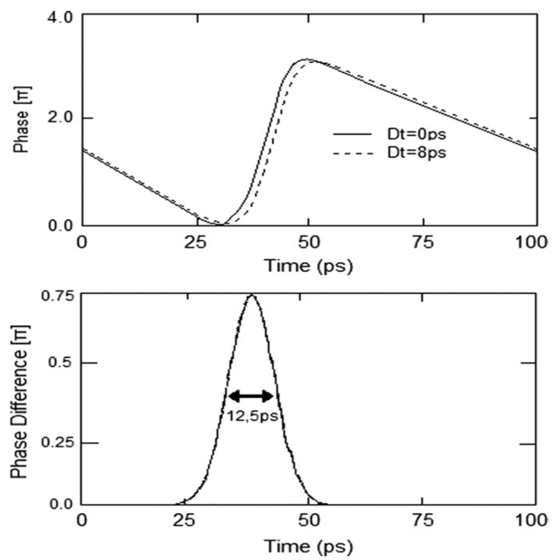

Fig 2. Evolution of (top) the modulated phase of the originally switched signal (Dt=0 ps) and its delayed replica (Dt=8 ps), and (bottom) of the phase window created by the ODI, at an arbitrary time interval and for the fixed values of the data signals and SOA parameters used in the simulation

Here the ODI can be employed to satisfy these requirements and eliminate the distortion of the pulses exiting the switch by benefiting from the shape of its transfer function [14], which is cosine-squared, as schematically illustrated in Fig. 4. Concurrently the negative chirp values, despite their peak difference, are nevertheless all confined within a small region (gray colored in the horizontal axis). For larger Dt, the slope of the curve becomes steeper and these spectral components are mapped on a narrower portion of it (gray colored in the vertical axis), thus perceiving almost the same transmittance, which enables the ‘1's to be smoothed to a greater extent. The spectral components of the ‘0's, in turn, are forced to fall in the notch and thus are filtered-out.

Finally, the positive chirp values are allowed to pass and the action of the ODI as frequency discrimination stage is completed.

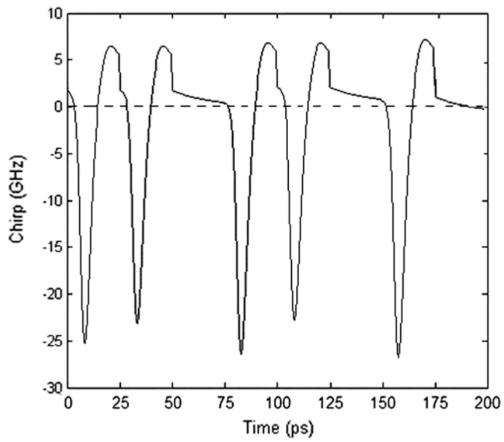

Fig 3. Evolution of chirp induced on signal switched from SOA-based UNI for the fixed values of the data signals and SOA parameters used in the simulation

A. Description & scrutinization of Variation:

The variation of the Q Factor based on control data pulses soa transit time and small signal gain is determined with the help of the model graph in which its helps us to understand the concept in crystal clear manner. The simulation results have shown that without the ODI it is not possible to achieve this goal for any selection of the critical parameters but the SOA carrier lifetime, for which the requirements are nevertheless rather strict

III. Simulation

The theoretical model that has been employed aims at simulating the concatenation of the two units of the setup by providing expressions that allow to describe and link their operation. For this purpose, we start inversely from the ODI, for which it is known that if a signal of initial power Pin, ODI(τ)and phase $\varphi in, ODI(\tau)$ is inserted in it then the power at its crossed output port

$$Pout, ODI(\tau) = 1/4\{Pin, ODI(\tau) + Pin, ODI(\tau - Dt) + 2\sqrt{Pin}, ODI(\tau)Pin, ODI(\tau - Dt) * \cos[\Delta\varphi ODI(\tau)]\}$$

where

$$\Delta\varphi ODI(\tau) = \varphi in, ODI(\tau) - \varphi in, ODI(\tau - Dt)$$

$$Pout, ODI(\tau) = 1/4\{Pout, XOR(\tau) + Pout, XOR(\tau - Dt) + 2\sqrt{Pout}, XOR(\tau)Pout, XOR(\tau - Dt) * \cos[\varphi out, XOR(\tau) - \varphi out, XOR(\tau - Dt)]\}$$

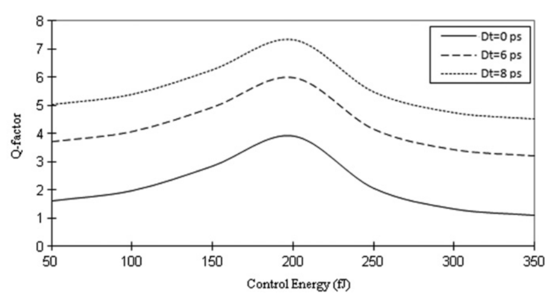

Fig 4. Q-factor variation versus energy of control data pulses

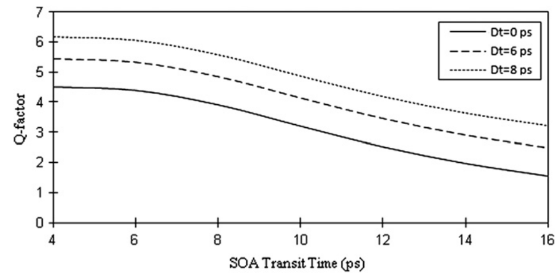

Fig 5. Q-factor variation versus SOA transit time

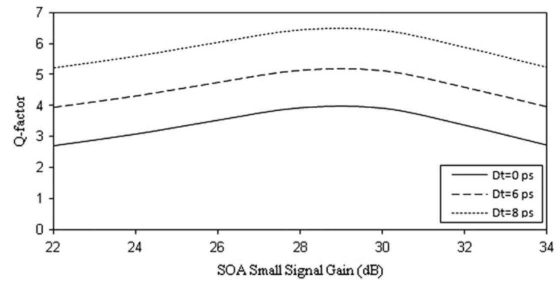

Fig 6. Q-factor variation versus SOA small signal gain

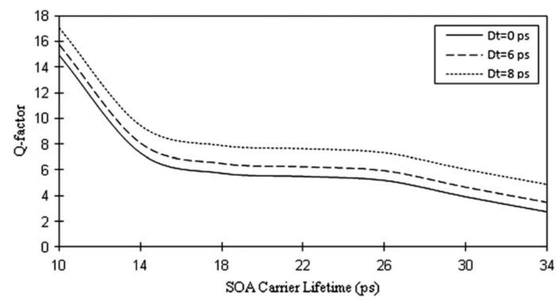

Fig 7. Q-factor variation versus SOA carrier lifetime

The clock signal that is transmitted as a result of the XOR operation at port O1 [8], which essentially is the required Pout, $XOR(\tau)$:

$$Pout, XOR(\tau) = PO1(\tau)$$

$$= 1/4\left\{Gf(\tau) + Gs(\tau - Tdelay) - 2\sqrt{Gf(\tau)Gs(\tau - Tdelay)} * \cos\left[-\frac{\alpha N}{2\ln\left(\frac{Gf(\tau)}{Gs(\tau - Tdelay)}\right)}\right]\right\} Pclk(\tau).$$

On the other hand, the phase of the switched signal is mathematically described through the relevant transfer function at port O1, which holds for SOA-based interferometric structures that exploit the idea of differential switching. This is given from the analytical form

$$\varphi out, XOR(\tau) = \varphi s(\tau - Tdelay) + \arctan\left[\frac{\sqrt{GR(\tau)\sin\left(\frac{\alpha N}{2lnGR(\tau)}\right)}}{1 - \sqrt{GR(\tau)\cos\left(\frac{\alpha N}{2lnGR(\tau)}\right)}}\right]$$

$$\varphi s(\tau - \tau delay) = -\alpha N/2\ln \begin{matrix}[gs(\tau - \tau delay)] and \\ GR(\tau) = Gf(\tau)/GS(\tau - Tdelay)\end{matrix}$$

This resultant phase transfer function has been derived after a consequent algebraic procedure which involves the corresponding isolation and handling the consequent terms of the phase shift suffered by the perspective clock components as they tend to transverse the SOA and recombine. Since it is in the closed form, it can facilitate the more complex circuits and subsystem specifically with feedback where the operation is inherently complicated in which all optical gate like XOR is the core logic unit. In contrast in the information for the phase contained in the Electric fields of the consequent clock counterparts and as a result it could be a bit difficult to maintain a good balance between the accuracy of description and the perspective efficiency computational efficiency in applications like the ones just mentioned. The role of ODI actually took place by means of polarization maintaining loop mirror and this issue has not been addressed in this case. Thus by using such type of explicit expressions the power of the signal at each one of these output points can be demonstrated simultaneously. The power of the signal at each one of these output points can be estimated for further numerical processing.

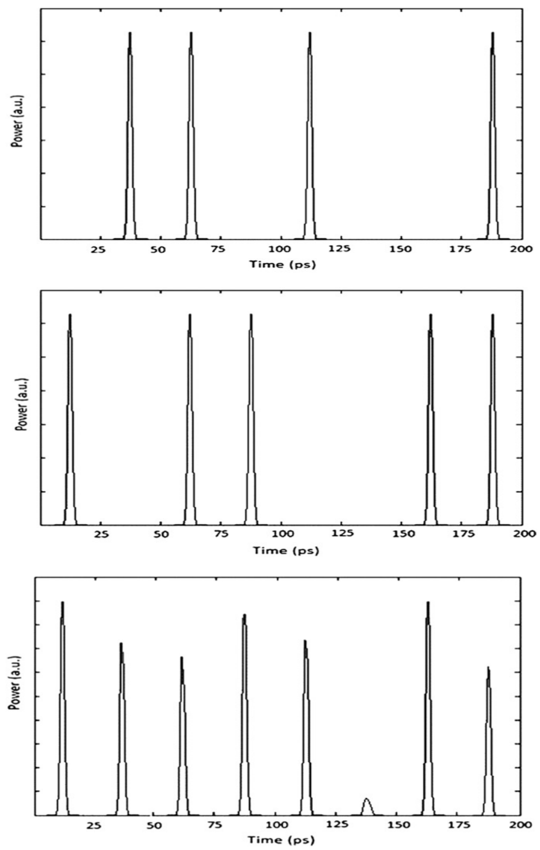

Fig 8. Simulation result (bottom) of the XOR operation between control data A/01101001 (top) and B/10110011 (middle) without the ODI

This phase transfer function has been derived after following a cumbersome algebraic procedure, which involves isolating and properly handling the terms of the phase shift suffered by the clock components as they traverse the SOA and recombine. Since it is in closed form, it can facilitate the simulation of more complex circuits and subsystems, especially with feedback where the operation is inherently complicated, in which an all-optical gate like the XOR is the core logic unit. In contrast in [9], the information for the phase was contained in the electric fields of the clock counterparts, and therefore it could be harder to maintain a good balance between accuracy of description and computational efficiency in applications like the ones just mentioned. Also in [10], the role of the ODI was actually played by a polarization maintaining loop (PML) mirror and this issue was not addressed as in our case. Therefore it is the first time that it is treated in this way for investigating the performance of the considered setup.

IV. RESULT &PERFORMANCE ANALYSIS

The performance of the considered scheme is evaluated at 40 Gb/s in terms of the Q-factor, In order to check if this goal can be satisfied, the energy and FWHM of the data pulses as well as the SOA transit time, small signal gain and carrier lifetime are assigned a fixed value (200 fJ, 7 ps, 6 ps, 28 dB and 25 ps, respectively) and then scanned one after the other to investigate their impact on the Q-factor in the presence or absence of the ODI after the XOR gate. These default values for the critical parameters have been specified and selected after going through an extensive searching, testing and checking procedure to find among their theoretically infinite combinations the one that is most appropriate for allow obtaining and inter.preting the curves in a concise and comprehensive manner. Although a different set of initial values would obviously change the quantitative details of the curves, yet it would not alter the qualitative conclusions drawn from their inspection. In effect running the model by assigning other values did not produce significantly different results while still enabling to assess the ability of the ODI to improve things as opposed to the SOA alone. The corresponding diagrams that have been obtained from this procedure are shown in Figs. 4-7. The initial form of the curves before connecting the ODI is defined according to the general trend governing those in Ref. [8] for half operating bit rate, which is particularly apparent for the SOA carrier lifetime but also holds in the case for example that the SOA small signal gain was increased as suggested in to achieve the degree of phase shift required for optimum switching, an action that is however insufficient. With the insertion of different, increasing time delays the curves retain their form but are shifted towards a better Q-factor.Based on the observation and the consequent interpretation of the above mentioned figures the utilization of the ODI that stimulates the sufficient time delay.The resultant need for employing the corresponding ODI can be evaluated by the fact that the values used for them all through the simulation fall in the consequent range yet they are not supposed to produce the outcome.The '1's are smoothed from peak to peak in an respective manner and '0's are strongly suppressed even with a consequent less tight selection of the critical parametersThus by selecting Ectrl=175fj,TFWHM=8ps,Ttransit=4.8ps,Gss=26db and T carrier=30ps,the form of the consequent output pulse profile and the resultant PED is acceptable .as predicted in above figures.This once again confirms and as a result it highlights the important contribution of the ODI in the corresponding accomplishment of the error free and patternfree ultrafast Boolean XOR operation.Finally it is worth mentioning that the corresponding specified delay can be providedby means of an optical path delay in a range of several picoseconds and nanoseconds.This as a result allows tuning with the time delay in a rapid accurate flexible and uninterruptible manner instead of having to adjusts the length difference between the ODI upper and the consequent lower armwhich is not easy.

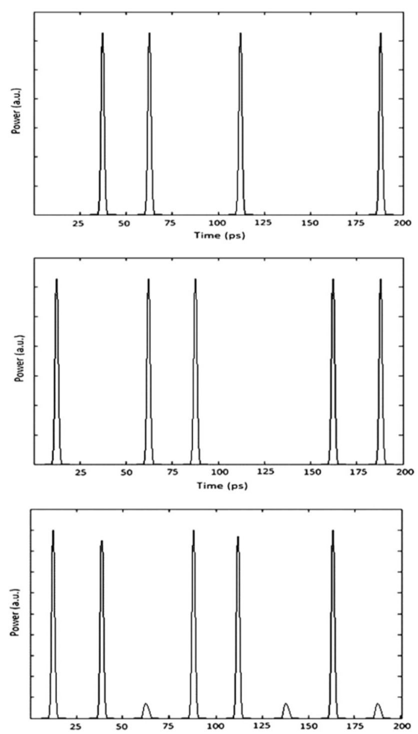

Fig 9. Simulation result (bottom) of the XOR operation for the same data patterns as in Fig. 10 and with an ODI of time delay Dt=8 ps

This behavior is attributed to the ODI's principle of operation, which relies on the crosswise interference of the switched signal with its delayed replica. Owing to this mechanism, which was extensively explained in Section 2 both in the time and in the frequency domain, the ODI has an averaging an equalizing effect on the incoming data stream. As a result of this function, it affects in an external only manner the inserted signal but it does not distort it as an entity while being capable of restoring its quality. For this reason, the curves in each diagram do not exhibit any pronounced differentiations or abnormalities but instead a smooth pattern. This is an exceptional feature offered by the use and nature of the ODI as a passive element that facilitates monitoring the influence of the key parameters and extracting rules for their proper selection. The main remark that can be made from Figs. 4-7 is that for all the critical parameters but the carrier lifetime it is not possible to meet the minimum performance standard unless the ODI is used. This designates the catalytic role played by this element both for allowing the doubling of the XOR repetition rate from our previous work [8], which otherwise would not be feasible, and making the technical requirements that should be fulfilled in its absence more relaxed as well, as it will be concisely discussed in the following. For the characteristics of the data pulses, concerning first their energy it is noticed in Fig. 4 that the Q-factor can surpass and stay above its desired minimum for an integer Dt that must definitely exceed 1/4th of the operating period, with just below 1/3rd being adequate. The bell-shaped variation is attributed to the way the operation of the SOA-based UNI and of any similar type interferometric switch is affected by the phase difference induced by the controls on their synchronized clock components, meaning that when this quantity is well below or above p, which happens when the SOA is under- or over-saturated, respectively, the Q-factor is accordingly dropped on either side of a maximum. The latter is reached at almost the middle of the examined span and implies that the SOA in the presence of two control beams is biased into the deep saturation regime. This clearly means that the ODI has external effectiveness, in the sense that it cannot have a direct influence on the dynamical behavior of the SOA. Nevertheless, it enables to open a dynamic range of about 2.4 dB, which otherwise, i.e. for Dt¼0 ps, would not be possible. Furthermore, as seen in Fig. 5, it allows the Q-factor to lie in the vicinity of its permissible limit using wider control pulses, which are favored as they can be provided from simpler laser sources. For the SOA features, we begin with its transit time in Fig. 6 and see that as Dt becomes higher the curves are shifted upwards, which indicates again the preferred time delay. Interestingly the Q-factor exceeds its borderline when the SOA longitudinal dimension is relatively small, which in turn is beneficial for avoiding the deleterious consequences of amplified spontaneous emission that could otherwise impair the performance of the switch while as explained in not disturbing the creation of the required degree of differential phase. Therefore the realization of the proposed work is technically possible .

V. CONCLUSION

Finally the capacity of an ODI to extend the working rate of the SOA-based UNI by 100%(cent) compared to its former one in dual rail full pattern-operated switching mode has been theoretically scrutinized and demonstrated. The simulation results have shown that without the ODI it is not possible to achieve this goal for any selection of the critical parameters but the SOA carrier lifetime, for which the requirements are nevertheless rather strict. If, however, the proper time delay of about 1/3rd of the bit period is inserted by an ODI serially connected at the output of the interferometric structure then not only a range of allowable parameters values is opened but these also can be relaxed, which is advantageous from a practical perspective. Therefore the proposed scheme can constitute a realistic option for enhancing the ultrafast potential of the considered switch configured as all-optical XOR gate in complex circuits and subsystems.

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