Non-linear Optical Gate based on Auto-Correlated Cross Gain Modulation Effect in Folded Tandem-SOAs

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Abstract
We propose a novel SOA-based nonlinear optical gate structure which uses a reflected input signal for the generation of cross gain modulation effect, instead of the conventional CW saturating tone. Comparison of the structures shows little or no degradation in the performances with the introduced modification for a highly integrated, simpler structure.

1 Introduction
Dispersion compensation and optical amplification compose those key developments enabling today’s ultra long haul, high-capacity optical transmission systems. Not defying the contributions of above technologies but also to counteract the result - the increased accumulation of penalties in ULH system, associated with the dispersion / loss compensation achieved via optical means - there also has been increased interests for the higher level of signal regeneration, especially utilizing optical elements.

Non-linear optical gates (NLOGs) providing extinction ratio enhancement and noise reduction have been investigated in depth from this reason [1], as one of the promising network element for the future all optical 2R regenerated transmission systems. The highly non-linear dynamics of Cross Gain Modulation (XGM) effects in process in SOAs (Semiconductor Optical Amplifiers) in this sense fits naturally, and have been used for the realization of efficient NLOGs. Utilizing cascaded SOAs, Extinction Ratio (ER) enhanced NOR-gate also has been demonstrated [2]. Signal ER can be enhanced as well based on the same principle. Most recently, ER enhancement and noise compression of the signal was achieved [3] using a similar device structure and principles.

In this paper, we suggest a novel NLOG structure, which utilizes auto-correlated XGM effects in folded tandem-SOA and does not require extra continuous wave (CW) source. Comparison of suggested structure with the CW-assisted tandem-SOA NLOG shows that compatible performance factors can be achieved with the optimization of mirror reflectance, but with much simpler structure and reduced cost.

2 Principles

Figure 1a) schematics of CW-assisted tandem-SOA NLOG

Figure 1b) schematics of folded tandem-SOA NLOG

Figure 1 illustrates the basic concept of; 1a) CW-assisted tandem-SOA NLOG [3], and 1b) folded tandem-SOA NLOG - proposed in this paper. Serially
connected two SOAs (SOA1, SOA2) with a 3-dB coupler each having non-connecting outer edges receiving original input signal \( P_{in} \) (input port of SOA1) or CW signal (output port of SOA2. For figure 1b, it is reflected, amplified input signal instead of CW) respectively. For the CW-assisted tandem SOA NLOG, CW signal propagating through the SOA2 becomes to have inverted patterns of input signal \( P_{in} \) from the XGM effect. These inverted signal patterns out of the SOA2 entering the SOA1 then again becomes to cross-gain modulate \( P_{in} \) in the SOA1. As a result, ‘0’-level of original input signal becomes even smaller, and ‘1’-level becomes even larger at the output port of the SOA1 \( (P_{out}) \) - leading to signal ER enhancement. This non-linear transfer characteristic between the input \( P_{in} \) and output \( P_{out} \) in this way effectively provides a NLOG function which can be used for all-optical regeneration or NOR gate [2, 3].

Noting that in this configuration usually the flight time of the signal can be neglected, and that the signal power at the output port of SOA2 is highly saturated (constant), there is no reason for one not to consider the reflected input power at the reflection point of SOA2 (fig 1b) as an alternative of another CW source - to reduce the device complexity and associated cost.

### 3 Simulation Result

Folded tandem-SOA NLOG was analyzed considering both forward and backward propagating signals. At the end of the SOA2, a mirror was assumed with reflectance of \( r \), defined in terms of field amplitude ratio \( r = E_r / E_i \).

<table>
<thead>
<tr>
<th>Length</th>
<th>500μm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>300mA</td>
</tr>
<tr>
<td>confinement factor</td>
<td>0.4</td>
</tr>
<tr>
<td>material gain coefficient</td>
<td>( 2.7 \times 10^{16} \text{cm}^2 )</td>
</tr>
<tr>
<td>material scattering loss</td>
<td>34cm^{-1}</td>
</tr>
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</table>

Fast and accurate analysis was possible utilizing the integral equation formalism of SOA [4]. In figure 2, we show the signal power distribution curves at different input power signal levels (-28dBm, -26dBm, and -24dBm, each labeled as ‘A’, ‘B’, and ‘C’ respectively in the figure. \( r = 0.01 \)). Output powers observed at the output extraction point (3dB-coupler located in the middle, see figure 1 and 2) for curve ‘A’, ‘B’ and ‘C’ were around -15.2dBm, -5.3dBm and 4.4dBm respectively (corresponding gain values are, 12.8dB, 20.7dB and 28.4dB). In terms of extinction ratio, this observation tells us that with the 4dB of input signal ER (-28dBm to -24dBm), the output becomes to have 19.6dB of ER (-15.2dBm to 4.4dBm), providing 15.6dB of net ER enhancement.

Important to note, the reflected power at SOA2 output point is almost identical irrespectively of the input signal power strength, due to the saturated operation of tandem-SOA. In this regard, with the adjustment of the mirror reflectance, it is possible to change the device optimum operation point - in equivalence to the CW power adjustment [3] for the CW-assisted tandem-SOA NLOG. In Figure 3 we plot the signal gain measured at the output port of SOA1.
as a function of input signal power at different mirror reflectance values ($r = 0.001, 0.01, \text{ and } 0.1$). Optimum operation input power was measured as -26dBm with $r = 0.01$, and -6dBm with $r = 0.1$, respectively. Finer adjustment for NLOG optimum input power should be possible with the change of mirror reflectance.

For comparison, we also plotted the response curves of CW-assisted tandem-SOA structure, assuming identical SOA parameters with different optimum CW power values. Can be seen in figure 4, difference in the extinction ratio up to $0 - 3.5\text{dB}$ (for CW input power of -6 ~ -26dBm) was observed when compared to folded tandem-SOA NLOG, especially in the lower input signal power regime. Still, considering the usual operation range of NLOG and achieved absolute ER values (as high as 19.6dB) from folded tandem-SOA structure, we conclude that these minor differences - in the ER value between these two structures - can be well ignored for most applications.

## 4 Conclusion

Recognizing / utilizing the highly saturated nature of CW-assisted tandem-SOA based NLOG operation; we suggested and demonstrated that an equivalent operation should be possible without an extra source, but only with a simple low-reflectance mirror at the output end of second stage SOA.

The authors believe that the proposed structure should benefit the realization of highly integrated, also simple and cost effective, future all-optical non-linear optical gate / 2R regenerator.

## 5 References