

# All-Optical Phase Modulation using MZI-SOA

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This paper experimentally demonstrate an all-optical phase modulation technique using both arms of a Mach-Zehnder interferometer structure with Semiconductor Optical Amplifiers (MZI-SOA), with NRZ modulated signals driven at 10 Gbit/s. The proposed optical phase modulator can be used in multi-level modulation signals generation, as an optical routing element, as well in optical code division multiple access transmission systems.

## 1. Introduction

In this paper, we present an optical phase modulation scheme using a single MZI-SOA, with significant low complexity and high scalability.

The proposed optical phase modulator uses both interferometric arms of a MZI-SOA and the operation principle is based on cross phase modulation effect (XPM). The XPM effect relies on the dependency of the refractive index on the carrier density in the active region of the SOA. An incoming signal that depletes the carrier density will modulate the refractive index and thereby result in phase modulation of a continuous wave (CW) signal coupled into the MZI-SOA [1].

The MZI-SOA is an element that performs a variety of optical functions and provides high extinction ratio, high operation speed, requires low switching energies to operate and also have high integration capability and compactness.

Optical phase modulators are widely used in many optical applications and several optical techniques have been proposed to implement them, such as the use of an acousto-optic modulator (AOM), followed by a fiber [2] or by a gain-transparent semiconductor optical amplifier (GT-SOA) [3].

In this paper, the effectiveness of the proposed optical phase modulator is experimentally demonstrated using several different scenarios of input power and changing the bias current of both SOAs.

## 2. System Description

The implemented experimental setup is depicted in Fig.1 and consists of an external cavity laser peaking at 1549.32 nm, followed by a polarization controller and a Mach-Zehnder external modulator, driven at 10 Gbit/s.

The NRZ data signal, generated by a Serial BERT (Agilent N4901B), is then amplified by an EDFA (IPG-EAD-500-C3-W), split into two equal parts using a 3 dB

coupler and then launched into the MZI-SOA ports A and D, through an optical delay line. Both signals present the same optical mean power.

The MZI-SOA used was a commercially available and hybrid-integrated optical regenerator (CIP40G-2R2-ORP).

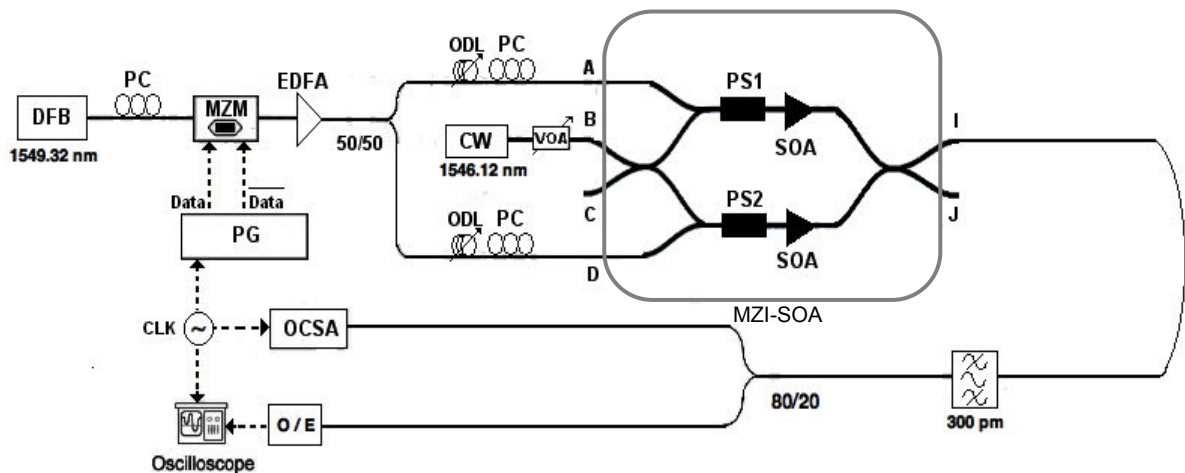
The voltage applied to the phase shifters and the polarization controllers, included at ports A and D of the MZI-SOA are adjusted in order to maximize the destructive interference at output port I.

The control signal, a CW light beam lasing at 1546.12 nm, is launched into port B of the MZI-SOA in a co-propagating direction with the data signals.

The MZI-SOA operates as a logic XOR gate and the intensity variations of the input NRZ optical signals cause a phase modulation of the control CW signal propagating through the SOAs.

The output signal is recovered at port I, using a filter with a 25 GHz bandwidth (X-tract Net Test) and centred at the control signal wavelength.

We use two measurement instruments to analyze the output signal: an oscilloscope (Agilent 86100A), connected through a PIN photodiode (HP-11982A), and an optical complex spectrum analyzer (APEX AP 2441A) to monitor phase and power information of the output signal, for time domain characterization.



**Figure 1:** Experimental setup of the proposed optical phase modulator: DFB: distributed-feedback laser; PC: polarization controller; MZM: Mach-Zehnder modulator; EDFA: Erbium Doped Fiber Amplifier; ODL: optical delay line; CW: continuous wave laser; VOA: variable optical attenuator; SOA: semiconductor optical amplifier; PS1, 2: phase shifters; OCSA: optical complex spectrum analyzer; PG: pattern generator; O/E: PIN photodiode. Solid lines represent fiber-optic paths and dashed lines indicate electronic connections.

### 3. Experimental Results

The experimental tests were performed using the following NRZ data pattern: 0101011010101101. Due to limitations of the optical complex spectrum analyzer, the length's sequence, at 10 Gb/s, were restricted to 16 bits [4].

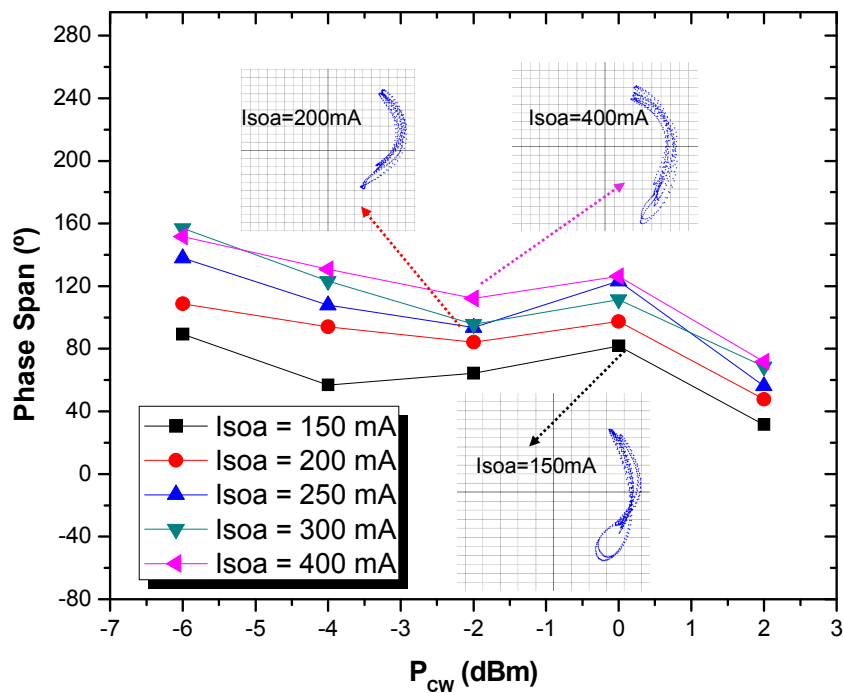
The bias current ( $I_{SOA}$ ) of both SOAs were varied simultaneously, from 150 mA to 400 mA, and for each bias current, the mean power of the control signal ( $P_{CW}$ ) was increased from -6 dBm to 2 dBm.

Fig. 2 and Fig. 3 display the values of phase span and output mean power. As bias current of both SOAs increase, both values of phase span and output mean power raises.

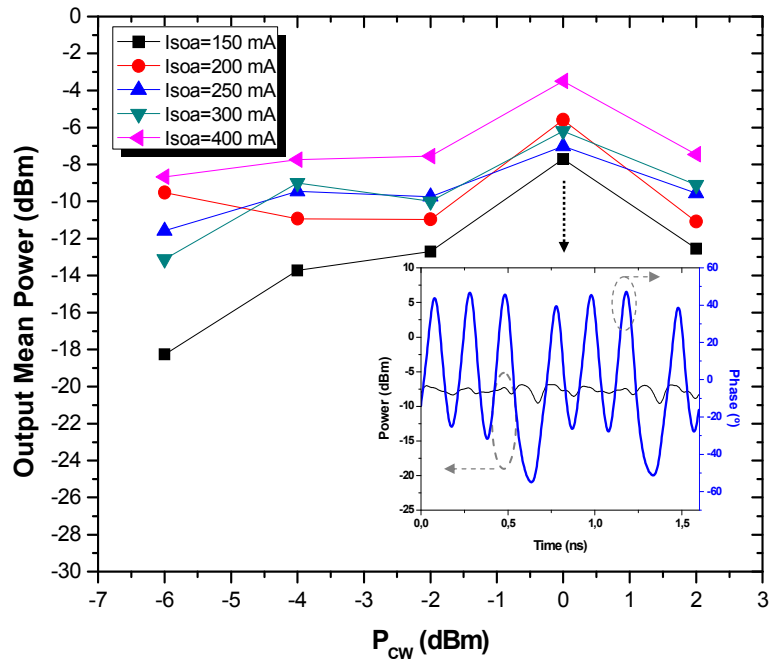
Phase constellation insets in Fig. 2 show that phase logic levels are evenly defined when the bias current is increased.

For  $P_{CW}$  ranging from -6 dBm to 0 dBm, SOAs are in linear amplification regime and the values of the phase span vary between  $55^\circ$  and  $160^\circ$ . For  $P_{CW}$  above 0 dBm, the SOAs saturates, which significantly reduces phase span values and output mean powers.

Fig. 3 inset illustrates the power and the values of phase span when  $P_{CW}=0$  dBm and  $I_{soa}=150$  mA. The phase shifts are inverted when compared with NRZ data pattern input.



**Figure 2:** Output phase span and constellation diagrams



**Figure 3:** Output mean power. Inset figure: Phase and power output for  $I_{soa} = 150$  mA and  $P_{CW} = 0$  dBm

#### 4. Conclusions

In this paper we experimentally demonstrate the feasibility of optical phase modulation technique, using both arms of MZI-SOA, and access the impact of using different scenarios of CW input power and bias current of the SOAs.

Experimental results indicate that an increase of the bias current produces higher values of phase spans and output mean powers. However, SOAs gain saturation has an opposite effect on the output signal.

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