Generic Platform Integrated Frequency Shifter for Low Bandwidth Heterodyne Detection Systems

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An integrated frequency shifter based on an IQ modulator fabricated through an open-access indium phosphide generic integration platform has been designed and characterized. It is intended for low bandwidth heterodyne detection systems. Its performance is demonstrated up to 300 MHz with a SMSRs greater than 15 dB. ***Keywords***: *Photonic Integrated Circuits, heterodyne detection, IQ modulator, frequency shifter.*

INTRODUCTION

Heterodyne detection systems are based on shifting the signal frequency away from DC, thus minimizing the effects of flicker noise and unambiguously detect beat notes around the carrier signal at both sides of the spectrum [1]. Low bandwidth heterodyne detection is used in systems such as coherent lidars or dual-comb spectrometers, that require frequency shifting ranges from tens to hundreds of MHz. This allows to use low-cost electronic devices in the detection system [1].

Traditionally, Acousto-Optic Modulators (AOMs) have been used to perform the function of frequency shifters in such systems. Nevertheless, these modulators are difficult to integrate. They require hybrid integration and open-access foundries do not offer it as a Building Block (BB) for their generic integration processes. An interesting alternative is using IQ modulators as frequency shifters [2], because they can be easily integrated using the standard BBs offered by a generic integration platform. Frequency shifts up to 10 GHz with a Side Mode Suppression Ratio (SMSR) between 16 and 23 dB have been demonstrated in [3] for a silicon-based Photonic Integrated Circuit (PIC). In the case of Indium Phosphide (InP), there are demonstrations of IQ modulators used as fast digital transmitters in coherent communication systems achieving rates up to 128 Gb/s [4], but its use as frequency shifter has not been reported.

In this contribution, an InP integrated IQ modulator designed through an open access generic integration foundry using its standard BBs is experimentally characterized and demonstrated as a frequency shifter, achieving good operation up to 300 MHz with SMSR greater than 15 dB.

DESIGN AND FABRICATION

The PIC has been fabricated by SMART Photonics in a Multi-Project Wafer (MPW) run. The design has been made using standard BBs of the 1st generation PDK from the foundry. As part of the design process, initial software simulations and theoretical conceptualizations were made. Fig. 1 shows a photograph of the fabricated device highlighting the different integrated devices. It consists of two dual-parallel branches, I and Q, each one composed by a dual-drive Mach-Zehnder Modulator (MZM), followed by an Electro-Optic Phase Modulator (EOPM) which allows to operate both branches in quadrature. Several couplers are used for combining and splitting the signal, and two Semiconductor Optical Amplifiers (SOAs) are used at the input and at the output respectively to boost the signal. It is important to remark that at the output of each MZM there is an integrated photodiode, which allow us to characterize each MZM separately.

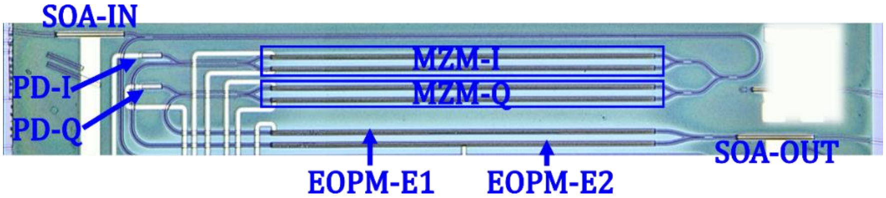

Fig.1. Scheme of the InP integrated frequency shifter.

RESULTS AND DISCUSSION

The 1st generation of the foundry PDK is characterized by having a shared common n-substrate for all the p-n junctions in which the DC BBs are based, i.e. all share the same ground contact. This, combined with the fact that EOPMs are based on electro-optic effects and therefore they can only operate in reverse bias, makes not possible to operate the MZMs in push-pull mode. Therefore, prior to the frequency shifter realization we need to set up an analytical model considering the mentioned features. This model is based on measurable parameters of the system, such as the π voltage of the EOPMs and the phase shift due to the difference in optical paths. These parameters can be measured for each MZM since the current measured in each integrated PD is given by

$$I_{PD} \propto cos^2\left(\frac{\varphi_i - \varphi_j - \varphi_0 + \pi}{2}\right) \qquad (1)$$

where $\varphi_{i,j} = \frac{\pi}{V_{\pi i,j}} V_{i,j}$ being $V_{i,j}$ the voltage applied to the EOPM and being φ_0 the phase difference due to optical paths in each arm.

Fig. 2 shows the response of each MZM (I branch and Q branch) measured the integrated PDs. This is done by injecting CW light into the chip and biasing the MZMs with different voltages. Unlike in the case of modulators based on $LiNbO_3$, this response has been observed to be very stable and repetitive over time.

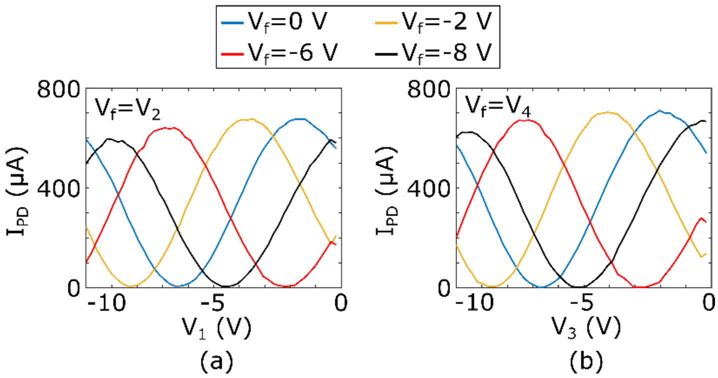

Fig. 2. Measured photocurrent at PD-I (a) and PD-Q (b) for different bias points.

After obtaining the MZM parameters, the voltages of each EOPM are set based on the analytical model to operate the IQ modulator as a frequency shifter. These voltages are as follows

$$V_1 = -V_{\pi 1}\left(1 - \frac{\varphi_0^I}{\pi}\right) - RV_{\pi 1}\sin(\omega_s t), \qquad \text{and} \qquad V_2 = -\frac{V_{\pi 2}}{2} - RV_{\pi 2}\sin(\omega_s t), \qquad (2)$$

for the MZM on the I branch, and

$$V_3 = -V_{\pi 3}\left(1 - \frac{\varphi_0^Q}{\pi}\right) \mp RV_{\pi 3}\cos(\omega_s t), \qquad \text{and} \qquad V_4 = -\frac{V_{\pi 4}}{2} \pm RV_{\pi 4}\cos(\omega_s t), \qquad (3)$$

for the MZM on the Q branch, where $R \ll 1$ to operate in low amplitude modulation regime. Notice that the shift that will be induced to the carrier is the one set by the frequency of the RF modulation signal, i.e, ω_s. Furthermore, the voltages of the EOPMs placed at the output of each MZM should be adjusted to make I and Q branches work in quadrature, i.e. with a phase difference of $\frac{\pi}{2}$. The optical carrier to be shifted is injected into the chip from an external tunable laser which has narrow linewidth (10 kHz). Fig. 2 shows the measured results for two different frequency shifts: 100 MHz (a) (b) and 250 MHz (c), These spectra are measured gathering the output light of the PIC with a lensed fiber and then using a high resolution (10 MHz) Brillouin Optical Spectrum Analyzer. The frequency shift can be controlled to be positive or negative just by adjusting the sign of the harmonic signals in Eq. (3). The SMSR worsens when increasing the frequency shift. This degradation is attributed to the electrical contacts of the EOPMs, which are designed for DC operation. However, up to 300 MHz a SMSR between 15-20 dB is maintained.

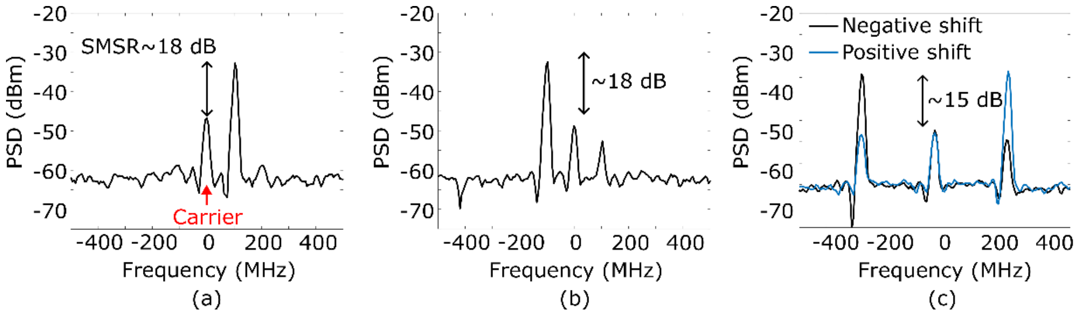

Fig. 2. Measured spectra at the output of the device for frequency shifts of (a) 100 MHz positive (b) 100 MHz negative and (c) 300 MHz positive and negative

4. Conclusions and outlook

We have demonstrated experimentally an integrated frequency shifter using standard BBs from an open access InP foundry. The proposed architecture is capable to induce a frequency shift up to 300 MHz with SMSRs greater than 15 dB, working the system better for low frequency shifts. The obtained performance is good enough for using the proposed design in more complex low-bandwidth heterodyne detection systems such as low-cost coherent lidars and dual-comb spectrometers.

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