Characterization of Third Order Distortion in InGaAsP Optical Phase Modulator Monolithically Integrated with Balanced UTC Photodetector

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Abstract

We demonstrate a novel, dynamic characterization technique for measuring third order distortion products in an InGaAsP phase modulator. The phase modulator exhibits an output phase IP3 of 4.4π.

I. Introduction

Optical phase modulators are well positioned for use in both next generation analog and digital transmission systems. For digital communications, phase modulation allows greater transmission distances due to larger tolerance to dispersion effects, and wide wavelength transparency due to a broad operating envelope. In analog links, phase modulators are promising to overcome the response of standard amplitude modulators by permitting modulation depths beyond the standard zero and full rail.

Traditionally, measurements of the efficiency and distortion in optical phase modulators has relied on DC characterization techniques such as Mach-Zehnder interferometers and Fabry-Perot resonators [1,2]. However, under large signal conditions these techniques are inherently limited by the nonlinearities generated in the phase to amplitude conversion process. Furthermore, because of the added nonlinearities in the phase detection process, it has been difficult to demonstrate a dynamic measurement of third order distortion at frequencies other than DC.

In this work we propose and demonstrate for the first time, a large signal, dynamic two-tone measurement technique for examining the third order distortion in an optical phase modulator without significant added nonlinearity from the phase recovery process. We use this technique to characterize a forward biased, InGaAsP quantum well (QW) phase modulator that is part of a monolithically integrated InGaAsP/InP photonic receiver chip. Experimental results show that the phase modulator can generate a phase swing of 4.4π before the magnitude of the third order distortion and fundamental response become equivalent.

II. Experiment

The experimental set up used to characterize the distortion products in the InGaAsP phase modulator is shown in Fig 1. An optical transmitter consisting of a single frequency laser source at an operating wavelength of 1545 nm, an EDFA, and a 1 nm FWHM optical bandpass filter is split into two optical paths in a Mach-Zehnder interferometer (MZI) configuration. In one of the arms of the MZI an external $LiNbO_3$ modulator is combined with the 500 μm long InGaAsP test phase modulator that is part of the photonic receiver chip. The photonic chip consists of two parallel optical waveguides, a 2x2 multi-mode interference (MMI) combiner, and a set of 100 μm long uni-travelling carrier photodetectors (UTC-PDs) similar to that in [3] in a balanced configuration. The 2x2 MMI and the balanced photodetectors convert the phase modulation produced by the $LiNbO_3$ and InGaAsP modulators to an amplitude response which can be examined in an electrical spectrum analyzer (ESA).

A set of electrical signal generators are used to create two electrical tones at 249.57 and 249.67 MHz. These two tones are combined using 2:1 combiner, then split into two separate pathways using a 1:2 splitter. One of the outputs from the 1:2 splitter is routed to the $LiNbO_3$ modulator, while the second output is routed to the InGaAsP modulator. A set of attenuators are used to control the amount of electrical power delivered to either the $LiNbO_3$ or InGaAsP phase modulator. External bias tees are used to set the bias conditions on both modulators. The center frequency between the two tones from the signal synthesizers is chosen

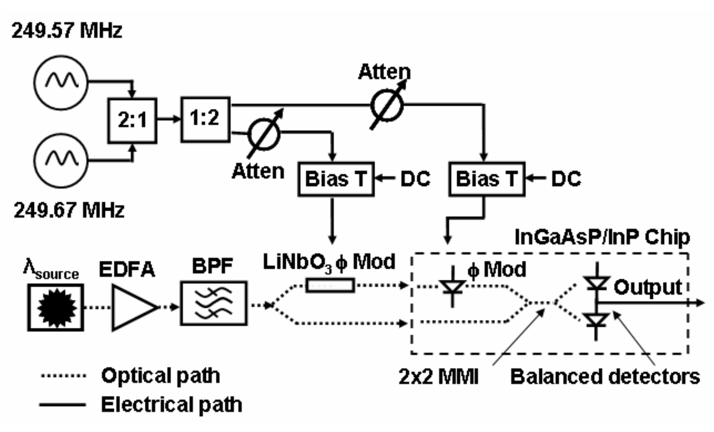

Fig 1. Experimetal set-up for dynamic two tone characterization of third order distortion products in the InGaAsP phase modulator. The optical and electrical paths are indicated by dashed and solid lines respectively.

so that the physical path length difference from the 1:2 electrical splitter to either the InGaAsP or $LiNbO_3$ modulator corresponds to a phase delay of π radians.

Device characterization requires two experiments. The first set of experiments is used to extract the fundamental response of the phase modulator, while a second set of experiments is used to characterize the distortion terms. In the first experiment only the electrical signal used to drive the InGaAsP phase modulator shown in Fig. 1 is enabled. The power out of the electrical signal generators is varied from -19 to -14 dBm, and the phase response of the device is characterized by examining the fundamental and third order distortion peaks generated during the phase to amplitude conversion process in the UTC-PDs. A sample ESA output spectrum from the balanced detector is shown in Fig 2 and labeled "uncompensated response".

In the second experiment, the electrical signals used to drive both the InGaAsP and $LiNbO_3$ modulators are enabled. Since these drive signals are delayed by π radians relative to one another, the phase response of the $LiNbO_3$ modulator compensates the response of the InGaAsP phase modulator. Assuming that the majority of the third order distortion is produced in the semiconductor modulator [4], the phase compensation affects mostly the fundamental response of the InGaAsP device while leaving the distortion products relatively unchanged. The reduction of the fundamental response allows the phase to amplitude conversion process in the UTC-PDs to remain within the linear regime of the Mach-Zehnder, and preserves the phase distortion produced in the InGaAsP modulator without adding nonlinearities from the detection process. A sample spectrum of the electrical response from the balanced detector with both modulators operating is shown in Fig 2 where the peak amplitude modulation is -58 dBm. The response is labeled "compensated response."

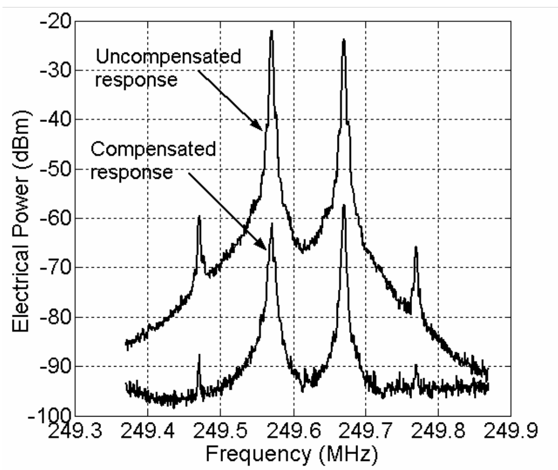

Fig 2. Compensated and uncompensated balanced detector response. Electrical drive power is -15 dBm and -10 dBm to the InGaAsP and $LiNbO_3$ modulators respectively

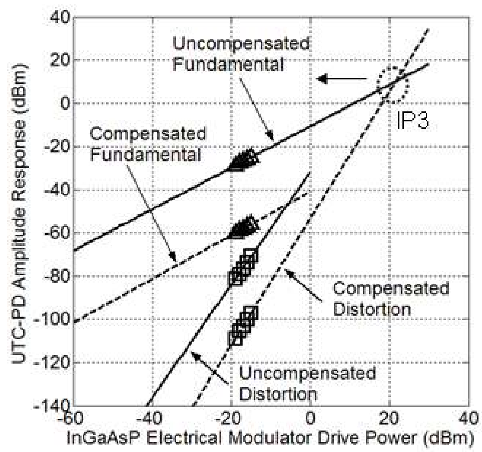

Fig 3. Fundamental and third order distortion in the amplitude response of the UTC-PDs for both compensated and uncompensated experiments.

III. Results

The response of the fundamental and third order tones from the balanced photodetector as a function of applied power to the InGaAsP phase modulator in both the compensated and uncompensated experimental cases are shown in Fig 3. As expected, the addition of the $LiNbO_3$ phase modulator (compensated fundamental and distortion curves) reduces the fundamental response of the InGaAsP modulator and enables the response of the balanced detector to operate under small signal conditions where the phase recovery process is linear. To extract the output phase response of the InGaAsP modulator where the third order intermodulation products have equal power to the fundamental tones (IP3), the amplitude response from the UTC-PDs must be converted to a phase modulation. Since the fundamental response in the uncompensated experiments represents the fundamental response of the InGaAsP modulator for the given range of input powers, and since the third order distortion generated by the InGaAsP modulator is represented by the distortion in the compensated measurements, the IP3 intercept point is taken as the intercept between these two data sets. From Fig 3, the output IP3 of the forward biased phase modulator is +10 dBm, which translates into a balanced photodetector current of 14.1 mA assuming a 50 Ω internal load in the ESA. Given that the average output photocurrent from the UTC-PDs for a π phase shift is 1.6 mA (3.2 mA pp), the output phase IP3 is 4.4π, calculated based on the ratio of the balanced photodetector current at the IP3 point to the current for a π phase shift.

IV. Conclusions

We have proposed and demonstrated for the first time a novel technique for measuring the dynamic distortion in optical phase modulators. Using this approach, we have characterized a forward biased InGaAsP phase modulator monolithically integrated with a set of UTC-PDs. The output phase IP3 of the forward biased InGaAsP phase modulator was measured to be 4.4π.

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