Monolithically Integrated Dual-Quadrature Coherent Receiver on InP with 30 nm Tunable SG-DBR Local Oscillator

Kimchau N. Nguyen¹, John M. Garcia¹, Erica Lively¹, Henrik N. Poulsen¹, Douglas M. Baney², and Daniel J. Blumenthal¹

¹Electrical and Computer Engineering Department, University of California, Santa Barbara CA 93106
²Measurement Research Laboratory, Agilent Technologies, 5301 Stevens Creek Blvd., Santa Clara CA 95051
kim@ece.ucsb.edu

Abstract: We demonstrate a monolithically integrated dual-quadrature coherent receiver with 30nm widely-tunable SG-DBR local oscillator, signal input SOAs, a 90° optical hybrid and four 10GHz photodetectors. We demonstrate recovered constellations from 10Gbaud NRZ-BPSK and NRZ-QPSK signals at four different wavelengths.

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1. Introduction

The increasing interest in multi-level phase and amplitude transmission formats for high capacity transmission like 100 GB Ethernet will require higher levels of integration for transmitters, receivers and test and measurement. Coherent detection offers high sensitivity and the potential for chromatic dispersion and polarization mode dispersion compensation [1,2]. Integrated coherent receivers that have been demonstrated to date [3,4,5] use an external cavity laser or an integrated DFB laser as the local oscillator. Monolithic integration of a receiver with a widely-tunable local oscillator offers a low-cost, compact, and wavelength flexible alternative with potential higher performance.

2. Design and Fabrication

The layout of the coherent receiver is shown in Fig. 1. The receiver consists of two pre-amplifier SOAs, an SG-DBR local oscillator (LO), a 90° optical hybrid and four single-ended photodetectors. The 90° optical hybrid is made up of four MMIs, intersecting waveguides, and phase shifters. All MMIs are tunable as proposed in [6] and the all branches of the optical hybrid are phase tunable to allow for compensation of fabrication variations. The signal (S) from the input waveguide is amplified by the two SOAs, then mixed with the LO signal from the SG-DBR in the optical hybrid. The optical hybrid is tuned to 90° to produce the four outputs: S+LO, S-LO, S+jLO, and S-jLO. These outputs are detected by four single-ended integrated photodetectors.

Fig. 1. Device layout (a) and photograph of the receiver PIC (b). The PIC is 0.6 mm x 4.9 mm.

The PIC is designed using an offset quantum well integration platform described in [7]. The MQW region acts as the gain medium for the SOAs and the SG-DBR and also the absorber section of the PDs. The surface ridge is 3 µm wide and the p-cladding is 1.9 µm tall. The input SOA1 is 3x200 µm² and SOA2 is 500 µm long and flares from 3
μm to 9 μm. The SG-DBR design is described in [8]. The 2x2 MMIIs are 14 x 330 μm² and have tuning sections of 1.5 x 100 μm² on each side in order shift MMI split ratio. The photodetector’s areas are 3 x 60 μm².

The fabrication process starts with active/passive definition using a wet etch, then gratings are patterned using electron beam lithography and etched. The waveguide p-cladding is regrown, then the surface ridge is defined by a dry etch with a cleanup wet etch. SiN is then deposited, followed by a SiO₂ patterning, leaving a 2.4 μm thick oxide layer for the detector contact pads. The vias through the oxide and nitride are etched, and p-metal is deposited, followed by isolation implantation, wafer thinning and back-side n-metal deposition. An AR coating was not applied to this device. The devices are then cleaved apart, mounted to a carrier and wire bonded; the PDs are wire bonded to 50Ω coplanar waveguide transmission lines.

3. Results

We first summarize the results of the receiver PIC component characterization. We then discuss the result of testing the receiver with 10 Gbaud NRZ-BPSK and NRZ-QPSK signals.

The SG-DBR is evaluated in terms of wavelength tuning range, side-mode suppression ratio (SMSR), and linewidth. The SG-DBR wavelength tuning map is shown in Fig. 3(b), was obtained by sweeping both front and back mirrors from 0-20 mA and measuring the peak wavelength in an OSA. As shown, the SG-DBR can be quasi-continuously tuned over 30 nm, from 1544 nm to 1577 nm. An SMSR of up to 48 dB was measured and varies depending on the wavelength position on the gain curve. SG-DBR linewidth of 200 MHz was measured using the delayed homodyne technique with a delay length of 100 meters. The SG-DBR linewidth is dominated by low-frequency jitter [9].

![Fig. 3. (a) SG-DBR wavelength (nm) vs. bias currents of front and back mirrors showing quasi-continuous tuning range of over 30 nm.  
Photodetector normalized frequency response (b) of all four photodetectors.](image)

The photodetector frequency response was measured with a 20 GHz LCA (Lightwave Component Analyzer) output, amplified to 10 dBm, and then coupled into the receiver PIC with a lensed fiber. Inputs SOA1 and SOA2 were biased to 40mA and 100mA, respectively. The PD CPW line was contacted with a GSG RF probe and reversed biased through a bias tee to -3V. The RF signal from the PD was connected to the LCA through the bias tee. The frequency response for all 4 detectors is shown in Fig. 3(b) showing detector 3-dB bandwidths of 10 GHz, sufficient for 10 Gbaud signals. With all PIC components biased, the dark current on each photodetector is 19 μA.

The optical hybrid was characterized using the method described in [10]. In our case, we mixed the SG-DBR output with CW light tuned close to the SG-DBR wavelength in the optical hybrid, and used the on-chip PDs to observe the beat signals in a real-time sampling oscilloscope. With this method we were able to tune the hybrid to 90° by biasing one phase shifter to 8.65 mA. Biasing the phase shifter to 4.72 mA and 16.38 mA tunes the hybrid to 0° and 180°, respectively.

![Fig. 4. Experimental Setup](image)
The experimental setup for 10 Gb/s NRZ-BPSK and NRZ-QPSK is shown in Fig. 4. CW output from a tunable laser was modulated by a QPSK LiNbO$_3$ modulator, driven by 10 Gb/s PRBS $2^7$-1 data on one arm and a delayed inverted data sequence on the other. The signal was then amplified by an EDFA, filtered, and input into the PIC with a lensed fiber. The input power at the lensed fiber was approximately 8 dBm for all measurements with high OSNR. Other than the bias for the 90° phase shift, no other tuning was done to the optical hybrid. The single-ended $I^+$ ($S^+LO$) and $Q^+$ ($S^-LO$) were sampled by a 40 GSa/s real-time sampling scope. Traces of 4096 samples at 40 GS/s were recorded and post-processed to recover the constellation using basic implementations of clock recovery, equalization, and carrier phase estimation. The recovered constellations at wavelengths of 1546.35, 1549.62, 1553.17, and 1556.72 nm are shown in Fig. 5. Received constellations can be improved using differential instead of single-ended detection, adding transimpedance amplifiers (TIAs), and with post-processing optimization.

4. Conclusions

We demonstrated an integrated coherent receiver with a monolithically integrated widely-tunable SG-DBR local oscillator, input SOAs, a 90° optical hybrid, and 10 GHz 3dB bandwidth photodetectors. The SG-DBR has a tuning range of over 30 nm and a linewidth of 200 MHz. The receiver was tested with 10 Gbaud NRZ-BPSK and NRZ-QPSK signals. Future work on these devices includes on-carrier capacitors and dual differential TIAs for balanced detection, BER measurements using larger trace data sets, and improvements on the post-processing algorithms.

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References