Linear Phase Demodulation using an Integrated Coherent Receiver with an Ultra-Compact Grating Beam Splitter

Chin-Hui Chen, Anand Ramaswamy, Leif A. Johansson, Nobuhiro Nunoya, Jonathan Klamkin, John E. Bowers, and Larry A. Coldren
ECE and Material Dept., University of California at Santa Barbara, Santa Barbara, CA 93106, USA
Phone: +1-805-893-7163, Fax: +1-805-893-4500, Email: janet@ece.ucsb.edu

With phase modulation, it is possible to realize high dynamic range analog optical links, provided the transmitted radio frequency (RF) signal can be linearly demodulated. The linearity of traditional interferometer-based phase demodulators, however, is often limited by their sinusoidal response. To achieve high linearity, negative feedback is introduced to suppress non-linearities arising from the phase demodulation process [1]. High feedback gain reduces the net phase swing across the demodulator such that it operates within the linear regime. Additionally, both the signal and the noise are reduced by the same feedback factor, so there is no penalty in signal-to-noise ratio (SNR) [1]. The challenge is to make a receiver incorporating feedback that is operable at high frequencies. Because high loop gain as well as a wide bandwidth is required for efficient phase tracking, the physical delay in the feedback path must be kept sufficiently short in order to prevent the loop from oscillating. Previously, we have demonstrated an ultra-compact grating-based beam splitter [2], which divides the incoming optical beams in a region, over 30 times shorter than a conventional surface-ridge Multimode Interference (MMI) beam splitter. This key feature leads to a significant reduction in loop delay.

In this paper, for the first time, we demonstrate the closed-loop operation of an integrated coherent receiver with the grating-based beam splitter. Fig. 1 shows both the schematic and the SEM photo of the integrated receiver with a direct interconnect (providing feedback) between the output of a balanced photodetector pair and a pair of optical phase modulators. The drive voltage to the modulator pair is obtained through the integration of the detector current across the capacitance of the detector and the modulator, and hence, the level of this drive voltage is proportional to the detected photocurrent level. When the photocurrent is sufficiently high to provide adequate loop gain, the integrated receiver can closely track signal phase. Consequently, the demodulated signal is very linear.

The integrated receiver consists of a balanced pair of uni-traveling-carrier photodiodes, multiple quantum well phase modulators, and a compact 2x2 grating-based beam splitter fabricated on an InGaAsP/InP platform. Deeply-etched periodic structures form a strongly reflective grating and enable an ultra-short splitting region. A symmetric waveguide grating in the vertical dimension is created when the etch depth is deeper than the thickness of the entire slab waveguide and thus, the radiation loss can be minimized.

We used an experimental analog optical link to characterize the linearity of the receiver. Details of the experimental setup are discussed in [3]. In Fig. 2(a) the signal-to-interference ratio (SIR) is 24.56 dB when the tracking modulators are turned off (feedback is negligible).When the modulators are turned on the SIR is 50 dB – an improvement of over 25 dB (Fig. 2(b)). Additionally, by measuring the noise floor we can determine the Spur Free Dynamic Range (SFDR) of the receiver (Fig. 3(a)). The measured noise floor (-130 dBm/Hz) is significantly higher than the calculated shot noise floor (-172.09 dBm/Hz) because of ASE noise from the optical source. Fig. 3(a) shows both noise floors. Assuming high loop gain and hence, complete phase tracking at 100 MHz and estimating the modulator $V\pi$ to be 4.37V, the resulting shot noise limited SFDR is 117.7 $\mathrm{dB \cdot Hz^{2/3}}$. The closed loop SFDR is expected to decrease as a function of frequency because at higher frequencies there is not enough loop gain for accurate phase tracking. Fig. 3(b) shows the SFDR at 1 GHz to be 11 dB lower than the SFDR at 100 MHz. Also, at higher bias voltages the SFDR decreases because of a combination of modulator non-linearity and reduced photocurrent.

This work was supported by the DARPA PHOR-FRONT under US Air Force Contract FA8750-05-C-0265.
[1] Chou et al. COTA, 2006. [2] Chen et al. OFC, 2008. [3] Ramaswamy et al. JLT 26(1), 2008

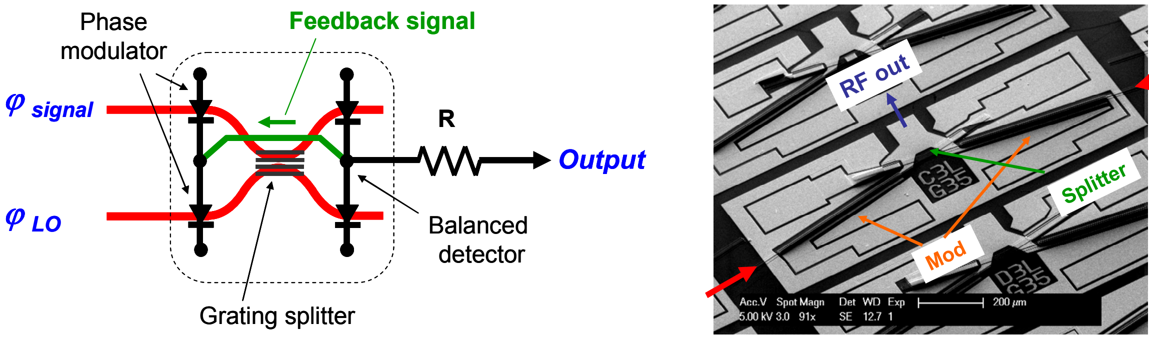

Fig. 1 Schematic and SEM of the integrated all-photonic receiver.

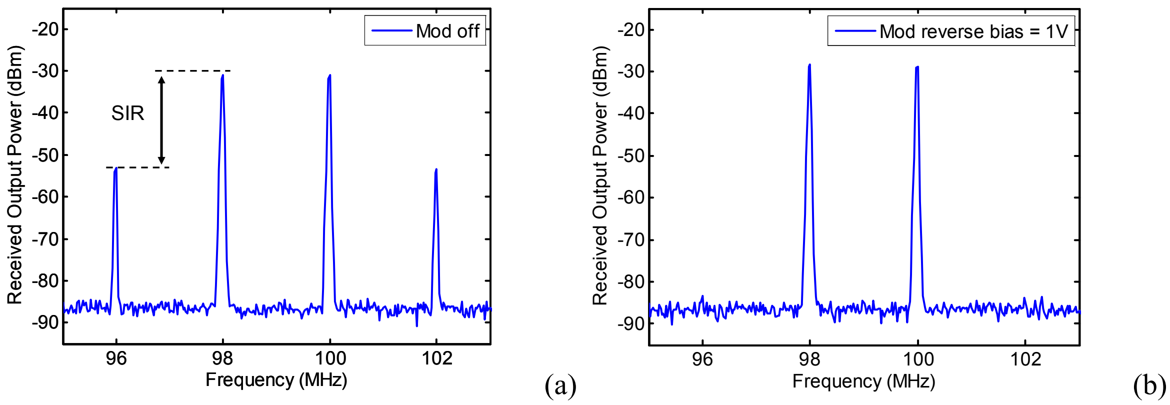

Fig. 2 Receiver output power spectra at 100 MHz, 10 mA photocurrent. (a) Modulator turned-off. (b) Modulator reverse-bias at 1 V.

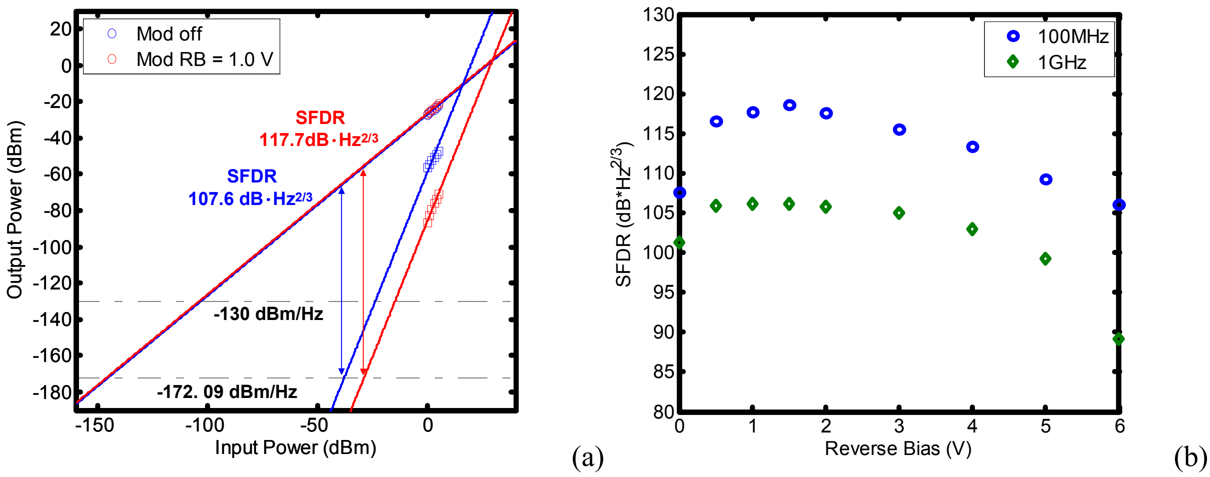

Fig. 3 (a) The two-tone measurement at 100 MHz with modulator off and reverse bias at 1 V. (b) Shot noise limited SFDR results versus different modulator reverse biases at 100 MHz and 1 GHz.