Optical Phase Demodulation using a Coherent Receiver with an Ultra-Compact Grating Beam Splitter

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Abstract: We describe the design and fabrication of an integrated coherent receiver incorporating a novel grating beam splitter for linear optical phase demodulation. The open loop behavior of the receiver is measured in a link experiment.

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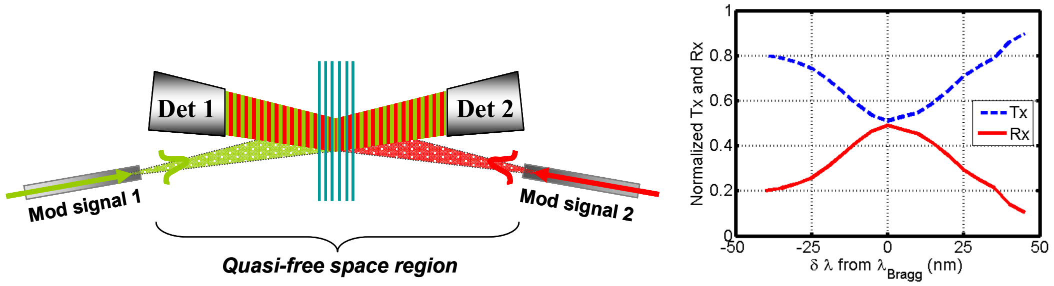
1. INTRODUCTION

Linear demodulation of phase modulated optical signals is needed to realize the extremely high dynamic range afforded by phase modulated analog photonic links. Interferometer based optical phase demodulators have a sinusoidal response that limits their performance [1]. In order to overcome the inherent nonlinearity associated with the phase recovery process we have utilized a phase locked loop (PLL) [2, 3]. The utilization of a PLL sets stringent requirements on the delay of each element in the feedback path. To operate at microwave frequencies, an integrated platform that is four orders of magnitude more compact than fiber optics is required [2]. Using an InP integration platform we were able to realize compact integration of electronics and photonics and measure an SFDR of 125dB.Hz$^{2/3}$ at 300 MHz under closed loop operation [4]. However, to achieve sufficient loop gain for a SFDR of 130dB.Hz$^{2/3}$ at 1 GHz, the loop delay must be <15ps to maintain stability.

In this paper we demonstrate open loop behavior of an integrated receiver with an ultra-compact grating beam splitter in an analog link experiment to show the potential for linear phase demodulation. We describe the design and fabrication of the novel grating-based beam splitter that can replace conventional directional couplers or multi-mode interference (MMI) based couplers in applications that require ultra-compact beam splitting [5]. This beam splitter is integrated with detectors and modulators to form the coherent integrated receiver.

2. GRATING-BEAM SPLITTER BASED INTEGRATED RECEIVER

Fig. 1 (a) shows the configuration of the balanced receiver in which the grating beam splitter is integrated with MQW phase modulators and uni-traveling-carrier photodiodes (UTC-PDs). The beam splitter includes a quasi-free space region and a short interference region consisting of grating grooves. The quasi-free space region allows the input and output beams to diverge freely in the lateral direction, confining them in the transverse direction only. The grating region splits an incoming beam into transmissive (undiffracted) and reflective (diffracted) beams.



(a) (b)

Fig. 1. (a) Schematic of integrated receiver with grating-based beam splitter. (**b)** Splitting ratio of grating-based beam splitter versus wavelength. Nearly equal splitting is observed at the Bragg wavelength.

In order to avoid the mode degradation due to oblique incidence of finite beams onto thick gratings, we firstly design the incident waveguides with a small angle that is sufficiently large to distinguish beams in the quasi-free space region. An angle of 10° from normal incidence is selected and is a reasonable compromise for short total propagation length. Secondly, to also achieve the targeted splitting with an ultra-short coupling length, a highly reflective Bragg grating for 1550 nm wavelength is utilized. Thirdly, the unique quasi-free space region is introduced in order to expand the incoming beams to be comparable or wider than the grating length. The divergence in the quasi-free space region is faster than that in the traditional adiabatic flaring so that the traveling distance can be kept as short as possible. The performance of an equal splitting grating-based beam splitter is shown in Fig. 1 (b).

The integrated receiver as shown in Fig. 2 consists of a balanced UTC-PD, a compact 2x2 grating-based beam splitter, and MQW phase modulators. The device platform and fabrication process used is similar to that reported in [6]. To form the deep gratings, a SiO_2 mask was patterned with holographic lithography. The gratings were then transferred into the MQW waveguide core with methane/hydrogen/argon/oxygen-based reactive ion etching with an alternating etching and oxygen descumming process [5]. The largest index contrast in the grating is achieved when the slab waveguide layer is completely etched through. The etch of the deep grating grooves is followed by a blanket p^+ - InP cladding and p^{++} - InGaAs contact layer regrowth. This regrowth yields no apparent air voids, which suggests low scattering losses in the grating region.

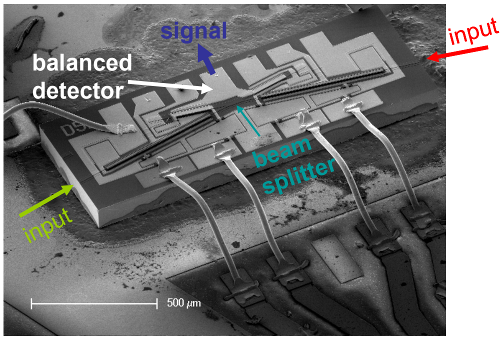


Fig. 2. SEM of integrated coherent receiver on carrier. The RF signal in-between a pair of balanced UTC-PD and gratings are indicated. Two fiber coupled incoming beams are illustrated with arrows in red and green.

3. OPTICAL PHASE DEMODULATION EXPERIMENT

Fig. 3 shows an experimental analog link that was built to evaluate the integrated receiver performance under open loop operation. The optical source consists of a tunable c.w. laser operating at 1545nm. The details of the link are described in [4]. In order to characterize the third order intermodulation distortion generated in the receiver we apply a two tone probe signal at the transmitter. However, as described in [4] we apply them separately to two $LiNbO_3$ modulators. Since, the grating is sensitive to the polarization of the incident light, the polarization controllers located before the device allow the polarization to be optimized for highest splitting ratio. The grating coupler in conjunction with the balanced photodiode forms an optical mixer that can demodulate the incoming signal phase applied at the transmitter.

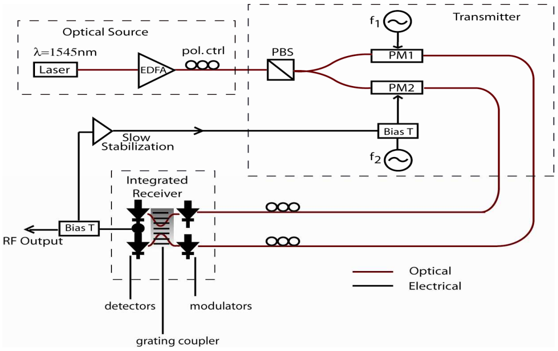
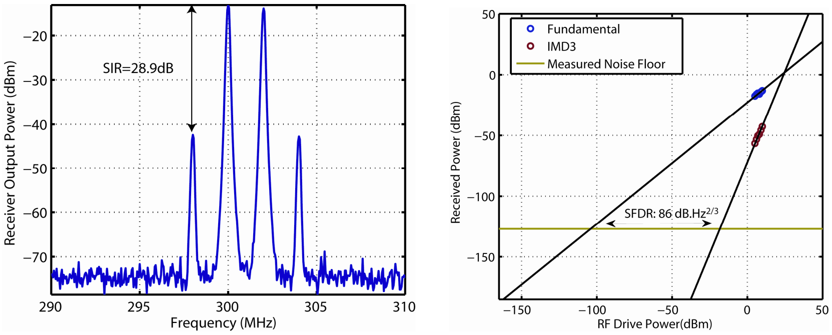


Fig. 3. Schematic of experimental analog link

Fig. 5. shows the power spectra at the output of the receiver under open loop operation. The frequencies of the two tones are 300 MHz and 302 MHz. The measured signal to intermodulation ratio (SIR) is 28.9dB for an input power

of 10dBm. As mentioned earlier, standard interferometer based demodulation of phase results in a sinusoidal relation between the detected photocurrent and incoming signal phase. Consequently, the linearity of the receiver is severely degraded by the phase recovery process. Fig. 5 (b) shows an SFDR of 86dB.Hz$^{2/3}$ at 300 MHz with 10mA of photocurrent per individual photodiode. The measured noise in the receiver was -127dBm/Hz and can be attributed to the spontaneous emission noise from the EDFA.



(a) (b)

Fig. 4. (a) Receiver output power spectra for open loop. **(b)** SFDR at 300MHz, 10mA photocurrent

The demonstrated open loop operation of the receiver illustrates the ability of the receiver to demodulate optical phase. The grating-based beam splitter successfully combines and splits the two incident optical beams so that the balanced UTC-PD demodulates the microwave signal phase. This demodulated signal can be amplified and fed back to the integrated phase modulators to perform linear optical phase demodulation.

4. CONCLUSION

In summary, we have demonstrated phase demodulation with a coherent integrated receiver incorporating a novel grating-based beam splitter. When combined with feedback, this receiver will realize short feedback loop delays in order to perform linear optical phase demodulation at microwave frequencies.

ACKNOWLEDGEMENT

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