Homodyne Dual-Quadrature Coherent Receiver with Injection-Locked Monolithically Integrated Local Oscillator

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Abstract: We demonstrate a homodyne dual-quadrature coherent receiver using a monolithically integrated, injection-locked local oscillator. For BER of 10^{-3} and 10^{-5}, the required OSNR is improved by 1.5dB and 5dB, respectively, compared to a free-running local oscillator.
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1. Introduction

Due to increasing capacity demands, Coherent receivers are of interest for their capability to receive multi-level phase and amplitude modulated signals. A typical optical coherent receiver consists of a local oscillator laser, a 90° optical hybrid, and photodetectors. In order to meet the requirements for higher level QAM, the local oscillator linewidth must be sufficiently narrow. Many coherent receivers use external cavity lasers that are large and costly. Monolithic integration of coherent receivers with the local oscillator is necessary in order to reduce footprint and lower costs, however in doing so there is a tradeoff in local oscillator performance. In order to maintain a widely-tunable local oscillator and narrow its linewidth, we can injection lock the local oscillator, resulting in a homodyne receiver.

The proposed scheme is shown in Fig. 1 and similar to one originally proposed and demonstrated for a PSK signal with a separate local oscillator [1,2]. The local oscillator of the receiver is injection-locked with a carrier on an orthogonal polarization to the QPSK or QAM data. For the transmitter, both TE and TM polarizations are input to a modulator that modulates only TE, but transmits both TE and TM [1,2]. The TM carrier is then used to injection lock the local oscillator of the receiver. For practical implementations, a control loop is used to keep the local oscillator within the injection locking range and also to phase lock it. With an injection-locked and phase-locked local oscillator, signal processing is not required for carrier phase estimation and frequency offset correction.

Using a carrier on an orthogonal polarization to injection lock an integrated local oscillator is a potentially lower cost alternative to an external cavity local oscillator in the receiver. This scheme is however not compatible to polarization-multiplexed modulation formats, as a carrier is needed to injection lock the local oscillator. The phase shift keyed signal it self cannot be used to injection lock the local oscillator, as the locked local oscillator with track the phase changes in the injected signal.

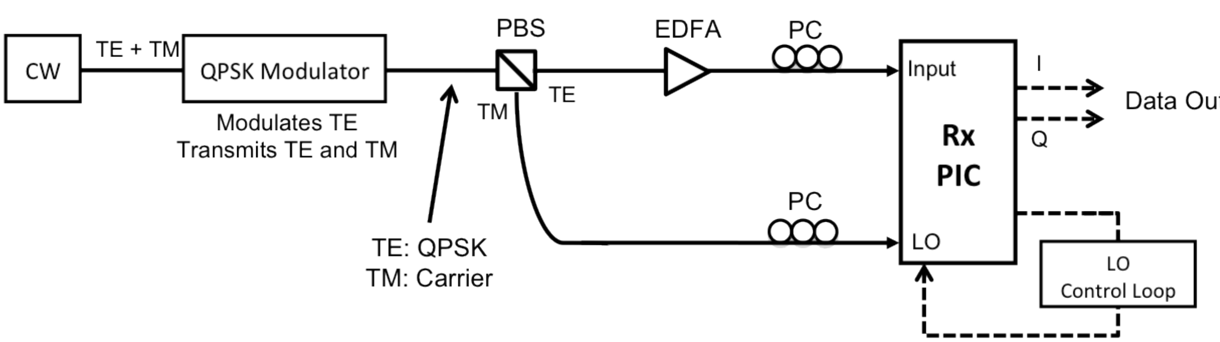


Fig. 1. Injection locking to orthogonal polarization carrier

2. Experimental Setup

The experimental setup to first demonstrate injection locking a receiver with a monolithically integrated local oscillator is shown in Fig.2. Due to the unavailability of a modulator described in Section 1, the transmitter CW light is split before the modulator in order to obtain a carrier for injection locking. A variable optical attenuator (VOA) and an EDFA is used to vary the OSNR of the 20 Gb/s QPSK signal. The signal is then pre-amplified to a constant output power of ~8 dBm and input to the receiver PIC with a lensed fiber. The receiver PIC is as described in [3], consisting of two preamplifier SOAs, a widely-tunable SG-DBR local oscillator, a 90° optical hybrid, and four 10 GHz 3-dB bandwidth photodetectors. The carrier is injected into the back facet of the SG-DBR laser with the absorber section biased to 40 mA. A VOA is used to adjust the injected carrier input power. Because a feedback loop for the local oscillator is not implemented, a circulator is used to mix the output SG-DBR laser power with CW that is wavelength-shifted 35 MHz by an acousto-optic modulator. The beat frequency is input to a photodetector, connected to an RF spectrum analyzer to determine if the SG-DBR laser is injection locked. When the SG-DBR laser is injection locked, a peak at 35 MHz is observed on the RF spectrum analyzer. The outputs from one I and one Q photodetector are input to the Agilent Optical Modulation Analyzer (OMA). In the case that the local oscillator is injection-locked, signal processing by the OMA is still necessary to derotate the constellation as the local oscillator phase offset is arbitrary. The OMA also provides a real counting BER.

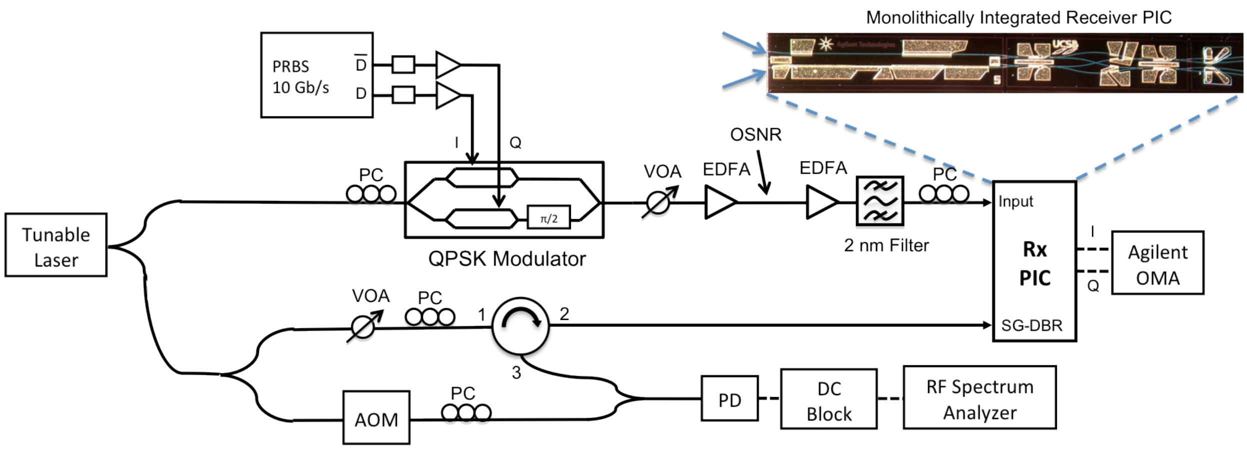


Fig. 2. Experimental Setup

3. Results

We first discuss the linewidth of the injection-locked SG-DBR laser and its input locking range, then discuss the performance of the receiver with an injection-locked local oscillator using 20 Gb/s QPSK.

Fig. 3(a) shows the injection locked linewidth of the SG-DBR laser at a wavelength of 1553.14. The FWHM linewidth is 130 kHz, showing a 900x reduction compared to free-running SG-DBR linewidth measured to be 116 MHz. The free running linewidth measurement includes noise from the current sources used to bias the laser. Using spectral width data measured at 30 dB down, the free-running FWHM linewidth is estimated to be 17 MHz. The minimum required input power for the injected carrier was found to be -8 dBm, measured at the input fiber. The wavelength locking range was approximately 0.005 nm or 600 MHz.

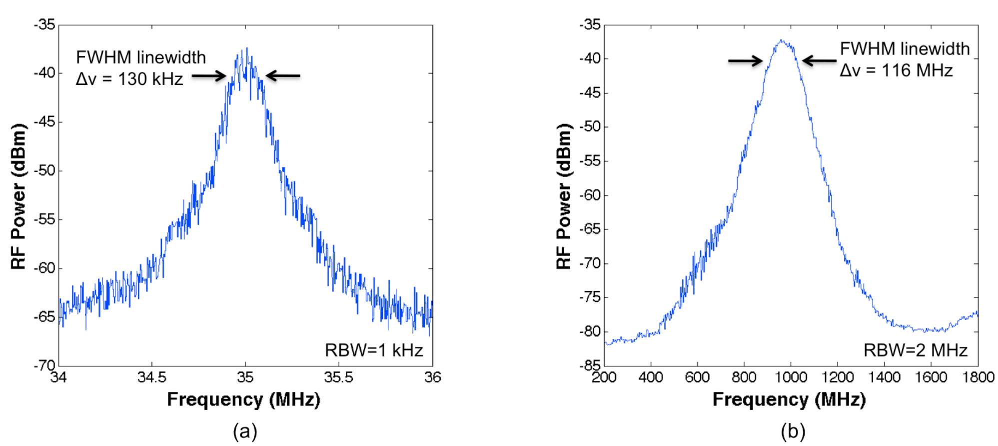
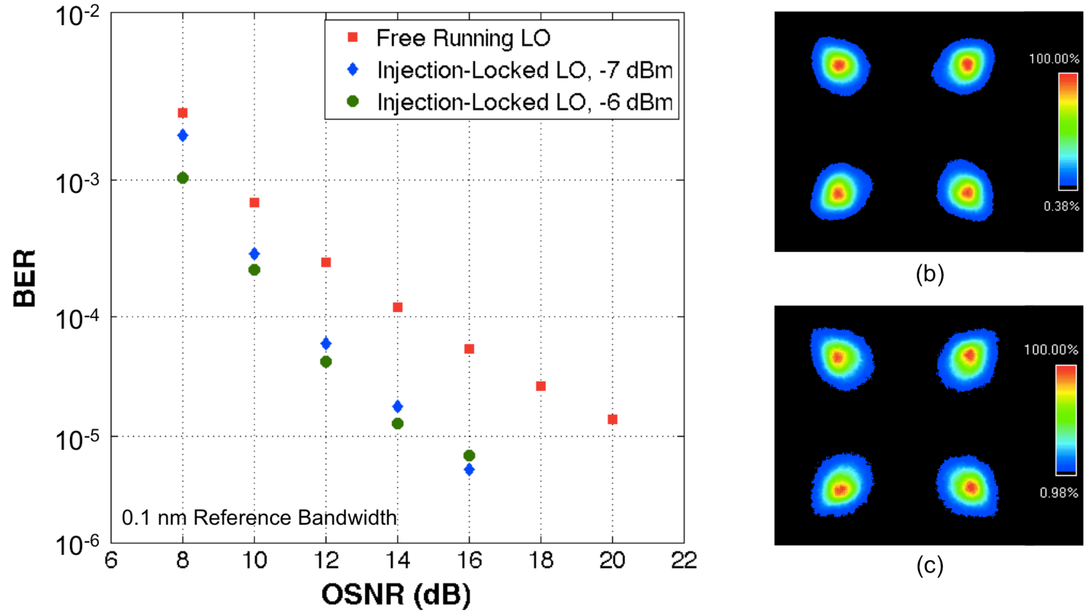


Fig. 3. Heterodyne linewidth measurements for (a) injection-locked SG-DBR and (b) free running SG-DBR. The FWHM linewidth of the injection locked SG-DBR is 130 kHz, ~900x reduction from the free running linewidth of 116 MHz.



(a)

Fig. 4. (a) BER vs. OSNR for the monolithically integrated receiver with a free running local oscillator, and injection-locked local oscillator with injected carrier input powers of -7 dBm and -6 dBm. Constellation for a receiver with a free-running oscillator at 20 dB OSNR (b) and for an injection-locked local oscillator at 16 dB (c).

Fig. 4. shows the BER vs. OSNR plot for the receiver with a free-running local oscillator, and injection-locked local oscillator with injected carrier powers of -7 dBm and -6 dBm. All three of these curves were measured at a wavelength of 1553.15 nm using PRBS 2^7-1 and FEC is not implemented. Compared to the free-running local oscillator, the injection-locked local oscillator exhibits an overall OSNR improvement. At BER of 10^{-3}, the OSNR is improved by approximately 1-1.5 dB, and at BER of 10^{-5}, the OSNR is improved by 5 dB compared to a free-running local oscillator. Fig. 4(b) snows the constellation for the receiver with a free running local oscillator with an input signal OSNR of 20 dB. Fig. 4(c) shows the receiver with an injection-locked local oscillator with an input OSNR of 16 dB, which shows comparable performance to the free-running measurement at 20 dB input OSNR. OSNR improvements for lower BER are also expected, however with the current setup BER below 5×10^{-6} is difficult to measure due to long term stability issues. Implementing a feedback loop as mentioned in Section 1 and also packaging the device to avoid fiber drift would mitigate this issue.

4. Conclusion

We demonstrate a homodyne dual-quadrature coherent receiver using a monolithically integrated, injection-locked local oscillator. For BER of 10^{-3} and 10^{-5}, the OSNR is improved by 1.5dB and 5dB, respectively, compared to the same receiver with free-running local oscillator.

Acknowledgements

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