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Active Control of an Optical 90° Hybrid for Coherent Detection

G. Harston, P.S. Cho, A.S. Greenblatt, A. Kaplan, Y. Achiam, and I. Shpantzer
CeLight, Inc.
12200 Tech Road, Suite 200
Silver Spring, MD 20904 USA

***Abstract*- An algorithm to control the biasing of a lithium niobate optical 90° hybrid for coherent detection was embodied in hardware. The control was able to provide optimal biasing with either homodyne or differential detection.**

I. Introduction

There is increased interest in coherent communications for high capacity transmission. The demodulation of coherent optical signals generally requires combining the received signal with a local oscillator (LO) before detection; this can be achieved using a 90° optical hybrid [1], [2]. Integration of an optical hybrid into a single Lithium Niobate (LN) substrate [3] allows for improved signal integrity, reduced footprint, and facilitates integration with other components in a coherent detection system [4]. The integrated optical hybrid provides the flexibility and fast response to adapt to the received signal for agile detection, for example frequency hopping for secure communications [5]. This entails adaptive biasing of the hybrid.

In this paper we describe the results of a novel, robust control technique that provides and maintains optimal biasing of the optical hybrid. This technique is based on the captured signal from a coherent receiver and does not require knowledge of the transmitted sequence. Also, this technique only requires the analog-to-digital converters (ADC) to capture the received signal at a rate of one sample per symbol. Test results for homodyne as well as differential (one-symbol delay-and-add) detection of RZ-QPSK are described.

II. LN Optical Hybrid and Coherent Receiver

The LN optical 90° hybrid device includes four voltage-controlled couplers and two voltage-controlled phase shifters, Fig. 1. For correct demodulation, e.g. an optical QPSK signal so that the constellation of the data bits on the complex IQ plane is oriented properly, all four couplers must be set to achieve 50/50 power splitting ratios and the phase shifters must be set to achieve an optical 90° phase shift between the I and Q signals.

Algorithms for setting and maintaining the control voltages at the proper levels have been developed and embodied in hardware. The hardware embodiment is part of a coherent receiver, Fig. 1, that is comprised of the optical hybrid, a pair of balanced receivers, and a receiver board. The receiver board houses ADCs (operating at 1 sample/symbol),

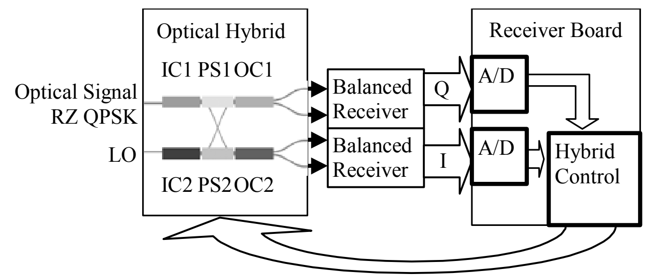

Fig. 1. Optical hybrid control path in the coherent receiver. Couplers: IC1, IC2, OC1, OC2; Phase Shifters: PS1, PS2.

hardware for hybrid control and signal compensation, and a connection to a storage device for recording the I and Q signals.

Testing of the algorithms was performed with homodyne and differential detection of RZ-QPSK signals. The testing reported here was conducted at 80 MSymbols/second to take advantage of existing electronic components but could be scaled to higher symbol rates without impacting the hybrid or the control algorithms.

III. Active Control of the Optical Hybrid

The hybrid bias control algorithm on the receiver board determines the correct bias voltage settings based on statistical computations of the captured I and Q signals. Specifically, the couplers are adjusted to maximize and balance the variances of and the phase shifters are adjusted to minimize the covariance between the I and Q signals. Note that the control algorithm does not require a training sequence and can be operated with live traffic. The hybrid controls can be updated at rates up to 1 MHz. Except for semiconductors, no other material platform can achieve such speed.

The hybrid control works in three stages: setting first the output couplers by maximizing the variances of the I and Q signals, then the input couplers by maximizing the sum variances while minimizing the difference, and finally the phase shifters by minimizing the covariance between the I and Q signals. Fig. 2 shows, in X-Y plots, I and Q signals from simulation after each stage of the hybrid control for homodyne detection of QPSK. A comprehensive model of the optical hybrid was developed in order to accurately simulate the control system response. The SNR of the input QPSK signal in this case is 30 dB.

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Fig. 3 shows the I and Q signals from the balanced receivers with homodyne detection of an RZ-QPSK signal. The test patterns for I and Q are PRBS with word lengths of 2^{23}-1 and 2^{31}-1. In Fig. 2a and 3a the control voltages are set far from the 50/50 and 90° settings, resulting in non-optimal mixing of the signal and the LO, i.e. the I and Q signals are neither orthogonal nor equal in amplitude. After running the hybrid control the bias voltages are set to the proper levels and optimal mixing is achieved, Fig. 2d and 3d. Note that the circular profile in these figures is due to the two laser frequencies not being exactly matched causing the constellation to rotate; even so the algorithm is robust and able to correctly bias the hybrid.

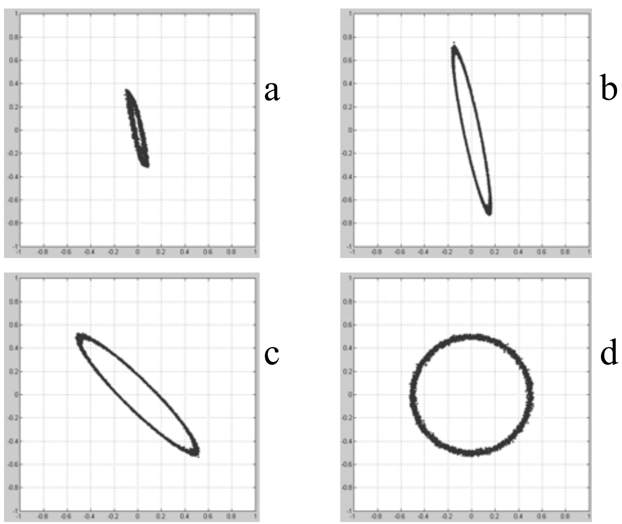

Fig. 2. Simulation of hybrid control: a. initial constellation of received IQ signals, b. after output couplers control iteration, c. after input couplers control iteration, d. after phase shifters control iteration.

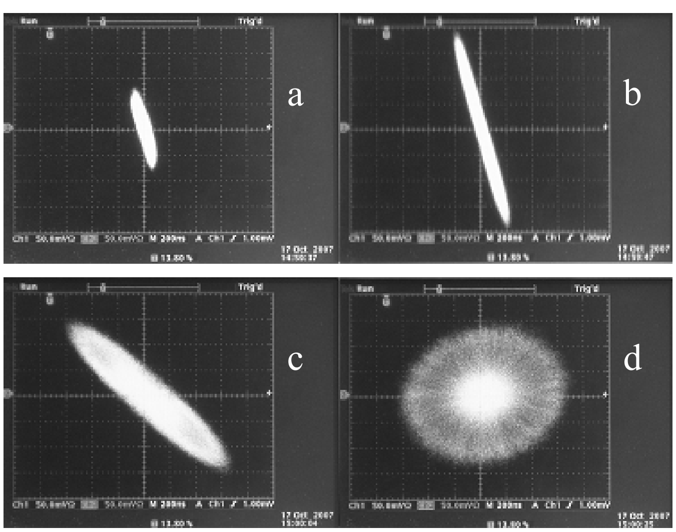

Fig. 3. Hybrid control with homodyne detection of RZ-QPSK: a. initial constellation of received IQ signals, b. after output couplers control iteration, c. after input couplers control iteration, d. after phase shifters control iteration. Displayed on a free-running oscilloscope.

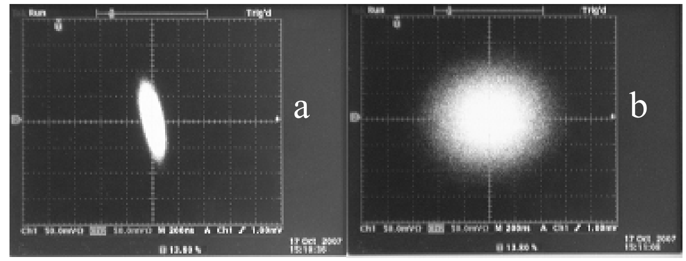

Fig. 4. Hybrid control with optical noise: a. initial constellation of received IQ signals, b. after control algorithm was run. OSNR 0.6 dB (RB: 0.01 nm).

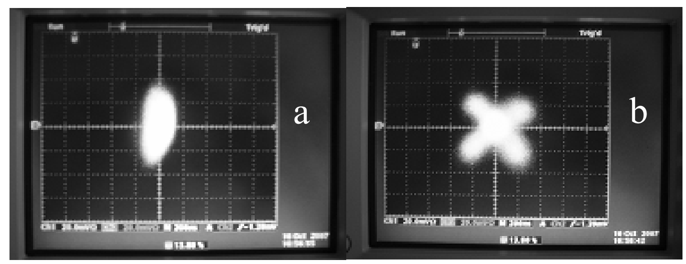

Fig. 5. Hybrid control with differential detection of RZ-QPSK: a. initial constellation of received IQ signals, b. after control algorithm was run. OSNR 9 dB (RB: 0.01 nm).

Fig. 4 shows proper biasing of the hybrid by the control on a homodyne QPSK signal with injected optical noise, OSNR of less than 1dB.

The control algorithm was also tested with differential detection, results in Fig. 5. For differential detection half of the received signal was delayed by one symbol and then coupled into the LO port of the hybrid. Since the optical signal was combined with itself there was no phase rotation of the demodulated signal.

IV. Summary

The embodied control is able to properly bias the hybrid with either homodyne or differential detection. The control is very robust to noise and, in homodyne detection, to differences in the optical carrier frequencies of the received optical signal and the LO. In addition, the control operates with data acquired with one sample per a symbol and does not require prior knowledge of the transmitted sequence.

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