

New intradyne receiver with electronic-driven phase and polarization diversity

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Abstract: A novel PSK receiver technique is proposed based on electronic-driven diversity, without optical hybrid and polarization beam splitters. It achieves high tolerance to phase noise and feasible implementation with commercial lasers.

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Introduction

Homodyne coherent optical reception is considered as the ideal method to detect Dense WDM optical signals, because of its excellent wavelength selectivity, low sensitivity and tuneability performances. However, its implementation has been so far excluded from commercial deployment because of its stringent requirements in terms of laser spectral linewidth, tuning bandwidth and delay [1, 2]. On the other hand, another type of receivers, known as intradyne systems, with phase diversity were studied at early 90s [3, 4, 5]. Recently, some approaches to solve this by using digital signal processing have been proposed [6, 7, 8], either using a parallelized phase acquisition or using an algorithm implementable with analog components.

We here propose a new optical intradyne receiver architecture, based on [9], that aims to be highly insensitive to the phase noise and to the polarization variation, with low cost components. No complex optical components, like the phase-critical optical 90° hybrids or the polarization beam splitters, are used. The basic idea is to detect both In-Phase (I) and In-Quadrature (Q) components, by introducing a controlled periodic phase shift at the local laser output, and performing a combined differential post-processing. This leads to a phase diversity system. Extending this approach to the polarization state (SOP), Horizontal (H) and Vertical (V) polarization diversity is achieved by means of synchronous polarization scrambling and post-detection.

Proposed Scheme

The diversity receiver has two main parts: the first is a coherent photo-receiver with added clock-synchronous phase (0 - 90°) and polarization (H-V) scrambling at the local laser output. The second part is an electrical post-processing performing the signal demodulation and the synchronous combination of the orthogonal components. The local laser does not need to be coherent with the incoming optical carrier, although an automatic frequency controller is convenient to maintain the two wavelengths close. It can be regarded as a heterodyne receiver with near-zero intermediate frequency

The coherent photo-receiver mixes the incoming optical field with the local laser carrier in the balanced photo-detector stage. These components are no coincident with the TX-generated ones due to the unlocked transmission phase, but, with post-processing performing the operations in [5], the phase-modulated information is fully recovered. The optical phase scrambler at the local laser output is controlled by the data clock (50% duty cycle) producing a 0° - 90° phase modulation, to obtain the I and Q signal components, at the first and second half part of each bit time (T_b) respectively, after the optical mixing. In a similar way, the polarization components V and H, are at even and odd quarters of the bit time, respectively. This is indicated in figure 1.

Correspondingly, the photo-receiver output is gated with the data clock signal, its inverse, and a doubled frequency version of them to obtain the I and the Q separately for every polarization component in the four branches, now with RZ shape. In order to re-synchronize the data clock signal with the signals introduced to the post-processing block and phase modulator, the respective relative delays are introduced in the branches, and a variable delay is added to compensate for the RX propagation delays.

The electronic signal processing stage performs the differential demodulation of the four components, separated by electronic switching, with a delay time equal to T_b . All demodulated components are synchronously combined with an adder.

Due to the phase noise and the SOP random variation, the signal power fluctuates between the four branches randomly, at a rate in the order of the laser linewidth and SOP fluctuation, and the detailed combination of all the outputs assures its recovery (figure 1). In terms of phase noise, compared to an oPLL, the phase-swing time has been shortened from the loop delay to only a bit time, which, in contrast, reduces while bit rate increases.

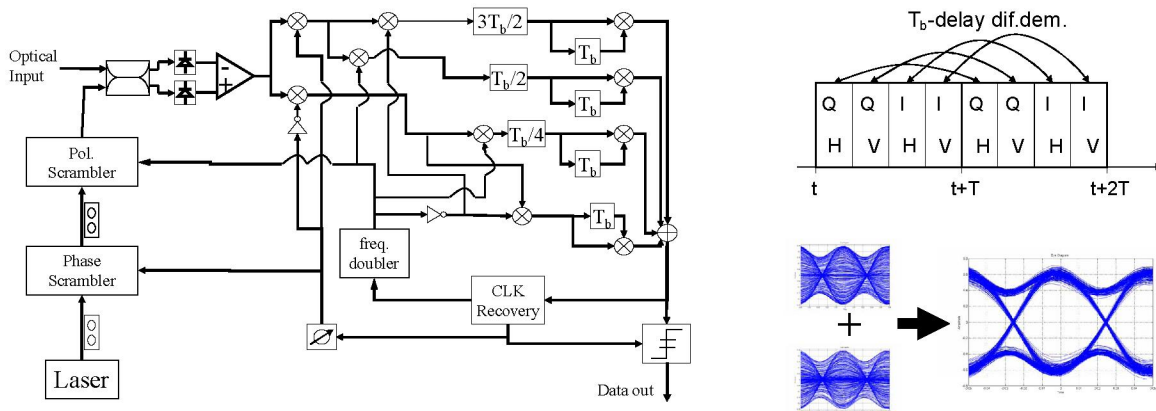


Fig. 1. Intradyne differential receiver with both polarization and phase diversities (left). I, Q, H, V time distribution of each bit (upper right). I, Q and I+Q outputs eye-diagrams at 50 MHz total laser linewidth when only phase diversity is used (bottom right).

To achieve the best performances in polarization diversity terms, the scrambler must introduce a clock-synchronous 90° rotation. It is implemented with a highly birefringent phase modulator, with its input 45° linearly polarized.

As a result, after combining all the branches we have the same theoretical results as obtained in [4, 5]. However, it must be taken into account that the reduced duty-cycle and the correspondingly increased electrical bandwidth produces 3dB SNR penalty.

System Performance

The proposed receiver (with I&Q diversity) is compared to a standard oPLL based on a lock-in amplifier. In these two cases, the output parameter measured was the statistical eye-opening of the received data, accounted as the mean amplitude minus twice the standard deviation, which provides a fair measure of the sensitivity penalty.

The eye-opening measures were made at several linewidths from 225 kHz to 1 GHz. Bit rate is 10 Gbps; also, a 4th order 7.5 GHz Bessel low-pass filter was placed before decision.

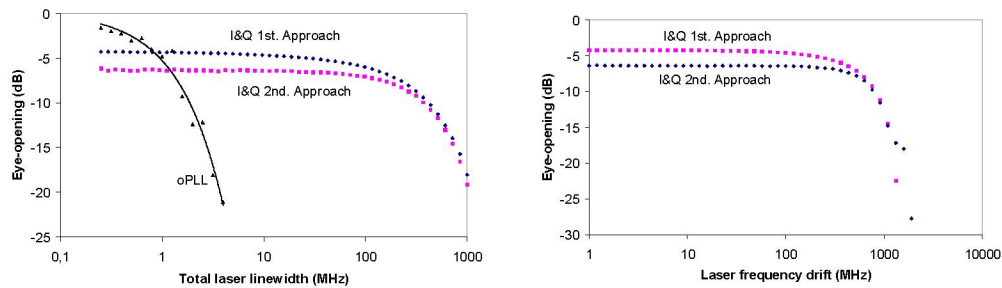


Fig. 2. Statistical normalized eye-opening (20log) for the I&Q receiver (both first and second approach) and a lock-in optical PLL, as a function of the total laser linewidth (left) and the laser frequency drift (right).

The resulting system tolerance to the laser phase noise is depicted in figure 2. It shows the normalized eye opening measured as a function of the laser linewidth, verifying that the phase noise tolerance is greatly extended, from 1 MHz to 100 MHz (for about 2 dB sensitivity penalty). Only for very low linewidths (below 1 MHz), it is better to use a classical PLL architecture; a penalty of about 4dB is incurred, which is due to the use of a duty cycle of 50% at the novel architecture and to the intrinsic nature of the differential demodulation.

Also, the processing demonstrates to be highly insensitive to the wavelength drift (up to 10% Rb), and does not require fast tuning lasers, as shown in figure 2 (right), for drift values from 1 MHz to 10 GHz. The reception is degraded at drifts higher than 1GHz.

Practical Implementation

In order to simplify the electrical processing implementation, a similar, but simpler architecture is proposed for the DPSK with phase diversity. In this scheme (shown in figure 3), only one analog multiplier and adder are necessary. For this second approach, performances are similar as it is shown in figure 2 (2nd approach); the eye diagram temporal aperture is slightly reduced because here the noise is not gated. There is about 2 dB penalty between this second approach and the first one.

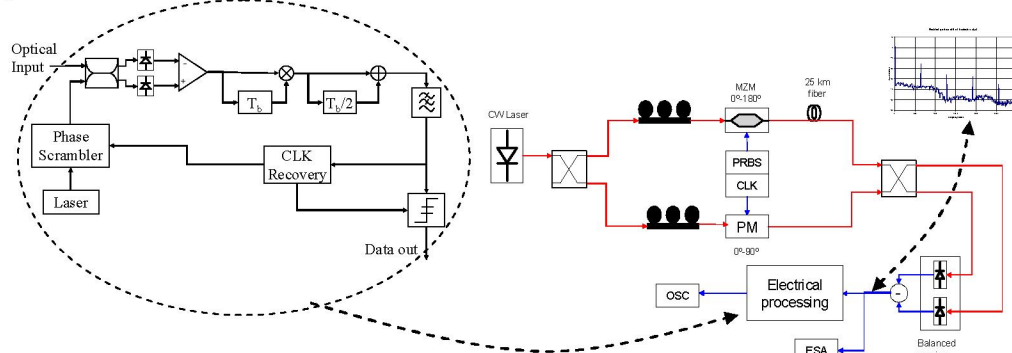


Fig. 3. I, Q intradyne differential receiver, second approach (left); and experimental setup with this configuration (right).

Because of its reduced complexity, this is the scheme used in the prototype and the experimental setup shown in figure 3, depicting the BPSK modulation system. The phase modulation (0° - 180°) is done with a Mach-Zehnder Modulator (MZM) controlled by a Pseudo-Random Binary Sequence (PRBS); the I/Q scrambling (0° - 90°) is done with a Phase Modulator (PM) driven by data Clock (CLK). Preliminary experimental results show the feasibility of the proposal.

Conclusion

We have proposed and demonstrated a new DPSK intradyne architecture based on RX time-multiplexed phase-diversity and polarization diversity set-up with differential post-processing. It remarkably increases, in more than one order of magnitude, the phase noise tolerance of conventional homodyne receivers, up to a linewidth of 1% Rb, and avoids the use of optical PLL.

This architecture is specially indicated for standard linewidth slow tuning semiconductor lasers and avoids the use of the phase-critical optical 90° hybrids. Thus, it constitutes an enabling technique towards Ultra Dense WDM networks, featuring few GHz spacing wavelengths with electrical channel filtering, simple tuning and low sensitivity.

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