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Simple Intradyne Receiver with Time-switched Phase Diversity for Optical Interconnects

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Abstract: A time-switched phase-diversity intradyne coherent receiver is proposed based on an 180° optical hybrid, which requires only half hardware than a traditional coherent receiver. Transmission of 10 Gbaud QPSK signals over 20km SMF is demonstrated successfully.

OCIS codes: (060.1660) Coherent communication; (200.4650) Optical Interconnects;

1. Introduction

Cisco forecasts a three-fold increase of global data center (DC) IP traffic by 2020 [1]. The surge of the cloud traffic will further drive the development of high capacity optical interconnects. Currently, 400 Gigabit Ethernet standards have chosen high-baudrate PAM4 signals with direct-detection technology because of its low IC power consumption [2]. To further improve link bandwidths, the spectrally-efficient high modulation format signal, which has been widely deployed for long-haul transmission, provides a possible solution for optical interconnections. However, a complex digital coherent receiver including a 90° optical hybrid and the following 4 balanced detectors is required to detect these optical signals. The high cost of the typical coherent receiver will restraint its deployment in the cost-sensitive DCs. In addition, the bulk size of the receiver is another main limitation for applications in DC networks, which high link densities are always preferred.

A cost-effective coherent receiver can be realized by using an inexpensive 3×3 fiber coupler as a 120-degree optical hybrid [3]. However, for each polarization, these receivers require three sets of electrical circuits, more than that of coherent receivers with 90° hybrid. [4] proposed a homodyne receiver with time-switching phase diversity by using a 3-dB coupler as an 180° hybrid. In this case, the time slot of one symbol is divided into two parts: the first is used to detect in-phase (I) signals and the second is for quadrature (Q) signals. The "I" and "Q" signals can be detected successively by a 3-dB coupler with a clock-synchronous phase switched local oscillator (LO). The challenge of this method is to extract a high-quality clock at twice symbol rate to switch the phase of the LO by +/-90° , which increases the complexity of the coherent receiver. The designed receiver can't extend to receive high-order modulation format signals.

In this paper, we generate 10 Gbaud time-switched QPSK signal with a typical 20-Gbaud QPSK transmitter. Two consecutive symbols will carry same data while the second symbol is obtained by rotating the first QPSK symbol by 90°. A simple intradyne coherent receiver, which consists a 3-dB coupler, a local oscillator and a balanced receiver, is implemented to detect the 10 Gbaud time-switched QPSK signal. Without using complex and bulk 90°optical hybrids, the proposed simple receiver detects both the in-phase (I) and quadrature (Q) components of the original QPSK signal sequence. Transmission of 10Gbaud QPSK signals over 20 km is experimentally demonstrated. Moreover, the receiver-side digital signal processing (DSP) are investigated.

2. Operation principle

The time-switching QPSK transmitter has a similar structure to a typical QPSK modulator. A continue-wave (CW) laser is modulated by an IQ modulator driven by two binary electrical signals. The time-switching operation is achieved by doubling the symbol rate of the transmitter, with the first symbol carries the original QPSK signal, and the following symbol carries a 90°-rotated QPSK signal, as shown in Fig.1(a). The 90°phase-rotation operation can be easily achieved by a pre-coder. Assuming the respective I and Q driving signals of the IQ modulator for an original QPSK symbol is 'I_d' and 'Q_d', the required I and Q driving signals for the following 90°-rotated QPSK symbol is 'Q_d' and '$-I_d$', respectively. The original QPSK symbols are interleaved by the 90°-rotated QPSK symbols. Such configuration will simplify the structure of the coherent receiver.

In a typical coherent receiver with 90°optical hybrid, the quadrature components of the signals are detected by beating between signals and LO with an extra 90°phase shift. The extra 90° phase shift is realized by adding a phase shifter in the LO path of a 90° optical hybrid. The traditional coherent receiver requires a bulk 90° optical hybrid and the followed two balanced detectors. In our setup, the introduced relative phase shift in the rotated QPSK symbols acts similarly as the phase shifter in the 90° optical hybrid. The beating of original QPSK symbols and LO are used to detect the in-phase components. While the beating of 90° -rotated QPSK signals and LO are used to detect the quadrature components. So as shown in Fig.1(b), a single optical 3dB coupler can be used to detect both the "I" and "Q" components of QPSK signals.

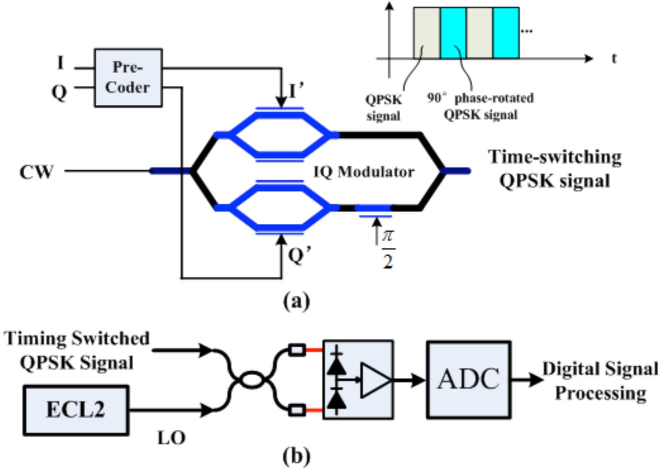
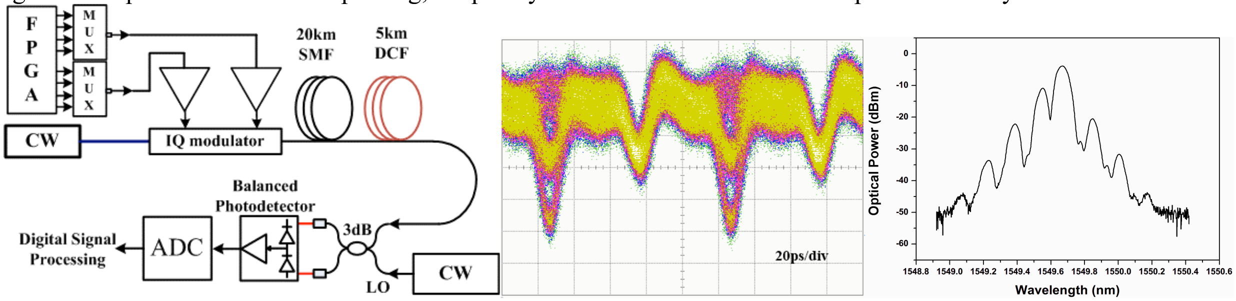


Fig. 1 (a) Proposed time-switched QPSK transmitter (b)the simplified phase-diversity coherent receiver

Compared to the traditional phase-diversity intradyne receiver, the proposed receiver uses a 2×2 3dB optical coupler as optical hybrid instead of a 2×4 90° optical hybrid. The design also simplifies the electrical components in coherent receiver dramatically and only uses a balanced detector and a one-channel analog-to-digital converter (ADC). Such simplification in the receiver design makes low-complexity coherent detection possible in DCN, where port density is critical. The drawback of such design is that the bandwidths of the transmitter and receiver are doubled. However, the deployment of advanced modulation format signals could provide more capacity with a reduced bandwidth.

After the ADC, the digital signal processing blocks are followed to recovery the original QPSK constellation. As in our setup, the in-phase and quadrature components are detected in sequence. So, the first step of the digital signal processing blocks is to detect the first sample of "I" components to separate "I" and "Q" samples. For a typical four-times sampling system, each QPSK symbol will be sampled twice. We can detect the value of the symbol power to separate the 'I' and 'Q' components. Then we can use the typical digital signal processing algorithms for QPSK signal to do polarization demultiplexing, frequency offset estimation and carrier phase recovery.



(a) (b) (c)

Fig. 2 (a) Experimental setup of time-switched QPSK transmission system; (b) Eye diagram and (c) optical spectrum of 10 Gbaud time-switched QPSK signal

3. Experimental results

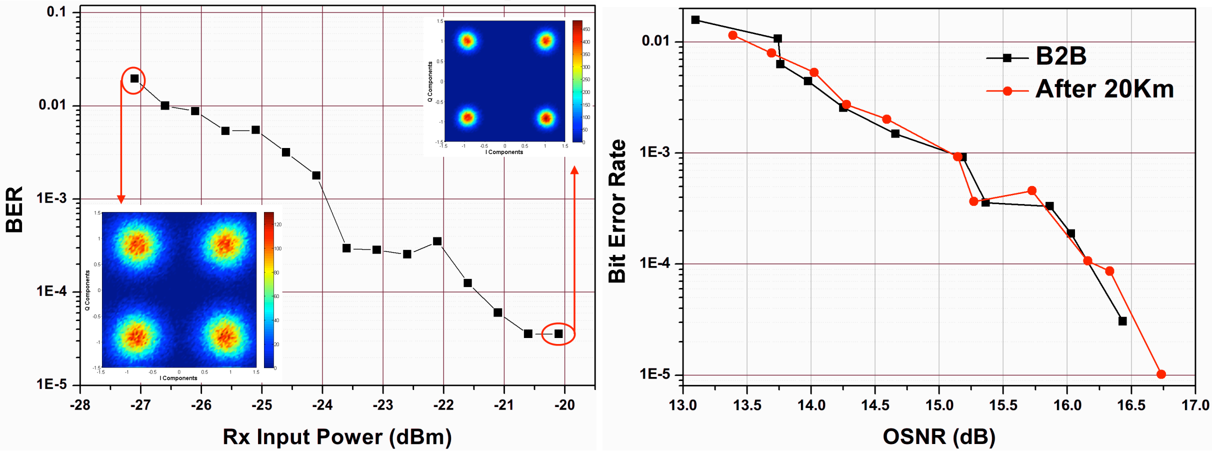
Figure 2(a) depicts the experimental setup of the time-switched transmission system. Eight user-defined 5 Gbit/s data streams, provided by an Altera FPGA Stratix IV Transceiver Signal Integrity development board, are feed into two 4:1 multiplexer (Mux) to generate two 20 Gbit/s binary data streams. The generated data streams are user-defined to simulate the pre-coding operation in the transmitter. Then the defined drive signals drive an IQ modulator to obtain 10 Gbaud time-switched QSPK signals, which can be regard as 20 Gbaud QPSK signals. The eyediagram of the generated 10 Gbaud time-switched QPSK signals is shown in Fig.2(b). In our design, the second-half part of the symbol is the copy of the first-half part with extra 90° phase rotation. So, we can observe only one eyelid in the center symbol. The corresponding optical spectrum is shown in Fig.2(c).

The generated time-switched QPSK signal is launched into a 20-km SMF. In order to avoid using complex chromatic dispersion (CD) compensation in DSP, a 5-km DCF is used to compensate the CD. At the receiver, another external cavity laser (ECL) is used as local oscillator. Both the signals and LO are launched into a 2x2 3dB coupler, then a balanced photodetector is used to convert the optical signal to electrical signal. The output of the balanced photodetector is sampled by a 50 GSample/s real-time digital sampling scope (DSA72004B). A sequence of 500 K samples is stored and post-processed off-line. In the setup, only one polarization is used. The transmitter and receiver can be updated to polarization multiplexing operation easily.

The DSP algorithms comprises of re-sampling down to 40 GSample/s, IQ separation, a 5–taps T/2 spaced time-domain finite impulse response (FIR) adaptive filters for timing phase recovery and down sampling to one sample per symbol, frequency offset compensation, carrier phase estimation, symbol detection, differential decoding and bit error ratio (BER) counting.

Figure 3(a) shows the back-to-back BER as a function of the received optical power. The recovered constellation is shown in inset. Lack of efficient transimpedance amplifier, the sensitivity of our receiver is limited by the electrical noise. The small electrical signals make the oscilloscope unable to make full use of the resolution of the ADC, so the quantizing noise also contributes to the low sensitivity.

We also test the optical signal noise ratio (OSNR) requirement of our proposed transmission system. Both the back-to-back performance and transmission after 20 km SMF are shown in Fig. 3(b). It can be observed that the 20km transmission won't introduce extra OSNR penalties.



(a) (b)

Fig. 3 (a)Receiver sensitivity of back-to-back transmission; (b) Bit error rate vs. OSNR for B2B and 20km transmission

4. Conclusion

A simple coherent transmission system is demonstrated successfully for low-complexity compact optical interconnections in DCN. By introducing a time-switched transmitter, a phase-diversity intradyne coherent receiver can be implemented with a 180° optical hybrid, i.e., a 3dB optical coupler, and one single ADC. Transmission experiments with 10 Gbaud QPSK signals are demonstrated successfully. Higher-order modulation format signals, such as 16QAM, can be used in future to improve capacity with the same operation principle. The simplified receiver with a simple structure and a compact size provides a potential solution in DCN for high-capacity optical interconnects.

Acknowledgement

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