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Optoelectronic Devices and Subsystems for Digital Coherent Optical Communication

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***Abstract*—40Gb/s coherent communication link's components are reviewed, including the electronic elements and supporting algorithms' stack. The migration to a 100Gb/s link is discussed in terms of respective component specification and different coherent communication formats.**

Keywords-coherent communication; QPSK; component;

I. INTRODUCTION

Today's additional bandwidth requirements revive the coherent optical communication approach, which has been abandoned for the past 20 years. A relatively simple version of a full coherent system, such as DQPSK scheme[1], is now deployed as a 40Gb/s solution for long-haul communication. However, it is not trivial to transfer such a solution to 100Gb/s long-haul links that are expected to emerge within the next few years. The modulation schemes suggested for the DQPSK-solution replacement are the full coherent QPSK and the coherent OFDM[2]. Currently, the effective deployment of these modulation schemes is limited foremost by the market unavailability of reliable mature building blocks; both in the electro-optical and the RF-domain. In this paper we will review the required building blocks with respect to functionality and feasibility.

II. THE DIGITAL COHERENT QPSK LINK

Optical coherent communication is based on the information encoded in the signal phase. Therefore, the phase of the signal has to be well-defined by appropriate modulation and demodulation techniques. The typical on-off key intensity modulators and detectors cannot perform these tasks. The 'standard' PSK-link includes a light source, QPSK phase modulator, pulse shaper, polarization combiner, DWDM interface, polarization controller, phase detector, and receiver, as shown schematically in Figure 1. The use of the phase to carry the data creates additional complexity, starting from the need to control the polarization at the receiver, followed by the requirements for a new generation of components. On the positive side, it enables a linear transformation of phase encoded optical carrier to base-band, thus opening a way for a variety of DSP and RF methods to enhance the link [3]. An algorithm layer is required on top of the optical layer to stabilize the electro-optical components at their optimal operating region. Additional real-time digital algorithms utilize DSP at the base band to improve the link performance. The digital compensation coefficients are computed at the phenomenon rate to mitigate chromatic dispersion, polarization compensation, vibration and other channel deficiencies as shown in [1][3].

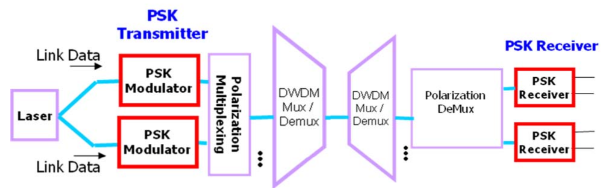

Figure 1. A tipical coherent optical QPSK link.

Typically, the lasers required in a coherent link do not have to be extremely narrow-lined. As shown experimentally [1][4], a standard DFB laser can be used with digital PLL and an appropriate algorithm. The QPSK modulation for each polarization can be achieved by two phase modulators. However, due to its environmental sensitivity, it is preferable to use a combination of Mach-Zehnder modulators with an additional stabilized 90° phase shifter in between [5]. An 18 GHz-bandwidth X–cut $LiNbO_3$ QPSK modulator is depicted in Figure 2.

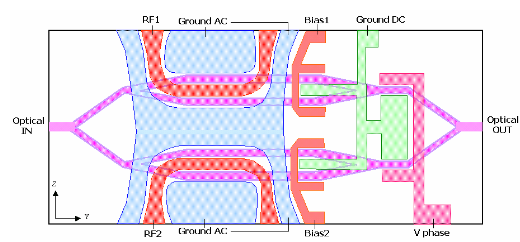

Figure 2. A LiNO3 X-cut QPSK modulator.

There are few versions of the modulator that currently exist; for example, a Z-cut version with domain poling that eliminates modulator chirp [6], and a QPSK modulator integrated with RZ pulse-shaper [7]. Both are suitable for 12.5 GHz applications that support a 40Gb/s transmission by dual polarization multiplexing. Polarization multiplexing/de-multiplexing is performed digitally, assisted by a standard polarization combiner-splitter.

Following the polarization splitter at the Rx, the signal is mixed with a local oscillator at the hybrid. A 90°-Hybrid, schematically presented in Figure 3, is comprised of four 3dB

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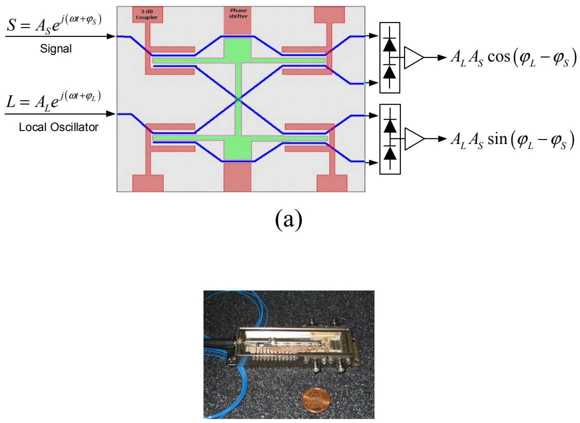
couplers and 90° phase shifter(s). The optical path lengths between the four output ports of the 90°-Hybrid and the balanced receivers has to be equal and stabilized. Therefore an integrated version of the coherent receiver is required. A coherent receiver that includes a 10GHz electrical front-end is also available [8]. The bandwidth is limited by the electrical front-end and by the following A/D converters.



(a)

(b)

Figure 3. Coherent receiver. (a) Schematics of the receiver. The colored section is the 90°optical hybrid. (b) A package coherent receiver.

The fast photo-diodes and trans-impedance amplifiers for the higher rates are already available. A/Ds with sufficient dynamic range operating at 12.5GHz have recently appeared on the market. There is a challenge to preserve the bandwidth of such elements during the packaging process.

The digital stabilization algorithms that are needed to keep the different components at their working region are relatively slow and can be realized by standard electronics. On the other hand, the digital polarization controller has to perform the final correction at the symbol rate of the link [3]. A schematic of such algorithm is given in Figure 4 and detailed in [3].

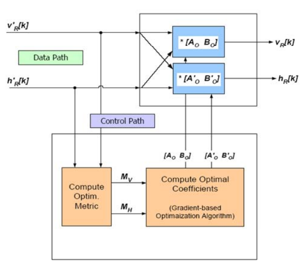


Figure 4. Schematics of the digital polarization rotator that is performed at the base-band

A dedicated ASIC to incorporate the digital algorithms stack layes (Components Stabilization and Link compensation) is used as described in [3]

III. ADDITIONAL COHERENT FORMATS AND MATERIALS

In order to reach the 100 Gb/s with the QPSK format a symbol rate that is close to 30GSy/s is required. However, different modulation formats can be used to continue working with a lower symbol rate, for example, using the M-ary QAM or M-PSK formats. Thus, the foregoing components with two additional D/A converters, at the RF inputs of the modulator, can be implemented to construct a M-ary QAM transponder.

A preferable method would be to use OFDM to form a coherent link. In this case, the electro-optical components are the same as for the QPSK format; however, two additional D/A-converters at the modulator are required. The DSP processor is also more complicated in this case since it has to perform inverse and forward Fourier transforms in the complex domain.

$LiNbO_3$ is still the major fabrication material for the described components since it has all the advantages of a mature manufacturing technology. It is also most suitable for the required communication rates. The disadvantage of the $LiNbO_3$ is a relatively large size and integration limitations. Since high integration is the key for cost efficiency, the InP substrate seems to be a preferred alternative. Other materials and technologies that are now emerging such as silicon-based ones can also serve as building blocks for digital coherent communication links.

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