AN OPTICAL COHERENT TRANSMISSION SYSTEM BASED ON POLARIZATION MODULATION AND HETERODYNE DETECTION AT 155 Mbit/s BITRATE AND 1.55 μm WAVELENGTH

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1. Introduction

The digital modulation schemes of optical coherent transmissions which show the highest efficiency are based on angle modulation techniques, such as frequency and phase shift keying (FSK, PSK). Their optimum performance are due to the advantage of a complete exploitation of the source emission, since sending an equal amount of energy for each bit, the maximum transmitted power remains unchanged at any time.

In the case of a binary FSK modulation, the aforesaid property is related to the signal structure, whose spectrum can be compared with a double ASK (amplitude shift keying) system (one for each tone) carrying a complementary information on the two superimposed channels. The pulse pattern of one ASK channel (at angular frequency ω₁) exactly compensates the sequence from the other (at ω₂), so the total power remains invariant as required. From this point of view the two frequency channels carry a bidimensional message in the modulation space and the information content can be represented with a redundant coding [1].

Such interpretation can be extended to the vector space of the electromagnetic field, where the state of polarization (SOP) of the light is defined. In this novel approach the two channels carrying the signal, correspond to different directions of the electric field vector and in particular to a pair of linear orthogonal SOPs of the same optical carrier. Using this modulation scheme, the binary information is transmitted by switching the lightwave SOP between the aforesaid two states at any bit change. Therefore, according to other classic modulation formats, this unconventional technique exploiting the vector properties of the electromagnetic field has been called polarization shift keying or POLSK [2, 3, 4].

As regards a typical drawback of optical coherent transmission systems with respect to radiowave communication apparata, it is known that the laser shows a phase noise which affects both the transmitter source and the local oscillator. A recent solution of this problem employed in heterodyne receivers in the case of angle modulation is called non-coherent postdetection and consists in an envelope, square-law or delay demodulation.

The first alternative has been applied on both detected channels of a double ASK (POLSK) experiment at 560 Mbit/s bitrate and 1.3 μm wavelength [3]. Another possibility realized in a POLSK experiment, is to detect the relevant phase shift (0, π) corresponding to the information bits (1, 0 respectively) through a cross product of the two output channels at intermediate frequency (IF), which provides a synchronous subtraction of the unwanted phase noise. Other receiver configurations experimentally demonstrated or simply proposed include delay schemes [5] or square-law devices [6]. Nevertheless the fundamental property which unifies all coherent POLSK versions is...
just the phase noise cancellation which purifies the baseband data improving the signal to noise ratio.

The main advantage of the POLSK technique, from the viewpoint of the bandwidth occupancy, is that the IF signal shows the spectrum of a single ASK channel, while the corresponding sensitivity is in principle the same as in the FSK system (as will be discussed in the following).

In the present paper an experimental POLSK system with square-law detection on two orthogonal polarization channels is demonstrated.

Transmission tests at bitrates up to 155 Mbit/s have been performed using two DFB lasers at 1.548 μm as source and local oscillator.

The system performance has been reviewed by taking into account the double-ASK configuration of the POLSK technique and by illustrating its analogy with FSK on the basis of the error probability function.

Moreover the optical setup is accurately described, in particular the polarization modulator (simply implemented modifying an OGW 2x2 switch) and the heterodyne receiver configuration.

As regards experimental results, specific tests on the phase noise subtractivity show an excellent ratio (about $10^7$) between the IF and the demodulated linewidth and an output eye-diagram at 155 Mbit/s which compares favourably with the simulated one.

2. Performance of the POLSK system

In the present experiment the digital polarization modulation has been accomplished, at the transmitter stage, by using a modified scheme of an OGW 2x2 matrix based on an integrated Mach-Zehnder interferometer. In this special application the four ports are equipped with polarization maintaining fibres and the two outputs provide linear orthogonal SOPs (corresponding to bits 0, 1). At the receiver stage after the fibre line the two input SOPs are completely recovered with manual compensation.

According to the vector diagram of Fig. 1, the received signal can be represented in the $x$, $y$ frame of the output polarization analyzer (parallel to the 0, 1 SOP directions respectively) as follows

$$\bar{E}_s = \sqrt{P_s} \exp\{i[\omega_s t + \phi_s(t)]]\{m(t)\hat{i} + [1-m(t)]\hat{j}\}$$

where $P_s$ is the signal power, $\omega_s$ the corresponding angular frequency, $\phi_s(t)$ the source phase noise, $m(t)$=0, 1 the information message, and $\hat{i}, \hat{j}$ the unit vectors of the chosen $x, y$ axes. Owing to this orientation of the SOP splitter, the data flow is divided between the two detectors, receiving the sequence $m(t)$ and $[1-m(t)]$ respectively at the same bitrate.

In a similar way the local oscillator (LO) beam at angular frequency $\omega_L$, linearly polarized at 45° in the same reference as the signal, can be represented in the form

$$\bar{E}_L = \sqrt{P_L/2} \exp\{i[\omega_L t + \phi_L(t)]\}(\hat{i} + \hat{j})$$

where $P_L$ is the LO power and $\phi_L(t)$ its phase noise, totally uncorrelated with respect to $\phi_s(t)$. To fulfill the condition of quantum limited detection, $P_L$ is assumed sufficiently high, which overcomes all the receiver noises.