Coherent Fiber Communications Analyzer

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Abstract—**This paper addresses an coherent fiber communication analyzer with digital signal processing (DSP). First we make an overview of the investigations that are being conducted at Instituto de Telecomunicações (IT) in the coherent communications area and then introduce the coherent receiver used in the IT laboratory. We also present an interface developed in GUI of Matlab to analyze coherent signals.**

Index terms—Coherent Optical Communications Systems; Digital Signal Processing.

I. INTRODUCTION

In the last decades, optical communications introduced a different concept in communications systems. If they did not exist, today would be difficult to answer the demand for bandwidth. This higher bandwidth is related to its physical characteristics, which make them overcome other media. However, its capacity is limited due to the performance of physical equipment and if we do not progress, it will not be possible to respond to the demands for the future telecommunications networks.

Thus, it is appropriate to continue searching for new solutions to overcome these issues. Coherent systems have been widely investigated in recent years to meet thisdemand [1]. Due to their increased sensitivity and selectivity of the received channel,coherent optical receivers allow that twoWDM (wavelength division multiplexing) channels coexist with very smallfrequency separations (ultra-dense WDM systems – UDWDM). One major advantage of these receivers is also the highest spectral efficiency, by enabling the use of multilevel modulation. The coherent optical modulation formats use in-phase and quadrature components, e.g. QPSK modulation, requires two times less bandwidth than a simpler amplitude modulation format like OOK (on-off keying) [1].

Coherent detection has additional advantages. In the last half century, the optical communication systems overcame other traditional transmission systems, primarily due to improvements achieved in the optical fiber, through the use of fibers with, for example, lower attenuation. But there are other phenomena that limited optical systems for many years, such as chromatic dispersion (CD), polarization mode dispersion (PMD) or non-linear effects. In the past two decades, particularly with the development
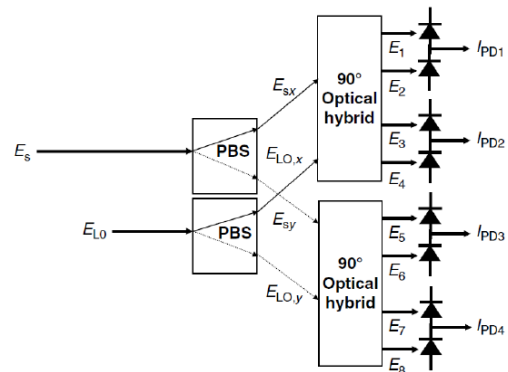

Figure1: Coherent receiver of the lab: phase and polarization diversity [1].

of digital signal processing, several post-detection techniques have been able to overcome these obstacles, through the use of coherent detection systems. Once this receiver maps both amplitude and phase of the optical electric field in the electrical domain, it is possible, using appropriate subsystems and algorithms incorporated in the receiver, to compensate several imperfections associated to transmission [4].

Optical communication research is currently highly focused in coherent communications and the IT is no exception. Besides the numerous simulations that were conducted by our research group,has recently been implemented in our lab the coherent QPSK (quadrature phase-shift keying) system using single polarization, which showed the transmission capacity on 20 km of a UDWDM QPSK signal at 16 x 1.25 Gbps with frequency grid of 3.125 GHz.

It is expected that further tests are carried out briefly for higher transmission rates and different modulation formats such as 8-PSK or 16-QAM (quadrature amplitude modulation) - dual polarization willbe also introduced. Since many of the future projects will be focused on this theme, IT has developed in recent months a interface in GUI of Matlab that maps a DSPcoherent receiver in offline processing, in order to make the system simpler for the common user, however more robust to the received information.

II. COHERENT THEORY

The coherent receiverpresent in the lab is shown in Figure 1. The received signal, having an arbitrary state of polarization, is separated into two linear polarizations by a PBS (Polarization Beam Splitter). Through a 90° Optical Hybrid the signal is mixed with the local oscillator, giving rise to the components:

$$E_{1,2} = \frac{1}{2}\left(E_{SX} \pm \frac{1}{\sqrt{2}}E_{LO}\right) \tag{1}$$

$$E_{3,4} = \frac{1}{2}\left(E_{SX} \pm \frac{j}{\sqrt{2}}E_{LO}\right) \tag{2}$$

$$E_{5,6} = \frac{1}{2}\left(E_{SY} \pm \frac{1}{\sqrt{2}}E_{LO}\right) \tag{3}$$

$$E_{7,8} = \frac{1}{2}\left(E_{SY} \pm \frac{j}{\sqrt{2}}E_{LO}\right) \tag{4}$$

where E_{SX} e E_{SY} are the two orthogonal received electric fields (divided by PBS), corresponding to x and y polarization, and E_{LO} is the electric field of the local oscillator. The output photocurrents are:

$$I_{PD1}(t) = R\sqrt{\frac{\alpha P_s P_{LO}}{2}}\cos(\theta_s(t) - \theta_{LO}(t) + \delta) \tag{5}$$

$$I_{PD2}(t) = R\sqrt{\frac{\alpha P_s P_{LO}}{2}}\sin(\theta_s(t) - \theta_{LO}(t) + \delta) \tag{6}$$

$$I_{PD3}(t) = R\sqrt{\frac{(1-\alpha)P_s P_{LO}}{2}}\cos(\theta_s(t) - \theta_{LO}(t)) \tag{7}$$

$$I_{PD4}(t) = R\sqrt{\frac{(1-\alpha)P_s P_{LO}}{2}}\sin(\theta_s(t) - \theta_{LO}(t)) \tag{8}$$

where α is the power ratio between the two components of polarization and δ is the difference between respective phases of the two components. It is easy to conclude that the receiver can measure separately the complex amplitudes of the two polarization defined by [4, 8]:

$$I_X(t) = I_{PD1}(t) + jI_{PD2}(t) \tag{9}$$

$$I_Y(t) = I_{PD3}(t) + jI_{PD4}(t) \tag{10}$$

III. SYSTEM AND COMPENSATION

The block diagram of the receiver system is shown in Figure 2. After the coherent detection, the four signals detectedby the receiver (equations 9 and 10) are directly connected to the oscilloscope, which in this system works only as ADC (Analog Digital Converter), ie only digitizes the signal with a specific sampling rate and sends the data to the computer through an ethernet communication. It is new application developed in GUIof Matlab that controls the oscilloscope settings, like as the sampling rate, record length or channel settings. In part of DSP, which runs within of the interface, five important steps are performed:

- Filter: low-pass or band-pass filter: Butterworth, Bessel or Chebyshev. The filter order and the cut frequency can be selected.
- Normalization, Orthogonalization and Resampling: In this block a signal conditioningis realized. Resampling is only used to adjust the sampling rate of the oscilloscope to the data rate of the consecutive digital signal processing algorithms [4]. Before the signal equalization, the sampling frequency (when it is high) may be reduced up to 1.5 samples per symbol, limit imposed to a correct equalization[5]. In order to recover the original signal using a receiver witha suboptimal hybrid, it is also used the Gram–Schmidt orthogonalization algorithm described in [4].
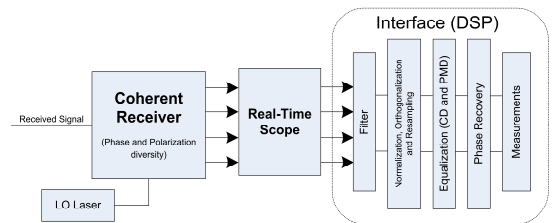- Equalization: The equalization of the signalconsists of chromatic dispersion

Figure 2: Coherent receiver with coherent analyzer.

compensation, in particular by Time Domain or Frequency Domain Equalizer (FDE) method (described respectively in [6] and [2]), and the Constant Modulus Algorithm (CMA) equalizer, which reduce the intersymbol interference (ISI). The description of this algorithm can be seen in [3, 4].

- Phase Recovery: In this block is performed the phase recovery using a "Viterbi and Viterbi" algorithm with phase unwrapping described in [4]. This algorithm can compensate some frequency shift occurred between the received signal and the local oscillator (often due to poor control in frequency of Lasers) and laser phase noise variation over the time. To obtain maximum performance in this algorithm is important to avoid signal transitions. To discard the transitions, we resample the signal detecting the clock of the received signal through a derivativeof the signal.The resample of the signal is done in the symbol's central part.
- Measurements: Performs several performance measures and analyzes the signal, such as EVM (Error Vector Magnitude), BER (Bit Error Rate), Quadrature Skew or Eye Diagram measurements.

IV. EVM MEASUREMENT TECHNIQUE

The EVM is the most popular measure for coherent signals.It is a measure that is based on the definition of error between the received and transmitted symbols,expressed mathematically as [7]:

$$ EVM_{RMS} = \sqrt{\frac{\frac{1}{N}\sum_{1}^{N}\left|S_{ideal}-S_{received}\right|^2}{\frac{1}{N}\sum_{1}^{N}S_{ideal}^2}} \qquad (11) $$

In our coherent analyzer developed three possibilities can be explored for measure the EVM: received symbols in relation to the ideal constellation, received symbols in relation to average received constellation or received symbols with respect to the exact transmitted symbols. The method 100% valid is the latter, but it is also the most complicated to the receiver, since it needs toknow the sequence of transmitted data. When the constellation is very good we can say that the first one is a good approximation and the second method hide the quadrature skew of the constellation. The reference of the two methods is shown in Figure 3.The BER measurement is
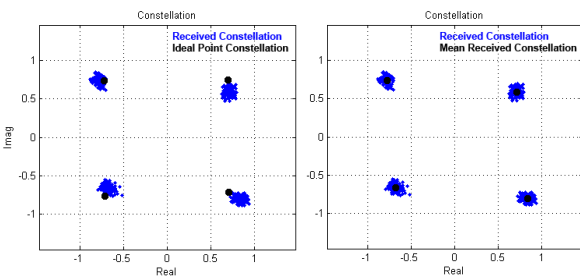

Figure 3: EVM reference measurement: (a) Ideal Constellation; (b) Mean Received Constellation

also possible when the receiver know the sequence of transmitted symbols. Since in certain situations it is necessary a long sequence of bits to correctly estimate the BER, the interface displays the number of errors that occur over time.

V. GRAPHIC INTERFACE

The interface, which can be seen in Figure 4, was developed in GUI of Matlab and provides the use of signs m-PSK, 16-QAM and QDB, with single and dual polarization. Additionally it also provides the use of OFDM modulation. All important system variables, like constellations, complex samples and settings are defined in handles and are easily accessible.

The user can run the program in a loop and stop it whenever he wants or run it only once. First stage of the

program is getting the settings and then the data. If selected the oscilloscope, configures its settings and then
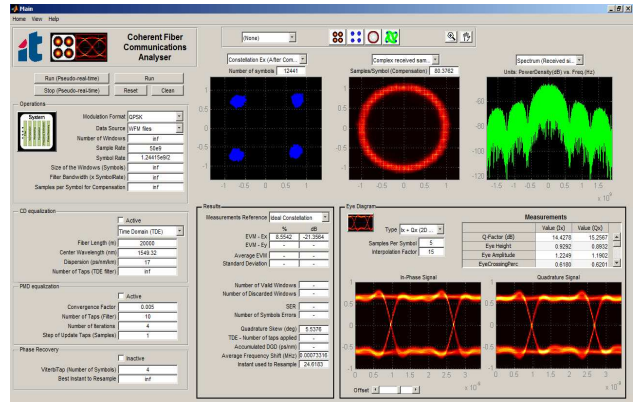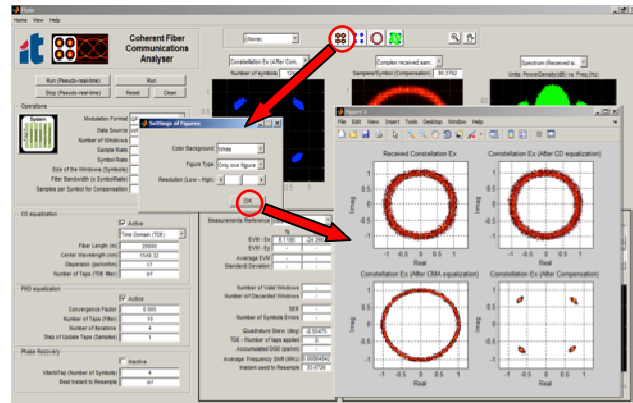

Figure 4: Interface desktop

Figure 5: Example of options to show different results.

getsthe received data (Ix, Qx, Iy or Qy vectors components).

The data passes through the DSP system present in Figure 2 and in the end there is provided a set of optional measures. When it is run in loop, the program performs EVM and BER averages and calculates the standard deviation. The user may also select a threshold value of EVM from which the program will discard the data windows in this statistics - becomes useful, for example because in some occasional casesthe compensation system cannot converge due to the initial conditions of the algorithms.

The user can choose to display a set of multiple images, such as: received constellations before, during or after compensation; complex received samples before, during or after compensation; eye diagram of in-phase component, quadrature component, intensity and of the phase (example in Figure 6); received and compensated spectrum of the signal; frequency response of the filters used for equalization; response of frequency shift and phase noise of the signal; in-phase and quadrature components in function of the time.

It is also possible to select different graphic layouts, such as resolution and color (if performed with an image data histogram), as shown in Figure 5.
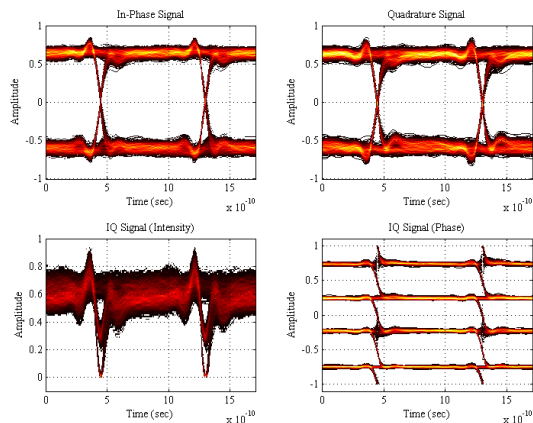

Figure 6: Different Eye Diagram of a QPSK signal:
(a)In-phase component; (b) Quadrature component; (c) Intensity of In-phase and Quadrature component; (d) Phase of In-phase and Quadrature component.

The application also allows saving the results and system settings to a text file and can automatically save all received data windows of the oscilloscope in a default folder for later use. The future aim is to present this information to users in a common server.
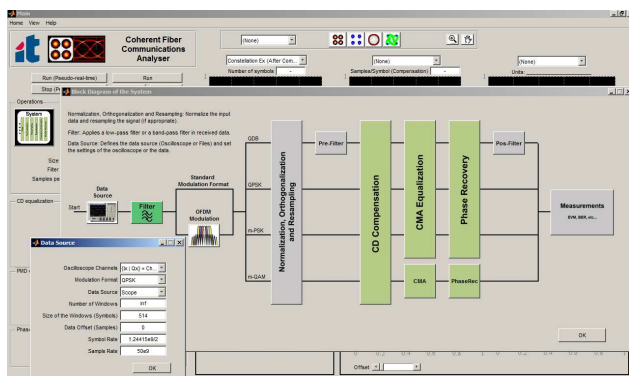
AN EDITABLE PLATAFORM

Figure 7: Editable block diagram settings.

The program provides a simple environment where the user can edit the parameters of the system block diagram (Figure 7). Clicking on each block the user can access the set of options available in each of the blocks. Some of the most important options are also available in the desktop interface, making their use more practical for those who are already more accustomed to the platform. From the editable block diagram, the user can also edit the code of the blocks.

VI. CONCLUSION

Constellations diagrams provide an intuitive way of displaying coherent signals that are modulated in phase or in amplitude. If the signals suffer impairments during transmission, the constellation or the eye diagrams are a good way to analyze the system and identifying what we need to do to remove or attenuates the impairments and optimizing the transceivers.

As a coherent receiver is involved by an unusual complexity, the platform now developed aims to overcome several steps and give to the common user an interactive and very simple way to analyze such system.It will certainly be one of the key platforms for upcoming projects in IT optical communication area, since coherent systems is a promising technique for future generations of optical networks.

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