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Supplementary Article

High Data Rate for Coherent Optical Wired Communication using DSP

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Abstract

The aim of this research is the development and analysis of digital signal processing techniques for enhancing performance in coherent optical communication systems. While much of the current digital techniques are identical to those found in the digital wireless literature, we will investigate improvements in performance to be obtained by tailoring modulation and DSP post-processing algorithms to the optical.

The combination of polarization-multiplexing and quadrature phase shift-keying (PM-QPSK or DP-QPSK) is emerging as one the most promising solutions to reach bit rates of 100 Gbps and higher. At the receiver end, the use of digital signal processing (DSP) [1, 2] results in significant deployment improvement over the traditional implementation. This application note shows a practical design of a 100 Gbps DP-QPSK transmission system using coherent detection with digital signal processing for distortion compensation.

Keywords: Digital Signal Processing, QPSK, Optical Receiver.

1. Introduction

The birth of optical fibre communications systems in the early 1970s produced an explosive growth in telecommunications with the introduction of low loss, high bandwidth silica fibers. Increases in line rates in these early systems were achieved simply by increasing the modulation rate of on-off keyed (OOK) signals. As symbol rates increased, systems were limited by the loss that could be tolerated before electrical regeneration was required [3]. At this stage, coherent detection was first investigated as a method of increasing the bit rate. Interest has been directed to coherent detection as an enabling technology for improving spectral efficiency. While optical line rates continued to increase to tens of Gb/s, EDFAs enabled a large increase in total capacity per fibre. This increase was due to the use of several optical carriers of differing wavelengths on a single fibre, known as wavelength division multiplexing (WDM) [5]. The carriers are de-multiplexed at the receiver with a wavelength selective device such as an arrayed waveguide grating (AWG), and detected individually.

Although direct detection, it is still limited by linear distortions such as CD and PMD.

2. Existing Work

The digital coherent detection requires additional optical components in comparison to other schemes (namely the optical hybrid, local oscillator and additional photodetectors), and therefore incurs additional cost, both

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robustness to distortion. Due to the fact that the signal is mixed with itself, the improvement in sensitivity is less than that of full coherent detection [4]. Signals are also limited by linear distortions such as polarization mode dispersion (PMD) and CD which scale linearly and with the square of baud rate respectively.

Due to the presence of Polarization mode dispersion and Chromatic dispersion in existing Optical communications. The limitation of bit rate also reduced drastically. In order to take care this mode of drawbacks we implemented the DSP algorithm.

3. Proposed Work

The aim of this work is the development and analysis of digital signal processing techniques for enhancing performance in coherent optical communication systems. While much of the current digital techniques are identical to those found in the digital wireless literature, we will investigate improvements in performance to be obtained by tailoring modulation and DSP post-processing algorithms to the optical channel.

This scheme allows the use of polarization multiplexing without the need for adaptive optics, and also enables full compensation of arbitrary amounts of previously limiting effects such as PMD and CD. This DSP method allows us to reduce the Polarization mode dispersion Chromatic dispersion. By implementing this DSP algorithm it is possible to achieve high data rate communication applications.

4. Technical Description

Digital signal processing is now the most interesting method to compensate for linear impairments of long-haul fiber transmission. After coherent detection of the DP-QPSK signal, four main functions are performed in digital domain before signal detection: 1) Analog to Digital conversion, 2) Dispersion compensation, 3) Polarization de-multiplexing, and 4) Carrier phase estimation.

4.1 Analog to Digital Conversion

The analog to digital conversion is basically a down sampling process. Here we have chosen a 2-bit sampling, however the sampling rate can be changed.

4.2 Dispersion Compensation

In the absence of fiber nonlinearity, the fiber optic can be modeled as a phase only filter with the following transfer function [6].

$$G(z,\omega) = \exp\left(-j\frac{D\lambda^2 z}{4\pi c}\omega^2 + j\frac{S\lambda^4\omega^3 z}{24\pi^2 c^2} \right)$$

In which the first part is the effect fiber dispersion and the second term is the dispersion slope for multi-channel application [7]. In order to compensate for the dispersion, we multiply the output field to the inverse of the channel transfer function (FIR filter). The order of the filter increases as the amount of dispersion (length of the propagation) increase.

4.3 Polarization De-multiplexing

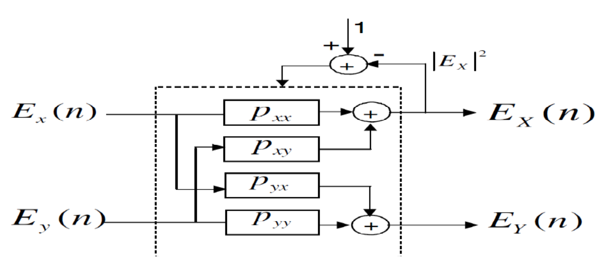
The Jones matrix of the fiber for transmission can be written as:

$$T = \begin{pmatrix} \sqrt{\alpha}e^{i\delta} & -\sqrt{1-\alpha} \\ \sqrt{1-\alpha} & \sqrt{\alpha}e^{-i\delta} \end{pmatrix}$$

Where α and δ denote the power splitting ratio and the phase difference between the two polarization modes. The SOP of the output signal can be written as:

$$\begin{pmatrix} E_x \\ E_y \end{pmatrix} = T \begin{pmatrix} E_{in,x} \\ E_{in,y} \end{pmatrix}$$

So if we can find the inverse of matrix T, we can do polarization de-multiplexing. The constant modulus algorithm (CMA) is a conventional way in the literature for this. Following figure shows the DSP circuit for channel expression and the corresponding equation:



$$\begin{pmatrix} E_X \\ E_Y \end{pmatrix} = \begin{pmatrix} p_{xx} & p_{xy} \\ p_{yx} & p_{yy} \end{pmatrix} \begin{pmatrix} E_x \\ E_y \end{pmatrix}$$

The matrix elements are updated symbol by symbol according to:

$$p_{xx}(n+1) = p_{xx}(n) + \mu(1-|E_X(n)|^2)E_X(n)E_x^*(n)$$
$$p_{xy}(n+1) = p_{xy}(n) + \mu(1-|E_X(n)|^2)E_X(n)E_y^*(n)$$

μ is the step-size parameter and n the number of symbol. The p matrix is basically an adaptive FIR filter and we use CMA for blind estimation [8, 9]. The initial values for pxx(0) and pyy(0) are:

pxx(0) = [00…010..00];
pyy(0) = [00…010..00];
pxy(0) = pyx(0) = [00…000..00];

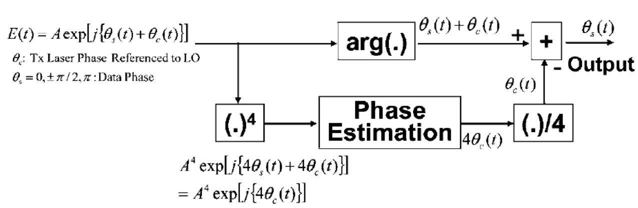
In our simulation we have chosen a 3-tap FIR filter, however the order can be changed.

4.4 Carrier Phase Estimation

Phase locking in the hardware domain can be replaced by phase estimation in digital domain by DSP [10]. The received QPSK signal can be presented by

$$E(t) = A\ \exp\{j[\theta_s(t) + \theta_c(t)]\}$$

We have used the following algorithm to estimate the phase of the QPSK signal in digital domain:



The inner structure of the DSP modules is shown in Figure 1.

5. System Design

Proposed System model for Optical fibre communications using DSP is shown in Figure 2.

6. Simulation Description

The 100 Gbps DP-QPSK systems can be divided into five main parts: DP-QPSK Transmitter, Transmission Link, Coherent

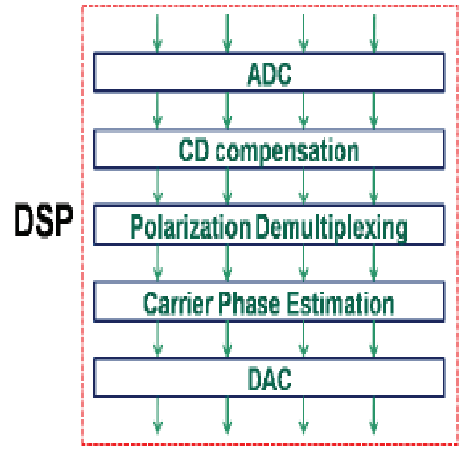


Figure 1. DSP Design algorithm [6].
Source: Savory [6].

Receiver, Digital Signal Processing, and Detection & Figure 3. Decoding (which is followed by direct-error counting).

The signal is generated by an optical DPQPSK Transmitter, and is then propagated through the fiber loop where dispersion and polarization effects occur. It then passes through the Coherent Receiver and into the DSP for distortion compensation. The fiber dispersion is compensated using a simple transversal digital filter, and the adaptive polarization de multiplexing is realized by applying the constant-modulus algorithm (CMA). A modified Viterbi-and-Viterbi phase estimation algorithm (working jointly on both polarizations) is then used to compensate for phase and frequency mismatch between the transmitter and local oscillator (LO). After the digital signal processing is complete, the signal is sent to the detector and decoder, and then to the BER Test Set for direct-error-counting. Figure 3 is an image of the optical spectrum of the 100 Gbps DP-QPSK signals after the transmitter, as well as the RF spectrum obtained after the Coherent DP-QPSK. The algorithms used for digital signal processing are implemented through a Matlab component [Figure 2].

By setting the Matlab component to debug mode, the generated electrical constellation diagrams after each step (compensation, Polarization De multiplexing, and Carrier Phase Estimation)

7. Simulation Results

Optical Spectrum Analyzer.

Figure 3 shows the spectrum analyser of receiver spectrum with center frequency of 193HTz.

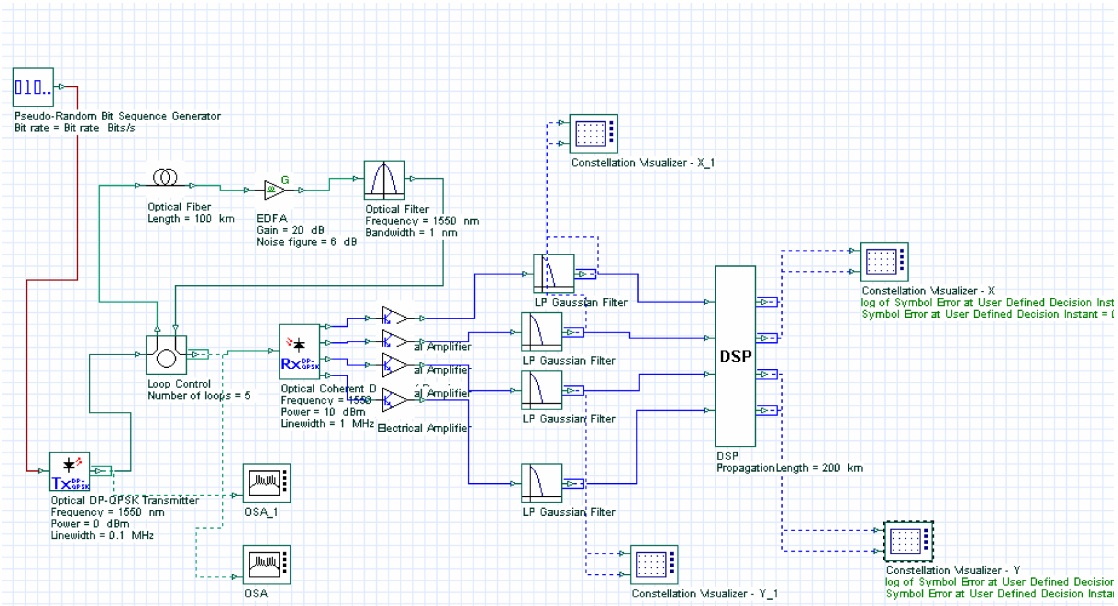


Figure 2. Proposed System model for Optical fibre communications using DSP.

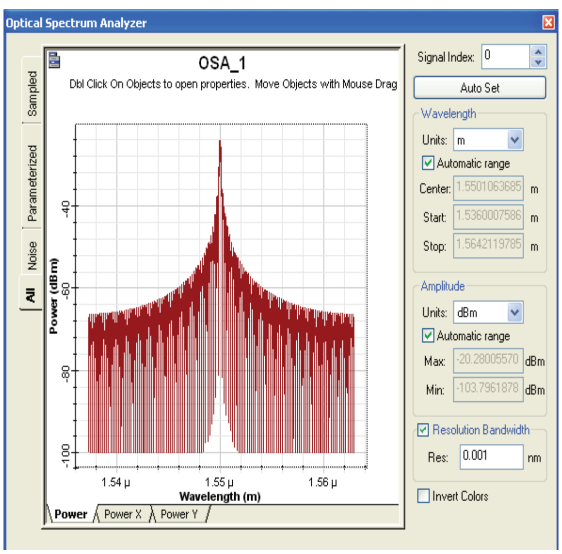


Figure 3. Optical Spectrum Analyzer.

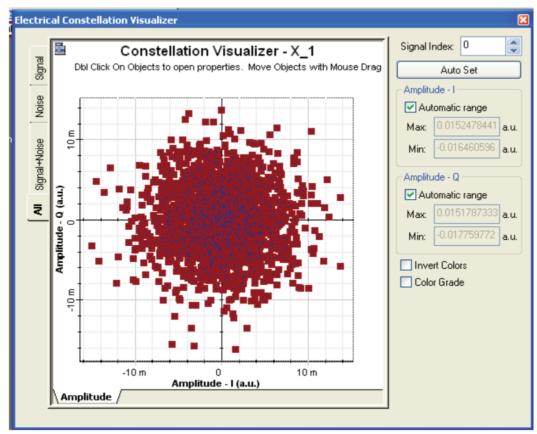


Figure 4. Received Constellation diagram before DSP Algorithm.

Figure 4 shows the receiver constellation diagram for the optical recievr. Its obviously explain that to polarization mode dispersion and CD. Figure 5 shows that receiver constellation diagram after DSP compensation. Due to implementation of algorithm, it gives effective spectrum efficiency in the view of High signal to Noise.

Table 1. Simulation Parameters

Bit rate	100 Gbps
Number of Samples	262144
Distance	500
Sampels Per Bit	32
Sequence Length	8192 bits

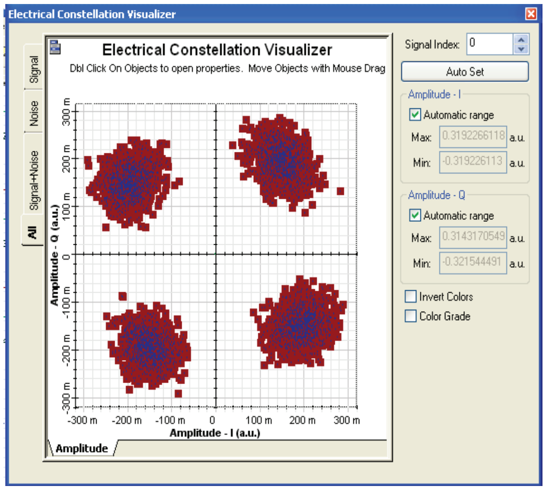


Figure 5. Received Constellation diagram After DSP Algorithm.

Table 1 gives define data implementation of system model for 500 kms Optical communication system design with DSP algorithm with 32 samples per bit.

8. Conclusion

We describe proposed future research topics in the field of DSP algorithms for coherent detection. Discuss performance bounds on the capability of digital back propagation for coherent systems; we described the 500km optical fiber communications systems using DSP with Optisystem 11.0.

9. References

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