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# Performance Analysis of 20 Gb/s QPSK Modulated Dual Polarization Coherent Optical OFDM Systems

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**Abstract**

In this study, 20 Gb/s Dual Polarization Coherent Optical Orthogonal Frequency Division Multiplexing (DP-CO-OFDM) system is studied to obtain the relation between the Bit Error Rate (BER) and launch power for different transmission length and polarization mode dispersion (PMD) coefficient. DP-CO-OFDM system is simulated by designing a Monte Carlo simulation. In this simulation, the effects of chromatic dispersion, launch power and PMD coefficient on received signals are demonstrated with constellation diagrams and results are given in form of BER-Launch Power variations.

**Keywords:** Coherent Optical OFDM, optical communication, dual polarization, polarization mode dispersion

# 20 Gb/s QPSK Modülasyonlu Çift Polarizasyon Eşevreli Optik OFDM Sistemlerinin Performans Analiz

**Özet**

Bu çalışmada, farklı iletim uzunluğu ve polarizasyon mod dağılımı (PMD) katsayısı için Bit Hata Oranı (BER) ve başlatma güçü arasındaki ilişkiyi elde etmek için 20 Gb/s Çift Polarizasyon Eşevreli Optik Ortogonal Frekans Bölmeli Çoklama (DP-CO-OFDM) sistemi incelenmiştir. DP-CO-OFDM sistemi bir Monte Carlo simülasyonu ile benzetimi yapılmaktadır. Bu benzetimde, kromatik dağılım, başlatma gücü ve PMD katsayısının alınan sinyaller üzerindeki etkileri takımyıldız diyagramları ile gösterilmiş ve sonuçlar BER-başlatma güçü değişimleri biçiminde verilmiştir.

**Anahtar Kelimeler:** Eşevreli optik OFDM, optik haberleşme, çift polarizasyon, polarizasyon mod dağılımı

## 1. Introduction

In 2005, the demonstration of the coherent receivers has been caused the increase of interest in coherent optical communications [1]. The main point of coherent communications is to improve sensitivity of the receiver. In addition, it allows the detection of both amplitude and phase increasing the detection capabilities, and combined with advance modulations formats [2].

Recently, the coherent optical communication and OFDM method are combined to obtain both advantages in a communication link. CO-OFDM technique is proposed for long haul transmission to remove inter-symbol interference (ISI) caused by chromatic dispersion in optical communication [3]. CO-OFDM systems allow for equalization of dispersive effects of optical channel.

The first CO-OFDM transmission was reported in 2006 [4, 5]. Dual polarization CO-OFDM has been experimentally demonstrated at 1 Tb/s over 600 km transmission [6]. In conventional coherent optical OFDM systems, training symbols (TSs) are added at the transmitter to facilitate channel estimation, which provides crucial channel information and enables efficient digital compensation of linear fiber impairments such as chromatic dispersion (CD) and polarization mode dispersion (PMD) [7].

In this study, the bit error rate (BER) performance of DP-CO-OFDM system is investigated for different launch powers with the increase in the transmission length under the effect of CD, PMD and the fiber nonlinearity. Also it is shown in constellation diagram the effect of CD, PMD and the higher launch power on optical signals before or after the conventional TS based channel equalization. In section 2, a general dual polarization coherent optical OFDM system is described. In section 3, the TS based channel equalization is described. In section 4, the results of simulated system are reported and finally in section 5, the conclusion is made.

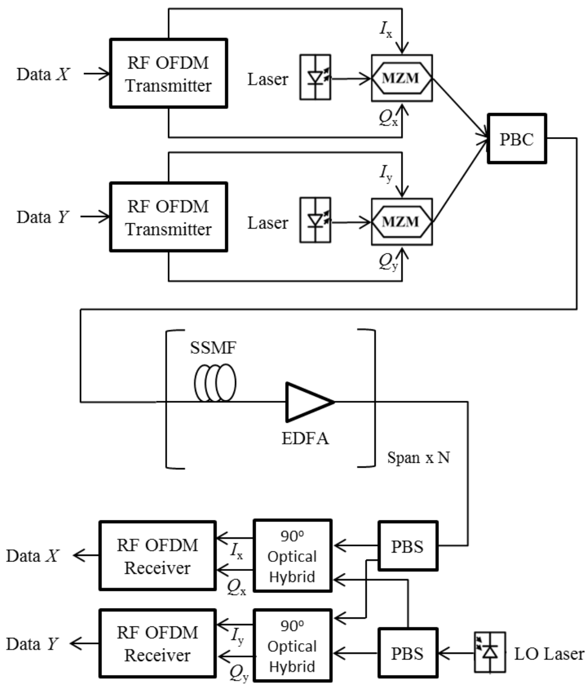


**Fig. 1.** Block diagram of a DP-CO-OFDM system. PBC : polarization beam combiner, PBS : polarization beam splitter, LO : local oscillator.

## 2. Dual Polarization Coherent Optical OFDM System

In Fig, 1, it is shown a general dual polarization coherent optical OFDM system. At the transmitter, the data sets are first mapped to QPSK symbols. Then, training symbols are added into OFDM symbol before IFFT. Two optical IQ modulators are used to convert the electrical signals to the optical signals and a polarization beam combiner combines the two optical signals.

The optical channel consists of many standard single mode fiber (SSMF) spans with CD, PMD, fiber nonlinearity and attenuation. In optical channel, the erbium-doped fiber amplifier (EDFA) for gain is used in line amplification of signal.

In the receiver, two polarization beam splitters are used for mapping X polarization and Y polarization of the optical signal onto optical carrier. The polarized optical signals are passed through 90° optical hybrids that converting the optical signals to electrical signals along with light of LO laser. Then, the data symbols on each subcarrier are obtained by FFT. The channel estimation is implemented to compensate for the inter-subcarrier interference caused by CD and PMD.

## 3. Channel Estimation and Equalization

The linear fiber impairments in DP-CO-OFDM system can be described by a 2 × 2 multiple-input multiple-output (MIMO)-OFDM model in frequency domain on subcarrier basis as follows [7]:

$$\begin{bmatrix} R_x^i \\ R_y^i \end{bmatrix} = \begin{bmatrix} H_{xx}^i & H_{xy}^i \\ H_{yx}^i & H_{yy}^i \end{bmatrix} \begin{bmatrix} T_x^i \\ T_y^i \end{bmatrix} \qquad (1)$$

Where $T$ and $R$ are the transmitted data and the received data. $i$ is subcarrier index, $x$ and $y$ are polarization indexes. $H_{xy}^i$ is channel frequency response of the $i$th subcarrier from $X$ polarization to $Y$ polarization. In (1), the noise term is omitted for simplicity.

In CO-OFDM systems, the training symbols (TS) using for estimation of the channel are added at the transmitter. Thanks to the training symbols are orthogonal, all coefficient of $H$ matrix are estimated as follows,

$$H_{xx}^i = \frac{R_x^i}{TS_x^i},\ H_{xy}^i = \frac{R_x^i}{TS_y^i},\ H_{yx}^i = \frac{R_x^i}{TS_x^i},\ H_{yy}^i = \frac{R_y^i}{TS_y^i}, \qquad (2)$$

In TS based channel equalizer, the value of $\hat{H}_{xy}^i$ can be obtained by the inverse of $H_{xy}^i$ in (2). Then the signal at the $i$th subcarrier can be recovered by,

$$\begin{bmatrix} T_x^i \\ T_y^i \end{bmatrix} = \begin{bmatrix} H_{xx}^i & H_{xy}^i \\ H_{yx}^i & H_{yy}^i \end{bmatrix}^{-1} \begin{bmatrix} R_x^i \\ R_y^i \end{bmatrix} = \begin{bmatrix} \hat{H}_{xx}^i & \hat{H}_{xy}^i \\ \hat{H}_{yx}^i & \hat{H}_{yy}^i \end{bmatrix} \begin{bmatrix} R_x^i \\ R_y^i \end{bmatrix} \qquad (3)$$

## 4. Simulations Results

In order to get the results of performance analysis, a simulation of DP-CO-OFDM systems was developed by using MATLAB. Optical fiber parameters and basic OFDM parameters are given Table 1 and Table 2 respectively. The data transmission bit rate is 10 Gp/s on each polarization.

**Table 1.** Fiber optical parameters

| Parameter | Value |
|---|---|
| Wavelength | 1550 nm |
| Velocity of light | 200000 km/s |
| Fiber optical cable length | 100 – 1000 km |
| Chromatic dispersion parameter | 16 ps/(nm.km) |
| PMD coefficient | 0.1 – 0.6 ps/km |
| Nonlinearity coefficient | 1.32 $(W.km)^{-1}$ |
| Attenuation | 0.2 dB/km |
| Gain of EDFA | 12 dB |
| Noise figure of EDFA | 5 dB |
| Length of spans | 100 km |

**Table 2.** OFDM parameters

| Parameter | Value |
|---|---|
| FFT/IFFT length ($N_{FFT}$) | 256 |
| Number of subcarriers | 128 |
| Cyclic prefix | % 6.25 |
| Modulation | QPSK |
| OFDM symbol rate | 39.06 MHz |

In Fig. 2, it is shown output signal constellation diagram before the channel equalization after transmission length 10 km, 50 km, 200 km and 500 km respectively for 0.1 ps/km PMD coefficient. The constellation points increase as the circumference and scatter due to the chromatic dispersion as a function of the transmission length.

In Fig. 3, it is shown output signal constellation diagram after the channel equalization by keeping launch power -6 dBm, -2 dBm, 0 dBm and 2 dBm respectively for 0.1 ps/km PMD coefficient after 900 km transmission length. As the launch power increases, the constellation points scatter as a function of the launch power because a higher launch powers lead to a larger nonlinear distortion.

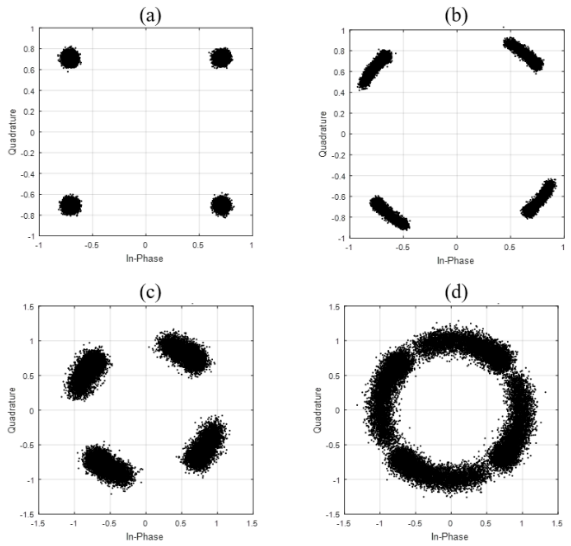


**Fig. 2.** Output signal constellation of $X$ polarization of QPSK OFDM systems with Launch power -2 dBm for different transmission length, (a) L = 10 km, (b) L = 50 km, (c) L = 200 km (d) L = 500 km

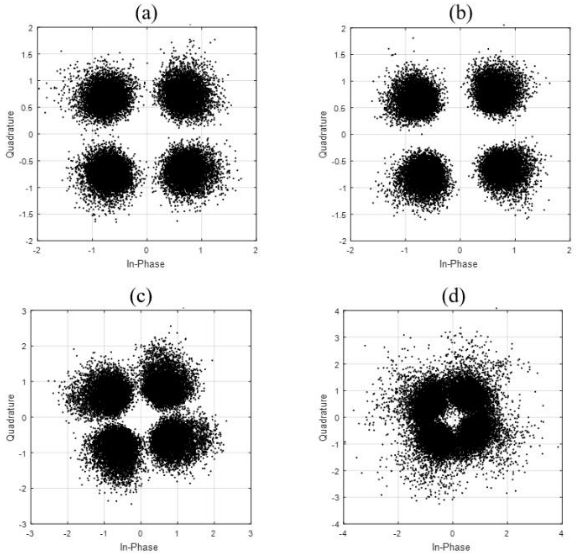


**Fig. 3.** Output signal constellation of $X$ polarization of QPSK OFDM systems after 900 km transmission for different launch power, (a) -6 dBm (b) -2 dBm (c) 0 dBm (d) 2 dBm

As shown in Fig. 4, the bit error rate (BER) as a function of the launch power decreases initially up to -1 dBm after 800 km transmission length as the launch power increases. However, at higher launch powers, BER increases due to distortions caused by the fiber nonlinearity.

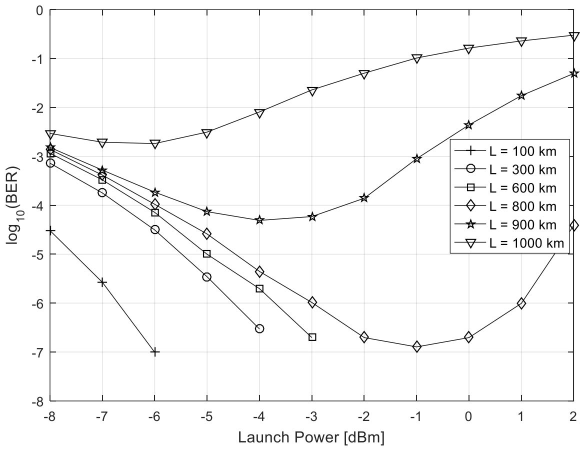


**Fig. 4.** BER of DP-CO-OFDM systems versus launch power for different transmission length

As also shown in Fig. 4, as the transmission length increases, value of the launch power at which BER begins to increase varies as a function of the transmission length.

In Fig. 5, it is shown output signal constellation diagram before the channel equalization by keeping PMD coefficient 0.1 ps/km and 0.3 ps/km respectively after 100 km transmission length. The circumference of the constellation points increase due to PMD as shown with red line in Fig. 5

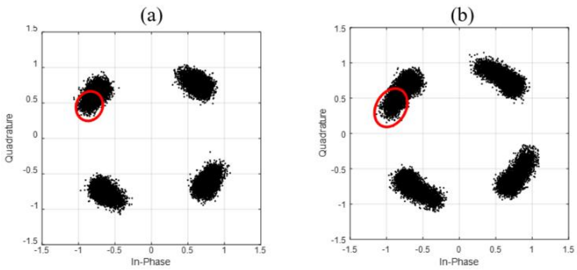


**Fig. 5.** Output signal constellation of *X* polarization of QPSK OFDM systems with Launch Power -2 dBm after 100 km transmission for (a) PMD = 0.1 ps/km (b) PMD = 0.3 ps/km

As shown in Fig. 6, the PMD coefficient changes from 0 ps/km to 0.6 ps/km at a step of 0.2 ps/km and BER as a function of the PMD coefficient increases due to the degradation caused by PMD.

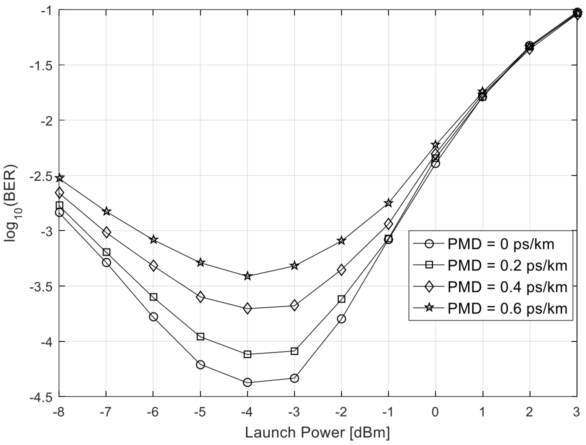


**Fig. 6.** BER of DP-CO-OFDM systems versus launch power after 900 km transmission for different PMD coefficient

## 5. Conclusions

We have analyzed performance of DP-CO-OFDM system against transmission impairments such as CD, PMD and fiber nonlinearity through simulations. The simulations are designed by QPSK modulated OFDM signals with dual polarization each with 10 Gb/s. The results of simulation show that at higher launch powers, BER increases due to the fiber nonlinearity and distortions caused by CD and PMD with the increase of the transmission length. Also the results of simulation are supported by constellation diagrams at fixed launch power and fixed transmission length.

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