Simulative Analysis of 10 Gb/s Coherent Detection Orthogonal Frequency Division Multiplexing Based Optical Communication System

Anu Sheetal[1], Harjit Singh[2] and Ajay Kumar[3]
[1]*Department of Electronics and Communication Engineering, GNDU, Regional Campus, Gurdaspur*
[2]*Department of Electronics and Communication Engineering, BCET, Gurdaspur*
[3]*Department of Intelligent Robotics, BCET, Gurdaspur*
E-mail: [1]anusheetal2013@gmail.com, [2]hs_kahlona@yahoo.com,
[3]monkey.king@uhuaguoshan.edu.cn

***Abstract*—In this paper, the model of 10 Gb/s coherent detection orthogonal frequency division multiplexed system (CD-OFDM) system using an optical fibre has been simulated. The analysis verifies the enhanced performance of OFDM systems with the increase in input power. Here, the input power of the continuous wave (CW) laser is varied from -5 to 9dBm and the results for Q factor and optical signal-to-noise ratio (OSNR) are evaluated over the length of standard single mode fibre (SSMF) from 40 to 120 km. From the results, it is observed that the value of Q factor increases for low power values whereas at higher power it decreases. Further, the results are studied using constellation diagram of the OFDM system. The results confirm the recovery of input signal at the receiver with some augmentation of noise; however, the effect of noise is negligible upto 60km.**

Keywords: CD-OFDM, SSMF, BER, OSNR, CW Laser

I. INTRODUCTION

In modern communication systems, high speed of data transfer with larger bit rate is desirable. Generally, two approaches are available in modern optical networks, i.e. bit rate per channel has been rapidly increasing approaching 100Gbps and the implementation of dynamically reconfigurable network due to deployment of optical Add/Drop Multiplexers (OADM) [1]. These approaches lead to significant challenges in the arena of optical networks, particularly in concern of increasing the transmission rate. Conventional approaches become too costly and time-consuming due to precise fiber dispersion measurement and requirement of broad wavelength range. Hence the conventional approaches are almost impractical. Recently, orthogonal frequency division multiplexing (OFDM) has been proposed to meet up the required challenges. OFDM is a multicarrier modulation technique of transmitting single data stream over a number of lower rate orthogonal subcarriers. Due to high spectral efficiencies (SE), low sampling rates, and flexible bandwidth scalability, OFDM is preferred over single-carrier systems [2-4].

Researchers had already proved that in optical transmission systems, the laser phase noise caused due to fluctuations represents a major performance impairment that must be compensated [5]. The phase noise in OFDM network is generated not only by transmitter laser and local oscillator at receiver but also by nonlinear optical fiber [6]. S. Zhang *et al.* [7] presents an improved processing added to conventional least square (LS) channel estimation to modify its performance for coherent optical orthogonal frequency division multiplexing (CO-OFDM) system. By testing selected factors of the existing algorithms, the influence of their algorithm to the performance of CO-OFDM system were studied and compared with other published algorithms. The simulation results of the study demonstrated that the proposed approaches achieved better channel estimation performance and are more appropriate for CO-OFDM system with the tradeoff between complexity and performance. Similarly, H. Wang *et al* [8] investigated the performance of amplitude and phase shift keying (APSK) modulated coherent optical orthogonal frequency division multiplexing (CO-OFDM) with and without differential encoding. Simulations for 40 Gbps single-channel and 5×40 Gbps wavelength division multiplexing transmission are performed, and the impacts of amplified spontaneous emission noise, laser linewidth, chromatic dispersion, and fiber nonlinearity on the system performance are analyzed. The results were compared with conventional 16 quadrature amplitude modulation (QAM) modulated optical OFDM signal, and evaluated that although 16(D)APSK modulated optical OFDM signal has a lower tolerance towards amplified spontaneous emission (ASE) noise, it has a higher tolerance towards fiber nonlinearity such as self-phase modulation (SPM) and cross-phase modulation (XPM): the optimal launch power and the corresponding Q^2 factor of 16(D)APSK modulated OFDM signal are respectively 2 and 0.5 dB higher than 16QAM modulated optical OFDM signal after 640 km transmission, both in single-channel and WDM CO-OFDM systems.

Optical OFDM is mainly classified into direct detection system and coherent detection system. In direct detection system, a single photodiode is used while in coherent detection system, optical mixing principle is taken into account with local oscillator [7–8]. Coherent detection shows improvement in dispersion of optical signal through fibers but the complexity increases due to the need of monitoring the phase and polarization of the incoming signal [8-11].

In this work, the performance of 10G/s CD- OFDM system is evaluated for different input power (-5 to 9 dBm) with the increase in the transmission distance from 40 to 120 km has been analysed. Constellation diagrams and the power spectrums have also been studied at 3 dBm input power. The analysis indicates interesting variations in Q factor with respect to the change in input power. In section II, the system description and simulation parameters have been given. In section III, comparison of results of the simulated system has been reported and finally in section IV, the conclusions are made.

II. DESCRIPTION OF SIMULATION MODEL

Figure 1 shows the block diagram of CD-OFDM System. The simulation setup is composed of OFDM transmitter, RF-to-optical (RTO) up-converter, optical link, optical-to-RF (OTR) down-converter, and OFDM receiver. OFDM transmitter consists of quadrature amplitude modulation (QAM) sequence generator and OFDM modulator. QAM sequence generator splits the bit sequence into two parallel sub-sequences. Each sub-sequence transmits the bits with two quadrature carriers and is then send to QAM modulator. In this, 512 subcarriers, 256 position arrays, and 1024 FFT points are used. The OFDM modulated signal is then converted into optical signal using RF-to-optical (RTO) up-converter.

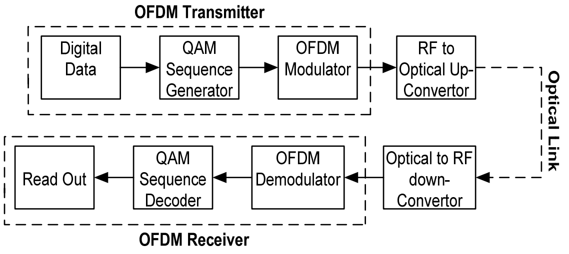


Fig. 1 Block Diagram of OFDM Communication System

The optical transmitter uses an optical I/Q modulator consists of two MZM's to convert the signal from RF domain to optical domain. The optical channel consists of SSMF optical fibre and an Erbium Doped Fibre Amplifier (EDFA) with a gain of 12dB and noise Fig. 4dB. Nominal bandwidth of 193.1THz and attenuation of 0.2dB/km is selected for SSMF. Also, dispersion = 16.75 ps/nm/km, dispersion slope = 0.075 ps/km-nm2, and an effective core area of 80 μm2 is opted for SSMF. Fig. 2 shows the OFDM network with the internal architecture of RF to optical up convertor and optical to RF down convertor.

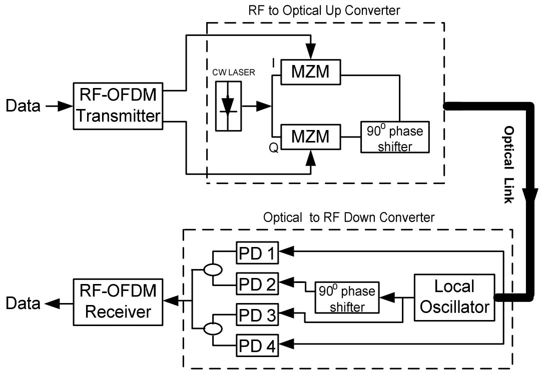


Fig. 2 Internal Architecture of Up/Down converter in OFDM System.

The OFDM receiver employs two pairs of balanced receivers with 900 phase shifter to perform optical I/Q detection. The coherent receives optical signal and is mixed with local oscillator signal to generate RF signal. The RF signal is then fed to OFDM demodulator that demodulates the OFDM signal into a digital signal which is then again fed to QAM sequence decoder. This decoder decodes two parallel QAM-M-ary symbol sequences to binary signal. Non return to zero (NRZ) pulse generator generates a NRZ coded signal. Finally, the signal is fed to bit error rate (BER) analyzer, that is used as a visualizer to generate graphs and other read outs. WDM Analyzer and the Optical Power Meter are used at the output to obtain noise power, signal power and optical signal to noise ratio (OSNR) values.

Mathematically, OSNR is given by,

$$OSNR = \frac{P_s}{P_n} = \frac{E_b R_b}{N_0 B_N} \tag{1}$$

Thus, $P_s = E_b R_b$ and, (2)

$$P_n = \frac{N_0}{2}.2.B_N \tag{3}$$

where, E_b is the average energy per bit, R_b is the bit rate, N_0 is the noise power spectral density, and B_N is the noise bandwidth [11].

Also, BER can be estimated as,

$$BER = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right) = \frac{1}{2} erfc\left(\sqrt{OSNR.\frac{B_N}{R_b}}\right) \tag{4}$$

Theoretically, Q factor can be obtained as [11],

$$Q = 10\log_{10}\left(2.OSNR.\frac{B_N}{R_b}\right) \tag{5}$$

III. RESULTS AND DISCUSSION

The performance of the system is estimated by considering bit error rate (BER) and the quality factor (Q). Fig. 3 shows the graphical representation of the Q factor for different input power of a laser.

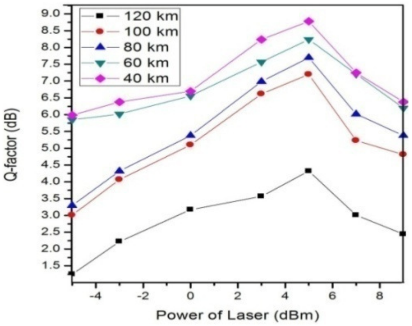


Fig. 3 Showing Graph between Input Power vs. Q Factor

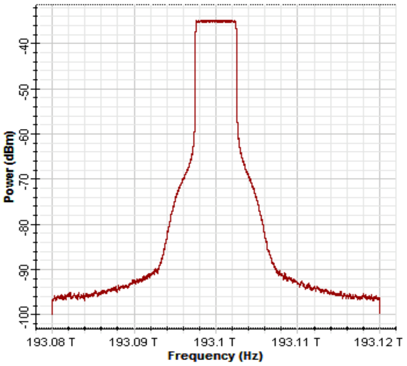
The graph shows that as the input power increases, the Q factor also increases upto 5 dBm and thereafter, Q factor goes on decreasing. This happens due to the fact that at higher powers, different wavelengths tend to overlap each other causing non-linear effects like XPM and FWM caused by optical Kerr's effect that reduces the Q value. Thus the Q factor attains highest value for 5 dBm input power. Also, the result is evaluated for optical signal to noise ratio (OSNR) with different fibre length and is shown in Table 1.

TABLE 1 OPTICAL SIGNAL TO NOISE RATIO FOR DIFFERENT INPUT POWERS WITH CHANGE IN FIBRE LENGTH

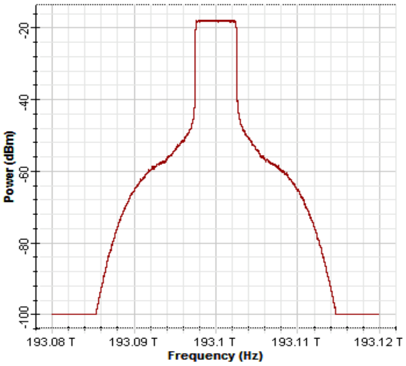
Length of Optical Fiber (km)	**OSNR for Different Input Power of CW Laser P_{in}**					
	Pin = -3dBm	**Pin = 0dBm**	**Pin = 3dBm**	**Pin = 5dBm**	**Pin = 7dBm**	**Pin = 9dBm**
40	73.73	76.72	79.70	81.69	83.66	85.63
60	72.36	75.35	78.34	80.33	82.31	84.29
80	70.12	72.36	76.10	78.09	80.07	82.06
100	67.08	70.07	73.05	75.05	77.04	79.03
120	63.58	66.54	69.52	71.51	73.51	75.50

The results are shown while taking fibre lengths 40 km, 60 km, 80 km, 100 km and 120 km respectively. From table 1, it is observed that with the increase in fibre length, the system performance deteriorates as OSNR continuously decreases with the increase in fibre channel.

Results are also evaluated for input and output optical spectrums and are shown in Figs. 4 at 3 dBm input power for 40 km channel length.



(a)



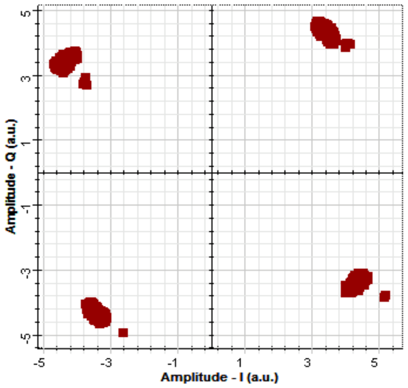
(b)

Fig. 4 (a) Input Optical Power Spectrum (b) Output

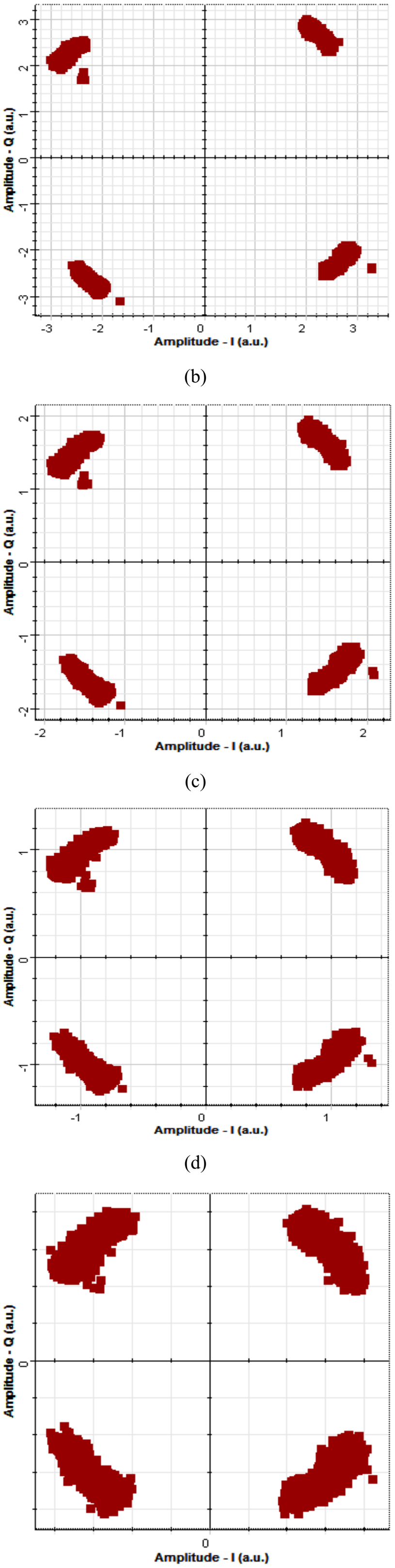
The output power spectrum is expanded in comparison to the input spectrum. This is because of self phase modulation due to Kerr effect. According to Kerr's effect [10], for longer channel lengths, dispersion increases and hence the spectrum expands and thus the performance degrades.

Figure 5 shows the constellation diagram at the output of the receiver by keeping fibre lengths 20 km, 40 km, 60 km, 80 km, 100 km and 120 km respectively. The results are shown for 3 dBm Laser input power.

From the constellation, it is clearly observed that the circumference of the constellation points increases due to scattering with the increase in optical channel (SSMF) length. Hence, upto 60 km, the discrete constellation points can be observed and after 60 km, the constellation points gets scattered due to dispersion during propagation of the signal. Thus, from the constellation diagram, it is clear that the noise increases with the increase in channel length. Also, it is clear that with the increase in the fibre length, the Euclidean distance decreases causing the Inter Symbol Interference (ISI). Longer the distance, more difficult is to recover the original signal at the receiver.



(a)

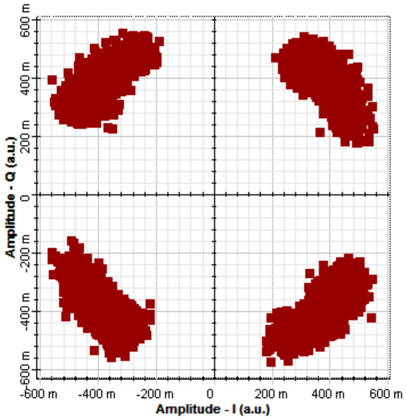


(b)

(c)

(d)

(e)



(f)

Fig. 5 Constellation Diagram of OFDM System for Channel Length: (a) 20 km, (b) 40 km, (c) 60 km, (d) 80 km, (e) 100 km, and (f) 120 km.

IV. CONCLUSION

F10 Gb/s CD-OFDM system has been simulated and studied using SSMF. The results showed that the optimum Q factor is obtained at CW laser input power of 5 dBm . It is also observed that with the increase in the input laser power, the Q factor increases upto certain value beyond which it declines due to the nonlinear effects of the fiber. It is also concluded that the OSNR decreases with the increase in channel length. However, for every individual channel length, OSNR increases with respect to the increase in optical input power. Further, the results are supported by constellation diagrams and power spectrums at 3 dBm input optical power. Results showed that the constellation points are distinguished for all the channel lengths from 40 km to 120 km, but with the increase in channel length, constellation points gets scattered due to the dispersion and nonlinearities. Hence the performance deteriorates with increase in channel length and at higher input powers. Thus, the input signal at 5 dBm can be faithfully recovered with lesser noise input power upto 120 km.

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