Design and Performance Analysisof OFDM-based Single mode and Multimode Optical Fiber Communication System

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Abstract:*Orthogonal Frequency Division Multiplexing(OFDM) has recently emerged in optical communication to support high data transmission rates over the dispersive channels. The OFDM technique provides combat to the various limitations such as chromatic dispersion, modal dispersion etc. existing in optical communication system. In order to achieve the improved performance of optical OFDM system, the effect of parameters related to laser source and optical fiber and nonlinearities of Mach-Zehnder Modulator(MZM) etc. must be considered in detail. Despite many advantages of OFDM technique, it has major drawbacks of high peak-to-average power ratio, sensitivity to carrier frequency offset and phase noise. This paper presents optical-OFDM system design for both single mode and multimode fibers along with the analysis of different modelling parameters and various performance parameters like Bit Error Rate (BER), Q factor etc. Further, effect of MZM nonlinearities on the system performance is also considered.*

Keywords:*Optical OFDM (O-OFDM), Quadrature Amplitude Modulation(QAM), Mach-Zehnder Modulator (MZM), Fast Fourier Transform (FFT), Inverse Fast Fourier Transform (IFFT), Intersymbol Interference (ISI), Bit Error Rate (BER).*

I. Introduction

Orthogonal Frequency Division Multiplexing(OFDM) isa multicarrier transmission scheme which is significantly used in both wireless and wired communication system[2]. OFDM offers several advantages which makes it suitable for high speed data transmission system such as it combats Intersymbol Interference(ISI) resulting from a dispersive channel[7]. OFDM provides more resistance to frequency selective fading as compared to a single carrier transmission system.OFDM[8] finds various applications in digital television and audio broadcasting and 4G mobile communication etc. OFDM is introduced in optical communication system to support high speed data transmission over both single mode and multimode fibers and it overcomes both linear and non-linear impairments in optical fiber communication[3]. OFDM is computationally efficient as it makes use of Fast Fourier Transform(FFT) techniques for various modulation and demodulation functions implementation.The processing at high data rates in optical is feasible due to advancement in digital signal processing[2]. The various limitations of optical fiber communication system as chromatic dispersion, modal dispersion,self-phase modulation, relative intensity noise etc. are overcome through the use of OFDM technique[8]. OFDM divides the available spectrum into several sub-carriers and each sub-carrier is modulated by a lower data rate causing reduction of symbol rate and making optical OFDM robust against polarization mode dispersion and chromatic dispersion[2].

In this paper, section II describes a simulation setup of Optical OFDM system for both single mode and multimode fiber. In section III simulative analysis is done to evaluate the various performance parameters of OFDM-based single mode fiber and multimode fibersystemmodel.Further the effect of nonlinearities of optical modulator(MZM) on the performance of optical-OFDM system is also examined. At last, conclusion is presented in section IV.

II. Simulation Setup

Figure 1 and 2 show the simulation setup for OFDM-based single mode fiber and multimode fiber system designed to study their performance with respect tothe different parameters such as Bit Error Rate(BER), Quality factor(Q), optical power etc. In case of single mode system, the optical field represents the OFDM signal but in case of multimode system, OFDM signal is represented by the intensity of optical signal[2].The OFDM Transmitter section consists of a data source, serial to parallel converter, M-QAM modulator, IFFT(Inverse Fast Fourier Transform) block, Quadrature-Mix Inphase-Inquadratureblock and an electrical combiner.
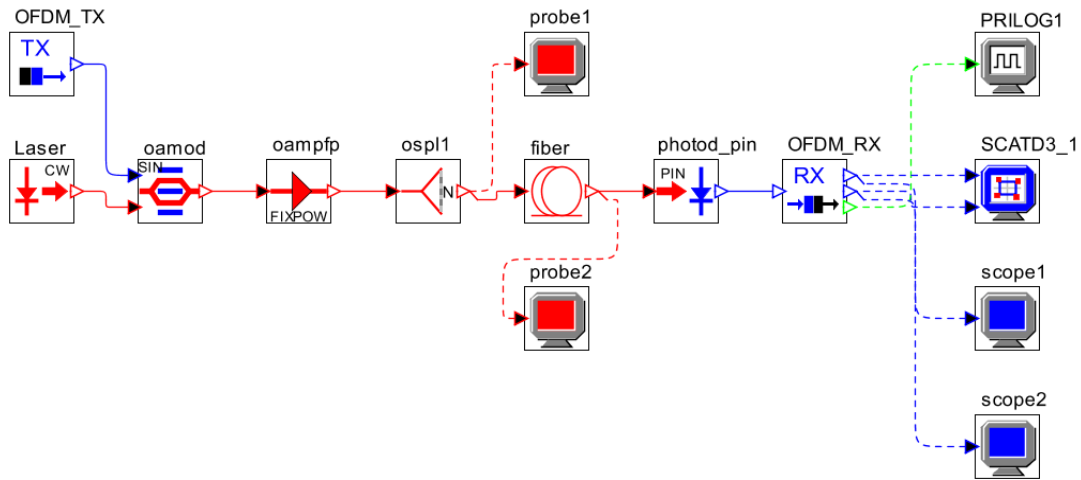
Figure 1. Simulation setup for OFDM-based single mode fiber system.
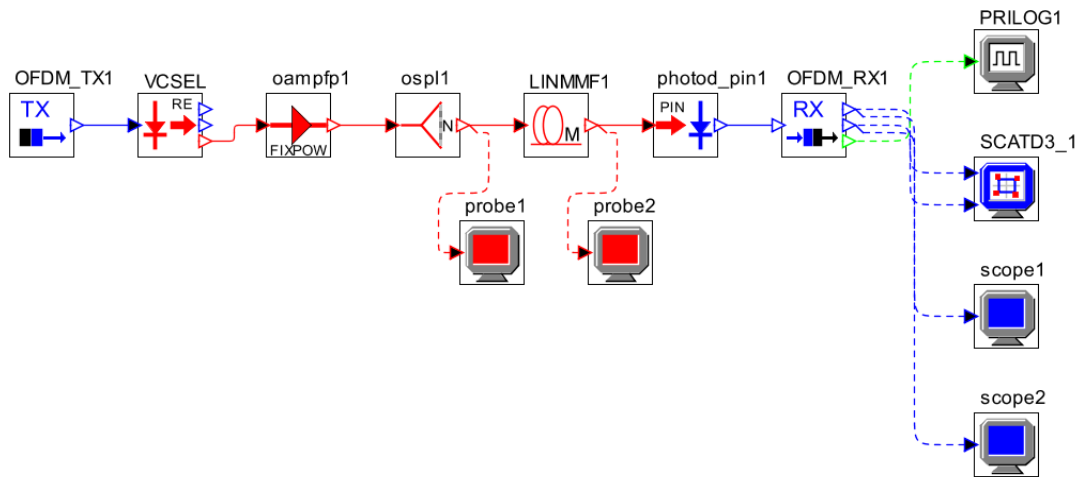

Figure 2. Simulation setup for OFDM-based multimode fiber system.

The OFDM signal is externally modulated with the help of a single arm Mach-Zehnder Modulator and transmitted over the fiber. At the receiver, optical signal is converted to electrical signal with the help of a PIN photodiode and drives a OFDM receiver section which consists of a electrical splitter, Quadrature-Mix Inphase-Inquadrature block, electrical filters, FFT (Fast Fourier Transform) block, QAM demodulator and a parallel to serial converter.In case of multimode system, Vertical Cavity Surface Emitting Laser (VCSEL) [9] is used to implement direct modulation scheme. The VCSELs have high coupling efficiency with optical fiber and most suitable for low power applications. Different parameters of the laser source are shown in Table-1.

Table-1: VCSEL Laser Emitter Parameters

Honeywell VCSEL Laser Emitter	HFE4080-32X/XBA
Threshold current	I_{TH} 3.5 mA
Peak Wavelength	850 nm
FWHM Linewidth	10 MHz
Turn on delay	0.457 ns
P-I slope	0.125 mW/mA
Relative Intensity Noise	-150 dB/Hz

The other parameters for single mode and multimode fibers are also shown in Table-2 and 3 respectively.

Table-2: Single Mode Fiber Parameters

Length	200 Km
Attenuation	<0.35/0.22 dB/Km
Zero dispersion Wavelength	1550 nm
Dispersion at Reference Frequency	-20 ps^2/Km
Reference Frequency for Losses	193.41449 THz

Table-3: Multimode Fiber Parameters

Length	0.5 Km
Attenuation	3.0 dB/Km
Dispersion	17 ps/nm/Km
Gamma cutback factor	0.75
Intermodal Bandwidth	160*Km

III. Performance Analysis Of Optical-OFDM System

The simulation of optical OFDM system as in Fig. 1 & 2 was carried out and the detailed performance analysis is presented in the subsequent figures. Some of the system parameters used include 8 number of subcarriers, FFT size of 256, the QAM technique is used to support a bit rate of 10 Gb/s.

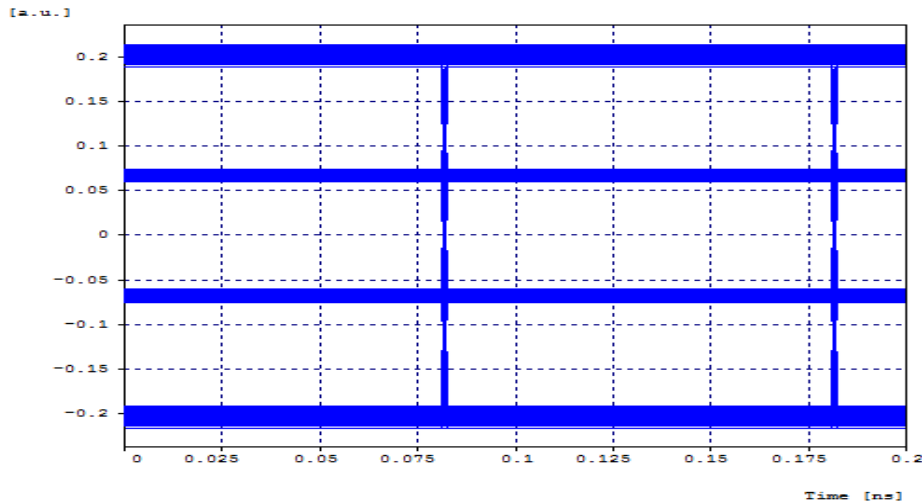Figures-3 and 4 show the eye diagrams of a single mode system and multimode system.

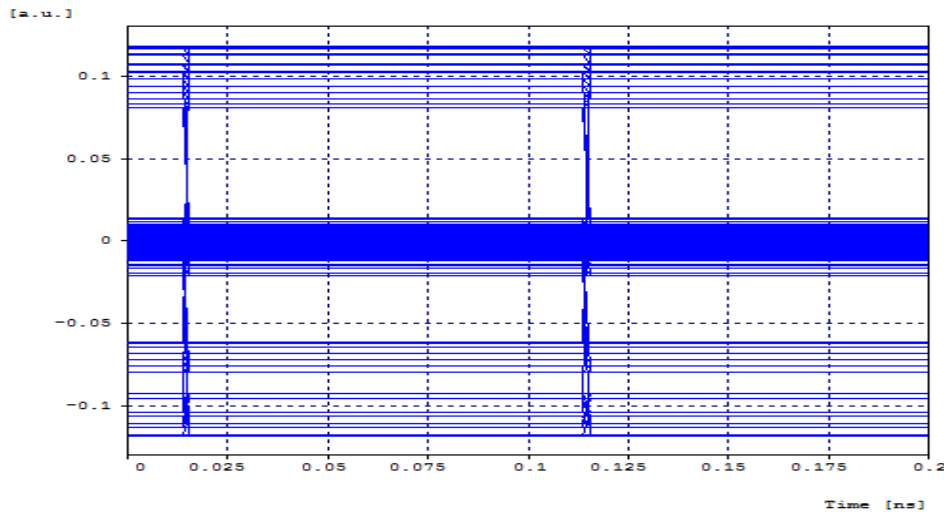**Figure-3.** Eye Diagram of a single modeSystem.

Figure-4. Eye Diagram of a multimode System.

It is clear from both the figures- 3 & 4 that single mode system has better resolution and improved quality than a multimode system. A comparison of different parameters of eye diagrams is listed in Table-4 which shows better eye opening and jitter for a single mode system in comparison with a multimode system.

Table-4: Parameters of Eye Diagrams

Laser	Eye opening	Jitter(ns)
Single Mode System	0.121571	0.0038688
Multimode System	0.004274	0.0049525

Figures-5 and 6 show the electrical spectrum for single mode and multimode system. A single mode laser provides better resolution over longer fiber cables as compared to a multimode laser.
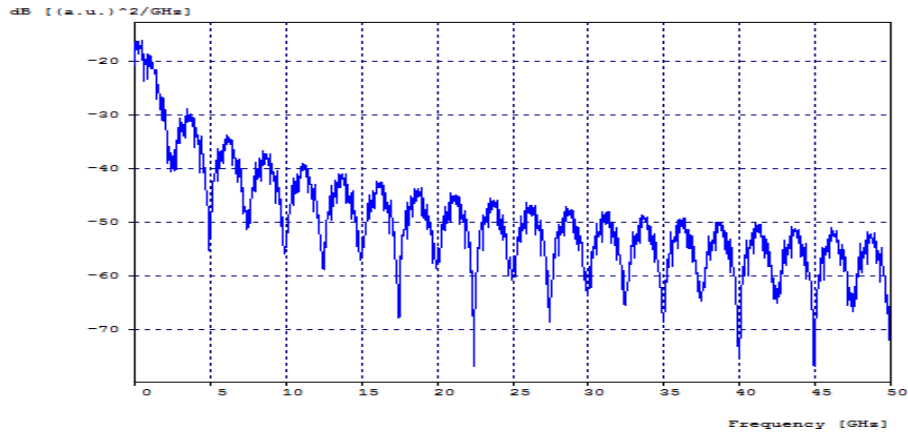

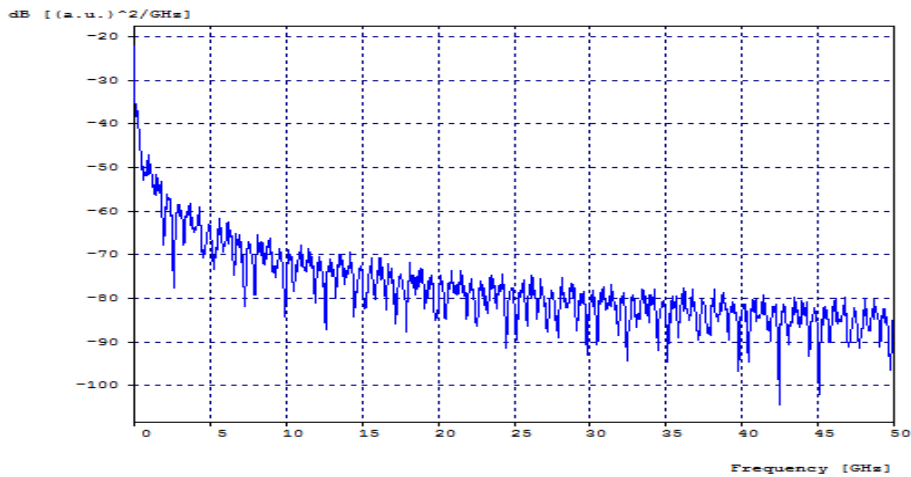**Figure-5.**Electrical Spectrum of a single mode system.

Figure-6. Electrical Spectrum of a multimode system.

Figure-7 showing the optical spectrum for a single mode laser indicates that a single optical carrier is used here to represent the each OFDM subcarrier.
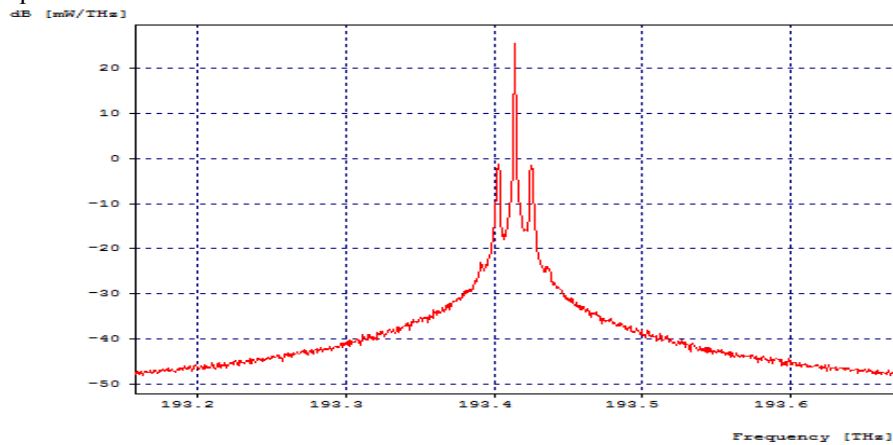

Figure-7. Optical spectrum for a single-mode laser.

Now, the performance analysis of single mode and multimode fiber system model has been carried out with respect to fiber length. Other OFDM system parameters used are: number of subcarriers of 64 and16-QAM modulation technique supporting a bit rate of 10 Gb/s.

The simulation results tabulated in Table-5 and 6 respectively indicate that the performance of single mode and multimode fiber system model is degraded with increase in the length of fiber. It is clearly observed from the Table 5 that as length of single mode fiber is increased from 200Km to 400Km, the BER is increased from 2.10E-04 to 3.04E-03, Q factor is degraded from 12.5887dB to 8.2597dB,jitter is increased from 0ns to 0.002515ns and eye opening is also degraded from 0.72568 to 0.02611 and a similar kind of behavior is observed for multimode fiber from the Table 6, as multimode fiber length is increased from 0.1Km to 5Km, the BER is increased from 3.6E-011 to 2.27E-02, Q factor is degraded from 16.31270dB to 6.020600dB, jitter is increased from 0.000816ns to 0.005189ns and eye opening is degraded from 0.130367 to 0.019082.

Table-5: Performance Analysis of OFDM-based Single Mode Fiber system

Distance(Km)	200	400	600
BER	2.1E-04	4.6E-04	3.04E-03
Q(dB)	12.5887	11.8058	8.2597
Jitter(ns)	0	0.00070	0.00251
Eye Opening	0.72568	0.30846	0.02611

Table-6: Performance Analysis of OFDM-based Multimode Fiber system

Distance(Km)	0.1	0.5	5
BER	3.6E-11	2.41E-05	2.27E-02
Q(dB)	16.31270	12.01027	6.020600
Jitter(ns)	0.000816	0.002530	0.005189
Eye Opening	0.130367	0.070248	0.019082

Figures-8 and 9 show the BER curves wrt varying fiber length in single mode system and multimode system respectively. It is observed that BER increases with increases with increase in fiber length for both single mode and multimode fiber system.
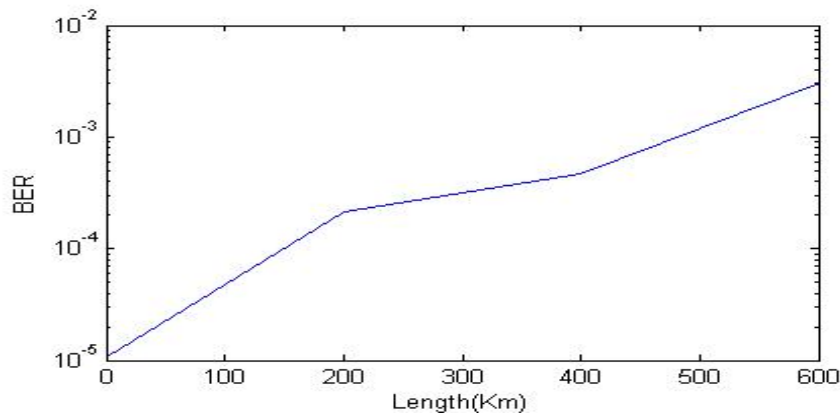

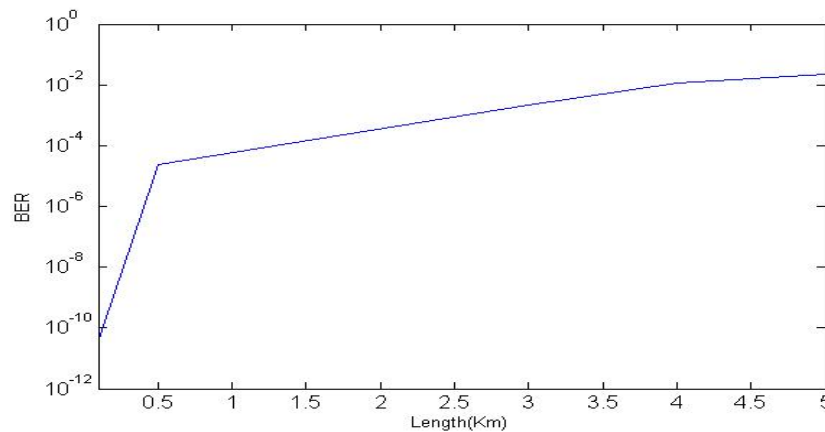**Figure-8.** Optical BER curve wrt varying single mode fiber length.

Figure-9. Optical BER curve wrt varying multimode fiber length.

Figures-10 and 11 are showing the Q factor curve (dB) wrt varying fiber length in single mode system and multimode system. It is clear from the results that a multimode system has better performance over shorter distances as compared to a single mode fiber system. Therefore, it is proposed that single mode fibers should be preferred for long haul data transmission.
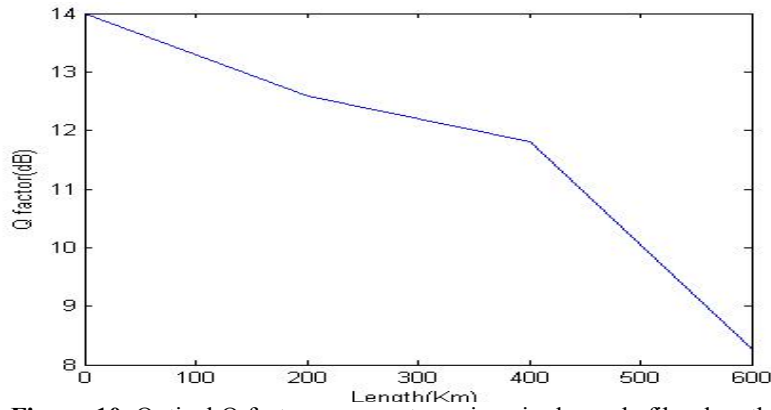
Figure-10. Optical Q factor curve wrt varying single mode fiber length.
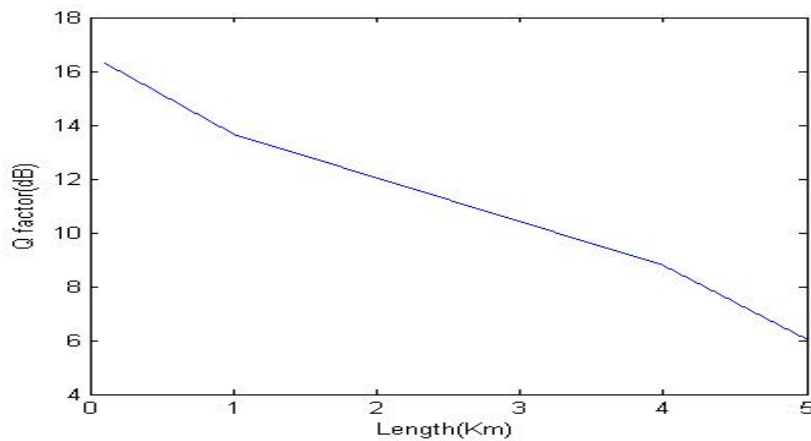
Figure-11. Optical Q curve wrt varying multimode fiber length.

Lastly, in OFDM-based single mode fiber system simulation, the effect of non-linearities of Mach-Zehnder Modulator(MZM) is also considered. The static phase shift or bias point(ϕ) of MZM is defined as-

$$\phi = V_{DC} * \pi / V_\pi$$

Where V_{DC} is the DC bias voltage of MZM, V_π is the half wave switching voltage of MZM. An effect of DC bias voltage of MZM on system performance is shown below. Figure 12 shows the performance variation of optical-OFDM system with variation in bias point of MZM.
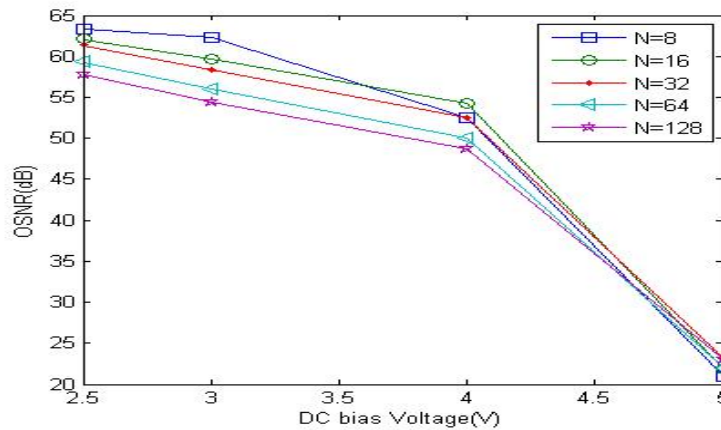
Figure-12. OSNR as a function of V_{DC} with $V_\pi = 5V$ for different subcarriers.

As the bias point is varied from π/2 to π. The optical signal to noise ratio decreases. From the results, it can be concluded that power transfer characteristics of MZM are better at quadrature bias point (π/2) for direct-detection optical-OFDM system.

IV. Conclusion

In this paper, we presented an optical-OFDM system design model for both single mode and multimode fiber. The limit of distance varies from single mode to multimode fiber. For long transmission distances, single mode fiber models are preferred but for smaller distances multimode fiber models are better. The various performance parameters as BER, Q factor etc. of OFDM signal are analyzed. The non-linearities of Mach-Zehnder Modulator are also considered. For better power transfer characteristics in direct-detection optical-OFDM system, Mach-Zehnder Modulator should be biased at quadrature point.

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