# Subcarrier Level Performance Investigation Of Post Compensated Direct Detection Optical OFDM System

Divya Dhawan, Neena Gupta

**Abstract**— High data rate demand owing to the extensive internet based applications has compelled the researchers to investigate and explore the advanced modulation formats together with the multiplexing techniques in optical fiber based communication systems so as to satisfy the needs of current applications. One solution proposed which has growing interests in optical communication systems is Orthogonal Frequency Division Multiplexing (OFDM). One main short coming of optical orthogonal frequency-division multiplexing is that it is susceptible to nonlinear fiber effects due to its high peak-to-average power ratio. Several digital signal processing techniques have been investigated for the compensation of fiber nonlinearities, e.g., digital back-propagation, nonlinear pre- and post-compensation and nonlinear equalizers (NLEs) based on the inverse Volterra-series transfer function (IVSTF). Digital Back Propagation suffers from computational complexity due to FFT in DSP domain, Pre and post compensation has complex and expensive design. OFDM based transmission systems suffer from one major drawback i.e high peak- to-average power ratio (PAPR) of OFDM signal. In this paper a Volterra based equalizer is used to perform non linear equalization and subcarrier level performance is investigated.

**Index Terms**— Direct Detection, OFDM, Equalisation, Non Linearities,Symbol Error Rate,OSNR



## INTRODUCTION

OFDM is preferred choice for wireless systems as it is spectrum efficient multicarrier modulation scheme[1]. Owing to the advantages offered by OFDM in wireless domain it has become the most suitable choice for optical transmission systems also as it offers high spectral efficiency and is robust against various channel impairments such as channel dispersion[2]. OFDM being a multicarrier transmission scheme has significant advantages over single carrier transmission schemes. The most important being the digital signal processing that can be done at the receiver as well as transmitter side so as to mitigate the effects of channel impairments. Also OFDM has a tightly bound spectral shape and is thus spectrum efficient. The basic principle involved is the transmission of high data rate stream using a number of parallel lower data rate streams, which are transmitted over a number of orthogonal subcarriers. The orthogonal subcarriers are overlapping. Each subcarrier is modulated with a separate symbol and then the various subcarriers are multiplexed in frequency domain[3]. Optical OFDM has become the most promising solution for long-haul and high-speed optical transmission systems, for its number of advantages like high spectral efficiency, robustness against channel dispersion, bandwidth scalability, DSP based pre and post compensation techniques and many more. Thus, incorporating OFDM in the optical domain not only retains the traditional advantages of the OFDM but also increases the transmission capacity of the signal.


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## OFDM Based Direct Detection Optical Communication system

OFDM based Optical Communication systems are categorized into direct detection and coherent detection systems.Direct Detection systems are immune to clipping noise and has a simple receiver architecture whereas Coherent Detection Systems have complex transceiver design but superior perforformance in terms of receiver sensitivity,spectral efficiency [4].Direct Detection is used in this paper.As shown in the Figure 1, the transmitter consists of PRBS generator to generate the bit stream which is then mapped to suitable modulation format like QPSK,QAM etc. After that Serial to parallel conversion takes place followed by Inverse Fast Fourier Transform. Cyclic Prefix is added to avoid Inter Symbol Interference. Again data is obtained in serial form. After that RF to optical upconversion takes place followed by optical modulation. OFDM signal consists of data and additional overheads such as cyclic prefix (for combating ISI and ICI) and training symbols/pilot subcarriers required for channel estimation. The OFDM signal can be expressed as

$$x(n) = \sum_{k=0}^{N-1} X(k) e^{-j2\pi\frac{n}{N}k} \text{ for } 0 \leq n \leq N\text{-}1 \quad (1)$$

Where, x(n) is transmitted information symbol for the $k^{th}$ subcarrier in the OFDM symbol. At the receiver FFT is used to recover data, which can be expressed as

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$$X(m) = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} x(n)\, e^{j2\pi\frac{n}{N}m} \quad (2)$$

From equations (1) and (2) it can be observed that OFDM transfers the complexity of transmitters and receivers from the analog to the digital domain by making use of IFFT operation at the transmitting side and the FFT operation at the receiving end.

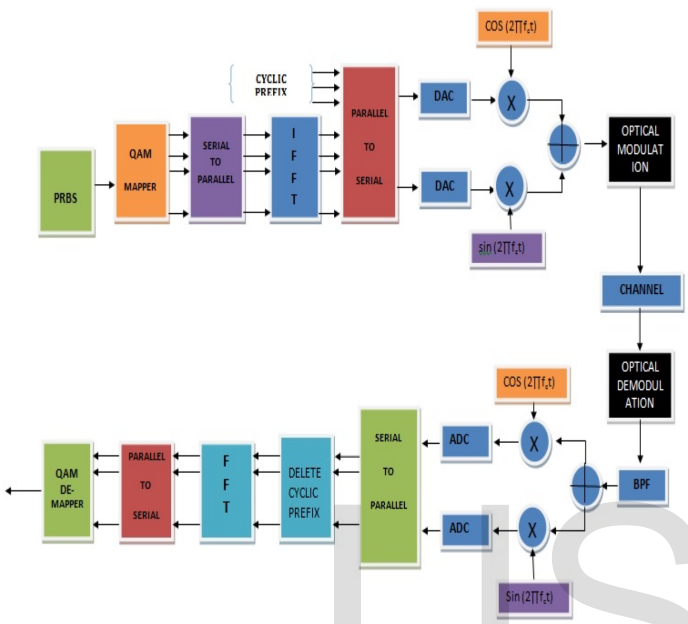


**Figure 1. Optical OFDM System**

The inter symbol interference (ISI) can be eliminated to a large extent by using the cyclic prefix (CP). A guard time is introduced for each OFDM symbol after the IFFT, where the OFDM symbol is cyclically extended, as shown in Figure 2. This cyclical extension is called the cyclic prefix (CP).

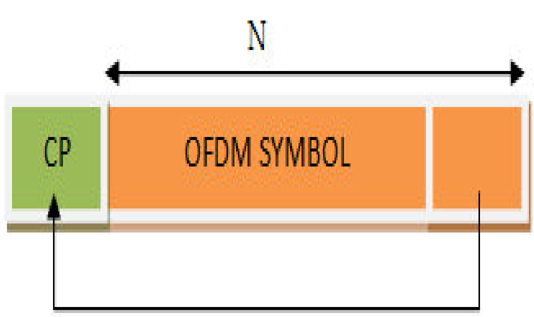


**Figure 2. Insertion of Cyclic Prefix**

At the receiver side all the reverse operations are carried out such as optical demodulation, Optical to RF down conversion and OFDM decoding. OFDM decoder consists of stages like serial to parallel conversion, removing the cyclic prefix, channel estimation, FFT and parallel to serial conversion.

## Volterra based Equalisation Approach

In this paper Volterra Equalizer is used to mitigate the effect of intra channel nonlinearities to improve the performance of externally modulated direct detection optical OFDM system. Earlier Volterra equalizer has been used at the receiver for directly modulated direct detection system to mitigate the effect of subcarrier to subcarrier intermixing caused due to interplay of Group Velocity Dispersion and Laser Chirp[5].Non linearities such as self phase modulation (SPM) and Cross Phase Modulation(XPM) are caused by intensity fluctuations .Four Wave Mixing(FWM) also affects the system performance because OFDM systems are multicarrier systems. The intra channel non linearities cause subcarrier to subcarrier intermixing interference. In this paper, Volterra series based equalization is used to overcome the intra channel non linearity distortion of direct detection optical OFDM system. A second order Volterra Equalizer is used. This equalizer provides compensation against ISI, SPM, FWM etc. The role of equalizer is to compensate for the losses that have occurred in the channel or equivalently it is the inverse model of the channel. The second order Volterra model used in the system is based on the adaptive least mean square algorithm. The error between the received signal and the reference signal is determined and the filter adapts its coefficients by minimizing (LMS) the error signal between the received signal and a reference signal.

## Simulation Set Up Details

OFDM coder generates the OFDM signal which is directly up converted.64 subcarriers are used. Discrete multi tone OFDM is used. Hence 32 subcarriers are zero padded. Cyclic Prefix of length 1/8$^{th}$ of symbol duration is used. External Modulation is used. Mach Zhender modulator is used for optical modulation. Symbol rate used is 2.5 Gb/s.16 QAM modulation format is investigated. LASER source is operating at 193.1THz. This modulated optical signal is now launched into fiber of length 100Kms length. At the receiver, Direct Detection (DD) is employed by means of a photo diode. After that equalizer is used to compensate for intra channel non linearities. After minimizing the error using Volterra Equaliser, OFDM decoder carries out all the reverse operations such as removing cyclic prefix, serial to parallel conversion and FFT. Simulations are carried out using VPI Photonics Simulation Software.

## Simulation Results

Subcarrier level performance is investigated for 16 QAM. Graphs have been plotted for symbol error rate versus subcarrier number. This performance is investigated by varying the optical signal to noise ratio. The range of OSNR is 20 dB to 35dB. Figure 3 shows the plot of Symbol Error Rate( SER) occurring in 32 subcarriers for OSNR=20dB. Blue coloured plot with circles is obtained without volterra equalization whereas magenta plot with rectangles is obtained when volterra equalizer is used.

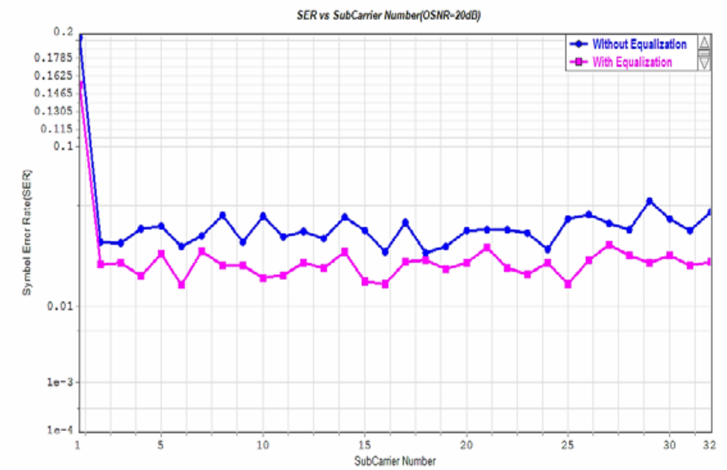


**Figure 3. SER vs SubCarrier Number(OSNR=20dB)**

It can be observed from Figure 3 that use of Volterra based Equalisation has improved the performance of the system in terms of Symbol Error Rate.The SER has reduced at subcarrier level with the use of Volterra Equaliser.. This trend is observed in other graphs also at OSNRs of 25,30,35dB.(Fig.4-Fig.6).

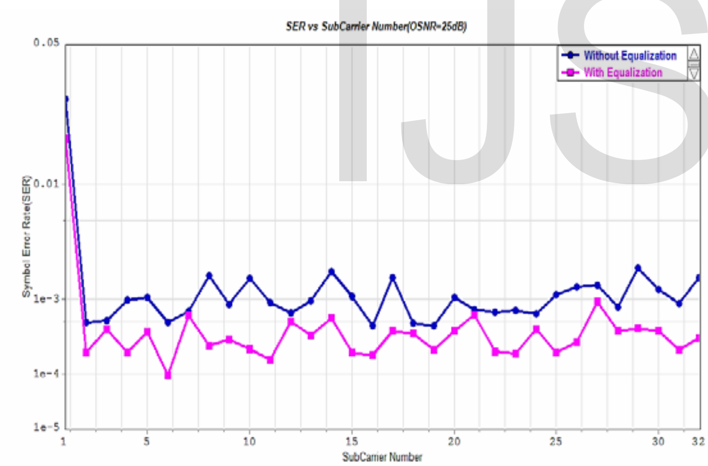


**Figure 4. SER vs SubCarrierNumber(OSNR=25dB)**

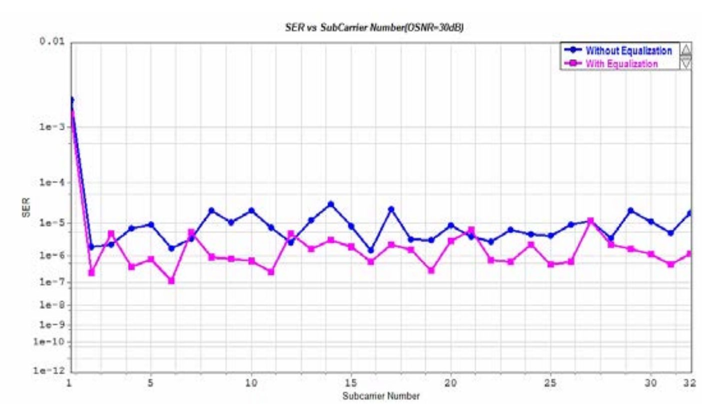


**Figure 5. SER vs SubCarrierNumber(OSNR=30dB)**

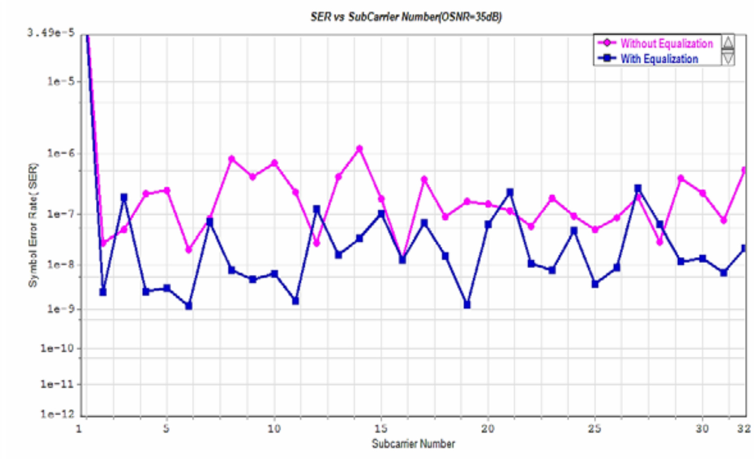


**Figure 6 SER vs SubCarrierNumber(OSNR=35dB)**

Also by comparing the different graphs , it is seen that as OSNR is increased from 20 dB to 35dB,SER is reduced and hence performance of the system improves.



## Conclusion

A Volterra based equalizer is proposed for mitigation of intra channel non linearities. This paper shows that the use of Volterra Series based equalizer has enhanced the system performance in terms of Symbol Error Rate at subcarrier level. The SER rate reduces by approx $1e^{-1}$ or $1e^{-2}$ for almost all the subcarriers. Also the increase in OSNR further improves the system performance. For every 5 dB increase in OSNR, SER reduces by $1e^{-2}$ to $1e^{-3}$.

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