A Study of Performance Enhancement of Coherent WDM Optical System with OFDM

Sunil Kumar Dahiya[1], Dr. Amit Kumar Garg[2]

[1]*Ph. D. Research Scholar, DCR University of Science and Technology, ECED, Murthal (Sonepat)-India*

[2]*Professor, DCR University of Science and Technology, ECED, Murthal (Sonepat)-India*

Abstract- Integration of OFDM with Coherent detection has potential to improve the spectral efficiency and capacity of optical communication by mitigating the transmission impairments present in optical transmission channel because of the linear conversion from the optical to the electrical domain, especially when polarization multiplexing is explored as a means of increasing spectral efficiency. The performance of OFDM - Coherent WDM can be analysed with metrics Bit Error Rate (BER) and the Optical Signal to Noise Ratio (OSNR) and the constellation diagram. Dispersion compensation fiber (DCF), high –level modulation format (m-QAM/PSK) and channel spacing play an important role to enhance the capacity of COOFDM system.

Keywords- OFDM, WDM, CD, CO-OFDM

I. INTRODUCTION

The major challenge is to enhance the throughput and distance limit of existing long-haul transmission systems without doing signal regeneration. Coherent systems are the key in order to accomplish these requirements. These systems were a topic of intense research during the 1980's, essentially because of their great sensitivity and capability of narrowband channel selection, until the emergence of Erbium Doped Fiber Amplifiers (EDFA) in the early 1990's. Recently, they have gained renewed interest, essentially because of the availability of high speed digital signal processing, which allows for the signal to be digitized and processed in the digital domain. The lower price of electrical components, partly relaxed receiver requirements at high data rates and capability of pushing the spectral efficiency limits beyond, while maximizing the power efficiency, also intensified the interest in the topic. In fact, if the outputs of a coherent homodyne receiver are sampled at the Nyquist rate, the digitized waveform contains full information of the electric field, preserving the amplitude, phase and polarization from the optical domain to the electrical domain, enabling new potential of multi-level signaling (M-ary PSK and M-ary QAM modulation), as well as the possibility of exploring polarization multiplexing. Therefore the symbol rate can be reduced while keeping the bit rate, increasing the spectral efficiency and easing the complexity of A/D (Analog to Digital) circuits used in demodulation/compensation schemes. Additionally, it enables quasi-exact compensation of linear transmission impairments such as Chromatic Dispersion (CD) and Polarization Mode Dispersion (PMD) by a linear filter, which can operate adaptively to overcome time-varying impairments.

Comparison the performance of both phase modulator and optical filter to compensate the higher order of dispersion, Q-factor was improved from 6.04 to 8.05dB with phase modulator to get desired BER in OFDM – optical coherent WDM system. The distance between symbols was increased on constellation diagram due to equaliser [4].

CO-OFDM has higher tolerance to chromatic dispersion and nonlinearity in single mode fiber as high data rate and high launching optical power. With the use of DCF along with EDFA amplifier can reach the beyond the 7000 Km. on the investigation with WDM, data rate improved and chromatic dispersion increases as the increases in data rate. On the expansion of channel spacing leads to improve the bit error rate and Q-factor. The maximum Q-factor i.e. 33.4dB achieved with channel spacing 150GHz [3]. Bit error rate is increases with distance, but BER should be maintained below 10-3 with large OSNR. Because large OSNR may leads to increase the nonlinear effects on the transmission medium [5].

As increased high data rate, Orthogonal Frequency Division Multiplexing (OFDM) is also increased the robustness to narrowband interference and frequency selective fading. In OFDM, high data rate streams divided into lower data rate streams and transmitted over subcarriers simultaneously. It increases the symbol duration that help to reduce significant amount of dispersion generated from delay spread of the multi-path.

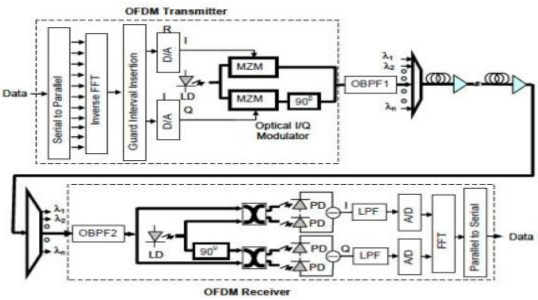

Fig.1: Model diagram of CO-OFDM communication system[4]

Low data rate streams, sub-carriers can be modulated by using different types of modulation, such as Quadrature Amplitude Modulation (m-QAM) or Phase Shift Keying (m- PSK). After that, the subcarriers are carried over a high frequency carrier. The Fast Fourier Transform (FFT) and the Inverse Fast Fourier Transform (IFFT) are very effective algorithms that can be use in the OFDM transceivers.

The OFDM modulation technique and coherent detection technique have to combat chromatic dispersion and polarization-mode dispersion using the robust equalization. One of the disadvantages of OFDM is a high Peak-to-Average power ratio (PAPR) due to a central limit theorem effect when modulating many symbols via an IFFT. PAPR problem increases the presence of nonlinear effects, which are proportional to the instantaneous signal power. An intelligent PAPR reduction algorithm is required to mitigate nonlinear effects. The nonlinearity threshold enhancement is directly translated into OSNR margin improvement. Also, it can give high spectral efficiency because the OFDM subcarriers spectra are incompletely overlapped.

Efficient use of the spectrum by allowing overlap, by dividing the channel into narrowband flat fading sub channels, cyclic prefix is used to eliminates ISI and IFI, adaptive equalization techniques used for channel equalisation with single carrier systems, use maximum likelihood decoding with reasonable complexity, use of computationally efficient FFT techniques for modulation and demodulation, less sensitive to sample timing offsets, and protection against co-channel interference and impulsive parasitic noise.

Linear transmission impartment can be mitigated by down sampling rate above the nyquist rate. Chromatic dispersion, polarization mode dispersion and sampling time errors can be compensated by linear equalization with negligible penalty. DSP enable multi-carrier transmission using OFDM. The DSP circuit brings the following benefits: 1. possible to synchronize the frequency and phase of transmitter with the LO light without the need for a bulky and expensive phase locked loop (PLL). 2. As a result the LO laser requirement will be relaxed, and a commonly available WDM laser can be used as free-running LO. 3. possible to track the continuously fluctuating state of polarization (SOP) of the incoming signal. 4. Compensation of transmission impairments will be possible by distorting the digital waveform

Table 1. OFDM parameters for 100 Gbit/s transmission using polarization-multiplexed 4-QAM, SMF (D-17 ps/nm-km) with 2% under-compensation of CD is assumed. Target excess bandwidth factor ≤ 0.25, oversampling ratio ≤ 1.25, and impulse energy containment factor ≥ 0.98 are assumed [13].

Transmission Distance (km)	**Polarization-Multiplexed Transmission**								
	4-QAM (4 bits/symbol)			**8-QAM (6 bits/symbol)**			**16-QAM (8 bits/symbol)**		
	N_{pre}	**N_c**	**N_u**	**N_{pre}**	**N_c**	**N_u**	**N_{pre}**	**N_c**	**N_u**
1,000	5	32	26	4	32	26	2	16	13
2,000	8	64	52	5	32	26	4	32	26
3,000	10	64	52	6	32	26	5	32	26
4,000	14	128	104	8	64	52	6	32	26

Table1. N_{pre} is number of cyclic prefix, N_c is number of subcarriers and N_u is number of used sub carriers.

Table.2. No of ADC bits required for different modulation formats at a target BER of 10^{-3}[13].

Modulation Format	**OSNR per symbol**	**Number of Quantization level**	**Number of ADC bits required**
4-QAM	15.1	28	5
8-QAM	38.0	44	6
16-QAM	71.5	60	6

Table 3. Comparison of the computational complexity of single-carrier transmission versus OFDM for polarization-multiplexed 4-QAM at 100 Gbit/s (symbol rate = 25 GHz). Listed are the numbers of complex multiplications required per symbol period [13].

Transmission Distance (km)	**Single-Carrier**			**OFDM**		
	Direct	**FFT**				
		Block-Size (B)	**Complexity**	**Trans-mitter**	**Receiver**	**Total**
1,000	12.0	6	13.3	6.2	10.2	16.4
2,000	24.0	27	16.6	7.4	11.4	18.8
3,000	32.0	25	17.9	7.4	11.4	18.8
4,000	52.0	52	19.7	8.6	12.6	21.2

The structure of this paper, section 2 is Experimental set-up. Section 3 is details of Simulation setup parameters. Section 4 results and discussions. At end of paper, conclusion of performed experiments and points covered from literature along with future direction.

II. EXPERIMENTAL SETUP

The system consists of three main parts: CO-OFDM transmitter, optical fiber link, and CO-OFDM receiver.

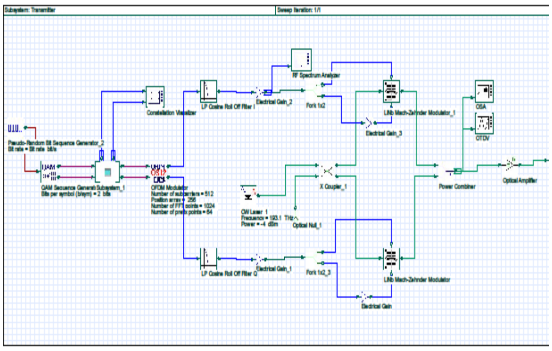

Fig.2: CO-OFDM Coherent system

A. CO-OFDM Transmitter

PRBS generator is connected to a 4-QAM sequence generator (coder) and modulated by the OFDM modulator (electrical modulator). The output of OFDM modulator is transmitted to I/Q optical modulator (electrical to optical modulator), which is combination two Lithium Niobate ($LiNbO_3$) Mach-Zehnder Modulators (MZMs) alongwith laser source and output signals from OFDM modulator are fed to the two MZMs. The output optical signals from the two MZMs are fed to the optical fiber span via WDM multiplexer.

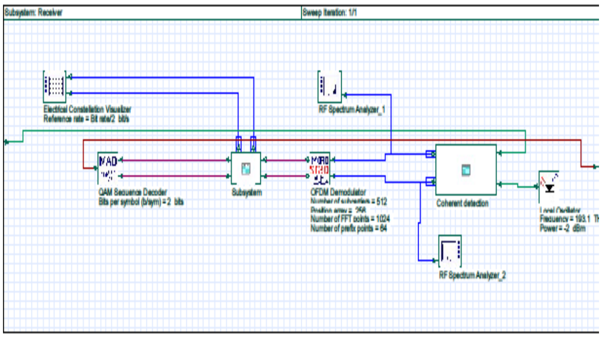

Fig.3: CO-OFDM Transmitter

B. Optical Fiber Link

The four OFDM signals are multiplexed using four channels WDM and then launched to the optical fiber link. A multi-span optical fiber is used, which consist of N-spans of Single Mode Fiber (SMF). The dispersion of the fiber is compensated using DCF (Dispersion Compensation Fiber) in each span. Two EDFAs are used in the fiber link to compensate the loss.

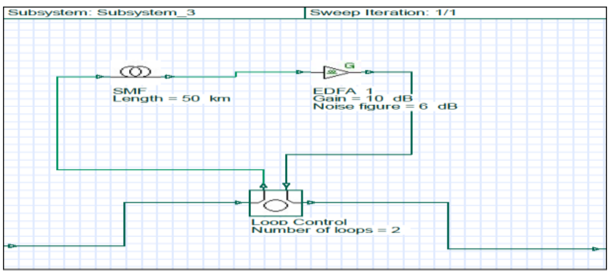

Fig.4: Optical Fiber Link (SMF)

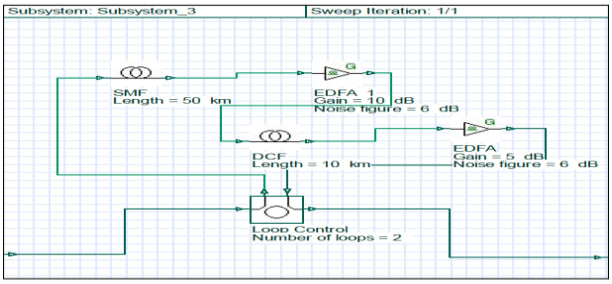

Fig.5: Optical fiber Link (SMF and DCF)

C. CO-OFDM Receiver

The resulting optical signal from the fiber link is separated into different wavelengths by WDM demodulator and each separately detected by coherent detector. CO-OFDM receiver is combination of four balanced PIN photo-detectors and a local laser (LO). LO is having a same center wavelength for respective channels. Noise cancellation is done by using the balanced detectors. The resulting optical signal from the optical fiber span is connected to the four balanced PIN photo detectors to convert the optical to electrical along with I/ Q (In-phase/ Quadrature) information of signals. The resulting signal is transmitted to OFDM demodulator (same parameters as modulator) to be demodulated and remove the guard interval. Then, the resulting signal is fed to the input of QAM sequence generator (decoder) to generate the binary signal.

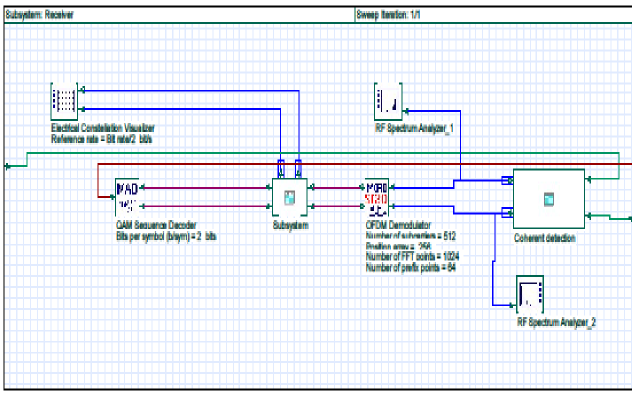

Fig.6: CO-OFDM Receiver

III. SIMULATION SET-UP PARAMETERS

Category	Parameters	Value
Global Parameters	Sequence length	16384 bits
	Sample per bit	4
	No. of samples	65536
Transmitter	Center emission frequency	193.1 THz-193.25 THz

	Channel spacing	50GHz
	Bit rate	50 Gb/s
	Number of channels	4
	OFDM Sub-carriers	512
	No. of FFT points	1024
	Source line width	0.15 MHz
SMF	Span length	50Km
	Dispersion	16 ps/nm-km
	Dispersion slope	0.08 ps/nm^2-km
	Attenuation	0.2 dB/Km
	Non linear index	2.6x10^{-20} m^2/W
	Core area	80 u m^2
	PMD link design	0.2 ps/(Km)$^{0.5}$
DCF	Span length	10 Km
	Dispersion	-80 ps/nm-km
	Dispersion slope	-0.45 ps/nm^2-km
	Attenuation	0.4 dB/Km
	Non linear index	2.6x10^{-20} m^2/W
	Core area	30 u m^2
	PMD link design	0.2 ps/(Km)$^{0.5}$
Optical amplifier	Noise figure	6 dB
	Gain	20dB
MZIM Modulator	Extinction Ration	60
	Bias voltage	4V

IV. RESULT AND DISCUSSION

Opti System 15 is used for simulation of CO-OFDM optical system. Results of simulation, as increase in transmission distance, distorted constellation diagram found at receiver side.

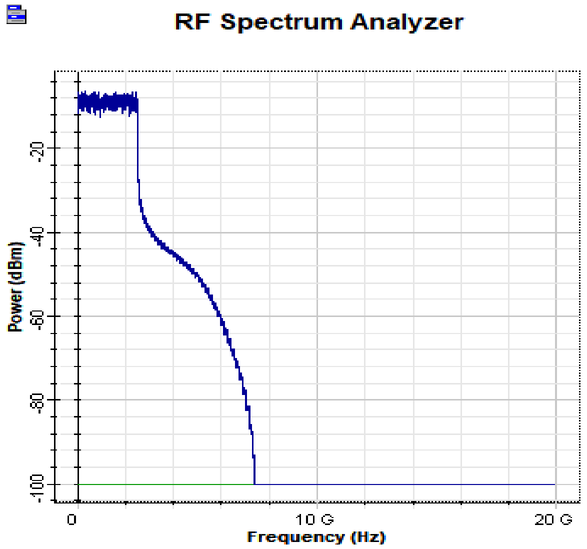

Fig.7: RF spectrum(In Phase) at OFDM Modulator

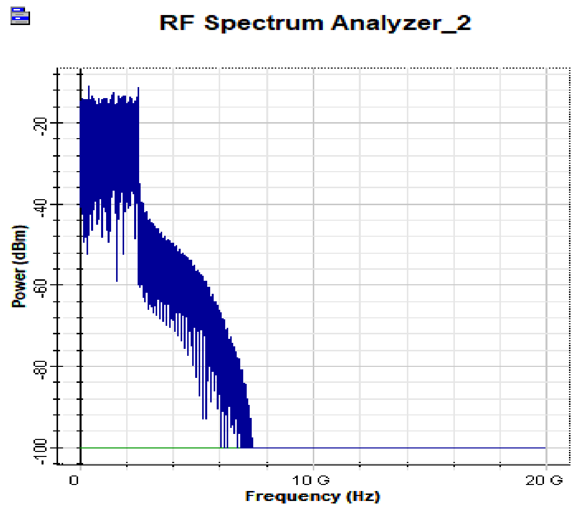

Fig. 8: RF spectrum(Quadrature) at OFDM Modulator

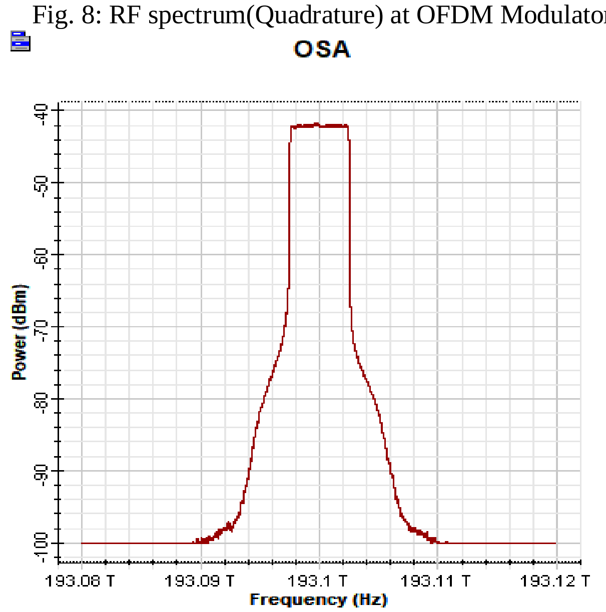

Fig.9: Optical Spectrum at Transmitter(after Two MZMs)

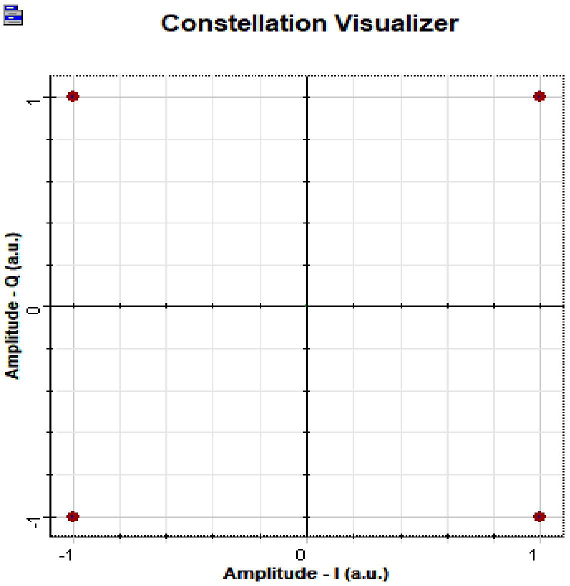

Fig.10: Constellation Diagram of QAM Modulator

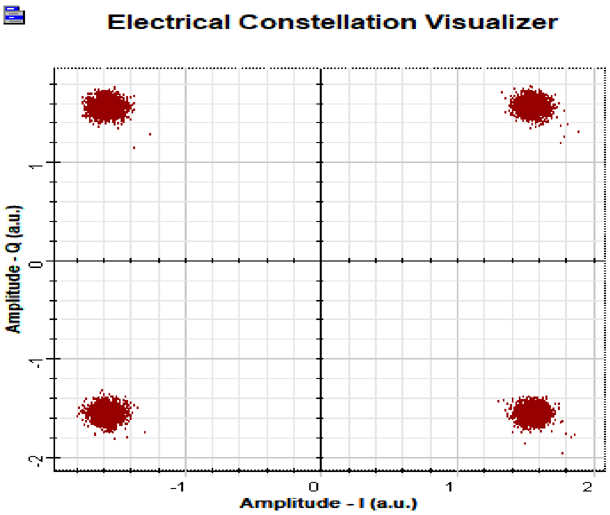

Fig.11: Constellation Diagram at Receiver(B2B)

Figure 11 shows the constallation diagram with using any optical link (BACK TO BACK).

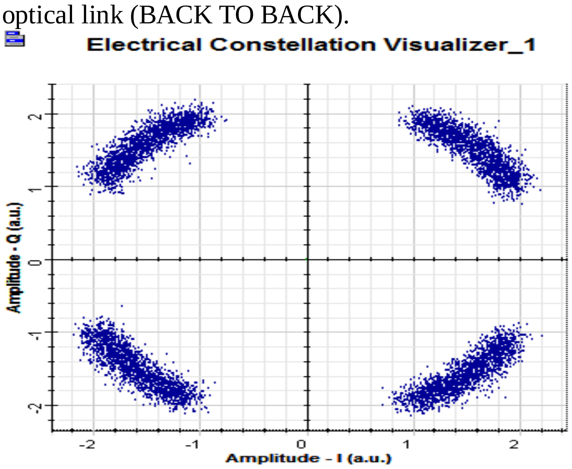

Fig. 12 Constellation Diagram at Receiver (After 2*50Km with SMF)

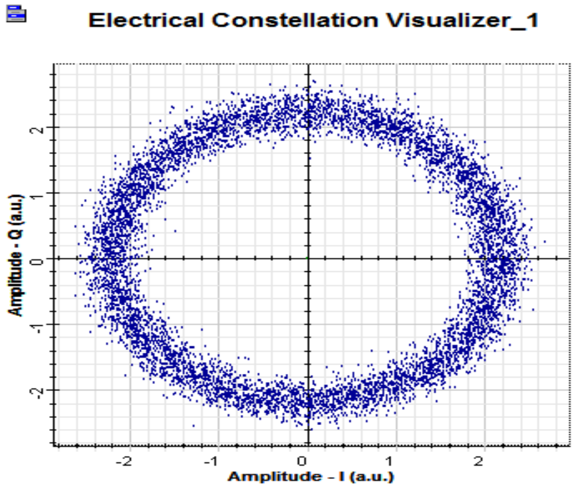

Fig.13: Constellation Diagram at Receiver (After 4*50Km with SMF)

Figure 13 shows that constalation diagram found distorted as increase in transmission distance(2*50Km with Single Mode Fiber).

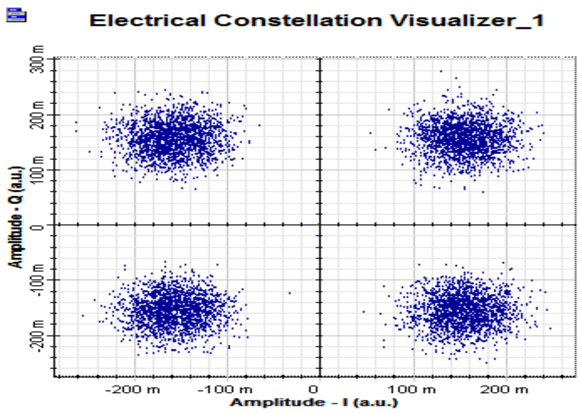

Fig.14: Constellation Diagram at Receiver(After 100Km with DCF)

Figuresh 14 ows that better constalation diagram(clear seperation between symbol) after using Dispersion compensation fiber(2*50Km with Single Mode Fiber + 2*10Km Dispersion compensation fiber).

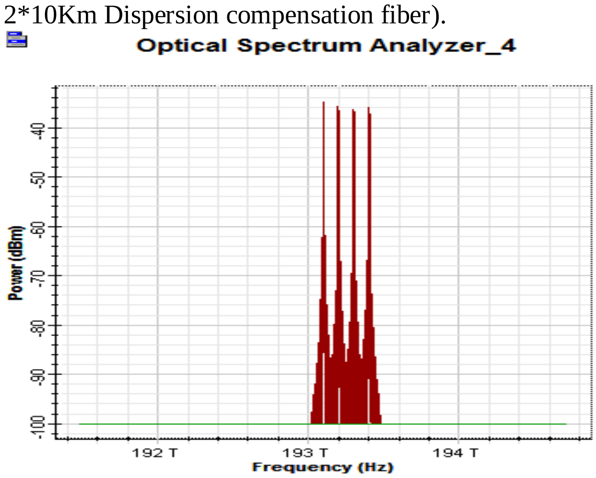

Fig.15: Optical spectrum at Transmitter (100GHz spacing)

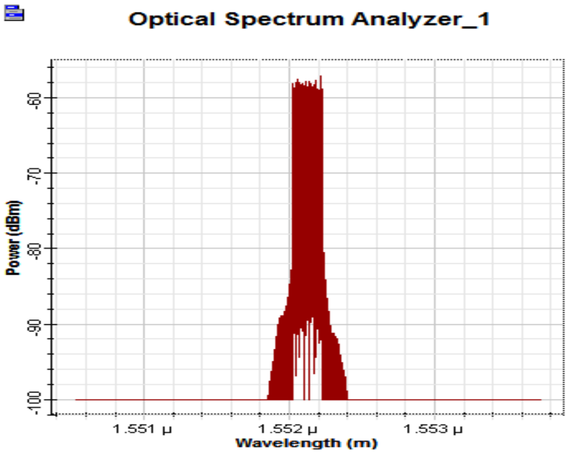

Fig.16: Optical Spectrum at Transmitter(after Two MZMs)

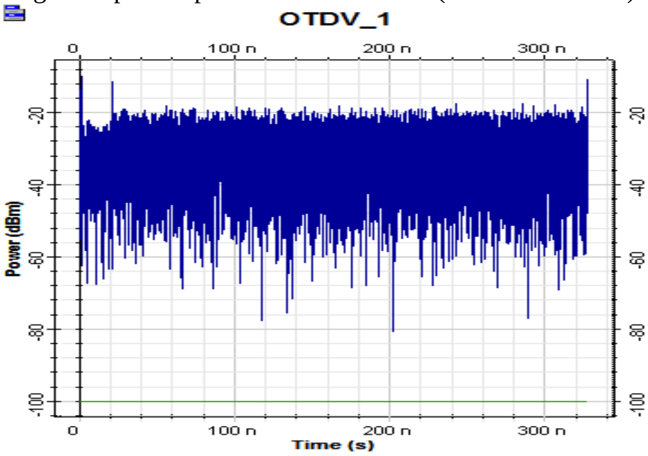

Fig.17: Optical spectrum at Transmitter (100GHz spacing)

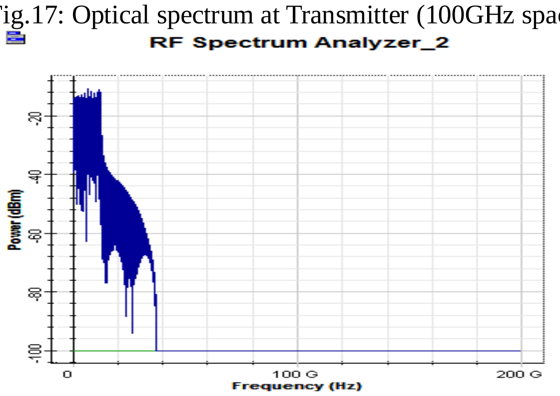

Fig.18: RF spectrum(In Phase) at OFDM Modulator

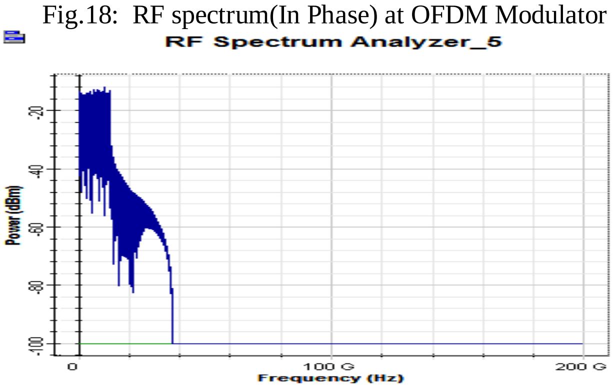

Fig.19: RF spectrum(Quadrature) at OFDM Modulator

V. CONCLUSIONS

CO-OFDM WDM system has enormous capacity to enhance the reach and performance in terms of BER, Q-factor and OSNR.

1. As the transmission distance increases, there is requirement of Large OSNR to maintain the bit error rate i.e. 10^{-3}. In contrast, increase in OSNR will be responsible for increase the non linear effects in transmission channel.
2. DCF play an important role for increase the transmission distance.
3. WDM with CO- OFDM decreases the interference as increase in the channel spacing. This leads to improve the performance.
4. High modulation format (e.g. m-QAM/PSK) are also play a major role to improve the system performance.
5. WDM with CO- OFDM has high tolerance to chromatic dispersion and PMD.
6. WDM with CO- OFDM can achieve the extreme data rate i.e. more than 1Tbit/sec.

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Author' Biography

Sunil Kumar Dahiya received M.Tech Degree from Panjab University, Chandigarh, India in 2004. He worked as Engineer at "Continental Device India Limited, New Delhi", India from 2004-2008. He has been worked as Lecturer in Government Polytechnic, Nilokheri (Karnal) Haryana from 2009 to 2017. Presently, he is working as Assistant Professor at "State Institute of Engineering and Technology, Nilokheri (Karnal)", India since 2017. He is also Ph. D. Research Scholar at "DCR University of Science and Technology, Murthal (Sonepat)", India. His area of interest is Optical Communication and Wireless Communication. He has 9 years' experience in Teaching and 4years in industry. He has Life Time Membership of "The Institution of Engineers (INDIA)".(dahiyasunilk@rediffmail.com).