Modeling of OFDM based System with Optical Components for BW Reconfiguration

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ABSTRACT
In this paper, an optical network model is presented where ISI is reduced considerably. The input to the network is optical orthogonal frequency division multiplexed (OOFDM) signal. Optimization of all optical components in the network is done to reconfigure the bandwidth, to minimize the bit error rate (BER). While modeling, the advantages and disadvantages of OFDM system are considered to ensure minimum distortion. The transmitter in the proposed model consists of 16- Laser sources with frequency ranging from 193.035 THz to 193.785 THz; the channel spacing is set to 50 GHz. The optical signal is launched onto a 200 km fiber link. Along the fiber link, after 100 km, a 4- channel optical add drop multiplexer (OADM) is used to select and to add channels. The dropped channels are detected by the receiver with an appropriate electrical filtering. Erbium doped fiber amplifier (EDFA) is being used in the link. All three types of compensation techniques such as pre post and symmetric using dispersion compensation fiber (DCF) is employed to enhance the network performance.

General Terms
RSoft's- OptSim, Matlab and Simulink software's are used for modeling of optical transmitter and receiver using OFDM based optical networks in this paper.

Keywords
OOFDM, ISI, EDFA, SOA, DCF.

1. INTRODUCTION
Orthogonal frequency division multiplexing (OFDM) is a frequency division multiplexing scheme utilized as a digital multi-carrier modulation technique. OFDM has many advantages over other modulation techniques such as a high resistance to inter-symbol interference (ISI) and is robust against fading caused by multipath propagation. Optical fiber cable as a transmission media is used for distortion less transmission of data at a very higher data speed. OFC cable has a lot of advantages over other media and OFDM over OFC cable will provide data speeds at a very high speed and with very less losses. This paper is divided into 6 sections. The section 2 will discuss the theory of OOFDM, section 3 will focus on modeling of OOFDM network, section 4 will explain the simulation details of various optical components and optimization, in section 5 simulation results are presented. Finally section 6 will give the conclusion of research findings. Using orthogonal frequency division multiplexing (OFDM), conservation of bandwidth up to 50% is possible. This is great achievement in comparison with frequency division multiplexing (FDM).

2. FDM Vs OFDM
Orthogonal frequency division multiplexing (OFDM) is a modulation technique which is used in most new and emerging broadband wired and wireless communication systems because it is an effective solution to inter-symbol interference (ISI) caused by a dispersive channel [1] - [3]. To achieve good performance in optical system, OFDM must be adapted in various ways. The constraints imposed by single mode optical fiber, multimode optical fiber and optical wireless are discussed and the new forms of optical OFDM which have been developed and outlined. The difference between FDM and OFDM is depicted in "Figure 1". The main drawbacks of OFDM are its high peak to average power ratio (PAPR) and its sensitivity to phase noise and frequency offset [4], [5].

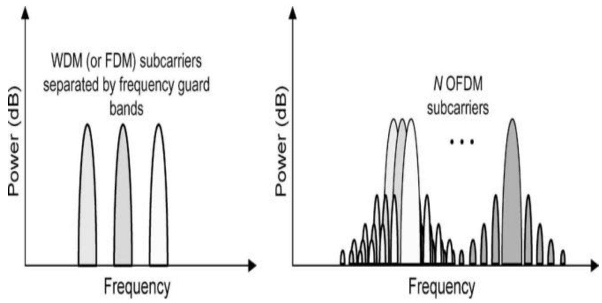

Fig 1: Spectrums of FDM and OFDM[4]

2.1 Optical OFDM for High-Speed Transmission
One of the main reasons for suitability of optical orthogonal frequency division multiplexing (OOFDM) for long-haul transmission is its ability to deal with large pulse spreads due to chromatic dispersion. As it will be shown in section 3, almost all operations except for those performed in a Mach-Zehender modulator (MZM), a distributed feedback laser (DFB) and a photo detector (PD) are performed in the RF domain. This is advantageous because microwave devices are much more mature than their optical counterparts and because the frequency selectivity of microwave filters and the frequency stability of microwave oscillators are significantly better than that of corresponding optical devices. The basic OOFDM transmitter and receiver configurations are given in "Figure 2" and "Figure 3" respectively. A serial-to-parallel converter (DEMUX) passes the information in sequence into blocks of B bits. The B bits in each block (frame) are subdivided into K subgroups with the i^{th} subgroup containing b_i bits,

$$B = \Sigma\, bi \qquad \ldots (1)$$

The bi bits from the i^{th} subgroup are mapped into a complex-valued signal point from a 2 bi- point signal constellation such is, e.g., quadrature amplitude modulation (QAM), which is considered in this paper. The complex-valued signal points from all K sub channels are considered as the values of the discrete Fourier transform (DFT) of a multicarrier OFDM signal. Therefore, the symbol interval length in an OFDM system is

$$T = K\, Ts \qquad \ldots (2)$$

where Ts is the symbol-interval length in a single-carrier system. By selecting K - the number of sub channels, sufficiently large, the OFDM symbol interval can be made much larger than the dispersed pulse-width in a single-carrier system, resulting in an arbitrary small inter-symbol interference [6] - [9].

3. OPTICAL OFDM NETWORK

An optical network consists of following components: optical transmitter, Modulator, optical amplifier, optical filter, optical receiver. The "Figure 2" and "Figure 3" shows the transmitter and the receiver employed in an optical OFDM network [10] - [12].

3.1 Optical Transmitter

The most commonly-used optical transmitters are semiconductor devices such as light-emitting diodes (LEDs) and light amplification by stimulated emission of radiation (Laser) diodes. Laser diode is being used in the simulation.

3.2 Optical Modulator

An optical modulator is a device, which is used to modulate a beam of light. The beam may be carried over free space, or propagated through an optical waveguide, depending on the parameter of a light beam which is manipulated, modulator may be categorized into amplitude modulator, phase modulator, polarization modulator etc. This sort of modulation called direct modulation, as opposed to the external modulation performed by a light modulator. The modulator shown in the transmitter module is Mach-Zehnder Modulator shown in "Figure 4".

3.3 Optical OFDM Modulator

There are several options to generate an optical OFDM signal. A popular technique shifts the electrical OFDM signal to an intermediate frequency (IF) and then uses it to drive a single MZ modulator [13], [14]. Another option is to use a quadrature MZ. A quadrature MZ modulates directly the baseband electrical OFDM signal to the optical domain without the need of an IF. Hence, this technique, sometimes called direct conversion reduces the required electrical bandwidth by a factor of two, at the expense of a more complicated modulator design [15], [16]. A conventional solution to the PAR problem is to reduce the operating range in the MZ to accommodate the OFDM peak.

3.3.1 Mach–Zehnder Modulator

If complementary drive signals are used, the transfer characteristic of a single-drive MZ modulator is :

$$\frac{E_{\text{out}}(t)}{E_{\text{in}}(t)} = \sin\left(\frac{\pi V_m(t)}{2V_\pi}\right) \qquad \ldots (3)$$

Where $E_{out}(t)$ and $E_{in}(t)$ are the output and input electric fields, respectively, $V_m(t)$ *is* the electrical modulator signal, and $V_\pi(t)$ is the voltage that must be applied to the single electrode to produce a differential phase shift of π between the two waveguides.

3.4 Optical OFDM Demodulator

At the receiver, each optical subcarrier is demultiplexed by an optical discrete Fourier transform (DFT), which consists of a splitter, optical delay lines, phase-shifters, an optical gate, and an optical coupler. This configuration allows low-cost direct detection transmitter and receiver modules to be used for subcarrier modulation and demodulation. In the electro-optical OFDM configuration, each optical subcarrier is modulated by a multi-carrier modulation technique, in which an optical IQ modulator is used to generate a multi-carrier signal around the optical subcarrier frequency. Electro-optical OFDM receiver is based on the digital coherent receiver configuration, the received OFDM signal is divided into several blocks by anti-alias filters in either optical or electrical domain, and each block is demodulated by an fast Fourier transform (FFT) based digital signal processing (DSP).

3.5 Optical Amplifier

An optical amplifier is a device that amplifies an optical signal directly, without the need to first convert it to an electrical signal. Optical Amplifier can be of as a LASER without an optical cavity, or one in which feedback from the

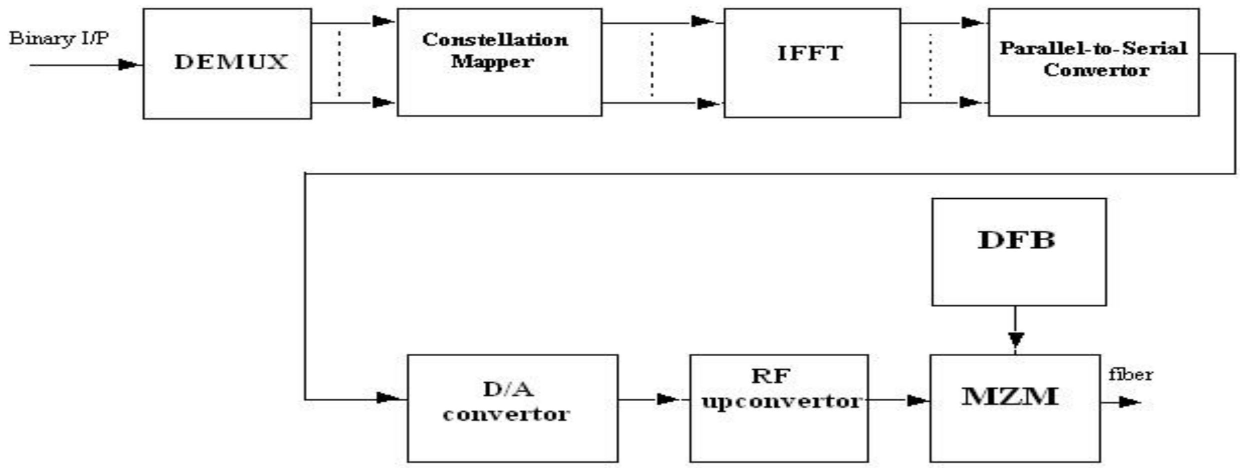

Fig 2: Block diagram of transmitter

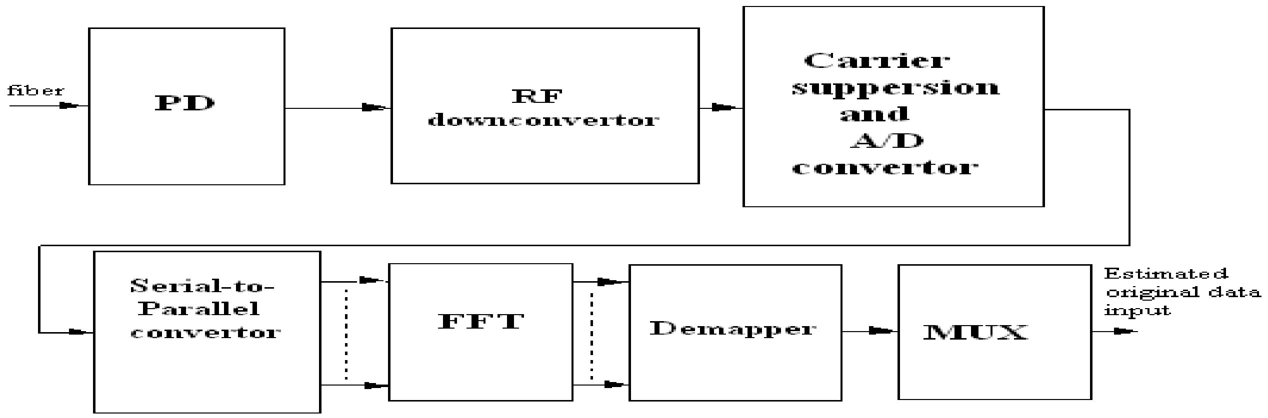

Fig 3: Block diagram of receiver

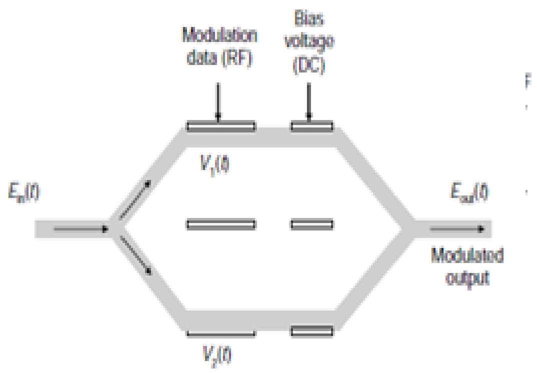

Fig 4: Mach–Zehnder modulator

cavity is suppressed. Several kinds of amplifiers have been developed, Semiconductor optical amplifiers (SOAs), Erbium-doped fiber amplifiers (EDFAs) are used most commonly for light wave systems, Raman fiber amplifiers work better for long-haul systems, fiber-optic parametric amplifiers are still at the research stage.

3.6 Optical Filter

Tunable optical filters are characterized primarily by their tuning range and tuning time. The tuning range specifies the range of wavelengths which can be accessed by a filter. An alternative to tunable filters is to use fixed filters or grating devices. Grating devices_typically filter out one or more different wavelength signals from a single fiber, used to implement optical multiplexers and demultiplexers or receiver arrays. The “Table 1” shows the tuning range of different filters. Fabry Perot filter is being used in the simulation.

Table 1. Performance of optical filters

Tuneable receiver	Approx. tuning range (nm)	Tuning time
Fabry-Perot	500	1-10 ms
Acousto-optic	250	10 µsec
Electro optic	16	1-10 ns
LC Fabry-Perot	30	0.5-10 µsec

3.7 Photodiodes

The photodiodes are basically of three types, p-n photo diode, p-i-n photodiode, avalanche photodiode (APD), metal–semiconductor–metal (MSM) photo detector PD is used in the simulation. At the receiver side three photodiodes are being used to convert the optical signal into electrical signal.

3.8 Optical Coupler- Combiner and Splitter

A coupler is a general term that covers all devices that combine light into or split light out of a fiber. A splitter is a coupler that divides the optical signal on one fiber to two or more fibers as shown in “Figure 5”. For a two-port splitter, the most common splitting ratio is 50:50, though splitters with any ratio can be manufactured. Combiners are the reverse of splitters, and when turned around, a combiner can be used as a splitter.

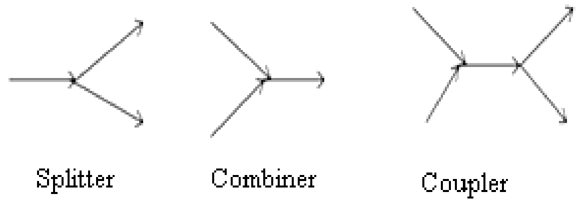

Fig 5: Coupler - splitter and combiner

4. OPTICAL OFDM SIMULATION

There has been extensive research on optimizing the placement of dispersion compensation fiber (DCF) along links, to mitigate the effects of fiber nonlinearity, allowing high transmission powers to give high signal to noise ratio with fewest optical amplifiers. A mixture of pre-compensation (DCF before the link), post-compensation (DCF after the link) and allowing a gradual build-up of dispersion by under compensating each amplifier span, has been found to be helpful in designing for ultimate performance, such designs require extensive simulation to optimize, which is usually performed for every different link length.

4.1 Model for Optical OFDM Transmitter

This compound component simulates an OFDM transmitter composed of: PRBS data source, SEPAR model to perform the conversion serial to parallel, MQAMODIQ model to generate the baseband I/Q components of QAM symbol, IFFT

OFDM to calculate the IFFT on the QAM symbol & obtain the OFDM symbol, QUADMIXIQ model to quadrature mix up the OFDM signal from baseband to carrier frequency.

4.2 Model for Optical OFDM Receiver

This compound component simulates an OFDM receiver composed of: QUADMIXIQ model to quadrature mix down the RF modulated OFDM signal to baseband, Two Bessel filters to filter out the replica of the signal centered at twice the carrier frequency, FFT OFDM model to calculate the FFT on the OFDM symbol to recover the QAM symbol, MQADEMIQ model to retrieve the parallel logical signal from the QAM symbol, PARSEV model to perform the conversion parallel to serial & restore the transmitted serial binary sequence.

5. RESULTS AND DISCUSSION

The basic input signal is as shown in “Figure 6”. This is the electrical signal, which is to be transmitted through the optical fiber link in order to study orthogonal frequency division multiplexing technique (OFDM). The signal when transmitted

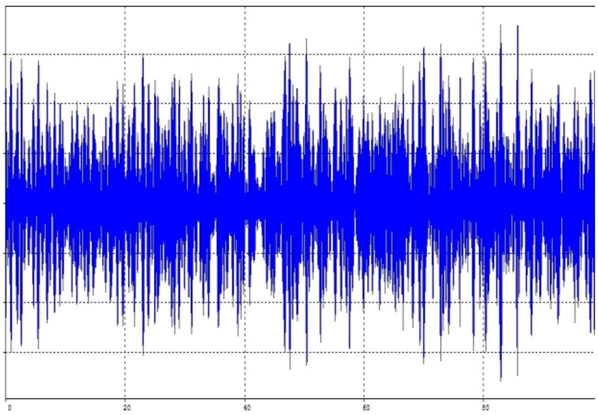

Fig 6: Basic input signal

goes through several losses which are overcome by using various optical network components. The main parameters which are taken into considerations optical spectrum of the signal and optical power spectrum in optical domain shown in “Figure 7” and “Figure 8”.The input of the signal is the PN sequence.

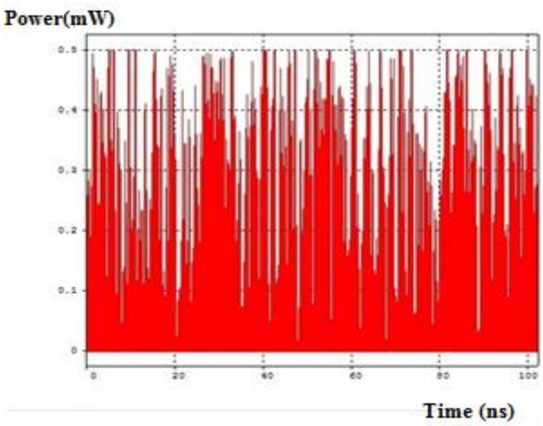

Fig 7: The power spectrum of the signal

It is observed before passing through the fiber. Its peak to peak amplitude is 0.5mw.

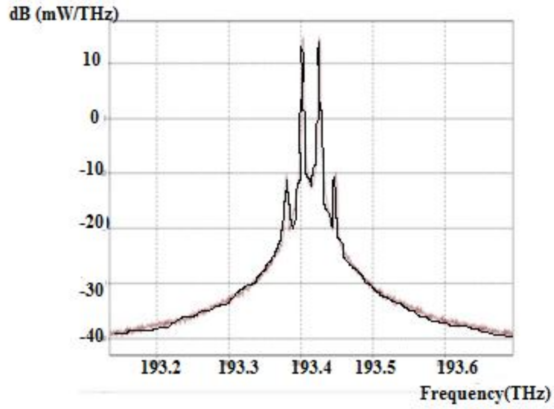

Fig 8: Optical spectrum of the signal before sending through the fiber.

Different dispersion compensation techniques such as pre, post and symmetrical methods for 10 Gb/s, non-return to zero (NRZ) links are simulated using standard and dispersion compensated fibers. This is to optimize high data rate optical transmission as shown in “Figure 9”, “Figure 10” and “Figure 11”.

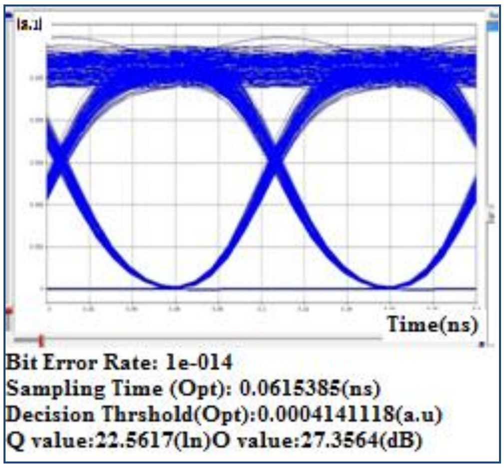

Fig 9: Post compensation eye diagram for 10 Gbps NRZ link

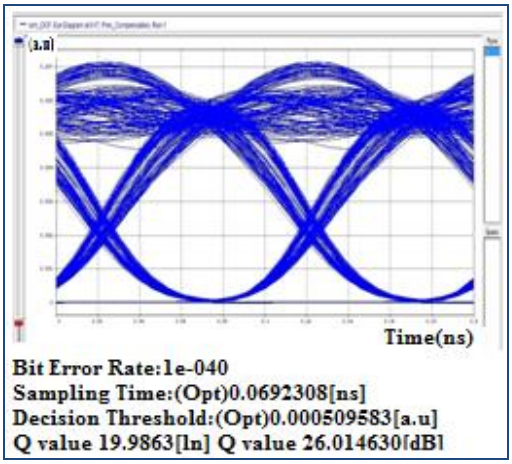

Fig 10: Pre compensation eye diagram for 10 Gbps NRZ link

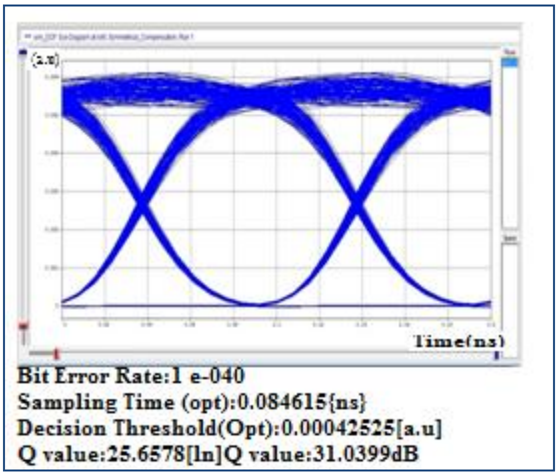

Fig 11: Symmetric compensation eye diagram for 10 Gbps NRZ link

After observing the eye diagram for all three compensation technique, for a fixed EDFA gain, a sequence length of 1024 bits, it is ascertained that symmetric compensation surpasses others in terms of eye closure penalty and bit error rate as shown in "Figure 12".

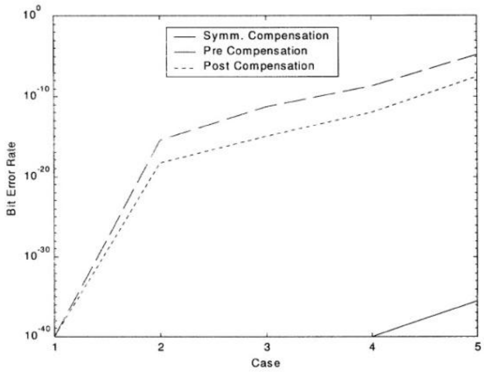

Fig 12: BER performance for all compensation techniques

The calculation of the propagation in the optical fiber is performed by standard split-step algorithm with adaptive step-size. The method illustrates optimization of high data rate optical transmission using dispersion compensated fiber. By varying the EDFA power, we realized that the fiber length required also changed. For post compensation is up to 288 km, whereas it is approximately up to 216 km for pre-compensation. The eye diagram and eye closure penalty also illustrate the same comparison results. Further, on varying the EDFA power and length of the fiber simultaneously, it is found that there is need of optimization between these two parameters. If the EDFA power is small, the length of the fiber should be small and if it is not so, the situation will deteriorate on account of more nonlinear effects.

5.1 Bandwidth Reconfiguration Using Optical Add Drop Multiplexer

10 GB/s, 16 - channels WDM system with a 4- channel optical add drop multiplexer (OADM) is added in the middle of the fiber link. The transmitter consists of 16- Laser sources with frequency ranging from 193.035 THz to 193.785 THz; the channel spacing is set to 50 GHz. The optical signal is launched onto a 200 km fiber link. Along the fiber link, after 100 km, a 4- channel OADM is used to select and to add channels. The dropped channels are detected by the receivers with an appropriate electrical filtering. The added channels are propagated together with the other ones and detected at the end of the fiber link. BER and Q values for the dropped channels and newly added channels are computed. The results are tabulated and shown in "Table 2". Finally the eye diagram for the dropped and added channel is computed. The added channel eye diagram shows maximum opening ensuring distortion less transmission. These results are depicted in "Figure 13" and "Figure 14".

Table 2. OADM performances

Channel	BER	Q - value
Channel 1	3.409 e^{-26}	20.72 dB
Channel 2 (dropped and added using AODM)	1 e^{-40}	25.51 dB
Channel 3	1.5266 e^{-19}	19.26 dB
Channel 4	1.01 e^{-19}	19.04 dB

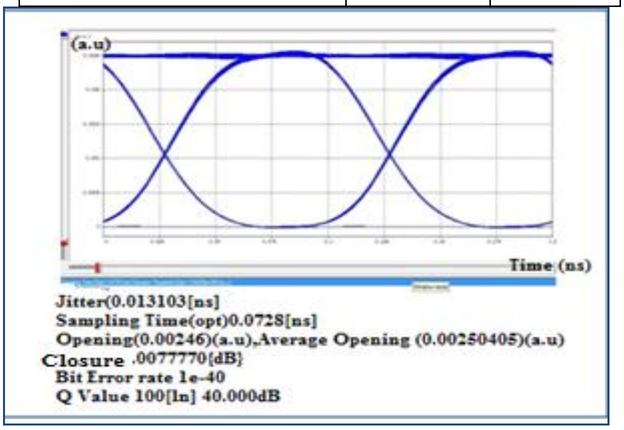

Fig 13: Eye Diagram for the added channel

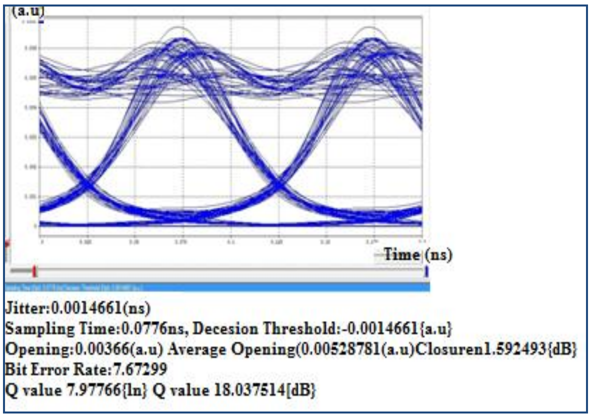

Fig 14: Eye Diagram for the dropped channel

From the above results OADM proves out to give better BER and Q value. OFDM, OOFDM with SOA and EDFA are simulated to obtain the power spectrum. The results shown in "Table 3" shows that insertion of EDFA along with power splitter and combiner gives a wide power spectrum enhances the link performance.

Table 3. Results obtained by using different optical components

Optical components	Power spectrum
Basic OFDM	0.5 mw (i/p)
	8.82 e^{-21} mw (o/p)
Using SOA	1.17 e^{-7} mw
Using splitter and combiner	5.58 e^{-17} mw
Using EDFA	0.27 mw
Using splitter, combiner and EDFA	0.00151 mw

We considered two types of modulation techniques DPSK and DQPSK and compared their performances. From "Table 4" we observe that, DPSK performs better.

Table 4. Comparison of DPSK and DQPSK

Parameter	DQPSK	DPSK
BER	4.6 e^{-8}	1 e^{-40}
Eye opening	105.1 a.u	0.00051 a.u.
Maximum peak to peak signal	412.6 a.u	0.000303a.u.
Minimum peak to peak signal	347.5 a.u	0.000661 a.u.

5.1.1 Remarks

While simulating the link, the driving voltage ($V\pi$) and its effect on the voltage bias, optical fibre losses at the input and at the output of the MZIM, signal to noise (SNR) generation within the MZIM, modeling of the non-linearity chirping of the MZIM, correct sampling of the formats, when outputting the eye diagrams for the required results.

5.1.2 Challenges

The difficulties have been resolved to produce an accurate model for various modulation formats such as: To measure the bit error rate of the MZIM, some of the measuring equipment has to be left for a long period of time until the result stabilizes actual polarization of the input optical strength; eye diagrams produced had unwanted noise from the optical fiber and from the system itself. This had made readings difficult to be analyzed, photo-detector required to convert optical signal to electrical signal can only operation between -5 dBm to 5 dBm. Therefore, experimental settings has to be precise to ensure that no damage is done to any equipment. Limiting our OptSim simulations to be within these values, input of the bit pattern generator has to be synchronized with the signal analyzer to produce the eye-diagram.

6. CONCLUSION

Optical OFDM is a promising technology, which is advantageous than wireless medium with EDFA, symmetric compensation technique and by the choice of suitable modulation technique, it is possible to obtain wide power spectrum, which means, we can reconfigure the bandwidth for higher data rate up to 1 Tbps. This will meet the growing internet traffic, digital audio broadcasting HDTV.

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