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NEXT GENERATION OPTICAL FIBER RESEARCH FOR THE ULTRA HIGH SPEED

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***Abstract*: The 'application 'of 'transmission 'through 'Optical 'Fiber 'is 'possible 'in 'each 'and 'every 'area 'where 'transferring 'of 'information 'is 'required 'from 'one 'location 'to the other. 'However, today's 'infrastructure 'of 'telecommunications 'relies 'on 'Data 'transmission 'through 'Optical 'Fibers, 'because 'of 'their 'low 'attenuation 'and 'higher 'bandwidth.**

Now 'a 'days 'the 'need 'of 'higher 'data 'rates 'of '100Gbit/s 'and 'above 'that 'has 'been 'increased 'in 'the 'metro, 'regional, 'enterprises, 'access 'and 'for 'long 'haul 'markets 'also. 'Therefore, 'it 'is 'the 'required 'to 'take 'the 'transmission 'systems 'to 'the 'next 'level 'to avoid the overloading of the Optical Infrastructure than 'its 'current 'capacity.

To fulfill 'increased 'demand 'of 'bandwidth 'in 'Broadband 'services 'one 'of 'the 'most 'trusted 'technology 'is 'Orthogonal 'Frequency 'Division 'Mulitplexing. '

Orthogonal 'Frequency 'Division 'Mulitplexing 'is 'becoming 'highly 'popular 'among 'the 'community 'of 'Optical 'Communication, 'specially 'for 'the 'features 'it 'provides 'in 'Long 'haul 'transmission 'Format 'in 'Direct 'and 'Coherent 'detection.OFDM 'is 'also 'considered 'for 'its 'ability 'to 'overcome 'many 'restrictions 'of 'Optical 'Fiber 'communication 'such 'as 'polarization 'mode 'dispersion '(PMD) 'and 'chromatic 'dispersion '(CD).However, 'integration of 'the 'coherent 'optical 'OFDM 'with 'Wavelength 'Division 'Multiplexing '(WDM) 'systems 'has 'advantages 'in 'the 'transmission 'system 'like '- 'higher 'bandwidth, 'a 'high 'spectral 'efficiency 'and 'significant 'data 'rates. 'Also 'the 'WDM 'systems 'can 'help 'to 'enhance ' 'data 'rate 'and 'capacity 'by using 'multiple 'wavelengths 'over 'a 'single 'fiber.

The Objective of this research is to focus on the implementation and to perform anlaysis of higher data rates using Direct and Coherent Optical OFDM for large distance transmissions. 'This 'study begins with a 'single 'user 'and then extends 'to 'the 'implementation 'of 'the 'OFDM - WDM 'system 'for achieving a transfer rate of 100Gbits/s. 'Optisystem 'simulation 'tool 'is 'used 'for 'design 'and 'implementation of 'the 'system. 'The 'system 'used is for 'carrying 'range 'of 'data 'starting 'from '10Gbits/s by using 'direct 'detection 'to '100Gbits/s when 'OFDM-WDM being used, 'the modulation type used is QAM 'for 'the 'OFDM 'signal, and at the transmitter I/Q modulation is deployed, while Coherent 'and Direct 'detection are 'used 'at 'receiver end. 'To study the System's Performance and Quality of Signal three parameters have been tested which are - Q Factor, the bit error rate and eye diagram.

***Keywords*: Direct Detection OFDM (DD-OFDM), Coherent Detection OFDM (CO-OFDM), Integration of WDM with CO-OOFDM for long haul high data rate transmission.**

DD-OFDM

The block diagram of DD-OOFDM system is shown below in Figure 3.5 which is having a DD-OOFDM transmitter and a DD-OOFDM receiver connected through a Optical Fiber.

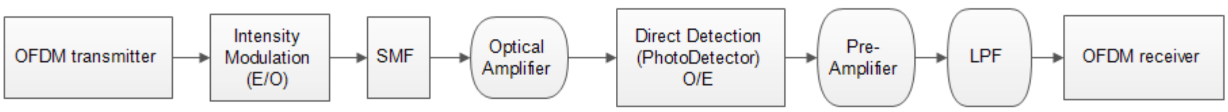

Figure 3.5 DD-OFDM Block Diagram

At Transmitter end, the OFDM electrical signal is produced by the OFDM transmitter which is converted up into the optical domain by using the electrical to optical(E/O) up converter which also does intensity modulation. The resulting optical signal is transmitted through the optical fiber and to compensate the loss within the Fiber an Optical Amplifier is used.

While at receiver end, the signal is converted back to electrical domain from the Optical domain by using the optical to electrical converter (O/E), which is a photo-diode.

And the received electrical signal is giving by:-

$$A_e(t) = |A_0(t)|^2 \otimes h_e(t) + w(t)$$

Where ($A_e(t)$) is the electrical signal at the receiver, $A_0(t)$ is the optical OFDM signal, $h_e(t)$ is the impulse response in the electrical domain, and w(t) is the system noise. After down converting, the signal will be amplified again and passes through a low-pass filter (LPF) and is transmitted to the OFDM receiver to get the original signal.

Coherent aOptical aOFDM a(CO-OFDM)

Figure 3.6 illustrates the CO-OFDM system. As can be seen, the CO-OFDM system is similar to the DD-OFDM system except for the real/imaginary (I/Q) modulator and the local oscillator. An optical local oscillator is used in optical coherent systems to generate optical signals at specific wavelengths. According to the frequency of the local oscillator, the optical coherent detection can be divided into two categories, heterodyne detection and homodyne detection.

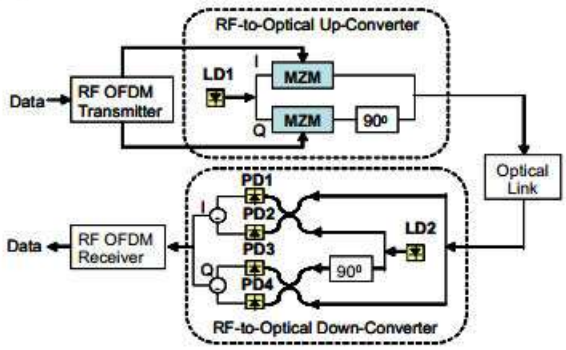

Figure 3.6 CO-OFDM Block Diagram

Heterodyne detection is where the local oscillator does not match the incoming signal frequency. At the photo-diode, when the two signals are mixed, a new frequency is generated. The new frequency is an intermediate frequency (IF) which is the difference between two frequencies. This technique will reduce the thermal noise and the shot noise which will lead to improved SNR performance. However, the optical source frequency tends to drift over time. As a result, the IF has to be regularly monitored, and the local oscillator must be changed to maintain the IF constant.

Homodyne detection which is used in this research is where the local oscillator frequency is matching the incoming signal.

The other component is I/Q modulator. The I/Q components of the digital signal are converted to an analog signal by two D/A converters at the transmitter. The I/Q modulator, which consists of two MZMs , up converts the complex OFDM signal to optical domain, and the modulated signal can be written

$$E(t) = x(t)\exp(j w_{LD1} t + \phi_{LD1}) \qquad 3.6$$

Where x (t) is the transmitted electrical signal, w, ϕ are the angular frequency and the phase of the transmitter laser diode respectively. The received signal is represented by

$$E_r(t) = E(t) \otimes h(t) + w(t) \qquad 3.7$$

Where h(t) is the channel response and w(t) is the channel noise. Then, the incoming signal is detected by two identical pairs of balanced coherent detectors and an optical 90º hybrid to perform the I/Q optical to electrical conversion. Each detector consists of two couplers and PIN photo-diodes. The output of the four 90º optical hybrid ports is given by

$$\begin{aligned} E_1 &= \frac{1}{\sqrt{2}}[E_s + E_{LD2}] \\ E_2 &= \frac{1}{\sqrt{2}}[E_s - E_{LD2}] \\ E_3 &= \frac{1}{\sqrt{2}}[E_s - jE_{LD2}] \\ E_4 &= \frac{1}{\sqrt{2}}[E_s + jE_{LD2}] \end{aligned} \qquad 3.8$$

Where Es, ELD2 are the incoming signal and local oscillator signal (LO) respectively. On the other hand, the In-Phase signal is recovered by using the two photo-detectors (PD1, PD2) whose photo-current can be given by

$$I_1 = |E_1|^2 = \frac{1}{2}\{|E_s|^2 + |E_{LD_2}|^2 + 2\mathrm{Re}\{E_s E_{LD_2}^*\}\}$$
$$I_2 = |E_2|^2 = \frac{1}{2}\{|E_s|^2 + |E_{LD_2}|^2 - 2\mathrm{Re}\{E_s E_{LD_2}^*\}\}$$
$$|E_s|^2 = |E_r|^2 + |n_o|^2 + 2\mathrm{Re}\{E_r n_o^*\}$$
$$|E_{LD_2}|^2 = I_{LD_2}(1 + I_{rin}(t)) \quad 3.9$$

Where LLD2, *I*rin(t) are the average power and relative intensity noise of the laser diode. Because of the balanced detection, the In-phase component of the photo-current becomes:

$$I_I = 2\mathrm{Re}\{E_s E_{LD_1}^*\} \quad 3.10$$

In the same way, the quadrature component from the other photo-detectors (PD3, PD4) can be derived as:

$$I_Q = 2\mathrm{Im}\{E_s E_{LD_2}^*\} \quad 3.11$$

From the equations (3.10) and (3.11) the complex photo-current

$$\tilde{I}(t) = I_I(t) + jI_Q(t) = 2E_s E_{LD} \quad 3.12$$

After completing the optical detection, the signal is transmitted to the OFDM receiver to extract the original signal.

Integration of WDM with CO-OFDM for long haul high data rate transmission

The wavelength division multiplexing (WDM) is an important factor in the development of optical fiber communication. It has the ability to provide more flexibility to the system and to simplify the design of the network. WDM technique multiplexes a number of optical carrier signals onto a single optical fiber by using different wavelengths or laser light. In optical OFDM, WDM helps to increase the capacity of the system and provide a significant increase in the data rate that is carried over a single fiber. This is by using multiple wavelengths, where each wavelength carriers a separate channel. WDM divides the optical spectrum to smaller channels, which are used to transmit and receive data simultaneously. Figure 4.36 shows the constellation diagram of 4-QAM.

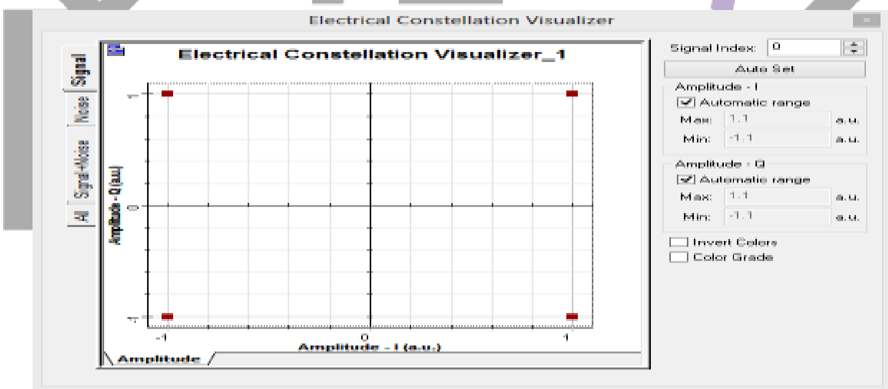

Figure 4.36 Constellation Diagram of 4-QAM

Figure 4.37 shows the system design of WDM CO-OFDM system with SMF-DCF of 120 km length. The CO-OFDM transmitter is built with a PRBS generator to generate a bit sequence; it is also built with 4-QAM (2 bit per symbol) encoder. The 4-QAM signal is connected to an OFDM modulator with a 512 subcarrier and 1024 FFT points. The In-phase (I) and quadrature (Q) of the resulting signal from the OFDM modulator is transmitted to the direct I/Q optical modulator which consists of two lithium Niobate (LiNbO3) Mach-Zehnder modulators (MZM). The optical modulator will modulate the electrical signal from the OFDM modulator to optical signal.

In order to support 100 Gbits/s four OFDM signals are needed, which means four OFDM receivers all have the same design and parameters. The exception is the optical carrier which has a laser wavelength which starts from 193.05 THz to 193.2 THz with a space of 50 GHz. The WDM system consists of four channels to support the four OFDM bands with channel space of 50GHz. Each OFDM signal has a 25 Gbps bitrate which will provide an overall data rate of a100Gbits/s.

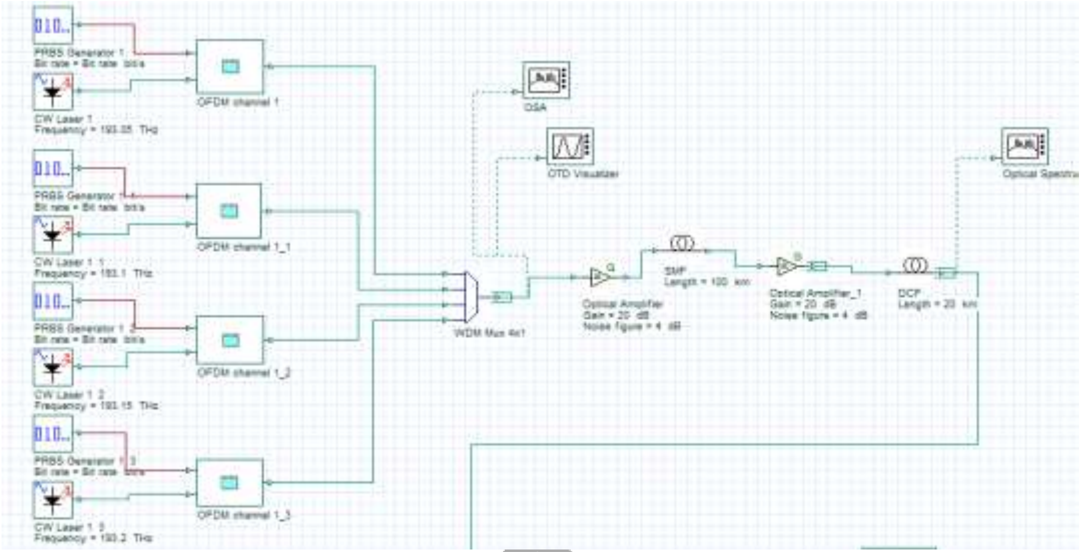

Figure 4.37 Block Diagram of WDM CO-OFDM System with SMF-DCF of 120km

The resulting signals from the OFDM transmitters are launched into the WDM MUX. The four different wavelengths are merged to produce one signal to be launched in the optical fiber. The resulting optical signal of the WDM MUX is then transmitted through the SMF-DCF system. The SMF attenuation is 0.2 dB/km and the DCF attenuation is 0.4 dB/km. The SMF dispersion is 16 ps/(km.nm) for 100km. SMF which will produce a dispersion of 1600 ps/nm. Therefore, to compensate for the dispersion of the 100km SMF, a 20 km long DCF is needed with dispersion of -80 ps/(km.nm) which will produce -1600 ps/nm. This dispersion is negative in order to cancel the positive dispersion of the SMF. An optical amplifier is used with 20 dB power to amplify the signal and to compensate for the loss. The parameters of SMF and DCF are given in tables 4.6 and 4.7.

The incoming optical signal from the optical link is separated into four wavelengths by the WDM DEMUX and each wavelength is detected by its receiver. Four receivers are designed to have the same parameters except for the center frequency of the receiver and the local oscillator which will be identical to the wavelength of the laser transmitter. Each receiver consists of two pairs of balanced coherent detectors with a local oscillator (LO) to perform the I/Q optical to electrical conversion and cancel the noise. Each detector consists of two couplers and two PIN photo-detectors. Each PIN photo-detector has a dark current of 10 nA, a responsivity of 1 A/W and thermal noise of 1×10^{-22} W/Hz. After detecting the signal, the signal is sent to the OFDM demodulator which has the similar parameters to the OFDM modulator. The guard interval is removed. Finally, the resulting signal is fed into a 4-QAM decoder to create a binary signal.

Table 4.6 SMF Parameters

Fiber length	100 (km)
Attenuation	0.2 (dB/km)
Dispersion	16 (ps/(km.nm))
Slope	0.08 (ps/(nm^2.k))
Effective Area	80(μm^2)
Nonlinear refractive index n_2	2.6×10^{-20}

Table4.7 DCF Parameters	
Fiber length	20 (km)
Attenuation	0.4 (dB/km)
Dispersion	-80 (ps/(nm.km)

Slope	0.45(ps/(nm^2.k))
Effective Area	30 (μm^2)
Nonlinear refractive index n_2	2.6×10^{-20}

SIMULATION AND RESULT

100Gbits/s WDM CO-OFDM System Simulation Results and Discussion

Figure a4.38 shows the RF spectrum of the I/Q component of the CO-OFDM WDM system at the transmitter side. The RF power is measured at almost -16 dB. Figure 4.39 shows the RF spectrum of the I/Q component of the CO-OFDM WDM system at the receiver side. The RF power is decreased to almost -39 dB compared with figure 4.38.

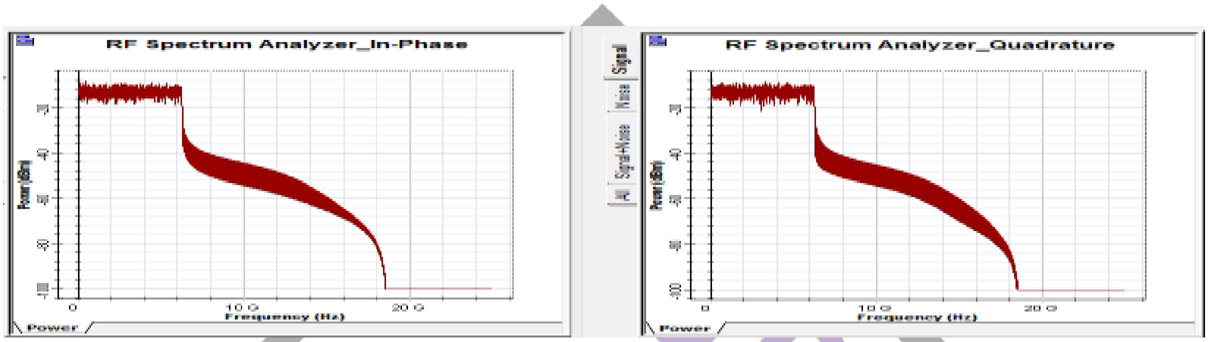

Figure 4.38 RF OFDM Spectrum I/Q Component at the CO-OFDM Channel

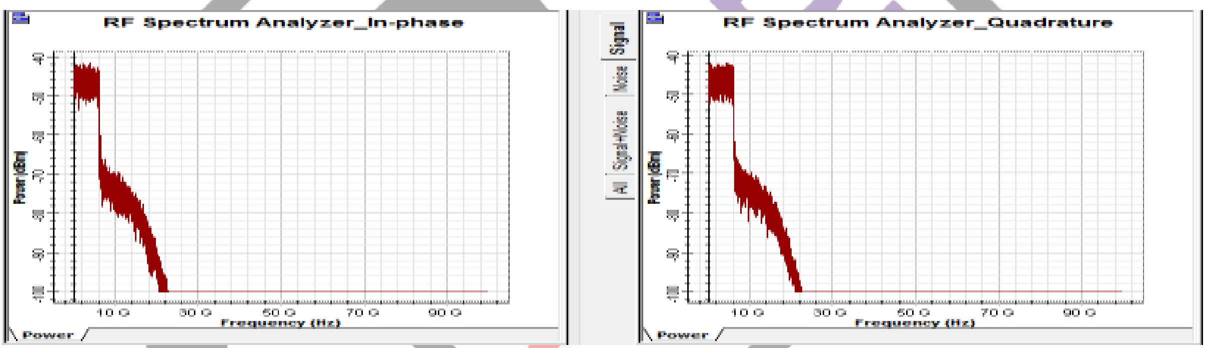

Figure 4.39 RF OFDM Spectrum I/Q Component at the CO-OFDM Receiver

Figure 4.40 shows the four OFDM spectrums after the WDM system. Four WDM channels start 193.05 THz to 193.2 THz with channel spacing of 50 GHz.

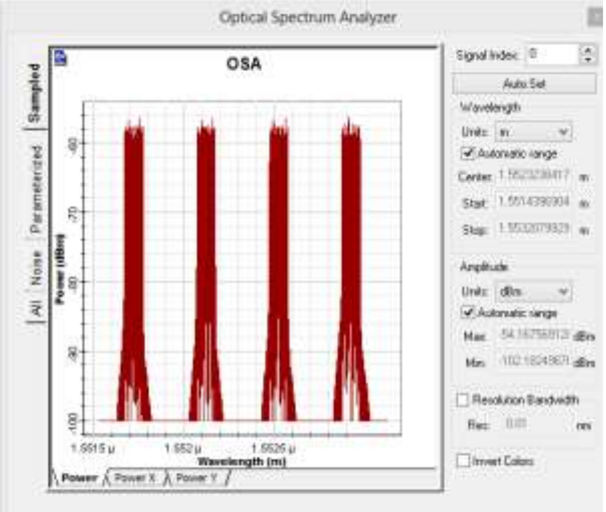

Figure 4.40 4- OFDM Signal after the WDM Channels

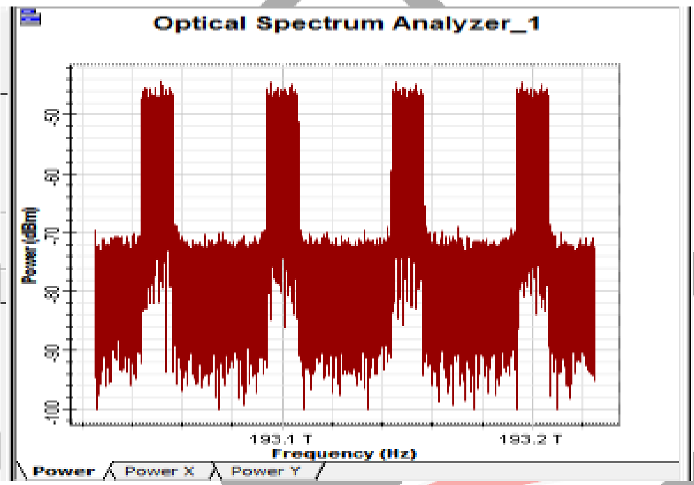

Figure 4.41 4-OFDM Signal after SMF-DCF Optical Link of 120km

Figure 4.42 illustrate the constellation diagram of the 4-QAM OOFDM signal at the receiver after SMF-DCF optical link. As can be seen from the graph, the red points represent the signal and the blue points represent the noise. Clearly, the signal is recovered after removing the chromatic dispersion from the optical fiber.

Figure 4.43 illustrate the constellation diagram of the 4-QAM OOFDM signal at the receiver after SMF-DCF optical link. As can be seen from the graph, the red points represent the signal and the blue points represent the noise. Clearly, the signal is recovered after removing the chromatic dispersion from the optical fiber.

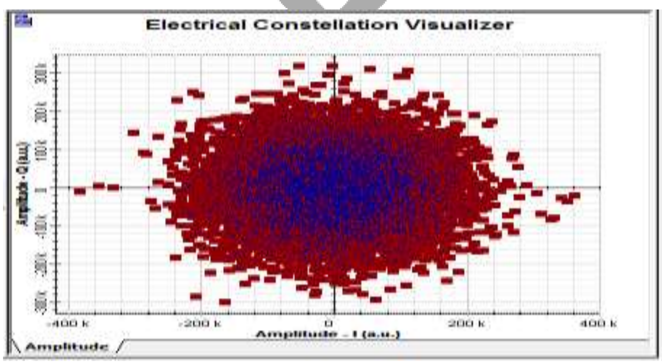

Figure 4.42 The Constellation of 100Gbps WDM CO-OFDM System after 120km

After designing the system, Q factor, bit error rate and eye diagram were tested to study the performance of the system and the quality of the signal. These parameters are shown in figures 4.43, 4.44 and 4.45, respectively.

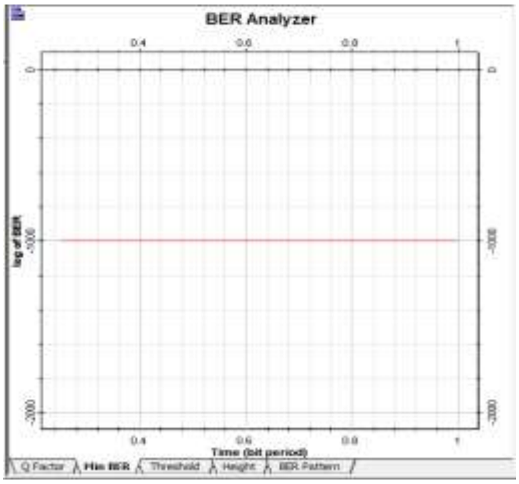

Figure 4.43 BER for Transmission Length of 120 km SMF-DCF Optical Link

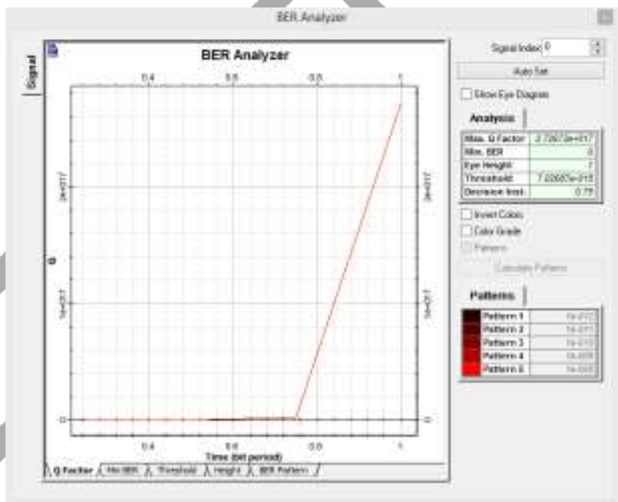

Figure 4.44 Q Factor

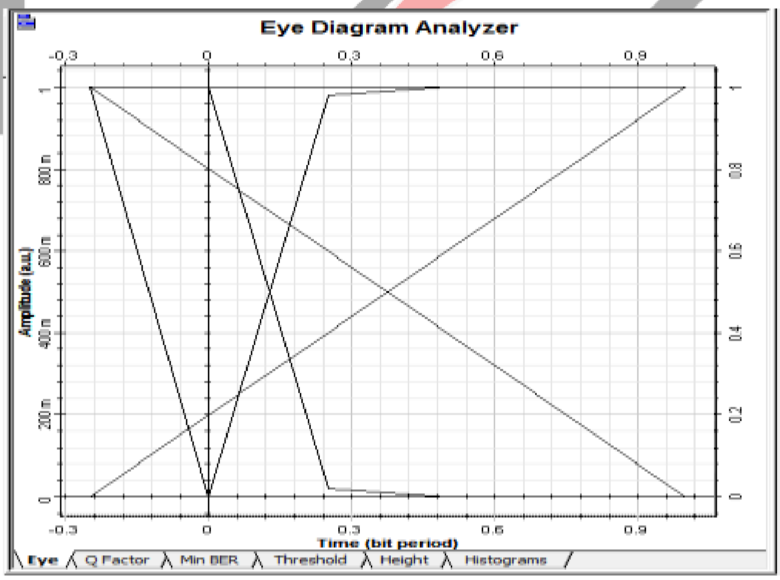

Figure 4.45 Eye Diagram for a Transmission Length of 120km SMF-DCF Optical Link

Table 4.8 gives the signal details at the Receiver for 100Gbits/s WDM CO-OFDM system.

Table 4.8 Signal Details at the Receiver for 100Gbits/s

Signal details at the receiver	
Max.Q Factor	2.7363×10^{17}
Min. BER	0
Eye Height	1
Threshold	7.02799×10^{-15}
Decision Inst	0.75

CONCLUSION

In this research three different systems were modeled for different data rates using direct and coherent OFDM detection. The first project was DD-OFDM, 7.5GHz frequency carrier is used in this system. The data rate was 10Gbits/s with modulation type of 16-QAM, 256 subcarrier and 512 FFT points, this system investigate different transmission links. In this system, it has been found that as the transmission length increases the Q-factor decreases with a lower value of BER. The best value of BER was zero.

The second project was CO-OFDM system with SMF, the data rate was 40Gbits/s with 16-QAM modulation type, 512 subcarrier and 1024 FFT points. The length of the transmission link was 150km. This system was designed and simulated to achieve the best value of BER which was zero.

The final project was WDM CO-OFDM with 120km SMF-DCF transmission link. In WDM system, 4 channels of 25Gbits/s 4-QAM OFDM signals were transmitted, the carrier wave frequencies were set from 193.05THz to 193.2THz with 50GH channel spacing, 512 subcarrier and 1024 FFT points. This system was designed and simulated to achieve the best value of BER which was zero.

In DD-OFDM, a photo-diode is used to perform the optical to electrical conversion, while in CO-OFDM detection, two identical pairs of balanced coherent detectors with a local oscillator (LO) is used to perform the I/Q optical to electrical conversion. Direct detection optical OFDM aims for simpler transmitter or receiver than CO-OFDM for lower costs. DD-OFDM has an advantage that it ais more immune to impulse clipping noise.

However, it can be seen that Coherent Optical OFDM (CO-OFDM) is considered the next generation technology for the optical communications rather than the DD-OFDM, since it integrates the advantages of both coherent systems and OFDM systems. It has the ability to overcome many optical fiber restrictions such as chromatic dispersion (CD) and polarization mode dispersion (PMD). Above all, integrating the coherent optical OFDM with Wavelength Division Multiplexing (WDM) systems provide a transmission system with a high bandwidth, a significant data rates, and a high spectral efficiency without increasing the cost or the complexity of the system. Integration of CO-OFDM and WDM has been proposed as a solution for the increased demand in bandwidth and the data rates.

Recently, it has been proved by many researchers that OFDM is better compared to the conventional single carrier modulation for long haul optical transmission.

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