

**People's Democratic Republic of Algeria**  
**Ministry of Higher Education and Scientific Research**  
**University M'Hamed BOUGARA – Boumerdes**



**Institute of Electrical and Electronic Engineering**  
**Department of Electronics**

Final Year Project Report Presented in Partial Fulfilment of  
the Requirements for the Degree of

**MASTER**

**In Electrical and Electronic Engineering**  
**Option: Telecommunications**

Title:

**Study and Simulation of the Optical  
Impairments in a CO-OFDM/RoF  
System**

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# *Acknowledgements*

In the name of Allah, Most Gracious, and Most Merciful, We would like to thank many people who have made my master project possible. First and foremost we would like to express our sincere appreciate to our supervisor, Mr. **A. ZITOUNI** , for being a dedicated mentor as well as for his valuable and constructive suggestions that made this project to run smoothly.

Special thanks go out to **Mr. M. Boumedién** for their expert help and recommendations.

Finally, we would like to thank all whose direct and indirect support helped us achieving our thesis in time.

## *Dedication*



*This work is dedicated to the soul of my friend “BELAGHIT Bachir” May God grant mercy on his soul.*

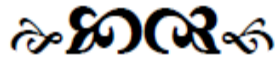
*To my family*

*To my mother for her encouragement;  
To my father for his support throughout my studies.*

*I also dedicate this project to*

*To my partner, SADALI Soraya for her invaluable friendship and patience throughout completion of this work.*

*ANBAR lahcene*



*This work is dedicated to the soul of my grandfather “EL HADJE SADALI Mohand Ouidir” May God grant mercy on his soul.*

*To my family*

*To my mother for her encouragement;  
To my brother Samir for his support throughout my studies.*

*I also dedicate this project to*

*All my brothers, sisters and friends for the support and advice you have given me throughout my studies.*

*To my partner, Anbar Lahcene for his invaluable friendship and patience throughout completion of this work.*

*SADALI Soraya*

## **Abstract**

One of the most advanced and attracting technologies in optical fiber communication systems that support efficient convergence of wireless and optical access network structure is Radio over Fiber (RoF). In RoF, light is modulated by using a radio signal and sent over an optical fiber link to simplify wireless access. As the demand for high-speed wireless communications is increasing rapidly, Coherent Optical Orthogonal Frequency Division Multiplexing (CO-OFDM) technology is considered to be a fundamental technique to satisfy this need.

The aim of this project is to investigate through simulation the impairments due to the integration of CO-OFDM with RoF for achieving high data rates over long haul optical fiber systems.

Solutions to combat the attenuation as well as the dispersion effects on such systems have been proposed and tested.

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## List of abbreviations

- ADC:** Analog to Digital Converter.
- BER:** Bit Error Rate.
- CWDM:** Coarse Wavelength Division Multiplexing.
- CP:** Cyclic Prefix.
- CO-OFDM:** Coherent Optical OFDM.
- CD:** Chromatic Dispersion.
- CFBG:** Chirped Fiber Bragg Grating.
- DWDM:** Dense Wavelength Division Multiplexing.
- DCF:** Dispersion Compensation Fiber.
- CW:** Continuous Wave.
- DFT:** Discrete Fourier Transform.
- DD-OOFD:** Direct Detection Optical OFDM.
- DEMUX:** De-multiplexer.
- DAC:** Digital to Analog Converter.
- DAB:** Digital Audio Broadcasting.
- DVB:** Digital Video Broadcasting.
- E/O:** Electrical to Optical Converter.
- EDFA:** Erbium Doped Fiber Amplifier.
- FDM:** Frequency Division Multiplexing.
- FWM:** Four-Wave Mixing.
- FBG:** Fiber Bragg Grating.
- IQ:** In-phase and Quadrature-phase.
- ISI:** Inter-Symbol Interference.
- ICI:** Inter Carrier Interference.
- IFFT:** Inverse Fast Fourier Transform.
- LAN:** Local Area Network.
- LTE:** Long Term Evolution.
- LED:** Laser Emitting Diode.
- LPF:** Low-Pass Filter.
- MMF:** Multimode Fiber.

**MUX:** Multiplexer.

**MCM:** Multicarrier Modulation.

**MAN:** Metropolitan Area Network.

**MZM:** Mach-Zehnder Modulator.

**OFDM:** Orthogonal Frequency Division Multiplexing.

**OSNR:** Optical Signal to Noise Ratio.

**O/E:** Optical to Electrical Converter.

**PSK:** Phase Shift Keying.

**PAPR:** Peak-to-Average Power Ratio.

**PMD:** Polarization Mode Dispersion.

**PAN:** Personal Area Network.

**PRBS:** Pseudo Random Binary Sequence.

**PD:** Photo Diode.

**QPSK:** Quadrature Phase Shift Keying.

**RF:** Radio Frequency.

**SMF:** Single Mode Fiber.

**SPM:** Self-Phase Modulation.

**SRS:** Stimulated Raman Scattering.

**SBS:** Stimulated Brillouin Scattering.

**TDM:** Time Division Multiplexing.

**WDM:** Wavelength Division Multiplexing.

**WLAN:** Wireless Local Area Network.

**WiMAX:** Worldwide Interoperability for Microwave Access.

**XPM:** Cross-Phase Modulation.

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## INTRODUCTION

Fiber optic networks are an integral part of nowadays digital communication system. In these networks, typical distances are linked together, and information is transferred at extremely high data rates. As the demands for capacity increases, finding new methods for cost effective long-haul transmission systems that can be used to increase the capacity becomes of high interest.

Orthogonal frequency division multiplexing (OFDM) is a widely used modulation and multiplexing technology, which is now the basis of many telecommunications standards including wireless local area networks (LANs), digital terrestrial television (DTT) and digital radio broadcasting in much of the world.

Orthogonal Frequency Division Multiplexing (OFDM) has grown to be the most popular communications systems in high speed communications, (OFDM) is a multicarrier transmission technique, which divides the bandwidth into many carriers and uses the spectrum much more efficiently by spacing the channels much closer together.

The Coherent optical orthogonal frequency-division multiplexing (CO-OFDM) has been extensively studied because of its advantages such as high spectral efficiencies, low required sampling rates, and flexible bandwidth scalability and allocation.

The transmission of microwaves and millimeter-waves through optical fibers for a long haul distance demand a high technics to archives this operation. The RoF links is such a technics that satisfies this transmission.

The scope of this thesis is on the design and the simulation of the OFDM in optical RoF communication using Optisystem v13. The report is organized as follows:

**Chapter 1:** this chapter is dedicated to introduce the OFDM system and optical fiber. So in the first part of this chapter, a historical perspective of OFDM is presented, and then discussed the OFDM signal, Orthogonality and OFDM system description we finish this part with the advantages and disadvantages of OFDM, the second part of this chapter provides a description for Optical Fiber communication system, including its basic units description. We finish this chapter with DCF technics of compensation.

**Chapter 2:** Describes Different blocks of OFDM system, its functions, and its components in the software.

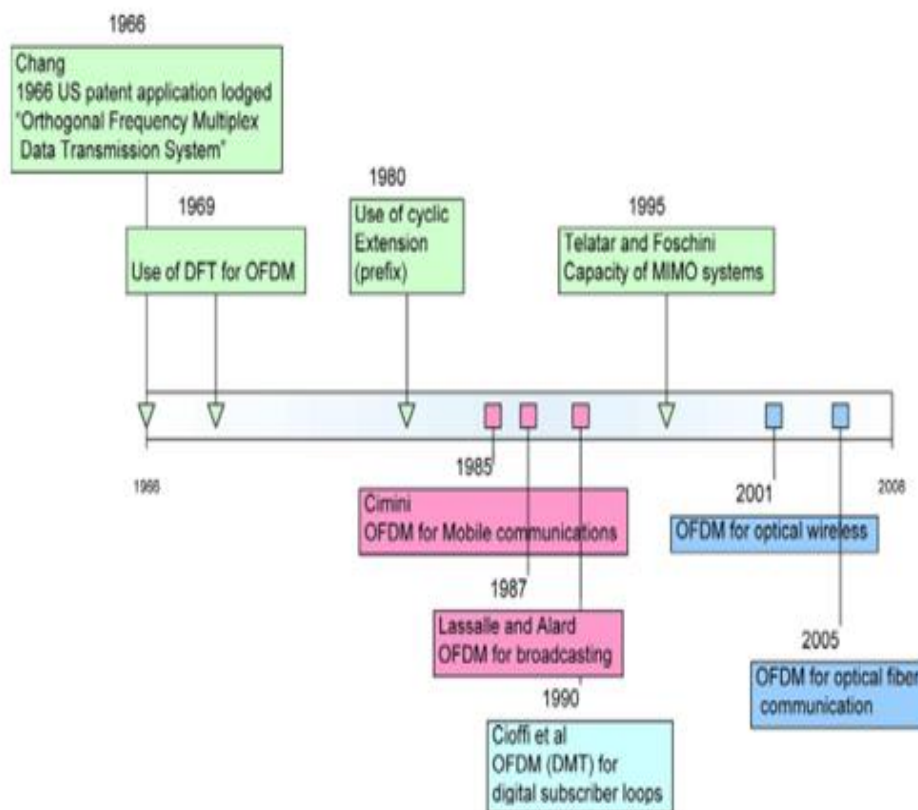
**Chapter 03:** In this chapter we work on the simulation and centering on the constellation diagrams results and how can we correct the distortion on it using ether the EDFA and the DCF technics.

**Conclusion:** General conclusion and future work.

## I.1 OFDM:

### I.1.1 OFDM history:

OFDM plays a significant role in the modern telecommunications for both wireless and wired communications. The history of frequency division multiplexing (FDM) began in 1870s when the telegraph was used to carry information through multiple channels. The fundamental principle of orthogonal FDM was proposed by Chang as a way to overlap multiple channel spectra within limited bandwidth without interference, taking consideration of the effects of both filter and channel characteristics. Since then, many researchers have investigated and refined the technique over the years and it has been successfully adopted in many standards. All those evolutions are shown in **figure I.1[2]**:



**Figure I.1:** Historical evolution of OFDM.

### I.1.2 Types of Multiplexing:

Different types of multiplexing are used in communication, the following two major multiplexing techniques are:

- Frequency division multiplexing
- Wavelength division multiplexing

#### Frequency Division Multiplexing:

Frequency division multiplexing is applied when the bandwidth of the link is greater than the combined bandwidth of the signals to be transmitted.

In this type of multiplexing, signals are generated by sending different device-modulated carrier frequencies, and these modulated signals are then combined into a single signal that can be transported by the link. To accommodate the modulated signal, the carrier frequencies are separated with enough bandwidth, and these bandwidth ranges are the channels through which different signals travel. These channels can be separated by unused bandwidth. Some of the examples for the time division multiplexing include radio and television signal transmission.

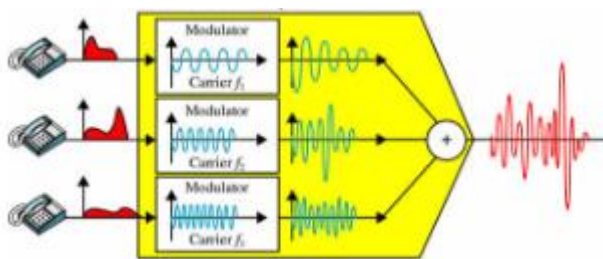


Figure I.2: frequency division multiplexing [2]

#### Wavelength Division Multiplexing:

wavelength-division-multiplexing (WDM) is a technology which multiplexes a number of optical carrier signals onto a single optical fiber by using different wavelengths (i.e., colors) of laser light.

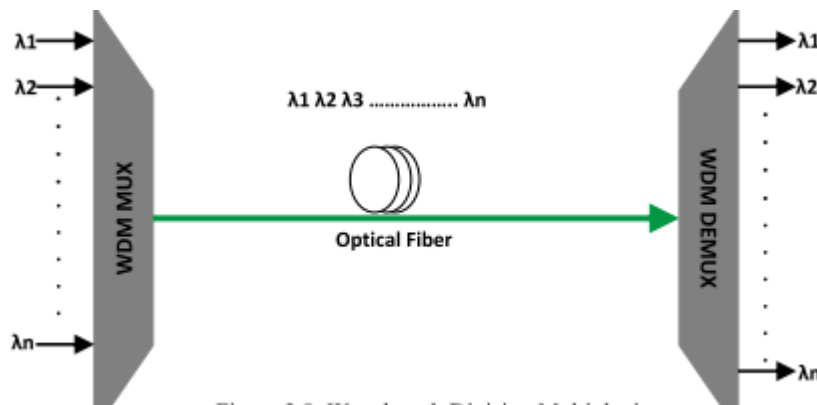
This technique enables bidirectional communications over one strand of fiber, as well as multiplication of capacity. For the high capacity communication systems, wavelength division multiplexing is the most promising concept. This system uses:

- **Multiplexer at transmitter to join signals**
- **De-multiplexer to split the signals apart at the receiver end.**

The purpose of WDM is to combine multiple light sources into a single light source at the multiplexer and at the de-multiplexer the single light is converted into multiple light sources.

WDM is designed to use the high data rate capability of the fiber optic cable. The data rate of this cable is higher than the metallic transmission cable's data rate. Conceptually, the wavelength division multiplexing is same as the frequency division multiplexing, except for The transmission through the fiber optic channels where in the multiplexing and de-multiplexing involves optical signals.

In WDM multiple optical carriers at different wavelengths are modulated by using independent electrical bit streams and are then transmitted over the same fiber. It increases the information carrying capacity of a fiber.



**Figure I.3: wavelength division multiplexing [2]**

#### Advantages:

- It has greater transmission capacity.
- Duplex transmission.
- Simultaneous transmission of various signals.
- Easy system expansion.
- Faster access to new channels.

The different types of WDM MUXS and DEMUXS: Depending on the wavelength spacing, WDM, MUXS and DEMUXS are classified into three types:

- Broad band WDMS (B WDM) they combine and separate 1310 and 1510 nm channels or even 850nm and 1310 nm channels.
- Narrow band WDMs (NWDM): they combine and separate wavelength channels with center to center spacing greater than 200 GHz.
- Dense WDMs (DWDMs): they combine and separate wavelength channels not more than 200 GHz.

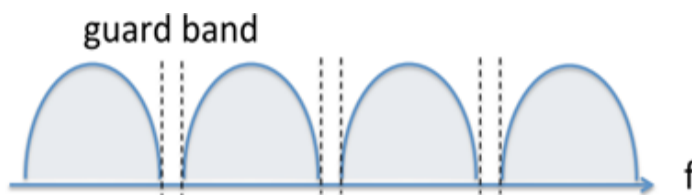
Most WDM systems operate on single-mode fiber optical cables, which have a core diameter of  $9\ \mu\text{m}$ . certain forms of WDM can also be used. Early WDM systems were expensive and complicated to run. However, recent standardization and better understanding of the dynamics of WDM systems have made WDM less expensive to deploy. WDM systems are divided into different wavelength patterns:

- Coarse (CWDM)
- Dense (DWDM)

### I.1.3 OFDM operations:

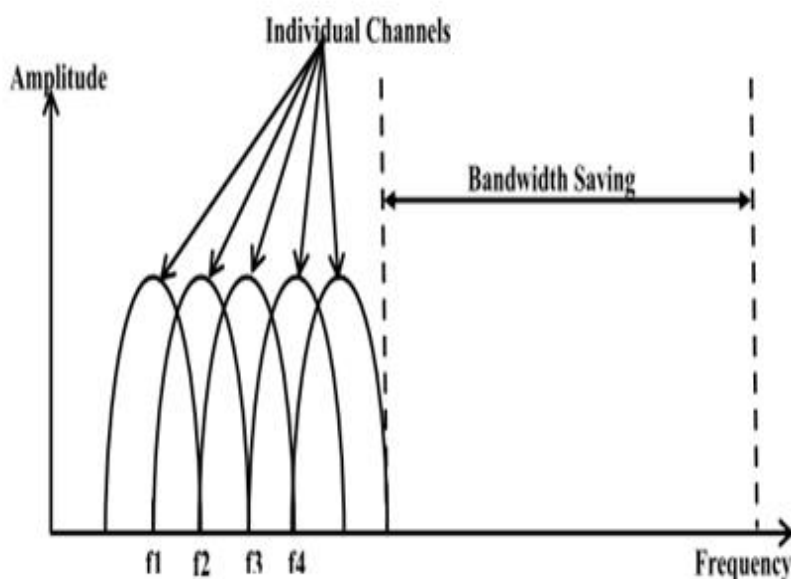
#### ❖ FDM to OFDM:

FDM is a technique where the main signal to be transmitted is divided into a set of independent signals, which are called subcarriers in frequency domain. Thus, the original data stream is divided into many parallel streams (or channels). Each subcarrier is then modulated with a conventional modulation schema and then they are combined together to create the FDM signal.



**Figure I.4:** FDM spectral [2]

if the subcarrier signals fulfill the orthogonality condition their spectrum can overlap, improving the spectral efficiency. This technique is known as orthogonal FDM or OFDM.



**Figure I.5:** Spectrum of an OFDM symbol with overlapping subcarriers[2].

OFDM is actually a modified version of frequency Division Multiplexing (FDM) .In the FDM technique ,different information for different users is transmitted at the same time over different frequency carriers shown in figure1.2.At the transmitter each subcarrier is set with wide guard band after it is modulates by the user's data to prevent it from overlapping with the adjacent subcarriers. However; this guard band will reduce the spectral efficiency of the system. The received signals at the receiver are then demodulated by oscillator banks

### Orthogonality:

The concept of Orthogonality is that the energy caused by the interference of the subcarriers becomes zero exactly at the central frequency of the others. If the spacing between the carriers is a multiple of 'N/T', where N is an integer than the carriers can be orthogonal.

In normal FDM (Frequency division multiplexing), guard band is used so that the subcarriers cannot overlap and to avoid ISI [1]. But in OFDM due to orthogonality, even if the subcarriers overlap, still the signals can be received without any interference.

OFDM due to the orthogonality property is preferred over other modulation techniques because it is resistant to ISI and Frequency selective fading.

Each OFDM symbol has a duration  $T_s=N/R$  . Hence, the OFDM signal in the time  $f_k$  domain  $s(t)$  can be expressed as a summation of each information symbol  $S_k$  being carried in the  $k$ th subcarrier within the  $i$ th OFDM symbol as illustrated in the equation 1 and 2 below:

$$S(t)=R\{\sum_{i=-\infty}^{\infty} \sum_{K=0}^{N-1} 1C_{i,k}e^{j2\pi f_k t} *P(t-iT_s)\} \quad (I.1)$$

Where  $P(t)$  is an ideal square pulse of length  $T_s$  ,

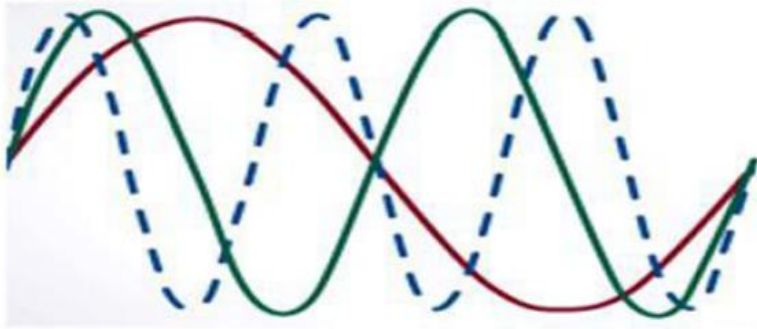
$N$  :the number of subcarriers

$f_k$  :the subcarrier frequency. This frequency has to fulfil the orthogonality condition  $f_k =1/T_s$

This means that each subcarrier must be separated from its neighbours by exactly  $1/T_s$  so each subcarrier within an OFDM symbol has exactly an integer number of cycles in the interval  $T_s$  , and the number of cycles differs by exactly one, as depicted in Figure I.4. This way, orthogonality between subcarriers is achieved. This property can be explained for any couple of subcarriers by the following expression:

$$\int_{-T/2}^{T/2} \cos\left(\frac{2\pi mt}{T}\right) \cos\left(\frac{2\pi nt}{T}\right) dt = 0 \quad , \quad m \neq n \quad (I.2)$$

If  $m$  and  $n$  are different natural numbers, the area under this product over one period is zero. The frequencies of these waves are called harmonics and for them the orthogonality condition is always fulfilled.



**Fig I.6.:** Time domain subcarriers within an OFDM symbol[2]

Figure I.6 shows three subcarriers from one OFDM symbol in a time domain representation. In this example, all subcarriers have the same phase and amplitude, but in practice the amplitudes and phases may be modulated differently for each subcarrier.

Note that each subcarrier is centred at  $fk$  and separated by  $1/T_s$  from its neighbours. When this happens, the orthogonality condition is being fulfilled so a great spectral efficiency for the transmission is achieved. This way, the subcarriers can be recovered at the receiver without intercarrier interference (ICI) despite strong signal spectral overlapping by means of the orthogonality condition (I.2) using a bank of oscillators and low-pass filtering for each subcarrier.

### I.1.4 OFDM Parameters

Designing an OFDM transmission system implies optimization of OFDM parameters: FFT size, Number of sub carriers, Constellation Diagram size, Cyclic Prefix and Guard Period.

There is no right way of deciding these parameters. The best settings values for this parameters are those which result in low BER values. In this work, many simulations were done to find the optimal OFDM parameters for fiber optic applications.

#### I.1.4.1 FFT size

The FFT size determines the number of available subcarriers for the OFDM symbol. All of the subcarriers can be used for data transmission, but some are zero padded and some are used as pilot tones. Zero padding is done to mitigate the influence of inter symbol interference (ISI). The preallocated subcarriers for pilot tones are used for synchronization purpose and phase estimation. The number of pilot tones and zero paddings are also adjustable parameters for the OFDM symbol generation.

#### I.1.4.2 Number of sub carriers:

The maximum number of carriers used by OFDM is limited by the size of IFFT. This is determined as per the equation (3) and (4) shown below [3]:

$$N \text{ carriers} \leq (\text{IFFT size} / 2) - 2 \text{ (real valued time signal)}$$

$$N \text{ carriers} \leq (\text{IFFT size} / 2) - 1 \text{ (complex valued time signal)}$$

Both IFFT size and assignment (selection) of carriers can be dynamic. The transmitter and receiver just have to use the same parameters. This is one of the advantages of OFDM.

### I.1.4.3 Constellation Diagram size

The QAM size is usually determined by the noise tolerance of the transmission. For transmissions with low noise, high QAM constellations can be selected for the OFDM symbol.

A constellation diagram is a two dimensional representation of a signal after it is modulated using digital modulation schemes such as: PSK or QAM. The modulated signal symbols are mapped as points in the complex plane. The y-axis represents the imaginary part of the symbols and the x-axis represents the real part. Constellation diagrams can be used to identify the distortion that occurs in the signal and determine the type of interference. Each different modulation scheme has a different format of constellation diagram.

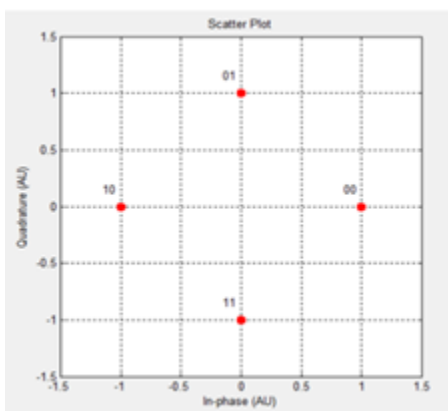


Figure a) QPSK constellation[2]

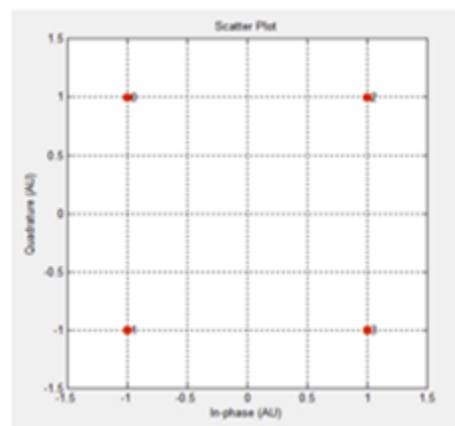
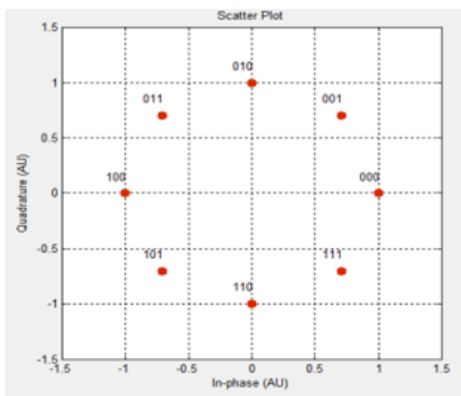
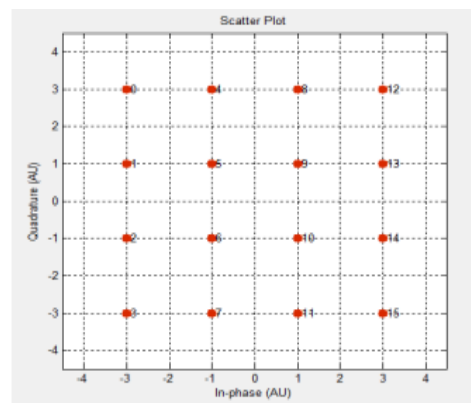


Figure b)QAM constellation[2]



c)8-PSK constellation diagram[2]



d)16 QAM constellation diagram[2]

Fig I .7:constellation diagrams

Figure a) shows the constellation diagram of the QPSK modulation.

Figure b) shows the constellation diagram of 4-QAM.

Figure c) shows the constellation diagram of 8-PSK.

Figure d) shows the constellation diagram of 16-QAM.

#### I.1.4.4 Cyclic Prefix:

The cyclic prefix determines the amount of tolerable multi path delay, or in fiber optic applications, dispersion. The number of samples, usually is determined by using OFDM training symbols. The cyclic prefix increases the reliability of the OFDM transmission, this is however at the cost of data throughput.

#### I.1.4.5 Guard Period:

guard interval that is to be added should be the cyclic extension of the end of the symbol transmitted during a period and it should be added in the front part of the next symbol. The symbol length will increase but the integration can be done between anywhere in the symbol since it is periodic extension only. Hence by this the ICI will also be eliminated from the scene. The explanation can be made very clear by the pictorial representation of it as shown in the next page in figure I.8[7]

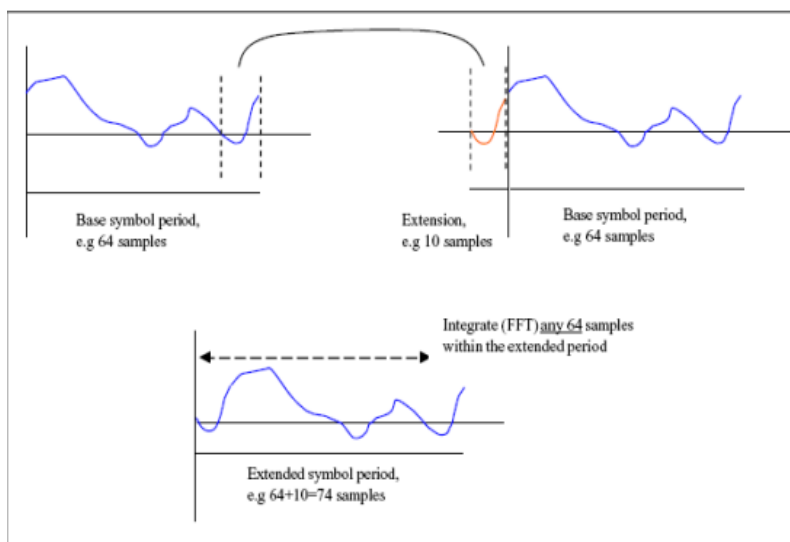


Fig I.8: Guard period via cyclic prefix [2].

### I.1.5 OFDM detection Technique

Basically there are two techniques in which an optical OFDM signal can be detected at the receiver: **direct detection** (DD) and **coherent detection** (CO-D). All of the existing applications or designs concerning an optical OFDM receiver are variations of these two options.

#### --Comparison between DD-OOFDM and CO-OFDM

When compared to DD-OOFDM, CO-OFDM provides great robustness against CD and PMD. This advantage is because of the linear coherent detection technique which enhances the receiver sensitivity. Therefore, in theory, CO-OFDM provides unlimited dispersion tolerance. In contrast, the DD-OOFDM tolerance to CD and PMD is limited because of the nonlinear direct detection. However, CO-OFDM requires frequency offset compensation because of the use of the local oscillator which complicates the receiver

when compared to the DD-OFDM. Also, the CO-OFDM is mainly used in long-haul applications due to the expensive and complex equipment used in the E/O and O/E conversion. On the other hand, DD-OFDM is a cost effective solution for cost sensitive applications such as LANs and MANs.

coherent detection-based systems represent the best performance in receiver sensitivity, spectral efficiency and robustness against polarization dispersion. The integration between OFDM and coherent optical communication brings two main benefits to communication systems. The coherent system brings linearity to the OFDM in both RF to optical up conversion and optical to RF down conversion. The OFDM provides the coherent system with high spectral efficiency and simple channel and phase estimation. Coherent Optical OFDM (CO-OFDM) is the next generation technology for optical communications since it integrates the advantages of both coherent systems and OFDM systems.

### **I.1.6 Applications:**

- Long-haul 100 Gbps and higher data rate DWDM transmission systems. (The communication system can be classified as a long-haul > 100 km and a short-haul < 50 km system).
- High-speed multi-mode fiber transmission for interconnects in data centers and high performance computing.
- Optical Ethernet in Automotive.

#### **-- Advantage of OFDM:**

After going through a discussion on OFDM in few sections it is evident that OFDM has certainly some advantage over the other multiple access techniques. The OFDM scheme has following key advantages:

- By allowing overlap of carriers it uses the spectrum very efficiently.
- Dividing the channel into narrow band flat fading sub channels, OFDM is more resistant to frequency selective fading than the single carrier system.
- Eliminates ISI and ICI with the use of guard interval via cyclic prefix.
- Using adequate channel coding and interleaving one can recover symbols lost due to frequency selectivity of the channel.
- Channel equalization becomes simpler than single carrier system by using adaptive equalization techniques.
- In conjunction with differential modulation there is no need to implement a channel estimator.
- It is less sensitive to sample timing offset than the single carrier system.
- Provides good protection against co-channel interference and impulsive parasitic noise.
- Interfaces with popular design tools.

- New BER Test Set enables the simulation of millions of bits for direct error counting.
- Transferring of complexities of Transceiver system from Analogue into Digital.
- If there is any variation of phase with frequency than it can be corrected very easily at the receiver with almost no cost.
- Easy and efficient in dealing with multi-path.

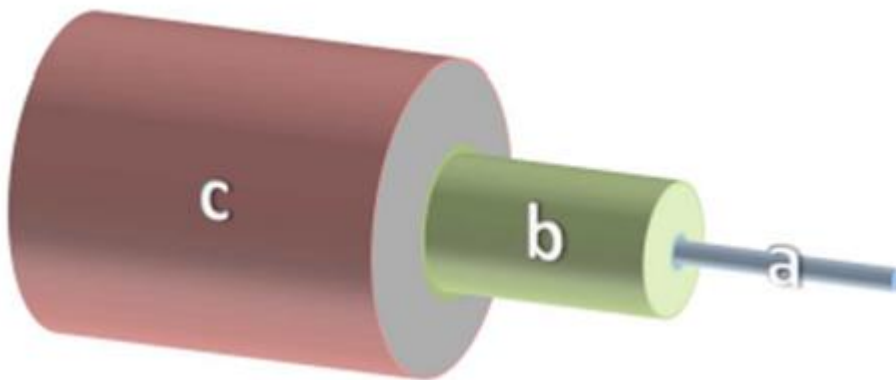
**Drawbacks of OFDM :**

- The OFDM signal has a high Peak to Average Power Ratio (PAPR).
- It is more sensitive to carrier frequency offset and drift than the single carrier systems due to leakage in the DFT(the difference between phase and frequency of the carrier of received signal and local oscillator which lead to degradation of the overall system performance).

Phase noise and Image Rejection are also a problem in OFDM.

## I.2 Generalities on Optical fiber

The simplest form of an optical fiber consists of a cylindrical core of silica glass surrounded by a cladding whose refractive index is lower than that of the core. The core has a refractive index  $n_1$  and the cladding's refractive index is  $n_2$ . The whole structure is covered with a protective gain



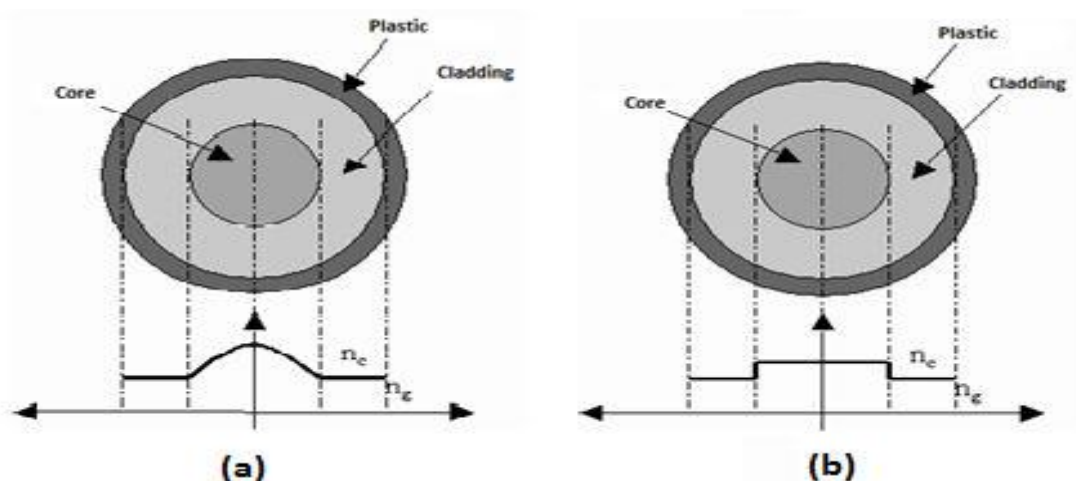
**Figure I.9:** General structure of optical fiber.

a-The fiber core with a refractive index  $n_1$ .

b-The cladding with a slightly lower refractive index.

c-The coating of the fiber for protection and structural integrity.

The majority of the power is concentrated in the core and there is a difference in both refractive indexes ( $n_1 > n_2$ ), which is achieved by a mix of dopants added to the fiber core. The fibers that present an abrupt change of the refraction index at the core-cladding interface are called step-index fibers. Whereas the ones that the refractive index decreases gradually inside the core are known as graded-index fiber.



**Figure I.10:** cross section of a graded index fiber (a) and a step index fiber (b).

Optical fibers are used to transport optical signals from source to destination. They present low loss and extremely large bandwidth allowing the transmission of high-speed signals over long distances before the regeneration becomes necessary. Nowadays every 80 km of fiber approximately, an optical amplifier is introduced.

### **I.2.1 classification of an optical fiber:**

Mainly, there exist two types of optical fiber: mono-mode and multimode fibers, they are classified depending on the number of ways that the light can follow inside the core. Thus, for a mono-mode fiber the light takes only one path, whereas, in multimode fiber it follows multiple paths.

It should be noted that for multimode fiber, various profiles of refraction indices are possible of which most widespread ones are the fibers called the step index and gradient index

### **I.2.2 Fiber optic impairments:**

Transmission impairments in the SMF can be divided into two categories: linear and nonlinear.

Power loss and dispersion are linear impairments and can easily be compensated. The Kerr-effect [3] and non-elastic scattering [2] belong to the nonlinear impairments and are generally very hard to compensate for. In this chapter we focus on linear impairments

#### **I.2.2.1 fiber Attenuation:**

Attenuation, also known as fiber loss, transmission loss, and power loss, means the reduction of the intensity of the light or the light power as it travels along the fiber. An attenuation unit is dB/km and, in an optical fiber, the main cause of attenuation is scattering and absorption. Attenuation can be expressed in dB/km as the ratio of input optical power  $P_{in}$  and output optical power  $P(z)$  after  $z$  length of optical fiber. This ratio is a function of wavelength and can be expressed as [13] :

$$\alpha = (10/z) \log_{10} (P(z) / P_{in}) \quad (I.3)$$

The signal power in an optical fiber attenuates due to the interaction of photons with the molecules ( $SiO_4$ ) of the fiber. The two dominant loss mechanisms that leads to power loss, also called fiber loss, are intrinsic absorption and Rayleigh scattering. If the launch power into the fiber is  $P_{in}$  [W] then the optical power  $P(z)$  [W] at distance  $z$  [km] exhibits an exponentially decay and can be written as:

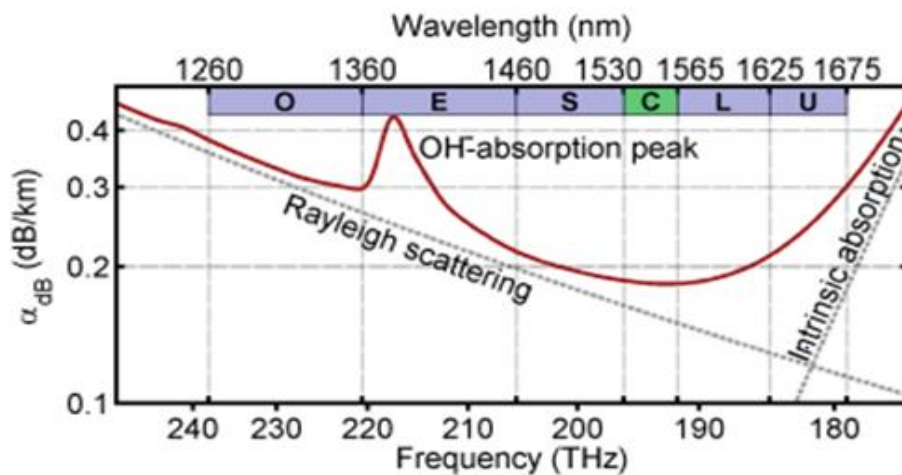
$$P(z) = P_{in} \exp(-\alpha z) \quad (I.4)$$

where  $\alpha$  is given in Neper per kilometer [ $Np \text{ km}^{-1}$ ]. Neper is a dimensionless, non SI

unit of measure for natural logarithm ratios. A more common way of describing the

attenuation coefficient  $\alpha$ , is in  $\alpha$ [dB/km] which is defined by

$$\alpha[\text{dB/km}] = (10/\ln(10)) \alpha[\text{Np/km}] \text{ or } \alpha[\text{dB/km}] \approx 4.343\alpha[\text{Np/km}].$$



**FigI.11:** Typical Optical Fiber attenuation coefficient as a function of the frequency and wavelength.

### Absorption:

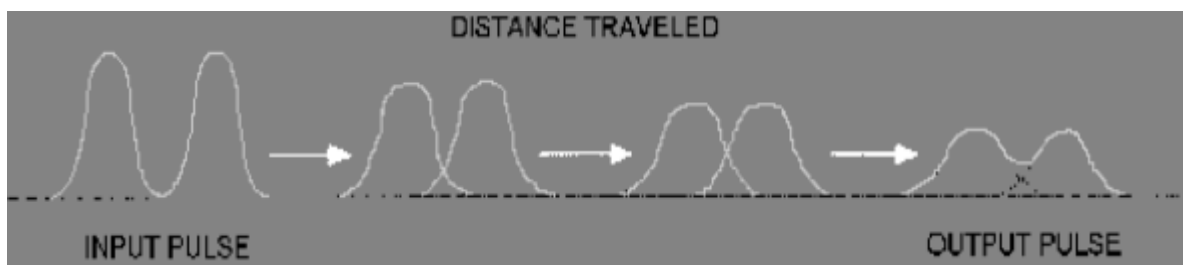
As mentioned above, the main cause of attenuation is scattering and absorption. The main absorption factor in fiber is the presence of impurities in the fiber material such as OH ions (water). These ions enter the fiber either during the chemical manufacturing process or from the environmental humidity.

### Rayleigh-Scattering:

Scattering losses occurs from material density microscopically variations, compositional fluctuations, and from defects during fiber producing process [15,12]. The collision between the light wave and the molecules of the fiber will result in the escape of the light from the fiber waveguide or in it reflecting back to the source. This is known as scattering.

### I.2.2.2 Dispersion

Fiber dispersion is the broadening of the light pulse while it travels along the fiber. This will lead the pulse to overlap with the closer pulses and eventually make it hard to recover the original signal accurately. There are different types of signal dispersion that can occur during the transmission of a signal such as Intermodal dispersion, Intramodal dispersion (chromatic dispersion), and polarization-mode dispersion [13].



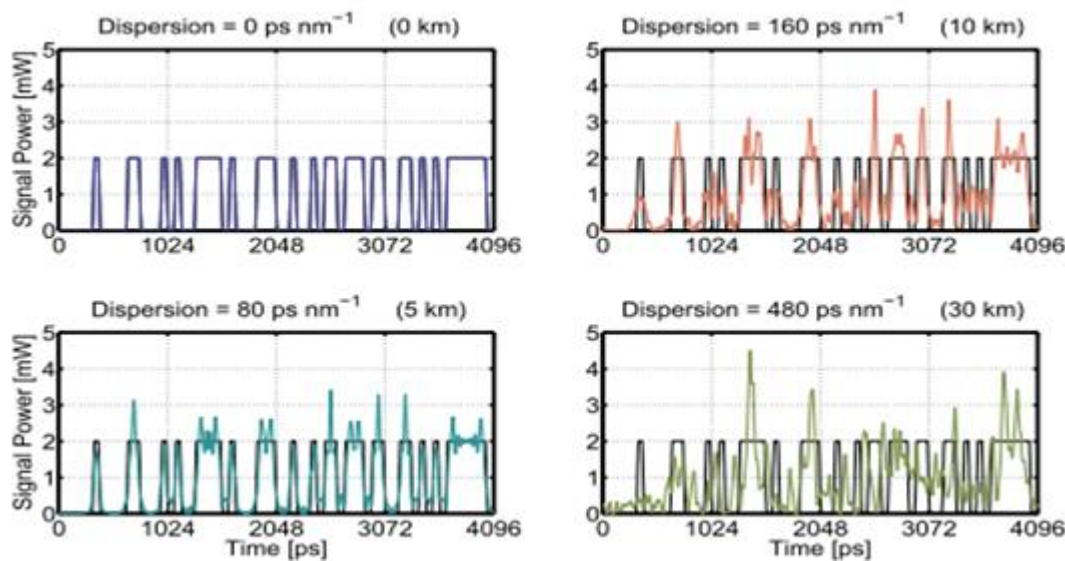
**Fig I.12:** Effect of pulse broadening due to dispersion as the transmission distance increases.

### Chromatic Dispersion (Intramodal Dispersion) :

Chromatic dispersion is the pulse broadening that happens in a single mode and multimode fibers. The main cause for this broadening is the finite spectral width of the optical source. Chromatic dispersion depends on the wavelength and therefore increases with the spectral width of the optical source. There are two causes for chromatic dispersion:

- material dispersion
- waveguide dispersion.

**Fiber loss and chromatic dispersion are linear impairments and can easily be compensated**



**Figure I.13:**The effect of dispersion on output signal power at different transmission lengths [2]

### Polarization-Mode Dispersion (PMD)

Polarization mode dispersion is caused by a fiber birefringence which affects the polarization state of the optical signal and causes a pulse broadening. Many factors can cause fiber birefringence such as: imperfections from the manufacturing process, the bending or twisting of the fiber. At specific wavelengths, signal energy takes two polarization modes and, because of the birefringence along the fiber.

#### I.2.2.3 Nonlinear distortion:

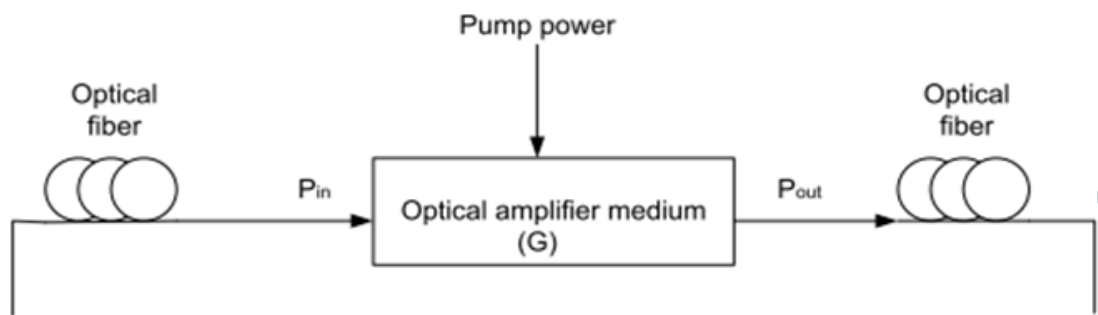
Another important source of impairment for high-speed optical transmissions are fiber nonlinear effects. The impact of nonlinearities is more relevant for increasing signalling rates, as it depends on the transmitted signal power. Basically, wave-length division multiplexing (WDM) communications suffer from distortions caused by the signal itself, like self-phase modulation (SPM) [7], and by other adjacent channels, like cross-phase modulation (XPM) [7] and four-wave mixing (FWM) [7]. As the impact of nonlinear effects increases

with the transmitted power, a trade-off must be found between the penalty given by the ASE noise and the penalty given by nonlinear effects. The transmitted power can be raised if techniques to mitigate nonlinear effects are employed, this can be defined as in [14].

### I.2.3: Techniques for solving impairment:

#### I.2.3.1 Optical amplifiers

The purpose of an optical amplifier is to restore the signal power level without any optical-to electrical conversion. Fiber attenuation is often a factor that limits the length of an optical fiber link. Hence, for very long fiber spans, it is necessary to periodically amplify the light signal. The optical amplifier is simply a higher-power replica of what came in the input. The main drawback of optical amplifiers is that they do not regenerate a signal that has been degraded by dispersion. However the use of dispersion compensation techniques reduce this effect. An example of one dispersion compensation technique can be to introduce at the end of the fiber a second piece of fiber with a dispersion coefficient of sign opposite that the first. The general form of an optical

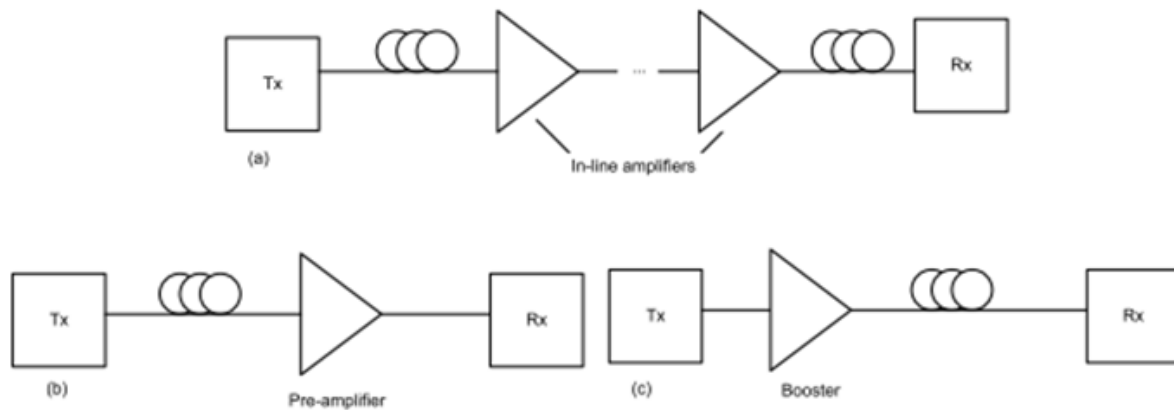


**Figure I.14:** optical amplifier principle [2]

The optical amplifier has three main applications:

- Boost
- in-line amplifiers
- pre-amplifier

that are depicted in figure I.15. The most important application for long-haul systems consists of using amplifiers as in-line amplifiers, figure 1.15(a), which replace electronic regenerators. Many optical amplifiers can be cascaded in the form of a periodic chain as long as the system performance is not limited by the cumulative effects of fiber dispersion, fiber nonlinearity, and amplifier noise. Another way to use the optical amplifiers is as a booster or power amplifier, figure 1.15(c), placing it just after the transmitter in order to increase the transmitted power. Moreover, optical transmitters can be also placed before the receiver to increase, in this case, the received power, figure 1.15 (b). Such amplifiers are called optical preamplifiers and are commonly used to improve the receiver sensitivity. There are different types of optical amplifiers:



**Figure I.15:** possible application of amplifier.

### **Erbium-Doped Fiber Amplifier (EDFA):**

It has the greatest impact on fiber optic communications, Semiconductor Optical Amplifier (SOA) and Raman amplifier. In the case of the EDFA the operating wavelength and the gain bandwidth are determined by the dopants. Rare-earth elements, such as erbium, and others can be used to amplify the signal. They also have become very attractive because the amplification peak is near of the wavelength region  $1.55\mu\text{m}$  (3rd window). On the other hand SOA amplifiers experience a relatively large feedback because of reflections. Finally, Raman amplifiers use stimulated Raman scattering, which occurs in silica fibers when an intense pump beam propagates through it.

As mentioned before, optical amplifiers solve the problem of attenuation in the fiber but make the fiber dispersion worse. However, fiber dispersion can be compensated by different techniques such as [8]:

- Dispersion Compensation Fiber (DCF)
- Fiber Bragg Grating (FBG)
- Chirped FBG

These techniques help control the dispersion and extend the transmission distance.

#### **I.2.3.2 Dispersion Compensation Fiber (DCF):**

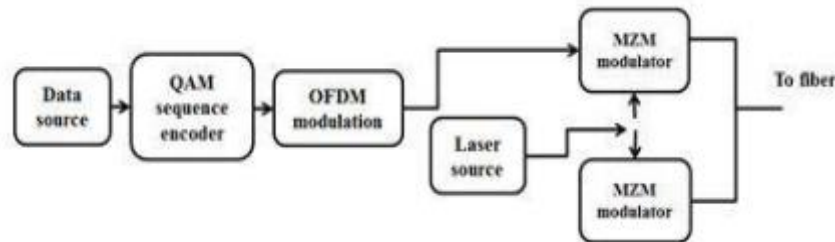
DCF is an effective technique to overcome the fiber dispersion because of its cost effectiveness and temperature stability. DCF can be designed to compensate for the dispersion of an optical fiber. This is by utilizing negative dispersion coefficients that can reach up to  $-80$  ps/nm to cancel the positive dispersion coefficients of the fiber. DCF has one disadvantage. It has a higher attenuation than the (SMF) which will produce high insertion loss to the system. One way to overcome this disadvantage is to increase the signal power in only a limited way.

In this chapter, we first present the structure of the optical OFDM system architecture (OFDM transmitter, optical link, OFDM receiver)

## II: OFDM Modulation Scheme

The OFDM scheme consists of two parts; transmitter and receiver, the transmitter and the receiver consist of number of modules and are illustrated and discussed in detail in this section.

### II.1 OFDM TRANSMITTER

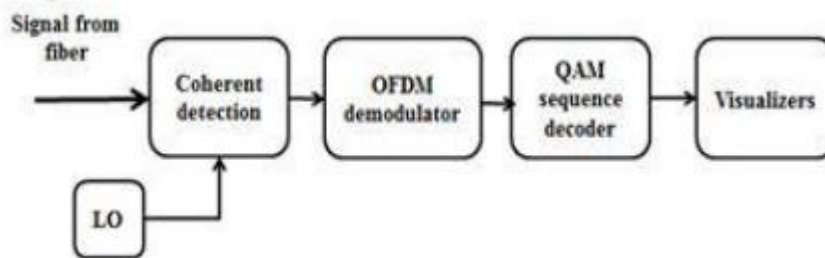


**Figure II.1:** Basic block diagram of CO-OFDM transmitter [2]

The transmission fiber is usually a single-mode fiber in the case of medium or long-distance transmission, but can also be a multimode fiber for short distances. In the latter case, intermodal dispersion can limit the transmission distance or bit rate. Long range broadband fiber channels can contain fiber amplifiers at certain points to prevent the power level from dropping to too low a level. Alternatively, it is possible to use a distributed amplifier, realized with the transmission fiber itself, by injecting an additional powerful pump beam which generates Raman gain. In addition, means for dispersion compensation and for signal regeneration may be employed. The latter means that not only the power level but also the signal quality is restored. This can be achieved either with purely optical signal processing, or by detecting the signal electronically, applying some optical signal processing, and resending the signal. Thus the signal from the CO-OFDM transmitter is then propagated through the optical link and becomes degraded due to fiber impairments.

## II.2 OFDM RECIEVER

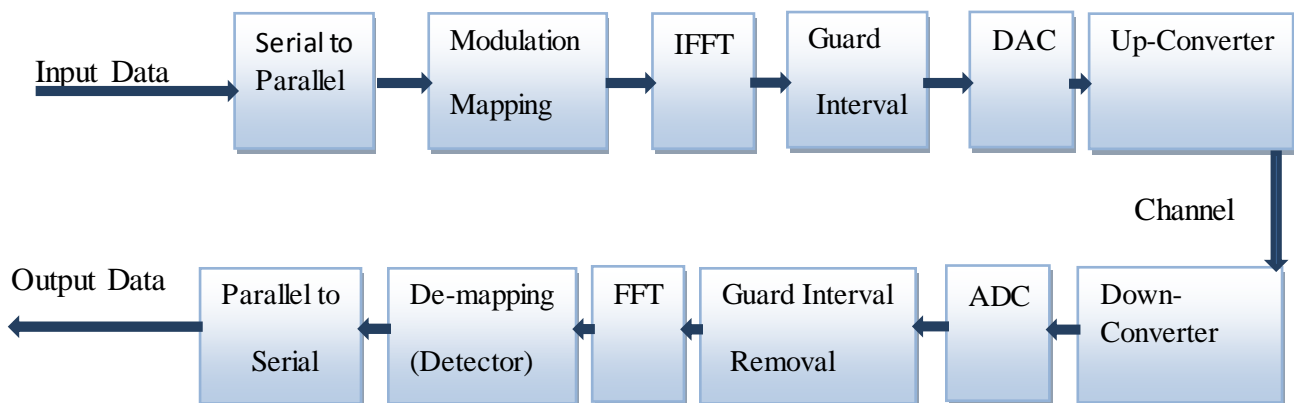
The main purpose of the optical receiver is to detect the signal and convert the received signal from optical back to electrical. The optical receiver (figure II.2 [2]) consists of a photodiode, which converts the optical signal to electrical, and an electrical demodulator, which extracts the original electrical signal that was sent. A coherent receiver with a local oscillator is used to down-convert the data to the RF domain. Homodyne detection is used here where the local oscillator frequency is same as the incoming signal.



**Figure II.2:** Basic block diagram of CO-OFDM receiver[2]

Finally data is demodulated and sent to the detector and decoder. Coherent detection provides linearity in RF to Optical up conversion, much needed for OFDM providing high spectral efficiency and great robustness against dispersion effects.

## II.3 OFDM System Description



**Figure II.3** the block diagram of the whole system of the OFDM.

## II.4 Block description

The block description of the OFDM is as follow

### II.4.1: Transmitter

#### II.4.1.1 Serial to Parallel

The input serial data stream is formatted into the word size required for transmission, e.g. 4 bits/word for QAM, and shifted into a parallel format. The data is then transmitted in parallel by corresponding each data word to one carrier in the transmission figureII.4 [2]

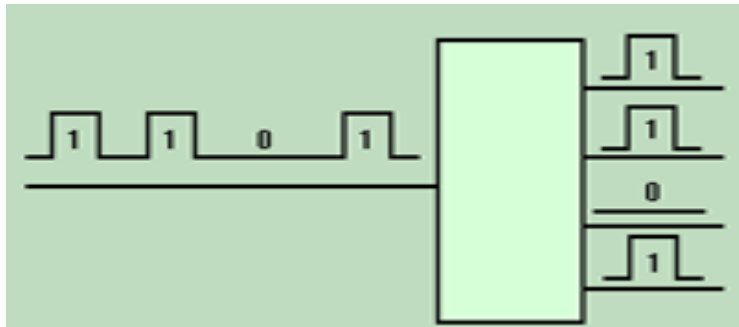


Figure II.4: serial to parallel conversion

#### II.4.1.2 Modulation mapping

The incoming bits to send have to be packed and mapped to a symbol generally using a complex modulation format such as for example M-QAM or QPSK. For the 4-QAM modulation used in this work's simulations, the incoming serial data uses two bits to create each of the 4 possible complex-valued QAM symbols (or information symbols).

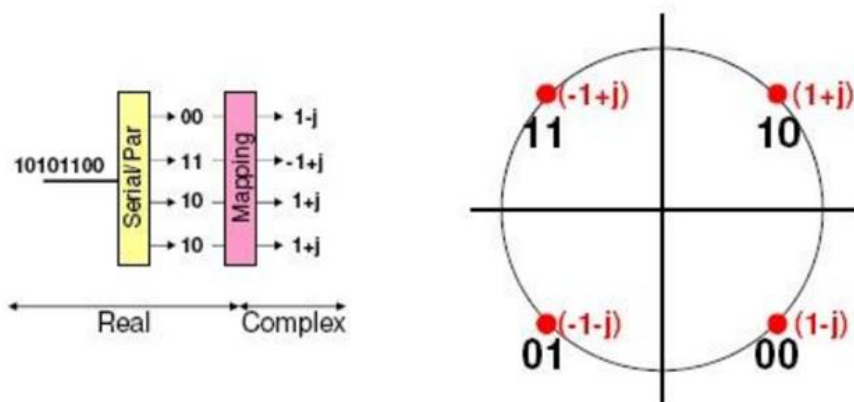


Figure: II.5: 4-QAM mapping[2]

### **II.4.1. 3 IFFT**

The OFDM is a multicarrier modulation technique. The generating the OFDM symbols is very challenging due to the large number of subcarriers and the difficulty of maintaining the orthogonality between the signals. The most effective method for creating the OFDM symbols is called Fast Fourier Transform (FFT). The complexity of the OFDM transceiver is reduced by using the FFT and its inverse IFFT. The FFT algorithm can be used to ensure no interference occurs between the adjacent signals by supporting the orthogonality of the system.

### **II.4.1.4 Guard Interval**

To make sure that a system achieves orthogonality and no Intersymbol Interference (ISI) occurs, the guard interval must be inserted between the OFDM symbols. Interference between the OFDM symbols occurs because some of the OFDM symbols are delayed through transmission. Therefore, a guard interval is used to keep a space between the adjacent symbols preventing interference. There are two methods to make guard interval between the OFDM symbols: the cyclic prefix (CP); and cyclic suffix (CS). In the cyclic prefix method, the last part of the symbol is copied and inserted at the beginning of the symbol. Using the cyclic suffix method, the head of the OFDM symbol is copied and inserted at the end of the symbol.

### **II.4.1.5 DAC**

Digital-to-analogue converter (DAC) is needed to convert the discrete value of (sample) to the continuous analogue value. The low pass filter requires the use of digital to analog conversion of the transmitted and received (baseband) signals and vice versa.

### **II.4.1.6 Up-Converter:**

In the RF up conversion technique, the complex baseband OFDM signal generated with QAM subcarrier modulation is up converted into a pass band signal centred at an intermediate frequency (IF).

## **II.4.2: Channel**

The channel used is a single mode fiber

### II.4.3: Receiver

#### II.4.3.1 Guard Interval Removal (GIR)

As mentioned before, the guard interval is inserted to prevent ISI. In the OFDM receiver, the guard interval must be removed to get the original form of the OFDM symbol. This guard is removed to recover the OFDM symbol's length.

#### II.4.3.2 FFT:

The Fast Fourier Transform is applied to the symbols of the OFDM after taking out GIR. In this step, the real values will be converted to a frequency domain by using the FFT. To recover the original information, the subcarriers are removed by using the FFT. The use of FFT offers an efficient method to take out the subcarriers in only one step instead of using a large number of oscillators and filters.

#### II.4.3.3 De-mapping (Detector)

The inverse procedure will take place at the receiver side: each complex-valued received symbol will be de-mapped and the obtained symbol sequence will be serialized to (ideally) obtain the original bit stream from the transmitter. However, because data is not going to be transmitted over an ideal channel, a decision of which constellation point is received has to take before de-mapping. This process is called slicing. Figure II.6 shows the mapping[2].

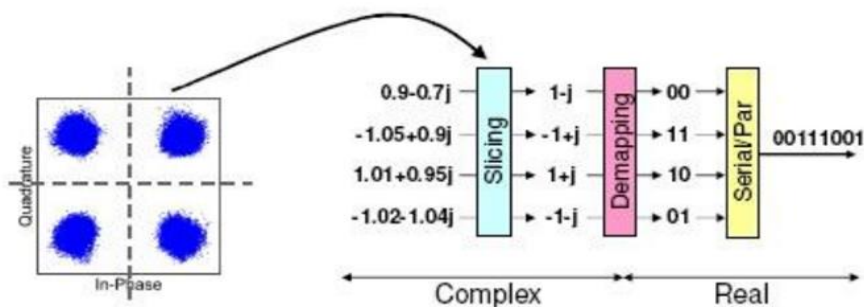


Figure II.6 4-QAM slicing and de-mapping[2]

#### II.4.3.4 Parallel to Serial

The operation of converting from a parallel symbol to serial is performed the same as in the OFDM transmitter block diagram. The aim of this step is to recover the original length of the duration because the parallel symbols have a shorter length of duration. By performing this process, recovery of the binary is easy after it is transmitted over the system.

In this chapter, we second care with some component witch are the most important to create the OFDM.

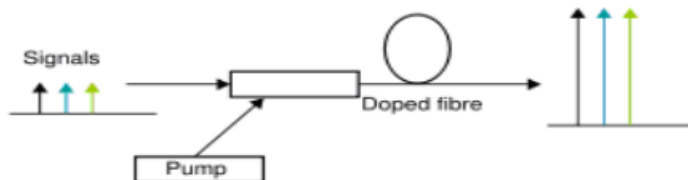
### II.5.1: Optical Source (Laser Diode)

The word "laser" is an acronym for light amplification by stimulates emission of radiation. The key word is stimulated emission, which is what allows a laser to produce intense high-powered beams of coherent light (light that contains one or more distinct frequencies). There are three main types of laser that can be considered for this type of application:

1. VCSEL (Vertical Cavity Surface Emitting Laser); these lasers operate at 850 nm and are predominantly multi (transverse) mode.
2. FP (Fabry Perot laser); these lasers are edge emitters and predominantly operate at longer wavelength (1310 or 1550 nm windows) with multiple longitudinal modes.
3. DFB (distributed feedback laser); these lasers are edge-emitters and predominantly operate at longer wavelength (1310 or 1550nm windows) with a single longitudinal mode.

### II.5.2: Optical Amplifier:

Doped fiber amplifiers (DFAs) are optical amplifiers which use a doped optical fiber as a gain medium to amplify an optical signal. They are related to fiber lasers. The signal to be amplified and a pump laser are multiplexed into the doped fiber, and the signal is amplified through interaction with the doping ions. The most common example is the Erbium Doped Fiber Amplifier (EDFA), where core of a silica fiber is doped with trivalent Erbium ions ( $Er^{+3}$ ), can be efficiently pumped with a laser at 980 nm or at 1,480 nm, and exhibits gain the 1,550 nm region. Figure II.7 show an Optical amplifier [2]



**Figure: II.7** optical Amplifier

Main parameters of the Optical Amplifier are:

Operation mode: gain control

Gain: Determines the signal gain range [0,100]

Power: Determines the signal output power range [-100,100]

Saturation power: Specifies the optical power at the gain compressed by 3 dB range [-100,100]

Noise figure: up to 100 dB

### II.5.3: Optical Receivers (Photodetectors)

The basic detection devices for direct detection optical networks are the PN photodiode (a p-n junction) and the Pm photodiode (an intrinsic material is placed between p- and n- type material). In its simplest form, the photodiode is basically a reverse biased p-n junction. Through the photoelectric effect light incident on the junction will create electron-hole pairs in both the "n" and the "p" regions of the photodiode. The electrons released in the "p" region will cross over to the "n" region, and the holes created in the "n" region will cross over to the "p" in a region, thereby resulting in a current flow.

#### II.5.3.1 Technical background

The PIN photodiode component is used to convert an optical signal into an electrical current based on the device's *Responsivity*. The model includes:

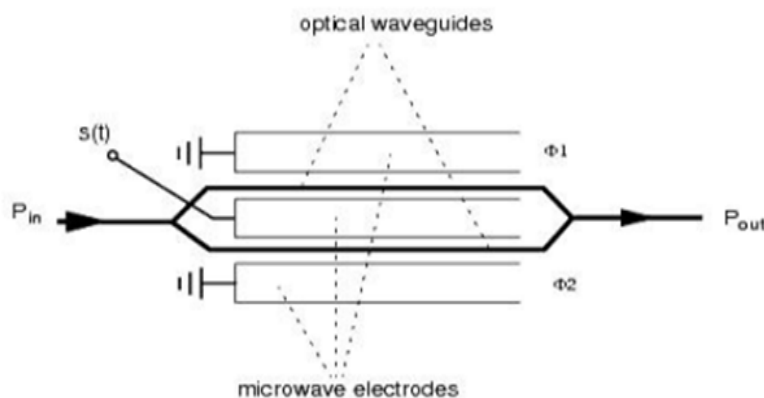
- Responsivity (constant, based on a predefined material, or user-defined)
- Noise source modeling (dark current, thermal noise, shot noise)
- Frequency response models (ideal, RC-limited, defined)

The incoming optical signal and noise bins are filtered by an ideal rectangle filter to reduce the number of samples in the electrical signal. The new sample rate is defined by the parameter Sample rate [10].

### II.5.4: Mach-Zehnder Modulator

The direct modulation of a laser is cheap and also easy to adapt to low cost applications for moderated distances or transmission rates. However, for advanced applications involving high data rates or long distance links, resorting to external modulation is a good solution.

The material for the MZM has electrooptical properties by which the phase of the optical wave propagating inside it receives a phase modulation proportional to the applied electrical field. Therefore, the optical power at the output of the MZM depends on the phase difference between the two arms of the modulator[2].



**Figure: II.8** Mach-zehnder modulator [2]

Where:

$P_{in}$ : is the input signal

$S(t)$ : the RF modulating electrical voltage

Main parameters of the Mach-Zehnder Modulator

Switching bias voltage: DC voltage required to turn the modulator from the OFF state to the ON state, or vice versa

Switching RF voltage: RF voltage required to turn the modulator from the OFF state to the ON state, or vice versa

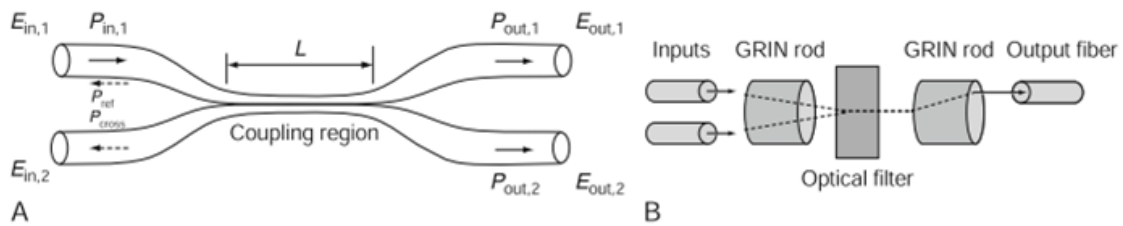
Modulation voltage 1

Modulation voltage 2

### II.5.6: Coupler

The 2\*2 optical coupler is a fundamental device that can be implemented using the fiber fusing or be based on graded-index (GRIN) rods and optical filters, the fused optical couplers are obtained when the cladding of two optical fibers is removed, the cores are brought together and then heated and stretched. The obtained waveguide structure can exchange energy in the coupling region between the branches.

If both inputs are used, a 2\*2 coupler is obtained; if only one input is used, a 1\*2 coupler is obtained, the optical couplers are recognized either as optical taps (1\*2) couplers or Directional (2\*2) couplers[10].



**Figure: II.9** Coupler

Where

$E_{in, 1}$ : Optical input

$E_{in, 2}$ : Optical input

$E_{out, 1}$ : Optical output

$E_{out, 2}$ : Optical output

Main parameters of the Coupler

Coupling coefficient: Coupling factor from port 1 to port 2

Additional loss: Loss applied to the signal after coupling

Conjugate: Defines whether the component uses the complex conjugate definition or not

### **III.1 Introduction to OptiSystem:**

The main goal of this part is to investigate the use of the OFDM as a modulation technique for a radio over fiber (RoF) in passive optical network.

In order to reach the design of the high data rate Coherent Optical OFDM system, a design and performance investigation of one user CO-OFDM with 4-QAM have been carried out. To achieve this goal OptiSystem Simulation software V.13 is used.

#### **III.1.1 OptiSystem Simulation Software**

Cost and time can be reduced when a system model design is done by using simulation software. Also, designers can extend their investigation by using simulation software. In this thesis, all the system models and simulations are performed by using simulation software called OptiSystem to study the performance of different system models. This software offers a broad range of wireless and optical parameters, which help researchers to design a complete optical fiber network. Because of this, it is used by different telecommunication companies, such as Alcatel, Huawei and Fujitsu.

#### **III.1.2 Applications**

OptiSystem allows users to design, simulate and test the performance of different optical parameters and networks:

- Design of SONET/SDH ring;
- Design of transmitter,
- Receiver and amplifier;
- Design of next generation of optical networks;

#### **III.1.3 Analysis Tools**

Spectrum analyzer, BER analyzer, Eye diagrams, Q-Factor measurement, Constellation diagrams, Power meter, WDM analyzer, SNR, OSNR, Optical spectrum analyzer, WDM analyzer

III.2: Simulation Setup:

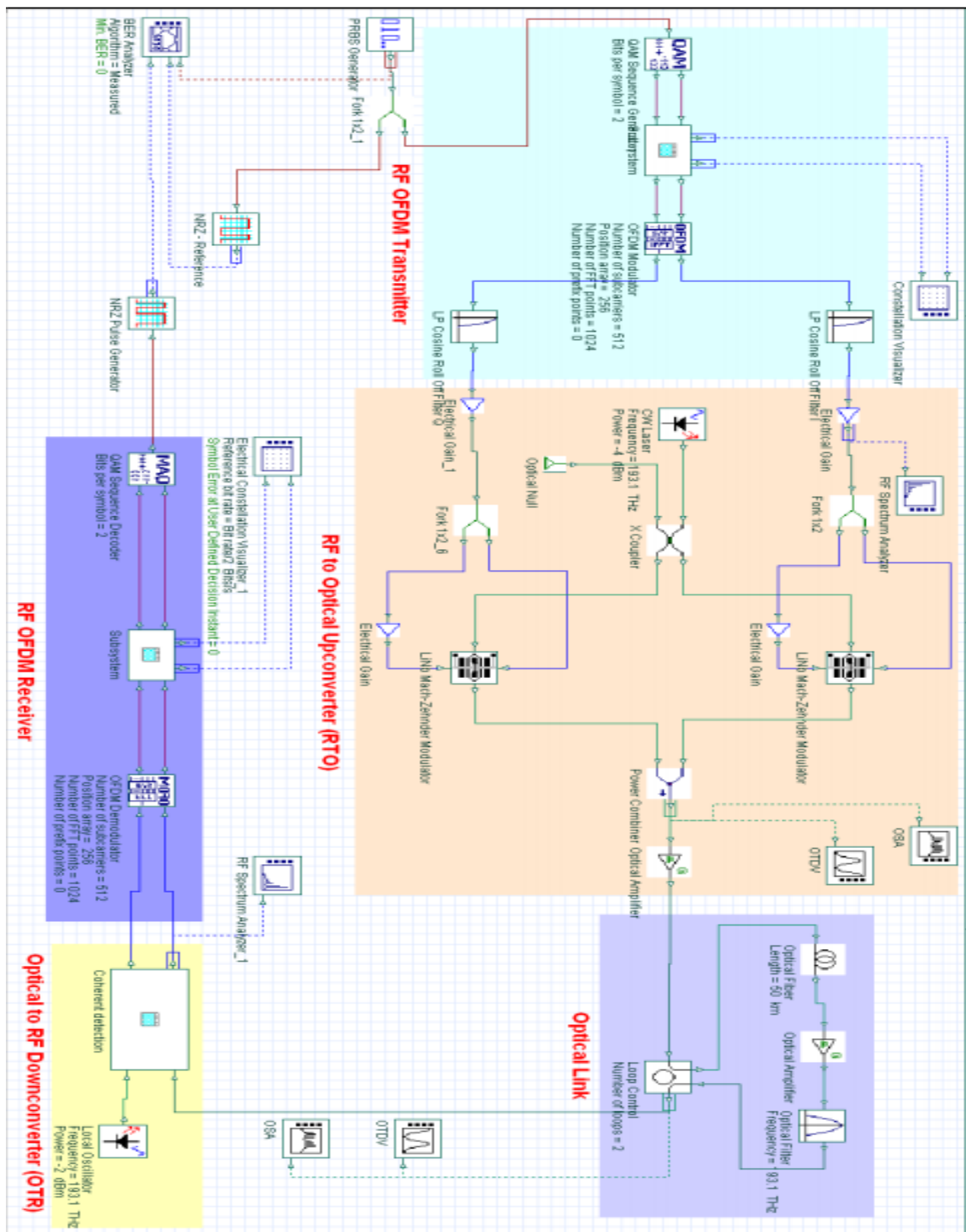
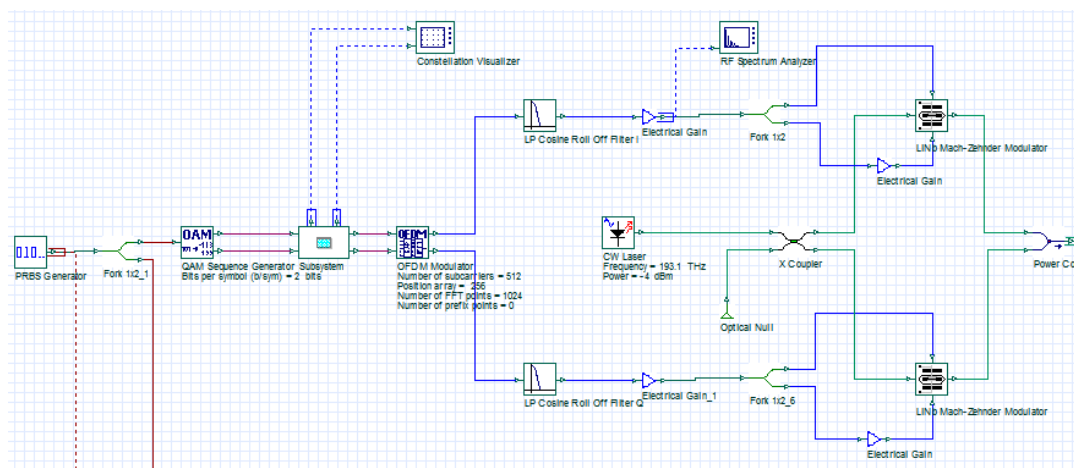


Figure III.1. the system design of the CO-OFDM system with a Single Mode Fiber (SMF) of 50 Km.

Figure III.1 shows the system design of the CO-OFDM system with a Single Mode Fiber (SMF) of 50 Km. The CO-OFDM system design consists of a CO-OFDM transmitter, a fiber link and a CO-OFDM receiver[10].

### III.2.1 Implementation of the Transmitter

The CO-OFDM transmitter figure III.2, is built with a 10Gbps, and a 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 are connected to the direct I/Q optical modulator which consists of two lithium Niobate (LiNb) Mach-Zehnder modulators (MZM). The MZM will modulate by the electrical signals from the OFDM modulator the optical carrier generated by a laser source at 193.4 THz (1550nm). The power delivered by the laser source is -4dBm.



**Figure III.2** the structure of the transmitter

Table III.1 summarizes the main parameters of the different components used in the implementation of our transmitter [10].

**Table III.1:** Simulation parameter values used by the transmitter

Component	Value
CW Laser	Frequency = 1550 nm
Electrical Amplifier (2 pcs)	Gain = 10 dB
MZM	Extinction Ratio = 30 dB
Optical Fiber	Length = 50 up to 250 Km
Photodetectors PIN	Responsivity = 1 A/W

The resulting optical signal from the two LiNb MZMs is then transmitted through the SMF with an attenuation of 0.22 dB/km, a dispersion of 17 ps/nm/km, a dispersion slope of 0.09 ps/nm<sup>2</sup>/km and a nonlinearity coefficient of  $2.6 \times 10^{-20}$ .

In this simulation we use real characteristics for the fiber link that we get from Algérie Télécom. An Erbium Doped Fiber Amplifier (EDFA) is used to amplify the signal and to compensate the loss.

### III.2.2 Optical Link

The transmission link is a part the system network, the signal modulated from OFDM transmitter would be sent through the optical link system network before being received by the OFDM receiver. In this work we have used a simple link which consists of a single-mode optical fiber, DCF fibers for dispersion compensation and EDFA amplifiers for loss compensation (figure III.3) [10].

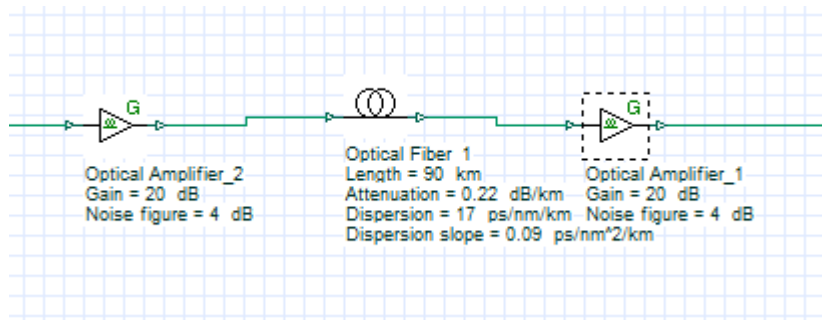


Fig III.3: Optical link with no dispersion compensation.

### III.2.3 The implementation of the Receiver

At the receiver side (figure III.4), the incoming optical signal is detected by two identical 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 photodetectors. Each PIN photo detector has a dark current of 10 nA, a responsivity of 1 A/W, thermal noise of  $100e^{-24}$  W/Hz, and a center frequency for detection of 193.4 THz. After detecting the signal by the balanced detectors, the signal is sent to the OFDM demodulator which has similar parameters as the OFDM modulator, and the guard interval is removed. Finally, the resulting signal is fed into a 4-QAM decoder to create a binary signal.

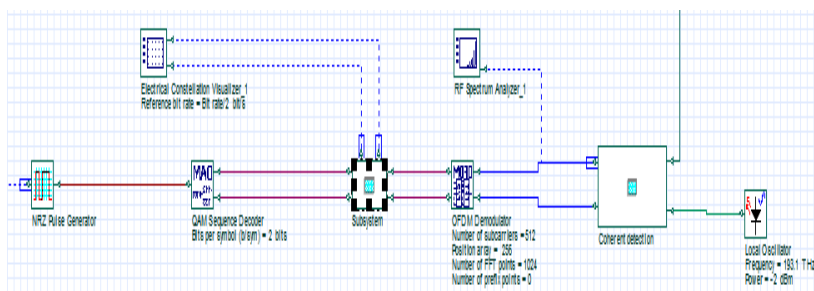
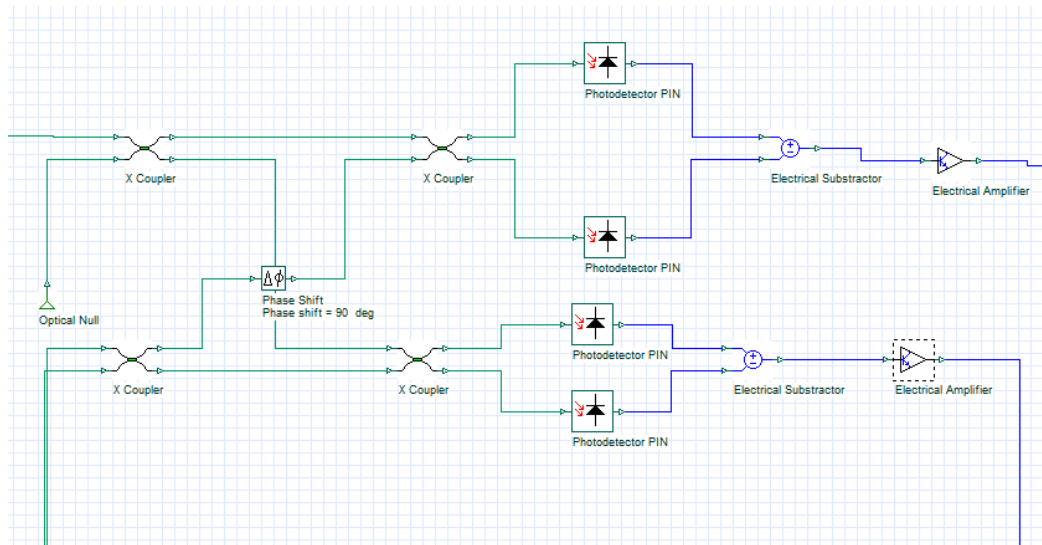


Figure III.4 The OFDM Receiver [10]



**Figure III.5** the coherent detectors

On Table III.2 are presented the simulation values we have used for the global parameters as required by the Optisystem software as well as the parameters values we have chosen for both modulation and demodulation.

**Table III.2:** the global parameter using in the simulation

Global parameters

Sequence length	16384
Samples per bit	8
Number of samples	65536

**Table III.3:** OFDM Modulator/De-Modulator

Number of subcarriers	512
Position array	256
Number of FFT points	1024
Number of prefix points	64
Modulation type	QAM

**Where:**

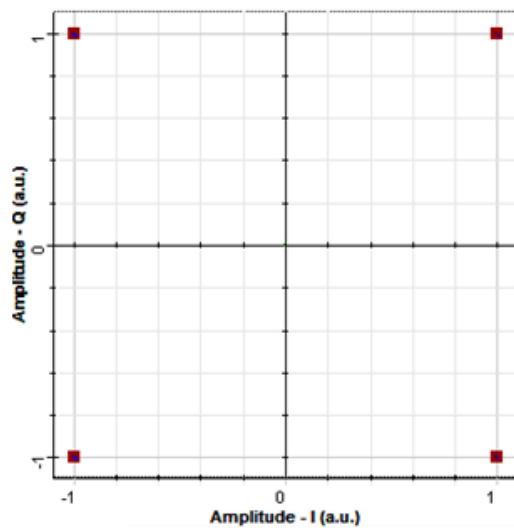
Sequence length: The length of the bit sequence in number of bits. It must be a power of two.

Samples per bit: Number of samples for bit used to discretize the sampled signals. It must be a power of two.

Number of samples: This read-only parameter shows the number of samples calculated by the product of Sequence length and Samples per bit.

### III.3 Simulation Results

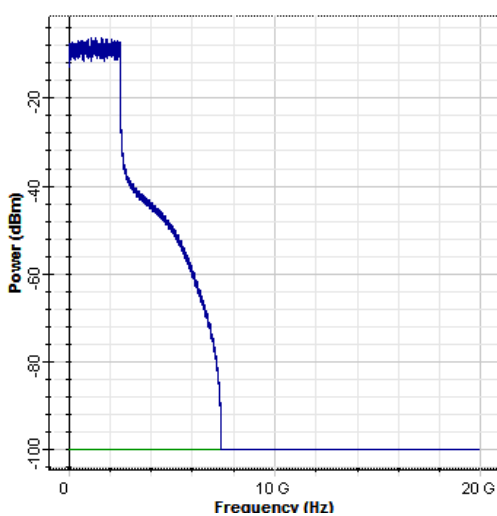
The simulation results for CO-OFDM for different transmission lengths starting from 50 km to 250 km are presented and discussed in this section.



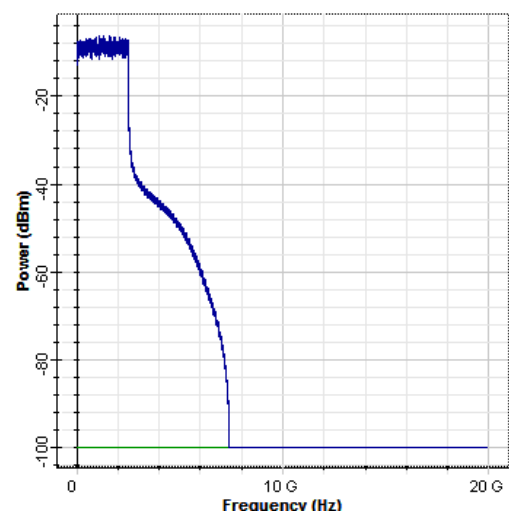
**Figure III.6:** Constellation Diagram of 4-QAM at the CO-OFDM Transmitter

Figure III.6: shows a clear constellation diagram of the 4-QAM modulator signal transmission at the transmitter side.

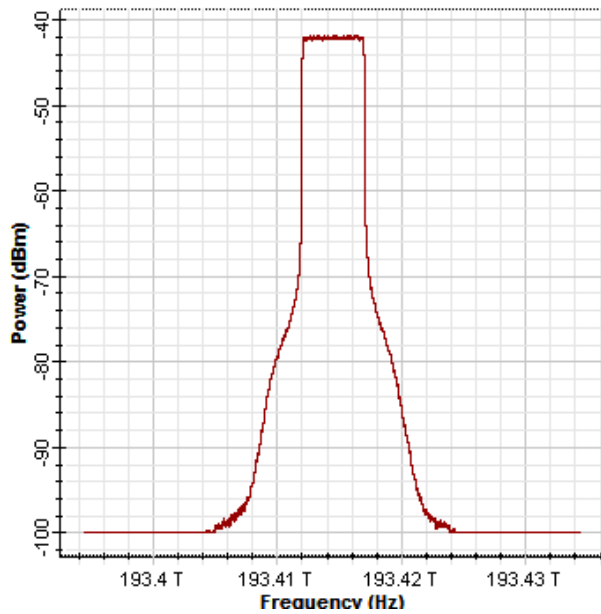
The constellation diagram displays the modulated signal as a two dimensional scatter diagram which helps to identify the distortion and interference that occurs in the signal.



**Figure III.7 (a)** I component



**Figure III.8 (b)** Q component



**Figure III.9:** Optical OFDM Spectrum after the Two MZM Modulation

Figure III.9 shows the optical signal spectrum, after modulating the electrical signal with the optical carrier using two MZMs.

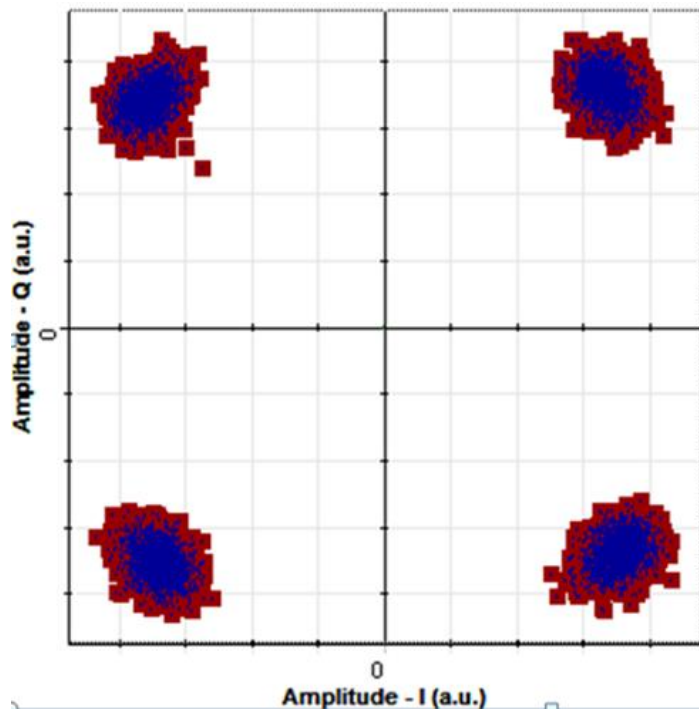
The RF power measured is almost -10 dBm.

#### **(A) Simulation with no dispersion compensation**

We start first presenting the simulation results of our system for different link lengths (from 50km to 250km with step of 50km) with no dispersion compensation means. In these results we used the optimum values for the EDFA to get the best (clear) constellation.

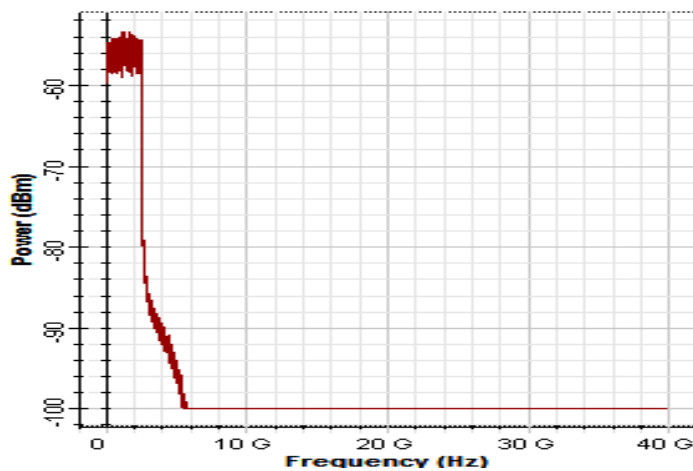
The results are presented in the form of constellation diagrams and RF spectra of the received signal in which the blue colored areas represent the noise introduced by the laser source.

## III.3.1 OFDM 50 km SMF System



**Figure III.10:** Constellation Diagram of the 10 Gbps Using CO-OFDM System at the Receiver Side after SMF of 50 km.

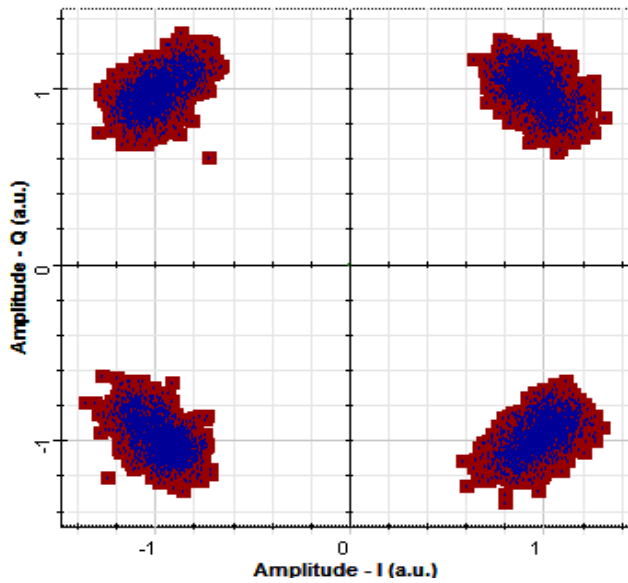
Figure III.10 shows the constellation diagram of the system after 50 km SMF with EDFA of 12 dB pre and post in the CO-OFDM receiver side.



**Figure III.11:** RF Spectrum at the CO-OFDM Receiver

Figure III.11 shows the RF spectrum of the system at the CO-OFDM receiver side after 50 km SMF. The measured RF power is -51.01 dBm.

### III.3.2 OFDM 100 km SMF System

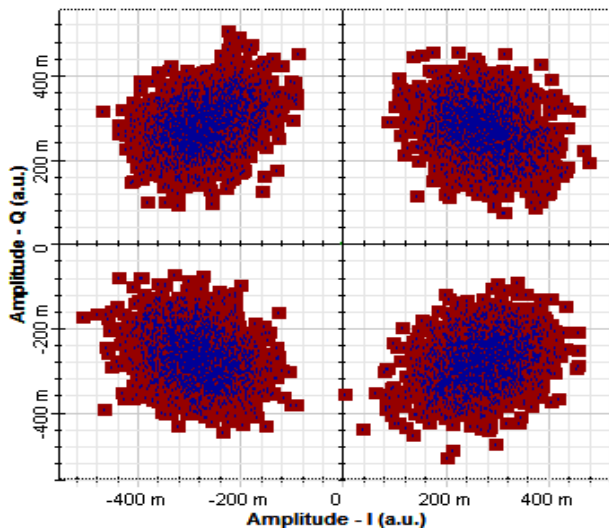


**Figure III.12**

the constellation diagram of the system after 100 km SMF

Figure III.12 shows constellation diagram of the system after increasing the power of the EDFAs to 20 dB.

### III.3.3 OFDM 150 km SMF System



**Figure III.13:** constellation diagram of the system after 150 km

Figure 111.13 shows constellation diagram of the system after 150 km using the 20 dB EDFA

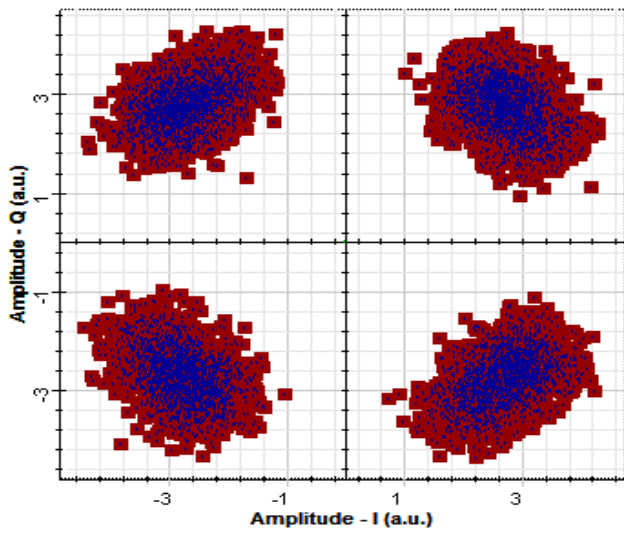


Figure III.14: constellation diagram of the system after 150 km after increasing from 20 to 30 dB

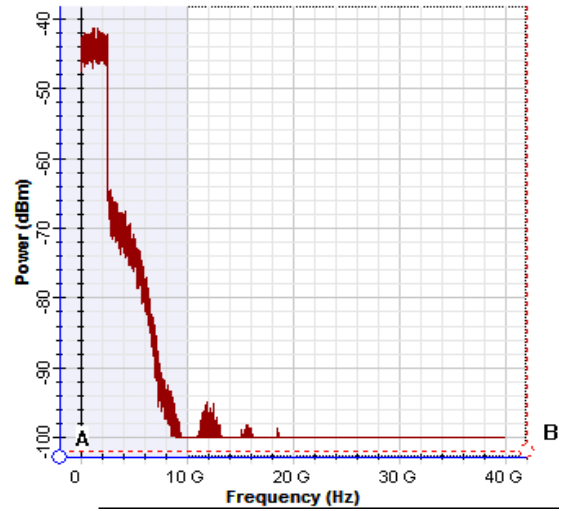


Figure III.15: RF Spectrum at the receiver after 150 km for 30 dB

### III.3.4 OFDM 200 km SMF System

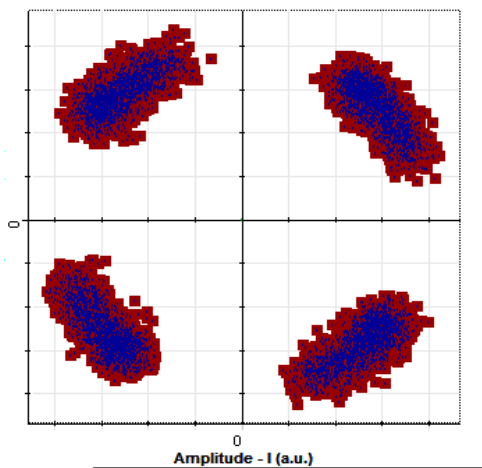
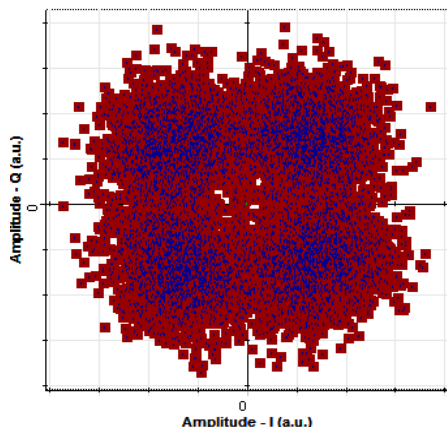


Figure III.16: constellation diagram of the system after 200 km

### III.3.5 OFDM 250 km SMF System



**Figure III.17:** constellation diagram of the system after 250 km

#### Discussion:

As shown from the obtained diagrams and as expected, the increase of the transmission length produces a gradual degradation of the transmitted signal even using pre and post EDF based amplifiers at optimum gain values. Reaching a certain length (250km) the received signal becomes unrecoverable and increasing the amplifier gain does not bring any improvement.

This result means that the optical amplification solution yet efficient to combat loss effects (absorption and scattering mainly) has reached its limit and that we must consider reducing the effects of dispersion (chromatic dispersion mainly) if we need to extend further the transmission length (more than 250km).

In addition to an increasing noise levels which results in a decreasing signal-to-noise ratio (SNR), the increase in the amplifier gain beyond a certain value, make the optical power level high enough to cause some non linear effects to appear. Those effects as seen in previous chapter produce a broadening of the transmitted pulse leading to degradation of signal.

Another nonlinear effect obtained from our simulation results when excessive power levels are used is the Self-Phase Modulation (SPM) effect which causes the constellation diagram to spin as the signal travels along the fiber as shown in figure III.18. To correct this rotation we have introduced an initial phase to the local oscillator laser signal to each simulation.

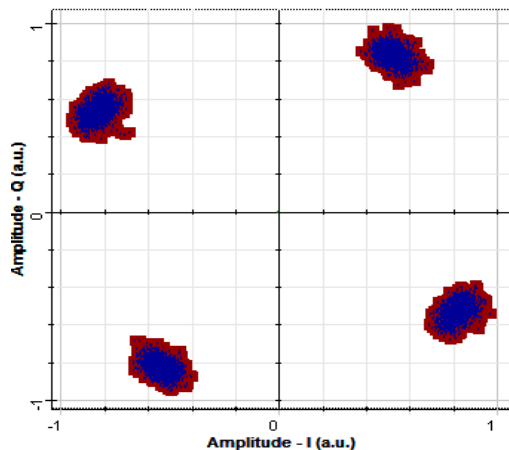


Figure III.18 the constellation spin caused by SPM effect

### (B) Analysis on Dispersion compensation with DCF:

In order to improve the overall system performance and reduced as much as possible the transmission performance affected by dispersion, several dispersion compensation techniques were proposed. Among the various techniques proposed in literature, the techniques that appear to hold immediate promise for dispersion compensation can be broadly classified as: Dispersion compensating fibers (DCF), Fiber Bragg Grating (FBG) and High order mode (HOM) fiber [17]

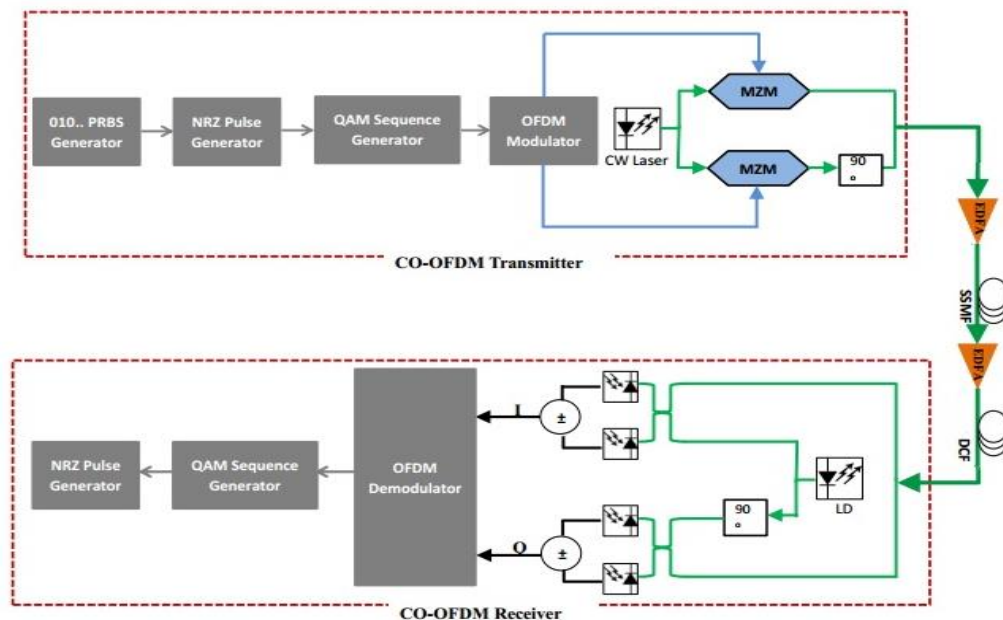


Figure III.19: System Design of One User CO-OFDM with SMF-DCF

Figure III.19 shows the system design of the one user CO-OFDM system with a post SMF-DCF. The CO-OFDM transmitter is built with a 10Gbs.

The transmission performance is degraded when the optical fiber length exceeds 60 Km according to the following Equation [REF].

$$L_C = \frac{0.8C}{\lambda^2 \times D \times B^2} = \frac{0.8 \times 3 \times 10^8}{(1550 \times 10^{-9})^2 \times 17 \times (10^{10})^2} = 58.76 \cong 60 \text{ Km} \quad (\text{III-1})$$

$L_C$ : Length of the fiber from which the compensation is indispensable.

C: speed of light  $C=3 \times 10^8$  [m/s].

D: Chromatic dispersion [ps/nm.Km]

B: Bandwidth [ $s^{-1}$ ].

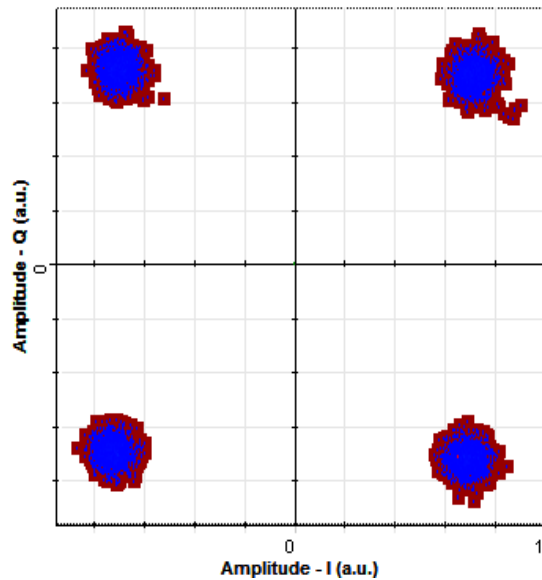
So the length of DCF= Length of the fiber used - 60 Km

Therefore, applying dispersion compensation to SMF is essential to control the dispersion for long distances.

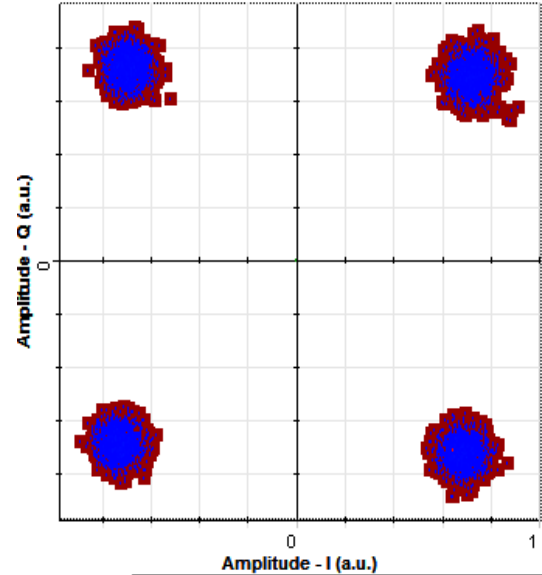
The DCF is used to compensate for the fiber dispersion. DCF attenuation is 0.22 dB/km. The SMF dispersion is 17 ps/nm/km for 100 km. The SMF will produce a dispersion of  $17 \times 100 = 1700$  ps/nm. Therefore, to compensate the dispersion of the 100 km SMF, a 22 km long DCF is needed with dispersion of -80 ps/nm/km. This will produce a dispersion of  $-80 \times 22 = -1760$  ps/nm, which will be negative to cancel the positive dispersion of the SMF. An Erbium Doped Fiber Amplifier (EDFA) is used with 20 dB power to amplify the signal and to compensate for the loss.

### Simulation Results

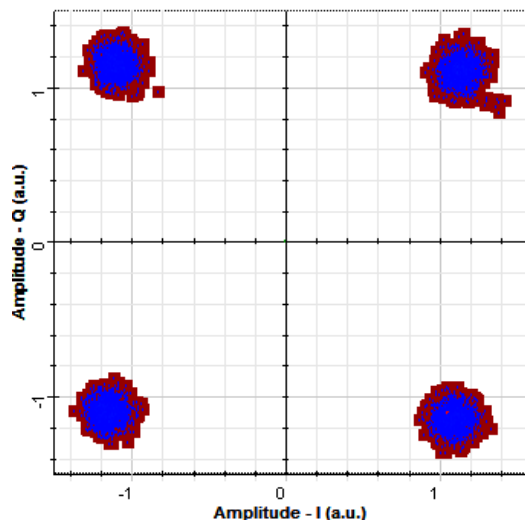
We have used DCF fibers in different of dispersion compensation schemes (pre, post and pre-post) in order to improve the results obtained previously. The obtained results are shown on figures below.



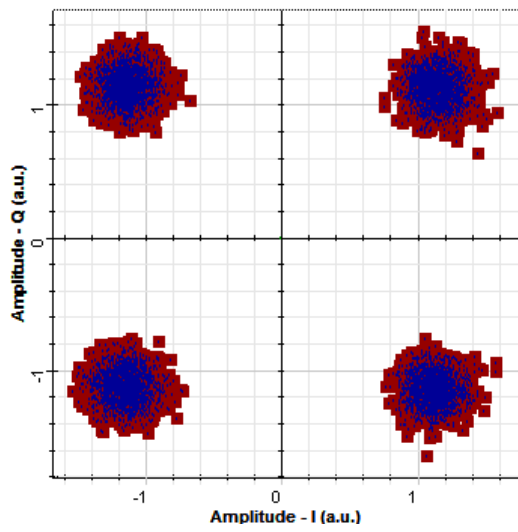
**Figure III.20** the constellation diagram of the system after 100 km SMF using pre DCF



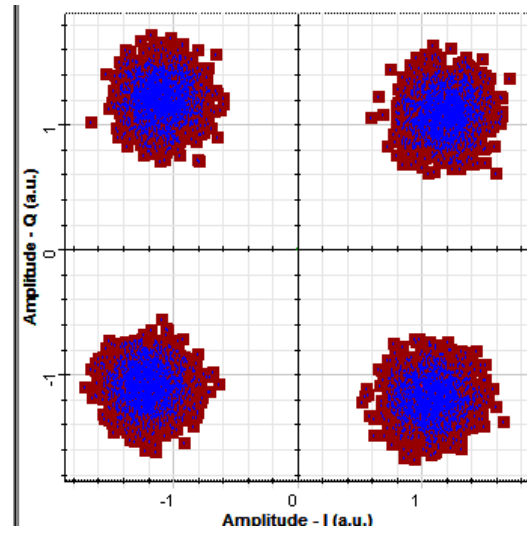
**Figure III.21** the constellation diagram of the system after 100 km SMF using post DCF



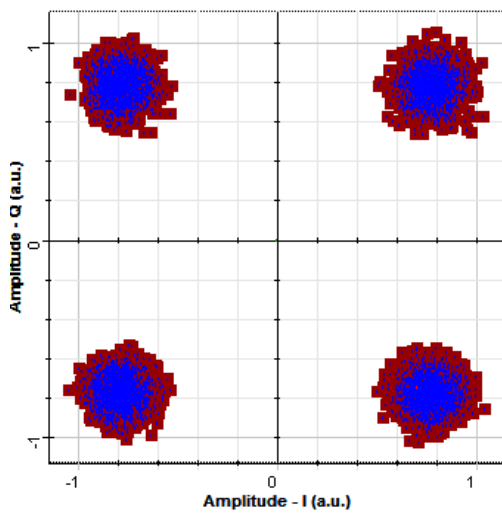
**Figure III.22** the constellation diagram of the system after 100 km SMF using pre/post DCF



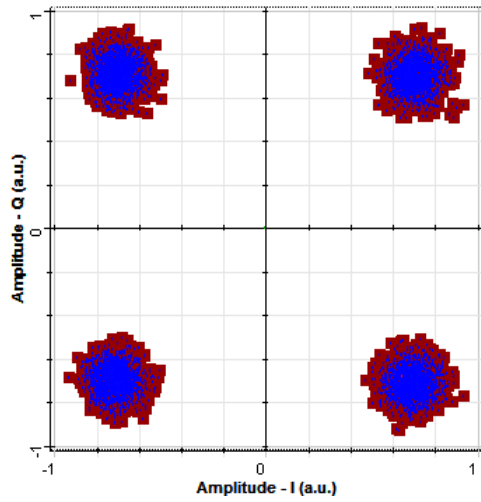
**Figure III.23:** The constellation diagram of the system after 150 km SMF using pre DCF



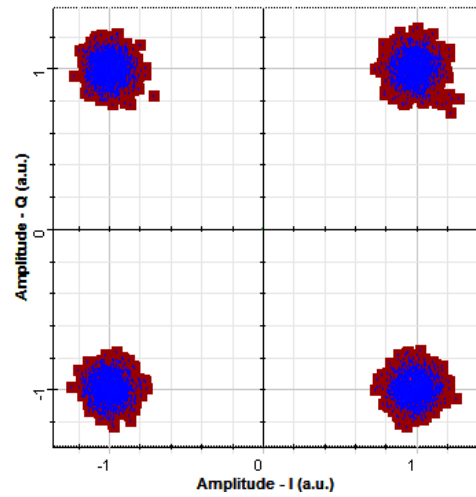
**Figure III.24:** The constellation diagram of the system after 150 km SMF using post DCF



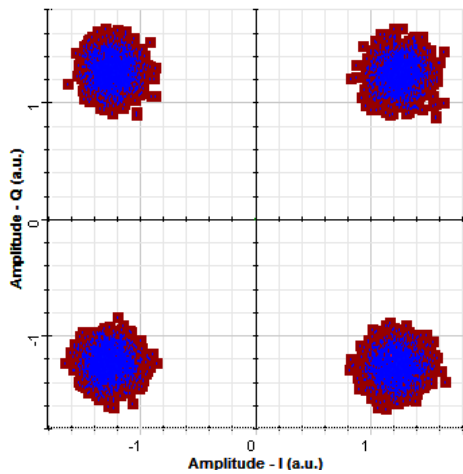
**Figure III.25:** The constellation diagram of the system after 150 km SMF using pre/post DCF



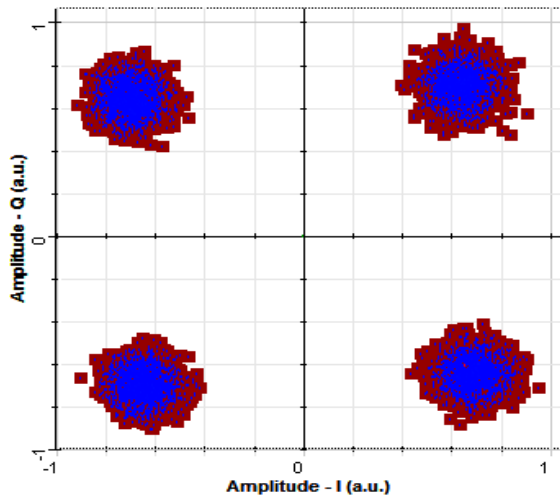
**Figure III.26:** The constellation diagram of the system after 200 km SMF using pre DCF



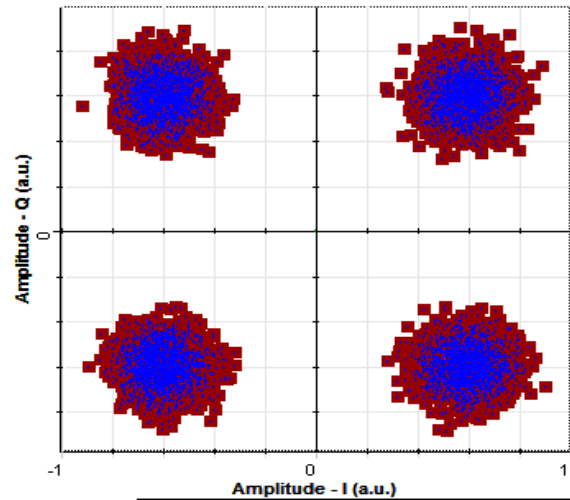
**Figure III.27:** The constellation diagram of the system after 200 km SMF using post DCF



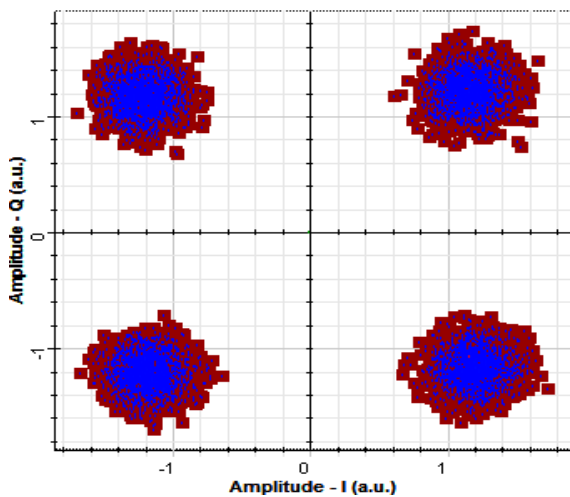
**Figure III.28:** The constellation diagram of the system after 200 km SMF using pre/post DCF



**Figure III.29:** The constellation diagram of the system after 250 km SMF using pre DCF



**Figure III.30:** The constellation diagram of the system after 250 km SMF using post DCF



**Figure III.31:** The constellation diagram of the system after 250 km SMF using pre/post DCF

The following table summarizes quantitatively the obtained results:

Distance	RF Power Level in dBm			
	Without	Pre	Post	Pre/post
50Km	-85.32	XX	XX	XX
100Km	-80.26	-82.55	-81.56	-78.92
150Km	-79.44	-74.13	-71.08	-69.86
200Km	-83.77	-79.23	-78.37	-73.95
250Km	-80.16	-78.86	-76.54	-71.90

**Table III.4:** shows the RF power of the different lengths without using the DCF and with the DCF for 3 cases pre, post and mix (pre/post)

The noise level has been also measured and recorded in the following table

	Noise Power Level in dBm			
	Without	Pre	Post	Pre/post
50Km	-51.01	XX	XX	XX
100Km	-52.87	-51.01	-50.87	-46.67
150Km	-59.44	-50.00	-46.52	-45.04
200Km	-53.14	-49.23	-47.78	-45.68
250Km	-59.02	-51.30	-52.42	-46.10

**Table III.5:** shows the noise of the different length without using the DCF and with the DCF for 3 cases pre, post and mix(pre/post)

These results have been reported on figures III.32 and III.33.

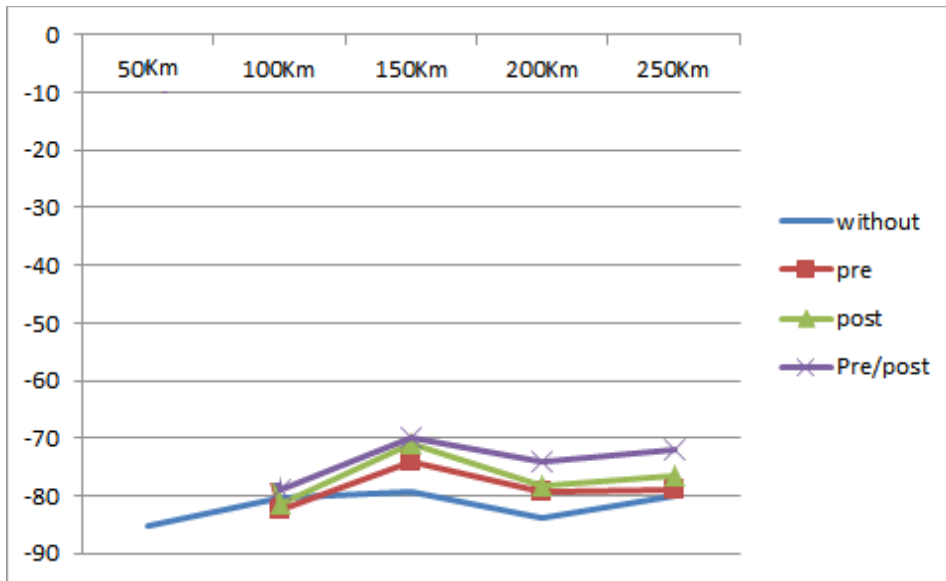


Figure III.32. RF Power level as function of transmission length

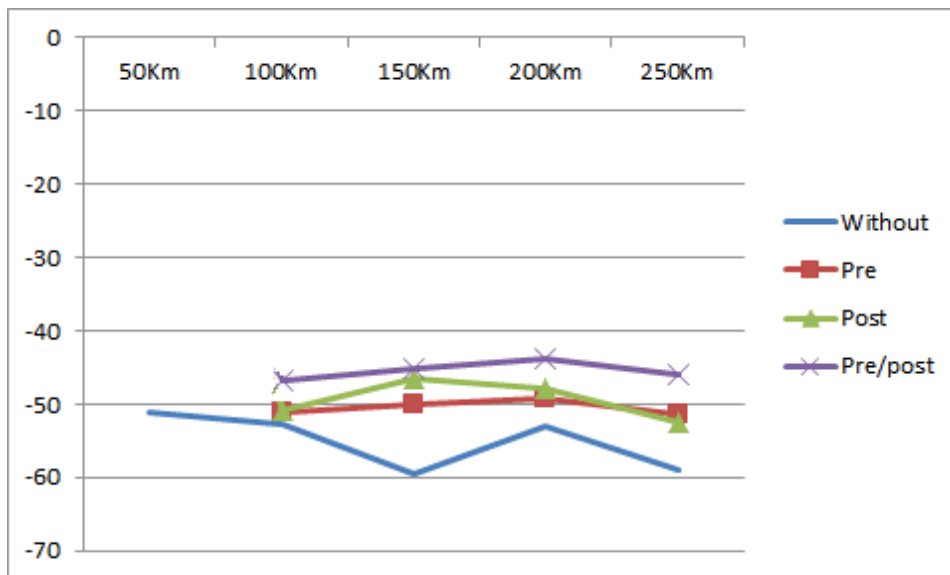


Figure III.33. Noise power level as function of transmission length

## Discussion

From the constellation diagrams it is clear that the signal quality has been significantly improved when dispersion is corrected. This implies that the transmission length can be extended beyond the 250km limit as obtained before.

Further, and from the curves of RF power and noise power, it seems that the pre/pos DCF solution gives better results in terms of RF power level but it introduces more noise. As a conclusion we can say from this study that there exist no significant difference between the three techniques (pre, pos and pre/pos) used to reduce the dispersion effects.

## Conclusion

---

### Conclusion:

In this project we studied and analyzed the performance of a typical passive RoF-OFDM system over different distance values (50 km, 100 km, 150km, 200km and 250km) without and with a DCF single mode fiber using OptiSystem simulation software.

The correlation between, chromatic dispersion, noise, and link distance has been demonstrated.

Simulation results are presented graphically in form of constellation diagrams and signal spectra from which numerical data (signal power and noise power) have been estimated.

From the simulation results, when only attenuation effects are compensated using EDF based optical amplifiers, the output data will become indiscernible after a limit distance of 250km. We have shown that increasing the amplifier gain does not bring any improvement and introduces severe signal degradation due to the resulting non-linear effects and to the increase of the noise power leading to a decrease of the signal to noise ratio (SNR).

The unique way to extend further the transmission length is then to compensate the dispersion effects. We have shown that the DCF dispersion compensation technique make the constellation diagrams clear for the three (pre, post and pre/post) versions even at distances as large as 250km.

Another effect which has been shown by our simulation is the constellation rotation which becomes more important after a certain amplification gain level. This non linear effect which is due to the Self Phase Modulation mechanism can be corrected by introducing an initial phase to the local laser oscillator at the receiver side.

As a further work for future students, we suggest to complete this study by testing the performance of this system using other modulation techniques such as BPSK or QPSK or using other dispersion compensation techniques such as Electronic Dispersion Compensation (EDC), Fiber Bragg Grating (FBG) and digital filters.

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