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ENHANCING THE PERFORMANCE OF RADIO OVER FIBER NETWORKS BASED ON WDM USING DIFFERENT MODULATION FORMATS

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This is to certify that I have read this thesis and that in my opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science

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HUMAM NEAMAH HUSSEIN

[Signature]

DEDICATION

I would like to dedicate this work to my very first teacher, my mother, my first supporter and role model, my father and my companion throughout the journey. Without you, this dream would never come true and to my brothers and my sister who stood with me in order to achieve my dream.

ACKNOWLEDGEMENTS

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ABSTRACT

ENHANCING THE PERFORMANCE OF RADIO OVER FIBER NETWORKS BASED ON WDM USING DIFFERENT MODULATION FORMATS

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In our system design, we use C-band because we want to design a radio system via optical fiber cable to provide high speed (bitrate) and large bandwidth. The modern system is configuring by interpolating the new group of devices together then the recent features are extracted like the bandwidth. In this thesis, three test beds are taken to demonstrate different proposals to studying the (RoF) architecture based the optical network with various modulation format, several bitrates, diverse fiber optic extents, and many users by Wavelength-Division-Multiplexing (WDM) techniques. Radio-over-Fiber (RoF) technique is used to modulate the light signal with a radio signal and transmit the signal through optical fiber cable. In the first experimental work, the DPSK as the modulation system, 40Gbps of bandwidth is utilized. In additional to the WDM in multiple channels, the fiber span is 50Km of SSMF, the wavelength (nm) or frequency (THz) on the ITU standards also used in the experimental tests.

There are many optimization techniques are being utilized on the CW laser power to get the best outputs, to overcome the nonlinearities phenomena we used the EDFA. In the second proposed experiment, the RoF architecture is used based on the subcarrier of ASK and WDM. In the last experiment, another RF network is utilized to Return to Zero (RZ) based on VCSEL.

In this work, all experimental results outcome from our simulation present respectively: the input power average is (4.8dBm), the max Q-factor average is (5.93), the min BER average is (6.17E-7), the total output power average is (-27.55dBm), the OSNR average is (33.73dB) on two channels, the average of OSNR is (53.36dB), the total output power average is (-48.87dBm), the average of the Max Q-factor is (5.28), the average of the Min BER (2.44E-7), the total power average of the RoF system is (6.53dBm), the average of the Max Q-factor is (6.67), the average of the Min BER is (3.43E-11) and the average of OSNR is (29.64dB).

They are good results and performance due to choosing an attractive characteristic of components which configure this structure.

Keywords: RoF; WDM; SSMF; CW; VCSEL.

Abstract in Turkish language

Abstract in Turkish language

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LIST OF ABBREVIATIONS

RoF : Radio over Fiber

FOCS : Fiber Optic Communication System

WDM : Wavelength Division Multiplexing

SSMF : Standard Single Mode Fiber

VCSEL : Vertical Cavity Surface Emitting Leaser

CW : Continues Wave

NRZ : Non Return to Zero

RZ : Return to Zero

ASK : Amplitude Shift Keying

DFSK : Deferential Phase Shift Keying

BER : Bit Error Rate

OSNR : Optical Signal to Noise Ratio

cr : Fall time coefficient.

$\Delta\varphi$: Phase difference between two successive time instants.

dt : Phase difference between two successive time instants.

v_i : Signal for each carrier.

N : Parameter Number of channels.

v_{bias} : Parameter Bias.

f_i : Frequency of each carrier.

v_{in} : Input electrical signal.

G : Parameter gain.

b : Bias.

f_c : Carrier frequency.

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1. INTRODUCTION

1.1 Introduction

Wireless communication offers a new phase of technology. Radio over fiber (RoF) has been addressed as one of the new technologies as how to distributing broadband wireless signals in access networks. RoF access points can be used at suitable locations throughout the network along to provide a low cost and high bandwidth solution [1].

A big data has been needed in a system which is providing more (carrier- frequency) for increasing the feeder network capacity, [2]. (RoF) is utilizing to transport data through an optical fiber by modulating the light with the radio signal. Modulation has been done immediately by utilizing radio signals. (RoF) systems have been utilizing optical fiber as low loss and wide bandwidth transmission medium, which is making distribution the broadband data and/or high-frequency signals to many base stations are easy, [3].

Increases the number of connected devices in the home or society lead to Increase bitrates between each client. The ultimate goal in a home network like Remote Backup, Video Conference, Video On Demand, Voice Over IP, Data Exchange in High-Definition, HD Streaming, Mobile. Broadband, Online Gaming. The wireless connectivity is generally preferred for the final link to the device due it is easy to use and very flexible. In the future, "IEEE 802.11.ad" will be the radio standard to transport data at very high throughputs. But, this radio standard has a short range (less than 10m) [4]. The RoF systems can be adopted as a new paradigm "Green Radio" as low power networks, like as; "safe connected home" and "future hospital". To enlarge the coverage area, provide new access networks based in fiber-to-the-X (FTTX) and Mobile (4G, LTE-advance). Deploy new wireless technologies with high datarate in short-medium ranges (ultra-wide-band (UWB), WiMAX, 60GHz, ...), [5].

1.2 PROBLEM DEFINITIONS

There are many considerations have been taken for accounting the radio-over-fiber systems. These procedures have been shown as modulation-format, bitrate, and fiber-type.

In this project, we have been enhancing the performance of a system by utilizing a good modulation format, convenience fiber length and type, multiple users by using (WDM.), and best using of the bit rate for getting the best output.

1.3 Contribution of thesis

In this section, the aim of our thesis is introducing as the following:

1. Enhance the (RoF) system performance through (WDM) and Modulation formats.
2. Merging of (RoF) and (WDM) systems for increasing input users at same link.
3. By using Few components, will be increased the reliability and reduce the operational expenses.
4. Overcome the nonlinearities problems by using (RoF)

1.4 Thesis organization

The thesis organization fall into six chapters, in chapter two we demonstrate the literature review that was introduced by previous researches, in chapter three give an introductory to radio over fiber system and Fiber Optic Communication System, our experiments are displayed and discussed in chapter four that include design, simulate and test our experiments, in chapter five we will give an explanation for our results, finally in chapter six will demonstrate the conclusion and suggestion for future works.

2. LITERATURE REVIEW

In this chapter, we present a literature review for the previous related works of the Radio over fiber system as the following:

Mikihiro and et.al. [6] is studied that the multiplexing of the wavelength division (WDM) approaches have been many advantages to build-up optical interconnect networks (OIN) for massively parallel processing (MPP) techniques. The (1024-channel) network of the (MPP) systems designing procedures have been depended on the interconnection-cached network (ICN). The (ICN) technique participates with the vertical-cavity surface emitting laser (VCSEL) arrays and the one wavelength. The previous approaches have been explained that how the (WDM) version with various wavelengths can be incremented the channel density. Also, the approaches have been displayed that how the (WDM) system can be decreased the fan-in loss by making the factor equal to four. Each (VCSEL) in the array have the same wavelength, but if the size of the arrays is different, the used wavelengths also are different.

LA Johansson and AJ Seeds [7] are stared to report the millimeter wave transmission by using the (radio-over-fiber substantiation and the optical phase-lock loop) techniques. The (36-GHz 140-Mb/s ASK) modulated carrier has been sending through standard single-mode fiber (SMF) with length equal to (65 km) and the Bit-Error Rate must be less than (10-9).

D. Wake and et.al. [8] have been proposed a novel architecture related with the switched RoF. They are tried to give important benefits in design terms by installation and running the used systems. Hong and Et. al. [9], have been also proposed a medium access control procedure that has the fast handover feature and has the dynamic bandwidth allocation properties by using the ability of centralized control of radio over fiber networks. Hong [10] was proposing a radio over fiber that is based on the broadband wireless access network architecture of the rural fields. It is utilized the wavelength division multiplexing to the allocation of the dynamic bandwidth through stations of the demand basis.

Peter and Renè [11] have been studied formats of the advanced optical modulation that have become a key component for the recent wavelength division multiplexing design (WDM) which is optically transported the networks. The work of the (R. Avo, and et. al.) authors [12] are considered limitations of the optical transmission on the digitally modulated system which have (60 GHz) carriers, and various optical modulation approaches. The distance of attainable transmission has discussed in the operating conditions systems.

The Sandeep and et. al. [13] have been proposed and simulated the full duplex data and video signal transmission through the single-mode fiber (SMF), that includes the wavelength division multiplexing (WDM), and the optical add-drop multiplexing (OADM) approaches. There are four data signals (1.25 Gb/s /9.1-9.4GHz) have been sent through the long-haul single-mode fiber to the downlink transmission. The uplink transmission involves four data signals, each signal uses the BS with (1.25 Gb/s/9.6-9.9GHz). The bit error rate (BER) performances are evaluated by applying both the downlink and uplink transmissions on the system of a full-duplex RoF transport.

The authors Ajay and Navneet [14] have been tried to enhance communication performance. The technologies represented by (RoF), the microwave and optical communication combinations) have been provided the unmetered access for the broadband wireless communications. Also, the authors Neelam and Parvin [15] have been explored the suitable ways to solve mobility and capacity increases problems.

Lakshmi and et.al. [16] have been supposed some solution ways for solving the integrated Radio over Fiber (RoF) and the Wavelength Division Multiplexing - Passive Optical Network (WDM-PON).

The authors (S. Revathi and G. Aarthi, [17]) have been increased performance of the optical fiber transmission systems by employing systems of the multi-channel optic that has a large bandwidth possible in the fiber optics. The high-speed signals have been relating with many sequences of the low-speed signals. Today, many limited individual applications are utilizing the high bandwidth. These lower-speed channels have been multiplexing together with the higher-speed channels. There are multiple procedures such as the Wavelength Division Multiplexing (WDM), subcarrier multiplexing (SCM) that has been developing for increasing the transmission systems performance.

The researchers (Arya and Anisha, [18]) have been introducing the RoF method together with the full duplex transmission links connected with the (WDM) over the single mode fiber. Other researchers (Amandeep, and et. al., [19]) tried to increase the performance of the RF signal processing services at the head end. Therefore, the complex (BSs) is greatly decreased by executing the optoelectronic amplification functions and conversion.

Also, the authors (Varghese and et. al., [20]) have been provided a simple review of (RoF) algorithm. In addition, they are discussed in detail the designing of the (RoF) approaches to enhance the performance of the negotiable systems. They conclude that the costs of (RoF) system installations are reduced by decreasing the number of the (RoF) methods.

The authors (Simarpreet and et. al., [21]) have been described the Wireless network procedures that are associated with the Radio over Fiber technology. The previous technology is offered suitable methods to decrease the cost of growing user bandwidth and wireless. They have been applied it on mobile cellular that represented the high-performance system. (Balinder and Davender, [22]) introduce how a large number of users are compared with the traditional wireless communication systems. (Deepika and Swatantra, [23]) are provided the large capacity of the transmission systems like broadband services and the high speed. It is used in different applications such as the radio over fiber comprise cable television and network design.

3. Radio over Fiber System (RoF) and Fiber-Optic-Communication-System (FOCS)

3.1 Motivation:

A communications system has transmits the information from one to another place, whether it is separated via little kilometers or long distance transoceanic distances. Often The Information carried by an electromagnetic carrier wave when frequency can vary from a few MHz to various hundred THz. Optical communication systems utilize great carrier frequencies (100 THz) in visible or near infrared region of electromagnetic spectrum. It is sometimes called lightwave systems to recognize it from microwave systems, who's the carrier frequency is usually minimal by five times of magnitude (1 GHz). (FOCS) are lightwave systems that use optical fiber to transmit information [24].

The motivation to develop (FOCS) began with the invention of the laser in early (1960s), this device has operational characteristics that encouraged researchers for examine the optical spectrum as an extension of microwave and the radio spectrum to provide extremely high-speed transmission links. From many pieces of research, it becomes obvious that many complex problems stood in the way of achieving like high-broadband-communication-system [25].

3.1.1 Structure of Optical Fiber

Optical fiber cable is consist of three layers they are core, cladding and buffer coating, in the following, there is short information on each layer.

- The core- It is a very thin central tube made up of optically transparent dielectric medium that carries light from transmitter to receiver [26].
- Cladding - The external optical material surrounding core that has a different reflecting, the Cladding has a lower reflecting than the core. The difference in refractive indices it is enables fibers to guide the light. Because of this guiding property, the fiber also indicates to as an optical waveguide [26].

- Buffer Coating – A plastic coating is used to protects the fiber made that made from silicon [26].

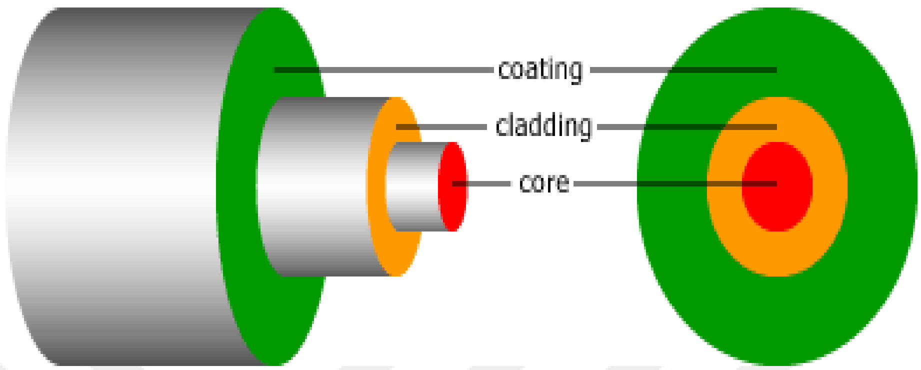

Figure 3-1: Cable layers of optical fiber (a high index core surrounding via a lower index cladding) and covered with a protective coating

3.1.2 Fibers types according to mode numbers

According to mode numbers of optical fiber propagation have been two kinds of mode as the following.

3.1.2.1 Single-mode fiber (SSM)

(SMF) are a common type of fiber optic that use to transport over longer distances. It has a narrow-core; the diameter is eight-microns or less. (SMF) features only one transmission mode. Compared with multi-mode fiber, it can carry higher bandwidths; however, it needs to have a light source having a narrow spectral width. Every year, millions kilometers of this fiber are installed to provide services like Telephone and cable television networks [27]. Figure 3-2 shown to us the single-mode fiber type.

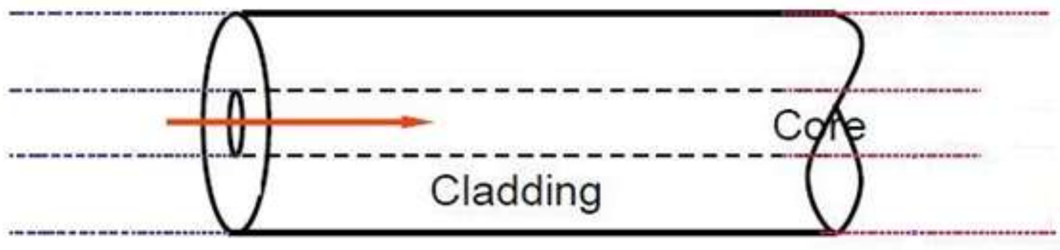

Figure 3-2: optical fiber type single-mode fiber

3.1.2.2 Multi-mode fiber (MMF)

There are two (MMF) types according to Refractive index, they are step- index, and graded-index. We have been explaining each of them in the following:

- **Step-index of Multi-mode fiber**

  It has a large big core, up to (100-microns) in diameter. As a result, some of the digital pulse that is formed by light rays may take a direct route, while others zigzag like it bounce off cladding. These alternative routes result in the arrival of various sets of light rays, indicate to as modes, to a separately arriving at the reception point. The pulses, a set of various patterns, start to spread, losing their well-defined shape. Leave a space that required between pulses to prevent overlapping cause limits bandwidth, that is the information-amount will be transmitted. Therefore, this fiber type considers as a best suited for short distances transmission, [28].

- **Graded index Multi-mode fiber**

  It is Contains a core that the refractive index approximately decreases from central axis towards the cladding. The high-refractive-index in the center make the light rays move down axis tardily than those close to the cladding. Also, instead of the zigzag of cladding, the light in the core curves helically because of graded index, which decrease travel distance. The shortest path and high speed allow light at periphery to access to a receiver at about similar time as slow and straight rays in the core axis. The result of that the digital pulse suffering from less dispersion [28]. Figure 3.3 has illustrated the behavior of the signals in two MMF types.

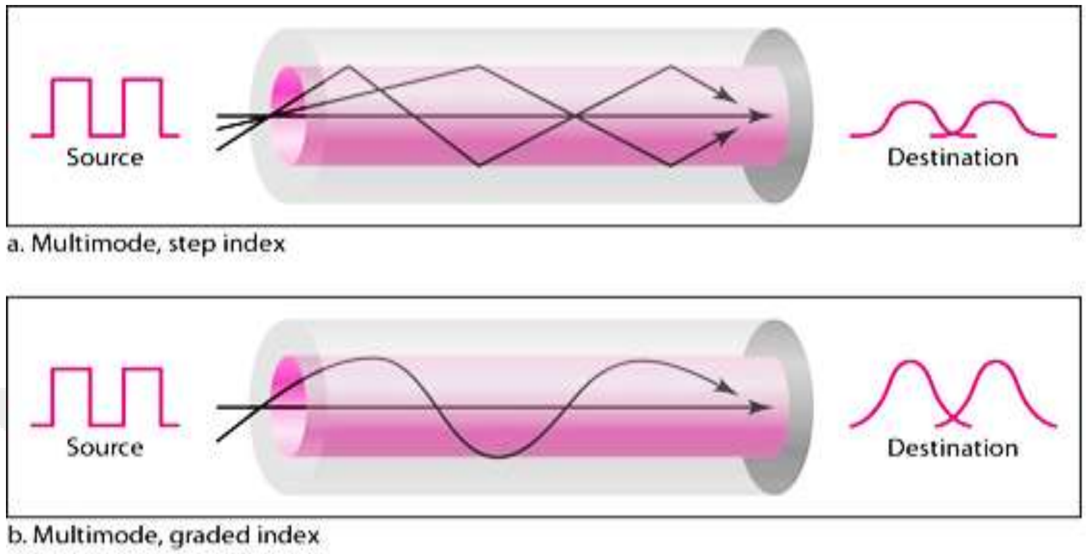

Figure 3-3: Show optical fiber type (M.M.F)

To transmit light over fiber optics, it must obtain a total-internal-reflection, an optical phenomenon that occurs when a ray of the light encounters a "medium boundary" an angle greater than a specific critical angle with respect to normal of the surface. If refractive index is lower on another side of the border, no light able to pass through it, and all light is reflected.

When the light crosses the boundaries between materials through various refractive indices, the optical beam will partially refracted over the surface of the boundary. However, if the angle of the incidence is bigger than the critical angle then the light stops crossing the boundary completely and be fully reflected back inside. This happens only when the light moves from a medium with a height to a lower refractive index. For instance, it will happen when passing from glass to air, but not Reverse when it is moving from air to glass. Figure 3.4 shows the total-reflection scheme.

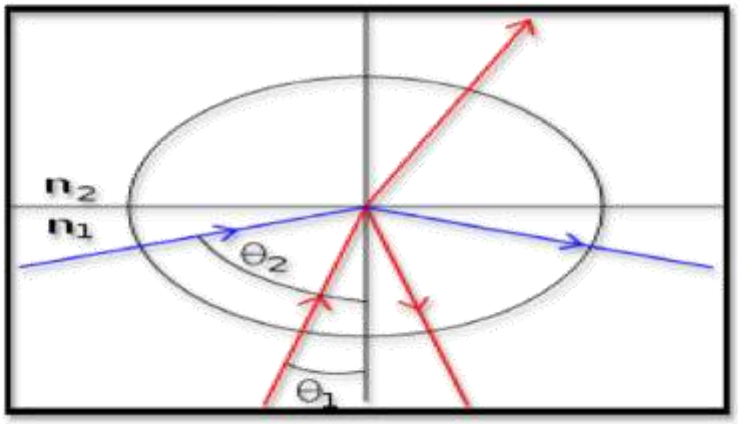

Figure 3.4: show total internal reflections (n1>n2)

The greater the angle to normal, the minimum part is the transmitted light, even the angle when total internal reflection occurs. The critical angle is the angle of the incidence above which the total internal reflection occurs.

The incidence angle can be measured in relation to normal at refraction boundary. The critical angle (θc) has given by:

$$\theta c = \arc \sin (n2/n1) \tag{3.1}$$

Eq. (1.1) is known as total internal reflection [29].

Where (n2) is refractive index of minimal optically dense medium, and (n1) is refractive index of maximal optically dense medium. when the fraction (n2 / n1) is bigger than (1), then (arcsine) is not defined in the sense that there is no total internal reflection until in the shallow or grazing incident angle, so the critical angle is considered just when (n2 / n1) is smaller than (1).

3.2 The Fiber Optic Communication System (FOCS) performance

A (FOCS) performance is done based on main three parameters as the following:

1- Bit-Error- Rate (BER): Is the probability that a bit is identified incorrectly by the decision circuit of the receiver, [24].
2- Optical Signal to Noise Ratio (OSNR): Indicates the degree of degradation when an

optical signal is carried in an optical transmission system. (OSNR) is the ratio of optical signal power to noise power in the channel, [24].

3.2.1 Fiber Optics Advantages

The Optic Fiber systems have been several attractive-features that are superior to electrical as the following specifications:

- Increased bandwidth and greater speed: The fiber-optic cable provides very huge bandwidth and speed. The information amount that able to transferred per unit through fiber optic cable is a most important feature.
- Cheap: Numerous miles made from the fiber cable would be cheaper than similar lengths of the copper cable.
- light weight and Thinner: Fiber Optic is thinner, and can be pulled to drawn of copper wire diameters. They are smaller in size and lighter in weight than a cable that made from copper, making them better suited to places when space is most important and concern.
- Higher carrying capacity: Since the fiber is much thinner than the copper cable, several fibers can be assembled and extend them in limiting diameter cable. This is allowing for several phone lines Passing through at the same cable or many channels to going over cable to your (cable TV box).
- Low signal degeneration: signal loss in optical fiber cable less than compared with copper cable.
- Light signals: No interference is there between fiber that transmits at same cable, Reverse the electrical signals when transmitted through copper wires, this is meaning clear conversations on the phone or TV reception.
- Long life - fiber optics typically have a greater lifespan of more than 100 years.
- Electrical noise immunity: noise immunity electromagnetic interference and radio frequency interference, [30].

3.2.2 Fiber Disadvantages

- Limited application: The fibers able to utilized just to install on the ground, and it's unable to left ground or working with mobile communications.
- Low power: low power is limited by the Light emitting sources. the high energy power is available to enhance the power supply, but they will add additional cost.
- Fragility: Fiber optic cable is somewhat fragile and more prone to damage compared to copper cable. It is best to don't bend or twist the fiber optic cables.
- Distance: required a short distance between transmitter and receiver, if they make long distance, the number of repeater devices should be increased to improve the signal, [28].

3.3 Radio over Fiber System

In this section, we will introduce the relationship between (RoF) properties that are effecting on the (RoF) system behaviors:

3.3.1 Radio-Wave

The propagate of the radio waves are very similar to the surface water waves. It travels near the Earth's surface and also radiates towards the sky at different angles to the Earth's surface. Accordingly radio waves travel, propagation their energy is increasing the surface area. The typical radio wave consists of two components, a top top part and a basin bottom part. These components move outward from a transmitter, one after other, at a constant speed. A wavelength is a term referring to distance between successive wave crests, [31]. The electromagnetic wave spectrum is showing in (Figure 3.5). This part Usable for radio communication ranges that the range of it between (3 kHz) to (300 GHz).

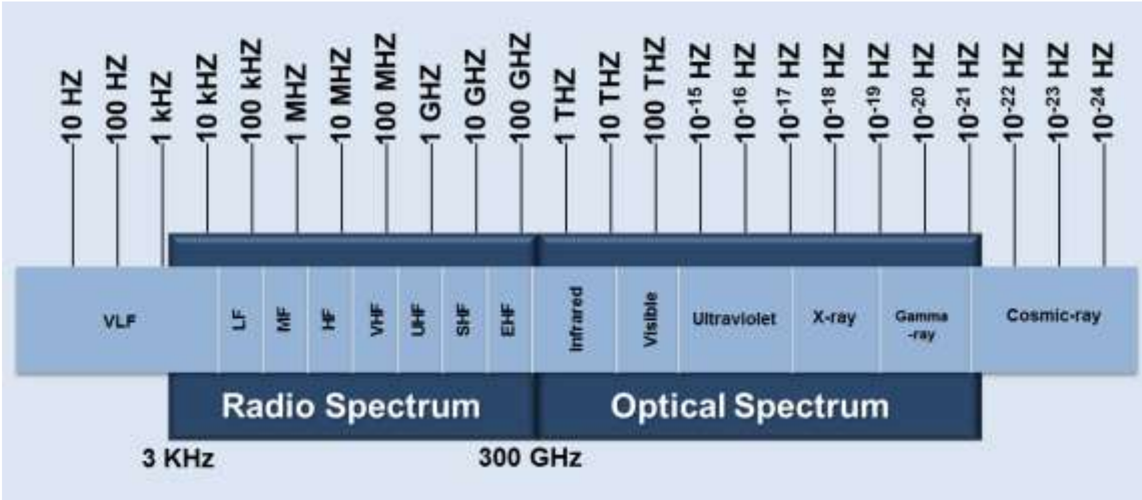

Figure 3.5: shows Radio Frequency Spectrum

The radio spectrum is separated into bands and designation of the bands. Waves of Various frequency is behaving differently, and their use is regulated with the amount of the spectrum offers in terms of radio communication channels in every band, governing their usage [32].

3.3.2 Radio over Fiber (RoF) Concept

(RoF) indicate to a technology when the light is utilized to modulate it with electrical signal as radio signal and transfer it through a fiber optic link to spread radio signals from the headend to the remote antenna unit (RAU).

The radio signal frequency is spread via (RoF) extend over a wide range typically in the GHz region and adopt on nature of the applications. The electrical signal might be baseband data, (IF modulated), or the (RF) signal to be spread. (RoF) systems are typically categorized within two main kinds, they are RF over fiber and IF-over-Fiber adopting on the frequency band of a radio signal that wants to transmit it, [33].

In an RF-over-Fiber architecture, a (RF) signal that carrying the data with high-frequency (typically higher than 10 GHz) is charged to a light-wave signal before being transmitted through an optical link, [33].

In the (IF-over-Fiber) architecture, an Intermediate Frequency (IF) radio signal with a low frequency doesn't exceed (10 GHz) is utilized to modulate the light signal before transmission via optical link [34]. (IF) through multi-mode fiber or single-mode fiber, the (RF) signal from a base station is downconverted to IF and transferred to remote antennas where it is upconverted back to the original (RF) [35].

3.3.3 (RoF) Architecture

The Transmission of high frequency (HF) signals are extra challenging since it needs (HF) components and a huge link bandwidth. This indicates that (HF) signals are more susceptible to transmitter, receiver, and transmit link signal impairments, [36].

The transmission (RF) signal on it is frequency, not always have required to do that. e.g., the local oscillator signal (LO), if offered, can be utilized to down-converted uplink carrier to an (IF) in the (RAU). Do that will support to utilize the low frequency components path in (RAU), thus saving system costs.

Rather than placing a separate (LO) in (RAU), it can be moved from the headend to (RAU) through (RoF) system. Once availability at (RAU), the (LO) can be utilized to obtain a down-conversion for uplink signals. The (RoF) system consists of a remote Site (R.S) and central Site (CS) connected via fiber optic link or network as displayed in Figure 3.6.

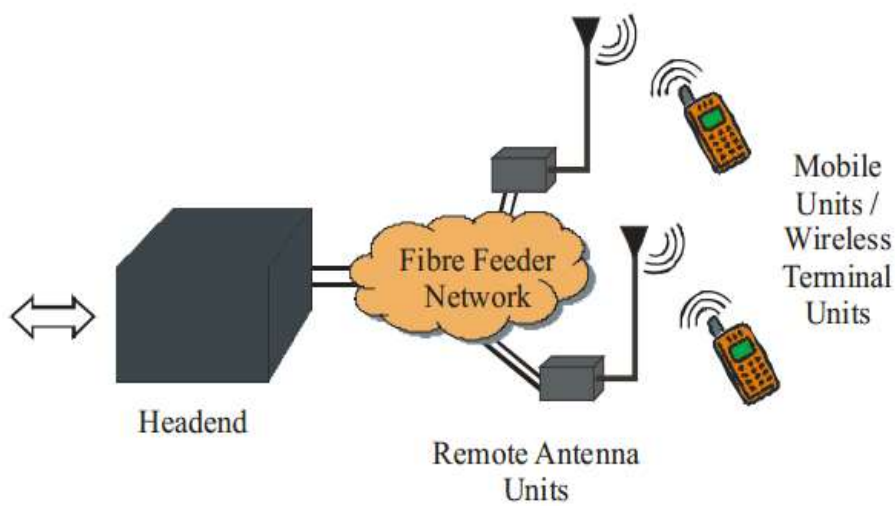

Figure 3.6: shows (RoF) concept [37]

The principal benefit of the (RoF) systems is an ability to focus utmost of the radio signal processing functions like frequency up-conversion, carrier modulation, and multiplexing, is performed at (BS) or Radio Access Point (RAP), and instantaneous insertion into an antenna. (RoF) enables centralization of (RF) signal processing functions through one headend shared location [36].

Easier (RAP) means smaller and light containers easy installation and more flexible and lower cost in terms of the costs of equipment and costs of the maintenance. the Centralized results in sharing the equipment, dynamic resource allocation and extra effective management. This will add to obtain on technology that makes life easier and lower cost for operators. The reduction in the base station or the complexity of the (RAU) is an attractive result of the use of (RoF) links. Reducing the complexity of the remote base station is also considered attractive because equipment, construction and maintenance costs will be decreased, [38].

Optical links in (RoF) is analog in nature, which has benefits like reproducing the carrier waveform. Digital modulation scheme can be utilized modulate radio carrier through (GMSK in GSM) or (QPSK in UMTS) [38]. The (RoF) architectures are displayed in Fig. 3.7

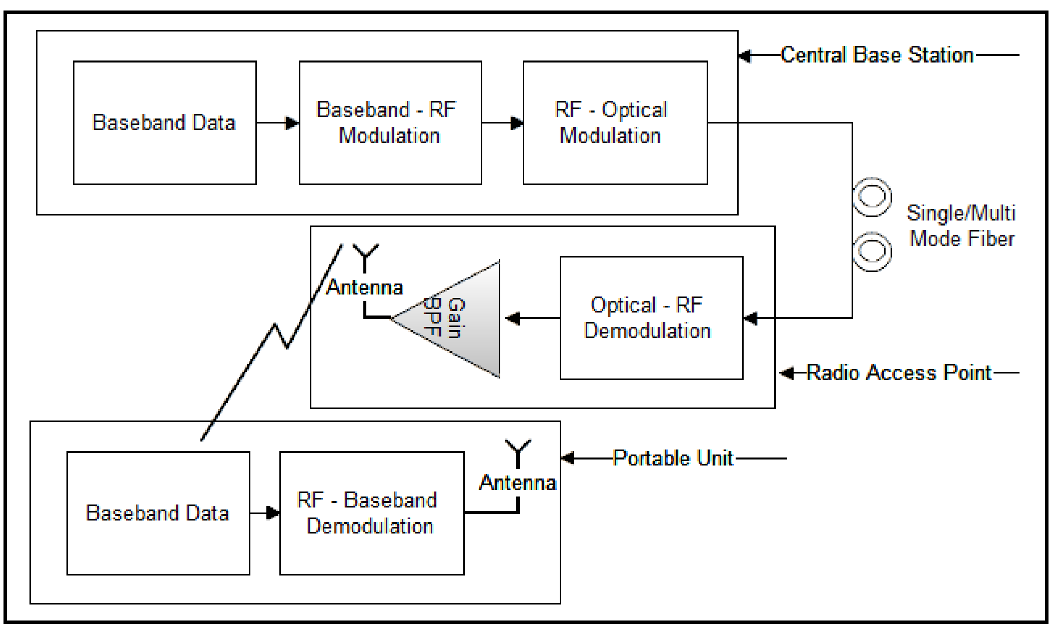

Figure 3.7: shows (RoF) Architecture

3.3.4 (RoF) technology benefits

The (RoF) technology has several benefits, in the following part we will discuss Some of them:

3.3.4.1 (Low-Attenuation-Loss)

It is a well-known fact that signals sent to fiber optic attenuate much lower than another media, essentially when compared to a wireless medium. The signal will be travel more via Using fiber optics, so the numbers of replicates will be reducing [39].

3.3.4.2 Large Bandwidth

Fiber optics has provided huge bandwidth. Three main transmission windows that provide low attenuation, they are (850 nm), (1310 nm) and (1550 nm) wavelengths. For an (SMF) fiber optic, the collective bandwidth of the three windows is more than (50 THz). The huge bandwidth provided via fiber optics has another advantage regardless of the high capacity to transmit microwave signals. High bandwidth allows processing the high-speed signal, which may be more complex or impossible to perform in electronic systems [39].

3.3.4.3 Maintenance and Easy installation

In (RoF) technology, the expensive equipment and complex are maintained in the headend, this is a way to making Remote-Antenna-System (RAUs) easier and simpler. Some of the equipments that kept at headend like switching equipment and Modulation are shared via many (RAUs). This arrangement offers a lighter and smaller (RAUs), which effectively decrease the maintenance costs and system installation [40].

3.3.4.4 Immunity for (R.F) interference

Immunity in the Electromagnetic interference (EMI) is consider as a attractive feature in fiber-optic communications, particularly to transmission microwave signal. The reason of that is the signals are transmitting in the light form over optical fiber [41]. Also because of immunity, fiber optic is better choice until in the short connection at in (mm-waves) [42].

3.3.4.5 (Dynamic Resource Allocation) & (Operational flexibility)

It is useful to put new modulation and switching equipments at Central Site (CS), it is allowing to the dynamic allocation of capacity, it is available to dynamically allocating at (peak time), while reducing the distribution of the capacity in (off-peak). The channels allocation for several users can be dynamically allocated to ensure efficient resource management as it will be a waste of the resources to allocate capacity to the Uninhabited area [43].

3.3.4.6 (Power Consumption reduction)

Because there are easier radio stations, power consumption is reduced. The complex equipment is put at the (CS). In many applications, inactive mode are turned on for antenna sites. E.g., many (5 GHz) radio systems that contain Pico cells that as represented as small radio cells which is can have base stations operating in an inactive state. [44]

3.3.4.7 (Low-complexity)

(RoF) utilizes the remote station (RS) concept. This station is only consisting of optical-to-electrical (O/E) and optional frequency that up or down converter and antenna and amplifiers [45]. This means the signal generation circuits of base station and resource management can be changed to a headend, and shared to various remote stations, so the structure will simplify, [39].

3.3.4.8 Lower cost

The easier structure for the remote base station (RBS) means low power consumption and minimal cost infrastructure via devices and easier maintenance that reduces overall the maintenance and the installation costs. Another reduction can be made by utilizing of low cost graded index polymer optical fiber [45].

3.3.4.9 (Proof Future)

A Fiber Optic is designed to deal with (Gigabit/s) speeds that is means they can be capable to deal with the speeds that available via future generations of networks for coming years. (RoF) system is considered as a protocol and transparent bit rate, so, it is can be utilized for use on the current and future technologies [39].

3.3.4.10 (Multi Operator) and (Multi-Service Operations)

(RoF) provides operational flexibility for the system. adopting on microwave generation technology, signal-format transparent can be made by the (RoF) distribution system [41]. e.g., the (Direct Detection) and (Intensity Modulation) (DD-IM) techniques capable of operating as a linear system and thus as a transparent system [40].

3.3.5 The Limitations of (RoF) technology

There is some (RoF) technology limitation are explained follow, [46]:

- Dynamic range is poor.
- Effects of the dispersion in fibers.
- Relative Intensity noise in the laser source.
- Nonlinearities device can be (detrimental).

The recent (RoF) technology includes as analogue modulation and the light detection, it's principally and analogue transmission system. The impairments signals like distortion and noise are very important for the analog communication system and (RoF) as well. These impairments are limit the Noise Figure (NF) and dynamic range (DR) of (RoF) links [47]. But inside the same cell. (SMF) adopt (RoF) technology, may limit the length of the fiber link so increase (RF) carrier phase noise. In the (MMF) adopt (RoF) technology, the model has a various limit like the distance and the bandwidth [48].

In this work, we try to overcome the above limitations by use multiple carrier, amplification process, VCSEL laser, and selected convince frequencies respectively.

3.3.6 (RoF) applications

The (RoF) applications involve cellular networks, wireless local area network (WLAN), vehicle communications and control, Orthogonal Frequency Division Multiplexing (OFDM)-(RoF) systems, military applications, high-speed sensing, Millimeter fiber transmission, satellite communications, In the following section, we will describe them:

3.3.6.1 (Cellular-Networks)

(RoF) technology via capable to be the best choice for use in the cellular system for the cell improvement style as it will be used simply in the (millimeter wave band) in addition to it will reduce the total price of the system. Mobile traffic between the base station (BS) and the central site (CS) is migrated through the (RoF) system [49].

3.3.6.1 (Wireless local area network) (WLANs)

As the computers and the portable devices are become more powerful and more widespread, (RoF) capable to utilized to distribute (WLAN) signals that run from (2.4) GHz to (5) GHz [50].

3.3.6.2 (Vehicle communication) and control

(RoF) capable to utilized for the road connection system and the intelligent transportation system. To achieve the coverage required for road network, many base stations are needed. These will be lower cost and easier via feeding them through (RoF) systems, making the whole of the system are manageable and effective in the cost [39].

3.3.6.3 (Orthogonal Frequency Division Multiplexing) (OFDM-RoF) Systems:

(OFDM) system via the (RoF) is evaluated for increasing modulation technology and overcoming multiple wireless transmission limitations like chromatic dispersion, power attenuation, and phase modulation via an optical link. The combination system has several benefits for a high speed data transmission system in the future [39].

3.3.6.4 (Military Applications)

For the security reasons, radio frequency signals (RF) or broadband microwave received via a radar through fiber optic are transmitted in the (RoF) communication method to the end of remote. This will result in fewer casualties in event of the radar strikes. [39]

3.3.6.5 (High-Speed) Sensing

A (RoF) communication is utilizing for the fast transmission of video monitoring signals on the jumbo jets and the high-speed trains, where broadband transmission and also less electromagnetic pollution can be achieved [39].

3.6.6.7 (Millimeter Fiber Transmission)

Millimeter wave at (60 GHz) and above produces fast attenuation and low electromagnetic interference, and is therefore well suited for indoor coverage. With each other of (RoF) communication, electromagnetic pollution and electromagnetic interference problems can be handled in the best way [39].

3.6.6.8 (Satellite Communications)

One application involves the transfer of antennas to appropriate locations in satellite earth stations. Short fiber optic link doesn't exceed than 1 km are utilized when operating at (1 GHz and 15 GHz) frequencies. Thus, some of equipment like high-frequency will be centralized. Another application includes reconnection of the earth stations themselves. Via utilizing (RoF) technology, antennas can be placed several kilometers away to improve satellite visibility or decrease interference from another terrestrial system, [51].

3.3.7 Important characteristics of (RoF)

The (RoF) has important characteristics which affected on its performance; therefore, we are summarizing these characteristics in the following parts:

3.3.7.1 Insensitivity to (Electromagnetic Radiation)

(RoF) was first implemented to obtain a cordless telephone service in the 1990s. The insensitivity of the cables that made from fiber to electromagnetic radiation is a key feature in their implementation as a wireless network backbone. The traditional link between antenna and radio base station (RBS) was a copper coaxial cable. The use of fiber optic cable lead to low power consumption, lower fiber attenuation and reduce the cost of maintenance. according to the easier structure of base station (BS), it is very reliable and also the system maintenance has become very simple. (RoF) can provide coverage in areas when the effect of direct reception is less, such as basements or large buildings, [52].

3.3.7.2 (Indoor and Outdoor) Environments

By the electromagnetic properties in indoor environments, the (EM) field is restriction via walls. However, in outdoor environments, particularly at the frequencies around (60 GHz), the additional attenuation is needed because the oxygen absorption is determinate the range of transmission. The result is a small cell for both cases compared with microwave bands such as (2.4 or 5 GHz), requiring the deployment of several base stations to cover a huge service area, [52].

3.3.7.3 Multiple services over a single fiber

The transparency of the protocol and the format of the radio interface that involves (modification, RF, bit rate etc.) are considered as one of the main motivations of (RoF) Therefore, multiple services at the same time can be provided via the single optical fiber. long transfer distances can be obtained between the central site (CS) and the base station, [52].

3.3.7.4 Low Attenuation

Other (RoF) motive is that the low attenuation, the lower attenuation is equal to (0.2dB/km) at a range of (1550 nm). Because of this lower attenuation, greater distances can be achieved without the need to use the repeaters. The attenuation is referred to manufacturer properties, so it does not depend on the modulation frequency, [52].

3.4 Wavelength Division Multiplexing (WDM) networks

Wavelength Division Multiplexing has particular to achieve huge capacity over fiber optic transmission for any type of modulation [53]. (WDM) is a device that allows sending various data streams over a single fiber. By sending (2) or more (2) signals on each fiber, so the transmission capacity will be doubling. (WDM) usually contains a common parameter with a number of (I/O) parameters. A (WDM) is essentially an optical transmission technique. In addition, (WDM) using the fiber optic for data transmission. The ability to use existing fiber optics more efficiently makes the (WDM) a very attractive business proposition. This is a motivation to develop existing of the optical communication systems to (WDM) according to achieve an optical network infrastructure to offering access to the plurality of persons living in urban and rural areas, since it is usually too expensive to install a new fiber in areas. The fiber network able to connect rest of world via an existing cable, and this would significantly reduce the access fee. In existing fiber optic communication systems as explained above, just a little fraction capacity of the fiber is utilized, but via utilizing the (WDM) it is able to exploit the large capacity more efficiently. Many (WDM) devices are offers on the market today, and more devices are emerging.

Many WDM devices are available on the market today, and there are more emerging devices [54]. Figure 3.9 illustrates the (WDM) concept

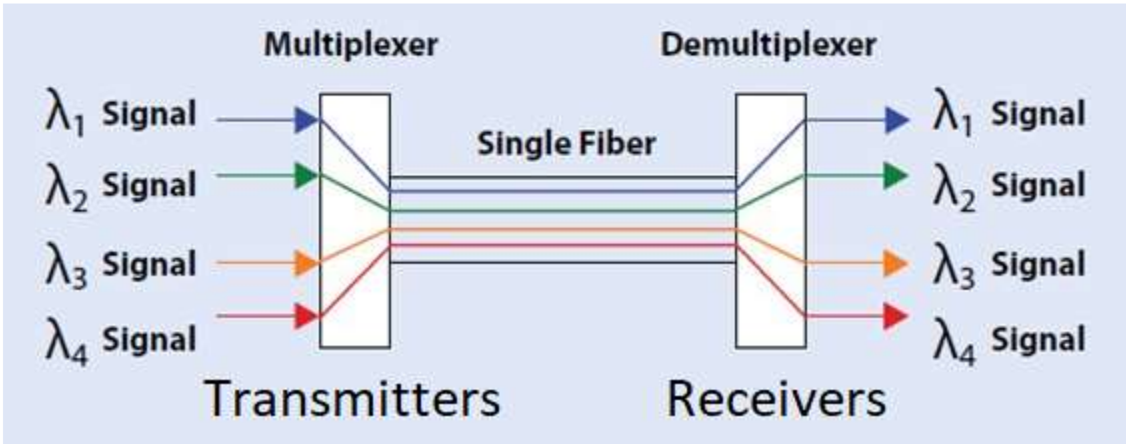

Figure 3.8: show (WDM- concept),[54]

4. SIMULATION MODEL

In this thesis, many of the optimization processes are implemented on the optical network by applying the RoF technology with fewer components (passive/active). The Optisystem software package is utilized to achieve each of the (designing, simulation, testing, and verifying), within C-band which refers to a wireless optical communication window, to the wavelength range between 1530 and 1565 nm (195.90THz, and 191.50THz), the reason of selection of these frequencies is to adaptive with the fiber optic nature as the ITU frequency grid and corresponding wavelength.

Three experiments have been proposed to competition the infrastructure components existing in the many optical networks and according to the monitors, at the end side receives; the output signals are fitting because there is the drawback of degradation and allowable errors in a bit. The output signals in our simulation viewed depending on the signal shape and the values of the output power and eye-opening based on the BER analyzer. In the following subsections three testbeds for ROF technology based on the various techniques are established as follows:

4.1 THE 40GB/S ROF ARCHITECTURE BASED DPSK:

This system consists of five subsystems as (2 transmitters, 2 receivers, transmission link). The bandwidth of this system is (40Gbps) equivalent to (80Gbps) for two channels. By utilizing the following subsection, we demonstrate each of them in details: each transmitter consists of many components Figure (4.1), the pseudo random bit sequence generator (PRBSG) used for generating the random seeds of the bit. After that, these bits entered precoder for taking some delay before launched to non-return-to-zero (NRZ).

The behavior model illustrated in Eq. (4.1), that is responsible for generating an electrical signal to forked into two ways of the input. The LiNb Mach Zehender used to modulate the electrical signal with an optical signal produced by the continuous wave (CW) laser with a wavelength of (1552.52nm) or frequency of (193.1THz) to obtain a good output. We optimize the input power ten times (1mW to 10mW), as the electronic devises properties we try to show an optimization on these values to exclude the best value, by the way of the LiNb MZ output as an optical signal. It is entered to the second one of LiNb MZ for modulating it with the sine signal (Radio Frequency) which has been generating by sine generator that will be gained by the electrical gain equal to (1).

The output signals from the MZ modulator channel_1 (193.1THz), and channel_2 (193.2THz) are considered as inputs to the WDM (2×1) with its properties (bandwidth=40GHz, depth=100dB, filter type of Bessel, and filter order equal to 2).

The output signals are entered to the loop control with an iteration of 6 and then launched to the transmission link subsystem as showing in Figure (4.2). That consists of the (two spans of SSMF 25km of length for each, with properties and values are displayed in Table (4.1), and (4.2), three EDFA with gain=5dB, and noise figure=6dB). These amplifiers utilized for amplifying the signals (pre-amplifier, In-line amplifier, and post amplifier). The DCF components are very important because it provides dispersion compensation which occurs through the signal journey with properties as displayed in Table (4.3), and (4.4), then the signal back to the loop control before entering to the de-multiplexer (1×2), to isolate each input signal at the output channel. At finally, the receiver side as illustrated in Figure (4.7) consists of two subsystems, each of them consist of (MZ) interferometer operate as tunable filter and coupler, and it has 2-inputs and 2-outputs ports, the output optical signal goes to two Photodetectors of type positive intrinsic negative PIN to convert it from an optical to an electrical, and each outputs entering to the electrical subtractor and filtered by the low pass filter with cutoff frequency=$3.2*10^{10}$ Hz, regenerated it by the 3R to reshape and amplified to monitored by the BER analyzer:

$$E(t)=\begin{cases} 1-e^{-(t/c_r)}, 0 \leq t < t_1 \\ 1, t_1 \leq t < t_2 \\ e^{-(t/c_f)}, t_2 \leq t < T \end{cases} \tag{4.1}$$

Eq. (4.1) is known as Non Return to Zero (NRZ), [55].

Where c_r is the rise time coefficient, c_f is the fall time coefficient, t_1, and t_2, together with c_r and c_f, are numerically determined to generate pulses with the exact values of the parameters Rise time and fall time and T is the bit period.

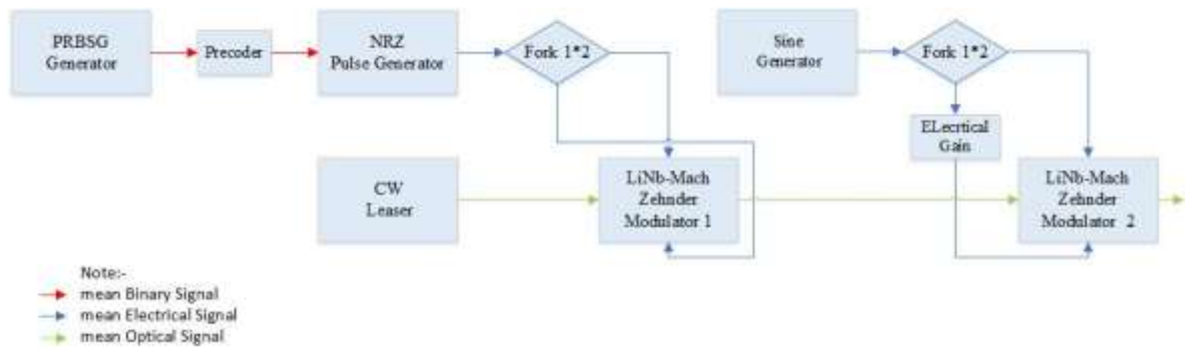

Figure (4.1): the transmitter components

In this experience we have two transmitter channel. Both transmitters have the same component, Figure (4.1) shows the components of one transmitter, each transmitter consists from many components, the pseudo-random bit sequence generator (PRBSG) used for generating the random seeds of the bit. After that, these bits entered precoder for taking some delay before launched to non-return-to-zero (NRZ), that is responsible for generating an electrical signal to forked into two ways of the input. The LiNb Mach Zehender used to modulate the electrical signal with an optical signal produced by the continuous wave (CW) laser with a wavelength of (1552.52nm) or frequency of (193.1THz), by the way of the LiNb MZ output as an optical signal. It is entered to the second one of LiNb MZ for modulating it with the sine signal (Radio Frequency) which has been generating by sine generator.

Figure (4.2): Transmission link components

While figure (4.2) demonstrates the transmission link subsystem, it is consisting of the (two spans of SSMF 25km of length for each), and three Erbium-Doped Fiber Amplifier (EDFA). These amplifiers utilized for amplifying the signals (pre-amplifier, In-line amplifier, and post amplifier). Using the Dispersion Compensating Fiber (DCF) components are very important because it provides dispersion compensation which occurs through the signal journey, then the signal back to the loop control before entering to the de-multiplexer (1×2), to isolate each input signal at the output channel.

Table (4.1): SSMF main properties

Name	Value	Units
Reference Wavelength	1550	nm
Length	25	Km
Attenuation	0.2	dB/Km

Table (4.2): SSMF dispersion properties.

Name	Value	Units
Dispersion	17	ps/nm/km
Dispersion Slope	0.075	ps/nm^2/k

The previous Tables (4.1 and 4.2) shown for us display the (main and dispersion) properties of the standard single-mode fiber (SSMF).in our system we used two SSMF, the length of each one is 25Km, they are using to send the signal through them.

Table (4.3): DCF main properties.

Name	Value	Units
Reference Wavelength	1550	nm
Length	10	Km
Attenuation	0.5	dB/Km

Table (4.4): DCF dispersion properties.

Name	Value	Units
Dispersion	-85	ps/nm/km
Dispersion Slope	-0.3	ps/nm^2/k

The two Tables above (4.3 and 4.4) are displayed the (main and dispersion) properties for a specific type of amplifier, it is Dispersion Compensating Fiber (DCF) components, this component is very important because it is providing dispersion compensation which occurs through the signal journey. (10Km) of this type is used to connect between two SSMF.

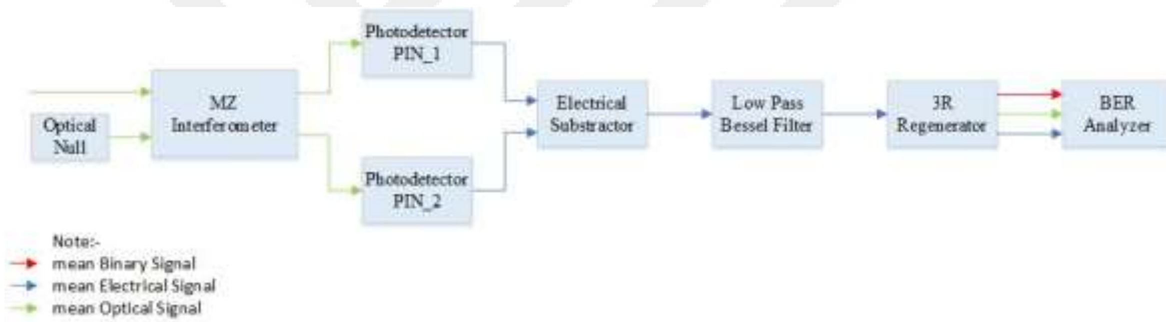

Figure (4.3): Optical receiver components.

Figure (4.3) shows receivers side. in our system we have two receivers, they have the same components, each of them consists of (MZ) interferometer operate as tunable filter and coupler, and it has 2-inputs and 2-outputs ports, the output optical signal goes to two Photodetectors of type positive intrinsic negative PIN to convert it from an optical to an electrical, and each outputs entering to the electrical subtractor and filtered by the low pass filter with cutoff frequency=$3.2*10^{10}$ Hz. Finally regenerated it by the 3R to reshape and amplified to monitored by the BER analyzer:

4.2 Experiment RoF based subcarrier of amplitude shift keying (ASK) techniques and WDM technology:

As mentioned in thesis methodology, we are proposed another experiment for RoF architecture based on the subcarrier of ASK and WDM. It consists of many devices that influence and influenced by the network behaviors. The main layout comprise from three main parts (*i.* optical transmitter, *ii.* optical transmission link, and *iii.* optical receiver). The first one is begin with CW laser with frequency of (193.1THz) to generate an optical signal with power of (6dBm) as showing in Eq. (4.2).

The sine generator used to generate the electrical signal with four frequencies (10, 19, 31, and 50GHz). The carrier generator produces four carriers (50, 54, 60, and 70GHz). These values are optimized as RF Table (4.5), and the mathematical model shown in Equations (4.3 and 4.4). The series of random bits are generated by the PRBSG, the electrical pulse signal as modulation formats coding obtains from NRZ components, to modulate them in other techniques. We used the amplitude modulator (AM) for modulating the electrical signal as Eq. (4.5), then the output from AM are added to the carrier signals by the electrical adder. The output from this component goes to the 90-degree hybrid coupler for coupling the RF signal generated by the sine generator. The output of the hybrid coupler take two output signals then goes to the input MZ modulator to modulate them with an optical signal that will be ready to launched to optical fiber showing in Figure (4.4).

The second transmitter consists of the same components except changing values like this (CW_2 with 193.2THz, and power (6dBm), the carrier_2 generator with the frequencies (72, 76, 87, and 100GHz) illustrated in Figure (4.5). The outputs of these two channels connected to two (EDFA with power=10dBm, and NF=5dB). The outputs of amplifiers go to the (WDM (2×1) with its properties (bandwidth=10GHz, depth=100dB, filter type of Bessel, and filter order equal to 2). Then the output of this components launched to the part two of the system SSMF with 50Km. The mathematical system of the signal behavior is shown in the Schrödinger Equation Eq. (4.6) and illustrated in Figures (4.6).

The third part of the system is the optical receiver that is consist of PIN photodiode, the fork, bandpass filter, electrical amplifier (Gain=15dB), AM demodulator to give us the output signal, 3R regenerator to reshape signal, and the BER analyzer to monitor the output signals as showing in Figure (4.7, and 4.8).

The bitrate of the main layout is (1Gbps), the time window is (1.28-7 s), the sample rate is (32000000000Hz), sequence length (128Bits), sample per bit (32), finally, the number of samples is (4096).

$$f(\Delta\varphi) = \frac{1}{2\pi\sqrt{\Delta f dt}} \cdot e^{-\frac{\Delta\varphi^2}{4\pi\Delta f dt}} \qquad (4.2)$$

Eq. (4.2) is known as CW Laser, [55].

Where $\Delta\varphi$ is the phase difference between two successive time instants, dt is the time discretization.

A Gaussian random variable for the phase difference between two successive time instants with zero mean and a variance equal to $2\pi\sqrt{\Delta f}$ has been assumed, Δf as the laser Linewidth.

$$v_{out} = \sum_{i=1}^{N} v_i(t) + v_{bias} \qquad (4.3)$$

$$v_i = A\sin(2\pi f_i + \phi_i) \qquad (4.4)$$

Eq. (4.3) and (4.4) are knowns as Carrier Generator, [55].

Where v_i is the signal for each carrier, N is the parameter Number of channels, v_{bias} is the parameter Bias and f_i is the frequency of each carrier.

$$v_{out}(t) = Gv_{in}(t)\cos(2\pi f_c t + \phi_c) + b \qquad (4.5)$$

Eq. (4.5) is known as Amplitude Modulator (AM), [55].

Where v_{in} is the input electrical signal, G is the parameter gain, b is the bias, f_c is the carrier frequency, ϕ_c is the phase of the carrier.

$$\frac{\partial E}{\partial z} + \alpha E + i\beta_2(w_0)\frac{\partial^2 E}{\partial T^2} - \frac{\beta_3(w_0)}{6}\frac{\partial^3 E}{\partial T^3} = i\gamma\left(|E|^2 E + \frac{i}{w_0}\frac{\partial}{\partial T}(|E^2|E) - \rho^{\tau}{}_{R1} E\frac{\partial |E|^2}{\partial T}\right) \qquad (4.6)$$

Eq. (4.6) is known as Nonlinear Schrödinger (NLS), [55].

Where $E = E(z, T)$, is the electric field envelope. A frame moving at the group velocity ($T = t - \frac{z}{vg} \equiv \mathrm{t} - \beta_1$) is assumed, β_2 and β_3 are the first and the second group velocity dispersion (GVD) parameters, respectively, w_0 is the reference frequency of the signal related to the parameter "Reference wavelength" ("Main" category of the components tool-box) through $w_0 = \frac{2\pi c}{\lambda_0}$ with c being the light speed in vacuum.

Table (4.5): Optimization parameters values

	Sine Generator_1	Carrier Generator_1	Sine Generator_1	Carrier Generator_2
Sweeps	Frequency(GHZ)	Frequency(MHZ)	Frequency(GHZ)	Frequency(MHZ)
1	10.00000012448	50.00000006224	10.00000012448	72.00000008713
2	19.46469948953	54.73234974477	19.46469948953	78.62528964267
3	31.88670306118	60.94335153058	31.88670306118	87.32069214281
4	50	70	50	100

In this experiment, as shown in the Table (4.5), we Optimized the Sine Generator and Carrier Generator. For the first channel, we Optimize the Sine Generator from (10 to 50) and the Carrier Generator from (50 to 70). While for the second channel the values of the Sine Generator are same as the first channel, but the Carrier Generator values are between (72 to 100).

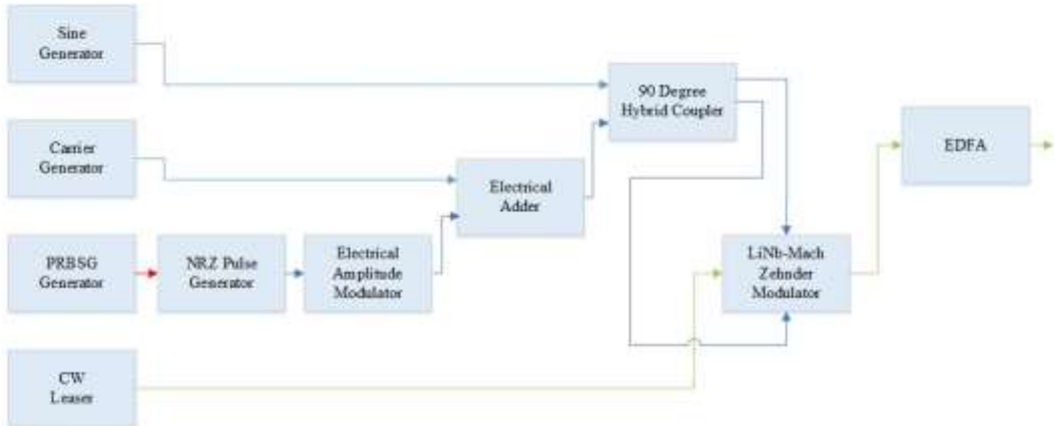

Figure (4.4): Transmitter_1 with its components

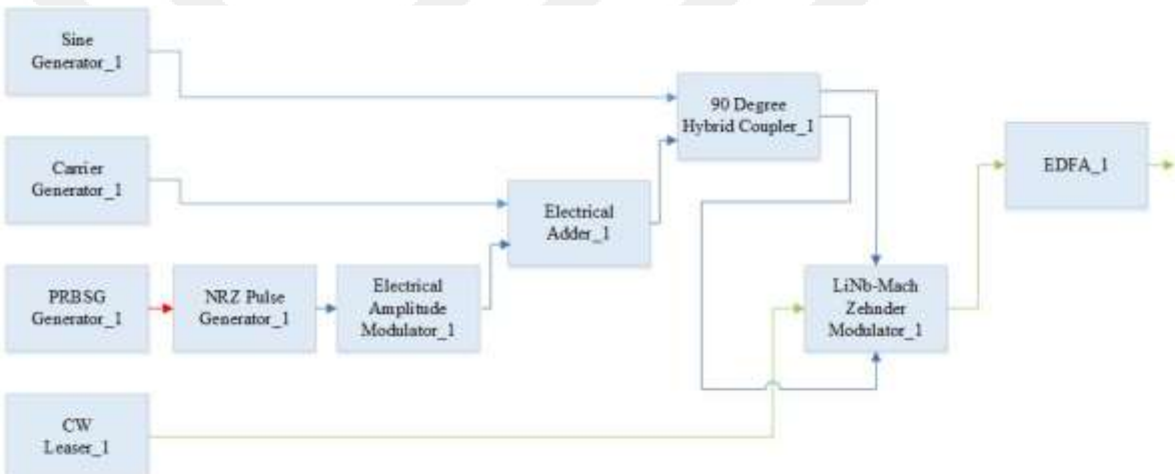

Figure (4.5): Transmitter_2 with its components

From previous Figures (4.4 and 4.5) we can see the component parameters of the two channels. The first one begins with CW laser with a frequency of (193.1THz) to generate an optical signal with power of (6dBm), the sine generator used to generate the electrical signal with four frequencies (10, 19, 31, and 50GHz). The carrier generator produces four carriers (50, 54, 60, and 70GHz). The series of random bits are generated by the PRBSG, the electrical pulse signal as modulation formats coding obtains from NRZ components, to modulate them in other techniques. We used the amplitude modulator (AM) for modulating the electrical signal, then the output from AM are added to the carrier signals by the electrical adder. The output from this component goes to the 90-degree hybrid coupler for coupling with the RF signal generated by the sine generator. The output of the hybrid coupler take two output signals then goes to the input MZ modulator to modulate them with an optical signal that will be ready to launch to an optical fiber. The second transmitter consists of the same components except changing values like this (CW_2 with 193.2THz, power (6dBm), and the Values of carrier_2 generator are (72, 76, 87, and 100GHz).

Figure (4.6): transmission link with WDM

Figure (4.6) as seen above, it is considered as a connector part between transmitter and receiver. The outputs from the two transmitter channels connected to two EDFA. and after that reach to the first part in the transmission link, it is (WDM), this component has 2 input with 1 output. Then the output of this components launched to the part two of the system SSMF with 50Km. finally, by third part the signal will be separated via the demultiplexer WDM (1×2).

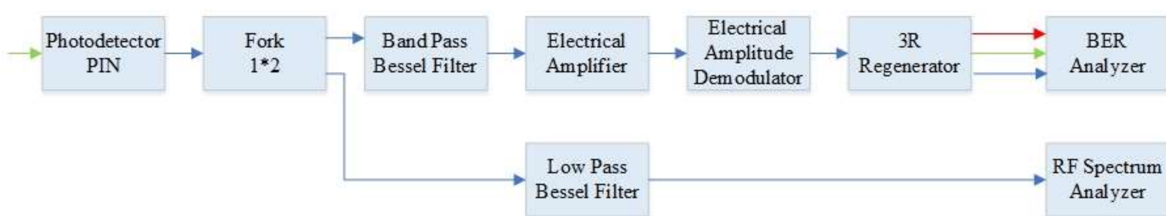

Figure (4.7): Optical receiver for channel_1.

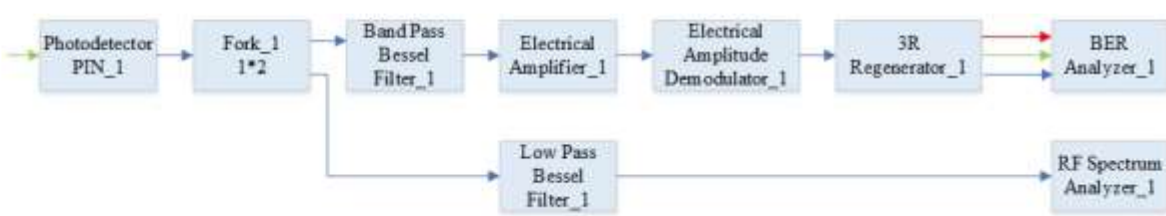

Figure (4.8): Optical receiver for channel_2.

The two previous figures (4.7 and 4.8) are considered as a third part of the system, they are the optical receivers, we have two optical receivers, both of them having the same components. Each optical receiver consists from PIN photodiode, the fork, bandpass filter, electrical amplifier, AM demodulator to give us the output signal, 3R regenerator to reshape signal, and the BER analyzer to monitor the output signals.

4.3 The RF system using RZ modulation format based on VCSEL and WDM:

In this architecture, we design another RF system using return-to-zero (RZ) as shown in Eq. (4.7) to coded input seeding data. There are three parts to configure that as shown in Figure (4.9) with the main layout properties in Table (4.6). The first one is the optical transmitter (Vertical Cavity Surface Emitting Laser (VCSEL) in Equations (4.8). This component produces an optical signal in the efficient properties, it takes the frequency with 193.1THz, the bias current is 5mA, and the temperature is 20Ċ. The seeds bits generate by the PRBSG, the sine generator used to get an RF with the frequency of 10GHz, and phase with 90deg), and two LiNb MZ. The other optical transmitter consists of the same components except for the sine generator_2 with the frequency of 100GHz). These two optical signals are input to the WDM (2×1). The second part of this system is the transmission link consists of SSMF with 25Km, and EDFA with 5m, and separated by the demultiplexer WDM (1×2), the SSMF main properties is displayed in Tables (4.7). The last one is the optical receiver with two components optical receiver with its properties (photodiode type PIN, gain=3, low pass Bessel filter (cutoff frequency(Hz)=0.75*Bitrate, depth=100dB, order=4)) Equations (4.9), and finally the BER analyzer to monitoring the output signal.

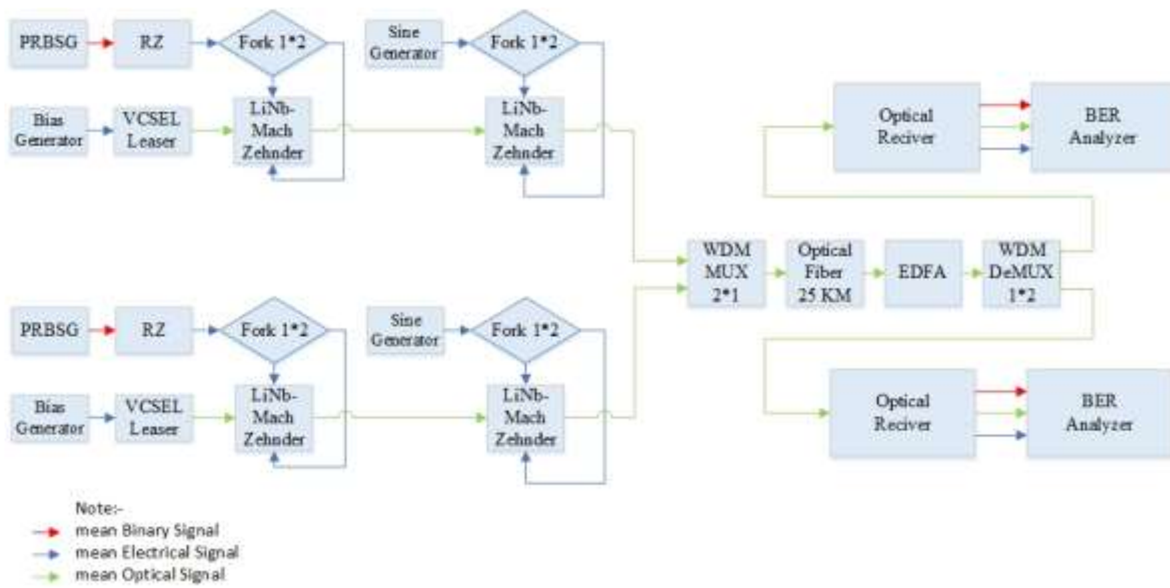

Figure (4.9): Show the RF based VCSEL and WDM

From Figure (4.9), we can show the architecture of the third experiment, In this architecture, we design another RF system using return-to-zero (RZ) to coded input seeding data. In this design, there are three parts. The first one is the optical transmitter (Vertical Cavity Surface Emitting Laser (VCSEL), this component produces an optical signal in the efficient properties. The seeds bits generate by the PRBSG, the sine generator used to get an RF with the frequency of 10GHz, and two LiNb MZ. The other optical transmitter consists of the same components except for the sine generator_2 with the frequency of 100GHz). These two optical signals are entered to the WDM (2×1). The second part of this system is the transmission link consists of SSMF with 25Km, and EDFA to amplifying the signals, and separated the signal by the demultiplexer WDM (1×2). The last one is the optical receiver with two components optical receiver. Finally, the BER analyzer to monitoring the output signal.

Table (4.6): Main Layout Properties

Name	**Value**	**unit**
Bit Rate	10000000000	Bits/s
Time Window	$1.28*10^{-8}$	S
Sample rate	640000000000	Hz
Sequence length	128	Bits
Samples per bit	64	None
Number of samples	8192	None

Table (4.7): SSMF main properties.

Name	Value	unit
Reference wavelength	1550	nm
Length	25	Km
Attenuation	0.2	dB/km
Sequence length	128	Bits

The previous Tables (4.6 and 4.7) shows the Main Layout Properties and the SSMF main properties. as seen above (10 Gbps) will be transmitted over (25 Km) SSMF.

$$E(t)=\begin{cases} 1-e^{-(t/c_r)}, 0 \le t < t_1 \\ 1, t_1 \le t < t_2 \\ e^{-(t/c_f)}, t_2 \le t < t_c \\ 0, t_c \le t < T \end{cases} \tag{4.7}$$

Eq. (4.7) is known as Return to Zero (RZ).

Where c_r is the rise time coefficient, c_f is the fall time coefficient, t_1 and t_2, together with $c_r$and c_f, are numerically determinate to generate pulses with the exact values of the parameters Rise time and Fall time, t_c is the duty cycle duration and T is the bit period.

$$\frac{\mathrm{dN(t)}}{\mathrm{dt}}=\frac{\eta_i\big(I(t)-I_{off}(t)\big)}{q\cdot V}-\frac{N(t)}{\tau_n}-\mathrm{g}_0\cdot(N(t)-N_t)\cdot\frac{1}{\big(1+\varepsilon\cdot S(t)\big)}\cdot S(t) \tag{4.8}$$

Eq. from (4.8) are known as (VCSEL) Leaser, [55].

Where g_0 is the gain slope constant, $\mathrm{g}_0=v_g\times a_0$, a_0 is the active layer gain coefficient, v_g is the group velocity, ε is the gain compression factor, N_t is the carrier density at transparency, V is the active layer volume, τ_n is the electron lifetime and η_i is the injection efficiency.

$$H(s)=\alpha\frac{d_0}{B_N(s)} \tag{4.9}$$

Eq. (4.9) is known as Low Pass Bessel Filter, [55].

Where α is the parameter Insertion loss and $B_N(s)$ an $\mathrm{n^{th}}$-order Bessel polynomial.

Finally, the output results obtain from the above three tests will be discussed in details in chapter five.

5. CONCLUSION AND RESULTS DISCUSSIONS

The RoF architecture is attractive in a communication system related to its good properties, adopting the new technologies leads to exploited communication system totally in an efficient manner. The OptiSystem software simulation is used to design, simulate, and tested our models.

5.1 THE 40GB/S ROF ARCHITECTURE BASED DPSK

The results are obtained depending on the software simulation which is used in many iterations and optimizations as shown in Figure (5.2-5.8). It is indicated for which iteration is best. The activity of these figures in this work is explaining such as the following:

1. Figure (5.2): illustrate the output signal Q-factor for the first channel. From the result, a good output obtains when the value of the output Q-factor is 6.

2. Figure (5.3): demonstrate (193.1THz) a bit error rate for the output signal. From the BER analyzer, the output will be clear and good.

3. Figure (5.4): showing the output signal Q-factor to the second channel, the good significance output value is (6.6).

4. Figure (5.5): demonstrate the output signal BER of (193.2THz), from the BER analyzer, the result in the output is very good.

5. Figure (5.6): demonstrate the eye height for all iterations (the light green, red, and black colors show the worst iterations), but the other colors are best iterations.

6. Figure (5.7): show the versus time of Q-factor for all iterations in the output side receiver.

7. Figure (5.8): illustrate alliterations for the Minimum value of the BER like the log of BER and time, which is showing the good properties of the system in each iteration except the last three iterations.

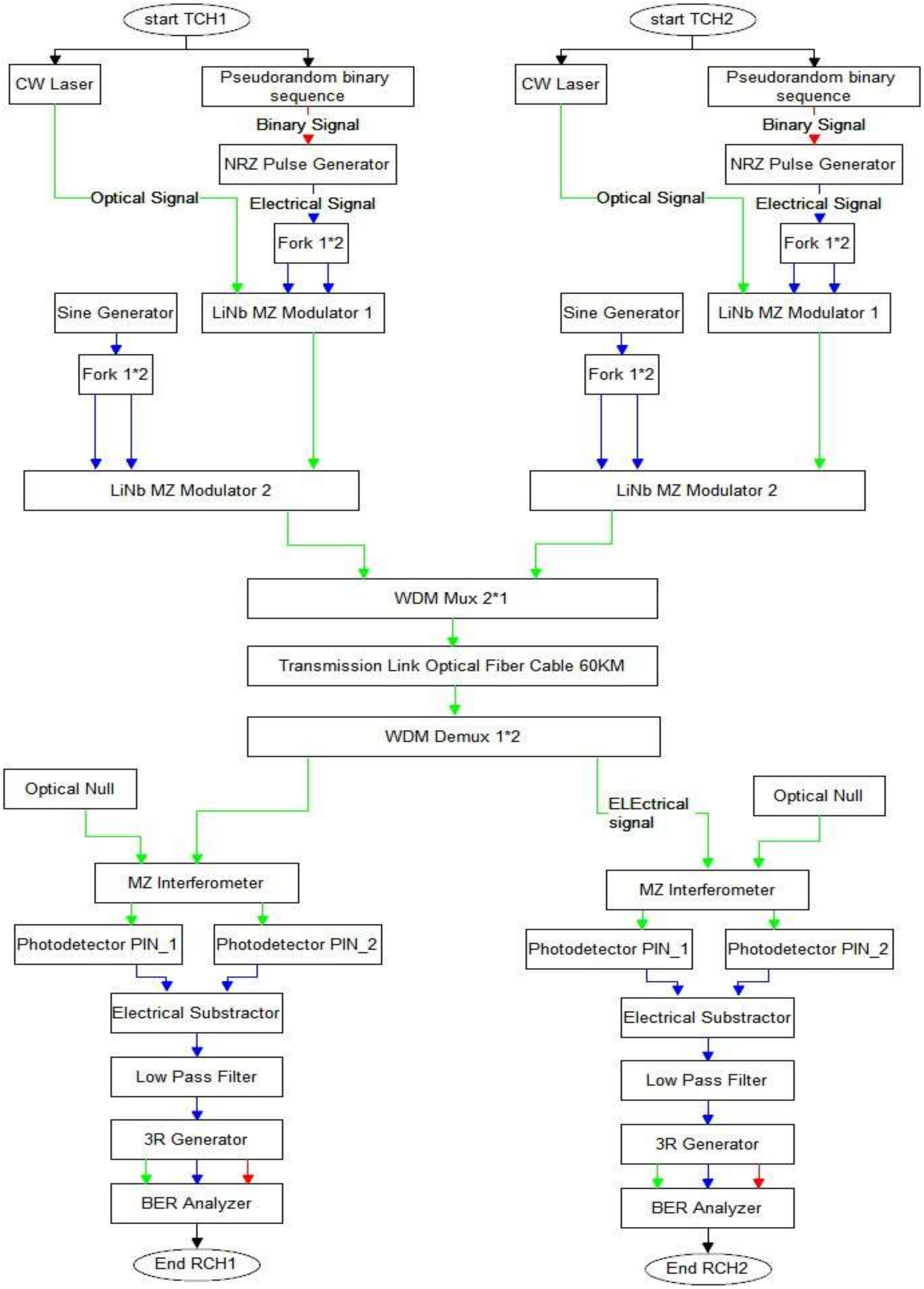

Figure (5.1): Demonstrate the flowchart of the first experiment.

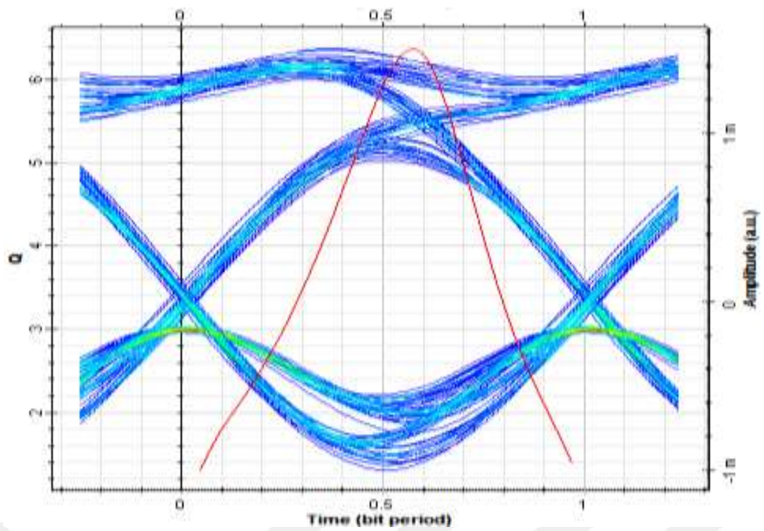

Figure (5.2): illustrate the Q-factor vs. time vs. amplitude for the output signal on the first channel, at 60Km SSMF, and 2×40Gb/s bitrate.

The good eye opening shows in Fig 5.2 for a data rate of 80 Gb/s over optical fiber length equal 60km, the received signals at the received side is well and demonstrate there are no ISI, and no crosstalk. The x-axis shows the values of the bit period (the intervals between transmitted bit), The bit time refers to ellipse time to one bit to be out from the network, while the amplitude measures the change over the single carrier, and the Q indicates the value Q-factor the high peak in the red color curve show the Q-Factor at this iteration.

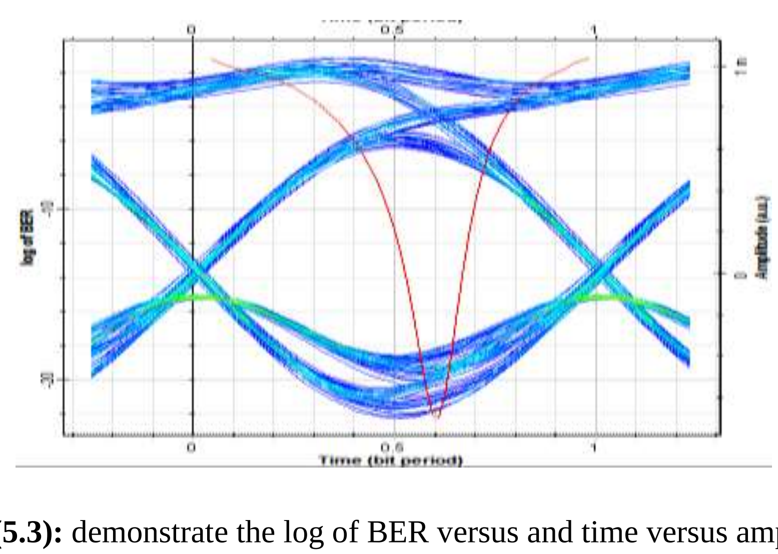

Figure (5.3): demonstrate the log of BER versus and time versus amplitude at the output signal of (193.1THz), at 60Km SSMF, and 2 × 40 GB/s bitrate.

Fig. 5.3 demonstrates the eye opening for a data rate of 80 Gb/s over optical fiber length equal 60km, the previous fig shows a good eye opening of the received signals at the received side is well and demonstrate there are no ISI, and no crosstalk. The x-axis shows the values of the bit period (the intervals between transmitted bit), the amplitude is an indicate the changing in period, and the Log of BER indicate the value of BER, the high peak in the red color curve show the Log of BER at this iteration.

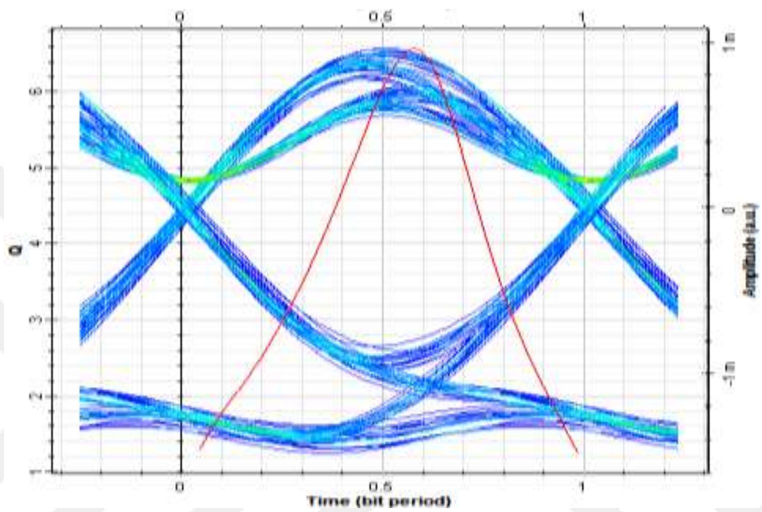

Figure (5.4): shown the Q-Factor versus and time versus amplitude to the output signal for channel_2, at 60Km SSMF, and 2 × 40 GB/s bitrate.

The good eye opening shows in Fig 5.4 for the second channel, when the data rate equal 80 Gb/s over optical fiber length equal 60km, the received signals at the received side is well and demonstrate there are no ISI, and no crosstalk. The x-axis shows the values of the bit period (the intervals between transmitted bit), The bit time refers to ellipse time to one bit to be out from the network, while the amplitude measures the change over the single carrier, and the Q indicates the value Q-factor the high peak in the red color curve show the Q-Factor at this iteration.

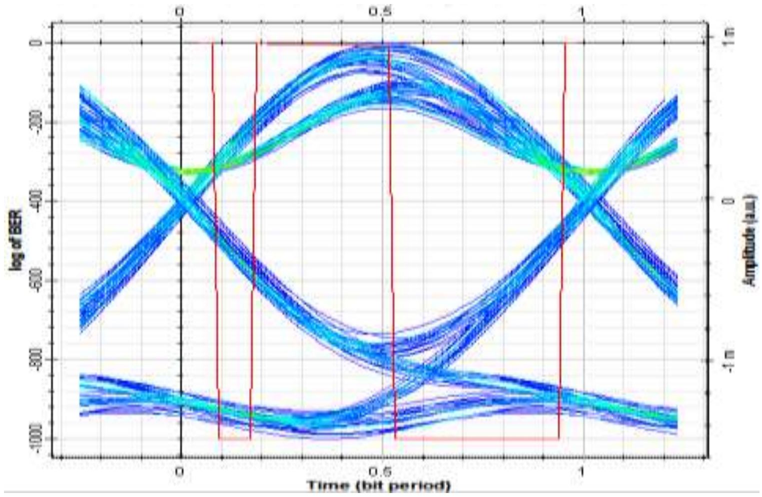

Figure (5.5): demonstrate the log of BER versus and time versus amplitude to the output signal of (193.2THz), at 60Km SSMF, and 2 × 40 GB/s bitrate.

Fig. 5.5 demonstrates the eye opening for a data rate of 80 Gb/s over optical fiber length equal 60km, the previous Fig shows a good eye opening of the received signals at the received side is well and demonstrate there are no ISI, and no crosstalk.

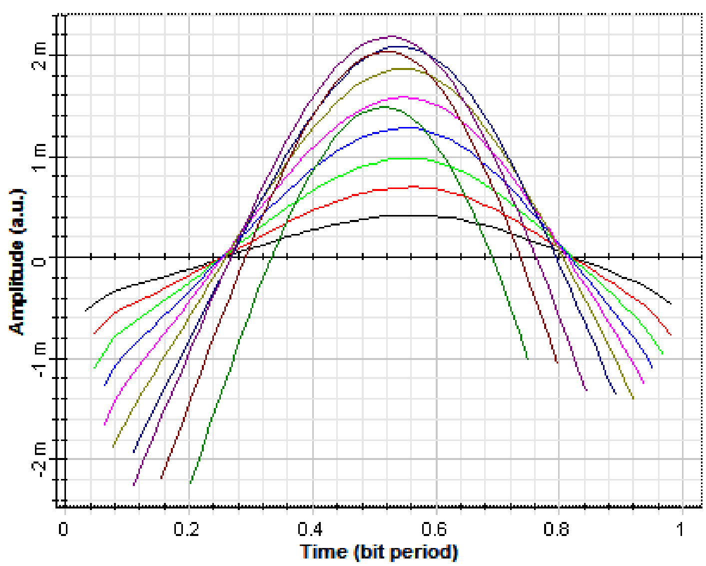

Figure (5.6): Eye Amplitude versus time for ten iterations (the light green, red, and black colors show the worst iterations), @60Km SSMF, and 2×40Gb/s Bitrate.

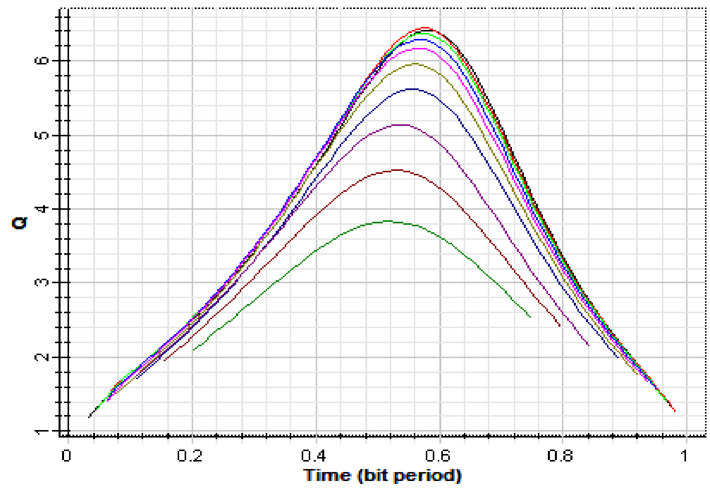

Figure (5.7): show the Q-factor from the output for all iterations, @60Km SSMF, and 2×40Gb/s Bitrate.

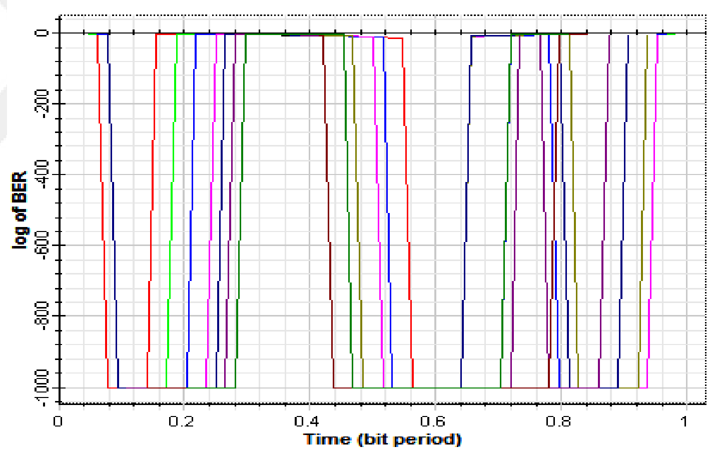

Figure (5.8): Minimum BER for all iterations shows the log of BER vs. Time, @60Km SSMF, and 2×40Gb/s Bitrate.

The last three figures (5.6-5.8) are shows all iterations at one figure, each iteration has a different color. In figure (5.6) we can show the eye Amplitude versus time for all iterations, for the second figure the Q-factor is clear for all iteration. While at last figure the log of BER versus Time is showing for all iterations.

Table (5.1): Summarize Results of RoF Architecture Based on DPSK.

iteration	Input Power (mW) channel_1	Input Power (mW) channel_2	Max Q-factor channel_1	Max Q-Factor channel_2	Minimum BER channel_1	Minimum BER channel_2	Total Output Power (dBm) channel_1	Total output power (dBm) channel_2	OSNR (dB) channel_1	OSNR (dB) channel_2
1	1	1	6.41705	6.57123	3.70E-18	4.21E-13	-39.11	-39.13	27.6368	28.0959
2	1.6	1.6	6.4392	6.5657	6.00E-23	2.02E-16	-34.74	-34.78	29.8373	30.2781
3	2.3	2.3	6.3715	6.56575	8.99E-31	2.50E-13	-31.69	-31.72	31.3734	31.8108
4	3.1	3.1	6.29379	6.56096	3.93E-21	1.75E-12	-29.28	-29.32	32.606	33.0259
5	3.9	3.9	6.17607	6.55543	1.13E-17	5.56E-11	-27.27	-27.33	33.6416	34.0436
6	4.8	4.8	6.95856	6.47757	3.98E-21	0	-25.52	-25.6	34.5564	34.9375
7	5.9	5.9	5.61463	6.24987	1.03E-20	8.64E-09	-23.96	-24.05	35.3905	35.7478
8	7	7	5.13354	5.81679	9.60E-14	0	-22.53	-22.63	36.1728	36.5011
9	8.4	8.4	4.52255	5.19279	5.43E-08	0	-21.2	-21.31	36.926	37.2181
10	10	10	3.8303	4.4305	3.63E-05	0	-19.94	-20.05	37.6708	37.1917
AVERAGE			5.775719	6.098659	3.64E-06	8.70E-10	-27.524	-27.592	33.58116	33.88505

The best iteration can be obtained when the input power of two channels are (1, 1.6, 2.3, 3.1, 3.9, and 5.9 dBm) respectively. the reasons for this due to selecting an optimum values for parameters in each components of our simulation. However, if the input powers are (4.8, 5.9,7, 8.4, and 10dBm), there is no output on the second channel at the receiver side because of the fiber nonlinearity caused from the interference between symbols. The Figures from (5.9) to (5.18) show some important values of total power of the input, maximum Q-factor, minimum BER value, total power of the output, and OSNR value of first and second channels.

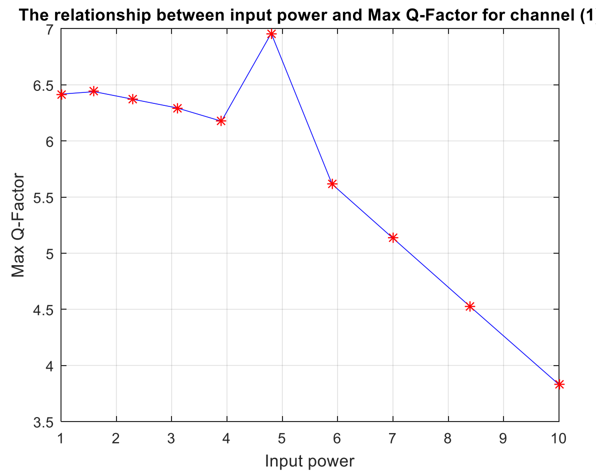

Figure (5.9): showing the relation of input power and maximum Q-factor in the first channel.

From figure shown above, that shows the relationship between input power and maximum Q-factor for the first channel, it is clear at the last three iterations the curve is going down, that is because the value of Max Q-factor is decrease, the reason is the nonlinearities phenomena.

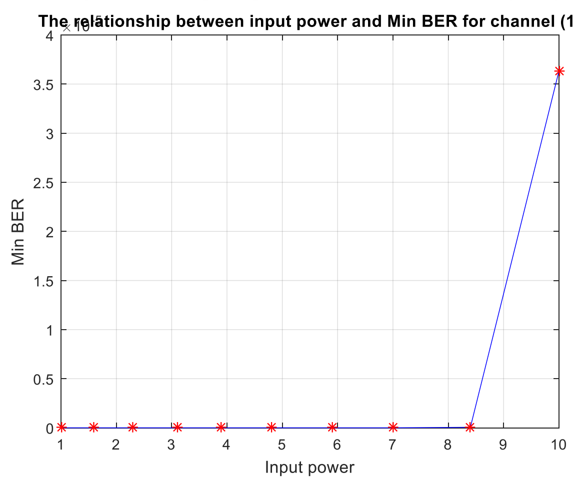

Figure (5.10): showing the relation of the input power and the minimum BER value in the first channel.

The last figure demonstrates the relation between input power and the minimum BER, as shown above, the value of BER is near to zero that is mean the error rate is very less (near to zero). While at last iteration the value of BER is increase due to nonlinearities problem.

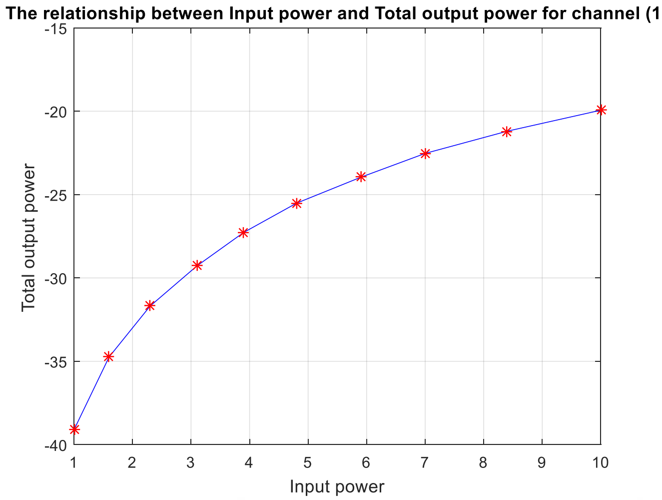

Figure (5.11): showing the relation of the input power and total power of the output in the first channel.

While Figure (5.11) shows the relation between input power and total output power for the first channel. the total output power is an increase that is because increase the values of the input power.

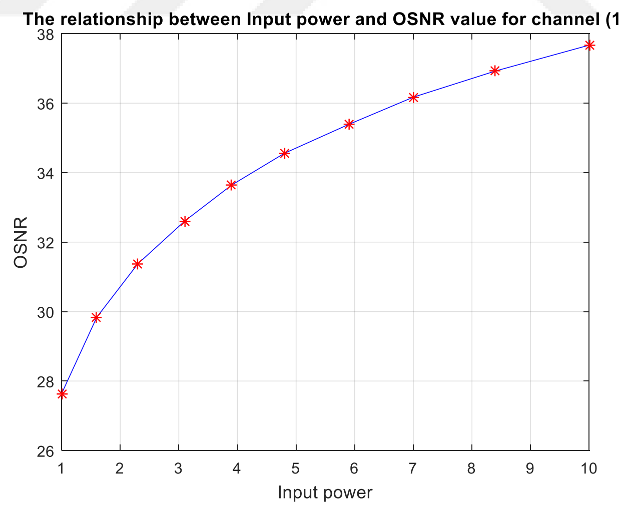

Figure (5.12): showing the relation of the input power and OSNR value in the first channel.

Figure (5.12) shows the input power and OSNR value for the first channel. Increasing input power leads to increase the OSNR at the last three iterations this due to the ISI.

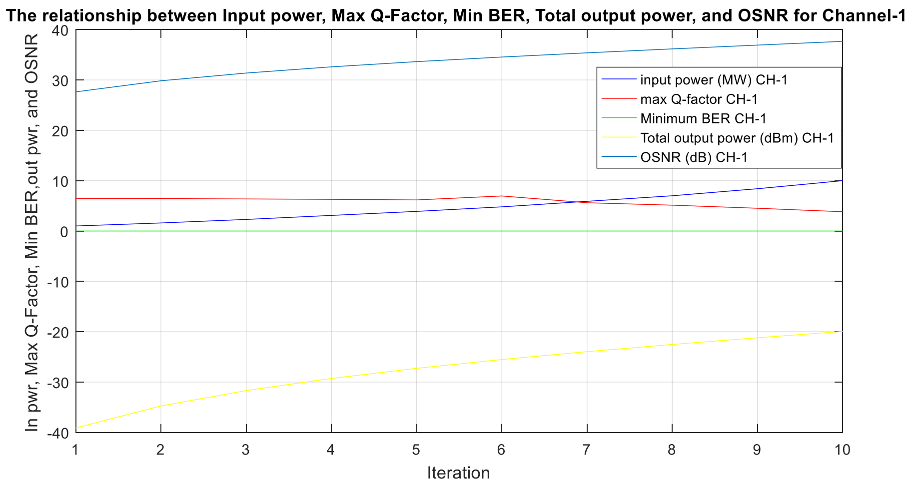

Figure (5.13): showing the relation of the power in the input, maximum Q-factor, the minimum BER and total power of the output in the first channel.

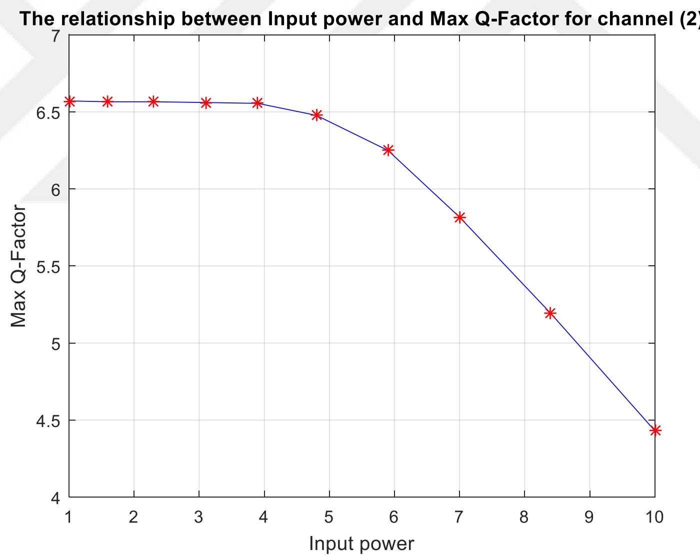

Figure (5.14): shown the relation of input power and maximum Q-factor in the second channel.

From figure shown above, that shows the relationship between input power and Maximum Q-factor for the second channel, for last three iterations the Quality appears decrease this due to the nonlinearities phenomena.

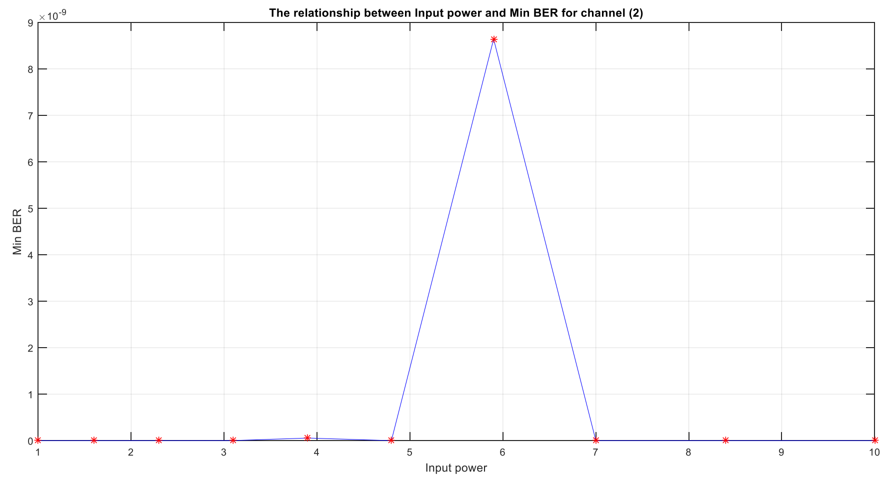

Figure (5.15): showing the relation of the power in the input and minimum BER value in the second channel.

At figure (5.15) the relation between input power and minimum BER are demonstrated, it is clear there is anomaly value at the iteration 7, this due to the changing input seed bit and nonlinearities problems.

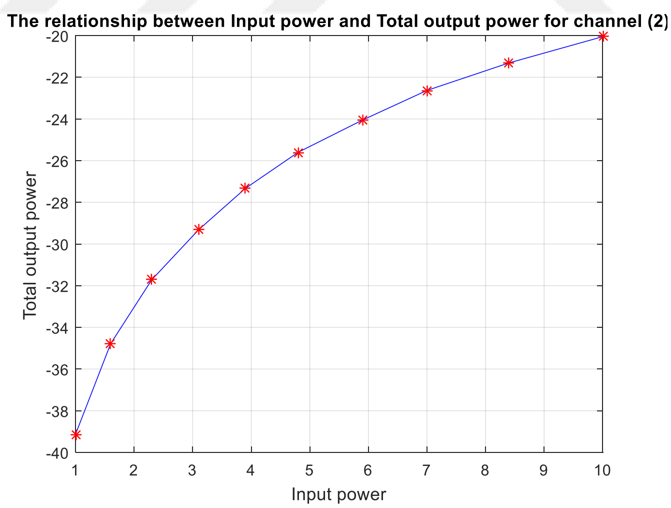

Figure (5.16): showing the relation of the power in the input and total power of the output in the second channel.

While Figure (5.16) shows the relation between input power and total output power for the second channel. The reason of increase the value of output power is increased the values of the input power.

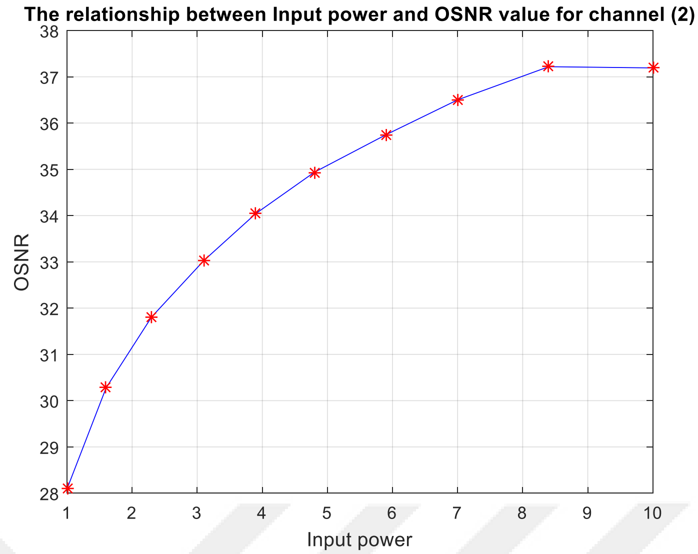

Figure (5.17): showing the relation of the input power and OSNR value in the second channel.

Figure (5.17) shows the input power and OSNR value for the second channel. Increasing input power leads to increase the OSNR at the last three iterations this due to the ISI.

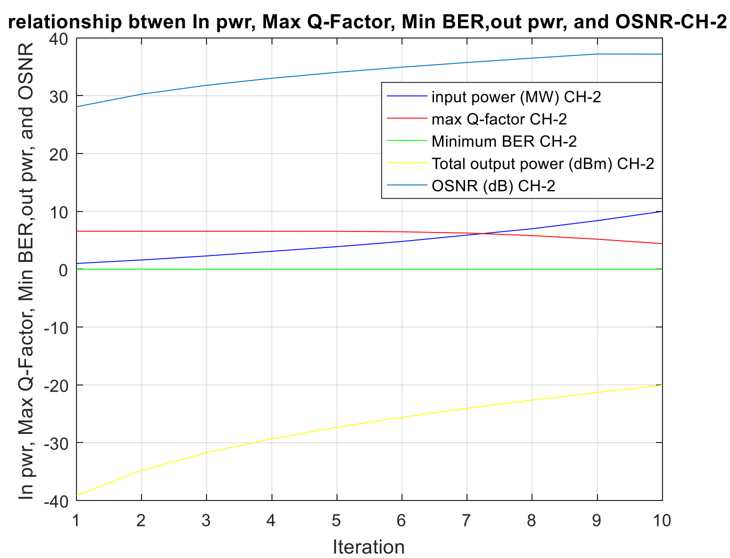

Figure (5.18): showing the relation of the input power, maximum Q-factor, minimum BER value, total value of a power of output and OSNR value in the second channel.

Practically, the figures above give a good result in the system outputs as radio over fiber based on differential phase shift keying modulation format. Also, the standard single mode fiber and for each user (60km and 40Gbps) respectively, for totally 80Gbps. The average power of the input is (4.8dBm), the average of maximum Q-factor value is (5.775719), the average of minimum BER value is (3.64E-5), the total average power of the output is (-27.524), and the average value of the OSNR is (33.58116dB) for the first signal. While at the second signal, the average power value in the input is (4.8dBm), the maximum average value of the Q-factor is (6.098659), the minimum average value of the BER is (8.7E-10), the total average value of the power in the output is (-27.592dBm), and the average of OSNR is (33.88505dB)), the result of the work is very acceptable because of the compatibility of the components and the parameters with each other.

5.2 SUBCARRIER MULTIPLEXING ROF BASED WDM AND SSMF PROPOSED EXPERIMENT

In the second experiment, the other techniques and approaches are used as entries of the software simulation by using different parameters and components. Some of these are amplitude shift keying like RF with two inputs WDM and 50Km SSMF which is utilized to obtain best outputs in the RoF system. The Figure (5.19) shows the flowchart of the previous architecture of the system, the results in the output explained in Fig (5.20) - Fig (5.28) as the following:

1. Figure (5.20): the oscilloscope visualizer component shows the relationship between the amplitude and time to the output signal at the receiver side. The figure shows the similarity of the input power with the output at the transmitter side.
2. Figure (5.21): at the receiver side, the BER analyzer component shows the Q-Factor and Time. The output amplitude value is (193.1THz), it is mean that there is no ISI.
3. Figure (5.22): shows the eye amplitude and the time through four iterations (sine and carriers). The shape of the signals at the optical receiver side is very good.
4. Figure (5.23): displays the log of BER and time of the BER analyzer at the receiver side for four iterations. The shape of the signals is very good at the optical receiver side.
5. Figure (5.24): explains the Q-factors and time values on four iterations of the BER analyzer components. The shape of the signals at the receiver side is acceptable.
6. Figure (5.25): Shows the amplitude and the time of the output signal (193.2THz).
7. Figure (5.26): shows the Q-Factor and the time of the output channel (193.2THz) for the BER analyzer at the optical receiver side

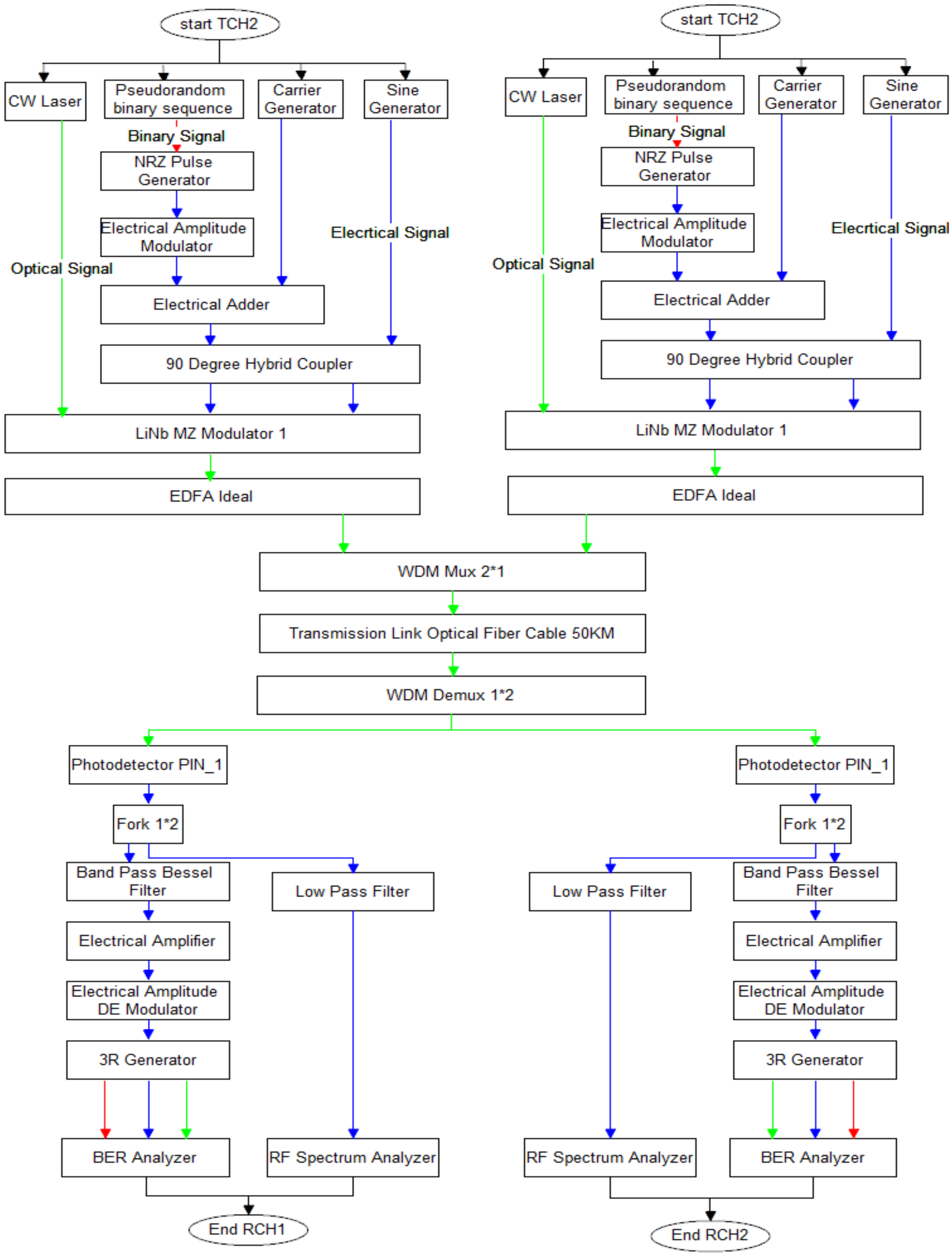

Figure (5.19): demonstrate the System flowchart

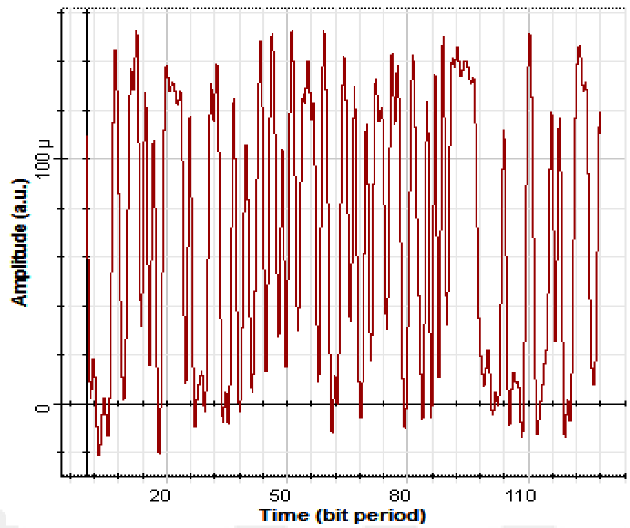

Figure (5.20): Shows the amplitude and the time of the output signal at the receiver side, 50Km of SSMF, 1×2GHz of Bandwidth, 2-WDM.

Figure (5.20): Shows the amplitude and the time of the output signal (193.1THz). The component oscilloscope visualizer shows that input power at the side receiver matches the input power at the transmitter side, only some noise generated from the devices and the amplifiers will be added to it.

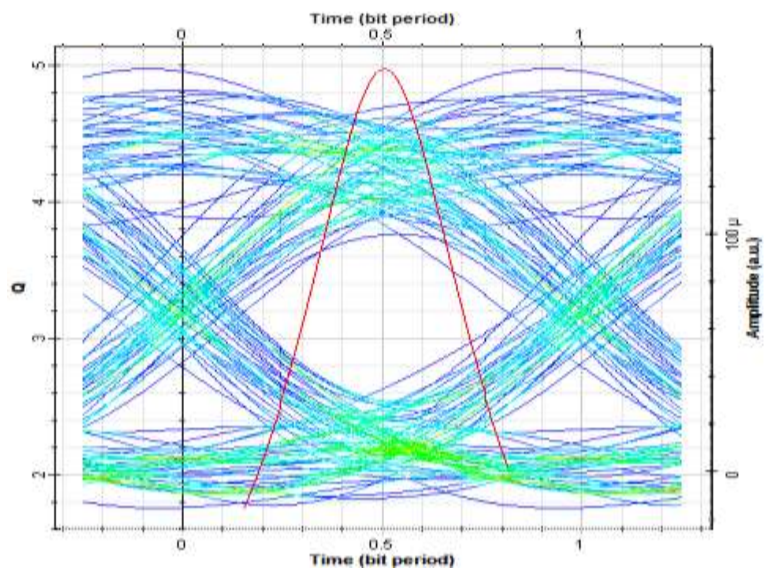

Figure (5.21): demonstrates the Q-Factor vs. Time vs. Amplitude for the output of channel_1@50Km of SSMF, 1×2GHz of Bandwidth, 2-WDM.

The good eye opening shows in Fig 5.21 for a data rate of 2 Gb/s over optical fiber length equal 50km, the received signals at the received side for the first channel is well and demonstrate there are no ISI, and no crosstalk. The x-axis shows the values of the bit period (the intervals between transmitted bit), The bit time refers to ellipse time to one bit to be out from the network, while the amplitude measures the change over the single carrier, and the Q indicates the value Q-factor the high peak in the red color curve show the Q-Factor at this iteration.

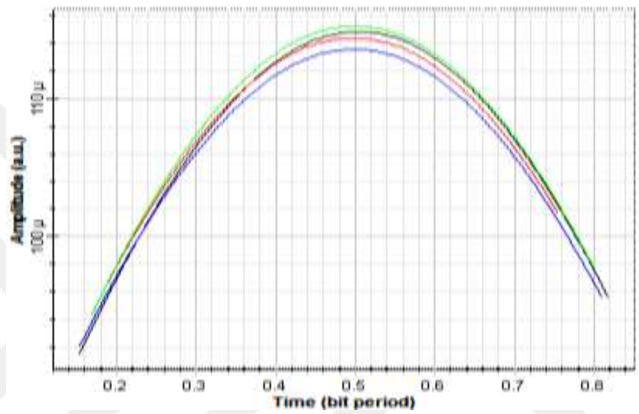

Figure (5.22): showing the eye amplitude vs. Time for four iterations at the optical receiver side @50Km of SSMF, 1×2GHz of Bandwidth, 2-WDM.

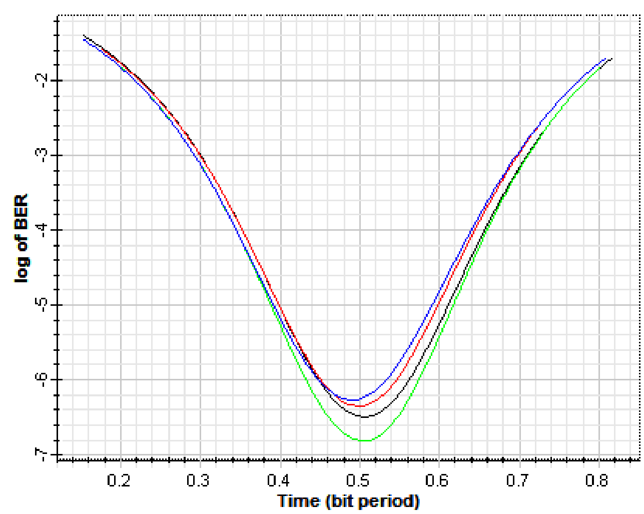

Figure (5.23): Show the log of BER and time of four iterations at the optical receiver side @50Km of SSMF, 1×2GHz of Bandwidth, 2-WDM.

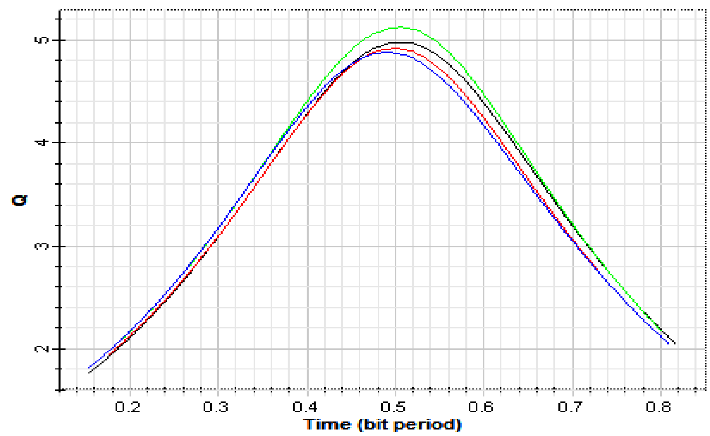

Figure (5.24): Illustrates the Q-Factors and time of all four iterations @50Km of SSMF, 1×2GHz of Bandwidth, 2-WDM.

The last three figures (5.22-5.24) are shows the all iterations at the same figure, each iteration has a different color. In figure (5.22) we can show the eye Amplitude versus time for all iterations, for the second figure the log of BER versus Time is showing for all iterations. While at last figure the Q-factor is clear for all of the iterations.

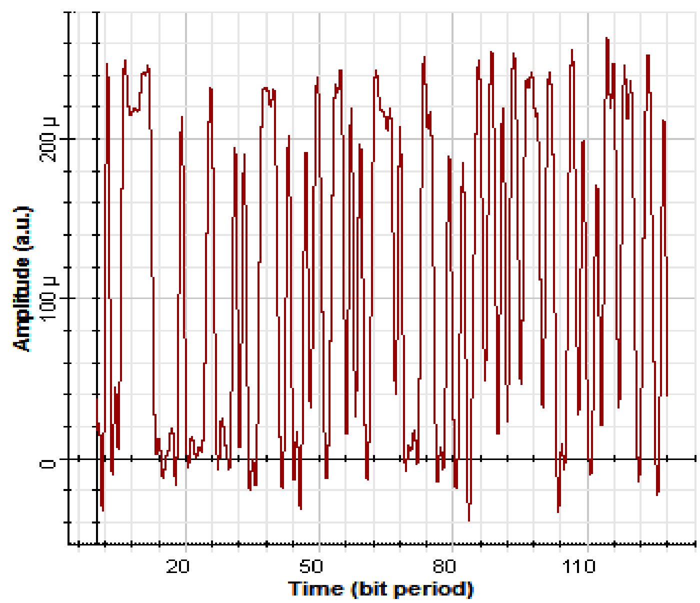

Figure (5.25): Show the amplitude and time of the output signal (193.2THz) at the side receiver, @50Km of SSMF, 1×2GHz of Bandwidth, 2-WDM.

Figure (5.25): Shows the amplitude and the time of the output signal (193.2THz). The component oscilloscope visualizer shows that input power at the side receiver matches the input power at the transmitter side, only some noise generated from the devices and the amplifiers will be added to it.

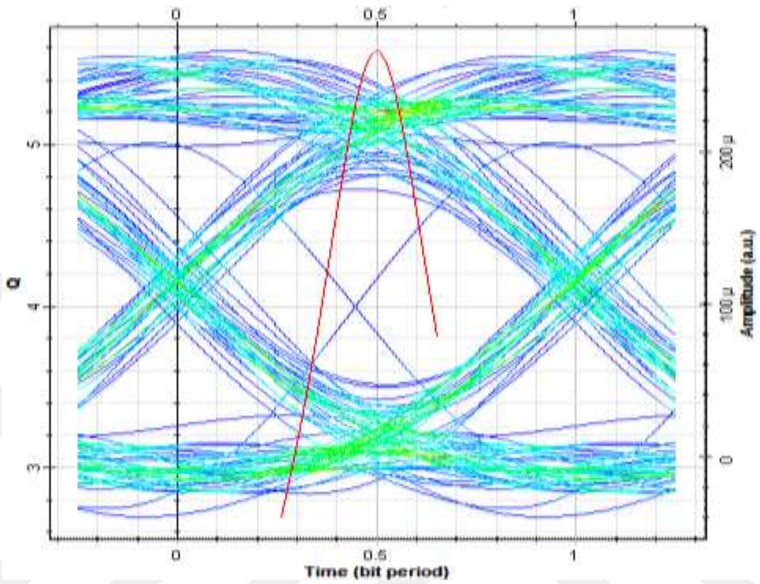

Figure (5.26): showing the Q-Factor vs. Time for the output channel (193.2THz), at 50Km of SSMF, 1×2GHz of Bandwidth, 2-WDM.

The good eye opening shows in Fig 5.26 when the data rate equal 2 Gb/s over optical fiber length equal 50km, the received signals at the received side for second channel is well and demonstrate there are no ISI, and no crosstalk. The x-axis shows the values of the bit period (the intervals between transmitted bit), The bit time refers to ellipse time to one bit to be out from the network, while the amplitude measures the change over the single carrier, and the Q indicates the value Q-factor the high peak in the red color curve show the Q-Factor at this iteration.

Table (5.2): Summarize Results Obtain from the SCM RoF Systems

Iteration	Total Output Power (dBm) Channel_1	Total Output Power (dBm) Channel_2	Max Q-Factor Channel_1	Max Q-Factor Channel_2	Minimum BER Channel_1	Minimum BER Channel_2	OSNR (dB) Channel_1	OSNR (dB) Channel_2
1	-51.1273	-46.591	4.97632	5.57697	3.20E-07	1.21E-08	52.07	54.64
2	-51.1568	-46.6225	4.91348	5.73472	4.43E-07	4.81E-09	52.08	54.64
3	-51.1437	-46.5923	5.11961	5.49297	1.51E-07	1.97E-08	52.11	54.68
4	-51.173	-46.5996	4.87576	5.55587	5.40E-07	1.36E-08	52.08	54.64
AVERAGE	-51.1502	-46.60135	4.9712925	5.5901325	3.63E-07	1.26E-08	52.085	54.65

From the Figures from (5.20) through (5.26), the RoF system is consisting of the subcarrier with NRZ modulation format, 1×2Gb/s, 50Km SSMF, and 2-WDM. The following results will be gotten: the OSNR average of the first channel at all iterations (52.085dB), the OSNR average of the second channel at all iterations (54.65dB), the average of total power in the output at first and second channels are (-51.1502dBm) and (-46.60135dBm) respectively, the maximum average of Q-factor at the first and the second channels are (4.9712925) and (5.5901325) respectively, the minimum average of the BER at first channel is (3.63E-7). At the receiver side, the outputs are very acceptable compared with the works of the many pieces of research because of selecting convince parameters, little components, and doing different optimizations for the generators of sine and carrier signals to get the optimum result.

5.3 Proposed RoF System Based on Vertical Cavity Surface Emitting Laser (VCSEL), WDM, RZ, 10Gb/s, and 25Km SSMF

In the experimental of transmitter side, the benefits of the VCSEL laser (with wavelength 1550nm) will be explained like low threshold current. This threshold enables the previous components to be directly modulated at high frequencies, small beam divergence which has been allowed a coupling of the good efficiency with the optical fiber, symmetrical output beam profile, small switching transients, circular light-output mode, high packaging density, and very low power using up compared to the conventional edge-emitting semiconductor laser components. VCSELs are the solution and principal source in optical networks, the RZ modulation offers enhanced performance, the WDM offer multiple input users at the same link, increasing bandwidth up to 10Gb/s over 25km SSMF as transmission media, the flowchart for this experiment showing in Figure (5.27). Figure from (5.28) through Figure (5.31) explain results of the system architecture.

1. Figure (5.28): Shows the Q-factor and time. The outputs amplitude (1550nm) obtained by using the BER analyzer component. From the result, there is no ISI.

2. Figure (5.29): demonstrates the log of BER and time. The output amplitude is 1550nm. By using the BER analyzer, the output signal is good.

3. Figure (5.30): shows the Q-factor and times amplitude at the output of the second channel.

4. Figure (5.31): illustrates the log of BER vs. Time vs. Amplitude for the output of the second signal, the output is very good.

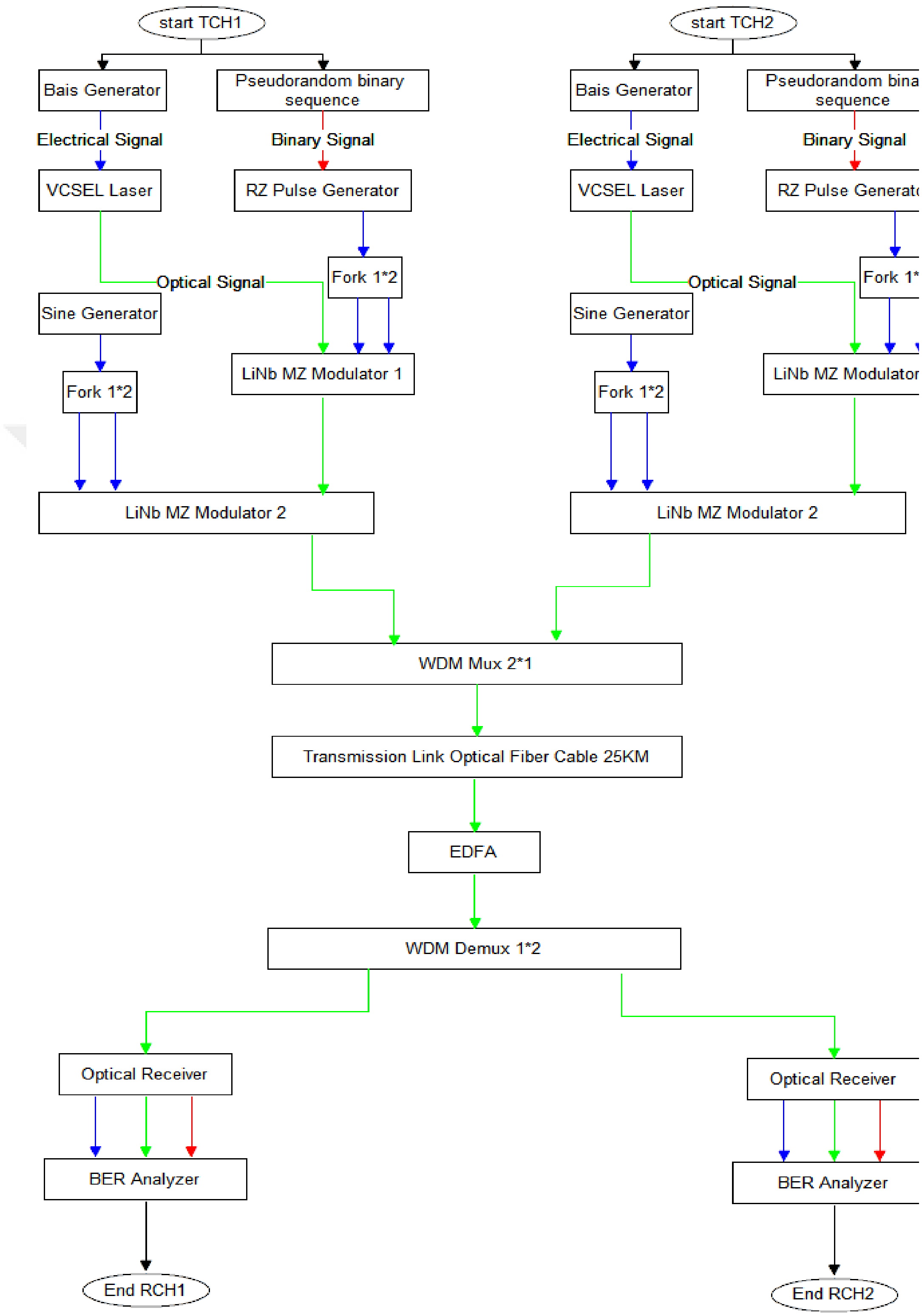

Figure (5.27): demonstrate the System flowchart for experiment 3

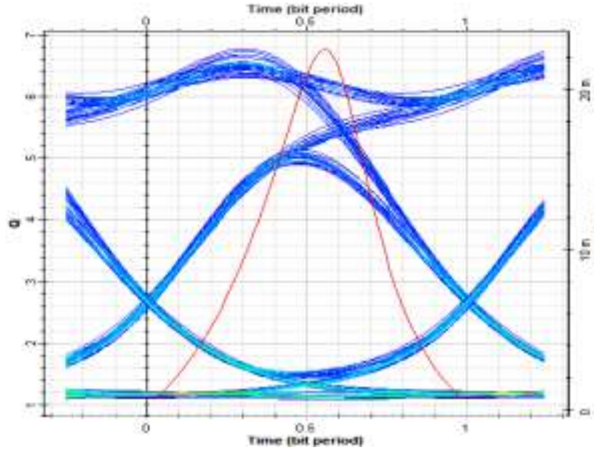

Figure (5.28): Shows the Q-factor vs. Time vs. Amplitude for the outputs from the first channel, @VCSEL, WDM, RZ, 10Gb/s, and 25Km SSMF.

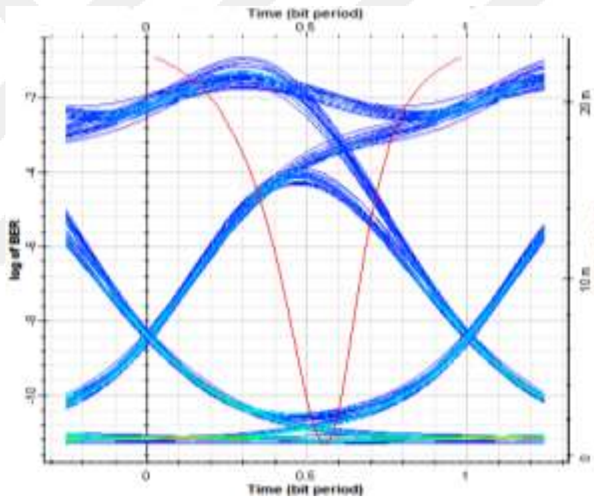

Figure (5.29): demonstrates the log of BER vs. Time vs. Amplitude for the output 1552.52nm, @VCSEL, WDM, RZ, 10Gb/s, and 25Km SSMF.

A good eye opening shows in Figures (5.28 and 5.30) for a data rate of 10 Gb/s over optical fiber length equal 25km, the good eye opening for the received signals at the received side for the channels are well and demonstrate there are no ISI, and no crosstalk. The x-axis shows the values of the bit period (the intervals between transmitted bit), The bit time refers to ellipse time to one bit to be out from the network, while the amplitude measures the change over the single carrier, and the Q indicates the value Q-factor the high peak in the red color curve show the Q-Factor at this iteration.

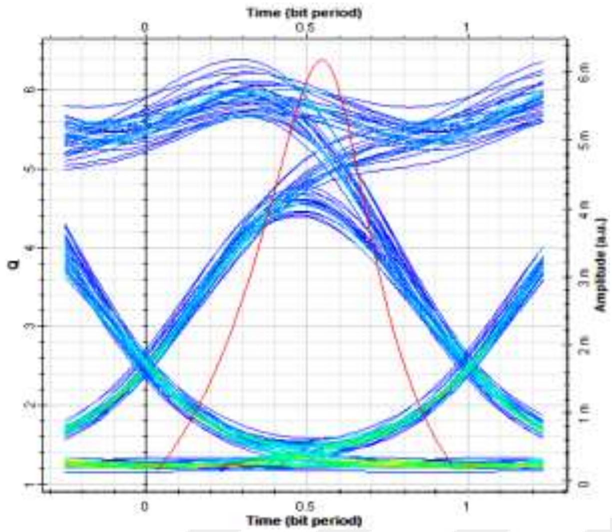

Figure (5.30): shows the Q-factor vs. Time vs. Amplitude for the output of the second signal, @VCSEL, WDM, RZ, 10Gb/s, and 25Km SSMF.

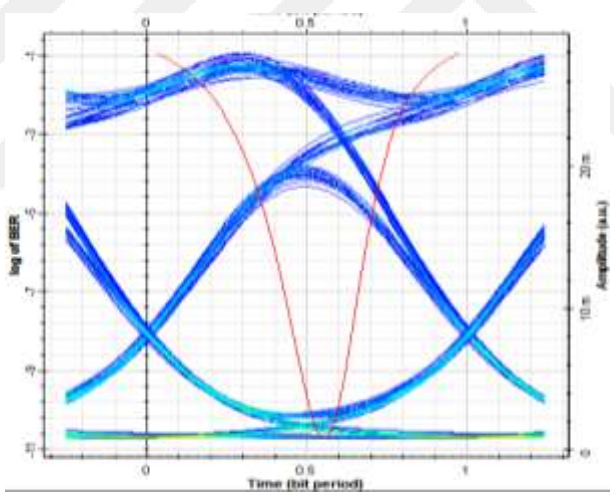

Figure (5.31): illustrates the log of BER vs. Time vs. Amplitude for the output of the second signal, @VCSEL, WDM, RZ, 10Gb/s, and 25Km SSMF.

While in Figures (5.29 and 5.31) shows a good eye opening of the received signals at the received side is well and demonstrate there are no ISI, and no crosstalk. The x-axis shows the values of the bit period (the intervals between transmitted bit), the amplitude is an indicate the changing in period, and the Log of BER indicate the value of BER, the high peak in the red color curve show the Log of BER at this iteration.

Table (5.3): Summarize the RoF output based on VCSEL.

Channel	Total Output Power dBm	Max Q-Factor	Minimum BER	OSNR (dB)
1	-6.93174	6.95692	1.41E-12	29.6399
2	19.9995	6.38672	6.72E-11	29.6399
AVERAGE	**6.53388**	**6.67182**	**3.43236E-11**	**29.6399**

From the previous figures, the RoF system has the following specifications: the total power average is (6.53388dBm), the maximum Q-factor average is (6.67182), the minimum BER average is (3.43236E-11), and the OSNR average is (29.6399dB), from the results, it has good outcome and high performance.

In all experiments, Optisystem software package was being used to design, simulate and test our system. The first experiment was RoF Based Differential Phase Shift Keying (DPSK). In this experiment, DFSK was used as a modulation type, CW was used as a laser light source, many parameters were used on the transmitter and receiver side, WDM was used for exploit the optical cable by sending many channels on the same cable. Many improvements have been done on (power) to reach the best possible result, in the end, the transmission of 40GHZ per channel was achieved along a distance of 60KM. This means that in the totally (80GHz) has been sent over 60KM and all the results that get from simulations were very good.

In the second experiment was (Subcarrier Multiplexing RoF Based WDM and SSMF) in this experiment was used (Subcarrier Multiplexing amplitude shift keying) as a modulation type, like the first experiment also used (CW) as a laser light source, many of the parameters were used in the side of transmission and receiver such as (carrier generator), (sine generator) and (amplitude modulation) at the transmission side. In the receiver side, (photodetector) is used to convert the optical signal to electrical signal, and (BER analyzer) to monitor the output. WDM was also used to exploit the optical cable by sending two channels on the same cable, some improvements on the (carrier generator) and (sine generator) have been done for reach to the best result. In the end, the transmission of

1GHZ per channel was achieved at a distance of 50KM. This means that the total rate was 2GHZ (50KM), at the receiver all the results were acceptable and attractive.

In the last experiment (RoF System Based on Vertical Cavity Surface Emitting Laser (VCSEL)), (return-to-zero) was used as a modulation type, in this experiment, a different type of laser was used (VCSEL) as a laser light source, this mentioned laser contains very attractive properties. Some of the components used in the transmitter side are (pseudo-random number generator), (RZ pulse generator). At the receiver, (RX) is used as an intelligent component. This is a very smart component and contains internal parameters that make it a very important and attractive. Like the previous experiments, WDM also used to exploit the optical cable by sending two satellites on the same channel. In the end, the transmission of (10GHZ) per channel was achieved along a distance of 25KM. This means that the total rate was sent (20GHZ) over 25KM. All the results were very good and acceptable.

At the last experiment (RoF System Based on Vertical Cavity Surface Emitting Laser (VCSEL)), (return-to-zero) was used as a modulation type, in this experiment, a different type of laser was used (VCSEL) as a laser light source, this mentioned laser contains very attractive properties. Some of the components used in the transmitter side are (pseudo-random number generator), (RZ pulse generator). At the receiver, (RX) is used as an intelligent component. This is a very smart component and contains internal parameters that make it a very important and attractive. Like the previous experiments, WDM also used to exploit the optical cable by sending two signals on the same link. In the end, the transmission of (10GHZ) per channel was achieved along a distance of 25KM. This means that the total rate was sent (20GHZ) over 25KM. All the results were very good and acceptable.

Table 5.4: The Comparison between previous works and our work

Works		Modulation type	Bandwidth (bitrate)	BER	References
Previous work		ASK	140 Mbps	10^{-9}	[7]
		OCS	1 Gbps	10^{-2}	[56]
		NRZ	15 Gbps	10^{-12}	[57]
Our work	EXP 1	DPSK	80 Gbps	$3.6 * 10^{-6}$	Our results
	EXP 2	SCM	2 Gbps	$3.6*10^{-7}$	
	EXP 3	RZ	20 Gbps	$3.4*10^{-11}$	

Table 5.4 shows the comparison between the previous researcher works and our work as we see above, our result shows an attractive result compared with other researchers, this is due to selecting good components (active/passive) and good values and properties for parameters, also we use multiple users by WDM without need to changing the exiting the infrastructure (transmission link).

The Bit Error Rate (BER) is an indicator is affected by the bandwidth. The increasing or decreasing is influenced by the components used in the design and vary from design to another. In our design the BER was very acceptable according to the components and bandwidth that was used.

6. CONCLUSIONS

6.1 Conclusions

C-band was used in our system to design a radio system on optical fiber to provide high speeds and wide bandwidth. The architecture of RoF has various components (active component and passive component). It is implemented on numerous series of the optimization and repetitions by using the simulation of the Optisystem application which is provided by the Canadian company. In this work, the oscilloscope and BER analyzer are used to monitor the behavior of the signal.

The experimental works divided into two stages (the first and second signals). In the first signal, the result was as the following: input power average was (4.8dBm), maximum Q-factor average was (5.775719), minimum BER average was (3.64E-5), total power average of the output was (-27.524), and the OSNR average was (33.58116dB). In the second signal, the result was as the following: input power average was (4.8dBm), maximum Q-factor average was (6.098659), minimum BER average was (8.7E-10), total power average of the output was (-27.592dBm), and the OSNR average was (33.88505dB). There is some ISI appears in the previous architecture because of the nonlinearities properties in the fiber phenomena and the second reason is the distance of the fiber span is very long.

In the second experiment, the system has a good result like the OSNR average for the first channel was (52.085dB) to the all iterations, the OSNR average for the second channel was (54.65dB) for all iterations, the total power average for the output on the first and second channels are (-51.1502dBm) and (-46.60135dBm) respectively, the Maximum Q-factor average for first and second channels are (4.9712925) and (5.5901325) respectively, the minimum BER average for the first and second channels are (3.63E-7), and (1.26E-8) respectively. In the final experiment, the RoF system uses an attractive behavior of the optical source (VCSEL). The average result of the total power is (6.53388dBm), maximum Q-factor average is (6.67182), the minimum BER average is (3.43236E-11) and the OSNR average is (29.6399dB).

The performance of the RoF is enhanced by many users, more bandwidth and new devices. Also, it provides a flexible and transparency properties of the system engineering. Therefore, the output results will be very acceptable.

In the future, the line of the work may be taking the following directions:

- Hybrid systems of optical add-drop multiplexer and RoF.
- Wavelength allocation or reuse wavelength.
- Raman amplifiers for amplification process.
- Multimode fiber and Solitons fiber.
- Use Equalization techniques.
- Use the mode division multiplexing.

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