MODELING AND SIMULATION OF OFDM SCHEME USING QAM FOR RADIO OVER FIBER

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Of

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In Electronics & Communication Engineering

By

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Under the supervision of

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CERTIFICATE

This is certified that the thesis entitled, "MODELING AND SIMULATION OF OFDM SCHEME USING QAM FOR RADIO OVER FIBRE" submitted by **Mr. Vijay Singh** to the **MNIT, Jaipur,** is a record of bonafide thesis work accomplished under my supervision and guidance in order to get considered for the award of degree of Master of Technology in Electronics & Communication Engineering.

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DECLARATION

I **Vijay Singh** declares that this thesis submission titled as MODELING AND SIMULATION OF OFDM SCHEMES USING QAM FOR RADIO OVER FIBER,' is my own work and that, to the best of my knowledge and belief.

I confirm that major portion of the report except the refereed works, contains no material previously published nor present a material which to be substantial extent has been accepted or the award of any other degree by university or other institute of higher learning. Wherever I used data (Theories, results) from other sources, credit has been made to that source by citing them (to the best of my knowledge). Due care has been taken in writing this thesis, errors and omissions are regretted.

Vijay Singh

2015pec5283

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ABSTRACT

This thesis investigates RoF-OFDM system model using the modulation techniques of Quadrature amplitude modulation (QAM) and orthogonal frequency-division multiplexing (OFDM). Radio over Fiber is arrangement of fiber optical link and Radio waves. Optisystem13 software is used for the simulation work and results. Two LP-CROF filter uses at output of OFDM and two LiNb-MZM used as optical modulators. In Radio-over-fiber (ROF) technology the signal is transmitted through optical fiber which has several advantages such as wide bandwidth, inherent immunity to EMI and lesser power consumption.

In this Thesis we proposed a Rof-OFDM system model, in which we use the fiber optical length up to 100 km with 16 - quadrature amplitude modulation (QAM) and 4-Quadrature amplitude modulation. Compares the output results for both 4 and 16 QAM and analysed that 16 QAM has the better spectral signal efficiency than 4 QAM. This model can increase the capacity of modulation radio frequency (RF) access with high speed and data transmission. The received output power value on fiber length 100 km for 10 Gbps signal is 11.039 dbm for 4 QAM and 71.565 dbm for 16 QAM. Therefore, OFDM –RoF system model is more effective with 16 QAM than 4QAM.BER performance is also better with 16 QAM.

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List of Abbreviations

RoF	Radio over Fiber
BS	Base Station
CS	Central Station
SMF	Single-Mode optical Fiber
RF	Radio Frequency
MMF	Multi-Mode optical Fiber
WDM	Wavelength Division Multiplexing
PD	Photodiode
PRBS	Pseudo Random Bit Sequence
MZM	Mach-Zehnder Modulator
MZI	Mach Zehnder Interferometer modulator
AROF	Radio (Analogue) over Fiber
BROF	Baseband (Digital) over Fiber
DROF	Digitized (Rf) over Fiber
ISI	Inter Symbol Interference
QPSK	Quadrature Phase Shift Keying
QAM	Quadrature amplitude modulation
FDM	Frequency Division Multiplexing
ICI	Inter Carrier Interference
MCM	Mullti-carrier modulation
IFFT	Inverse fast Fourier trans-form
FFT	Fast Fourier trans-form
PAPR	High peak to Average Power Ratio
STO	Symbol Timing Offset
CFO	Carrier Frequency Offset
RHD	Remote Heterodyne Detection
Q-factor	Quality-factor
OFDM	Orthogonal Frequency Division Multiplexing
IM-DD	Intensity Modulation-Direct Detection
BER	Bit Error Rate
GUI	Graphical User Interface
FSO	Free space optic
PON	Passive optical networks
Tx	Transmitter
Rx	Receiver
TIR	Total Internal Reflection
RTO	Radio to optical up convertor
OTR	Optical to radio down convertor
PSK	phase shift keying
DSL	digital subscriber loop

Chapter (1) Introduction

1.1 INTRODUCTION TO OPTICAL FIBER COMUNICATION

The global internet protocol traffic is growing at a massive pace and a Fifth generation (5G) network technologies will become key enablers for the environmental sustainability of modern societies [1]. This growing demand for high data rate communication system has heralded optical fiber communication system as the potential solution. Optical fiber communication involves transmission of data in the form of light pulses from one to other place that are sent over an optical fiber. Electromagnetic carrier wave is developed by light and to carry information the wave is modulated. Optical Communication was introduced in the 1970s and since then it has not only reform the Telecommunications Industry but also played a big role in the initiation of the Information Age[2] .The main benefit provided by optical communication is extremely broad bandwidth which is associated with an Optical Carrier. The carrier frequency of optical fiber (180 to 300 THz) is greater than the microwave carrier frequency (1 GHz) by five orders of magnitude. Then, modulation bandwidth is restricted usually to a narrow fraction of carrier frequency in digital systems; it roughly translates to 100,000 times more capacity for an optical fiber communication system.

1.2 NEED OF RADIO OVER FIBER TECHNIQUE

In initial phase of telecommunication, services like GPRS and GSM agreed with low information rates. But, currently, the users demand services that are capable of providing them with a faster transmission, anytime anywhere and flexible solutions. Also, the rapidly growing number of users will limit the available bandwidth. One possible solution is to reduce the cell size for accommodating more number of clients. This is known as micro-cells or pico-cells concept. Another method involves utilization of new operational bands because there is already congestion in the unlicensed ISM frequency bands. Currently, several designers are preferring millimeter-wave as the new operational band [3].

It lies in 40 to 90GHz optical frequency region and offers higher bandwidth. But, some other problems will arise when these methods are implemented. Larger quantity of base stations needed to cover the whole area of service if the cell size is reduced. On the other hand, increasing the frequency will require more equipment's, maintenance and installation costs. Radio over Fiber (RoF) concept is developed for eliminating these issues. RoF is a spectacular incorporation of optical and wireless networks leading to high information rate, high capacity and mobility solution [4].

1.3 Overview of Radio over Fiber (RoF) technology

Radio over fiber technology was first explored in 1991. The reason behind this solution was to provide mobility to residential and business users. The problem of mw photonics became relevant only after big success of Cellular communications. Due to the development of solid state lasers in early 1960s, large number of Improvements has happened to the laser sources such as the linewidth is extremely narrow and customized laser sources have been developed

The demand for Broadband services has triggered the research on mm-wave frequency band for WAN, because of compacted size and spectrum obtainability of RF devices. These radio signals have attenuation and due to that it has loss during the transmission.

RoF is a method in which the light signal is modulated with RF signal and pass through the optical fiber. A RoF system consists of a CS and RS and connected by an optical fiber link or network [5]. In the fig 1.1 Diagram of RoF basics has shown, which has radio transmitter to provide RF spectrum and signal goes to E/O conversion frequency up conversion and transmitted through optical fiber link.

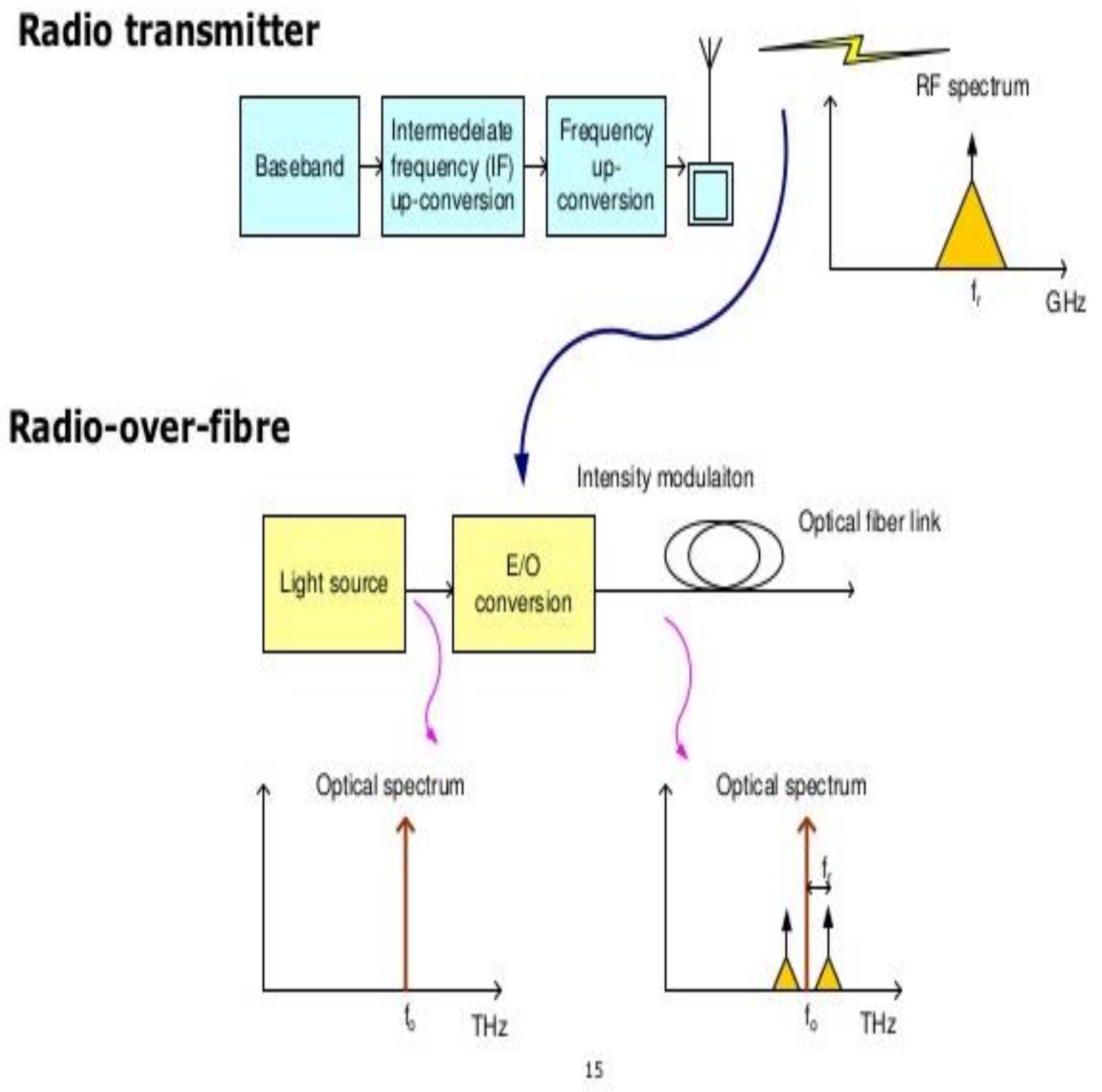


Figure 1.1 Radio over Fiber Basics

1.3.1 Topology of Rof Network

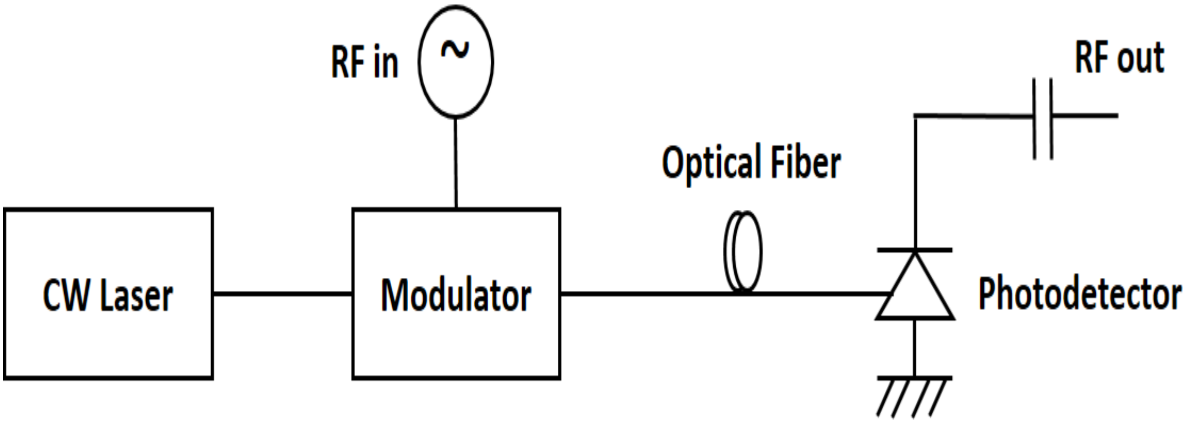


Figure 1.2 Topology of RoF network

The concept of RoF involves modulation of light by a radio signal followed by transmission through optical fiber in order to support wireless applications. In conventional optical systems, transmission of digital signal occurs. Fundamentally, it is an analog transmission system due to involvement in distribution of Radio signals, directly on RCF which are transmitted between control unit and BS. However, the information signal can be digital. RoF network comprises of a transmitter and a receiver which are joined by optical fiber. At transmitter, the optical source laser is modulated by an electrical signal. The output resulted signal is in optical domain which is further transmitted through the optical fiber. At receiver, photodetector converts back the information signal into electrical form. Figure 1.2 depicts the framework of RoF network [6,7].

1.3.2 BENEFITS OF RADIO OVER FIBER

RoF is an incorporation of both optical and wireless domains. So, it exploits the advantages of both the techniques. Some of the benefits are described below:-

- **Enormous bandwidth and high data rate:** The radio signals are preferably transmitted over fiber because it offers huge bandwidth, up to THz. High bandwidth also supports high speed for processing the signals. This may be more difficult to implement electronically and it has high spectral efficiency [7].
- **Low attenuation**: Signals transmitting through fiber optical suffer from less attenuation than through other Channels or Media (such as metal cables). The signal travel further when optical fiber is used, reducing the need of repeaters.
- **Low complexity:** RoF uses the concept of BS. BS only comprises of an optical-to-electrical converter, amplifiers and an antenna. This implies that the signal generation circuitry and resource management is shifted to a centralized location which is shared among several BSs, thus simplifying the network.
- **Dynamical allocation of resources:** The resources are controlled at the central station (CS). Thus, resources like bandwidth will be allocated dynamically according to priority and demand.
- **Lower cost:** Centralization of expensive equipment and complex equipments utilized for processing the signal are placed into CS and minor and lighter remote unit of antennas are placed at BSs. Thus, the system can be easily installed and maintained resulting in reduction of system cost [7].
- **Security:** RoF does not suffer from radio frequency interference because signal transmission occurs in light wave form. It provides security to the signals that are transmitted through the fiber.
- **Future-proof:** Fiber optics is developed to support data rate in Gbps. Thus, they are capable of handling the data rate required in future high speed networks. RoF technique is also bit-rate and protocol transparent.

1.3.3 LIMITATIONS OF RADIO OVER FIBER

RoF technique offers a number of advantages as discussed earlier. Apart from them, there are also certain limitations in this concept. Some of them are listed below:

- **Nonlinearities:** RoF suffers from a number of nonlinear effects. This is a result of the nonlinear condition of devices (such as laser) that are used in communication link. This puts a limit on the noise figure and dynamic range that are very important parameters of radio signal transmission.
- **Single-mode fiber limitations:** Chromatic dispersion in single-mode optical fiber (SMF) puts a limit on the length of fiber link. This might also cause de- correlation which increases the radio frequency (RF) carrier phase noise.
- **Multi-mode fiber limitations:** In multi-mode optical fiber (MMF), modal dispersion puts a limit on the total available bandwidth and the transmission distance.

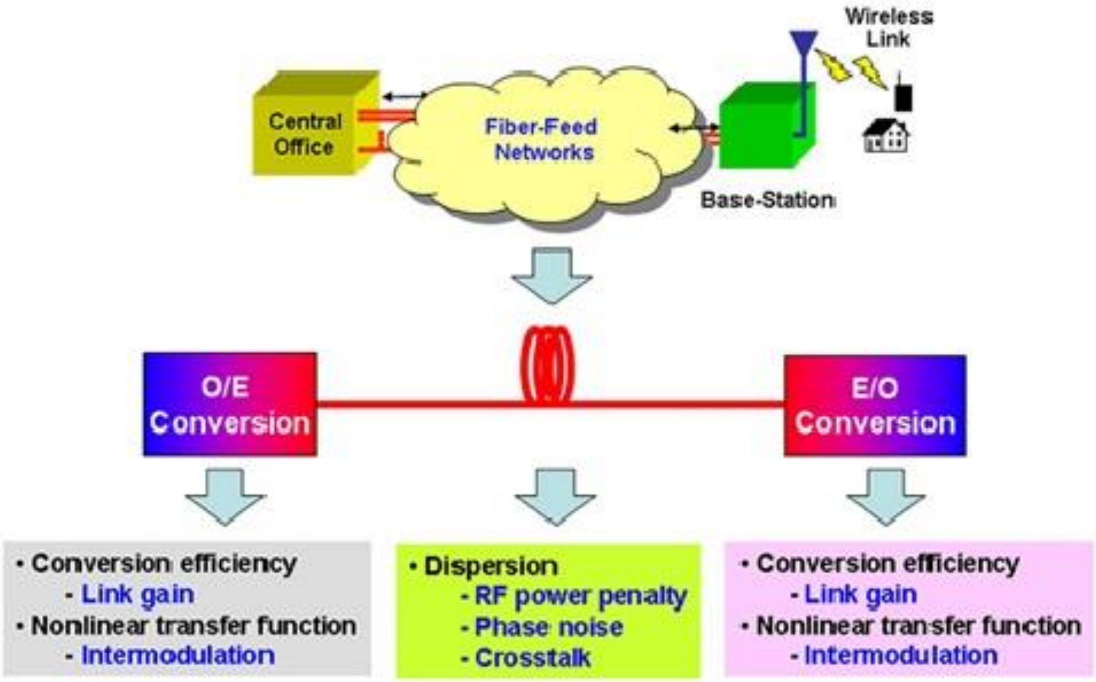


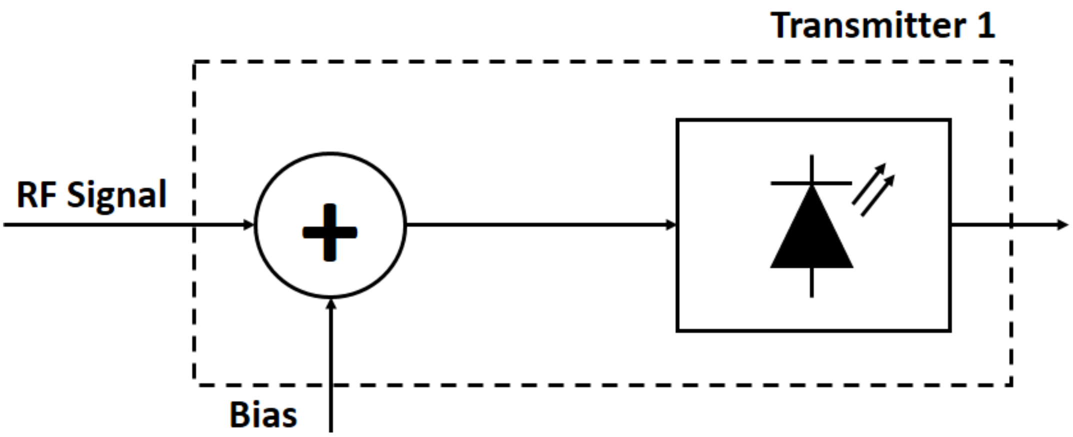
Figure 1.3: Limitations for Radio over Fiber

1.4 CLASSIFICATION OF RADIO OVER FIBER TECHNIQUE

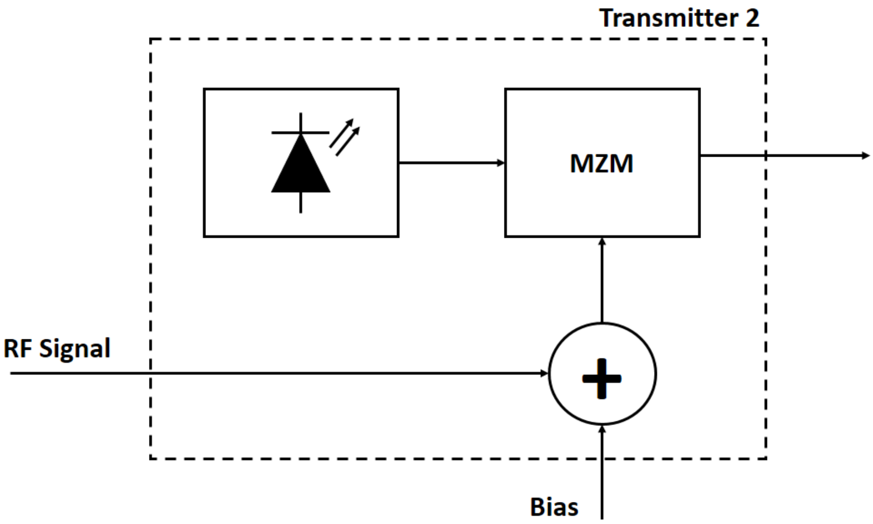
At present there are various techniques to generate and transport radio signals through the optical fiber and in terms of modulation and demodulation format, it is classified into the two categories that are, Intensity Modulation-Direct Detection and Remote Heterodyne Detection.

- **IM-DD** (**Intensity Modulation-Direct Detection**):

It involves in modulation of light source intensity directly with radio frequency signal. DD is performed by photodetector for recovering the RF signal. Laser modulation can occur by two methods. In first method, direct modulation of laser occurs using RF signal for driving the laser bias current. This has been depicted in figure Other method involves operation of laser in continuous wave followed by modulation of light intensity by external modulator (for example, Mach Zehnder modulator) as shown in figure 1.4 .The Photocurrent The photocurrent obtained at the PIN photodiode replicates the modulating RF signal whose connections are made with external modulator or with laser placed at transmitter and IM DD is mostly used with external modulator for RoF techniques [7]



(A)



(B)

Figure1.4 Intensity Modulation-Direct Detection Technique (A) directly modulated RF signal (B) using external modulator

- **RHD (Remote Heterodyne Detection)**

It is necessary for a system to have good transmission and reception performance according to the network terms when very high frequency signals are transmitted through the optical fiber link. The involved processes should be linear. For achieving this purpose, optical heterodyning is used for the remote generation of modulated microwave signal. Two laser diodes having narrow spectral line width are utilized, where the spacing of central optical and microwave frequencies are equal as shown in figure 1.5 Out of the two lasers, one involves intensity-modulation of information and other involves emission of CW light. Combination of light from the two lasers occurs followed by transmission via the optical fiber. At receiver, radio signal appears by using optical heterodyning in photodiode which is further amplitude-modulated with the information signal.

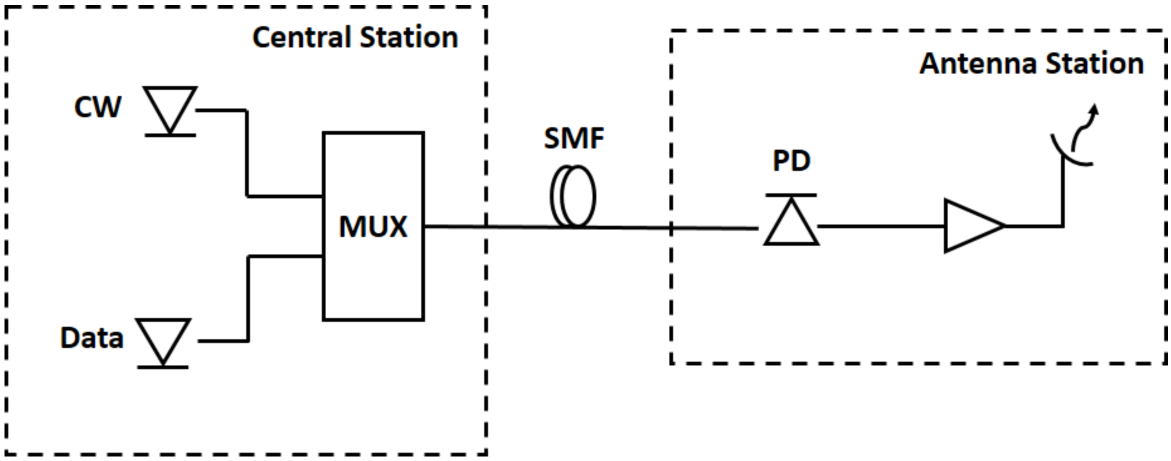


Figure 1.5 Remote heterodyne detection by using two lasers

Figure 1.6 shows that if a single laser is used then the Mach Zehnder Interferometer modulator will be biased on its inflexion point of Modulation characteristic. Sinusoidal signal drives the MZI and is at half the desired frequency of microwave signal. So, at the MZI output a two-tone optical signal appears whose spacing of tone and microwave frequency are equal accompanied by suppression of optical carrier. In the case of IM of laser with information signal, self-heterodyning in PD produces modulated radio signal at receiver end.

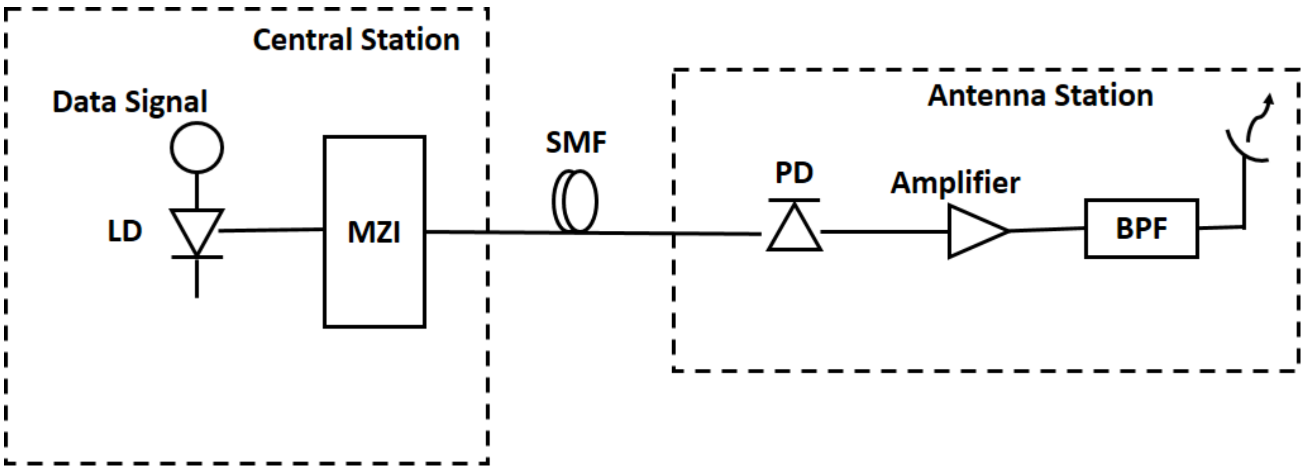


Figure 1.6 Remote Heterodyne detection by using single laser

The classification of RoF is based on the type of RF signal which is transmitted through the Fiber. Mainly three types of RoF, which are AROF, BROF, and DROF.

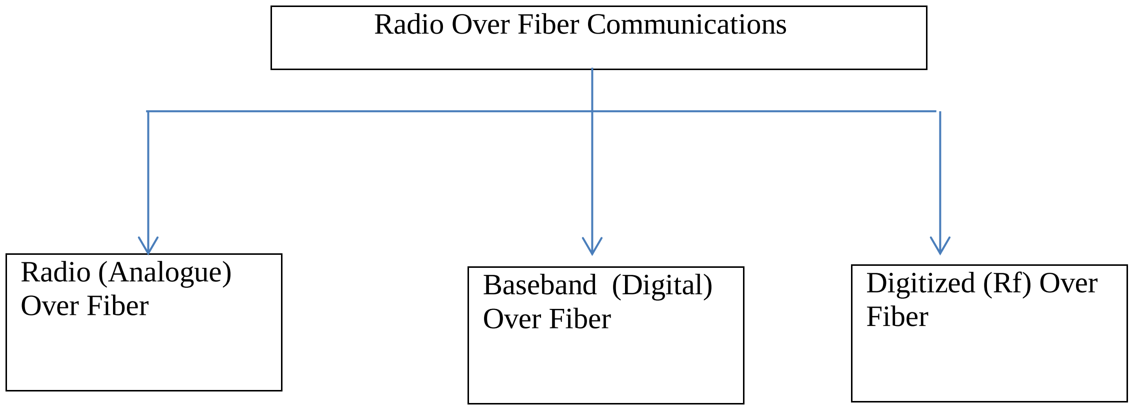


Figure 1.7 ARoF, BRoF and DRoF communication System

The BRoF is simplest form of transmission, but does not compatible with high datarates.Because of the effects of nonlinear modulator, the analog millimetre-wave is weakly intensity modulated onto the light carrier. The nonlinear property of external modulator played a very important role in mitigation of actual signal. Chromaticdispersion in fiber places an upper bound for the transmission distance [8].

1.5 Objective

Main objective of this thesis to study the performance of Rof-OFDM scheme using 4 and 16 QAM for fiber length up to 100 km .To make a Rof-OFDM model with the help of Software Optisystem. Compares the results of this model for 4 and16 QAM in the reference of BER, OUTPUT power, Length of optical fiber.

ROF-OFDM scheme is a technique by which microwave (electrical) signals are delivered through optical components and techniques. ROF is an incorporation of both optical and wireless domains. This system is the most suitable combination of optical fiber links and radio waves. It can increase the ability of modulation radio frequency access with high speed data transmission.

1.6 Organization of Thesis

Chapter 1 gives the introduction about RoF and discusses various concepts and techniques that can be integrated with it.

Chapter 2 briefly describes the OFDM and QAM modulation techniques for use the concepts of radio over fiber and to state the main objectives of thesis.

Chapter 3 Overview of Optisystem Software .In this we discussed about the component of optical fiber communication which is used in this software to simulate the results according to the thesis.

Chapter 4 demonstrates a RoF-OFDM system model based on orthogonal frequency wavelength multiplexing using QAM. This framework supports long haul transmissions. It results in simplifying the design of RoF-OFDM system for 100 km fiber length.

Chapter 5 Discussion of Simulation results presented in this dissertation.

Chapter 6 Includes the Conclusion and Future scope of the work presented in this dissertation.

Chapter (2) OFDM AND QAM MODULATION TECHNIQUES

2.1 Introduction to OFDM

OFDM, the multi-carrier modulation procedure (MCM) has been seen with make total effective to channels with frequency selective fading [9]. It will be extremely difficult to manage frequency selective fading reported by the receivers as design of the receivers becomes complicated. This OFDM system efficiently uses the accessible channel data transfer capacity by dividing the channel total bandwidth into N number channels [9]. Instead mitigating frequency selective fading as an entire, OFDM mitigates the problems with flat fading by converting the entire frequency selective fading channel into n number of small bandwidth channels. Flat fading makes the receiver simple to combat channel tracking and Inter Symbol Interference (ISI) by employing simple equalization schemes.

OFDM is a multi-carrier communication transmission method that modulates different transporters at the same time. OFDM lead the idea about single sub-carrier modulation by presenting parallel various sub-carriers through a channel. Vast number of nearly divided orthogonal sub-carriers utilized the OFDM that are transmitted parallel and all sub-carriers would adjusted with low symbol rate by any one of conventional digital modulation scheme, such similarly as QPSK, 16QAM, and so on. All sub-carriers in combination that enables the data rates equivalent to conventional modulation scheme same as single carrier modulation [9, 10].

Hence, orthogonal frequency division multiplexing method needs to be acknowledged similarly as comparable of the FDM. In FDM, different data streams which has been transmitted are mapped through parallel frequency channels by separating to each other and every channel is separated from the other channel by a guard band to minimize the possible interference among the adjacent channels.

The OFDM Method is different in comparison with the traditional FDM as:

a. numerous carrier carries single information stream.

b. sub-carriers shows orthogonality with each other.

c. Guard band Tg is added between adjacent symbols for the minimization of the channel delay spread and ISI.

2.2 Principle of orthogonality and Block Diagram of OFDM

In multi-carrier system, occupied channel bandwidth must be reduced as minimum as possible. This minimization of chancel bandwidth is only possible by reducing the frequency space between carriers. The narrow space among the carriers is obtained when they are orthogonal to each other. For orthogonality, the time averaged integral product of two signals should equal to zero [11].

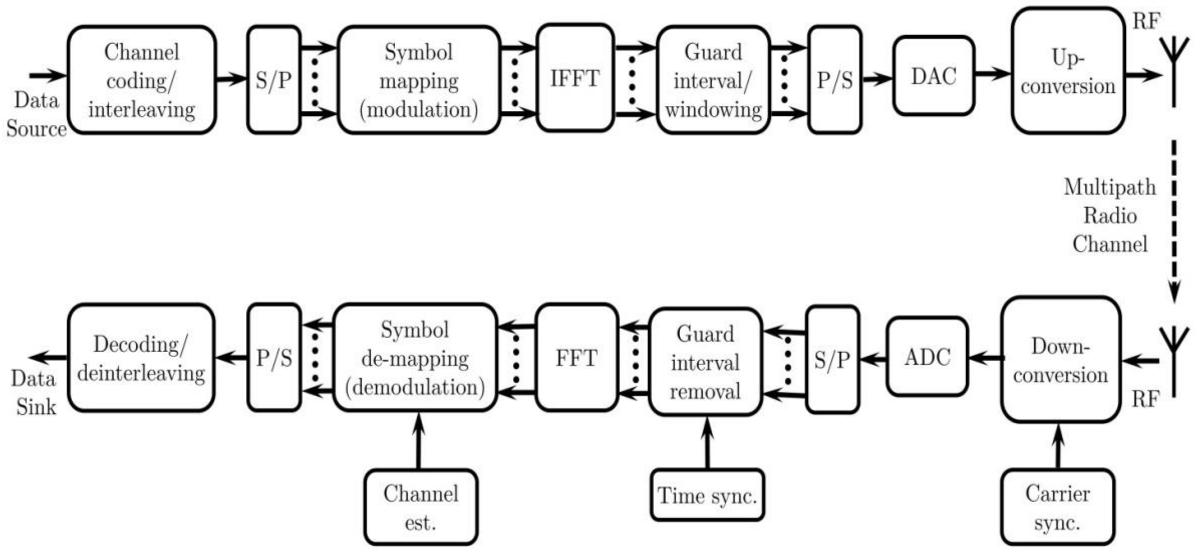


Figure 2.1: Block Diagram of OFDM Transmitter and Receiver

2.2.1 Importance of Orthogonality

OFDM signals are stated as a set of nearly divided Frequency Division Multiplexing sub-carriers. In frequency domain, every transmitted sub-carrier would become a sinc function spectrum with side lobes. These side lobes transform covering spectra among the sub-carriers. It is illustrated in figure and outcome demonstrates the sub-carrier interference excluding the orthogonally spaced frequencies. The specific peaks of sub-carriers align with nulls of all other sub-carriers [10]. The spectral energy overlapping doesn't interfere to the ability of system, for recovering the signal. The use of orthogonal sub-carriers provides large number of sub-carriers per bandwidth and also increases the spectral efficiency. In an ideal OFDM signal, orthogonality prevents it from interference among the overlapping carriers which is also known as Inter Carrier Interference. In OFDM systems, if there is a loss of orthogonality then the sub-carriers interfere with each other [9, 10].

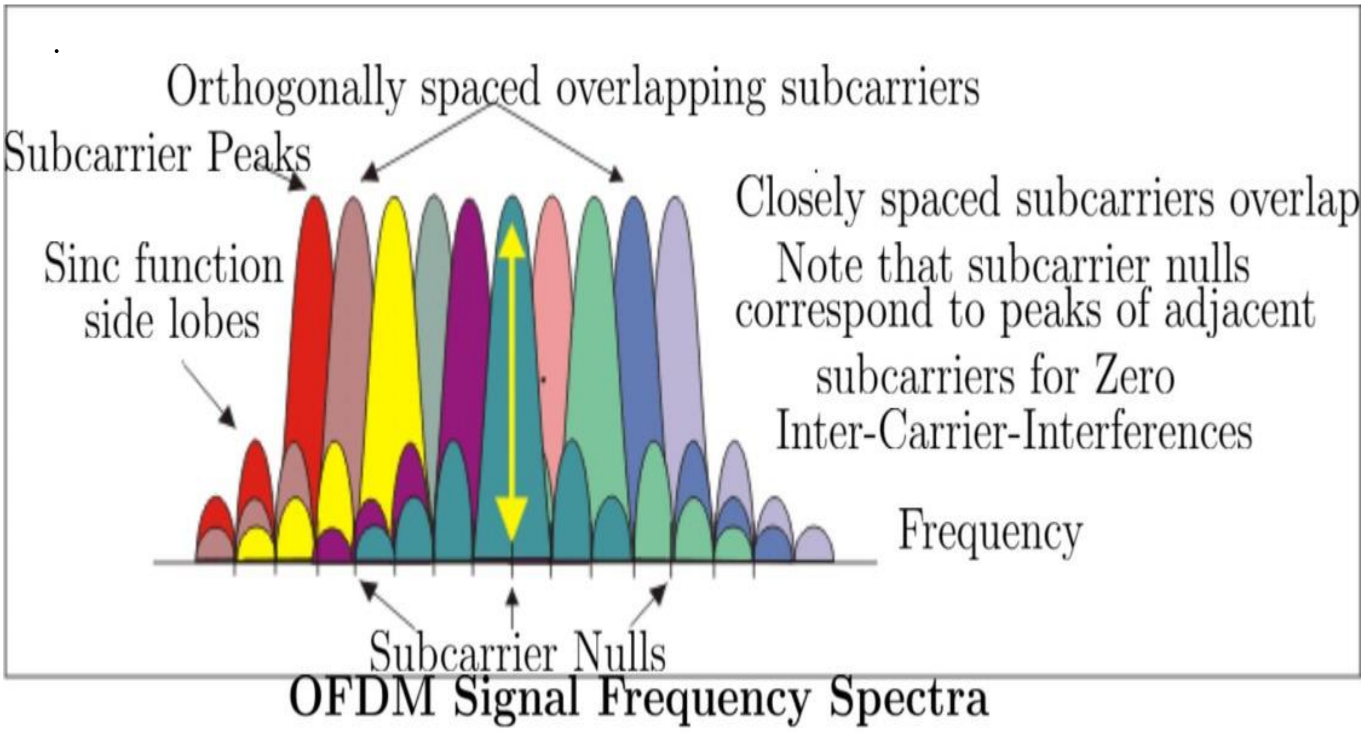


Figure 2.2: OFDM spectrum

2.2.2 Mathematical description

If N number of sub-carriers are transmitted and modulated by M ary signalling, then the OFDM symbol alphabet consists of one out of MN number of combined symbols.

The LP equivalent Orthogonal Frequency Division Multiplexing signal can be given by:

N 1

Xk

x(t) =Xkej2 kt=Ts ; 0 t < Ts

=0

Where,

Xk are the data symbols,

N is the quantity of sub-carriers,

Ts is the OFDM symbol time

In OFDM, Guard band of length Tg is introduced before OFDM block for avoiding ISI in multipath fading channels. A cyclic prefix is additionally transmitted during time period Tg. The signal transmitted during time period Tg t< 0 is same as the signal during time period (Ts Tg) t < Ts. Hence, the Orthogonal Frequency Division Multiplexing signal with utilization of cyclic prefix can be calculated as

N 1

Xk

x(t) =Xkej2 kt=Ts ; Tg t < Ts

=0

2.3 Guard Period and Cyclic prefix

Guard Period

For starting and ending of transmitted symbol period synchronization is needed in OFDM demodulation. IF OFDM demodulation is not synchronized then Inter Symbol Interference will arise i.e. since data signal will be decrypted and combined for two end-to-end symbol periods. Due to loss of orthogonality ICI will also occur that means. Integrals of the carrier signal products will not become zero over the total integration period.

To resolve from this problem, a guard period (Tg) is added to each OFDM symbol period. By adding Tg simply make the symbol period longer and decoding should be done in inside a single period. Longer guard intervals reduce the channel efficiency but allow more distant echoes to be tolerated [9].

Cyclic prefix

Mainly Two problems occurred when data is transported through a dispersive channel. First is channel dispersion which breaks orthogonality among transmitted sub-carriers and results in ICI. Secondly, dispersive channel results in inter symbol Interference among two successive OFDM symbols. The addition of guard interval Tg among two consecutive OFDM symbols provides avoidance of ISI in a dispersive channel. But the addition of guard band among two successive OFDM symbols, do not prevent the loss of orthogonality. Peled and Ruiz provided a solution to overcome this issue with the addition of a cyclic prefix. This cyclic prefix is used to prevent it from both the orthogonality of the subcarriers as well as Inter symbol Interference among the successive OFDM symbols. So, the equalization at the receiver becomes simple. Hence, this makes OFDM suitable for wireless systems [9, 10].

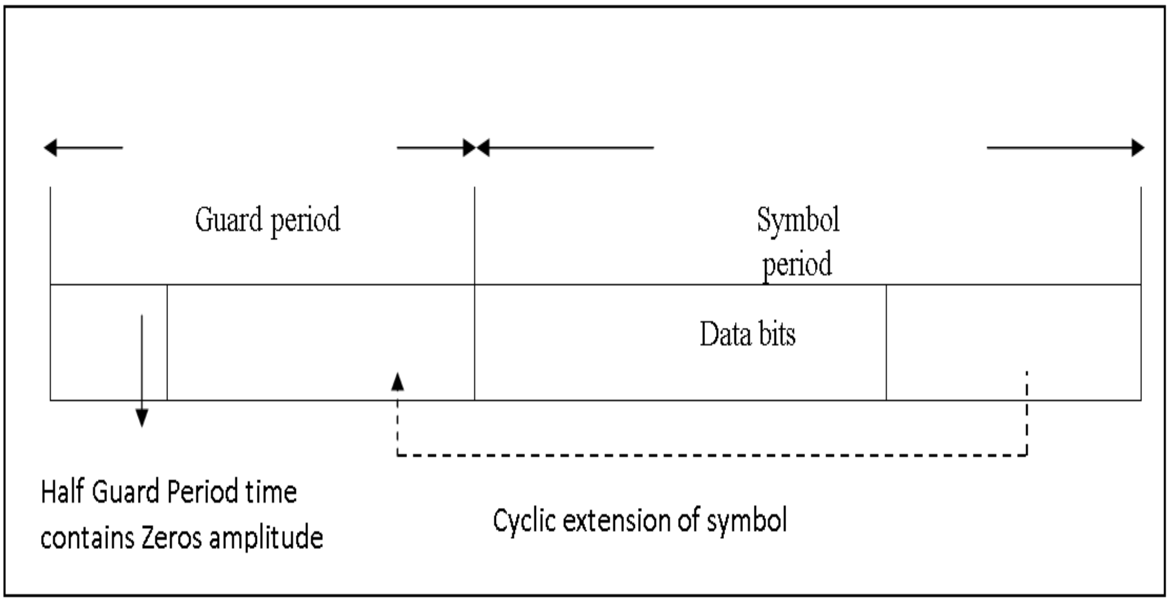


Figure 2.3:- Insertion of Tg (guard band) interval with symbol

2.4 Advantages of OFDM system

The main advantages of OFDM system are given as-

a) Saving of Bandwidth

While comparing with Frequency Division Multiplexing, OFDM technique is highly bandwidth efficient. As illustrated in figure, in FDM method number of different carriers is placed separately without overlapping, whereas in OFDM technique due to orthogonality, the sub-carriers overlapped to each other. Due to this overlapping the bandwidth reduces radically. This also minimizes guard bands for distinguishing the sub-carriers [9,10].

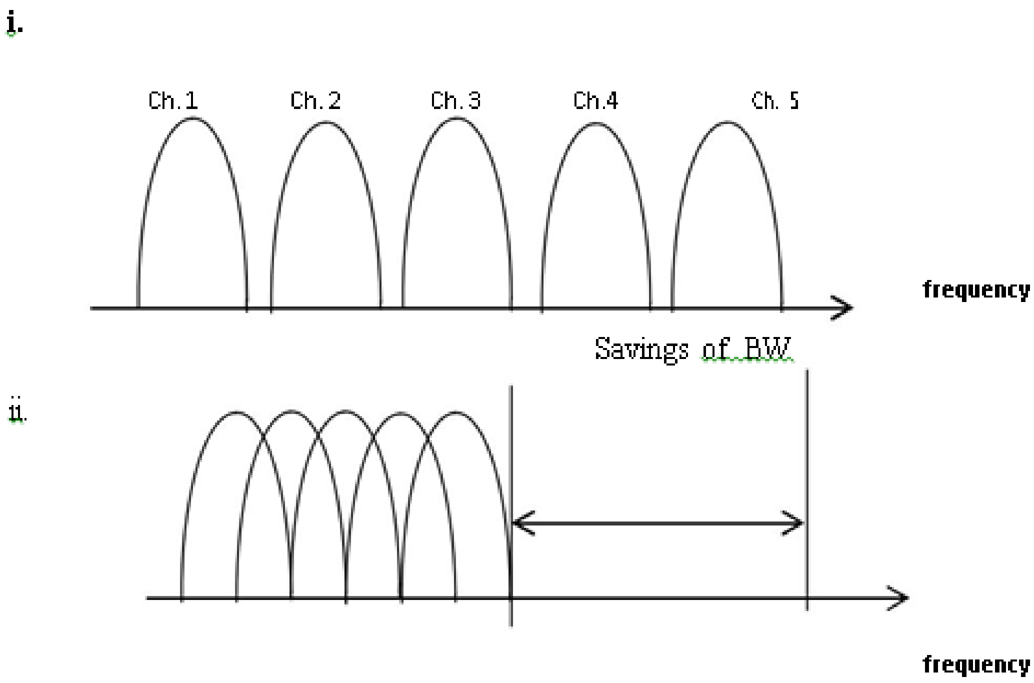


Figure 2.4: Comparison of (i) FDM and (ii) orthogonal multi-carrier modulation technique

b) Simple implementation of Modulation and demodulation

Bank of modulators and demodulators implementation is a most challenging task in OFDM. To overcome this challenge IFFT and FFT are used for efficient "Data transmission" in OFDM [9].

c) Ease of Equalization

In a single carrier Frequency Division Multiplexed system, equalization makes frequency channel response flat. But where channel response is very poor it also amplifies noise in frequency domain. If all use frequencies are given equal importance, then some bands affect single carrier display due to high attenuation. To reduce the difficulty of equalization or similarity of carriers the wideband channels are divided into small flat fading sub-channel in the receiver. [10]

d) Adaptable to frequency selective fading

OFDM is highly prone to frequency selective fading because of the ability to parallel transmission (all sub-carrier have very small bandwidth in comparison with overall bandwidth of signal). Frequency selective fading channel are translated into multiple flat fading channels with the help of OFDM [9, 10].

e) Protection against ISI

The extended symbol produces the signal is lesser prone to effects the channel, like as ISI. Utilization of Cyclic Prefix among two successive OFDM symbols prepares it more resistant to ISI and reduces its sensitivity to sample timing offsets [9].

2.5 Major Disadvantages of OFDM system

Although the OFDM systems have several advantages but it also have some limitations-

a) High PAPR of transmitted signal

Large numbers of subcarriers are present in the OFDM system with changing amplitude produces a high peak to average power ratio. It shows direct effect on RF amplifier efficiency [11].

b) Timing and Frequency synchronization at the receiver

OFDM system is affected by STO and CFO. At the receiver end time synchronization among FFT and IFFT is require. This system is extremely sensitive to Doppler effect which generates the ICI [11].

2.6 Quadrature Amplitude Modulation (QAM)

QAM is a modulation scheme for joining two AM signals on a single channel. This modulation scheme doubles the channel bandwidth. This scheme can be particularly applied in wireless applications with PAM. There are two carriers in a QAM signal, each having the equal frequency and 90 degrees phase difference. One carrier is known as the Q -signal, and another one is I-signal [12].

Mathematically, First signal is denoted by a sinusoidal wave while another is cosine wave. At the source end two modulated carrier signals are added for information transmission. These carriers separated at target end and data is extracted from complete carrier signal, then mixed this data with original signal [11, 12].

2.6.1Constellation diagrams for QAM

The constellation diagrams are a most appropriate representation for modulation methods used in digital systems. In qam, the points of constellation are settled in the form of square grid with same spacing in vertical and horizontal direction. In digital telecommunication system the data is in the form of binary data. Hence, the total point in the square grid is given by the power of 2. Thus, QAM is generally square grid and the most general classification of QAM are 16- QAM, 64-QAM, 128-QAM and 256-QAM [12, 13].

When QAM is used for RF applications then QAM is capable for carrying high data rates than general PM and AM schemes. The number of points on the constellation is specified as per modulations scheme description for example 16-QAM utilizes 16 point constellation.

It is possible to transmit more bits per symbol using QAM but the points are closer to each other and hence they are more prone to noise and data errors. So, higher order QAM can deliver more information, less reliably in comparison with low order QAM. In figures shown below of example of constellation diagram for 4,16,32,64 QAM[13].

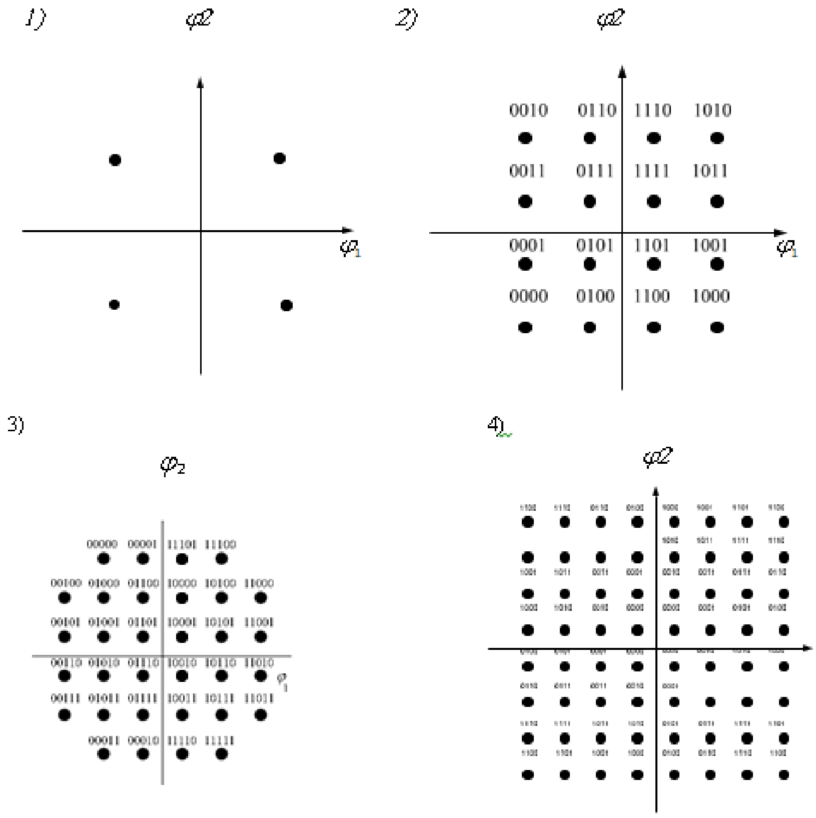


Figure 2.5: Signal constellations of(1) 4-QAM, (2)16-QAM, (3) 32-QAM, (4) 64-QAM

2.6.2 Benefits and limitations of QAM

a) Benefits

By using both phase and amplitude varieties QAM demonstrates an increment in the transmission efficiency for RF systems and It also gives more bits per carrier, for example, 16 QAM utilize 4 bits for every transporter, 64 QAM utilized 6 bits for each bearer and results that its variations effective use to more transmission capacity [12,13].

b) Limitations

Because of closer states it is more susceptible to noise. Low noise is likely to propagate the signal to an alternate destination point and collectors with phase and frequency modulation. Both modulation scheme needs to utilize limiting amplifiers that can remove any amplitude noise. This improvement in noise dependence results in increase in complexity of QAM receiver [11]. The second disadvantage is similarly related to amplitude segment of the signal. At the point when a PM and FM signal is amplified in a radio transmitter, there is no convincing cause for utilizing direct enhancers. However, when utilizing QAM comprises an amplitude element, linearity must be kept up. Unfortunately, Linear amplifier are expending more power and less proficient, so it is less suitable for mobile applications. [13].

2.6.3 Applications of QAM

QAM is widely used in data delivery and radio communications applications. In digital cable television and modem broadcast applications 64 -QAM and 256 -QAM are often used[].For digital terrestrial television using DVB (Digital Video Broadcasting) 16- QAM and 64 -QAM is presently used in United kingdom. As standardised by the SCTE in the standard ANSI / SCTE 07 2000, 64- QAM and 256 -QAM are the essential modulation for digital cable in the US. Furthermore variants of QAM are also used by various cellular and wireless applications [12, 13].

Chapter (3) Optisystem Software

3.1 Introduction to Optisystem

This is a comprehensive software design suite that allows users to plan, test, and simulate optical components in the transmissions layer of the modern optical network. It is built for the modelling of optical fiber communications and allows to GUI for Controlling the layout, reports, and Visualizer graphics. This allows the design automation system of nearly automation links to analyse the broad spectrum of optical links and optical networks in the physical layer, from the Long-Hour Network, Metropolitan Area Network (MAN) and Local Area Network (LAN).

It has file format in sample optical design (.osd) files. These (.osd) files can be used as optical link design projects and templates for learning and display purposes. Optical capabilities can be enhanced by adding user components, and it can be easily related to a wide range.

3.2 Optisystem - Main Features

- **Component Library**: The Component Library of Optisystem has Components in hundreds. All components have been sensibly approved to provide results that are equivalent with real life applications.

- **User-defined components:** In this software user can create new components according their requirement. They are formed the subsystems and user-defined libraries. Also it can add external secondary tool like as MATLAB or Simulink for simulation.

- **Mixed or Combined signal representation:** It can control the mixed data formats for user simulation work of optical and electrical signals.

- **Quality and performance:** The Optisystem can calculate parameters like as BER and Q- Factor to predict the system performance.

- **Measurement of components:** The Component Library of Optisystem allows users to feed parameters which are compared or observed from real components or equipment. Optisystem tool components integrate with test and measurement tools from various merchants.
- **Monitoring of Data**: In Optisystem project, user can select any component from his project and save the data, after simulation completion they can monitors results. Also user may assign a random number of visualizer components to monitoring the results at the same port.

- **Multiple layouts**: It allows to user to create multiple designs for same project file. Advantage of this is user can modify the project designs any time very quickly and efficiently.

- **Sweeps and Optimizations of project parameters**: In this software sweep is a parameter of simulation tool by use of this sweep parameter simulations can be repeated with and multiple iterations by variation of the parameters. The user can mix several sweeps and many optimizations.

- **Report page:** This page allows to user to show any set of parameters and their results after project simulation. It can make reports are organised into moveable spreadsheets, text, and 2D, 3D graphs.
- **BOM:** It manages a total budget analysis table for the system being designed.

3.3 Optisystem – Applications

- Optisystem has a wide variety of applications which includes: Design of optical fibre communication system from component on the physical layer.
- Network design as such CATV or TDM/WDM/CDM.
- Implementation of PON.
- Design of free space optical systems.
- Design of Radio over fibre models.
- Design of SONET ring.
- Design of Optical Transmitters, amplifiers and receivers.
- Approximation and analysis of BER and system drawbacks with various receiver models.
- Linked budget analysis.

3.4 Optisystem Components

A Basic optical fibre communication system has main elements that are Transmitter, communication media or channel and Receiver**.** To convert the signal from electrical domain to optical domain by transmitter and then launch the resultant signal through the optical fibre. Channel used to carries this signal to receiver without any distortion. At the output end the optical receiver is to convert it back into the original electrical signal.

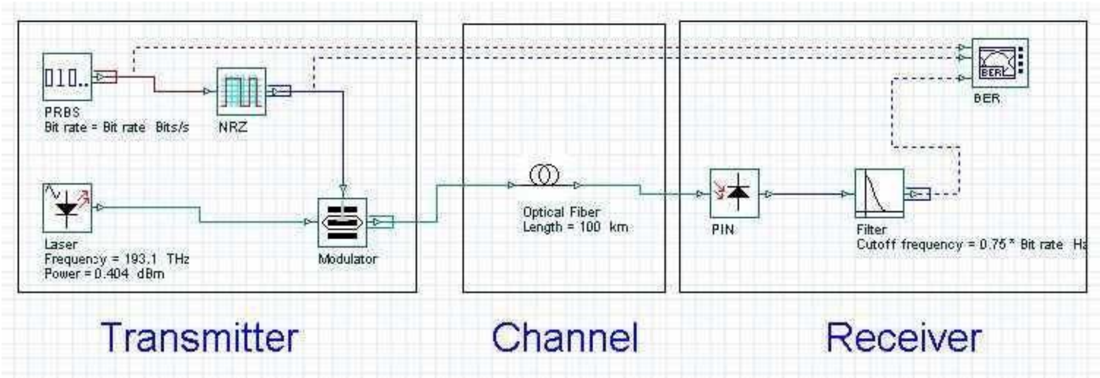


Figure 3.1 Diagram of basic optical communication system in Optisystem

In Optisystem there mainly five libraries used for system design:

1. Transmitter Library

2. Optical fiber library

3. Amplifier Library

4. Receiver Library

5. Visualizer Library

In this we brief on main Transmitters, Channel and Receivers Library.

1. Transmitter Library: Transmitter is a used to produce and transmit EM waves carrying information signals. The main components of transmitter library are Optical sources are LED, Continuous Wave Semiconductor Laser and MZM.

LASER (Light amplification by stimulated emission of radiation):- The output of a laser source is coherent. It is based on the concept of stimulated emission in which excited electrons in a higher energy state are stimulated through a nearest photon. By stimulation, the electron drops into a low energy level and discharges one another photon with similar configuration as the one that was stimulated.

LASER is composed by gain medium, pumping and optical feedback mechanism. That is illustrated in Figure 3.2.

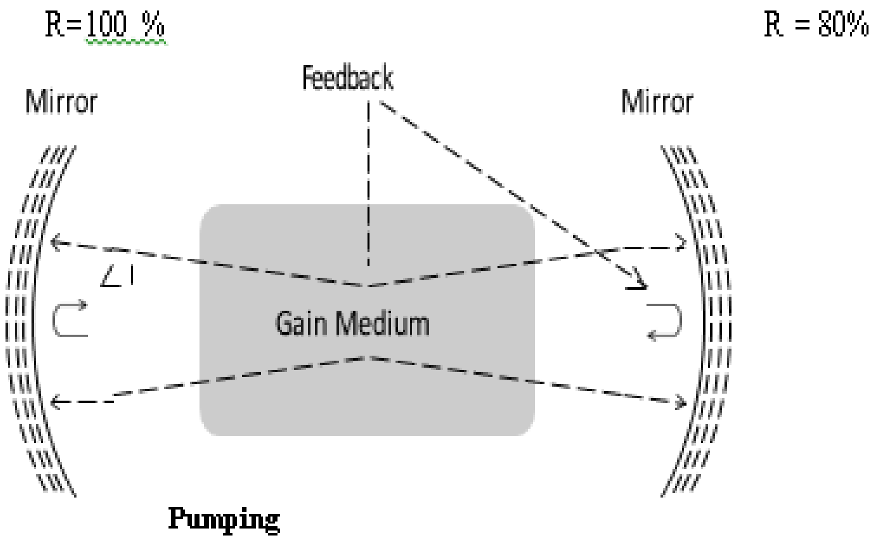


Figure 3.2: Operating principle of a laser.

Gain medium continuously pumped by external energy source to excite electrons. Due to this pumping, electrons are stimulated and jump in high energy state, this is called population inversion. The photons oscillate in the laser cavity due to stimulated emission, as illustrated in Figure. The laser cavity is providing a feedback by reflecting maximum number of the photons reverse to the cavity. But some of few photons escape through the suitably planned cavity walls. The wall has reduced reflectivity. All runaway photons increase to coherent light on a definite wavelength which is reliant on the specific material, which is used in the gain medium. The electrons in the high energy level emit photons spontaneously without any stimulation and spontaneous emission of photons is main source of noise in lasers.

To emitting light continuously by a laser, the amount of stimulated emission represented by Rstim should be bigger than the amount of spontaneous emission represented as Rspon. Mathematically this relation represented by:

$$Rstim/Rspon = \{\exp(hf/kBT) - 1\}-1 >> 1,$$

Where, Plank's constant is h and emitted light frequency f, kB is the Boltzmann constant and T is the absolute temperature. The above equation can be fulfilled if the number of electrons in the excited state is greater than the number of electrons in the ground state.

LED (Light emitting diode): It is light emitting diode belong to semiconductor family, which emits visible light because of electric current passes through it in forward direction. These wavelengths may range from 700nm to 400nm. Some LEDs also emits infrared IR. There are two types of LEDs.

a) **Surface emitting LEDs**: Surface emitting LEDs radiate light at a wide angle. They are not suitable as sources for coupling to an optical fiber because radiation is highly coherent.

b) **Edge emitting LEDs:** Its primary active region is narrow strips that lies b/w the semiconductor substrate .semiconductor is cut & polish , so emission strip region between from and back.

2. Optical fiber library

Optical fibre: fibres are used as communication medium in optical systems. It is based on the Total Internal Reflection (TIR), wherever light fed into the fiber at a particular angle residues kept to the core due to reflections from the boundary of the core. The light reflected, because of the significant variation in the refractive index at the core boundary. As given in Fig (3.3) It is made of silicon and shape in cylindrical containing of two sections, first is the inner core and second is the outer cladding. The RI of the cladding is made significantly lower than that of the core. Since a change in refractive index results in the reflection of light, the light entered at a certain angle into the fiber remains confined to the core.

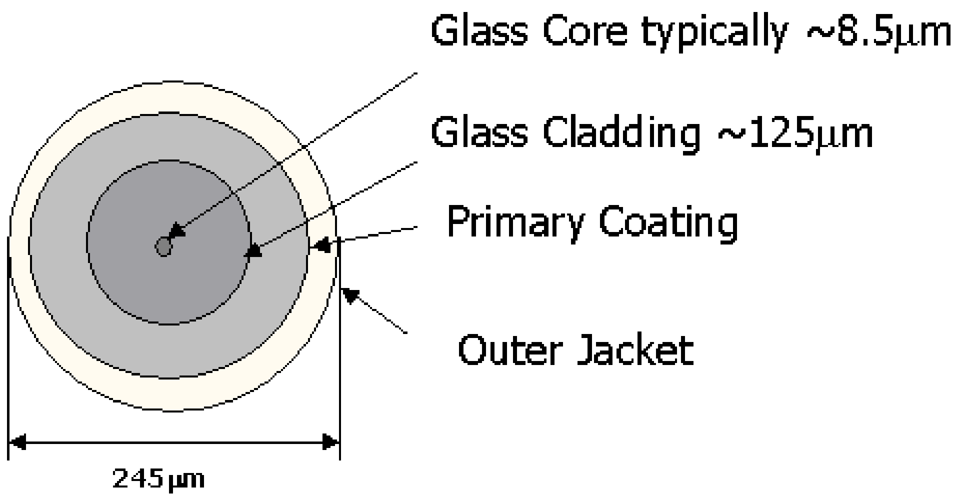


Figure3.3: Structure of (SMF) optical fiber

Optical fiber is categorized in two types that is Step Index and Graded Index fiber and on the basis of number of modes of propagation the optical fiber are classified:

1) Single mode fiber

2) Multimode fiber.

In optic fiber technology for long distance communication single mode fiber is used. Multimode fiber is used for short distance; it allows a large number of modes for light ray travelling through it.

3. Amplifier Library

Basically three types of optical amplifiers associated with amplifier library. These are Fibre Raman amplifier, Semiconductor Optical amplifier and Erbium doped fibre amplifier (EDFA), the main function of these amplifiers is to amplify an optical signal directly.

Semiconductor Optical amplifier is based on a semiconductor gain medium and it uses undoped InGaAsP. **Erbium doped fiber amplifier** is amplifies a modulated laser beam directly without opto-electronic and electro-optical conversion. The amplifying medium is a glass optical fiber doped with erbium ions. **Fiber Raman Amplifier** is an optical amplifier based on Raman gain, which results from the effect of stimulated Raman scattering.

4. Receiver Library:

The main components of this library are PIN, APD, and Spatial PIN photodetector .Receiver library components used to execute signal from Optical to electrical conversion. We will discuss in brief to the process of photo detection.

Concept of Photo detection: Photodetector works when light drops on it, then photons are absorbed by the electrons which are existing in the valence band. Electrons present in valance band gains energy from the absorbed photon and move to the conduction band. Hence, an electron-hole pair is made, due to an external potential, it gives increase to the flow of electric current, denoted to as photo current. The process of photo-detection is shown of Figure, where an electron absorbs a single photon to move into the conduction band.

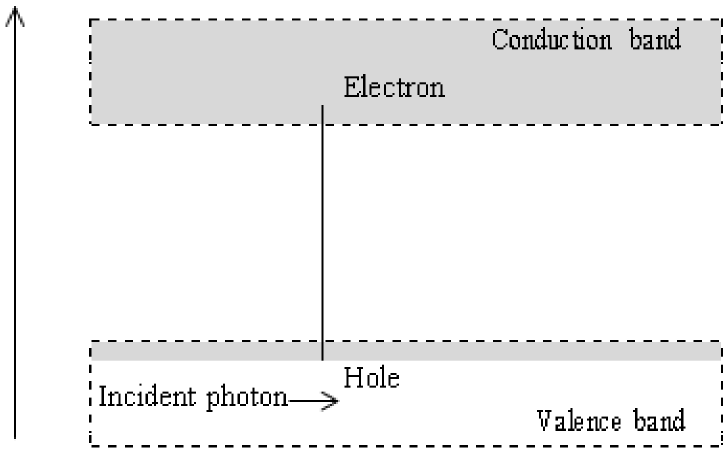


Figure 3.4: Principle of photo detection

5. Visualizer Library

This library incorporates various optical and electrical visualizers which help us to measures different parameters during the simulation of project design.

Electrical Visualizers are Electrical power meter, Eye diagram visualizer, BER analyser, Oscilloscope visualizer. Electrical power meter is used for calculate & display the signal, noise and avg. power of electrical signals at various ports in the design. BER analyser allows to the operator to compute and display the BER of an electrical signal automatically.

Optical Visualizers are used to measures the input and output power, frequency and time analysis and also polarization of optical link. Components of Optical visualizers are Optical power meter, optical spectrum analyser, WDM analyser.

Chapter (4) Proposed Architecture

4.1Introduction

In wireless systems RF signals are widely used in fiber systems for increasing the accessibility at sub-carrier frequencies. RoF is a system of a suitable arrangement of an optical fiber and radio waves. It provides next generation broadband wireless system with high speed data transmission. It enhances channel capacity for RF modulation. It can be linked with OFDM and it has large number of application with increase RF modulation.

RoF system performance is depends upon various components such as laser power and RF signal, non-linearity in optical power, bit-rate, optical modulator, optical fibre channel, and modulation method. The RoF- OFDM model explains the problem of limited distance and solves it. Previously OFDM technique with carrier frequency 1550 nm is used to enhance RF transmission response using 16-QAM constellation in a SMF with a 7.5 GHz Quadrature modulator.

16-QAM and 16-PSK techniques show an improvement in bit rate with decrement in cost and power consumption for medium increase in channel capacity. RoF System can transmit micro and milli-metre waves to optical system for long & short distance communication []. Hence, it is the most useful technique in present RF application. RoF enables radio access for connecting many applications in new generation wireless system. RoF system is capable for many communication standards because of its large bandwidth and Low power consumption.

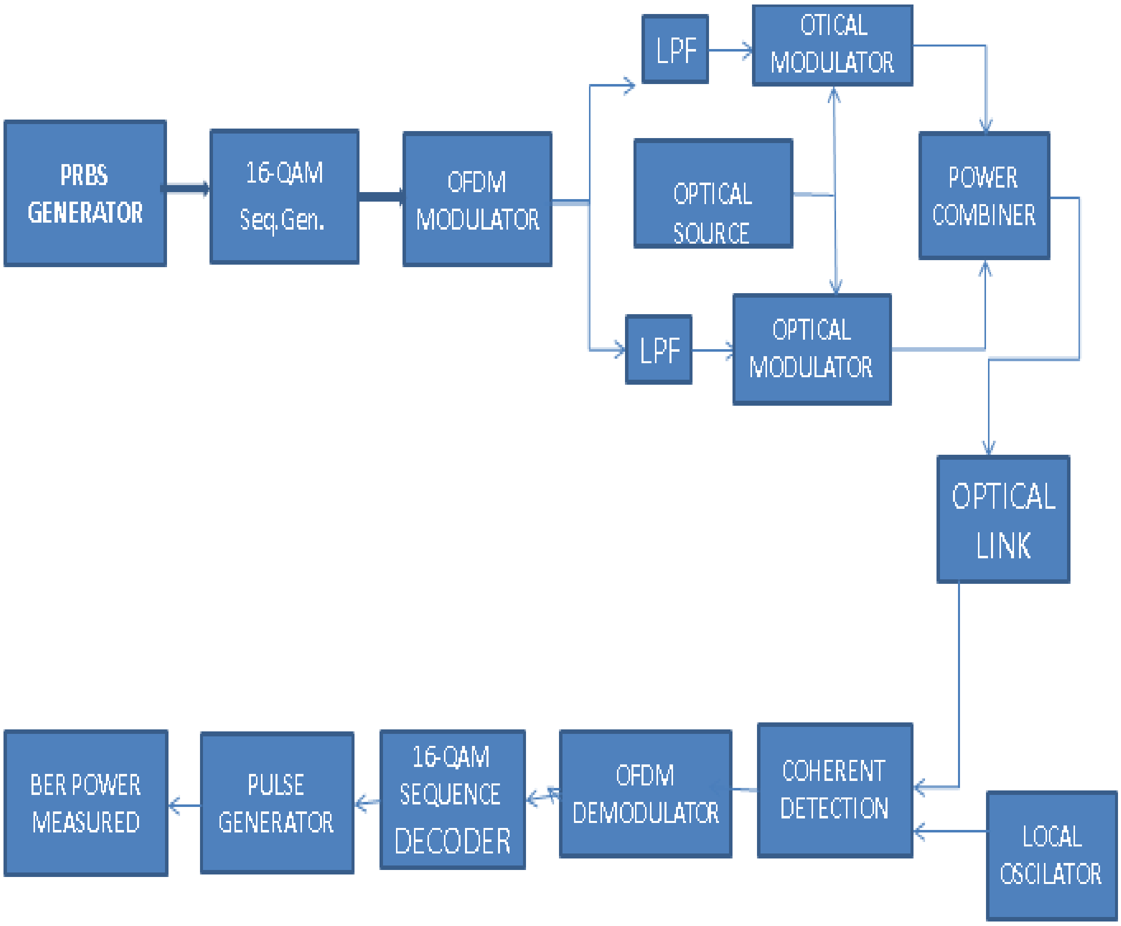


Figure 4.1: Block Diagram of Proposed Model

4.2Simulation Set Up and Working

Proposed RoF-OFDM system using16 QAM technique is composed of

1. RF-OFDM transmitter,
2. RF to optical up-converter (RTO),
3. Optical link,
4. Optical to RF down-converter (OTR),
5. RF OFDM receiver

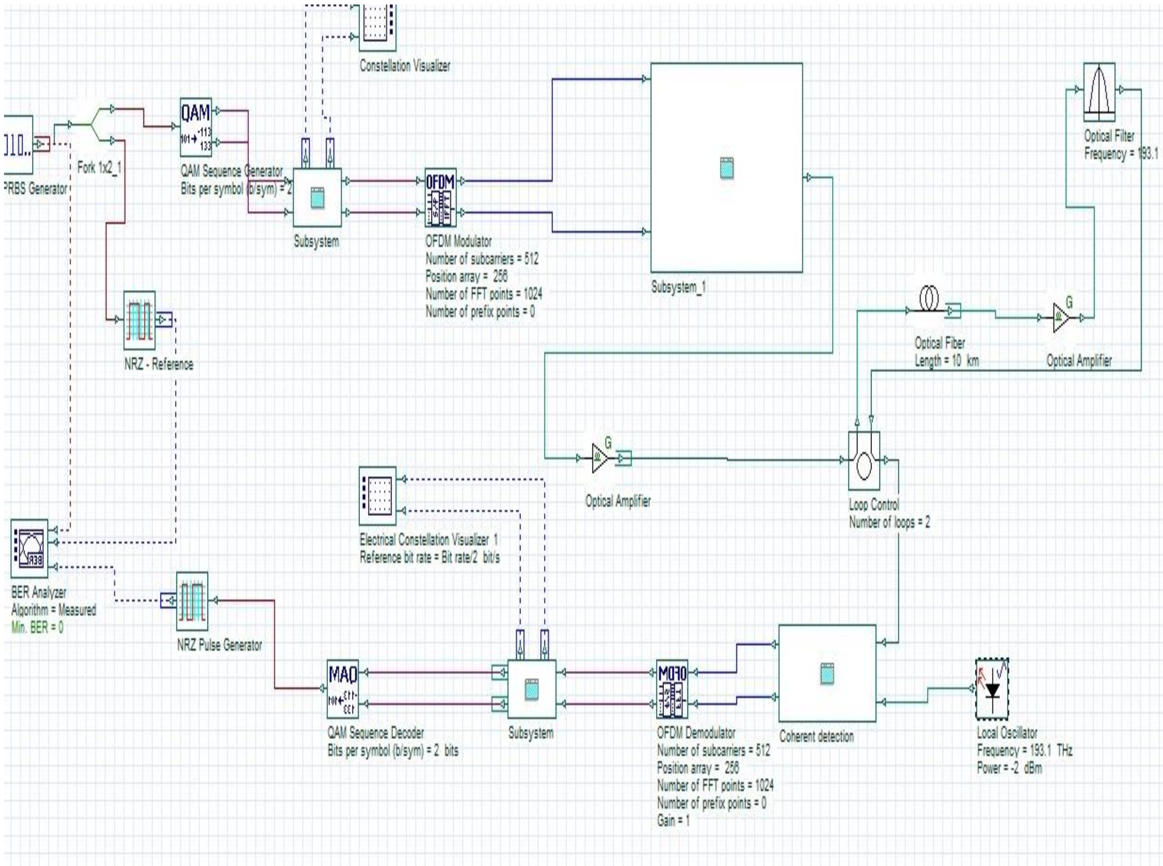


Figure 4.2: Optisystem Simulation setup for Rof-OFDM system model using 16-QAM.

RF-OFDM transmitter and RTO

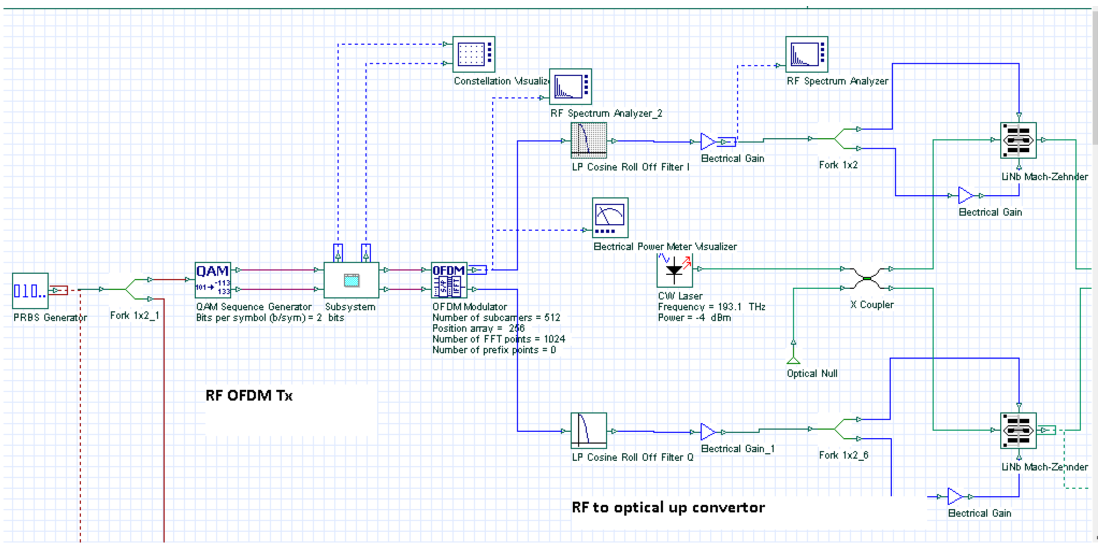


Figure 4.3. RF-OFDM transmitter and RTO

RF OFDM Transmitter: Pseudo random sequence generator finds numerous of applications in digital electronics**.** The *m*-bit shift register has highest number of states is given by 2^m states and normal states is less than that of maximum number of states. An *n* bit linear feedback shift register (LFSR) can have normal states state almost equal to the maximum i.e. $2^m - 1$. This counter is generally known as maximum length sequence generator. The LFSR design is based on finite field theory given by Galois. The operation of an LFSR is related to processes in a finite field with 2^m elements. The feedback polynomial of this circuit is given by

$$f(x) = xm + xk + 1$$

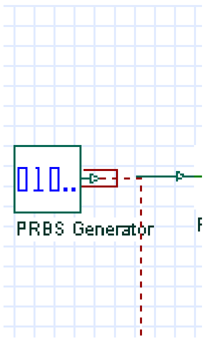


Figure 4.4: PRBS generator in Optisystem

In this system we go to Library and then select the PRBS generator shown in figure 4.4, after that setting of input signal will be done at properties shown below in figure 4.5

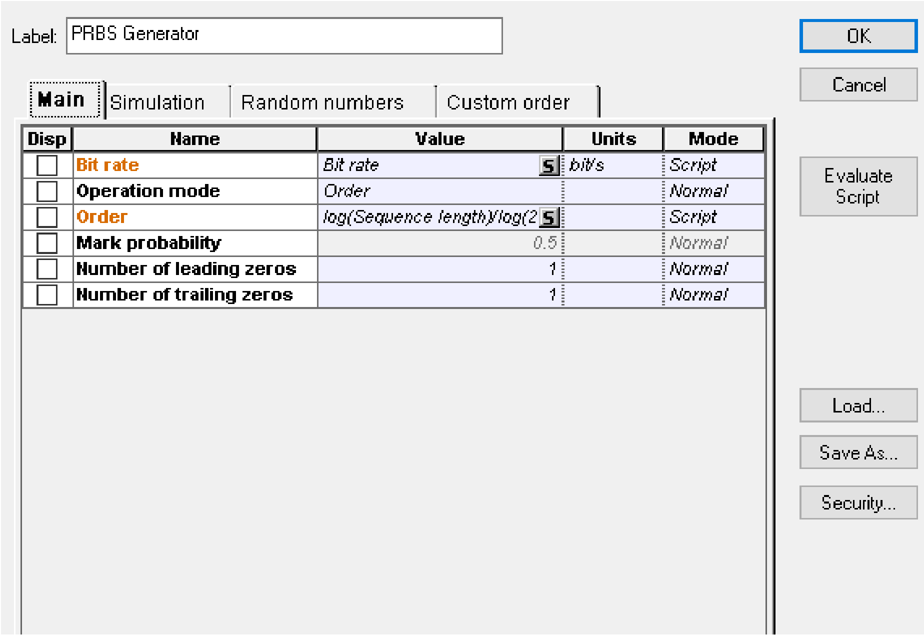


Figure 4.5: Properties of PRBS generator

Here bit rate mode will be set as script where signal 10 Gbps is given in layout properties in figure 4.6.

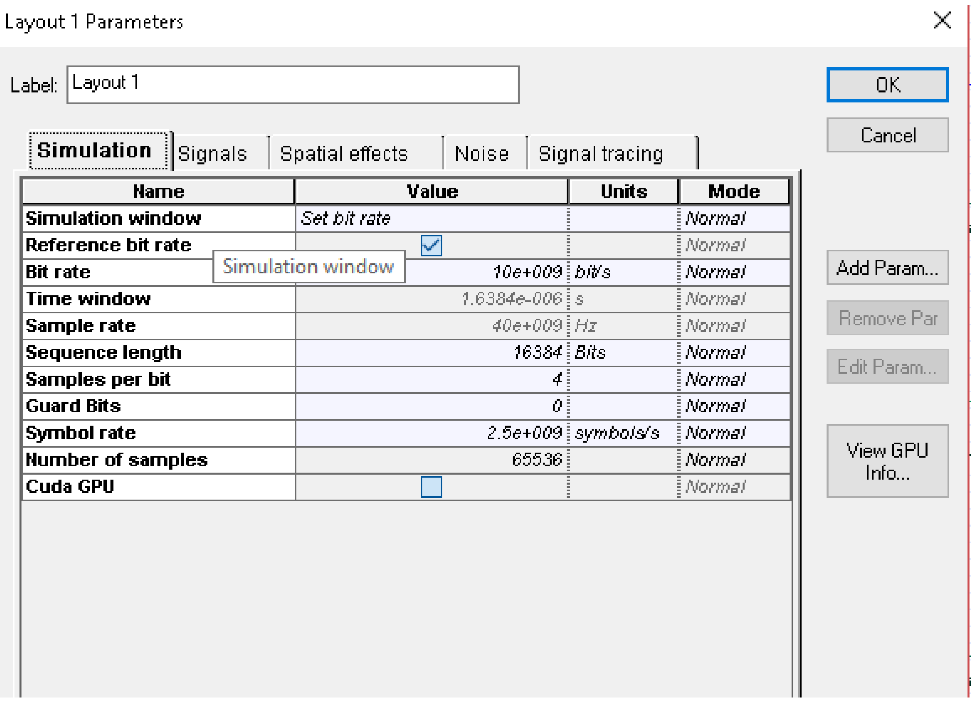


Figure 4.6 Layout parameters of model.

The output signal from PRBS will fed in fork which divided the signal in two equivalent signals. Then Signal will go to QAM sequence generator followed by different frequencies from each subcarrier that it part of all 16 subcarrier. This generator produces bit grouping of OFDM motion with 4 bits/Symbol. OFDM modulation results in 512 subcarriers at 16-QAM & 1024 points of FFT. This system utilizes part of OFDM Opti System13, where output I and Q are flowed to LP-CROF. The estimation of roll off factor r can be maintained from 0 until 1. Roll off Factor significantly affects system execution and finally specifically decide complexity of receiver [14]. OFDM signal is prepared by utilizing IFFT and it adding a cyclic augmentation to get spectral modulator [15]. In OFDM transmitter, the present signal modulation methods such as QPSK and QAM, sends signal to IFFT transformation. After that, signal is fed to D/A converter for further processing. At the OFDM receiver demodulator format the data and fed it to FFT transformation. At the receiver end RF signal is demodulated and send to user.

RTO: This is step Electrical to optical conversion, where optical modulator is used in this system model is LiNb MZM. This modulator is an important module for high bit rate. Light wave systems are placed between RF and laser [16]. In this project, CW laser is used to provide continuous optic waves as illustrated in Figure 4. Output of optical field modulator LiNb MZM is given by [17]:

$$E_O(t) = \frac{E_{in}(t)}{10^{\frac{IL}{20}}}.\gamma e^{\left(\frac{j\pi V_2(t)}{V_{\pi RF}}\right)+\left(\frac{j\pi V_{bias2}(t)}{V_{\pi Dc}}\right)} + (1-\gamma)e^{\left(\frac{j\pi V_1(t)}{V_{\pi RF}}\right)+\left(\frac{j\pi V_{bias1}(t)}{V_{\pi Dc}}\right)}$$

where $E_{in}(t)$ is input optical signal, IL is parameter of insertion loss, V_1 (t) and V_2 (t) are input electrical voltage for the upper 1 and lower 2, V_{bias1} (t) and $V_{bias2}(t)$ are bias voltage 1 and 2,$V_{\pi RF}$ (t) and $V_{\pi DC}$ (t) are switching modulation and bias voltage, γ is denote the power splitting ratio of both Y-branch waveguided, and is given by :

$$\gamma = \frac{1 - \frac{1}{\sqrt{\varepsilon_r}}}{2} \quad , where\ \varepsilon_r = 10^{\frac{Ext\ Ratio}{10}}$$

Where, Ext. Ratio is linked to the parameter Extinction ratio.

Optical link

This system uses loop control for long variation of fiber optic with wavelength/time 200. Optical Filter frequency used to avoid the losses that are due to noise fiber scattering and signal dispersion. Length of optical fiber link is simulated from 10 to 100 km. Scheme of optical link is illustrated in Figure 4.6

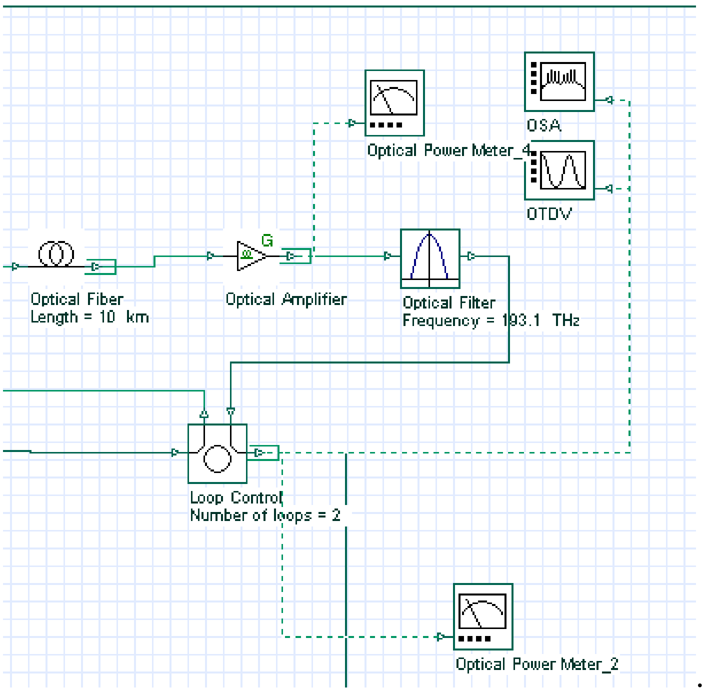


Figure 4.7 Optical Link

Optical to RF down-converter (OTR)

It is called an optical detector. Optical detector is composed of four PIN photo-detector with external source. as shown in Figure 4.8. The PIN photodiode is used to transform an optical signal into an electrical current based on the devices responsivity. For reducing the number of samples in the electric signal rectangle filter is used to filter the incoming optical signal and noise bins. The new sample rate is defined by the parameter sample rate. We can define the centre frequency, or it can be calculated automatically by centring the filter at the optical channel with maximum power. To avoid phase shift in Constellation Diagram at Output, Local Oscillator is used for Coherent Detection.

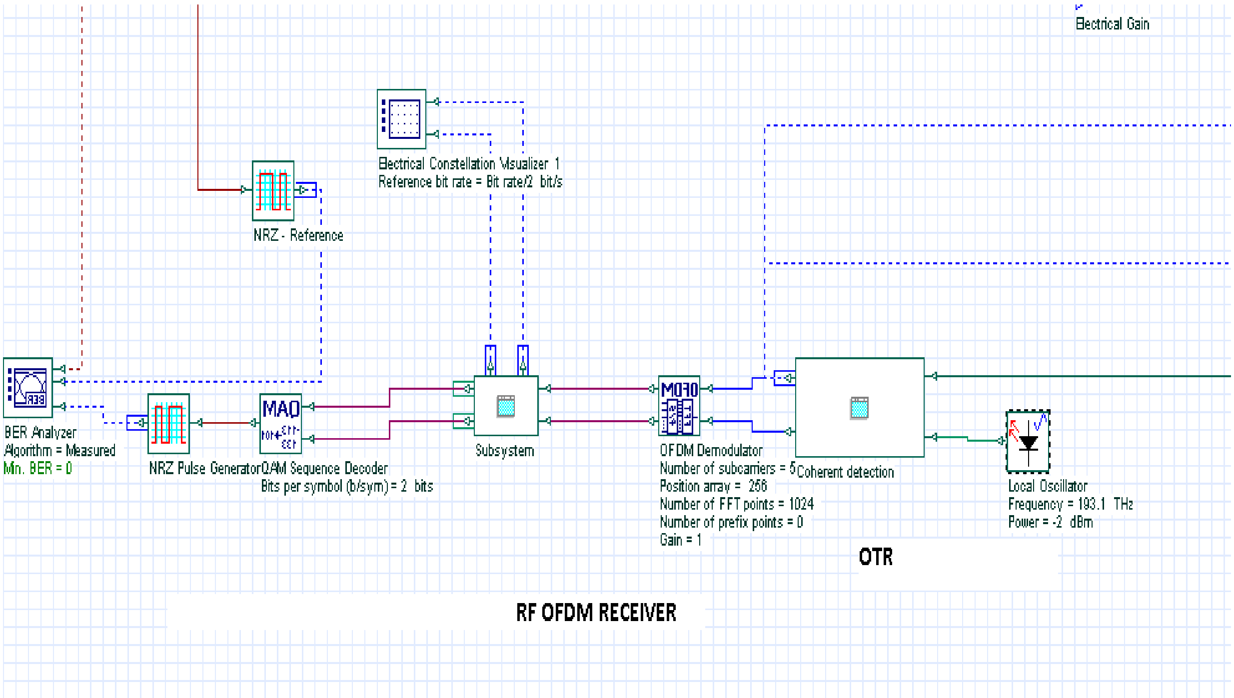


Figure 4.8 OFDM RECEIVERS and OTR

RF-OFDM Receiver

This part is the inverse of the RF OFDM transmitter. It is composed of OFDM demodulator and QAM decoder. Carrier frequency signal as result of Optical to electrical received conversion will be de-multiplexed to get output signal [18-19]. All output will be shown as constellation diagram before coming to QAM sequence decoder. Scheme of simulation RF OFDM receiver is illustrated in Figure 4.8.

Chapter (5) Simulation Results

OFDM signal Spectrum is Shown in figure and it is much harmonics in spectrum sideband with respect o the baseband data rate at 10 Gbps.

As per results it is observed that the output of OFDM is modulated by 16QAM has interval until 20Ghz with higher amplitude is near about 40 dbm.

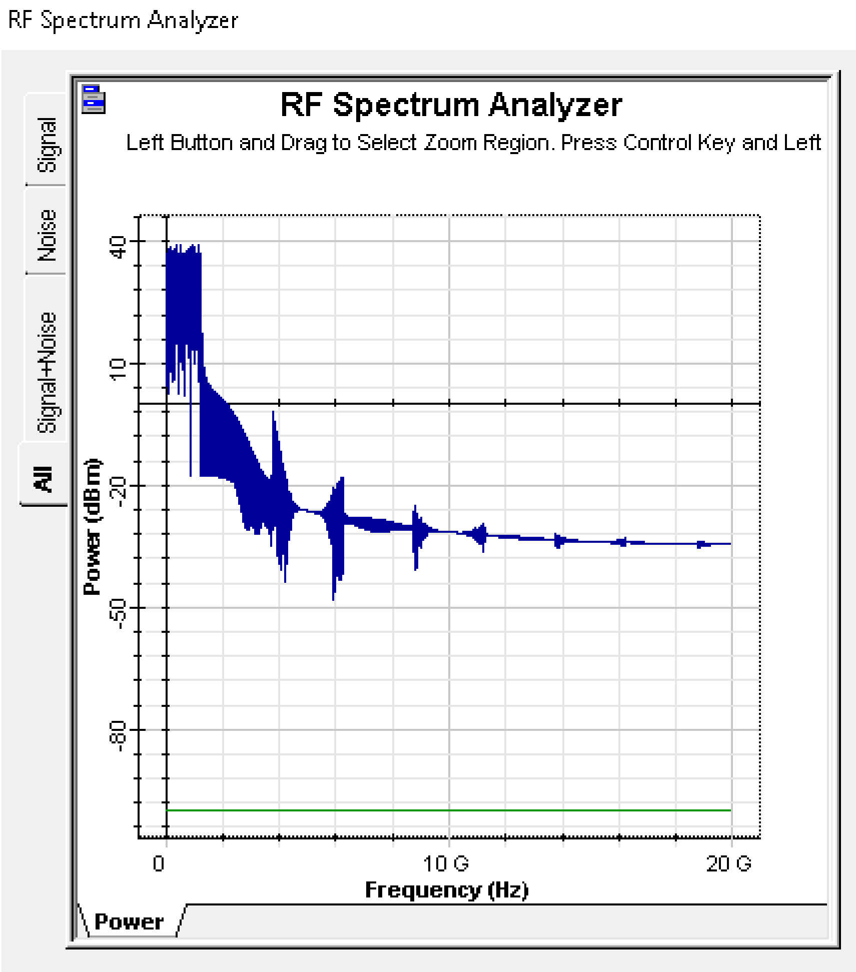


Figure 5.1 Signal Spectrum output of OFDM before Filtering

By Using of LP-Crof filters   low signal spectrum   with maximum noise at 10 Ghz with and Higher amplitude is 4 dBm .This will be input signal in electrical form on drive LINb MZM.

The Roll of factor (r=0) in LP-CROF filter is main causes the filter signal get shart overshooted, because of constriction value of band transition. If, **r** increases from 0.5 to 1then broadening in band transition filter. It will certainly effect when maximum transmitters with adjacent frequency channels.

RF Spectrum Analyzer

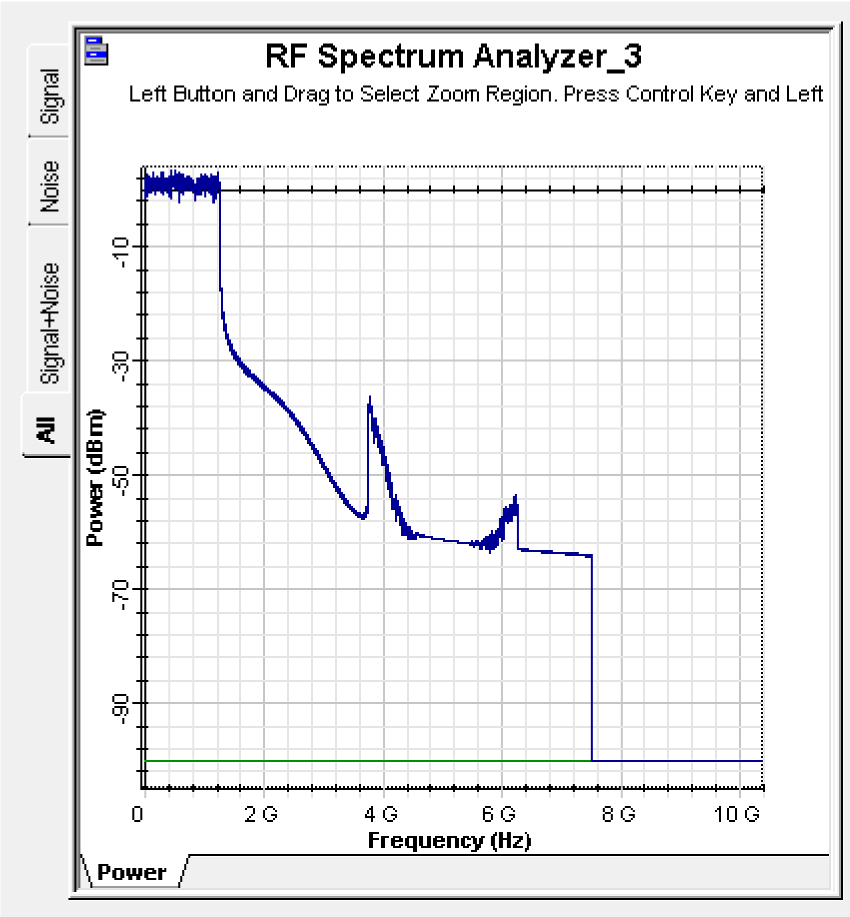


Figure 5.2 Spectrum Signal Output after Filtering for r=0

By considering all the spectrum efficiency, signal power and wide band, the value of roll of factor r 0.5 is ideal in simulation to avoid interference between channel. The signal spectrum is shown in figures as r=0, r=0.5,r=1.

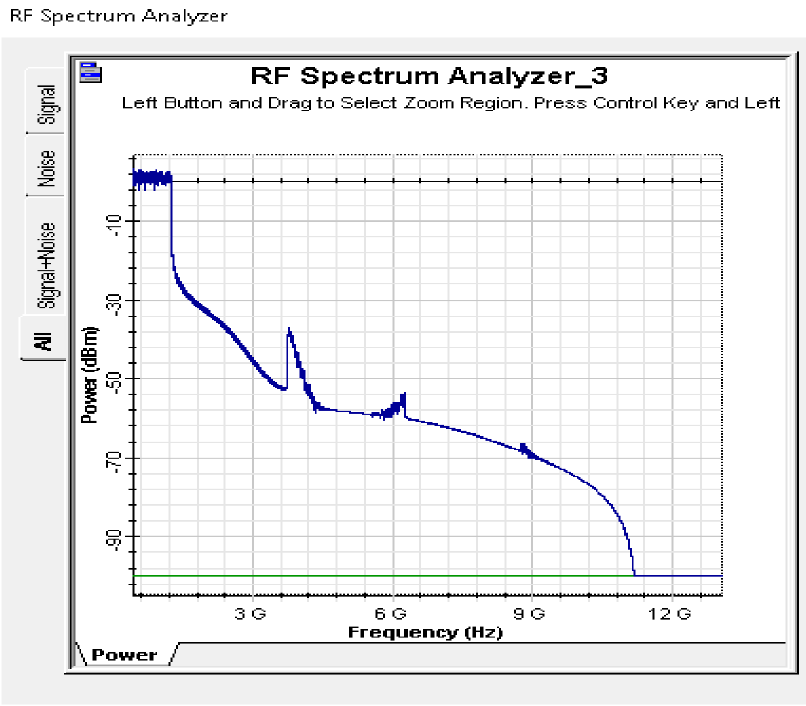


Figure 5.3   Spectrum Signal Output after Filtering for r=0.5

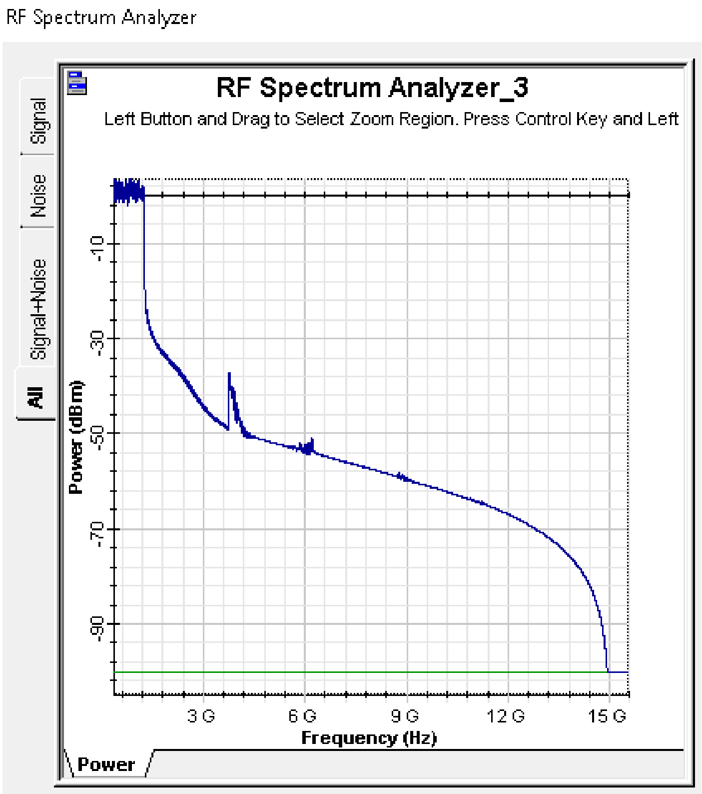


Figure 5.4   Spectrum Signal Output after Filtering for r=1

Signal Spectrum for LiNb-MZM has power value -34 dBm, which is shown in figure. 0.2 dB/km dispersion at the output of optical link and after optical amplification and optical filtering resulted frequency shown in figure. Where ,power is increases to be -22dBm.

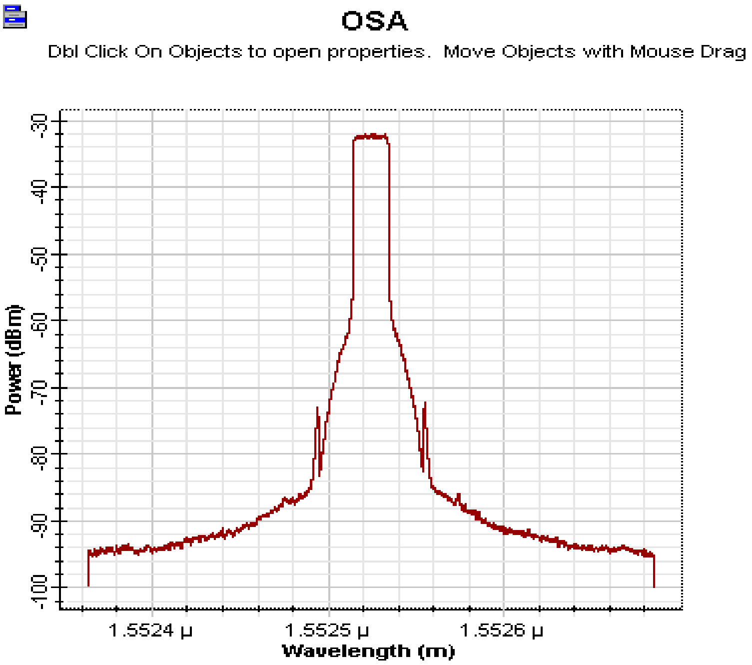


Figure 5.5 Spectrum Optical Signal before Optical Filtering

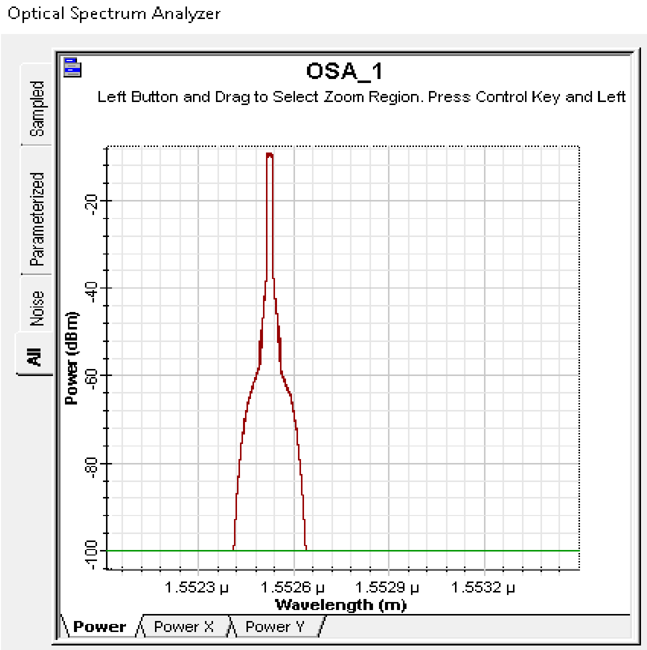


Figure 5.6 Spectrum Optical Signal after Optical Filtering

Coherent Detection subsystem (CDS) works to change optical signal to electrical signal using PIN photodetectors. This extracts phases and gave by amplification for each output before be input in OFDM modulator. Resulted Spectrum Shown in figure and in CDS there are bit noise which is show by green wave in fig and it is small relatively.

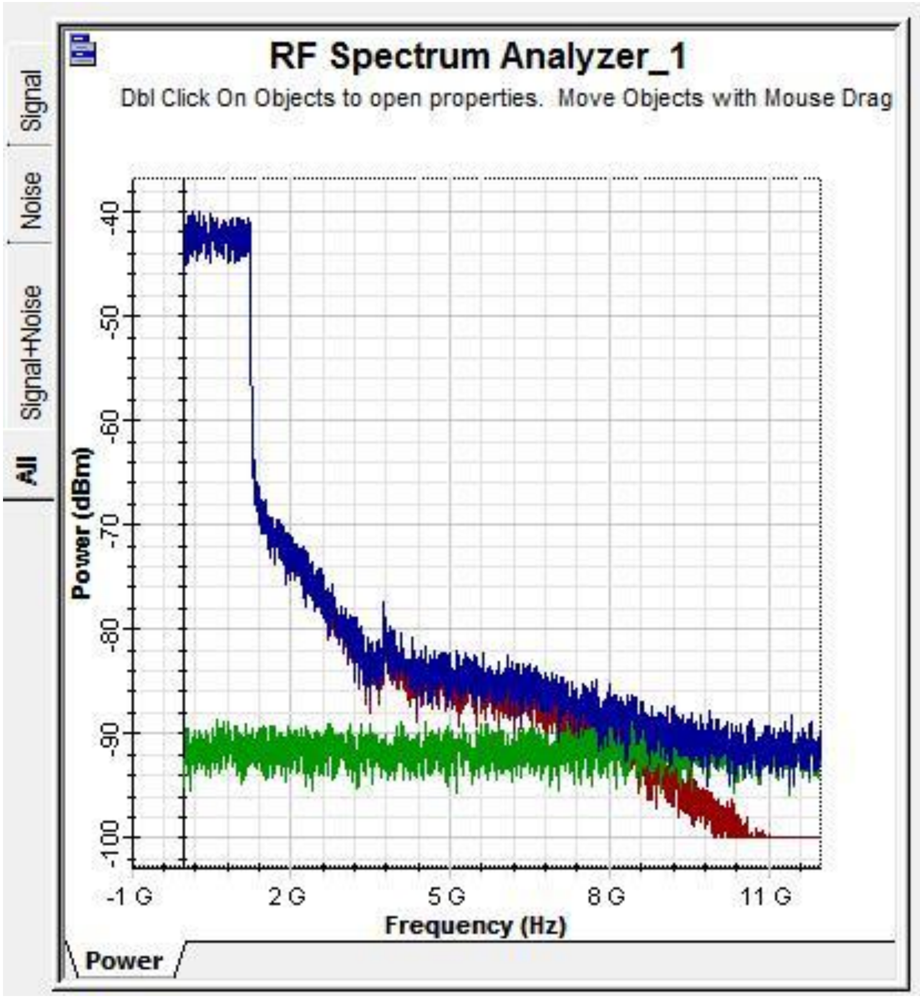


Figure 5.7 Spectrum Signal of Coherent Detection Output

Results of OFDM demodulator are validate by constellation visualizer diagrams as shown in figures. The longer the optical fiber cable, because of that received power will decrease, whereas noise of constellation will be greater shown in figures

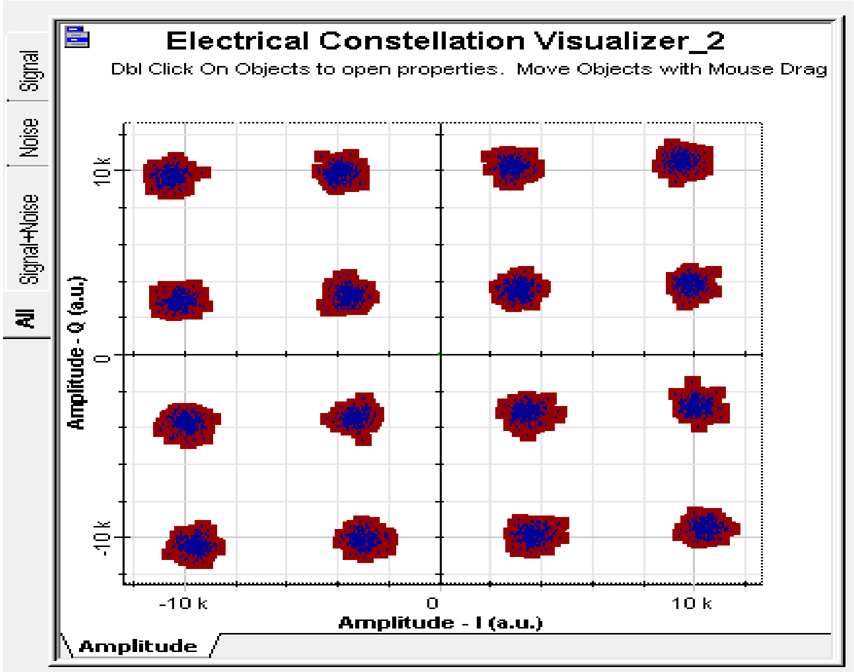


Figure 5.8 Constellation Visualizer Received Signal for Fiber Length 10 km

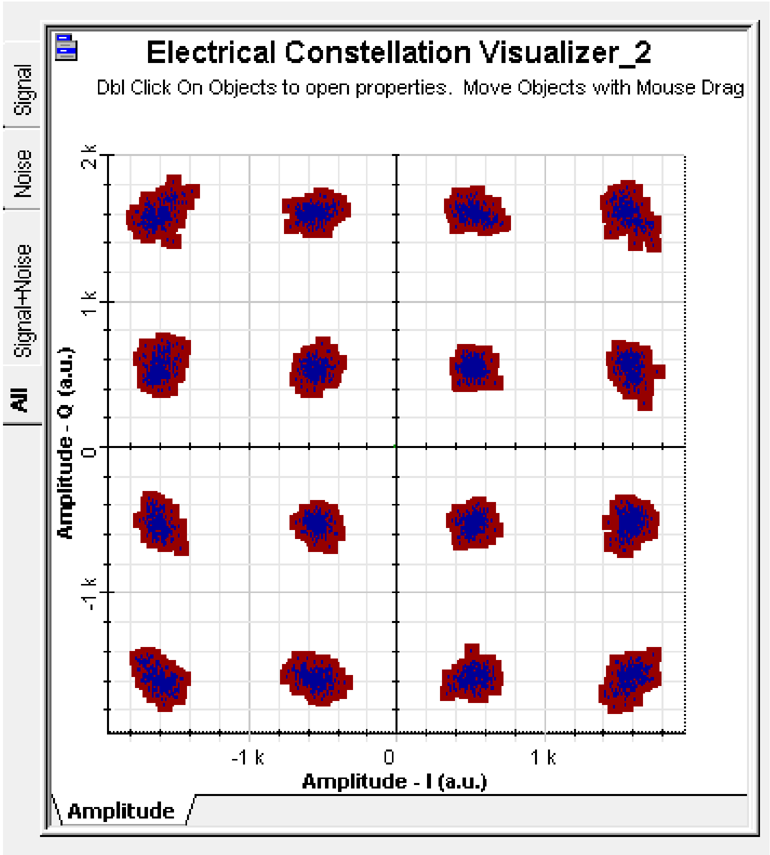


Figure 5.9 Constellation Visualizer Received Signal for Fiber Length 50km

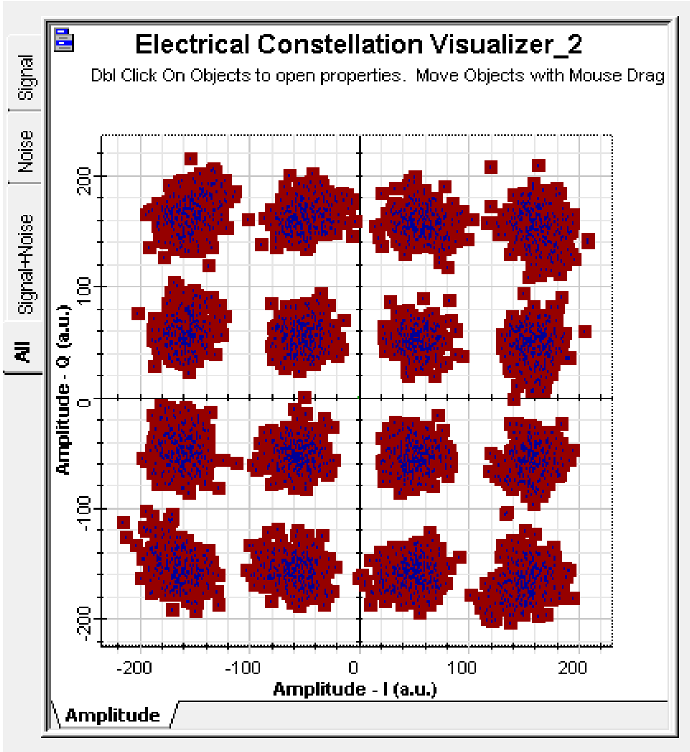


Figure 5.10 Constellation Visualizer Received Signal for Fiber Length 100 km

Power measurement is performed at the output of OFDM. Loop optical fiber, RTO, optical link, and Coherent detection receiver by using of electrical and optical power meters.

The comparison of 16 QAM and 4 QAM shown in table

Output	4-QAM (dBm)	16-QAM (dBm)
OFDM	57.049	64.057
RTO	-26.041	-19.445
Loop Optical	-3.039	3.732
Optical Link	6.929	13.574
Coherent Detection	-12.089	-5.433
Subsystem Receiver	46.837	107.560

Output power will change when optical fiber length in km has been changed, shown in figure and after evolution found that the 16 QAM scheme is have less loss of power when length changed. The output power at 100 km in 16 QAM is near to 72 dBm and for same parameter in 4 QAM it is near to 12 dBm.

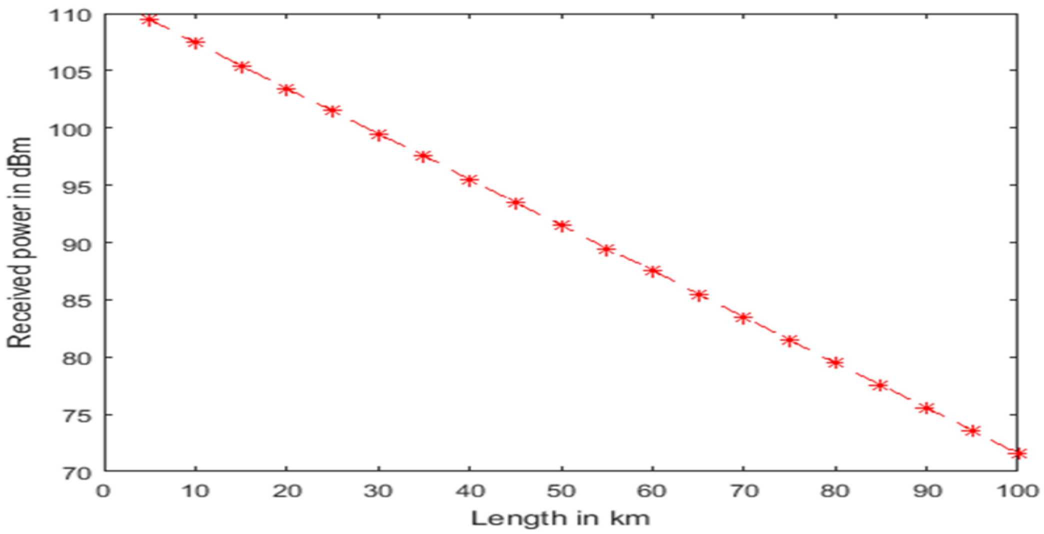


Figure 5.11 Length Vs Received power at output for 16 QAM

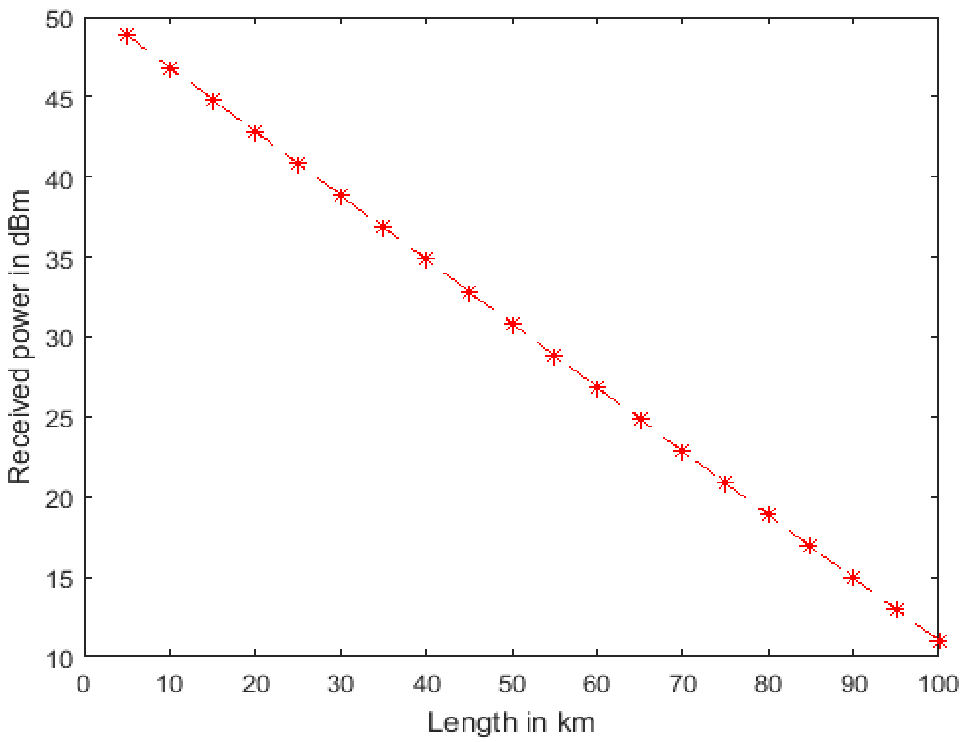


Figure 5.12 Length Vs Received power at output for 4 QAM

BER performance using 16 QAM

By using 16 QAM BER shows that when length will increase from 10 to 100 km , BER will near to log of BER=-0.6 , but after 100 km it will increased .In 4 QAM BER will increased from 70 km length of optical fiber. Thus it is proved that the Rof-OFDM model using 16 QAM is better than 4 QAM.

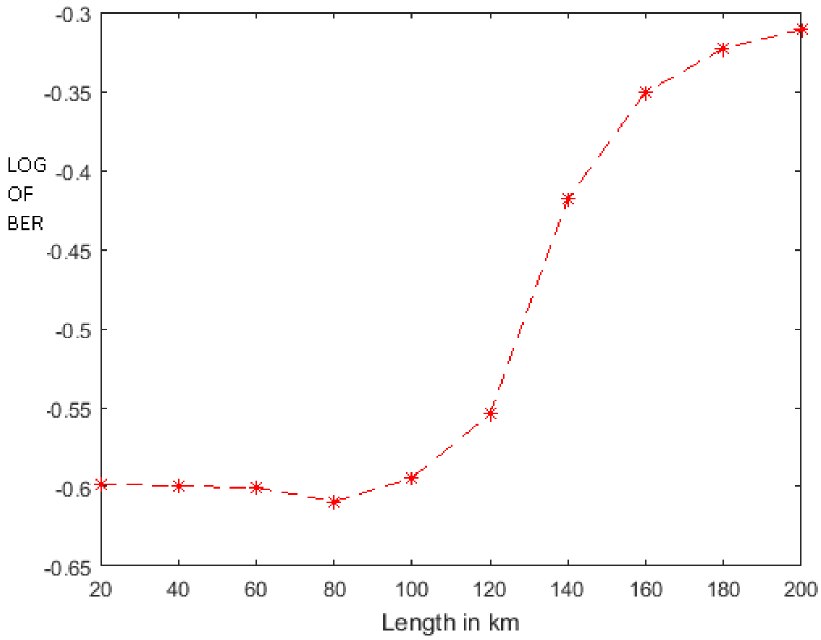


Figure 5.13 Performance of BER of RoF-OFDM model for 16 QAM

Chapter (6) Conclusion and Future Work

The Simulation Results proves that the Rof –OFDM system model by using of 16 QAM is achieved power 71.687 dBm for 100 km optical fiber length by use of electrical and optical amplification for 10 Gbps signal.

In 4 QAM the power is 11.856 dBm for same parameters of input and amplifications, the results of simulation in the subsystem have shown that by increasing of roll off factor value, this will be broadening in filter band transition. This system provides a good BER performance for 16 QAM and BER is 1 for 4QAM after length of optical fiber is increased after 70 km .So this model has better performance by use of 16 QAM.

This work can be enhanced by modifying the architecture in such a way that it provides the performance 16 QAM for above 100 km in terms of BER and output power and also same can be done for 4 QAM in terms of output power may increase.

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