Investigation on Dispersion Methods For Smart Optical Fiber Supported Wired/Wireless Broadband Access Networks

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A Final Research Report Submitted to Adama Science and Technology University

Adama, Ethiopia

May 16, 2017

Abstract

The worldwide telecommunication technology industries are moving very fast to provide service including 4G and beyond with many Wired and Wireless-Broadband Access Networks (WW-BAN) standards. Ethiopian Telecommunication Corporation (ETC) has started telecommunication service, which is offering urban to rural more than four decades and it is operating with fiber optic network as backbone in entire Ethiopia. ETC has Optical Transport Network (OTN) in the transmission system set up. OTN has many series of Optical Switching and Networking (OSN) and it is interfacing line rate from 625 Mbps up to 80 Gbps. Since 2014, the recent telecommunication transmissions are distributing all the line rates from OTN to all over Ethiopia, with different architectures like Gigabit / Gigabit Ethernet Passive Optical Network (GPON /GEPON), Course / Wavelength / Dense Wavelength Division Multiplexing (CWDM / WDM / DWDM). Presently, ETC is providing high bit rate / line rate (HBR/HLR) through backbone Optical Fiber -BAN (OF-BAN) from Addis Ababa core network to rural network and finally access wireless through microwave and Radio Frequency (RF) link conversions. The ETC with OTN and network topological configurations helps to access present Wi-Fi / WiMAX as per the IEEE 802.11 / 802.16 standards. Though, HLR provision using OTN is in Ethiopia, still a major constraint is unable to access HBR from OF-BAN. Especially, growing Fiber -to -the-Home (FTTH) with various Passive Optical Networks (PONs) and multiplexing secured architectures have affected by many interference's occurrences in the OF-BAN medium due to the linear / Non-linear effects and mainly Chromatic and Dispersion (CD). Hence, the OF-BAN degrades and unable to provide necessary received signal powers and HLR support to end users. In this research work, we have taken a complete study about the optical fiber effective utilization for Optical Wired / Wireless -BAN (OWW-BAN), accessing issues in Dynamic Bandwidth Allocation (DBA) 10 Gbps and beyond with measuring parameters of GEPON /GPON - DWDM PON. In addition, we analyzed the CD, dispersion co-efficient impacts, optical modulator, optical amplifier, and other non-linear effects performance for long distance transmission with available and collected ETC data measures. In particular, the experiment as a fiber transmission model to support for HBR 10 – 20 Gbps WDM / DWDM GPON using hybrid OAs at input OSP 20 dBm have in smooth operation. In specific, the 4 x 4 WDM / DWDM GPON architectures are supporting maximum of 5, 20, 40 and 80 Gbps since each channel of 4x4 WDM / DWDM considered to transport high bandwidth with 1.25, 5, 10 and 20 Gbps.

***Keywords**: GPON, TDM GPON, FSO GPON, Chromatic Dispersion, Optical Amplifier*

Acknowledgments

First of all, we acknowledge and thank in sincere way to all who approved and given research motivation to do this research funded project the President, Vice-President, Dean of Research, Dean of FECE and Chair of Communication Engineering in Adama Science and Technology University (ASTU).

We thank and acknowledge to Addis Ababa Ethiopian Telecommunications Corporation (ETC) General Manger - Main Division, Managers and Technical Engineers in OAM - Transmission section and all technical team members, though their busy schedule, they gave lot of support officially for various technical specifications as per the ETC standards to complete this research project. We also acknowledge and thank to IEEE standard Optiwave - Optisystem software distributors and technical team members in Ottawa, USA for their consistent software installation support through online communication.

Finally, we thank FECE staff, lab instructors and scholars whoever helped technically for this research project from these three Inter - Universities ASTU, Addis Ababa Science and Technology (AASTU) and Bahir Dar Institute of Technology – Bahir Dar University (BiT-BDU), Ethiopia.

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List of Abbreviations

ADSS	All Dielectric Self Supporting
BAN	Broadband Access Network
BER	Bit Error Rate
BR	Bit Rate
CAPEX	Capital Expenditure
CD	Chromatic Dispersion
CO	Central Office
CWDM PON	Course WDM PON
DBA	Dynamic Bandwidth Allocation
DC	Dispersion Compensation
DWDM PON	Dense Wavelength Division Multiplexing PON
EDFA	Erbium Doped Fiber Amplifier
EPON	Ethernet PON
ETC	Ethiopian Telecommunication Corporation
FTTH	Fiber -To -The-Home
FWM	Four Wave Mixing
GEPON	Gigabit Ethernet PON
GPON	Gigabit PON
GVD	Group Velocity Dispersion
HBR /HLR	High Bit Rate / High Line Rate
ITU – T	International Telecommunication Union -Telecommunication
LR	Long Reach
MD	Material Dispersion
MZI	Mach Zehender Interferometer
MZIM	MZI Modulator
OA	Optical Amplifier

OC	Optical Carrier
OF-BAN	Optical Fiber -BAN
OF-WW-BAN	Optical Fiber -Supported WW-BAN
OLT	Optical Line Terminal
ONU	Optical Network Unit
OPEX	Operational Expenditure
OSNR	Optical SNR
OTN	Optical Transport Network
OWC	Optical Wireless Channel
OWW-BAN	Optical Wired and Wireless BAN
PD	Profile Dispersion
PMD	Polarization Mode Dispersion
PON	Passive Optical Network
Q-Factor	Quality Factor
SDH	Synchronous Digital Hierarchy
SINTEL	Singapore Telecommunication
SMF	Single Mode Fiber
SNR	Signal -to -Noise Ratio
SOF	Smooth Optical Fiber
SPM	Self Phase Modulation
STM	Synchronous Transport Module
TD	Time Delay
TDM PON	Time Division Multiplexing PON
WD	Waveguide Dispersion
WDM	Wavelength Division Multiplexing
WW-BAN	Wired and Wireless-Broadband Access Networks
XPM	Cross Phase Modulation

List of symbols

a	Attenuation (or) Loss
A_{eff}	Effective Aperture
b	Normalized propagation constant
D	Dispersion
dB	Decibel
D_{DCF}	Dispersion of Dispersion Compensation Fiber
D_M	Material Dispersion
Km	Kilometer
mm	Millimeter
nm	Nanometer
ns	Nanosecond
Pi	Input Power
Po	Output Power
P_R	Received Power
P_S	Picosecond
S_{DCF}	Slope of Dispersion Compensation Fiber
THz	Tera Hertz
v	Normalized frequency
α_{con}	Connector attenuation or connector loss
α_f	Fiber Attenuation (or) Fiber loss
α_{max}	Maximum Attenuation (or) Maximum loss
λ	Wavelength
μ_m	Micrometer

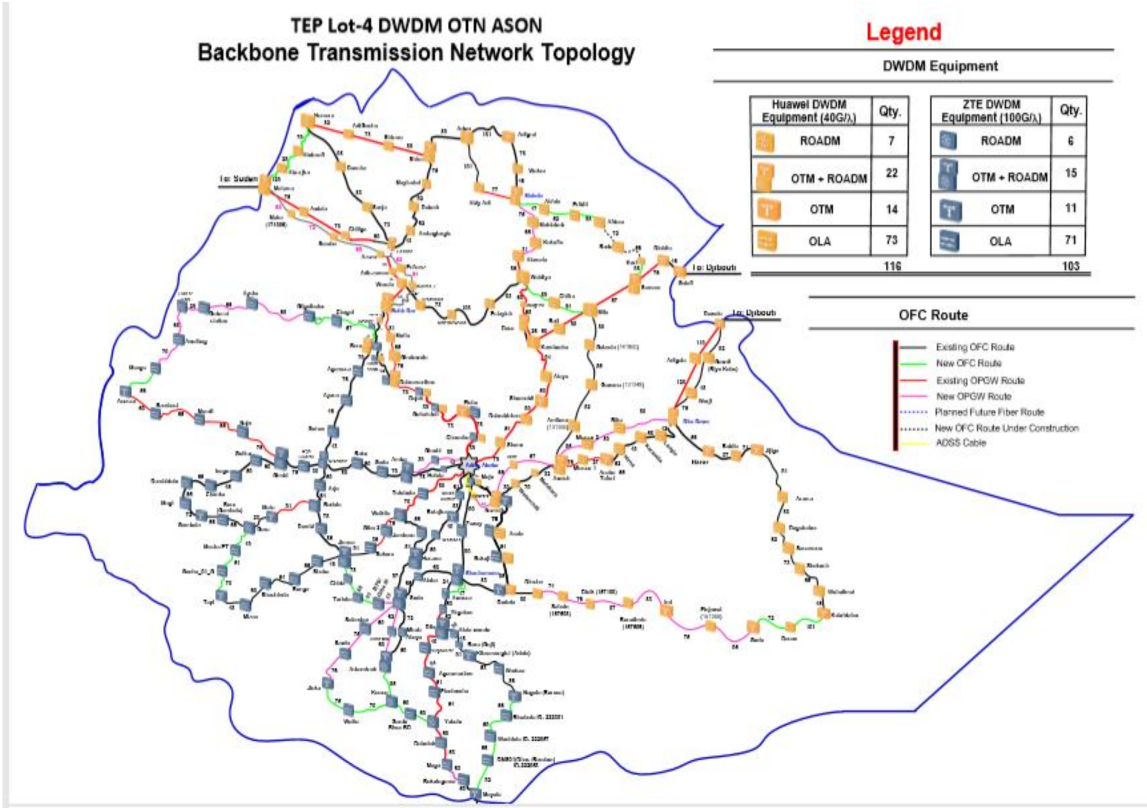
1 Introduction

The expansion of ETC for all generations of telecommunication technology and its standards necessary to care especially 3G-4G-5G migrations in 2020, since high bandwidth accessing consumer's rate both in wired and wireless BAN are growing day-by-day. The core telecommunication network from Addis Ababa city to local access remote area consumers accessing high bandwidth is a technological challenging task for Operation, Administration and Maintenance (OAM) division, and transmission section of ETC. Hence, the following sections describe the various telecommunication technological recent OWW-BAN models with few research experimental studies. Ultimately, these experimental studies somehow support in future though ETC is having good and massive technological infrastructure at present.

1.1 Background

The expansion of Ipv4 to IPv6, e-governing, e-tele-medicine and all social media applications the high line rate is necessary to fill full the end user bandwidth demands. OF-BAN has also promising the unlimited bandwidth access for all accessing end users like corporate, low scale to high scale industries, residing in hills, metro to rural areas. Also, the vision of the modern telecommunication system is converging to smart city and extending support to society needs. Presently, the OF-BAN and OWW-BAN has carried out HBR to all end user almost with the support of many PONs.

The ETC has rapid growth in its architecture with various network topological configurations and the Figure 1 (a) and (b) have shown the layout of the ETC backbone fiber optic network DWDM OTN with various optical equipment's and components interconnected set up.


TEP Lot-4 DWDM OTN ASON
Backbone Transmission Network Topology
Legend
DWDM Equipment
Huawei DWDM Equipment (40G/λ)
Qty.
ROADM
7
OTM + ROADM
22
OTM
14
OLA
73
116
ZTE DWDM Equipment (100G/λ)
Qty.
ROADM
6
OTM + ROADM
15
OTM
11
OLA
71
103
OFC Route
Existing OFC Route
New OFC Route
Existing OPGW Route
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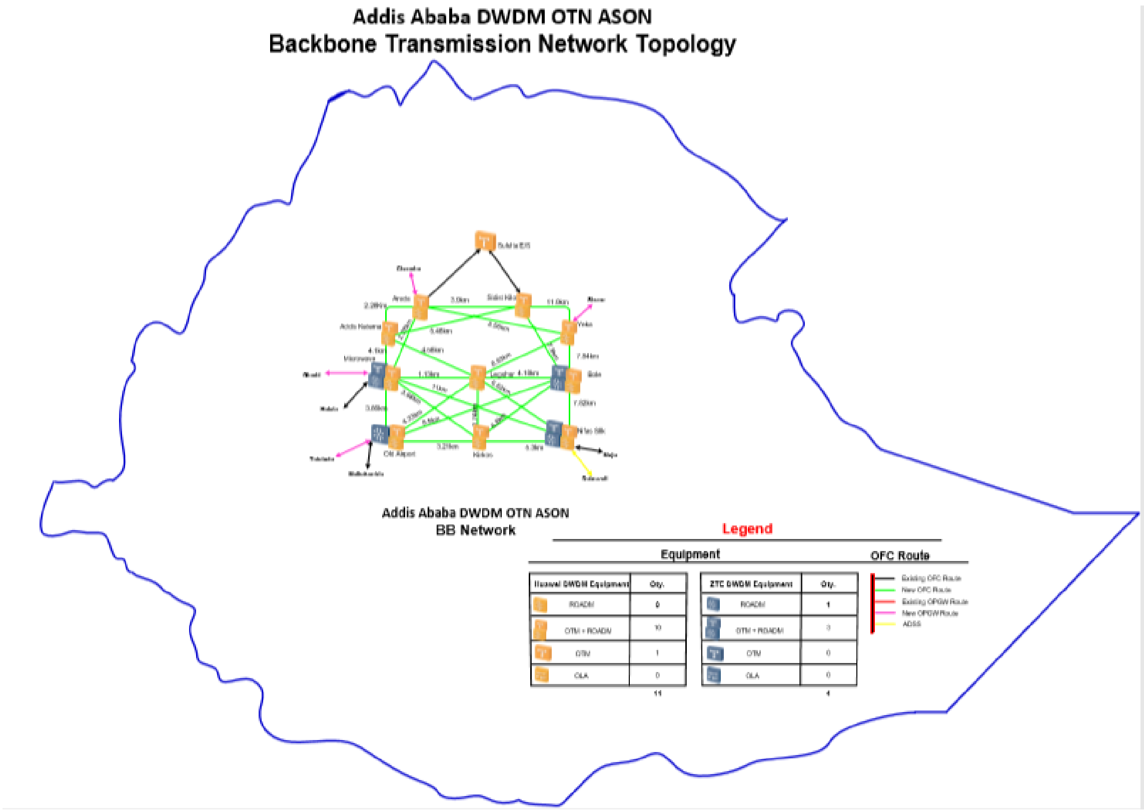
Planned Future Fiber Route
New OFC Route Under Construction
ADSS Cable
To: Sudan
To: Djibouti
To: Djibouti

(a)



(b)

Figure 1 ETC backbone DWDM OTN topology (a) in Ethiopia (b) in Addis Ababa

1.2 Statement of Problem

For clarity of the statement of problem, the research issue and problem formulation help to identify the statement of problem. Hence, we brief it based on research issue, problem formulation and ended with originality of the research work below in this subsection.

Research Issue and Problem Formulation

The pulse dispersion or pulse broadening or optical pulse swinging is a phenomenon and it is a critical issue in still in the fiber supported higher bit rate wired / wireless transmission using passive optical networks (PON) architectures including Ethernet PON (EPON), Gigabit PON (GPON), DWDM PON and all other PON architectures. In this way, the problem formulated for the above critical issue of optical pulse dispersion in the present PON Architectures.

Problem Definition

In this research, the problem has been defined / identified to optimizing and grooming the occurrence of pulse dispersion due to defective phenomenon especially of dispersion, different inter and intra-chromatic dispersion impacts. This defective phenomenon occurrences at present, especially when the DBA rate (samples per symbol) nano-second (ns) to pico-second (ps) optical pulse or electrical pulse signal transmission through the physical wired medium optical fiber long distance transmission of 10 Gbps and above with GEPON / GPON, WDM / DWDM PON, TDM GPON and other PON architectures.

Originality

The above defined / identified problem has extended to deal the study of research gap. It has also to analysis fiber optical pulse dispersion impacts even the transmission rate process extend from nano-second (ns) - pico-second (ps) up to femtosecond (fs) in high bit GPON PON and other PON architectures (10 Gbps and above) for the futuristic applications in all optical fiber backbone supported wired / wireless 5G-BAN.

1.3 Objective

1.3.1 General objective

The general objective of this research work is that obtain uniform broadband distribution / bandwidth access at least 10Gbps based GPON architecture.

1.3.2 Specific objective

i. To analyze smart optical fiber (SOF) for smooth HBR transmission for long distance using selective PON architecture.
ii. To analyze the methods of dispersions and its impacts while upgrading the PON Architecture's including GPON, DWDM PON
iii. To analyze the various dispersion issues and its effects both linear and non-linear transmission condition.
iv. To analyze the C- band and L-band wavelength range based GPON and WDM / DWDM PON performance in the long-distance transmission for the improvement of ETC present PON architecture.
v. To analyze the stages of optical amplifier performance for DBA access Using GPON and DWDM PON.

vi To analyze the various optical modulator performance for support of both OWW-BAN architecture.

1.4 Significance

The various telecommunication service providers in Ethiopia including ETC have been offering many upgraded schemes to every year for the last five years. However, the ETC including broadcasting technology advancement still not reached to urban to rural due to many technological reasons. Hence, few of the points are given below as significance of research to:

i Aware of OTN technology version up-gradation of ETC national wide consumers and in specific among societies.

ii Minimize the cost trade-off and provision of higher bandwidth at lower cost among ETC consumers / customers from rural to urban and revere versa.

iii expand the ETC- OTN set up for roaming and international roaming signal access at low cost per message/ voice call / tele video conference etc.,

iv Minimize the long-haul amplification, modulation / demodulations and multiplexing / demultiplexing processing stages etc., which support for minimization of cost of ETC -OTN transmission systems.

1.5 Goal

i This research work is for present and it has to be used for the future of Ethiopia to enhance the domain of Smart Optical Fiber (SOF) for linear and non- linear digital optical communication systems. (SOF denotes minimizing the degradations in the fiber optic transmission systems)

ii The research helps to know more on utilization of SOF by the telecommunication technocrats and optical fiber industries in Ethiopia.

iii It establishes to help for Under Graduate, / Post Graduate and PhD Research scholars and staff whoever working in the domain of fiber optical communication and systems for School of Electrical Engineering and Computing (SEEC) in Adama Science and Technology University (ASTU) and other Universities in Ethiopia.

1.6 Overview of OWW-BAN Research Project Organization

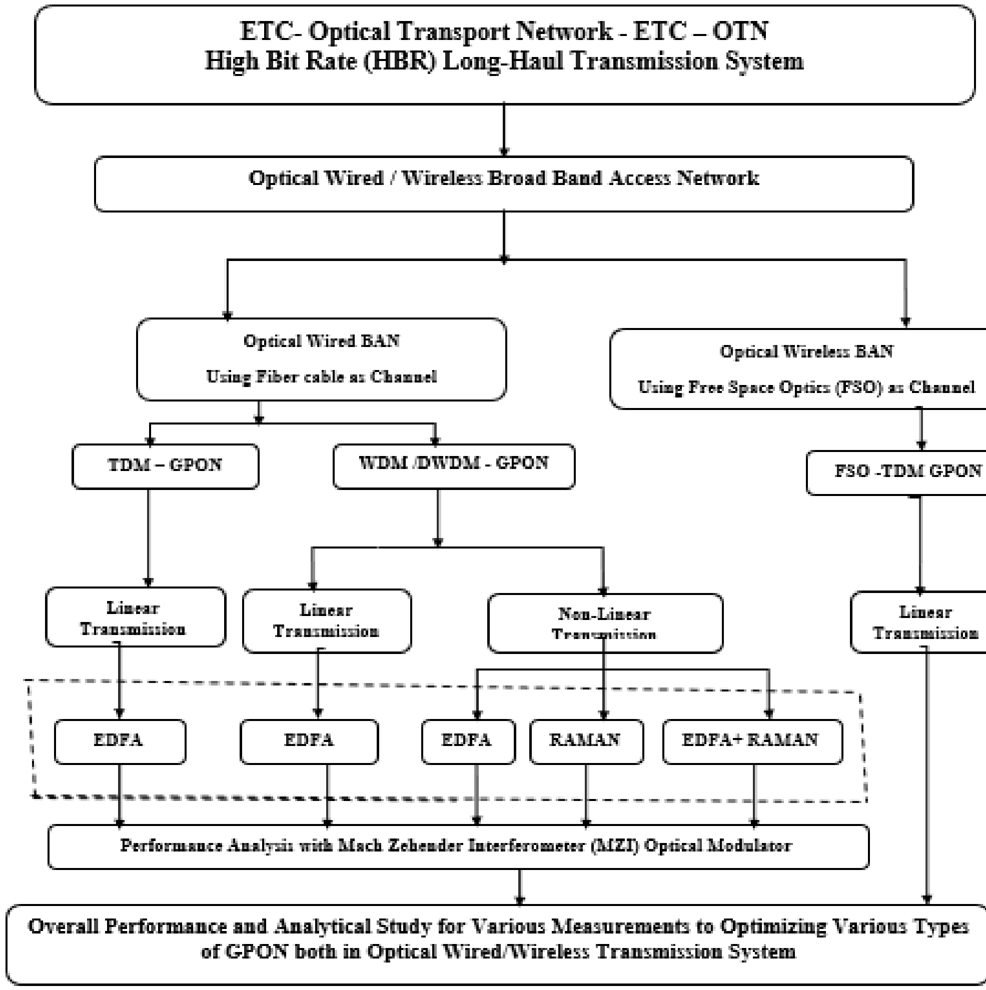


Figure 2. Overall research work organization for HBR -OWW-BAN

2 Literature Review

The next generation access network already started from TDM to WDM and Long Reach (LR) -PON to GPON as per ITU-T G 984.6 standard in 2010 for high-capacity Gigabit rate, wired and wireless line integration, long reach, and cost-effective Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) [15]. The OF-BAN has carried out for HBR provisions with the support of Various PON. The Singapore Telecommunication (SINGTEL) has first introduced next generation 10G GPON for FTTH applications to accessing high speed bandwidth for residential service, industries and domestic customers in 2015[8].

In Ethiopia, the EPON and GPON major steps started 80 /100 Gbps of transmission capacity by ETC with ZTE in 2017[9]. The OTN engineering transmission section operation of ETC with many OSN series 6800, 8800 and 9800 for the HBR /HLR from 10 Gbps up to 100 Gbps through many multiplexing and demultiplexing process under the support of GEPON and DWDM PON and various optical amplifiers [10]. GPON with ITU-T G.984 standard offers higher bandwidth, split ratio which results reduce number of optical line terminal [11, 12]. One side, Optical Line Terminal (OLT) is shared by many Optical Network Unit (ONU) in Time Division Multiplexing PON (TDM PON) is to access Gigabit hence TDM-GPON is a promising technology in the most part of the world [11]. On another side, WDM PON is a key innovation technology support for 25 Gbps and it is an ideal for 5G + FTTH front haul as per the Zhongxing Telecommunication Equipment ZTE Corporation mobile world report in 2019 [16].

WDM /DWDM PON is another strong support for BAN access and helps for HBR from 10 to 80 Gbps in core networks and all consumers access in Ethiopia [10]. Recently in 2019, 32 X 10 Gbps DWDM PON has analyzed by simulation for FTTH application in the suburban areas with the channel spacing 100 GHz, different dispersion 2,4,6,8,10 ps/nm/km, optical power ranges -10dBm to 10dBm and obtained Q-factor 6.16 and BER 3.44e-10 for the maximum distance 129 Km in the presence of non-linearities [14]. Dispersion compensation with various scheme like pre, symmetry and post dispersion compensation schemes for Chromatic Dispersion (CD) are more important during long haul transmission [20]. An analytical issue is that in any CD compensation, severely limited when extending DWDM PON for long distance, recommended to use Fiber Bragg Gratings (FBG) with Dispersion Compensation Fiber (DCF), 7 Km long DCF improves the CD compensation 19.3% (57 to 68 Km) and FBG improves network distance reach upto 26.3% (57 to 72 Km) [4]. Any CD compensation for long distance transmission, both linear EDFA and non-linear Raman optical amplifiers (hybrid) are placing in the optical fiber transmission system to provide pre, symmetry and post dispersion compensation [13].

Apart from these bottleneck issues of WDM / DWDM GPON, still TDM GPON / GEPON as a competitive technology and its supporting 1 Gbps (IEEE 802.ah standard) to 10 Gbps (IEEE 802.3 av standard) with XG PON (ITU-T G.987 standard), and planning to extend 40 Gbps with XGPON 2 (TWDM) hybrid multiplexing set up. All have been overviewed in 2019 BICSI middle East and Africa conference report as a vision of XG PON 3 in 2020 support for Downstream / Upstream (DS /US) of 40Gbps [18]. The energy efficient and latency of the pulse are the major issues in the TDM -GPON among inter and intra Optical Network Units (ONUs) [20].

Additionally, Free Space Optics (FSO) GPON (FSO-GPON) is an alternative technology for OWW-BAN and supporting wireless channel and providing maximum reach of 10Km to 15 Km for 10Gbps and obtained Q- factor is 6.3 [21].

Based on the all-valuable reviews that various research issues and standards, in this research project we have planned to focus the CD and its impacts in the linear and non-linear long haul optical wired / wireless transmission systems.

3 Methodology

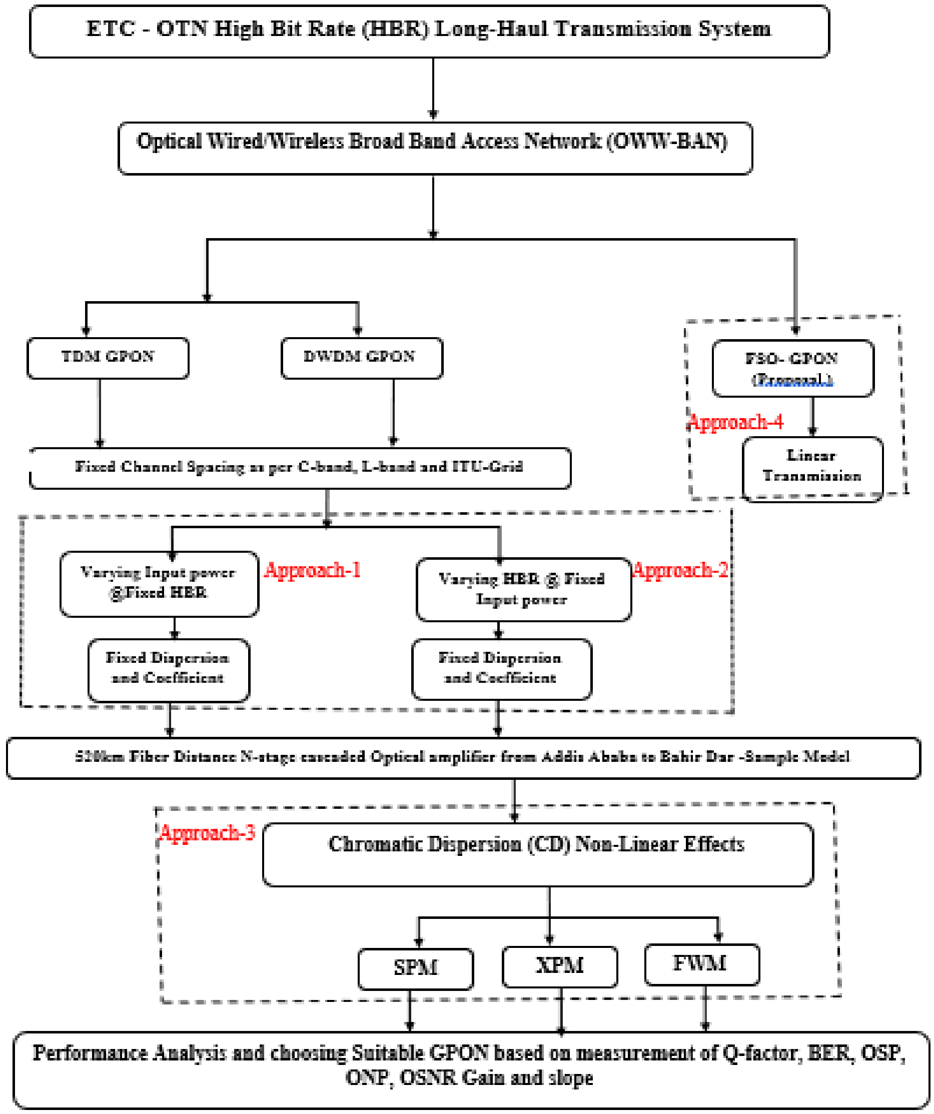


Figure 3.1 Various Approaches in the methodologies of OWW-BAN for ETC-OTN

The Figure 3.1 illustrates the approaches whichever we have planned to carry out in this research work ETC-OTN supported OWW-BAN.

- The approach1 to 2 we have processed with fixed channel spacing of 100GHz as per ITU-T grid / IEEE standard, fixed dispersion and coefficient in the WDM /DWDM PON whereas the;

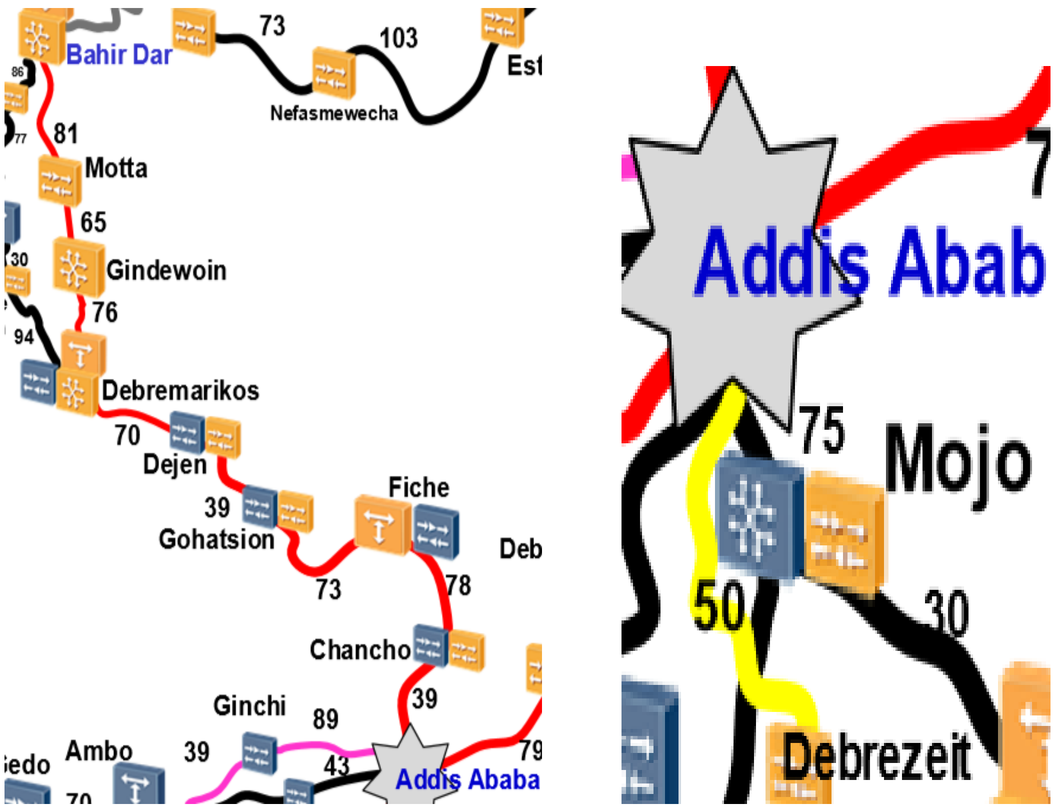
- TDM -GPON fixed wavelength and varying the time slot in different time of interval for HBR transmission.
- Specifically, the TDM -GON from approach 1, the methodologic is varying the HBR with fixed input power for long reach and varying input power with fixed HBR by the default value of diffent time-slot period of transmission (as per TDM).
- In approaches 2 in the WDM /DWDM -GPON, similar to TDM -GPON but four wavelengths have operated with fixed channel spacing of 100 GHZ.
- The approach 3, mainly for non-liners effects with various methods like SPM, XPM and FWM due to the occurrence of CD linearity and non-linearity effects in optical fiber long haul transmission.
- Finally, the approach 4, it is a new proposal for ETC-OTN that introduces the FSO -GPON technology as an alternative BAN with Optical Wireless Channel (OWC) link for HBR transmission in future.

As per the reference [10] of OTN board in ETC, the Optical Transponder Unit (OTU) accesses one or multiple channels. It converges or converts the signals to output standard DWDM wavelength compliant with ITUT G.694.1 or standard CWDM wavelength compliant with ITU-T G.694.2. In this way, it helps the multiplexer board to perform WDM on signals of different wavelengths.

Based on the above standard of ETC and approach of WDM / DWDM, in this research, the various parameters have been chosen for 10 Gbps to 20 Gbps HBR / HLR long haul transmission comparatively with ZTE – ETC -OTN specifications and its parameters in the following Tables 3.1 to 3.3. Even the analysis is one of the approaches for Addis Ababa core network to Bahir Dar metro network fiber cable distance nearly taken as 520 Km given Figure 3.2 (a) below.

Specifically, the distance location from Addis Ababa to Dejen nearly half of the fiber route maximum distance 240 Km (on the way from Addis Ababa to Bahir Dar) has taken as long-haul fiber network transmission distance as our assumption and default. Based on the approach, we analyzed the 1.25 Gbps to 20 Gbps 4 X 4 WDM /DWDM GPON performance for the CD impacts with various OAs to investigate the non-linear effects such as SPM, XPM and FWM. Also, in the TDM GPON architecture analysis, we have taken same fibre route distance nearly 240Km from the Addis Ababa up to Dejen.

Additionally, in the proposed model FSO - GPON, we have initiated and taken as default and assumption for the architecture design from the location of Addis Ababa to Bishafu (Debrezeit) with All Dielectric Self-Supporting (ADSS) aerial cable distance of 50 Km. Instead of ADSS aerial cable 50 Km link between these two network nodes, we approach with FSO channel link between Addis Ababa to Debrezeit network link as proposed model with FSO-GPON at 30 Km assumption of distance by air for HBR/HLR transmission at normal climate conditions.



a (b)

Figure 3.2(a) Fiber distance route Addis Ababa to Bahir Dar 520 Km and Addis Ababa to Dejen 230 Km (almost 240 Km). (b) ADSS aerial cable route distance from Addis Ababa to Debreziet 50 Km. (by air assumed the distance 30Km for design of FSO GPON proposed architecture)

Table 3.1 ETC –OTN fiber transmission few major specifications / Parameters/ values

Components	Parameters	Values /types
OSN6800 OSN8800 OSN9800	Line Rate (Gbps)	10, 40, 100, 40/80(hybrid)
Wavelength	C-band (nm) L-band (nm)	1530 – 1565 1625 - 1665
Optical Amplifier	C- Band	EDFA, RAMAN
Laser Safety Level	CLASS 4	Above 27 dBm (500 mW) for optical interface
Optical Amplifier (FOR OSN 8800)	Gain range (dB)	20-31, 16-25.5, 24-36, 23-34
Service Category	SDH: STM -64 SDH: STM-256 SONET: OC-192 SONET OC -768	9.95 Gbps as per ITU-T G.783 39.81 Gbps as per ITU-T G.825 9.95 Gbps 39.81 Gbps
Long haul transmission limitations of CD, PMD nonlinear effects occurrence OSN 8800	Lin Rate (Gbps)	10, 40, 80 40/80 ×100 Gbps(Hybrid transmission)
Optical Fiber and Cables distance (Km)	Single Mode Fiber (SMF) ADSS aerial cable	40, 50, 70, 80 Km approximate range between node to node (location to location) 50 Km range
Dispersion (ps/nm.km) Dispersion Coefficient (ps/nm.km) Dispersion slope (ps.nm^2.km)	C-band at wavelength 1530 nm	16. 75 (ps/nm.km) 12.580(ps/nm.km) 0.071(ps.nm^2.km)
PON Technology	Multiplexing /demultiplexing board / unit	GPON, GEPON, TDM PON, WDM /DWDM PON

Table 3.2 Chosen Specifications for HBR / HLR -WDM /DWDM GPON -OWW-BAN

Parameters	Specifications with values
Number of channels used in wavelength (nm)	Four ($\lambda_1, \lambda_2, \lambda_3, \lambda_4$) $\lambda_1 = 1552.524, \lambda_2 = 1551.721, \lambda_3 = 1550.918, \lambda_4 = 1550.12$ i.e. equal to $\lambda_1 = 193.1THz \quad \lambda_2 = 193.2THz$ $\lambda_3 = 193.3THz \quad \lambda_4 = 193.4THz$
Optical Bit Rate (Gb/s)	10 and 20 Gbps (@Fixed channels spacing 100GHz)
Optical Bit comparison (Gb/s) Variable HBR	1.25, 2.5, 5, 10, 20(@ Fixed input power 5dBm and optical fiber length)
Optical Input power(dBm)	5(@ Fixed channels spacing)
Optical Power comparison (dBm)	0, 2, 5, 8, 10, 15, 20, 25 (@ Fixed Bit Rate and Optical fiber length)
SMF length (km)	55, 115, 175, 235 with 5km DCF(@ Fixed Bit Rate and input power)
Attenuation(/dBm)	0.2 at wavelength 1550nm
Dispersion (ps/nm/km)	16.75 at wavelength 1550nm
Dispersion slope(ps/nm^2/km)	0.075
Effective area (A_{eff}) inμm^2	80
EDFA Pump wavelength(nm)	980
EDFA Length(m)	5
Distributed Raman length in km	40, 80, 120, 180(2/3 of a SMF Length + DCF length)
DCF length(km)	5
EDFA backward pumping power(mW)	1000, (100-1000) for sweeping)
Raman counter propagating pump wavelength	four pumping wave length @ 500mW (1462, 1462, 1462, 1462 nm – 4 stages constant wavelength)
EDFA + Raman	EDFA pumping source, 980nm and RAMAN Four pumping source (each 1462nm wavelength with,500mW pumping power)
Isolator	Ideal Isolator
Coupler	Pump coupler counter propagating

Measuring parameters and pulse waveform display (sample of results):

- Bit BER – Bit Error Rate / Mi. Log of BER
- Q -Factor: Quality Factor
- OSNR – Optical to Signal Ratio
- Input HBR Non-Return-to-Zero (NRZ) Pulse waveform
- Optical Channel Pulse waveform using Optical Spectrum Analyzer (OSA)
- Output HBR NRZ and Optical pulse signal and Noise Power waveform spectrum using OSA
- HBR Non-Return-to-Zero (NRZ) Waveform
- Eye Diagram output etc.,

4 System Logical Models for Types of GPONs Architecture in OWW-BAN

The various GPONs logical system model for WDM / DWDM GPON has given in the Figure 4.1 to Figure 4.6. All the WDM / DWDM models have been approached with both linear and non -linear OA in various aspects. The Figure 4.1 describes the general WDM / DWDM GPON with both linear and non-linear OA set up. The Figure 4.2 has illustrated the linear OA EDFA with forward pumping concept whereas Figure 4.3 describes the logic of non-linear OA Raman with backward Pumping. Both linear and non-linear OA with EDFA and Raman have been said as hybrid set up as in the Figure 4.4.

Next, the TDM-GPON has considered with OLT, RN distribution with splitters and N number of ONUs set up as shown in Figure 4.5. Finally, in the proposed system model of FSO- GPON logic that the optical fiber is replaced and introduced FSO- OWC as channel for HBR transmission in OWW-BAN as shown in Figure 4.6.

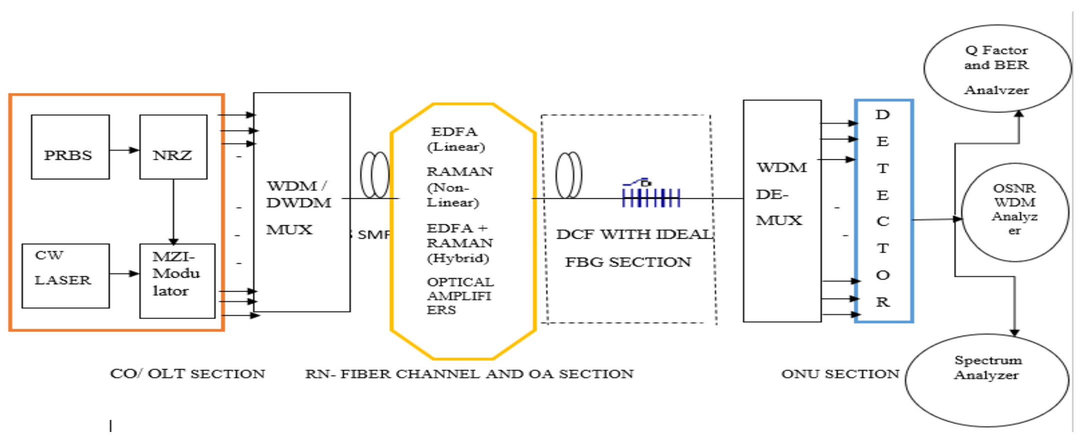


Figure 4.1 WDM / DWDM – GPON system model for HBR – Optical Fiber based BAN

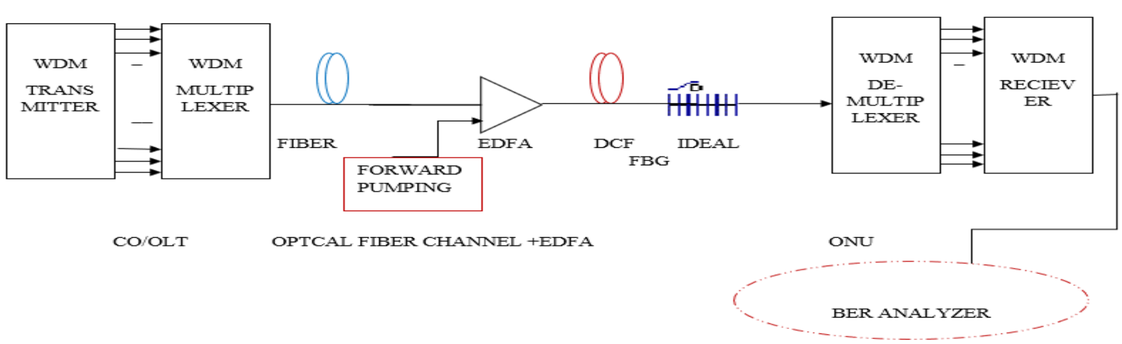


Figure 4.2 WDM / DWDM – GPON system model for HBR with linear OA EDFA

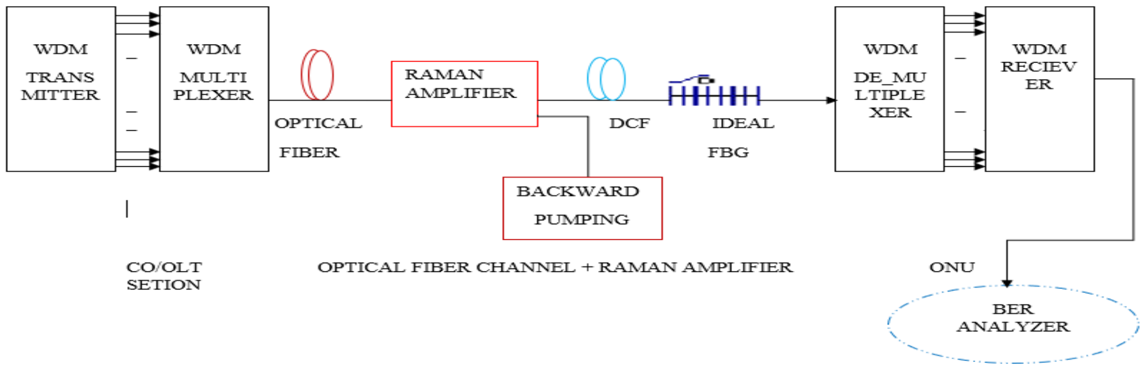


Figure 4.3WDM / DWDM – GPON system model for HBR with Non-linear OA RAMAN

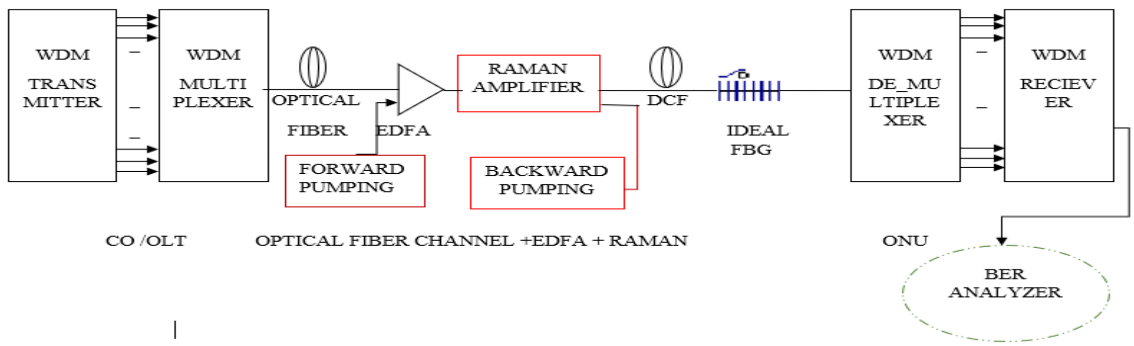


Figure 4.4 WDM / DWDM – GPON system model for HBR with both OA linear EDFA and Non-linear RAMAN (Hybrid OA)

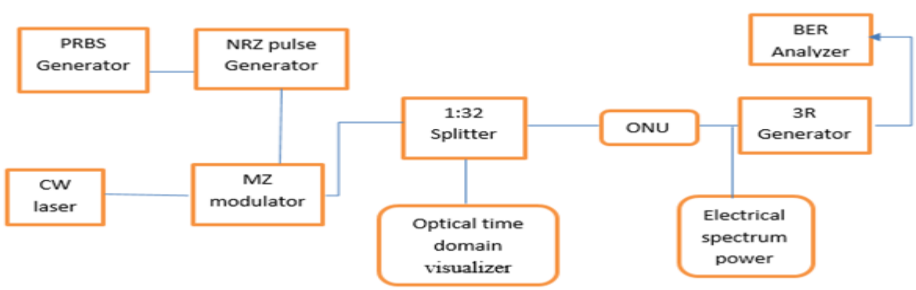


Figure 4.5 TDM – GPON system model for HBR – Optical Fiber based BAN

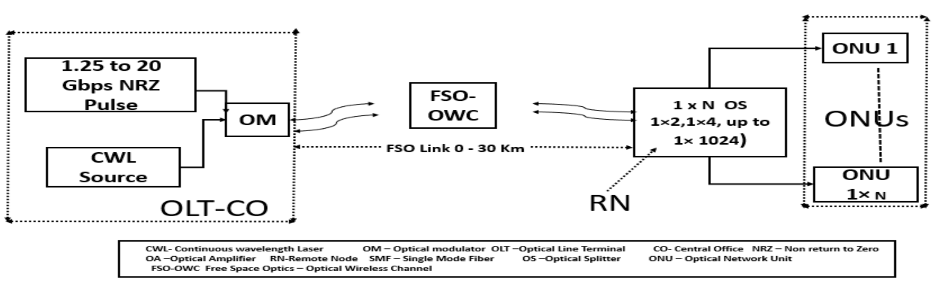


Figure 4.6 FSO -GPON system model for HBR as proposed one.

5 System analytical models with main parameters for GPONs in OWW -BAN

The system analytical models have been analyzed in the following section 5.1 and 5.4 mainly for various components in the types of GPON architectures. Mainly, the necessary analytical parameters and performance to measure the dispersion, fiber distance, link power estimation / budget, various dispersion improvements, DCF with FBG, dispersion of DCF, slope of DCF and attenuation and other supporting parameters importance in the long haul / long reach GPONs transmission performance. All the analytical model and necessary expressions have been analyzed in this section follows with various diagrams and tabular columns.

5.1 Optical Transmission Link Design for Long-Haul Transmission System

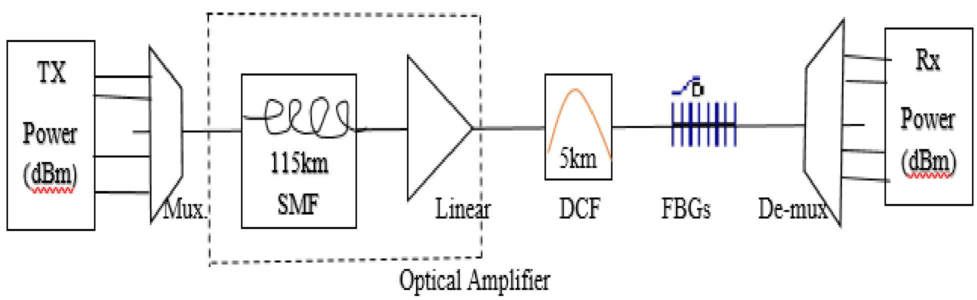


Figure 5.1 Transmission Link Design for fiber distance 120 Km Using Linear Optical Amplifier (LOA)

As per the Figure 5.1, 120 km long-haul transmission system to calculate the optical received power in dBm by considering every one span is containing the distance 4×30 km of fiber. Chosen dispersion, fiber attenuation and DCF attenuation have been given below:

$$\lambda_2 = 193.2 THz$$

$$Attenuation(SMF) = 0.2\, dB/km$$

$$Attenuation(DCF) = 0.5\, dB/km$$

Table 5.1 Calculated Received Optical Powers(dBm) for using Linear Optical Amplifier (EDFA) Link Design

Parameters	**Specifications**	**Ranges**
Transmitter Power dBm)	Four ($\lambda_1, \lambda_2, \lambda_3, \lambda_4$) $\lambda_1 = 1552.524, \lambda_2 = 1551.721$ $\lambda_3 = 1550.918, \lambda_4 = 1550.12$	5 (Fixed)
Modulator loss(dBm)	$P_T - P_r @ MZM$ 5 - 2.515 = 2.485	2.485
Attenuation SMF (dB) + (SPM + XPM) loss	$SMF_{length} \times Dispersion(SMF)$ 115× 0.2 = 23	23
Mux loss(dB)	$4 \times P_r @ MZM - P_r Mux.$ $4 \times 2.515 dB - Pr@MUX.$ = 10.06 – 7.931 =2.129	2.129
DCF insertion loss(dB)	$DCF_{Length} \times Dispersion(DCF)$ $5 \lambda_3 = 193.3 THz$	2.5
FBG loss(dBm)	0.1	0.1
De-mux loss(dB)	$P_{rafterDCFandFBG} - P_r @ deMux(4-channel)$ 22.184 -15.506 – 15.74 – 16.14 – 15.97 = -41.172	6.678
Photo Detector sensitivity(dBm)[24]	-40(as per the reference)	-40

- **Respective Received Optical powers at each consecutive point**:

  After Modulator =2.515dBm after the SMF (115km) = -15.069dBm

  After multiplexer =7.931dBm after EDFA =27.473dBm

$$P_{Rtotal} = P_T - MZM_{loss} - (\alpha_{SMF} + (SPM + XPM)_{loss}) - \alpha_{Mux} - \alpha_{DeMux} - DCF_{insertionloss} - FBG_{loss}$$

$$P_R = 5dBm - 2.485dBm - 23dB - 2.129dB - 6.678dB - 2.5dB/km - 0.1dB/km$$
$$Hence, P_R = -31.89dBm$$

The Table 5.1 above and Table 5.2 below have been calculated for the received optical power using Linear EDFA (LOA) and Nonlinear Raman Amplifier (NLOA) with reference [24].The XPM also considered in the calculations and simulations for obtaining optical received power in the SMF trasnmission.

5.2 Optical transmission link Design for Non-Linear Optical Amplifier (NLOA)

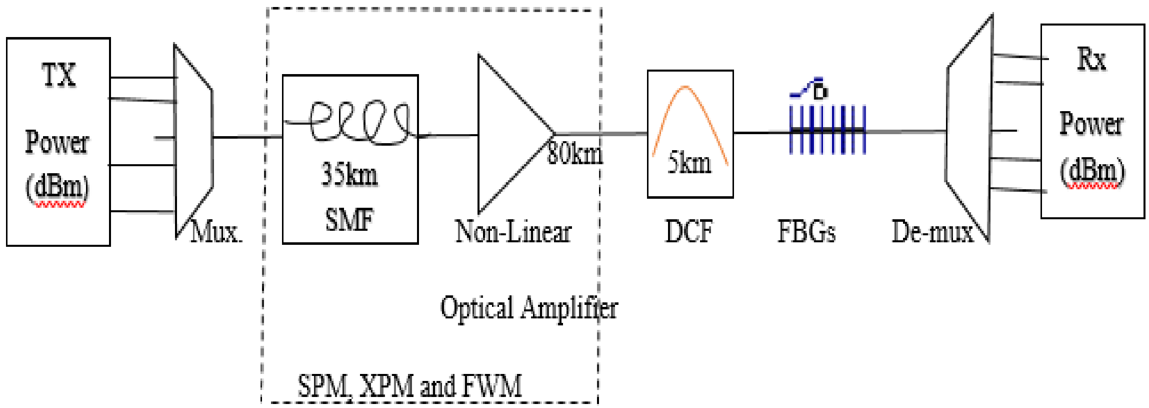


Figure 5.2 Transmission Link Design for 120 Km Using Non-Linear Optical Amplifier (NLOA)

Table 5.2: Calculated Received Optical Powers(dBm) for using Non-Linear Optical Amplifier (RAMAN) Link Design.

parameters	**Specifications**	**Ranges**
Transmitter Power (dBm)	Four ($\lambda_1, \lambda_2, \lambda_3, \lambda_4$) $\lambda_1 = 1552.524, \lambda_2 = 1551.721$ $\lambda_3 = 1550.918, \lambda_4 = 1550.12$	5(fixed)
Modulator loss(dBm)	$P_T - P_r @ MZM$ 5 - 1.719 = 3.281	3.281
Attenuation SMF (dB) + (SPM + XPM) loss	$SMF_{length} \times Dispersion(SMF)$ 35× 0.2= 7	7
Distributed RAMAN loss(dB)	80× 0.2= 16	16
Mux loss(dBm)	$4 \times P_r @ MZM - P_r Mux.$ $4 \times 1.719 - Pr@MUX.$ = 6.876 – 7.125 = -0.249	-0.249

DCF insertion loss(dB)	$DCF_{Length} \times Dispersion(DCF)$ $5\times 0.5 = 2.5$	2.5
FBG loss(dBm)	0.1	0.1
De-mux loss(dBm)	$P_{rafterDCFandFBG} - P_r @ deMux.(4-channel)$ -18.287 $-(-24.557 - 24.63 - 24.506 - 24.606)$ = 80.012	6.27
Photo Detector sensitivity(dBm) [24]	-40 (As per the reference)	-40

- **Respective Received Optical powers at each consecutive point:**

After Modulator =1.719dBm after the SMF (35km) = 0.125dBm

After multiplexer =7.125dBm after RAMAN = -15.781dBm

After DCF and FBG = -18.282dBm after De-Multiplexer = -24.557dBm

$$P_{Rtotal} = P_T - MZM_{loss} - (\alpha_{SMF} + (SPM + XPM)_{loss}) - RAMAN_{dis} - \alpha_{Mux} - \alpha_{DeMux} - DCF_{insertionloss} - FBG_{loss} \quad ...(5.2)$$

$$P_R = 5dBm - 3.281dB - 7dB - 16dB - (-0.249dBm) - 6.678dBm - 2.5dB/km - 0.1dB$$
$$Hence, P_R = -30.31dBm$$

5.3 Optical Transmission Link Design for Hybrid Optical Amplifier (LOA + NLOA)

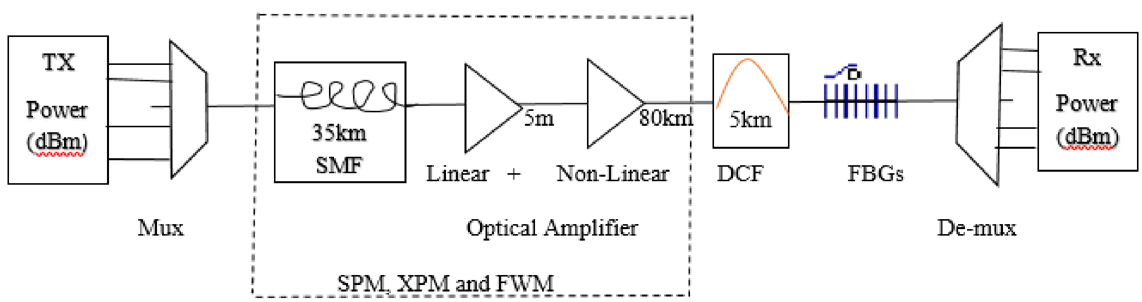


Figure 5.3 Transmission Link Design for fiber distance 120 Km Using Linear Optical Amplifier and Non-Linear Optical Amplifiers (LOA + NLOA).

Table 5.3 Calculated Received Optical Powers(dBm) for using Linear and Non-Linear Optical Amplifier (EDFA + RAMAN) Link design.

Parameters	**Specifications**	**Ranges**
Transmitter Power (dBm)	Four ($\lambda_1, \lambda_2, \lambda_3, \lambda_4$) $\lambda_1 = 1552.524, \lambda_2 = 1551.721$ $\lambda_3 = 1550.918, \lambda_4 = 1550.12$	5 (Fixed)
MZ Modulator loss(dBm)	$P_T - P_r @ MZM$ 5 - 2.560 = 2.44	2.44
Attenuation SMF(dB) + (SPM + XPM) loss	$SMF_{length} \times Dispersion(SMF)$ $35\times 0.2 = 7$	7
Distributed RAMAN loss(dB)	$80\times 0.2 = 16$	16
Mux loss(dBm)	$4\times P_r @ MZM - P_r Mux.$ $4 \times 2.56 - Pr@MUX.$ = 10.24 – 7.969 = 2.271	2.271
DCF insertion loss(dB)	$DCF_{Length} \times Dispersion(DCF)$ $5\times 0.5 = 2.5$	2.5
FBG loss(dBm)	0.1	0.1
De-mux loss(dBm)	$P_{rafterDCFandFBG} - P_r @ deMux.(4-channel)$ -6.706 $-(-13.138 - 13.036 - 12.96 - 12.885)$ = 45.313	6.432
Photo Detector sensitivity(dBm) [24]	-40(As per the reference)	-40

- **Respective Received Optical powers at each consecutive point:**

After Modulator =2.560dBm after the SMF (35km) = 0.968dBm

After multiplexer =7.969Bm after EDFA = 29.960dBm

After RAMAN = 13.956dBm after DCF and FBG = -6.706dBm

After De-Multiplexer = -13.138dBm.

$$P_{Rtotal} = P_T - MZM_{loss} - (\alpha_{SMF} + (SPM + XPM)_{loss}) - RAMAN_{dis} - \alpha_{Mux} - \alpha_{DeMux} - DCF_{insertionloss} - FBG_{loss} \ldots(5.3)$$

For 120km SMF the total accumulated chromatic dispersion is:

$120km \times 16.75 ps/nm-km = 2010 ps/nm$ to yield the net chromatic dispersion zero the DCF is needed, with - $2010 ps/nm$ .Therefore, using the formula [22,23,24]

$$L_{SMF} \times D_{SMF} = -D_{DCF} \times L_{DCF} \ldots\ldots (5.3)$$

and , $$S_{DCF} = S_{SMF} \times \left(\frac{D_{DCF}}{D_{SMF}}\right) \ldots\ldots\ldots (5.4)$$

Using the above formulas / equations (5.3) and (5,4), we can determine the dispersion and dispersion slope for DCF respectively**.** The following Table 5.4 shows dispersion and dispersion slope parameters for SMF land DCF;

Table 5.4 SMF and DCF Parameters

SMF parameter	**Value**
Attenuation (a or α)	0.2 dB/km
Dispersion parameter (D)	16.75ps/nm.km
Dispersion slope (S)	0.075ps/$\lambda_4 = 193.4 THz$
Effective area (A_{eff})	80μm^2
DCF Parameter	**Value**
Attenuation (a or α)	0.5dB/km
Effective Area (A_{eff})	22μm^2

The above Table 5.4 shows that the design of DCF length, with their appropriate Dispersion of DCF (D_{DCF}) and Slope of DCF(S_{DCF}) to compensate/mitigate the dispersion occurred for a different optical fiber length transmission just keeping the attenuation of DCF 0.5dB/km and effective area of DCF $22nm^2$ constant or an alternative way considered the calculation of D_{DCF} and S_{DCF} with the following conceptual Figure 5.4 .and its corresponding equations (5.5) and (5.6) below.

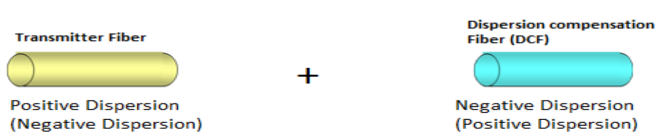


Figure 5.4 Conceptual idea of postive dispersion in SMF and negative dispersion in DCF

$$L_{SMF} \times D_{SMF} = -D_{DCF} \times L_{DCF} \dots\dots (5.5)$$

$$S_{DCF} = S_{SMF} \times \left(\frac{D_{DCF}}{D_{SMF}}\right) \dots\dots\dots (5.6)$$

Table 5.5 Optical Amplifier calculated Dispersion of DCF (D_{DCF}) and slope of Dispersion for DCF (S_{DCF}) for various fiber distances 60 Km to 240 Km

DCF Calculated values for Respective SMF length	**Optical Amplifiers**			
	EDFA, RAMAN, EDFA +RAMAN	**EDFA, RAMAN, EDFA + RAMAN**	**EDFA, RAMAN, EDFA + RAMAN**	**EDFA, RAMAN, EDFA + RAMAN**
Length (km)	60	120	180	240
Dispersion parameter (D)	A_{eff} [22,23] **(1)**			
	-184.25ps/nm.km	-385.25ps/nm.km	-586.25ps/nm.km	-787.25ps/nm.km
Dispersion slope (S)	μm^2 [24] **(2)**			
	-0.825 Ps/80	-1.725 Ps/$nm^2.km$	-2.625 Ps/$nm^2.km$	-3.525 Ps/$nm^2.km$

5.4 Optical Fiber transmission system and and its analysis of Link power Budget / Estimation for Various PON in OWW -BAN

The link power estimation of any PON in OWW-BAN is necessary for received signal power which support for maximum distance reach of optical signal. Power link budget analysis is based on the following equation [25]. System reliability and case system margin loss is introduced and it could tolerate some degradation in component or system.

Maximum allowable loss $\alpha_{Max} =$ Where

Power from the Transmitter in dBm P_r : Sensitivity of receiver in dBm for given BER

$$\alpha_{Max} = \alpha_f(dB) + \alpha_{con}(dB) + \alpha_{splice}(dB) + Msys(dB) \ldots \ldots (5.8)$$

$$\alpha_f(dB) = \alpha_{max} - (\quad) \ldots\ldots (5.9)$$

For maximum link length under attenuation limited condition or power limited link length can be express in the following way:

$$L_{MAX} = \frac{\alpha_f(dB)}{\alpha\left(\frac{dB}{km}\right)} \ldots \ldots .. (5.10)$$

If the distance of the fiber beyond this the SNR is below acceptable level.

In other word, the expression of optical communication / transmission system, the optical power budget has given by following way [25,26].

$$P_i(dB) = P_o(dB) + C_L(dB) + M_S(dB) \ldots \ldots . (5.11)$$

$$\Rightarrow P_o(dB) = P_i(dB) - C_L(dB) - M_S(dB) \ldots .. (5.12) \ :$$

$C_L(dB)$ is the channel loss of the optical communication system.

$$C_L^{\text{Attenuation(DCF)= 0.5dB/km}} = \alpha_f(dB) + \alpha_{con}(dB) + \alpha_{splice}(dB) \ldots \ldots (5.13)$$

Where: α_f is fiber attenuation (dB/km), α_{splice} is fiber splice loss (dB), α_{con} is connector loss (dB), P_i is the mean input power in to the fiber, P_o is optical power required at the receiver, M_S is the system margin degradation introduced in the component or system due to temperature variation and aging of the laser transmitter.

Thus, the general expression allows the maximum link length without repeaters or amplifiers are to be determined by the equation given in Eq. (5.10) and (5.11) and it can be written as equation (5.14) [25]

$$P_i(dB) = P_o(dB) + \alpha_f(dB) + \alpha_{con}(dB) + \alpha_{splice}(dB) + Ms(dB) \ldots \ldots .. (5.15)$$

The purpose of power budget calculation is needed for enough power suppose reach at the receiver to maintain reliable performance during transmission system and also minimum average power is required for the receiver sensitivity [25,26].

Signal attenuation within the optical fibers usually expressed in the logarithmic unit of the decibel (dB). The decibel, which is used for comparing two power levels, can be defined for a particular optical wavelength as the ratio of the input or transmitted optical power (P_i) into a fiber to the output or received optical power (P_o) from the fiber can be expressed in equation

$$\alpha(dB) = 10log$$

$$\Rightarrow)= 10^{\frac{dB}{10}} \dots\dots\dots\dots\dots\dots (5.17)$$

$$\Rightarrow \alpha(dB) = \frac{10}{L} * log$$

Dispersion values in optical fiber communication system generally can be expressed for Material dispersion (MD), waveguide dispersion (WD) and Profile dispersion (PD) components in the following way [27,28,29]

The material dispersion parameter(D_M) is expressed by equation (5.19)

$$D_M = \frac{\lambda}{c}\frac{d^2(n)}{d\lambda^2} \dots\dots (5.19)$$

Where n is fiber refractive index; n = n_1 or n_2 for core or cladding

Also, the Waveguide dispersion parameter ($D_W$can be obtained from equation

$$D_W = -\left(\frac{n_1 - n_2}{\lambda_c}\right) v \frac{d^2(vb)}{dv^2} \dots\dots (5.20)$$

Where:

- v is the normalized frequency for the fiber in range of [0≤v≤2.405]
- b is the normalized propagation constant for a specific fiber [0<b<1]
- $v\frac{d^2(vb)}{dv^2}$ $isthe$normalized waveguide dispersion coefficient universal parameters in single mode fibers.

Profile dispersion parameter ($D|\quad|P$) which is proportional to loss of optical signal due to aging of the fiber. This parameter (D_P) can be quite small (e.g. < than 0.5 ps nm−1 km−1). Therefore, the total dispersion in optical single-mode fiber is given in the sums of equation (5.19) and (5.20) and profile dispersion [27,28,29]

$$D_T = D_M + D_W + D_P (psnm^{-1}km^{-1}) \dots\dots (5.21)$$

Where, (D_M) is material dispersion, (× 0.2) is waveguide dispersion and (4×2.5 dB- Pr@MUX.) is the profile dispersion components. Finally, the standard SMF, the total dispersion dominated by the material dispersion.

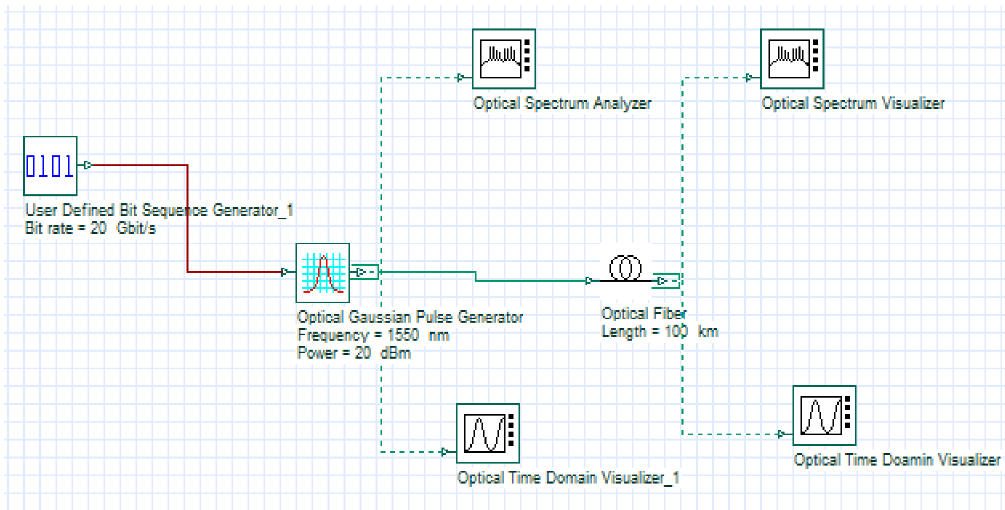
6 System Model of Major PONs Architecture Design Performance/ Implementation for OWW -BAN and Its Experimental

In this section, all the performance of Linear / non-linear effects and various GPONS for WDM / DWDM GPON, TDM -GPON and FSO- GPON and other performance input and output analyzed results have been illustrated. All the results of linear / non-linear effects and types of GPONs are performed / implemented with IEEE standard software Optisystem. In specific, the fixed and varied HBR / HLR, DBA, fiber optic distances, OSP, DCF with FBG achievements with various linear and non-linear OAs performances studied as major part in this research. First, the performance study for the core issues of CD and non-linear effects such as SPM, XPM and FWM and its results have been given in the following Figure 6.1 to 6.3. Next, the corresponding GPONs design performance study have been followed with various experiments / implementation results in collective ways.

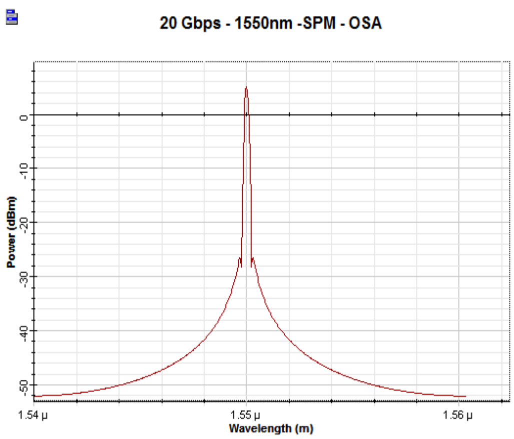
6.1 Non-Linear effects through experiment / implementation and its results

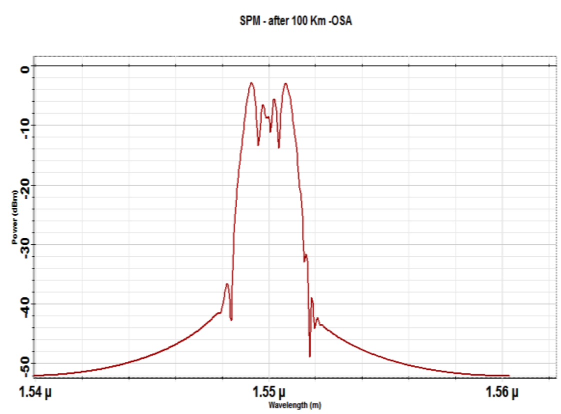
In this sub-section, we have been taken the critical study of non-linear effects compared with linear effects. So, we have been started the research and study the experiment and implemented results with various plots for SPM, XPM and FWM as first whichever related logical and analytical model of non-linear effects. All SPM, XPM and FWM are signal propagation effect in non-linear medium. SPM defined that it is a nonlinear phase modulation which arises by the refractive index of the fiber has an intensity -dependent component. This nonlinear refractive index causes an induced phase shift which is proportional to intensity of the pulse through Kerr effect. In the HBR system operating with 10 Gbps below or above, SPM method needs to considered while significantly increase the pulse broadening effects of chromatic dispersion. The XPM referred that the intensity- dependent phase shift, and consequent chirping, induced by SPM alone is enhanced because of the intensities of the signals in the other channels. Also, one wavelength of light can affect the phase of another light wavelength through the optical kerr effect which referred as XPM and normally it is occurring in WDM system. Finally, in WDM system with multiple channels, the main non-linear effect is FWM. In FWM is an intermodulation phenomenon, which creates interaction between third wavelength produce a fourth wavelength. FWM creates crosstalk among the existing signals in the WDM system, Particularly, FWM effect is severe when the channel spacing is tight or channel space is close to each other. Hence, all these nonlinear effects SPM, XPM and FWM methods have been taken as major study in this research work, and we have taken as core issues for the analysis of 10 to 20 Gbps HBR long haul WDM / DWDM GPON transmission System.

6.1.1 Self-Phase Modulation (SPM)



(a)



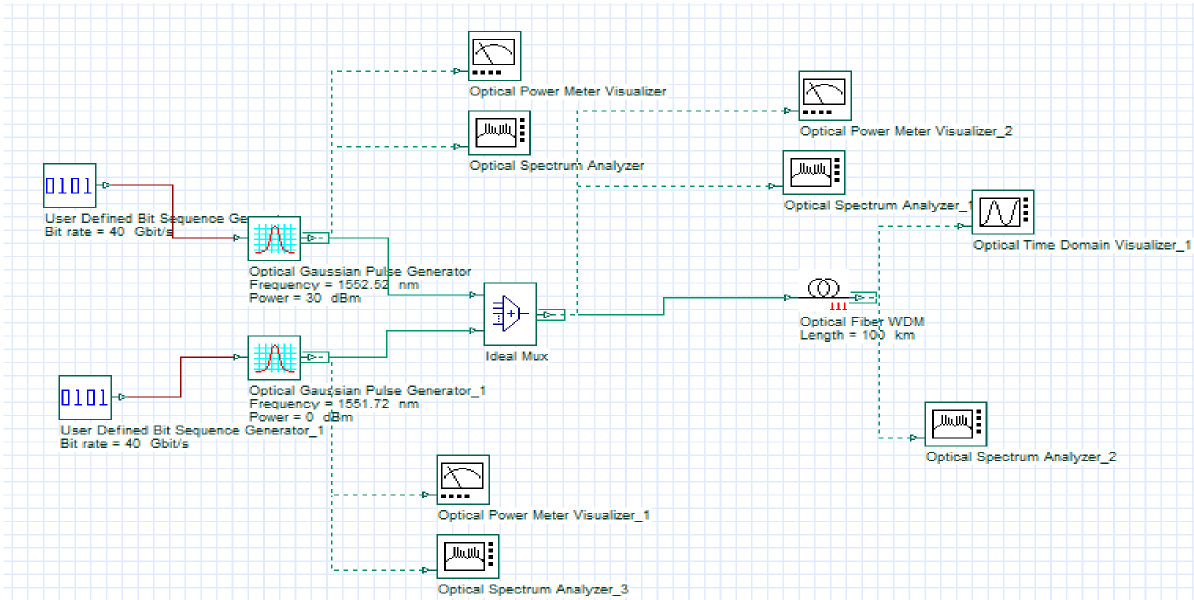


(b) (c)

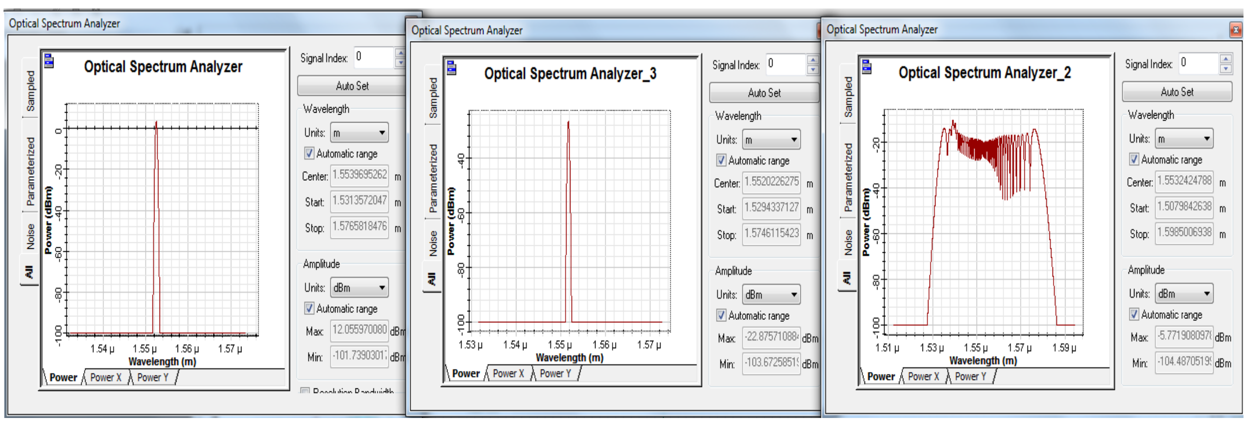
Figure 6.1.1 SPM non-linear effect for 20 Gbps at 1550nm as model (a) SPM design (b) input OSP (c) after 100Km without OA in long haul fiber transmission

The significance of the Fig.6.1.1(a),(b) and (c) describes the SPM non-linear effect design simulation model and its input and oputput OSP graphical results . It distinguished that how the SPM occurred in the 20 Gbps HBR WDM system. SPM is an important one for other non-linear effect study like XPM.

6.1.2 Cross Phase Modulation (XPM OR CPM)



(a)

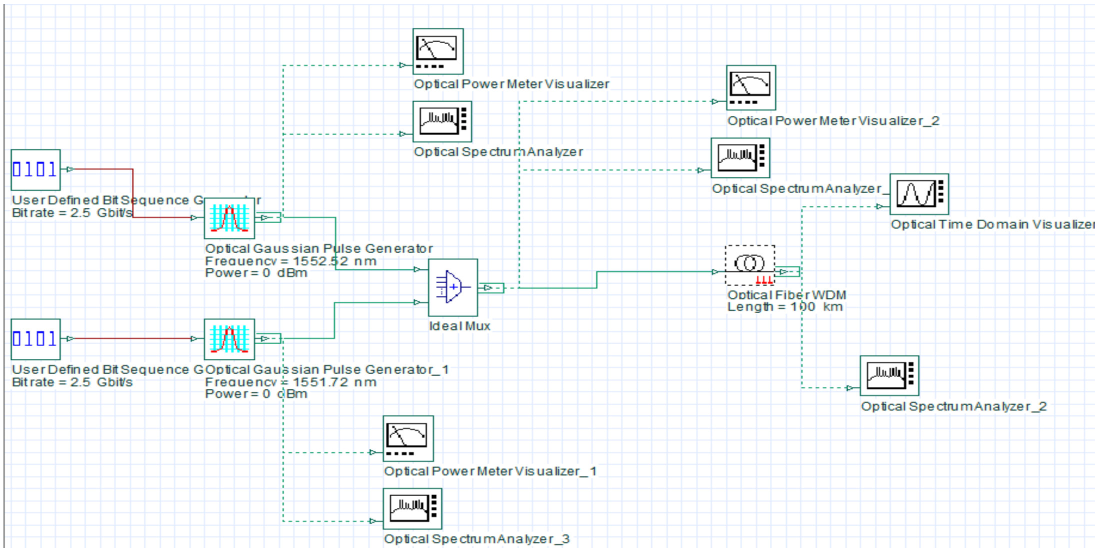


(b)

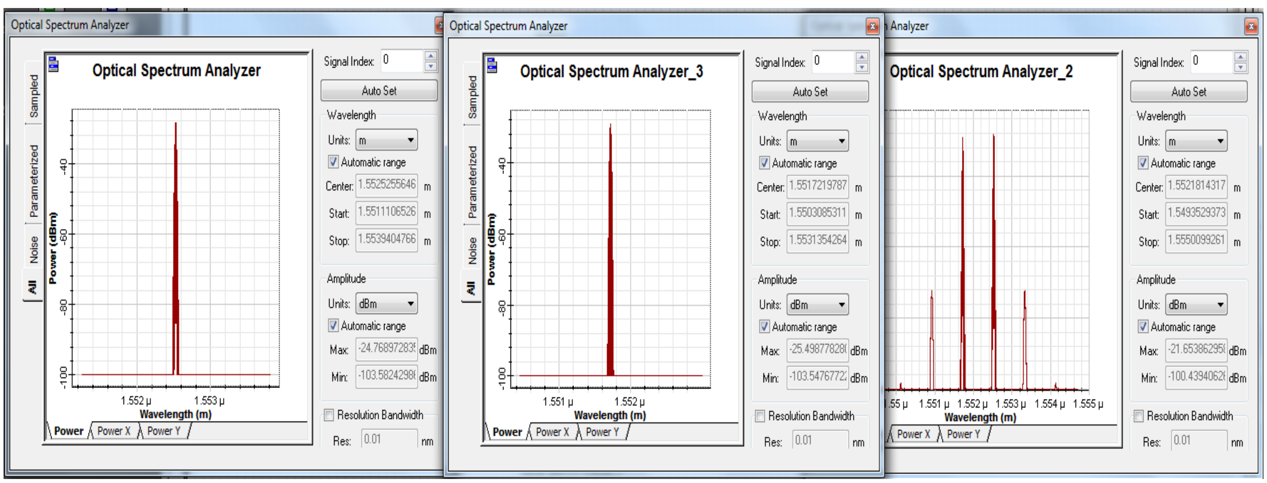
Figure 6.1.2 XPM non-linear effect for 40 Gbps as model. Chosen λ_1 =1552.52nm@30dBm and λ_2 =1551.72nm@0dBm (default) (a) XPM design (b) input and output OSP after 100Km without OA in long haul fiber transmission

The Figure 6.1.2(a) illustrates the XPM non-linear effect simulation design set up and (b) represents the two wavlelengths creating the phase interference after 100Km and hence ocurrence of XPM as in the output OSP.

6.1.3 Four Wave Mixing (FWM)



(a)



(b)

Figure 6.1.3 FWM non-linear effect for 2.5 Gbps as model. λ_1 =1552.52nm@0dBm and λ_2 =1551.72nm@0dBm (default) (a) FWM design (b) input and output OSP after 100Km without OA in long haul fiber transmission.

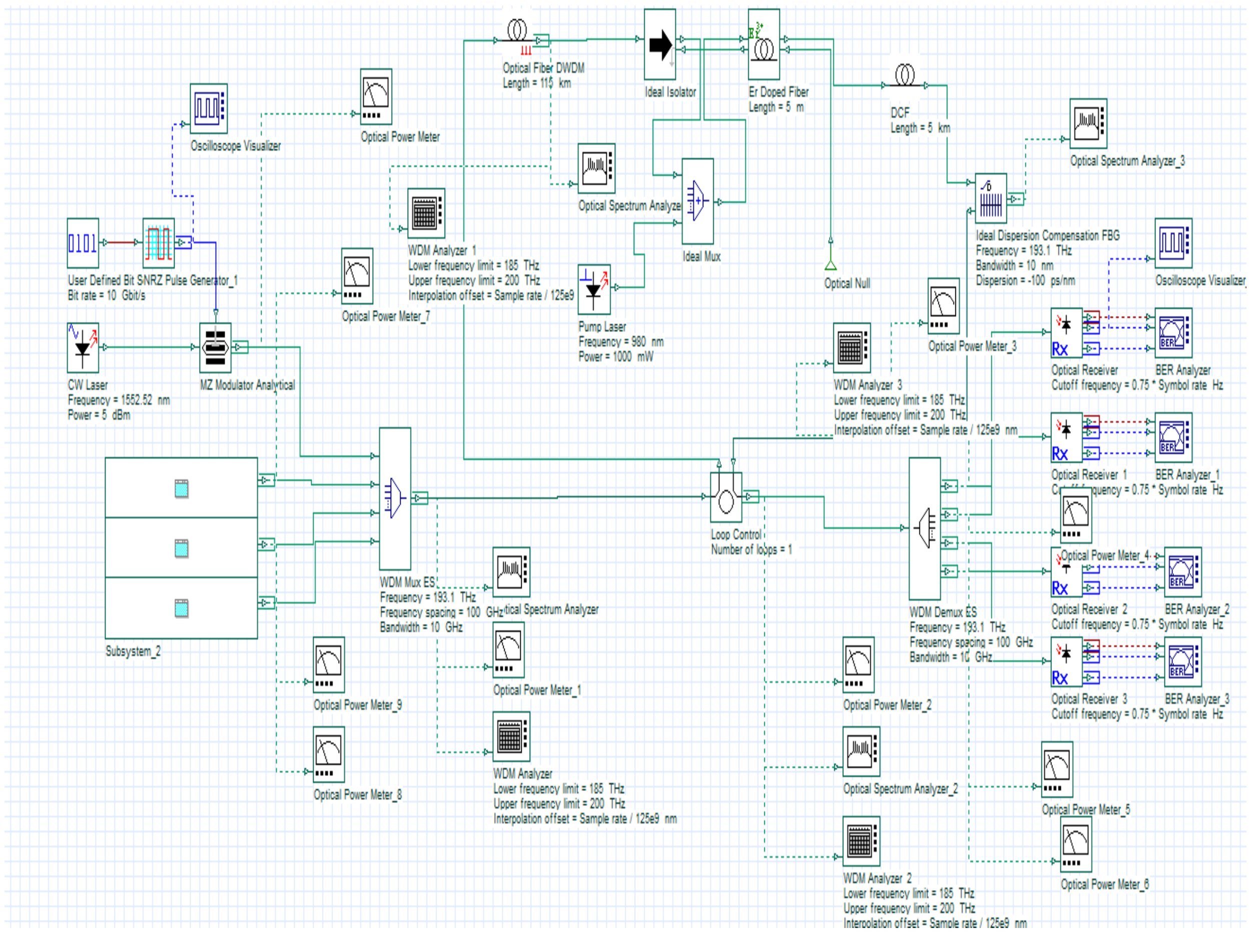
The Figure 6.1.3 (a) expalins the FWM simulation design set up diagram for 2.5 Gbps. (b) represents the graphical waveform for obtained FWM and created 3rd and 4th wavlength while trasmitting λ_1 =1552.52nm@0dBm and λ_2 =1551.72nm@0dBm through SMF transmission.

Based on the above research study of all non-linear effects such as SPM,CPM and FWM simuation results from Figures 6.1.1 to 6.1.3, it has been noted that the occurrence of interferences in the signal modulation, CD and multichannels fiber long haul transmission due to the lack of gain or strength of the signal when transmitting more than 30 to 50 Km and hence non-linear effect occurred. From these interferences, we have been observed and confirmed keenly in the research work that the amplification using OA is one of the most important for any information or signal through fiber transmission to strengthening the signal modulations and maintain the constant gain till end of the transmission process. Hence , we extended the research study for major types of GPONs analysis in OWW-BAN have been carried out with linear and non-linear OA to minimize the non-linear effects for the HBR /HLR long haul transmission.

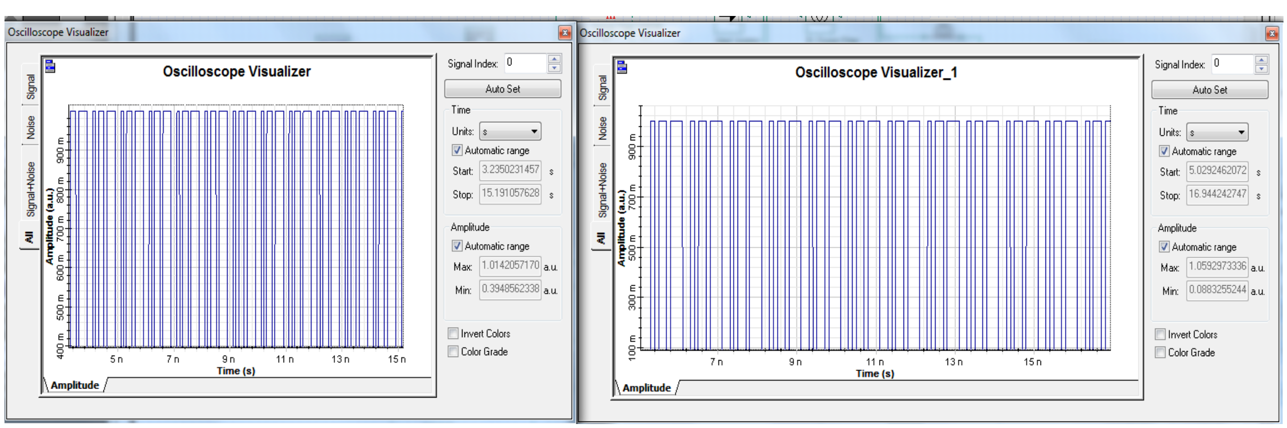
6.2 WDM /DWDM GPON experiment / implementation and its results

The WDM /DWDM GPON have been experimented with different methodological and operational studies. All design, experiment and simulation study have been dealt with different linear and non-linear OAs, corresponding pumping powers support with DCF and FBG set up. Also, different ranges of HBR /HLR, fiber distances, other issue of CD and designing parameters requirements of DCF and FBG for experimental analysis. Totally, four wavelength channels λ_1 = 1552.52 nm (191.1THz), λ_2 = 1551.72 nm (193.2THz), λ_3 = 1550.91 nm (193.3THz), λ_4 = 1550.12 nm (193.4THz) have been used for multiplexing and demultiplexing of WDM / DWDM GPON in all the experiments as per C-band, ITU-T WDM / DWDM Grid and ETC -OTN standards. Apart from many experimental analyses, in this research work the major part of implementation simulation analyses performed for various experiments of WDM/DWDM GPON have been given below.

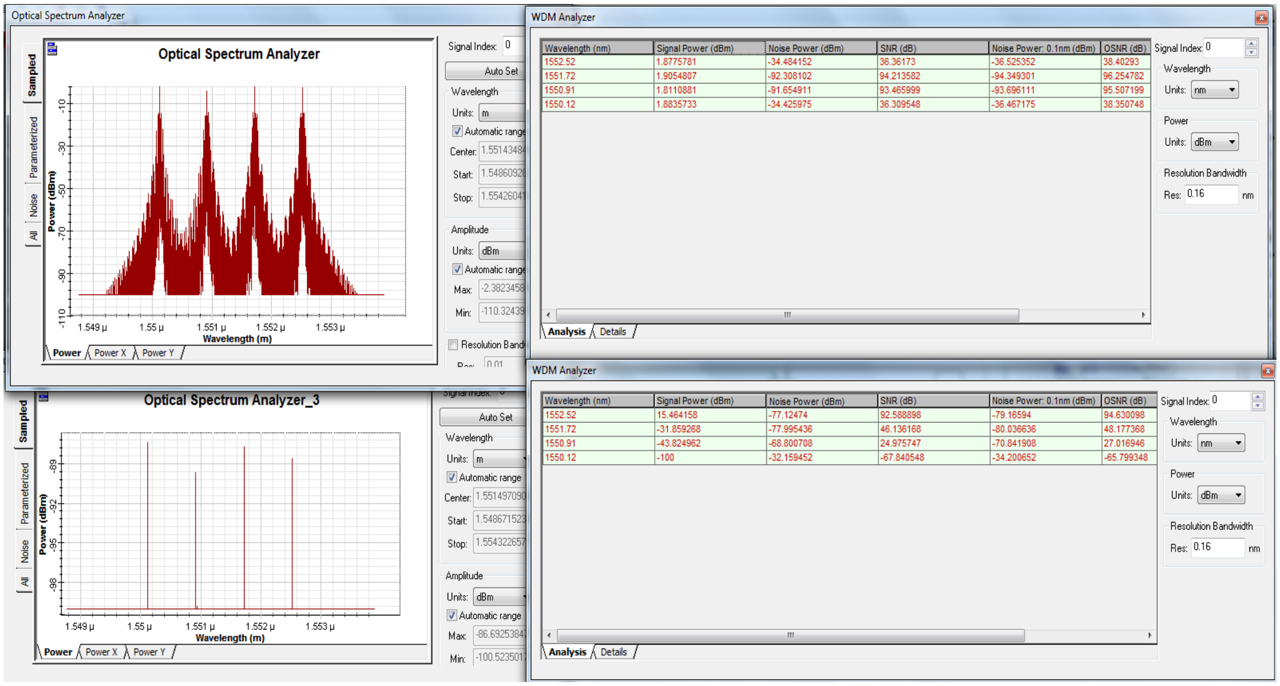
6.2.1 Experimental Analysis for the performance of 10 Gbps 4×4 WDM /GPON Using Linear OA EDFA and DCF with FBG @120Km – Input Optical Signal Power (OSP) is 5dBm(fixed)



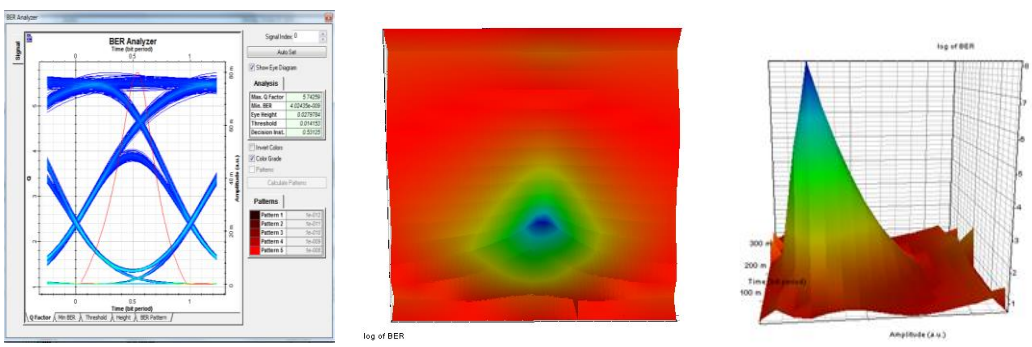
(a)



(b)



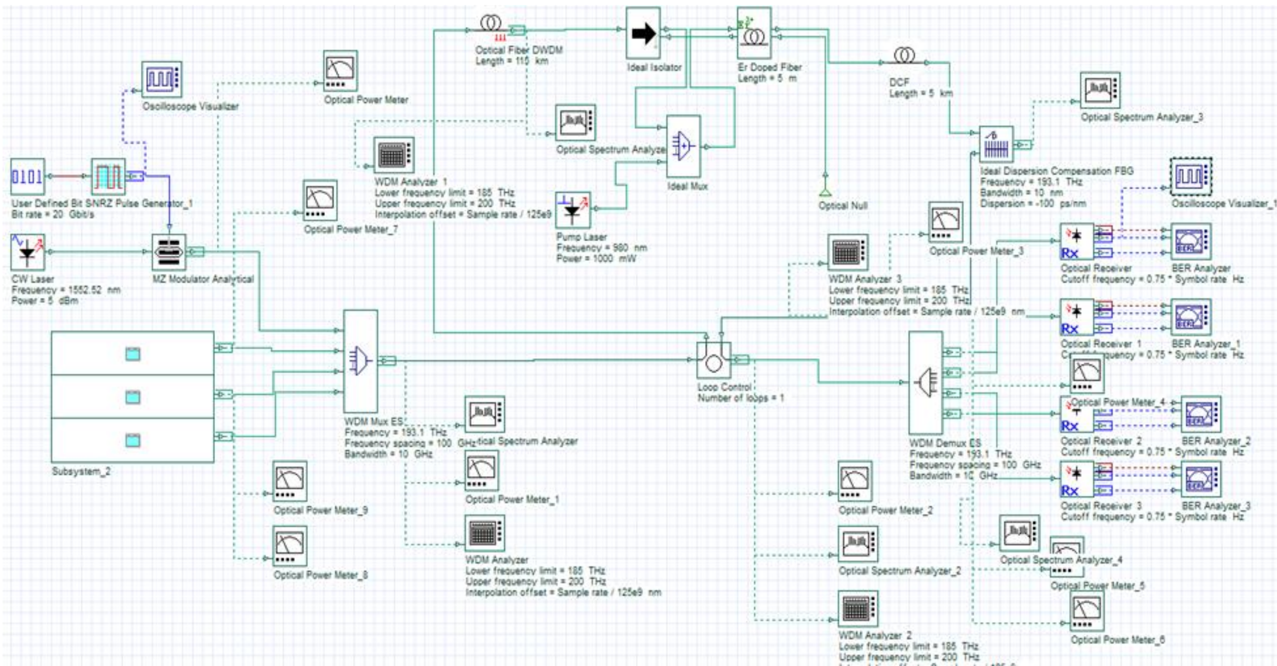
(c)



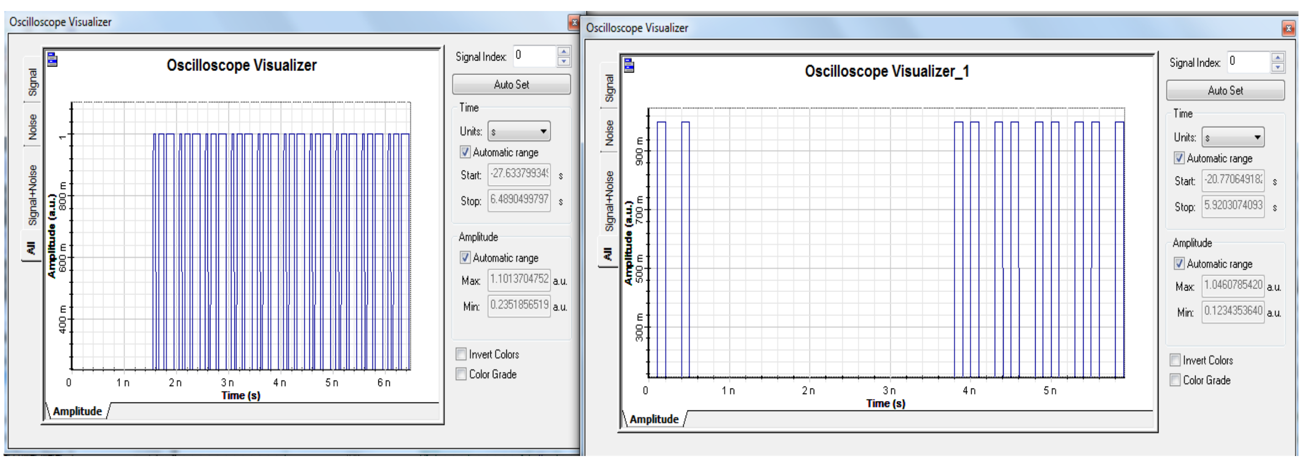
(d)

Figure 6.2.1 Experimental design of 10 Gbps 4 ×4 WDM / DWDM GPON using Linear OA EDFA @ 120 Km. (a) EDFA support Fiber distance @ 120Km for 10 Gbps (b)10 Gbps input and output NRZ pulse shape waveform (c) measured values of input and output for four channels wavelengths using OSA, and its corresponding mux and demux output values of OSP, ONP, SNR and OSNR using WDM Analyzer (d) Eye pattern and Log of BER with 3D graph

6.2.2 Experimental Analysis for the performance of 20 Gbps 4×4 WDM /GPON Using Linear OA EDFA and DCF with FBG @120Km -Input OSP is 5dBm

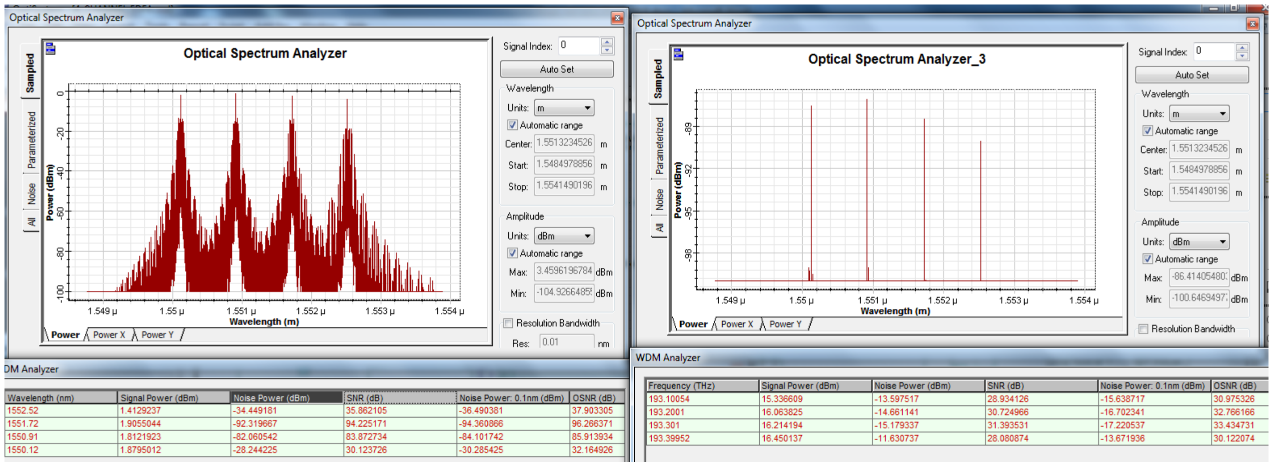


(a)

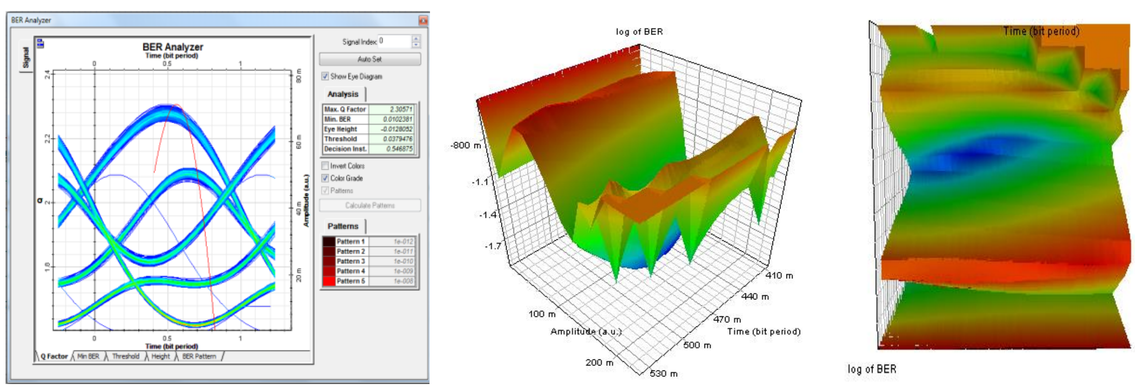


Oscilloscope Visualizer
Oscilloscope Visualizer_1
Amplitude (a.u.)
Time (s)

(b)



(c)

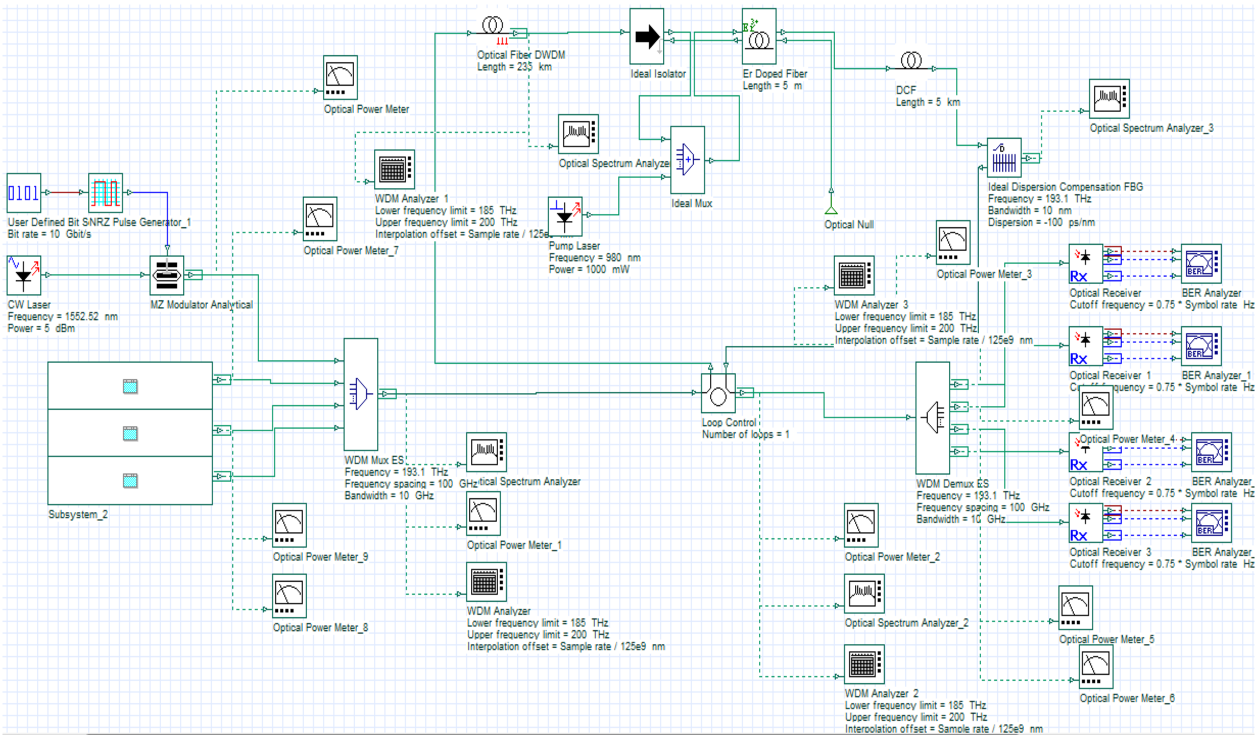


(d)

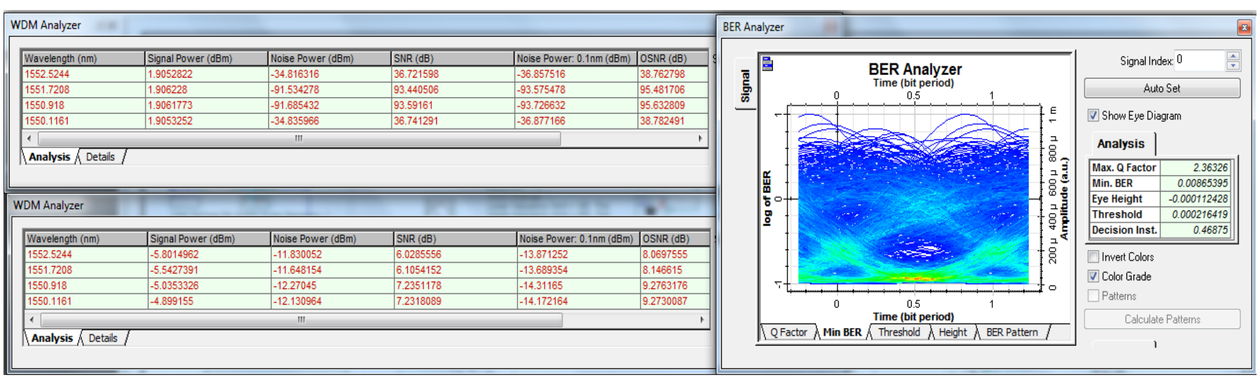
Figure 6.2.2 Experimental design of 20 Gbps 4 ×4 WDM / DWDM GPON using Linear OA EDFA @ 120 Km.(a) EDFA support for fiber distance 120Km for 20 Gbps (b)10 Gbps input and output NRZ pulse shape waveform (c) measured values of input and output for four channels wavelengths using OSA, and its corresponding mux and demux output values of OSP, ONP, SNR and OSNR using WDM Analyzer (d) Eye pattern and Log of BER with 3D graph.

Compared with 10 Gbps from previous results of Figure 6.1.1, no eye pattern is opening due to low Mi. Log of BER, Q-Factor and OSNR for 20 Gbps HBR long haul transmission.

6.2.3 Experimental Analysis for the performance of 10 Gbps 4×4 WDM /GPON Using Linear OA EDFA and DCF with FBG @240Km-Input OSP is 5dBm



(a)



WDM Analyzer

Wavelength (nm)	Signal Power (dBm)	Noise Power (dBm)	SNR (dB)	Noise Power: 0.1nm (dBm)	OSNR (dB)
1552.5244	1.9052822	-34.816316	36.721598	-36.857516	38.762798
1551.7208	1.906228	-91.534278	93.440506	-93.575478	95.481706
1550.918	1.9061773	-91.685432	93.59161	-93.726632	95.632809
1550.1161	1.9053252	-34.835966	36.741291	-36.877166	38.782491

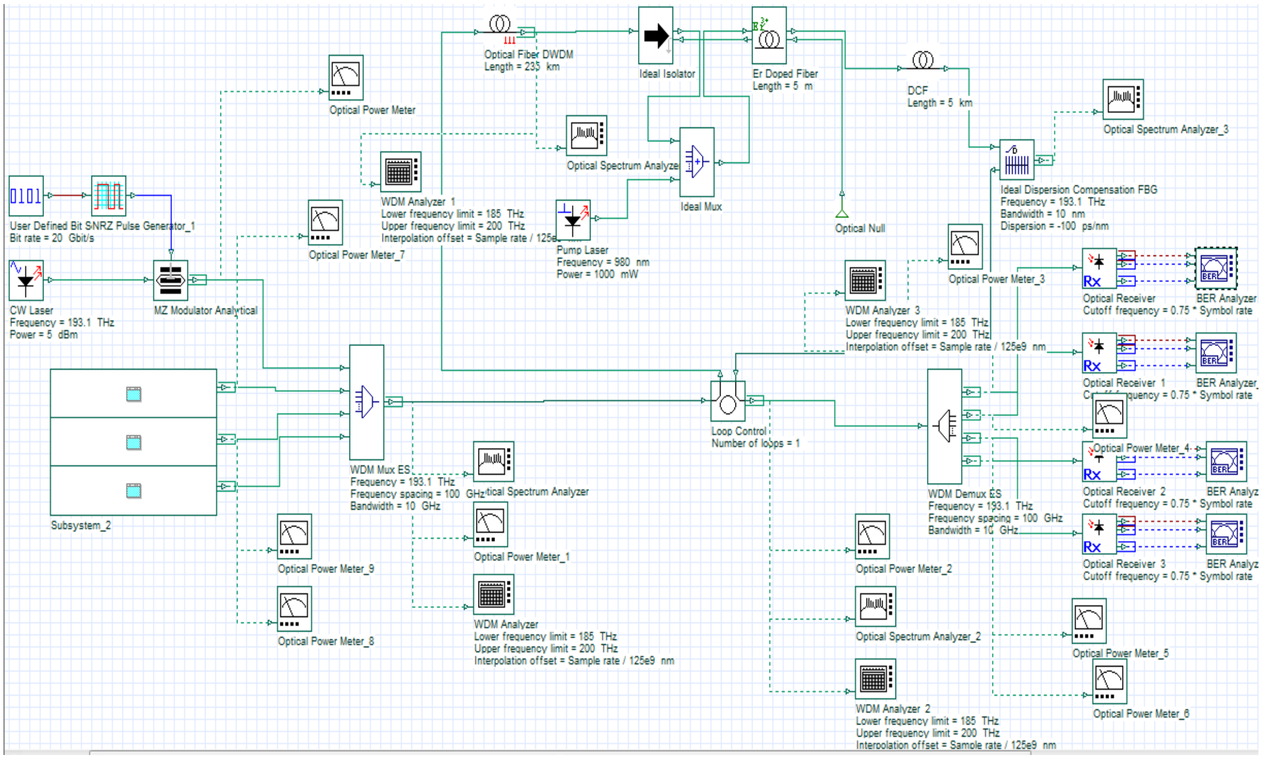
WDM Analyzer

Wavelength (nm)	Signal Power (dBm)	Noise Power (dBm)	SNR (dB)	Noise Power: 0.1nm (dBm)	OSNR (dB)
1552.5244	-5.8014962	-11.830052	6.0285556	-13.871252	8.0697555
1551.7208	-5.5427391	-11.648154	6.1054152	-13.689354	8.146615
1550.918	-5.0353326	-12.27045	7.2351178	-14.31165	9.2763176
1550.1161	-4.899155	-12.130964	7.2318089	-14.172164	9.2730087

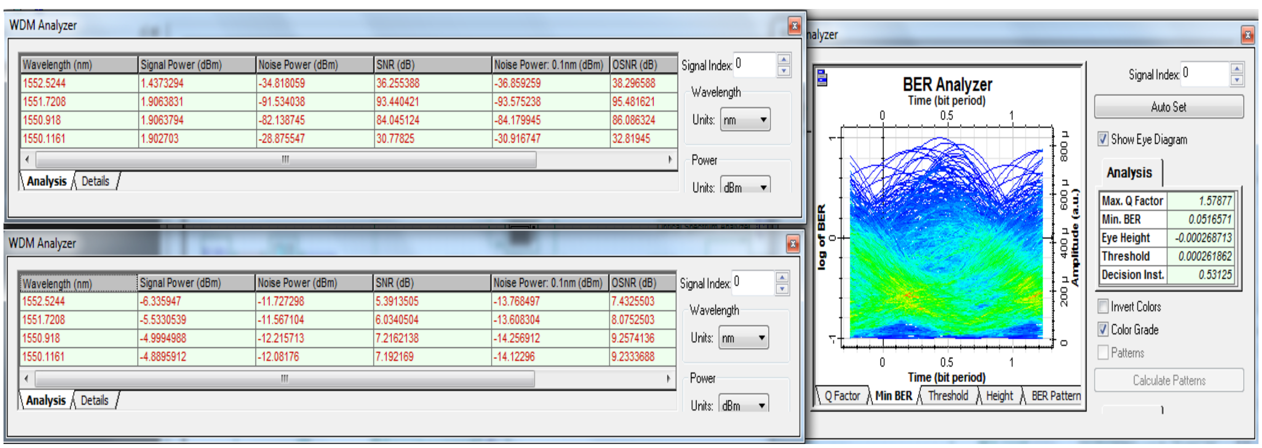
(b)

Figure 6.2.3 Experimental design of 10 Gbps 4 ×4 WDM / DWDM GPON using Linear OA EDFA @ 240 Km.(a) EDFA support fiber distance @240 Km for 10 Gbps (b) measured values of input and output for four channels wavelengths using OSA, and its corresponding mux and demux output values of OSP, ONP, SNR and OSNR using WDM Analyzer with Eye pattern and Log of BER graphical view using BER Analyzer.

6.2.4 Experimental Analysis for the performance of 20 Gbps 4×4 WDM /GPON Using Linear OA EDFA and DCF with FBG @240Km-Input OSP is 5dBm



(a)



Wavelength (nm)	Signal Power (dBm)	Noise Power (dBm)	SNR (dB)	Noise Power: 0.1nm (dBm)	OSNR (dB)
1552.5244	1.4373294	-34.818059	36.255388	-36.859259	38.296588
1551.7208	1.9063831	-91.534038	93.440421	-93.575238	95.481621
1550.918	1.9063794	-82.138745	84.045124	-84.179945	86.086324
1550.1161	1.902703	-28.875547	30.77825	-30.916747	32.81945

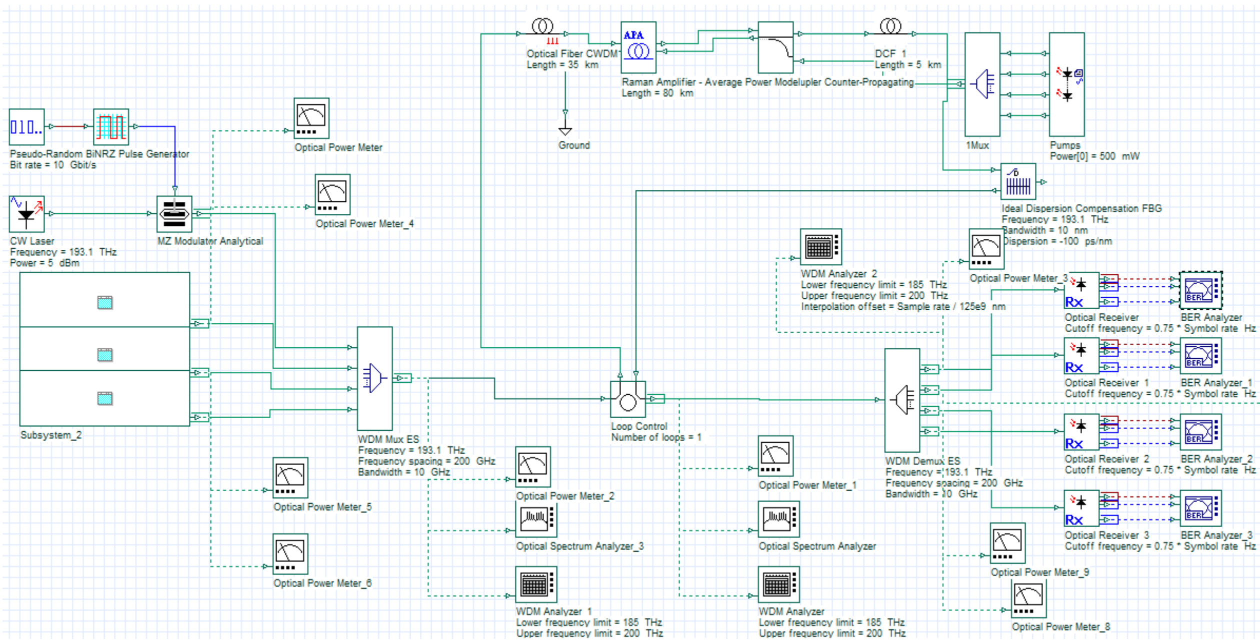
Wavelength (nm)	Signal Power (dBm)	Noise Power (dBm)	SNR (dB)	Noise Power: 0.1nm (dBm)	OSNR (dB)
1552.5244	-6.335947	-11.727298	5.3913505	-13.768497	7.4325503
1551.7208	-5.5330539	-11.567104	6.0340504	-13.608304	8.0752503
1550.918	-4.9994988	-12.215713	7.2162138	-14.256912	9.2574136
1550.1161	-4.8895912	-12.08176	7.192169	-14.12296	9.2333688

(b)

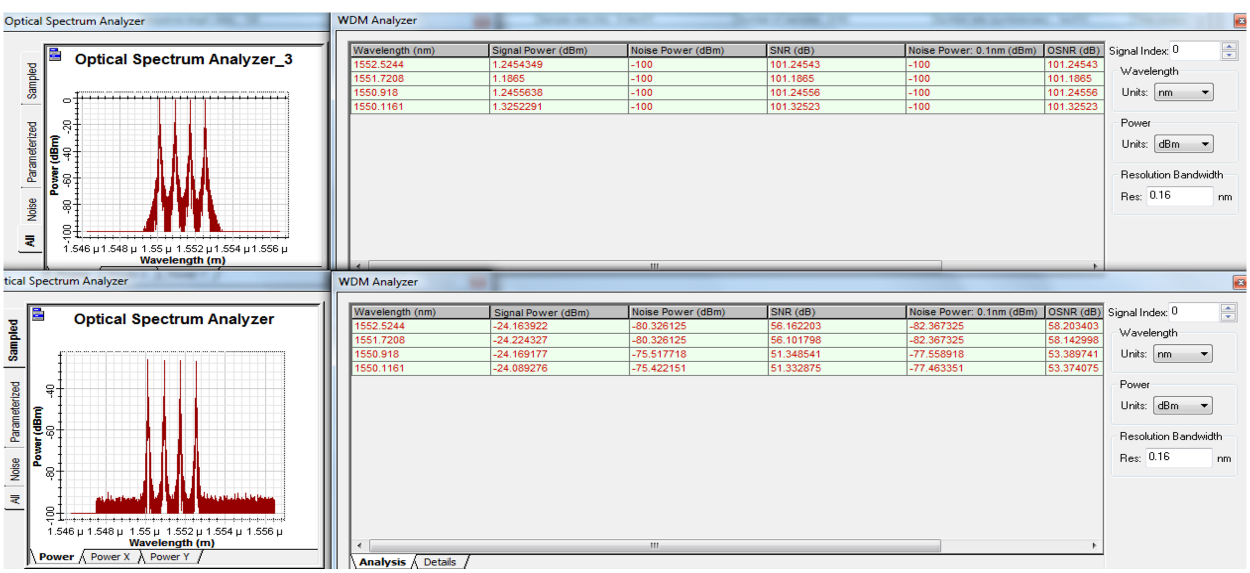
Figure 6.2.4 Experimental design of 20 Gbps 4 ×4 WDM / DWDM GPON using Linear OA EDFA @ 240 Km. (a) EDFA support @ 240 Km for 20 Gbps (b) measured values of input and output for four channels wavelengths using OSA, and its corresponding mux and demux output values of OSP, ONP, SNR and OSNR using WDM Analyzer with Eye pattern and Log of BER graphical view using BER Analyzer.

Based on experiments from 6.2.3 and 6.2.4, no eye pattern is opening due to insufficient Min.Log of BER, Q-Factor and OSNR when transmitting HBR 10 to 20 Gbps for 240 Km though forward pumping power has given with EDFA.

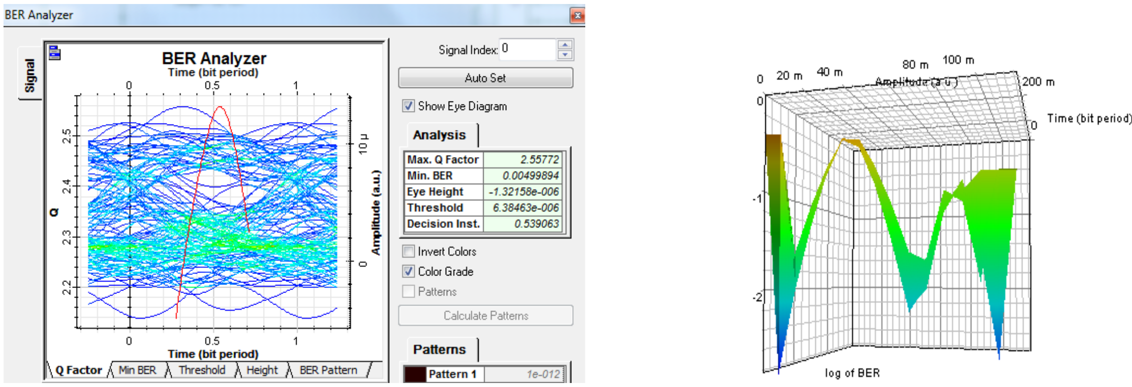
6.2.5 Experimental Analysis for performance of 10 Gbps 4×4 WDM /GPON Using Non-Linear OA Raman and DCF with FBG @120Km – Input OSP is 5 dBm



(a)



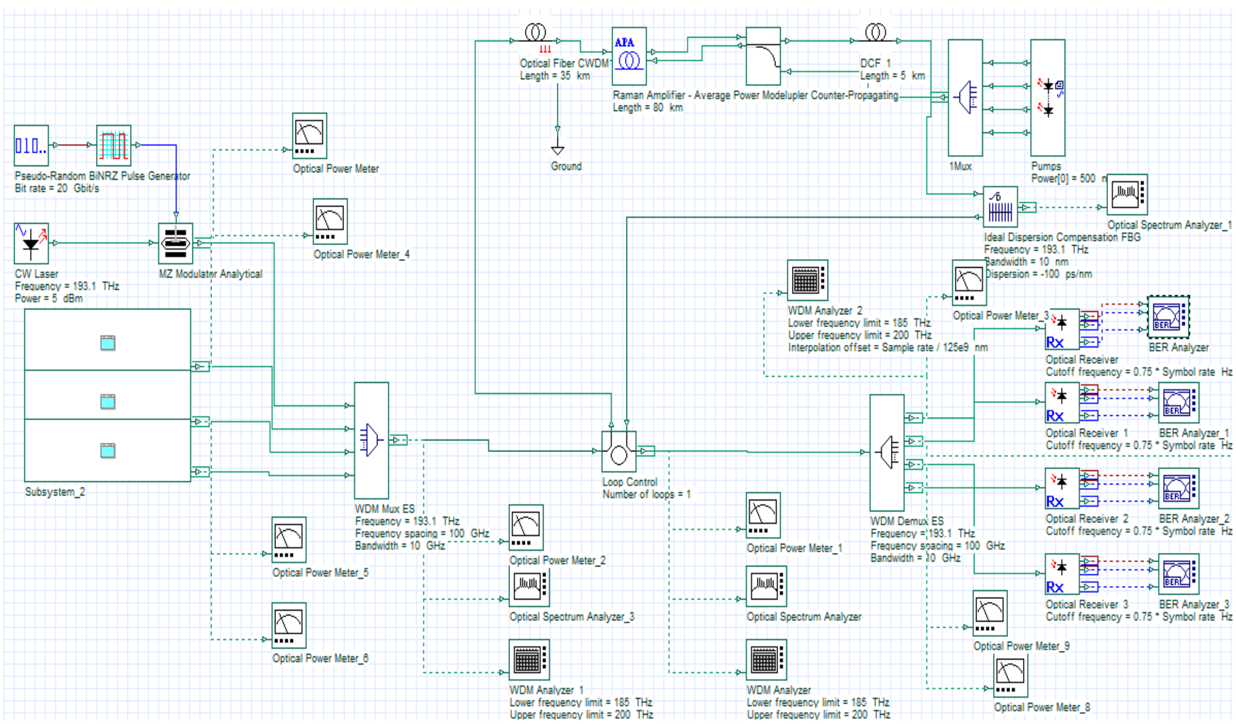
(b)



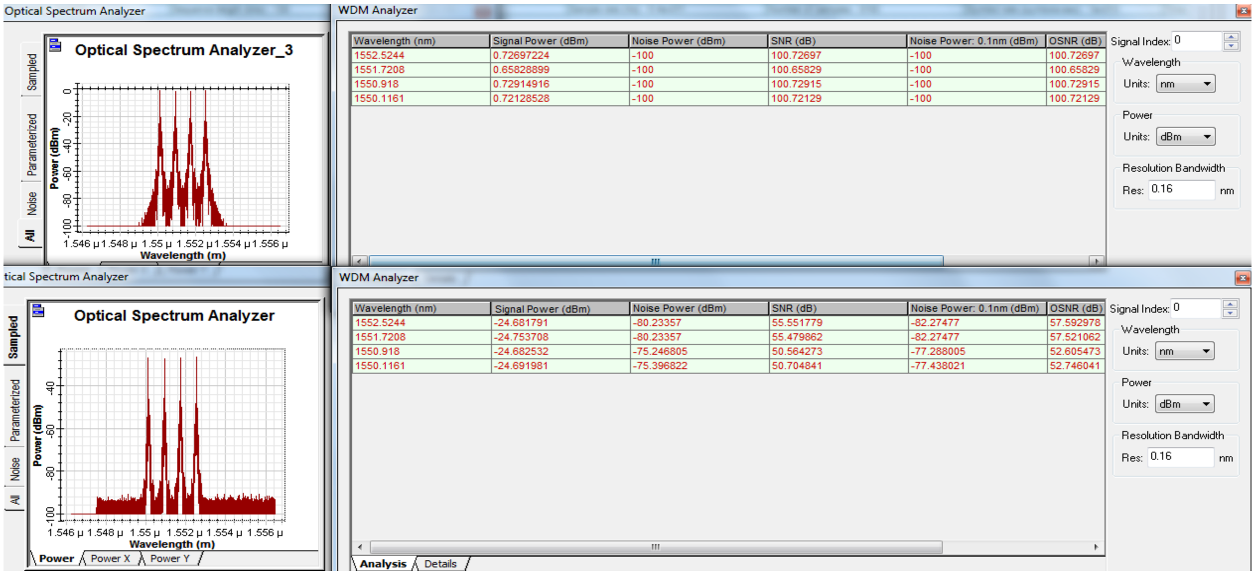
(c)

Figure 6.2.5 Experimental design of 10 Gbps 4 ×4 WDM / DWDM GPON using Non Linear OA Raman @ 120 Km. (a) Raman OA support fiber distance @120 Km for 10 Gbps (b) measured values of input and output for four channels wavelengths using OSA, and its corresponding mux and demux output values of OSP, ONP, SNR and OSNR using WDM Analyzer (c) Eye pattern and Q-Factor graphical view using BER Analyzer.

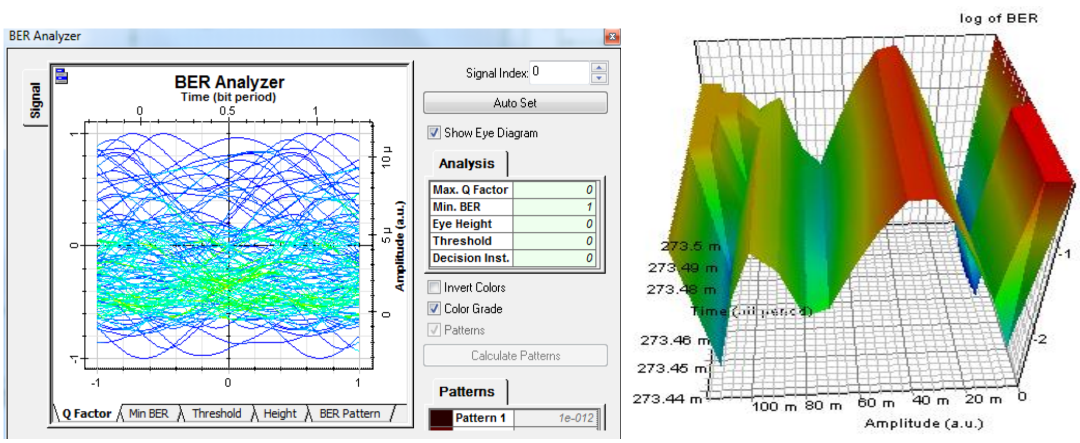
6.2.6 Experimental Analysis for the performance of 20 Gbps 4×4 WDM /GPON Using Non-Linear OA Raman and DCF with FBG @120Km-Input OSP is 5dBm



(a)



(b)

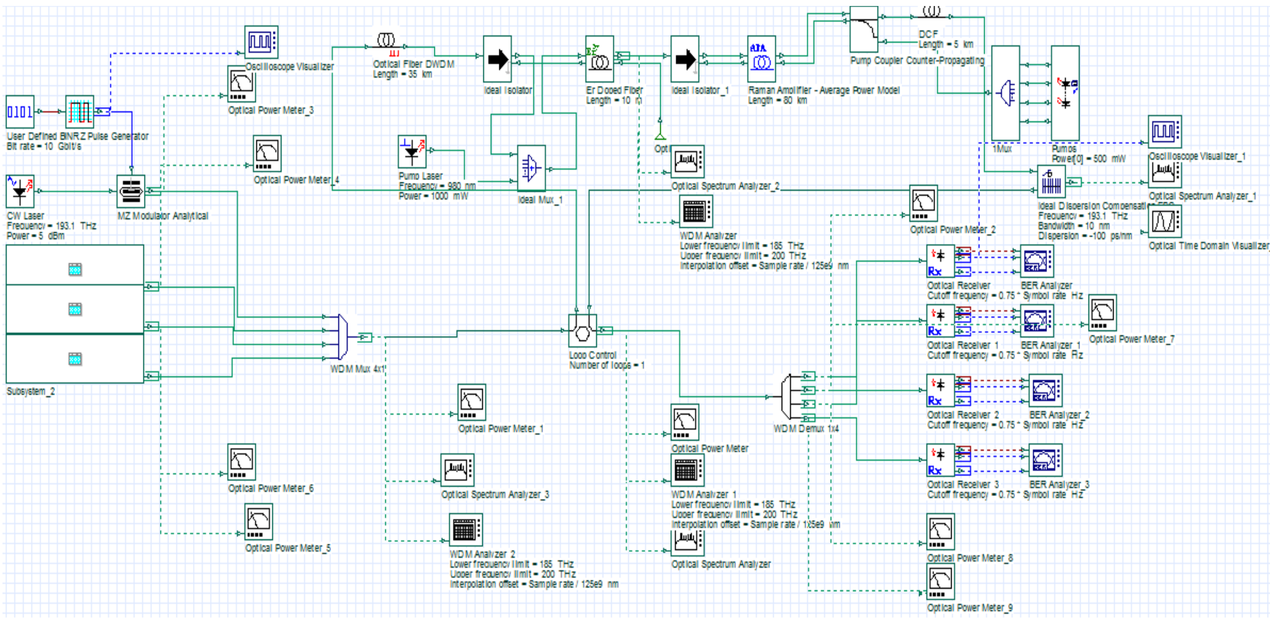


(c)

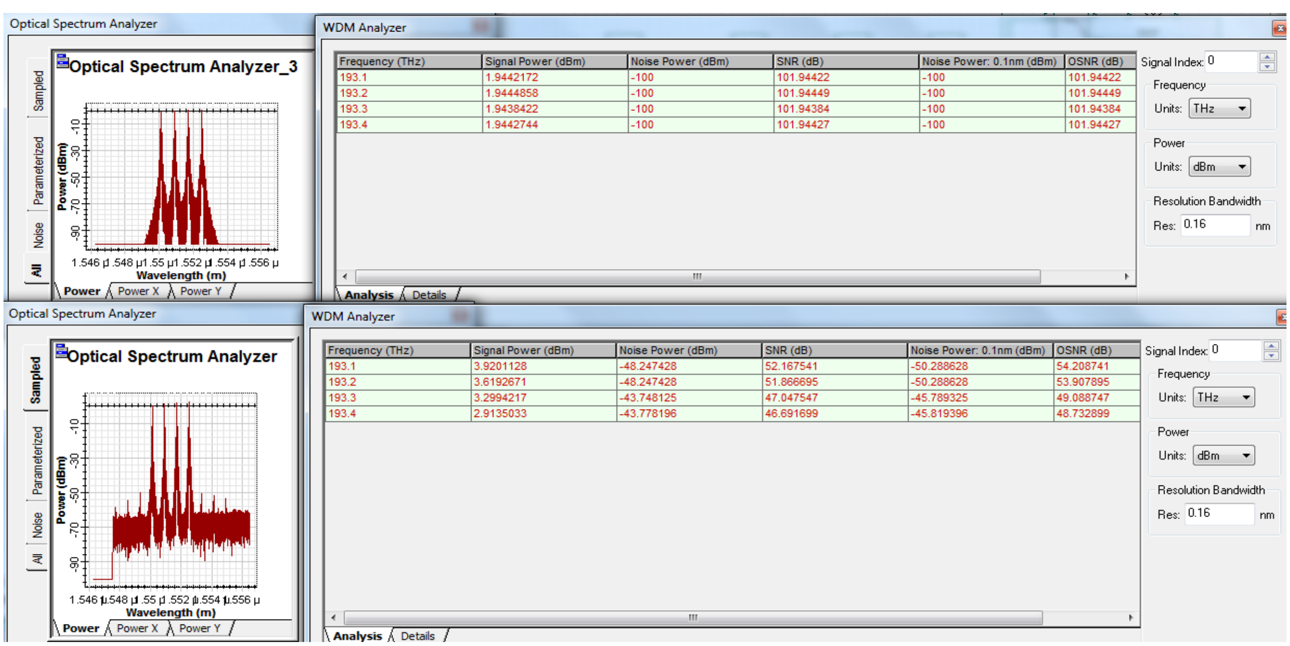
Figure 6.2.6 Experimental design of 20 Gbps 4 ×4 WDM / DWDM GPON using Non Linear OA Raman @ 120 Km. (a) Raman OA support fiber diantace @120Km for 20 Gbps (b) measured values of input and output for four channels wavelengths using OSA, and its corresponding mux and demux output values of OSP, ONP, SNR and OSNR using WDM Analyzer (c) Eye pattern and Log of BER graphical view using BER Analyzer.

The previous experiments 6.2.5 and 6.2.6 results for 10 Gbps and 20 Gbps at 240 Km, the NON –OA Raman does not support due to gain of the amplifier system even though backward pumping power is provided. Pre, symmetry and Post compensation techniques are needed for transmission of above 10 Gbps. Hence, in this research we combined both Linear OA EDFA and Non-Linear OA Raman combined (Hybrid) for HBR long haul performance. The Hybrid OA performance and results have been given consecutive way in this section below.

6.2.7 Experimental Analysis for the performance of 10 Gbps 4×4 WDM /GPON Using both Linear OA EDFA and Non-Linear OA Raman (Hybrid) and DCF with FBG @120Km-Input OSP is 5dBm



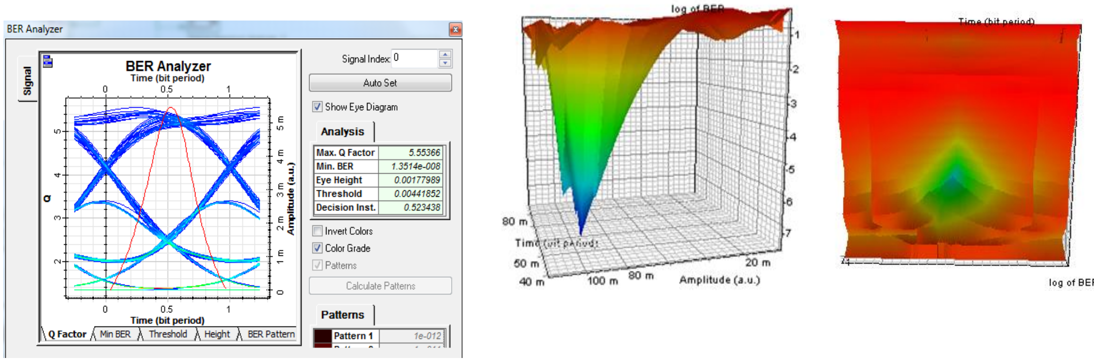
(a)



Frequency (THz)	Signal Power (dBm)	Noise Power (dBm)	SNR (dB)	Noise Power: 0.1nm (dBm)	OSNR (dB)
193.1	1.9442172	-100	101.94422	-100	101.94422
193.2	1.9444858	-100	101.94449	-100	101.94449
193.3	1.9438422	-100	101.94384	-100	101.94384
193.4	1.9442744	-100	101.94427	-100	101.94427

Frequency (THz)	Signal Power (dBm)	Noise Power (dBm)	SNR (dB)	Noise Power: 0.1nm (dBm)	OSNR (dB)
193.1	3.9201128	-48.247428	52.167541	-50.288628	54.208741
193.2	3.6192671	-48.247428	51.866695	-50.288628	53.907895
193.3	3.2994217	-43.748125	47.047547	-45.789325	49.088747
193.4	2.9135033	-43.778196	46.691699	-45.819396	48.732899

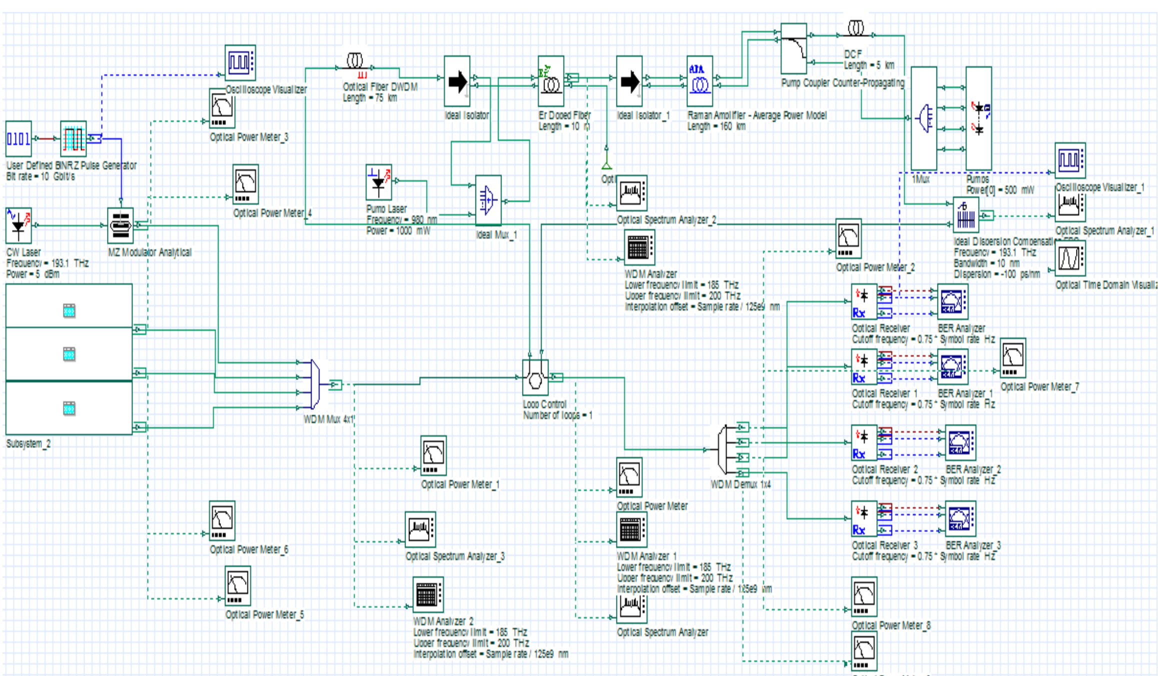
(b)



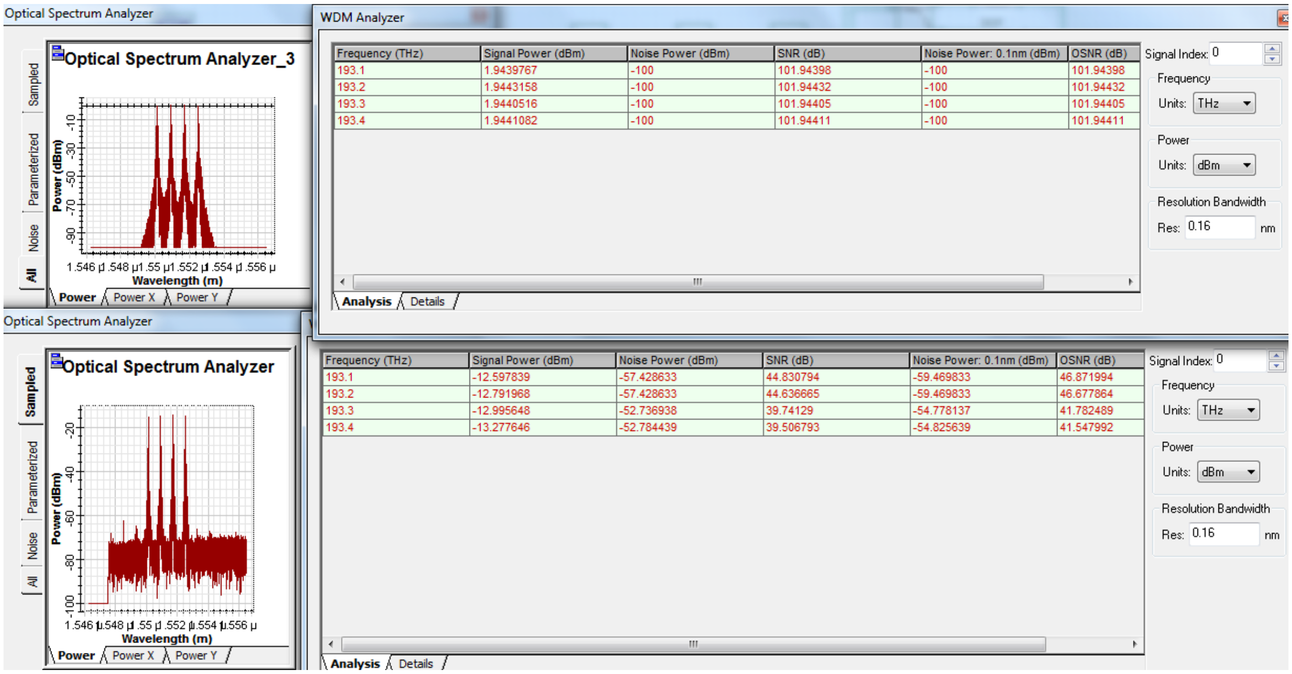
(c)

Figure 6.2.7 Experimental design of 10 Gbps 4 ×4 WDM / DWDM GPON using Linear OA EDFA and Non-Linear OA Raman @ 120 Km (Hybrid). (a) Hybrid OA support @ 120 for 10 Gbps (b) measured values of input and output for four channels wavelengths using OSA, and its corresponding mux and demux output values of OSP, ONP, SNR and OSNR using WDM Analyzer (c) Eye pattern and Q-Factor graphical view using BER Analyzer.

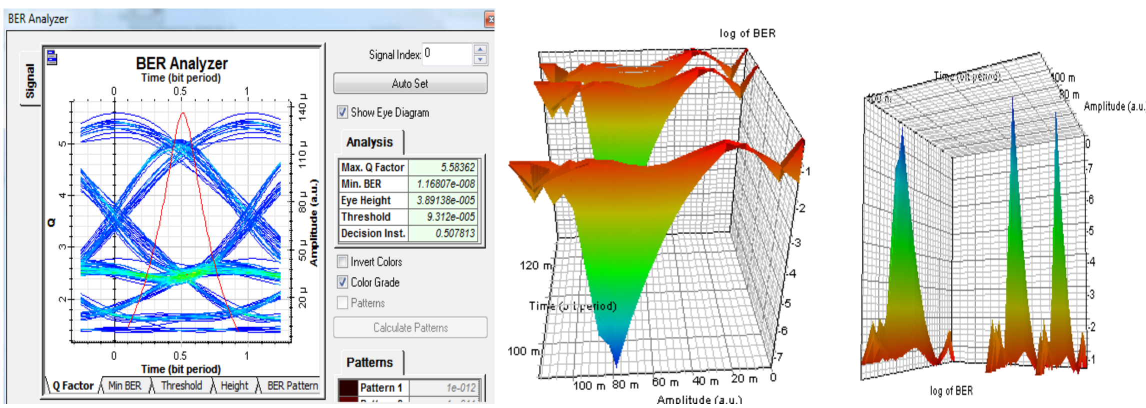
6.2.8 Experimental Analysis for the performance of 10 Gbps 4×4 WDM /GPON Using both Linear OA EDFA and Non-Linear OA Raman (Hybrid) and DCF with FBG @ 240 Km-Input OSP is 5dBm



(a)



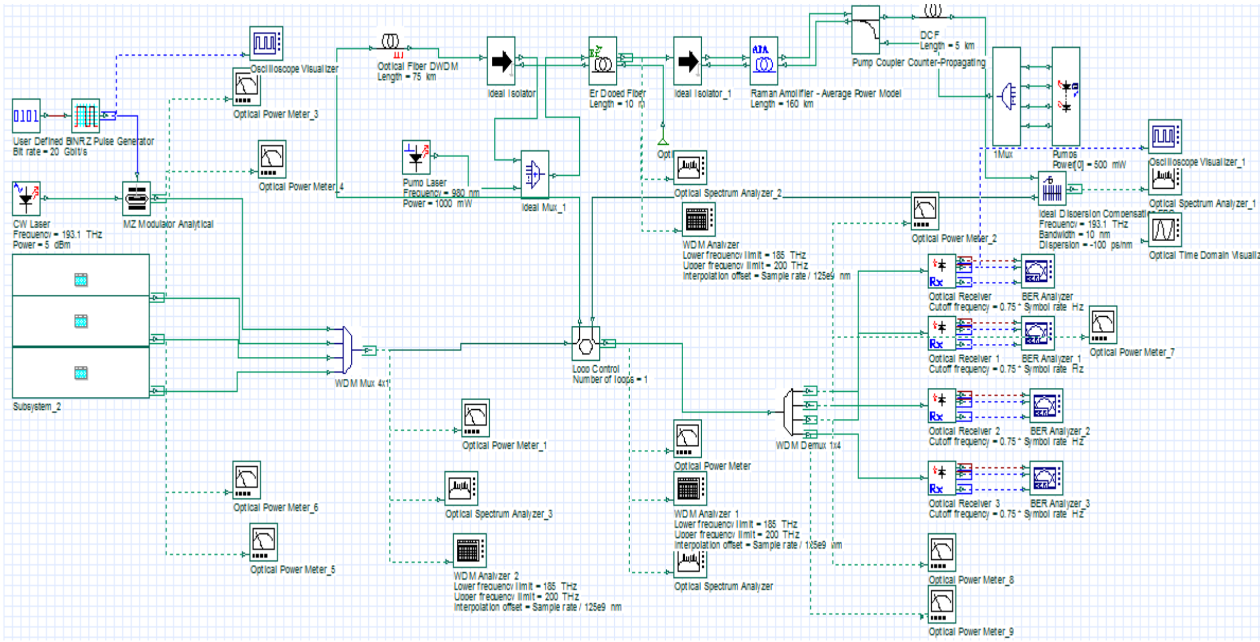
(b)



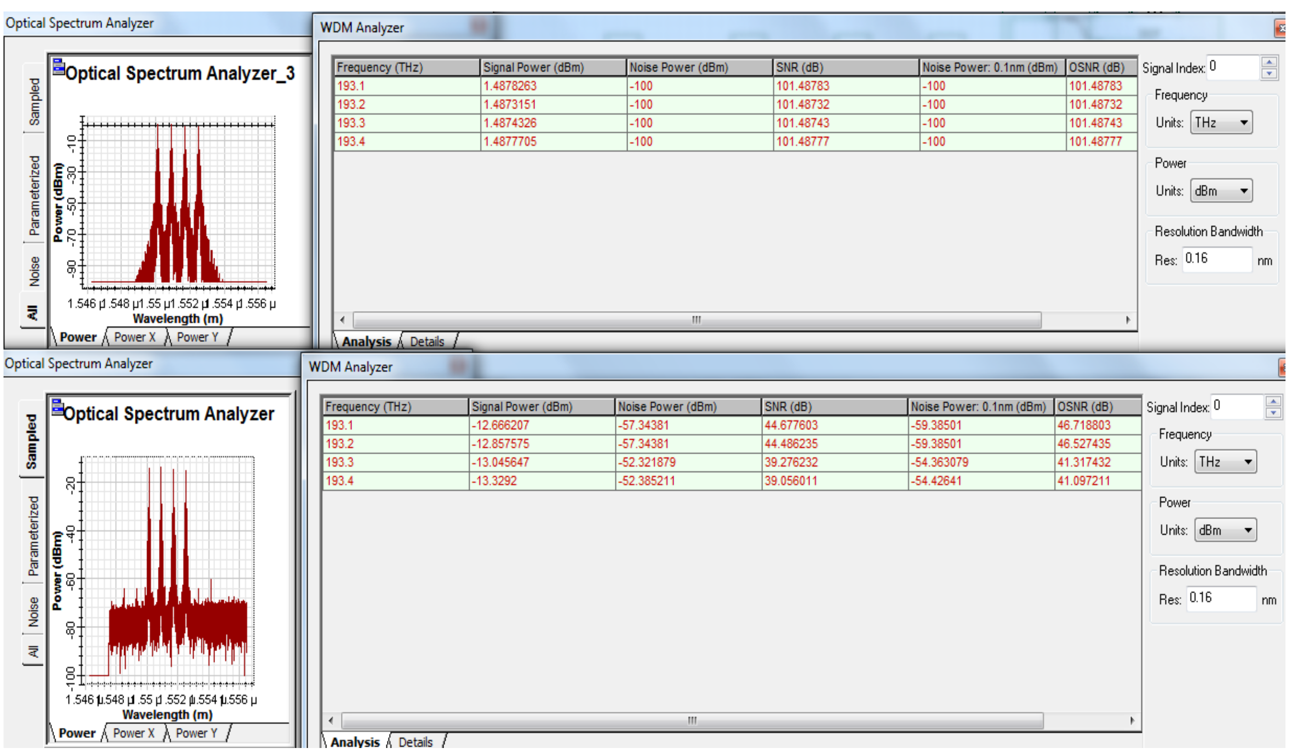
(c)

Figure 6.2.8 Experimental design of 10 Gbps 4 ×4 WDM / DWDM GPON using Linear OA EDFA and Non-Linear OA Raman(Hybrid) @ 240 Km (a) Hybrid OA support for fiber distance 240 @10 Gbps (b) measured values of input and output for four channels wavelengths using OSA, and its corresponding mux and demux output values of OSP, ONP, SNR and OSNR using WDM Analyzer (c) Eye pattern and Q-Factor graphical view using BER Analyzer.

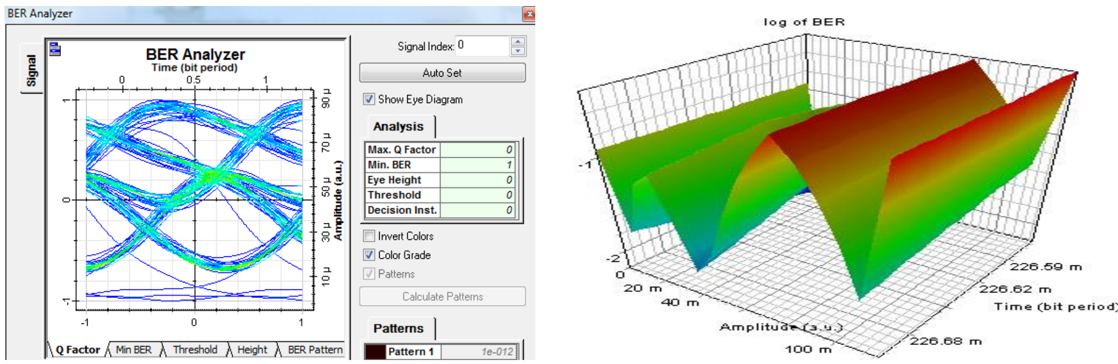
6.2.9 Experimental Analysis for the performance of 20 Gbps 4×4 WDM /GPON Using both Linear OA EDFA and Non-Linear OA Raman (Hybrid) and DCF with FBG @ 240 Km-Input OSP is 5dBm



(a)



(b)



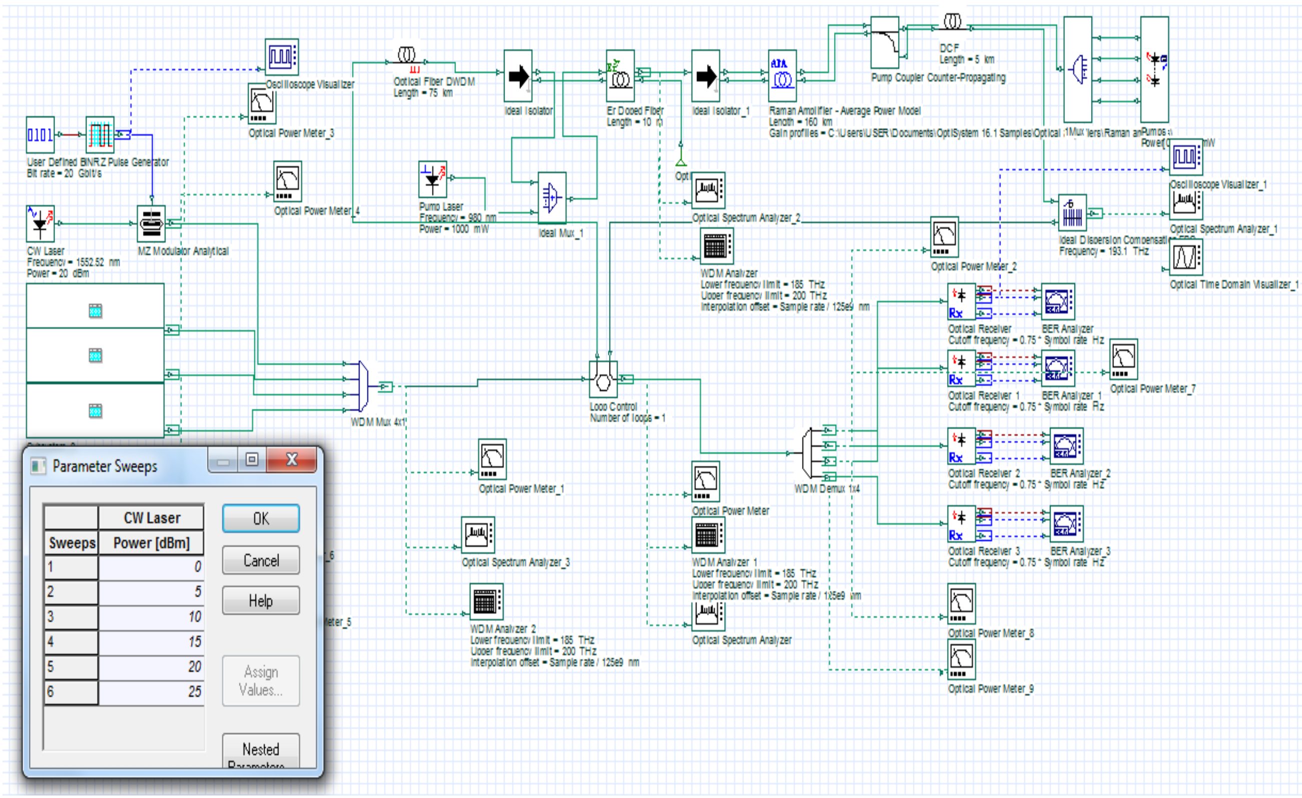
(c)

Figure 6.2.9 Experimental design of 20 Gbps 4 ×4 WDM / DWDM GPON using Linear OA EDFA and Non-Linear OA Raman (Hybrid) @ 240 Km (a) Hybrid OA support for fiber distance 240 Km @20 Gbps (b) measured values of input and output for four channels wavelengths using OSA, and its corresponding mux and demux output values of OSP, ONP, SNR and OSNR using WDM Analyzer (c) Eye pattern and Q-Factor graphical view using BER Analyzer.

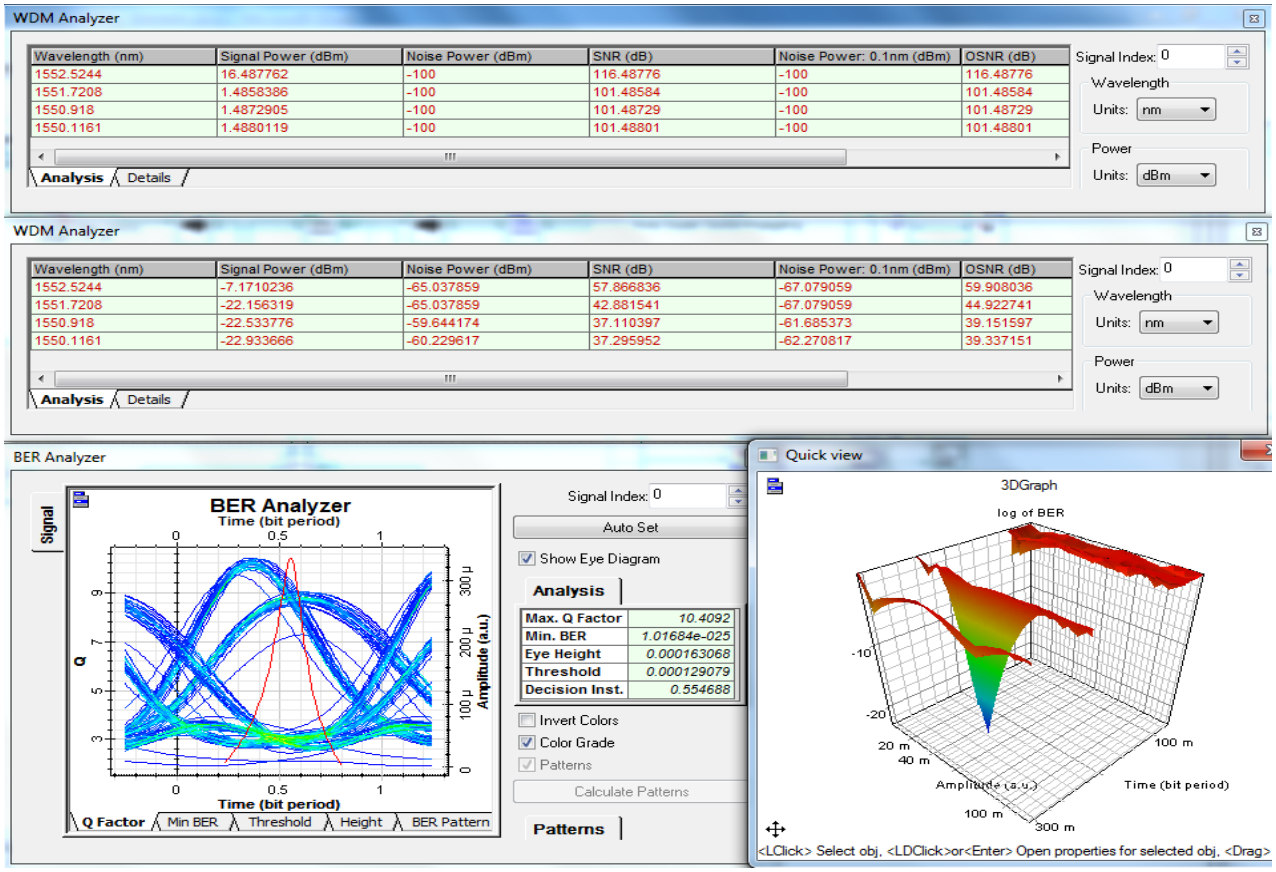
Mainly from the results of experiments, the experiment 6.2.7 satisfied performance. But, the results of experiments 6.2.8 and 6.2.9, we noted that not opening the eye pattern for 10 to 20 Gbps and respective HBR transmitting to the range of distance limit both 120Km and 240Km. This hybrid OA non-performance, we understood and noted that due to the input OSP (from CW laser input source) has an inadequate to hybrid OAs performance support and hence we have analyzed by increasing the input OSP with sweeping iterative method.

We have approached as per methodology from fixed to variable input OSP for HBR long haul transmission. Finally, we have varied the fixed 5dBm of the input OSP as sweep from 0 dBm to 25 dBm as per class 4 laser safety power level (at CW Laser source). As a special attempt of experiment for varied input OSP range from 0-25 dBm and its design and results have been displayed in sub-section 6.2.10 below.

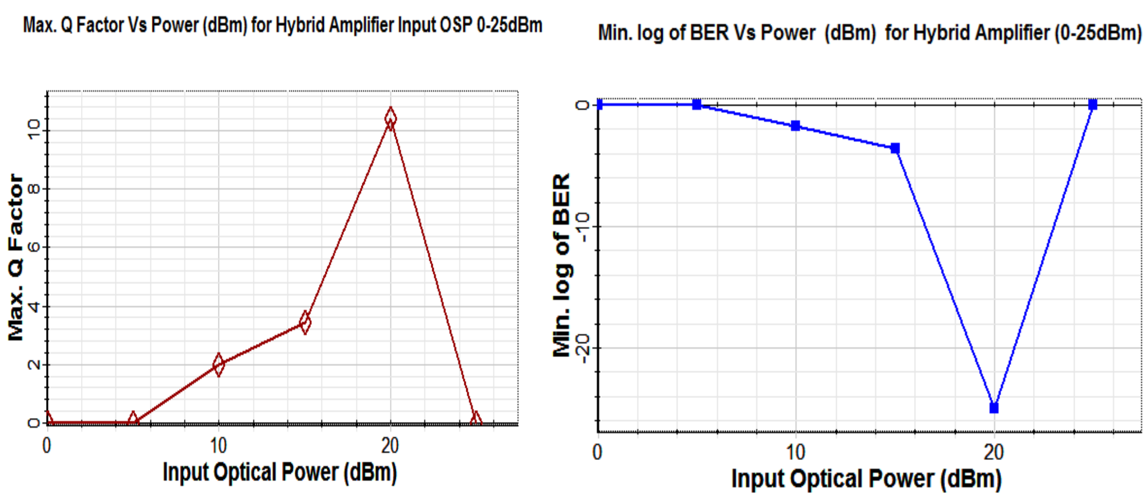
6.2.10 Experimental Analysis for the performance of 20 Gbps 4×4 WDM /GPON Using both Linear OA EDFA and Non-Linear OA Raman (Hybrid) and DCF with FBG @ 240 Km-Varying Input OSP 0dBm to 25 dBm -Iterative Technique



(a)



(b)



(c)

Figure 6.2.10 Experimental design of 20 Gbps 4 ×4 WDM / DWDM GPON using Linear OA EDFA and Non-Linear OA Raman (Hybrid) @ 240 Km (a) Hybrid OA support for fiber distance 240 Km @ 20 Gbps (b) measured values of input and output for four channels wavelengths using OSA, and its corresponding mux and demux output values of OSP, ONP, SNR and OSNR using WDM Analyzer, Eye pattern and Q-Factor graphical view using BER Analyzer (c)

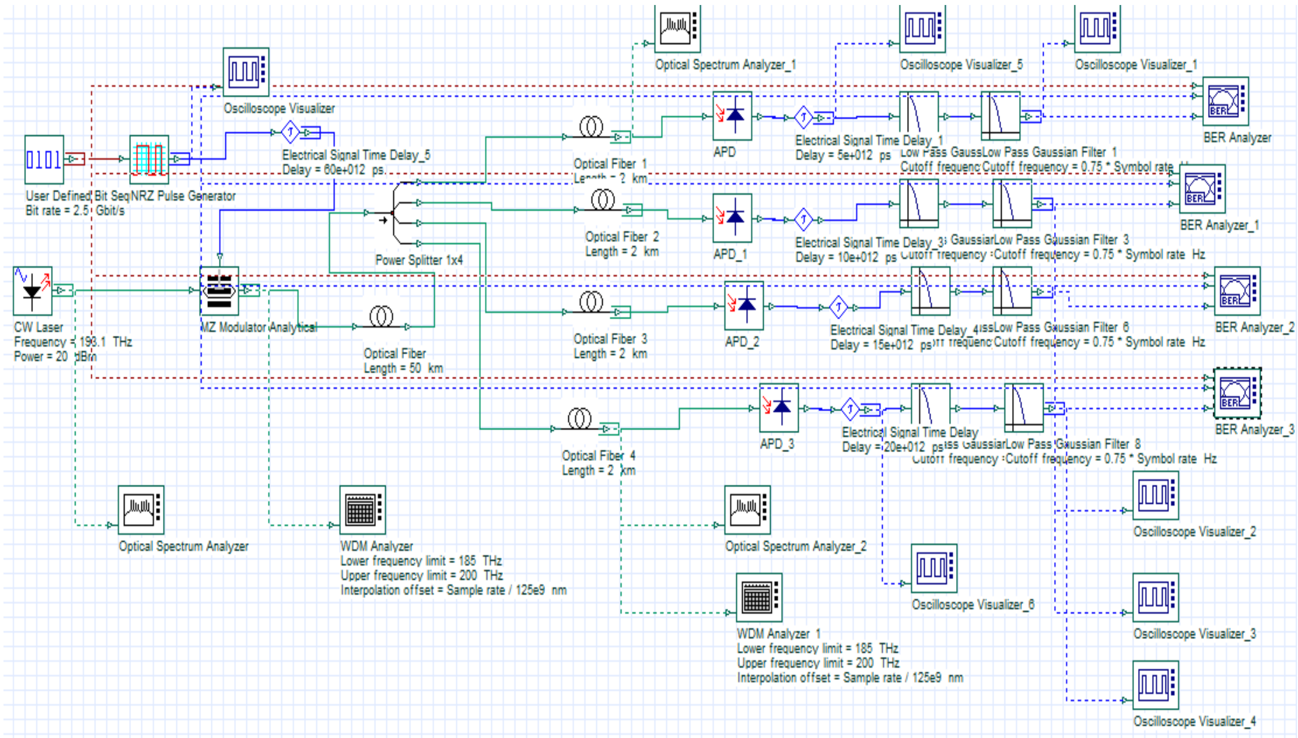
Sweep Iterative method to varying input OSP from 0dBm to 25 dBm and obtained Max Q-Factor and Min.Log of BER.

6.3 TDM GPON experiment / implementation and its results

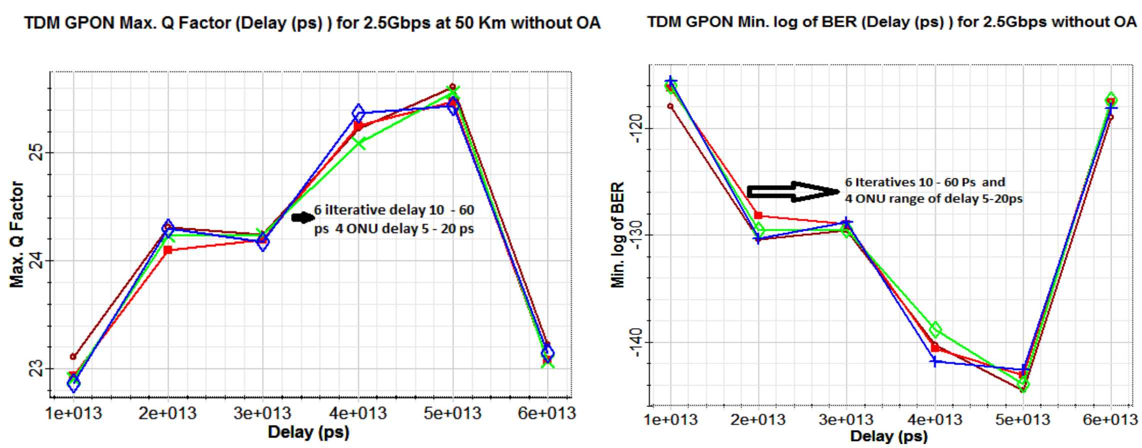
The TDM GEPON or TDM GPON has also a major support for OWW-BAN technologies at present as per IEEE and ITU-T standard. It is operated with single wavelength using SMF. In the TDM GPON technology, many ranges of Gigabit - HBR / HLR have been transported both in downstream and upstream C-band and L-band. In major, downstream is having more priority in the ratio of 2:1 than upstream. All the streaming accessing processes of TDM GPON have been considered with different time-slot allocation from CO – OLT to many ONUs through 1 × N Power Splitters (PS) which located at Remote Node (RN).

Normally, in the TDM GPON, the signal, information or packets have been transmitted by different Time-Slot (TS) or varying the Time -Delay (TD) of single wavelength reach through SMF in the entire transmission. The TD can be considered either in electrical or optical signal form in the fiber optic transmission. In this research, based on the above approach/ methodology and different TDs have been taken in the entire TDM GPON transmission process. Also, we have been chosen mainly 1×4 TDM GPON with different TDs for four ONUs to access different range of HBR from 1.25 Gbps to 10 Gbps beyond using single wavelength 193.1 THz (1552.52nm) as per C-band. All the experiments have been carried out with sweep six iterative analysis with different TD ranges from 10ps to 60ps at NRZ signal source and minimum ranges of TDs 5ps-20ps have been chosen at four ONUs. Overall, from CO-OLT (source) to four ONUs (destinations), total account TDs range 15ps as minimum and 80ps as maximum. The design and performance study of HBR TDM GPON carried out with many results have been given below.

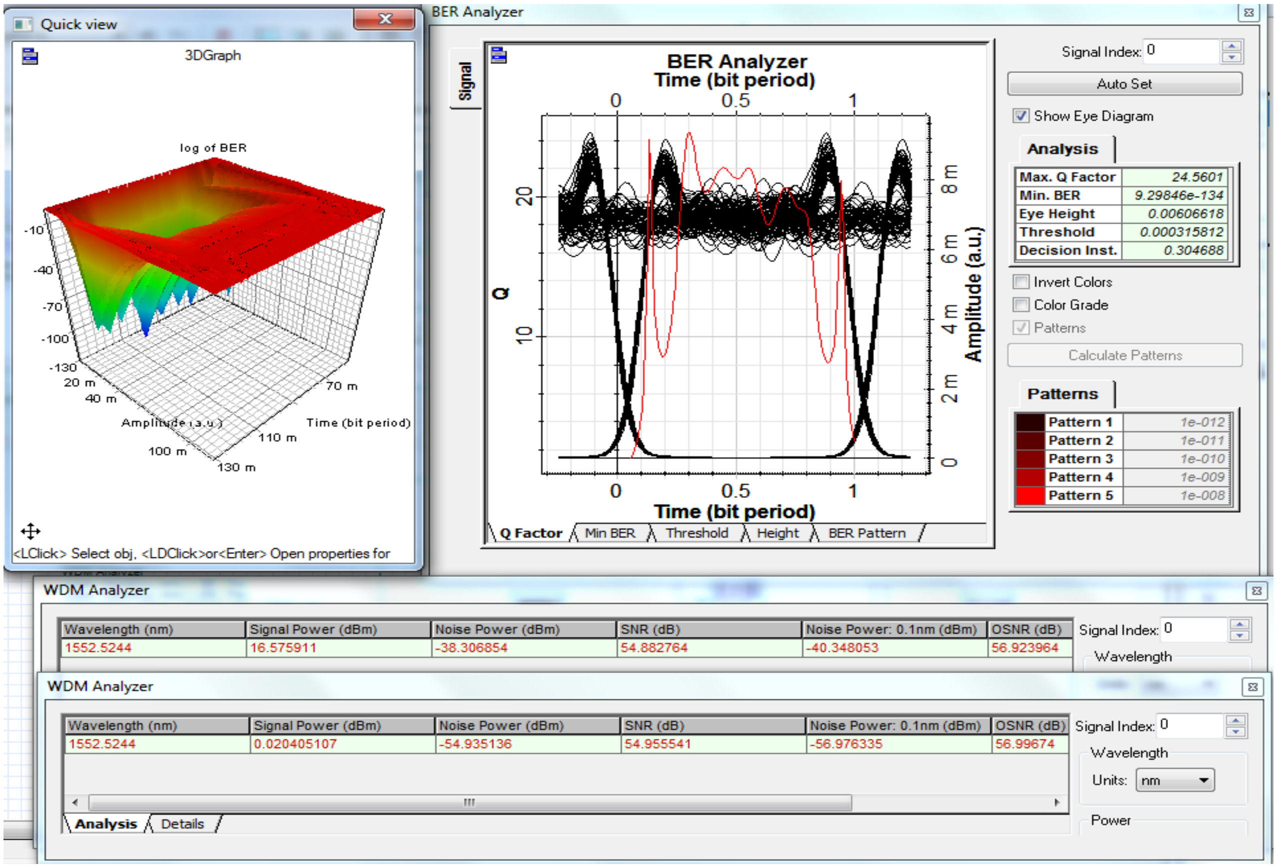
6.3.1 Experimental Analysis for the performance of 2.5 Gbps 1×4 TDM GPON without OA @ 50 Km -TDs from 10ps to 60ps- Sweep Iterative Technique @ fixed Input OSP 20 dBm


User Defined Bit Seq
Bit rate = 2.5 Gbit/s
NRZ Pulse Generator
Oscilloscope Visualizer
Electrical Signal Time Delay_5
Delay = 60e+012 ps
CW Laser
Frequency = 193.1 THz
Power = 20 dBm
MZ Modulator Analytical
Optical Fiber
Length = 50 km
Power Splitter 1x4
Optical Fiber 1
Optical Fiber 2
Length = 2 km
Optical Fiber 3
Length = 2 km
Optical Fiber 4
Length = 2 km
APD
APD_1
APD_2
APD_3
Electrical Signal Time Delay_1
Delay = 5e+012 ps
Electrical Signal Time Delay_3
Delay = 10e+012 ps
Electrical Signal Time Delay_4
Delay = 15e+012 ps
Electrical Signal Time Delay
Delay = 20e+012 ps
Low Pass Gaussian Filter 1
Low Pass Gaussian Filter 3
Low Pass Gaussian Filter 6
Low Pass Gaussian Filter 8
Cutoff frequency = 0.75 * Symbol rate Hz
BER Analyzer
BER Analyzer_1
BER Analyzer_2
BER Analyzer_3
Optical Spectrum Analyzer
Optical Spectrum Analyzer_1
Optical Spectrum Analyzer_2
Oscilloscope Visualizer_1
Oscilloscope Visualizer_2
Oscilloscope Visualizer_3
Oscilloscope Visualizer_4
Oscilloscope Visualizer_5
Oscilloscope Visualizer_6
WDM Analyzer
WDM Analyzer_1
Lower frequency limit = 185 THz
Upper frequency limit = 200 THz
Interpolation offset = Sample rate / 125e9 nm

(a)


TDM GPON Max. Q Factor (Delay (ps)) for 2.5Gbps at 50 Km without OA
Max. Q Factor
Delay (ps)
6 iIterative delay 10 - 60 ps 4 ONU delay 5 - 20 ps
TDM GPON Min. log of BER (Delay (ps)) for 2.5Gbps without OA
Min. log of BER
Delay (ps)
6 Iteratives 10 - 60 Ps and 4 ONU range of delay 5-20ps

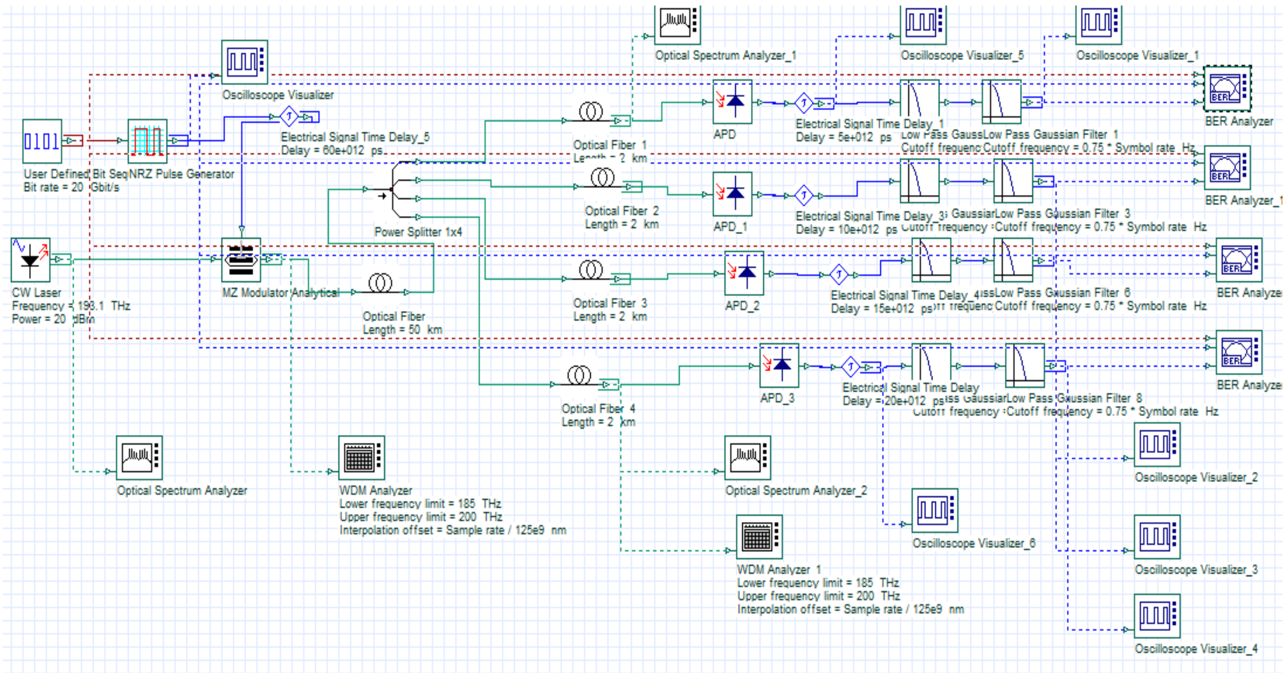
(b)



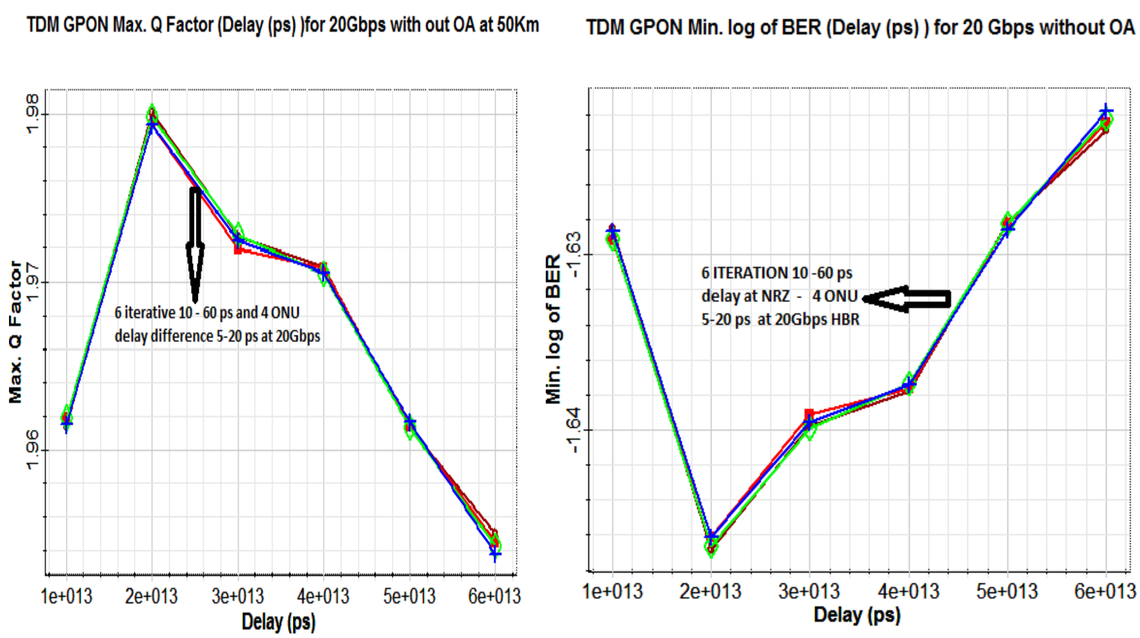
(c)

Figure 6.3.1 Experimental design of 2.5 Gbps 1 ×4 TDM GPON without OA @ 50 Km (a) Without OA supporting fiber distance 50 Km @2.5 Gbps (b) measured values of Q factor and Min.Log of BER for six iterative analysis - NRZ TDs 10ps – 60ps and 4 ONUs fixed TDs ranges 5ps, 10ps,15ps and 20ps. (c) 3D views of Min.Log BER with Eye pattern using BER Analyzer and input(OLT) and output (ONUs) measured values of OSP, ONP , SNR and OSNR using WDM analyzer for single channel 1552.52nm.

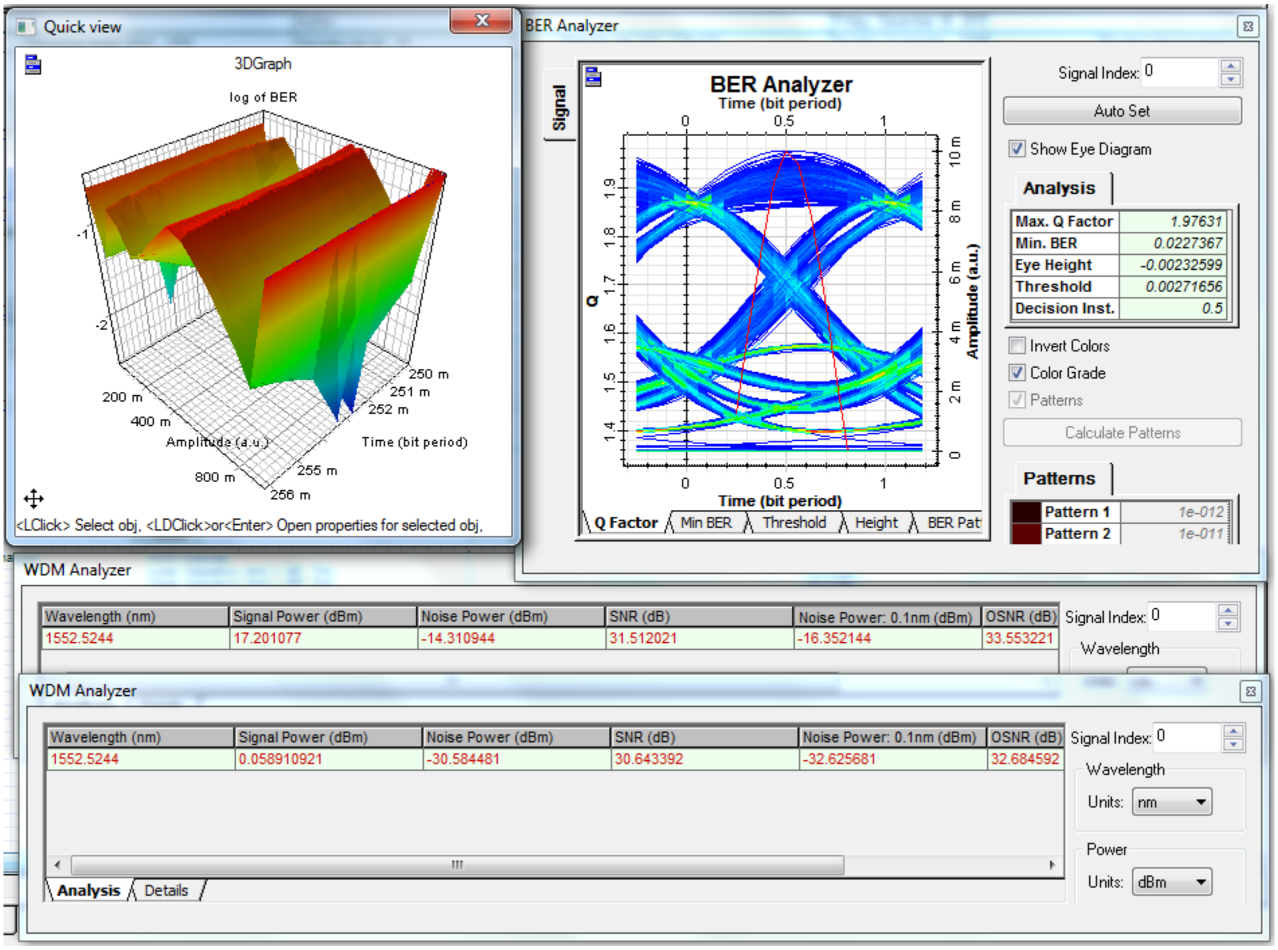
6.3.2 Experimental Analysis for the performance of 20 Gbps 1×4 TDM GPON without OA @ 50 Km -TDs from 10ps to 60ps- Sweep Iterative Technique @ fixed Input OSP 20 dBm



(a)



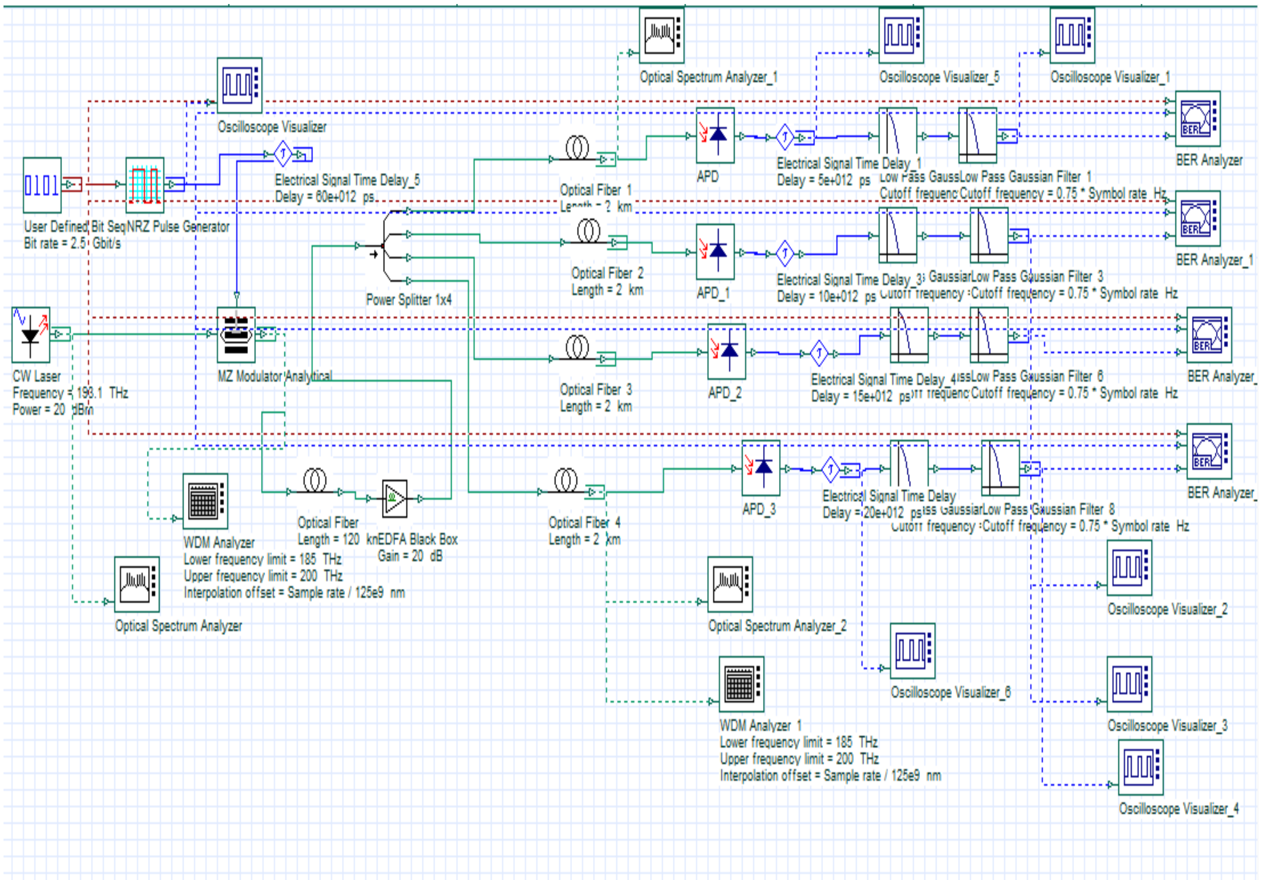
(b)



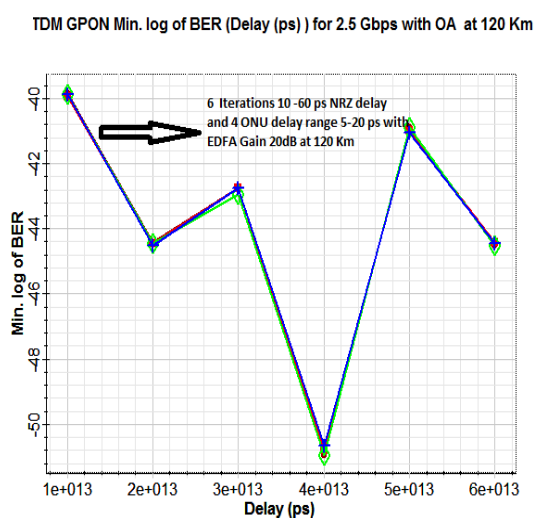
(c)

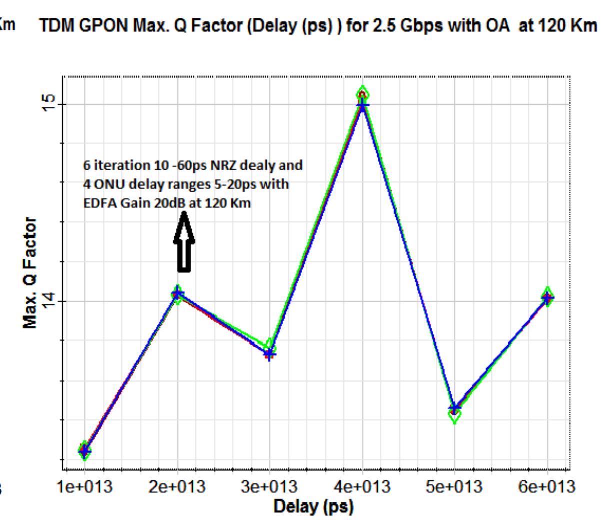
Figure 6.3.2 Experimental design of 20 Gbps 1 ×4 TDM GPON without OA @ 50 Km (a) without OA support fiber distance 50 Km for 20 Gbps (b) measured values of Q factor and Min.Log of BER for six iterative analysis - NRZ TDs 10ps – 60ps and 4 ONUs fixed TDs ranges 5ps, 10ps,15ps and 20ps. (c) 3D views of Min.Log BER with Eye pattern using BER Analyzer and input(OLT) and output (ONUs) measured values of OSP, ONP , SNR and OSNR using WDM analyzer for single channel 1552.52nm.

6.3.3 Experimental Analysis for the performance of 2.5 Gbps 1×4 TDM GPON with Linear OA EDFA @ 120 Km -TDs from 10ps to 60ps- Sweep Iterative Technique @ fixed Input OSP 20 dBm

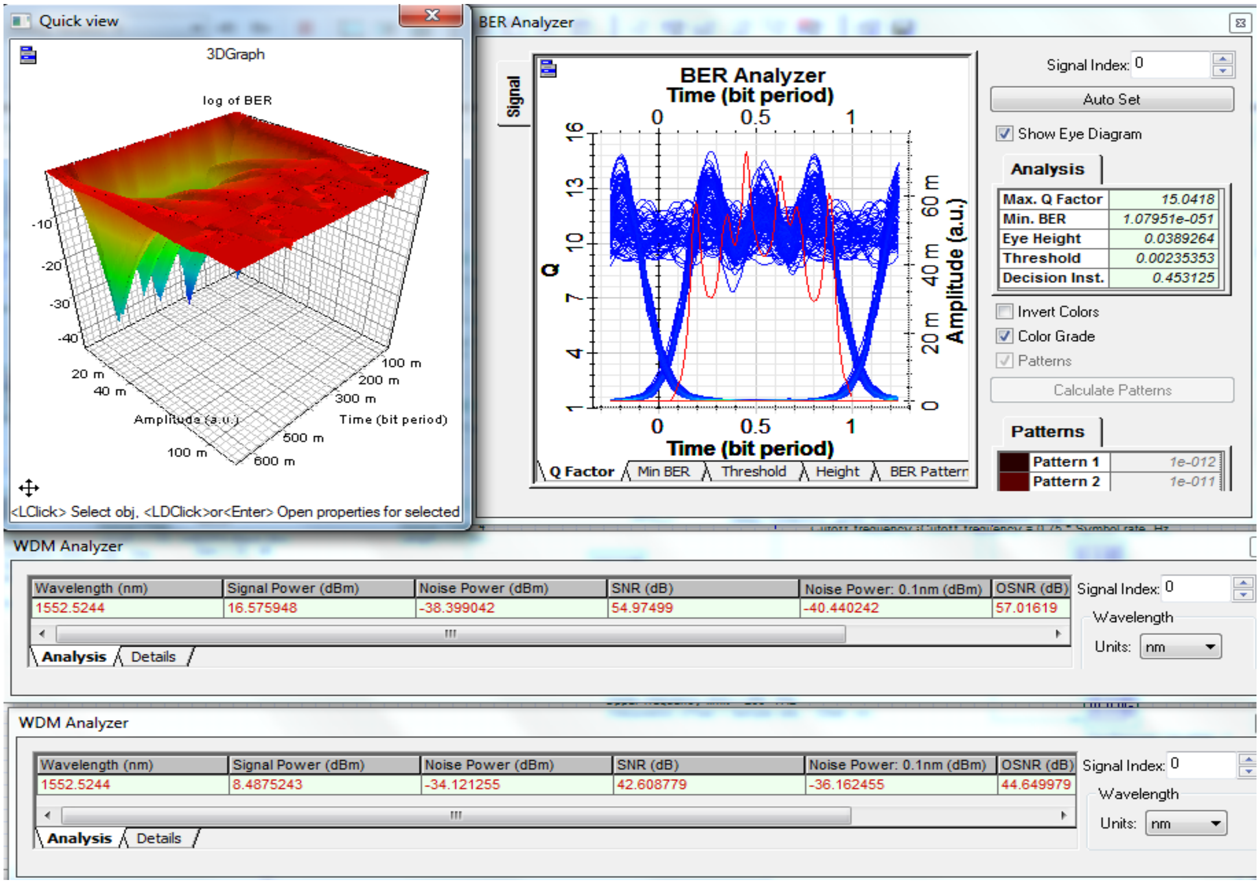


(a)





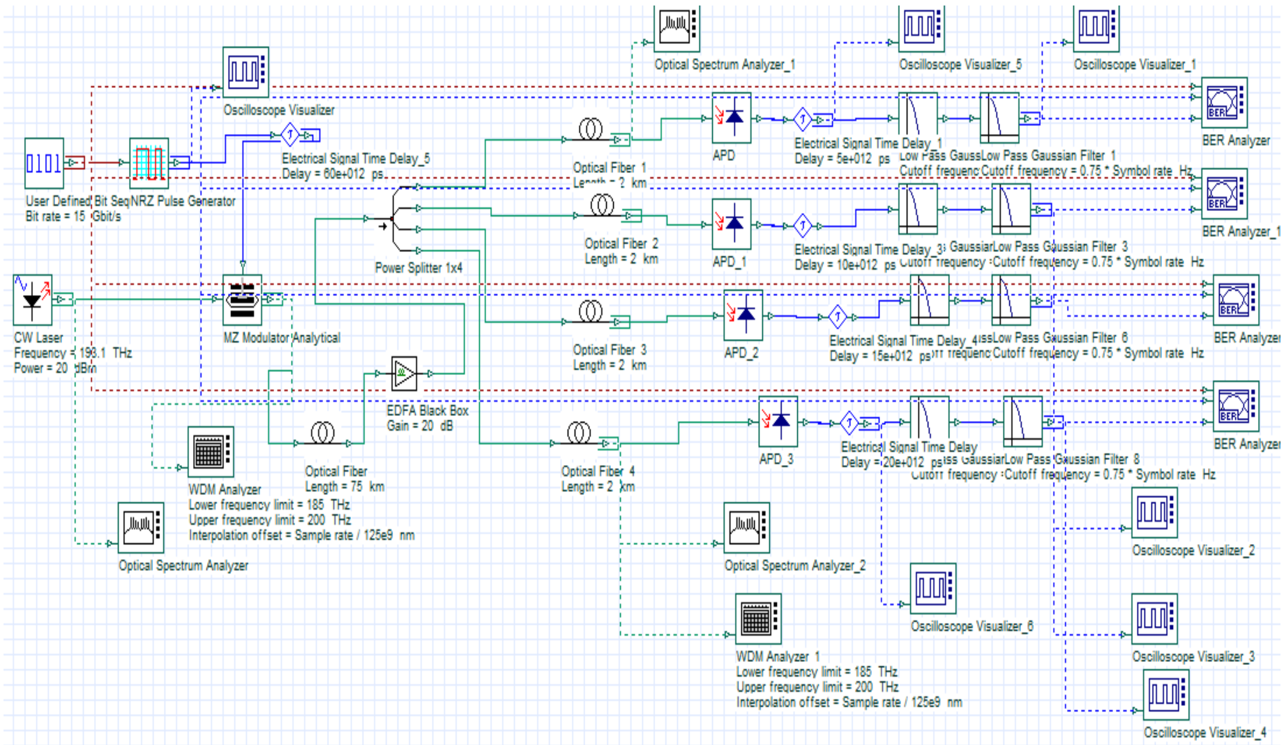
(b)



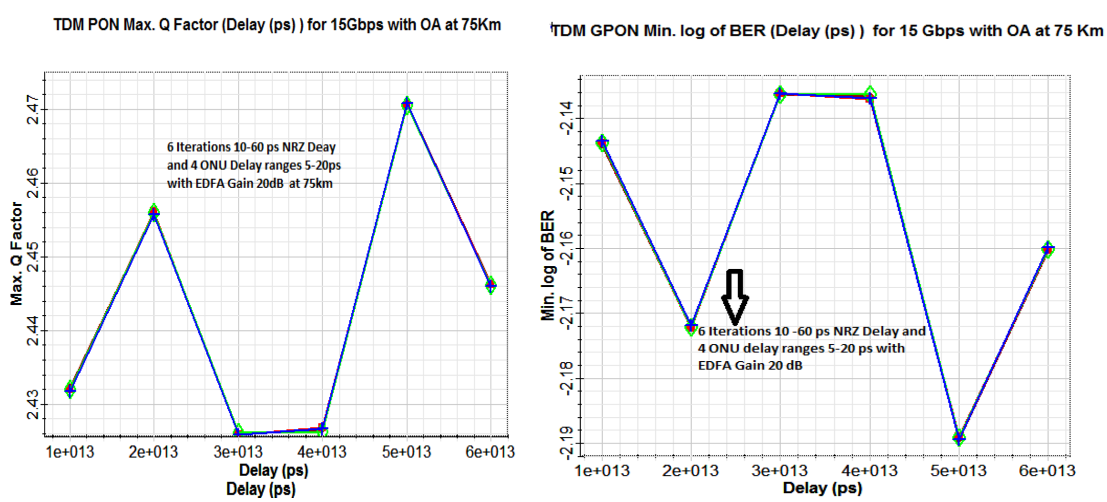
(c)

Figure 6.3.3 Experimental design of 2.5 Gbps 1 ×4 TDM GPON with Linear OA EDFA @ 120 Km (a) EDFA support fiber distance 120 Km for 2.5 Gbps (b) measured values of Q factor and Min.Log of BER for six iterative analysis - NRZ TDs 10ps – 60ps and 4 ONUs fixed TDs ranges 5ps, 10ps,15ps and 20ps. (c) 3D views of Min.Log BER with Eye pattern using BER Analyzer and input(OLT) and output (ONUs) measured values of OSP, ONP , SNR and OSNR using WDM analyzer for single channel 1552.52nm.

6.3.4 Experimental Analysis for the performance of 15 Gbps 1×4 TDM GPON with Linear OA EDFA @ 75 Km -TDs from 10ps to 60ps- Sweep Iterative Technique @ fixed Input OSP 20 dBm and EDFA Gain 20dB



(a)



(b)

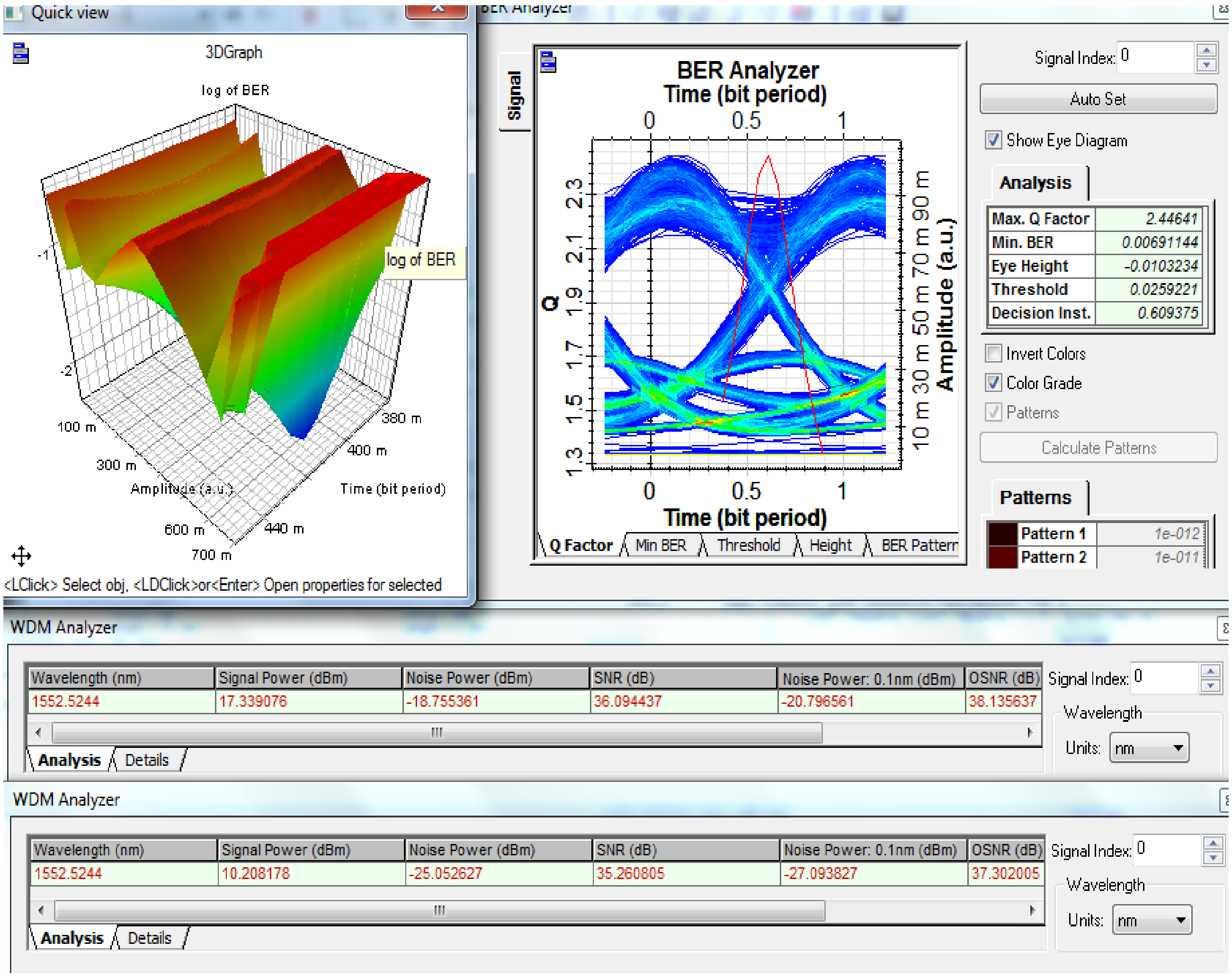


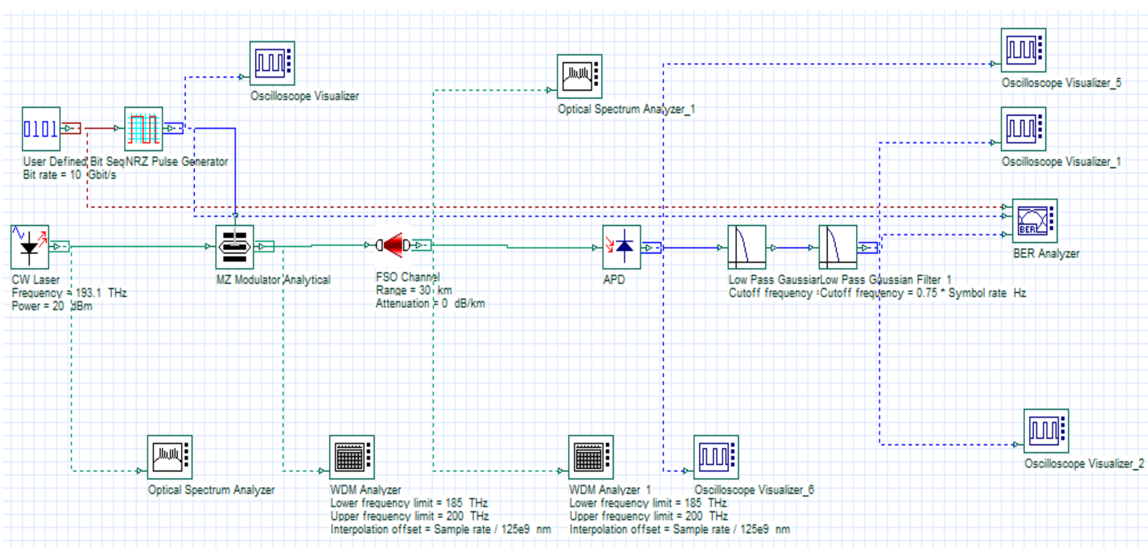
Figure 6.3.4 Experimental design of 15 Gbps 1 ×4 TDM GPON with Linear OA EDFA @ 75 Km (a) EDFA support for fiber distance 75 Km FOR 15 Gbps (b) measured values of Q factor and Min.Log of BER for six iterative analysis - NRZ TDs 10ps – 60ps and 4 ONUs fixed TDs ranges 5ps, 10ps,15ps and 20ps. (c) 3D views of Min.Log BER with Eye pattern using BER Analyzer and input(OLT) and output (ONUs) measured values of OSP, ONP , SNR and OSNR using WDM analyzer for single channel 1552.52nm.

From the all above experiments of TDM GPON, especially from experiment 6.3.4, even though the EDFA gain 20 to 40 dBm (default) has increased but the Q factor and Log of Min. BER is very poor at 20 Gbps transmission and do not support to transmit above 15 Gbps and fiber transmission distance is restricted maximum of 75 Km.

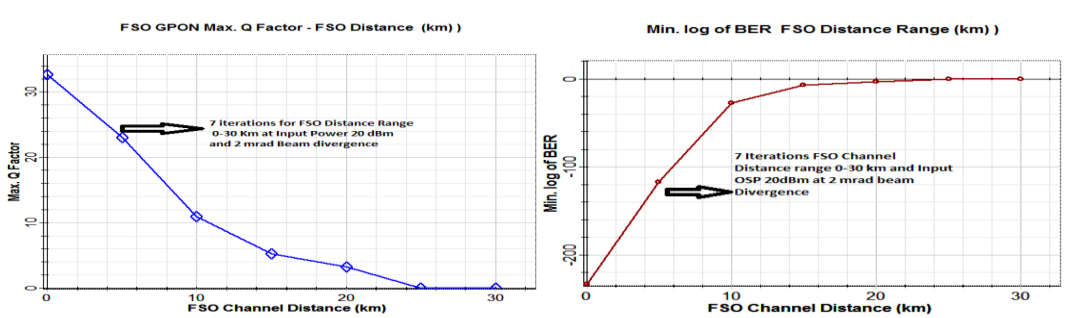
6.4 FSO GPON (Proposed) experiment / implementation and its results

The proposed research HBR / HLR FSO GPON architecture and its technology one of the new attempts for the ETC, Ethiopia and other telecommunication sectors benefits to upgrade as an alternative Optical Wireless -BAN (OW BAN) in near future. In this section, mainly concentrated fixed access of HBR / HLR 10Gbps, Input OSP 20 dBm as CW laser source power, beam divergence 2mrad of FSO-OWC links in the all experiments. Mainly the core parameter FSO-OWC channel distance ranges 0-30 Km and attenuation ranges 0-0.3 dB /Km have been chosen with seven iterative analyses and its performance study carried out with results. The results focused on the Q-Factor and Min.Log of BER as a bench mark to determine the suitability of this technology for ETC and other broadband service. The following sub-sections illustrates the design and experimental study of FSO GPON for many research issues on amplifications, attenuations and HBR capacity importance in short and long-haul transmission while choosing the FSO Link distance ranges 0-30Km as a model of FSO air distance assumption between Addis Ababa to Debrezeit.

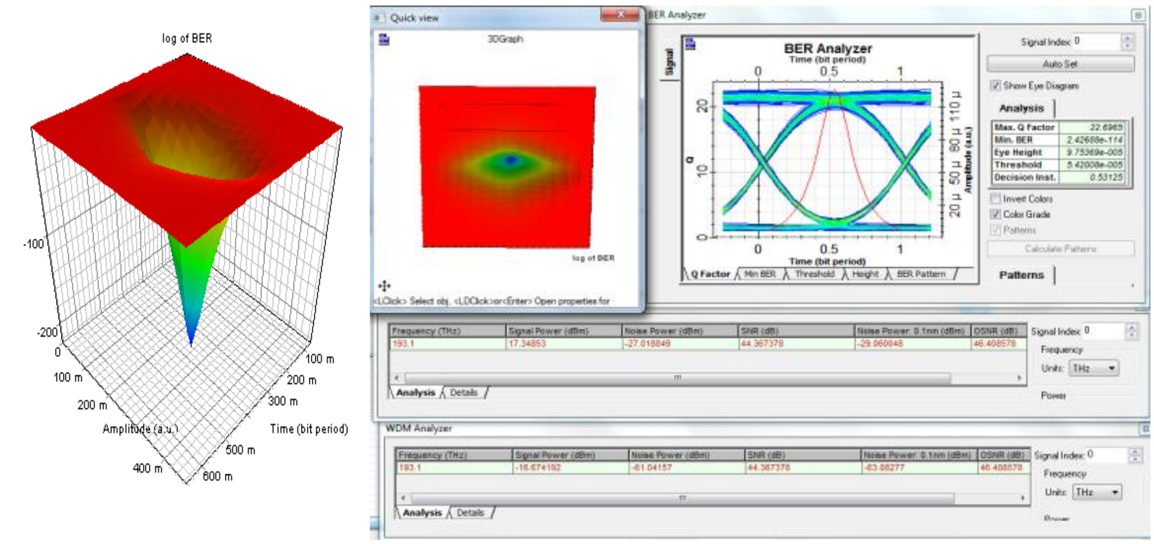
6.4.1 Experimental Analysis for the performance of 10 Gbps FSO GPON without OA – Fixed input Optical OSP 20 dBm @ beam divergence 2mrad



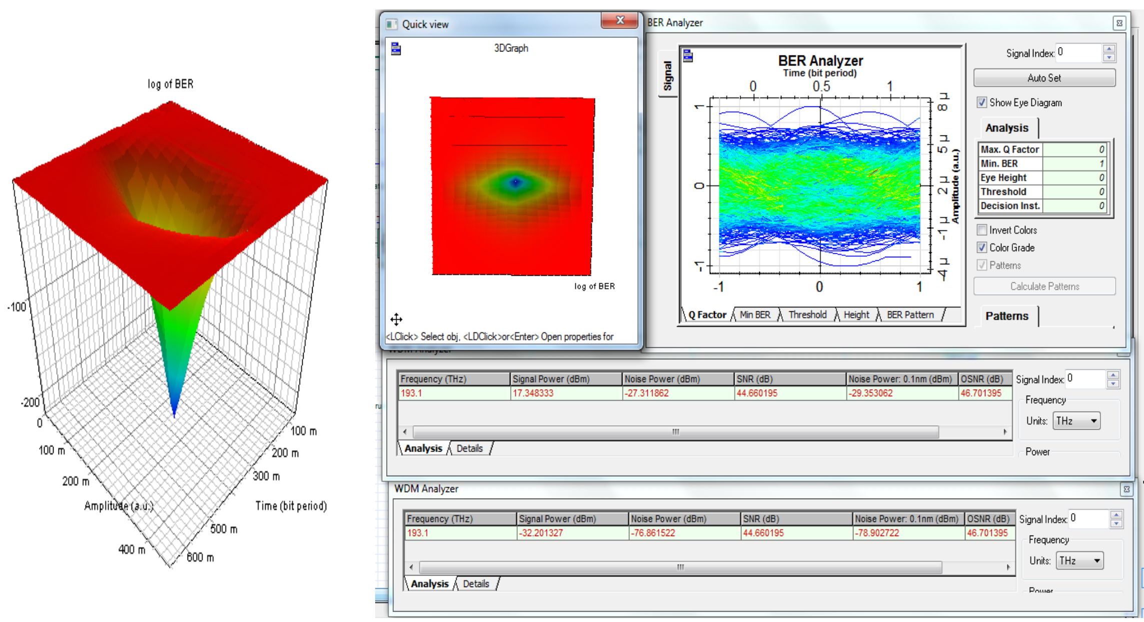
(a)



(b)



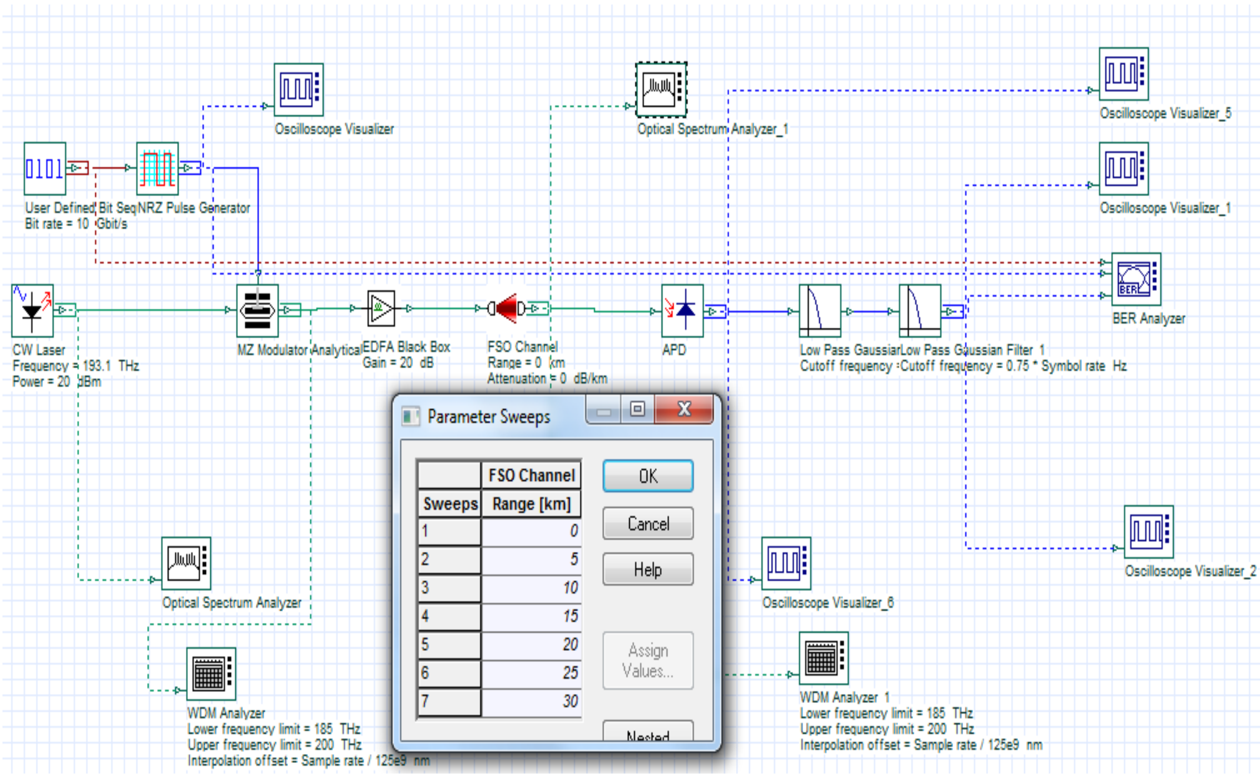
(c)



(d)

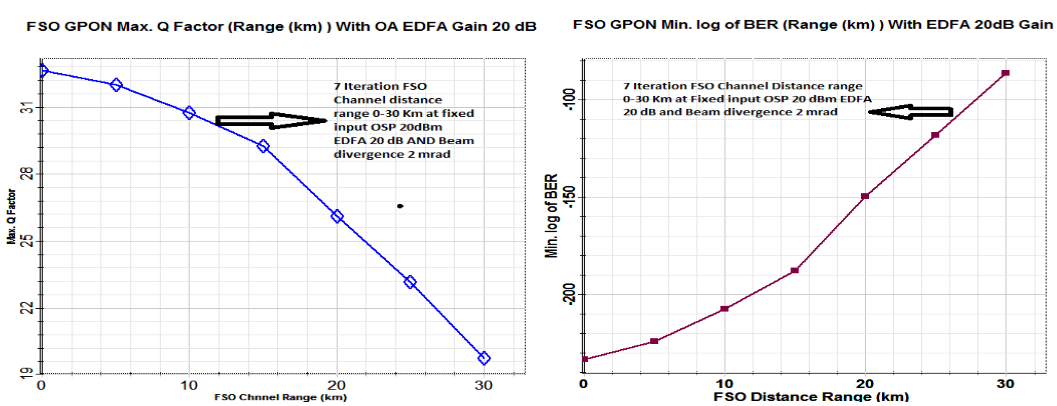
Figure 6.4.1 Experimental design of 10 Gbps FSO GPON without OA at 30Km (a) Implementation diagram with core parameter of FSO distance range 0-30 Km and attenuation 0dB /Km (b) measured values of Q factor and Min. Log of BER for seven iterative analysis- fixed beam divergence 2 mrad and Input OSP 20dBm (c) for iteration 2 at distance 5Km and (d) iteration at distance 30 Km . Also (c) and (d) are respective iteration 3D views of Min.Log BER with Eye pattern using BER Analyzer and measured values of OSP, ONP, SNR and OSNR using WDM analyzer for single channel 1552.52nm FSO GPON Link transmission.

6.4.2 Experimental Analysis for the performance of 10 Gbps FSO GPON with Linear OA EDFA- Fixed input Optical OSP 20 dBm @ beam divergence 2mrad – attenuation 0 dB /Km

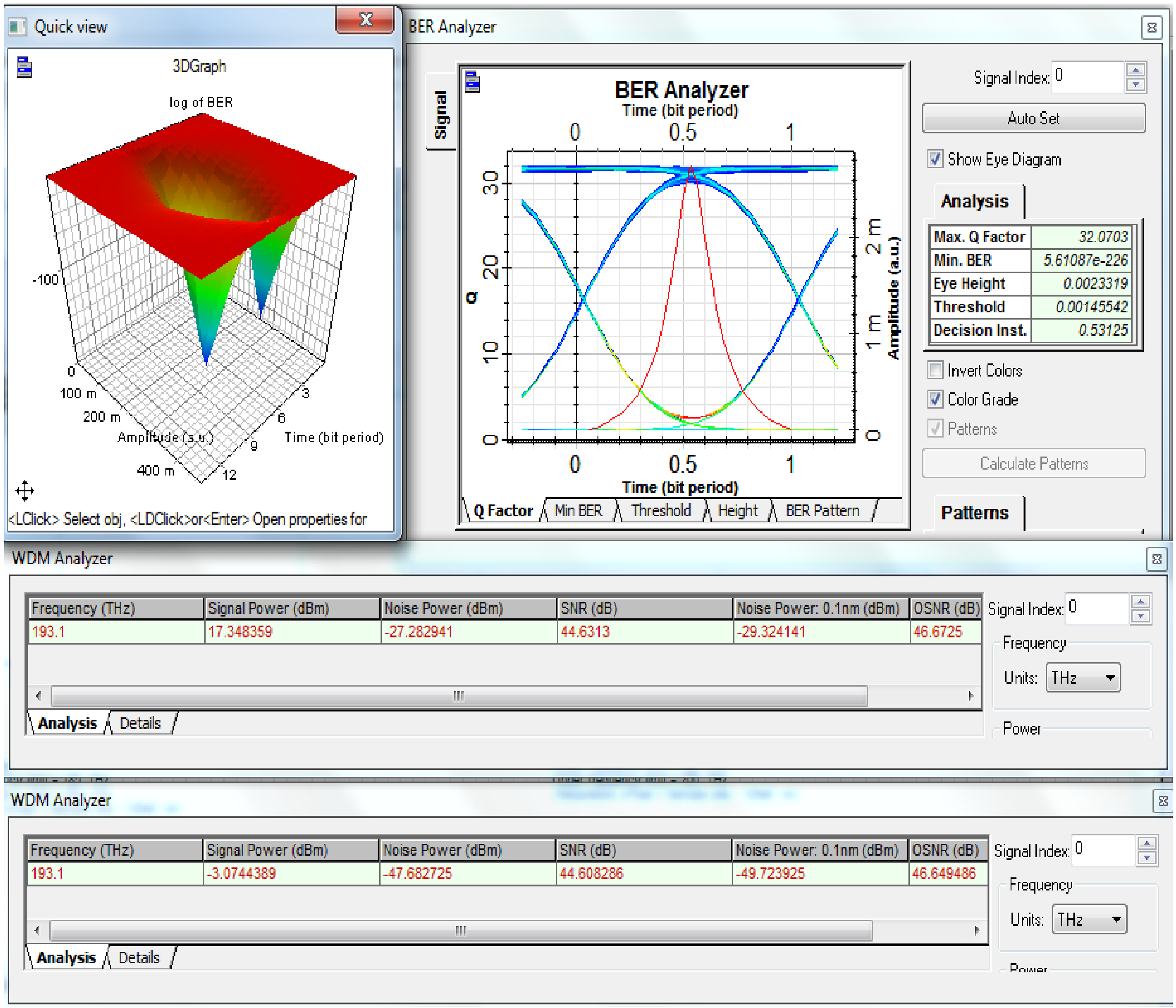


Sweeps	FSO Channel Range [km]
1	0
2	5
3	10
4	15
5	20
6	25
7	30

(a)



(b)

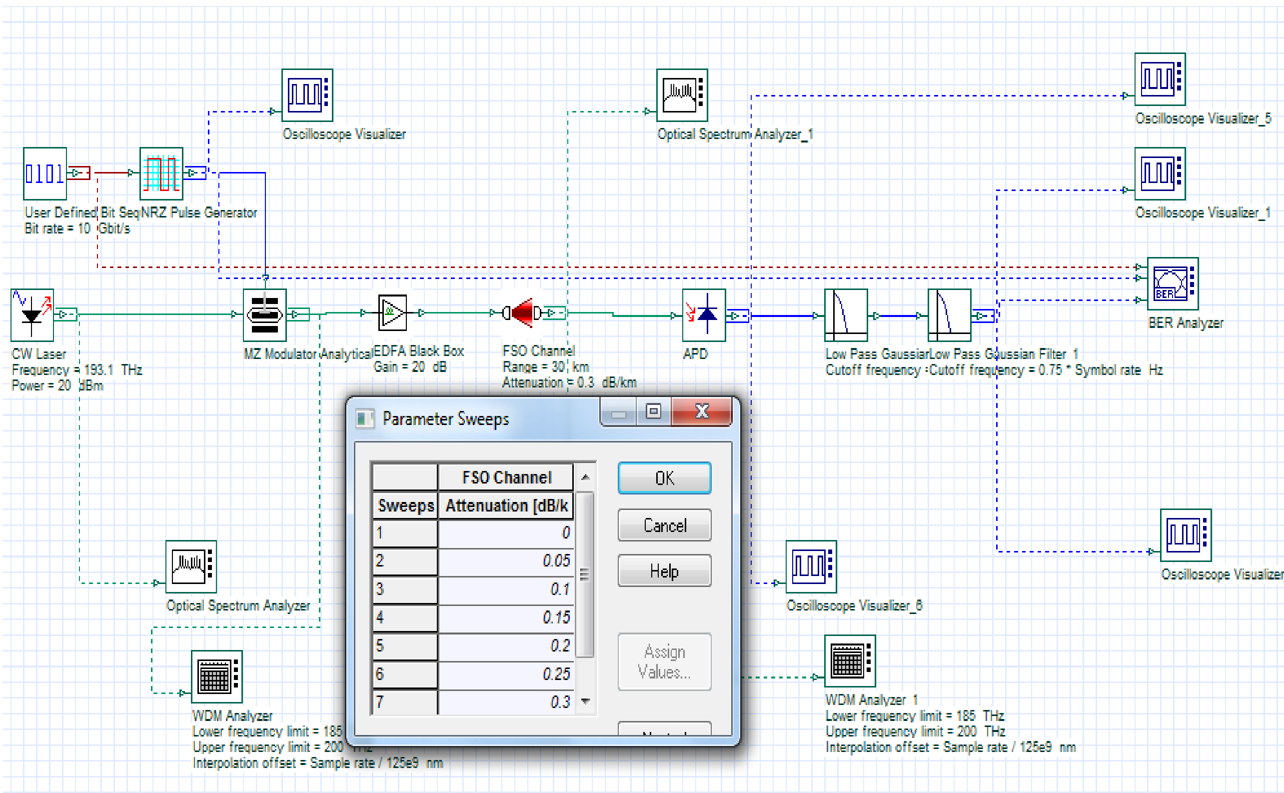


(C)

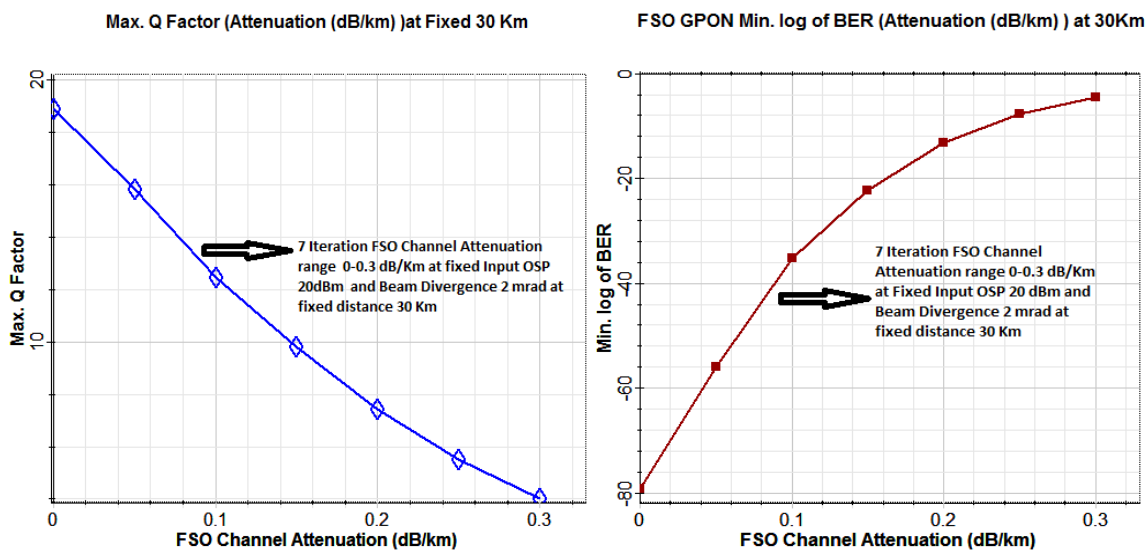
Figure 6.4.2 Experimental design of 10 Gbps FSO GPON with OA EDFA @ 30Km (a) Implementation diagram with core parameter of FSO distance range 0-30 Km and attenuation 0dBm /Km (b) measured values of Q factor and Min. Log of BER for seven iterative analysis-fixed beam divergence 2 mrad and Input OSP 20dBm (c) for iteration 2 at distance 5Km and (d) FOR iteration at distance 30 Km . (c) Iterative analysis for 2 and 3D views of Min.Log BER with Eye pattern using BER Analyzer and measured values of OSP, ONP, SNR and OSNR using WDM analyzer for single channel 1552.52nm FSO GPON Link transmission.

From the above experiments 6.4.2, after chosen EDFA 20 dB the Q-Factors and Log of Min.BER are improved at 0 dB / Km attenuation.

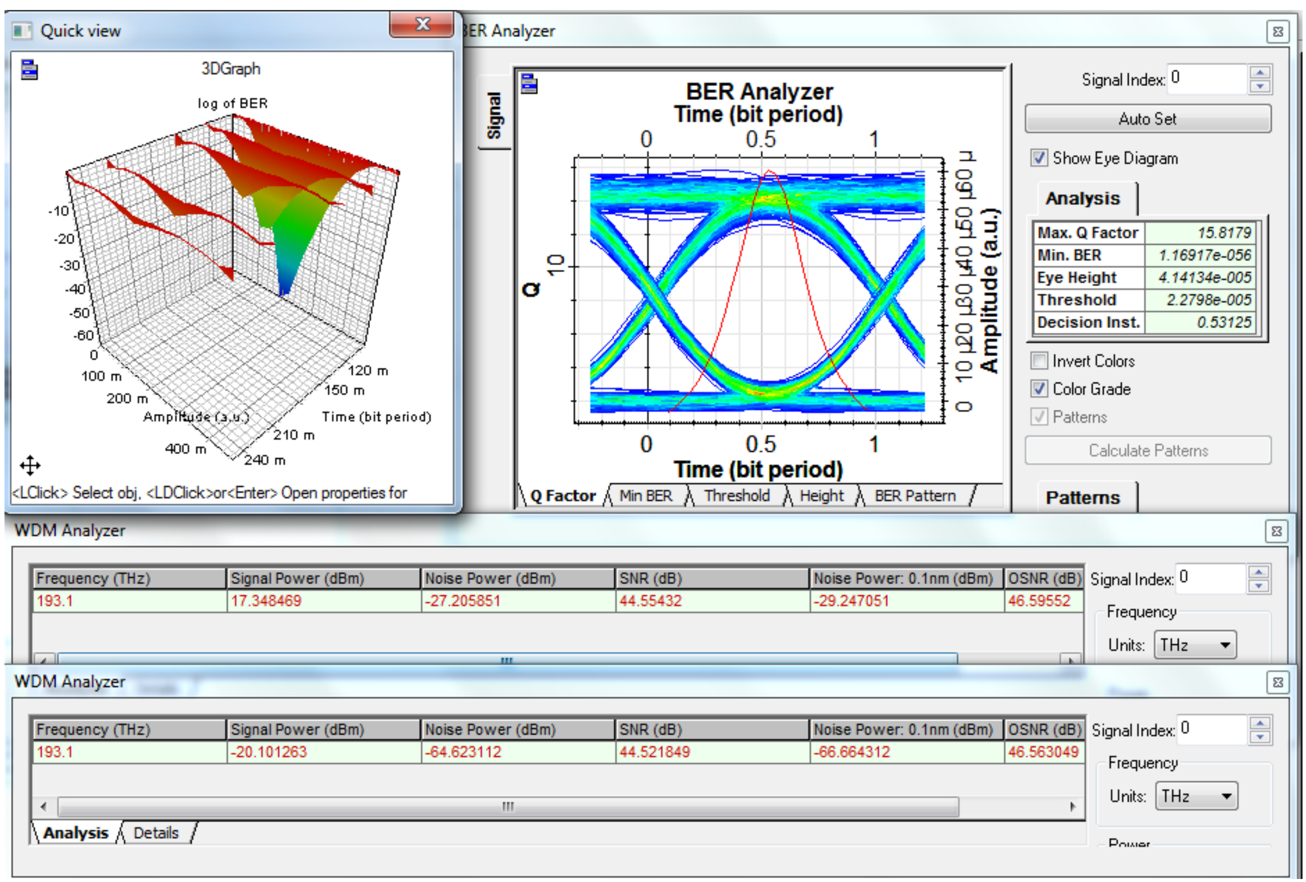
6.4.3 Experimental Analysis for the performance of 10 Gbps FSO GPON with Linear OA EDFA- Gain – Varied Attenuation 0- 0.3 dB / Km Fixed input Optical OSP 20 dBm - beam divergence 2mrad and FSO distance fixed 30Km



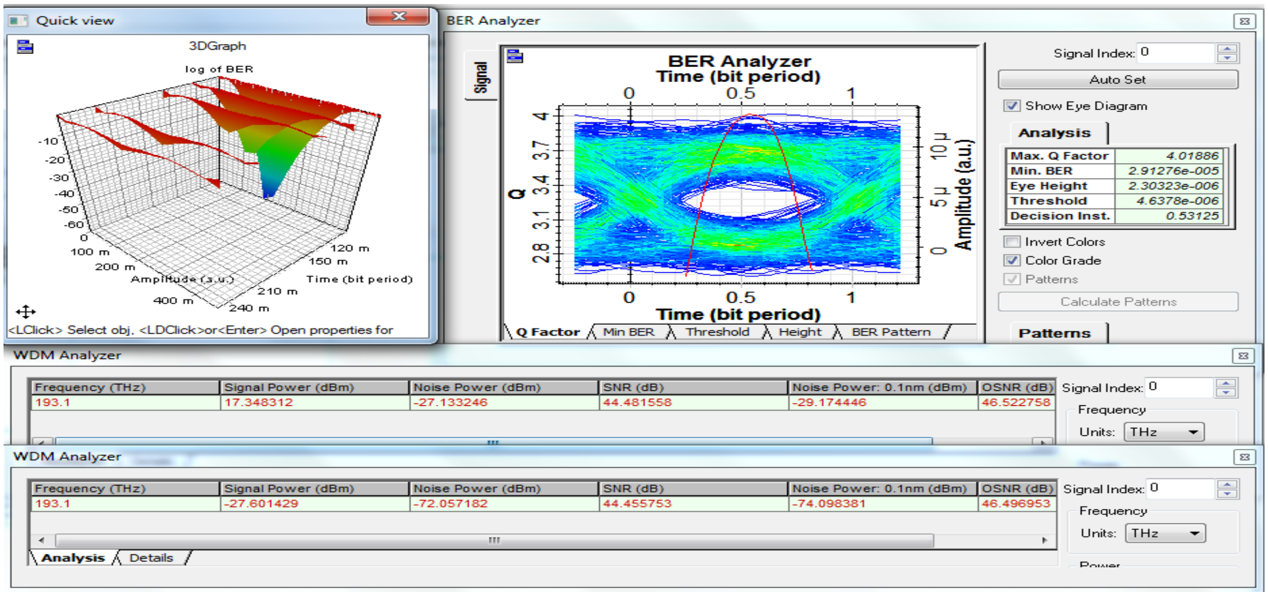
(a)


Max. Q Factor (Attenuation (dB/km))at Fixed 30 Km
Max. Q Factor
FSO Channel Attenuation (dB/km)
7 Iteration FSO Channel Attenuation range 0-0.3 dB/Km at fixed Input OSP 20dBm and Beam Divergence 2 mrad at fixed distance 30 Km
FSO GPON Min. log of BER (Attenuation (dB/km)) at 30Km
Min. log of BER
FSO Channel Attenuation (dB/km)
7 Iteration FSO Channel Attenuation range 0-0.3 dB/Km at Fixed Input OSP 20 dBm and Beam Divergence 2 mrad at fixed distance 30 Km

(b)


Quick view
3DGraph
log of BER
Amplitude (a.u.)
Time (bit period)
<LClick> Select obj. <LDClick>or<Enter> Open properties for
BER Analyzer
Time (bit period)
Amplitude (a.u.)
Signal Index: 0
Auto Set
Show Eye Diagram
Analysis
Max. Q Factor 15.8179
Min. BER 1.16917e-056
Eye Height 4.14134e-005
Threshold 2.2798e-005
Decision Inst. 0.53125
Invert Colors
Color Grade
Patterns
Calculate Patterns
Q Factor
Min BER
Threshold
Height
BER Pattern
WDM Analyzer
Frequency (THz) | Signal Power (dBm) | Noise Power (dBm) | SNR (dB) | Noise Power: 0.1nm (dBm) | OSNR (dB)
193.1 | 17.348469 | -27.205851 | 44.55432 | -29.247051 | 46.59552
WDM Analyzer
Frequency (THz) | Signal Power (dBm) | Noise Power (dBm) | SNR (dB) | Noise Power: 0.1nm (dBm) | OSNR (dB)
193.1 | -20.101263 | -64.623112 | 44.521849 | -66.664312 | 46.563049
Frequency
Units: THz
Analysis
Details

(c)



(d)

Figure 6.4.3 Experimental design of 10 Gbps FSO GPON OA for attenuation range 0-30 dB/Km (a) Implementation diagram with core parameter of fixed FSO distance 30 Km and attenuation range varied from 0-30 dB /Km (b) measured values of Q factor and Min. Log of BER for seven iterative analysis- fixed beam divergence 2 mrad and Input OSP 20dBm (c) for iteration 2 attenuation at 0.05 dB/Km and (d) for iteration 7 attenuation at 0.3 dB/Km . Also (c) and (d) are respective iteration 3D views of Min.Log BER with Eye pattern using BER Analyzer and measured values of OSP, ONP, SNR and OSNR using WDM analyzer for single channel 1552.52nm FSO GPON Link transmission.

7 Result Analysis and Discussions

Finally, as per methodology, all approaches from 1 to 4, we have been made simulation study for C-Band HBR transmission. The approach 1 and 2 have been analyzed with fixed / various input optical power range from 0 to 20 dBm for 2.5 to 20 Gbps HBR transmission at 16.75 ps/nm.km as fixed dispersion and 12.580 ps/nm.km as dispersion coefficient, and obtained better performance parameters results including OSNR achievements for C- band range TDM GPON and WDM / DWDM GPON. Based on approach 3 in methodology, various CD including nonlinear effects SPM, XPM and FWM have been taken for all simulations results and found out the performances of HBR C-band in the DWDM GPON architecture. From the approach 4 in methodology part, it has been simulated for linear FSO GPON transmission for C-band at maximum OWC distance 30 Km with HBR 10 Gbps as an alternative approach of fibreless transmission. From the previous sub-section simulation based experiments from 6.1 to 6.4, we have obtained many results for WDM /GPON, TDM GPON and FSO GPON. All the simulated experiments results have been analyzed comparatively and illustrated based on their performance parameters and diffent methodologies of fixed and varying input OSP, diffent range of distance minimum 120 Km and maximum of 240 Km for the HBR / HLR 10 to20 Gbps 1×4 WDM /DWDM GPON OF-BAN long haul transmission. Generally, any source input OSP with low power and getting good output OSNR range is a satisfied result (relatively better) for of any fiber transmission link power estimation. On the basis of this approach, the input OSP has been considered first as fixed input OSP 5dBm for all experiments from 6.2.1 to 6.2.9 and we obtained many critical results and acquired various transmission issues while choosing fixed low input OSP for WDM / DWDM GPON performance by the validation of results and measured values from Figure 6.2.1 to Figure 6.2.9. The result of Figure 6.2.1 has shown that the Max. Q -factor 5.7, Min.Log of BER 4.02e-009 and output OSNR ranges 94 to -65dB, whereas Figure 6.2.2 has result shown that Max.Q-factor 2.3, Min.Log of BER 0.0102 and output OSNR ranges 30 to 32 dB, for all four wavelengths in WDM / GPON as per forward pumping EDFA and Set up with DCF an FBG. We understood that the huge impacts and many transmission issue occurrences caused when extending the HBR from 10 Gbps to 20 Gbps at fiber distance 120 Km due to not only amplification, it depends upon the CD impacts and designing the Dispersion Compensation (DC) components performance.

Next, we made another attempt instead of 120 Km. We have extended the fiber distance analyses for 240 Km using EDFA. As per results from the Figure 6.2.3 illustrated that the Max.Q-Factor 2.36, Min.Log of BER 0.0086 and output OSNR ranges 8.0 to 9.2 dB for 10 Gbps and as per Figure 6.2.4 results, the obtained Max.Q-Factor 1.57, Min.Log of BER 0.05 and OSNR ranges was very low ranges 7.4 to 9.23 dB. Based on these two Figures 6.2.3 and 6.2.4 measured values and mainly BER analyzer eye opening results, the severe impacts of CD caused 20 Gbps architecture degradation compared with 10 Gbps transmission using EDFA at a distance 240 Km.

As a continuation of this research work that we replaced the linear OA EDFA and attempted experimental research study with non-linear OA Raman. The obtained results from Figure 6.2.5, the Max.Q-Factor 2.5, Min.Log of BER 0.0049 and output OSNR ranges 53 to 58 dB, whereas Figure 6.2.6, the Max.Q-Factor 0, Min.Log of BER 1 and OSNR ranges 52.7 to 57.2 dB for 10 Gbps transmission. These above two experiments 6.2.5 and 6.2.6 research report communicated very serious CD cautionary measures are necessary for OA Raman when transmitting HBR 20 Gbps compared with 10 Gbps even at 120 Km.

Based on all above experimental research study with all experiments from 6.2.1 to 6.2.6, we have perceived that certain limitations and delimitations of CD both in linear OA EDFA and non-linear OA Raman. Hence, we made a research study for combining both OA as Hybrid OA transmission set up and attempted a research study for same fixed input OSP 5dBm at minimum distance of 120Km. The experiments 6.2.7 and 6.2.8 for hybrid OA approach, we obtained good result through the response of Max.Q-Factor 5.5, Min.Log of BER range 1.35e-008 to 1.67e-008. Especially, the output OSNR ranges 48.7 to 54.2 dB at 120 Km and OSNR ranges 41.5 to 46.6 at 240 Km for HBR 10 Gbps long haul transmission as per Figure 6.2.7 and 6.2.8 results with eye opening pattern and make sure that the minimization of CD improves the long-haul performance.

Additionally, we extended the research study with experiment 6.2.9 for 10 Gbps to 20 Gbps at 240 Km (20 Gbps transmission at 240 Km) using hybrid OA. We found that the Max. Q-Factor 0, Min.Log of BER 1 and output OSNR ranges 41.09 to 46.71dB as per Figure 6.2.9 result. Hence, we have observed and obtained the inference from previous experiments 6.2.9 that we extended the CW laser source power from fixed input OSP from 5dBm variable (dynamic) range as per class 4 (0dBm to 27 dBm safety level of Laser source power as per ETC standard). Eventually, we made research study for link power estimation analysis (end-to-end analysis) with variable input OSP by sweep iterative method.

The experiment 6.2.10 and its obtained results as per Figure 6.2.10, illustrates the hybrid OA performance with sweep iterative ranges 0-25 dBm for 20 Gbps at 240 Km as maximum reach using WDM /DWDM GPON. The obtained results from Figure 6.2.10 have been completed / confirmed that suitability of expected / satisfied results and maximum CD suppressed for HBR 20 Gbps at input OSP 20dBm and 240 Km long haul fiber transmission using hybrid OA. Finally, in the WDM / DWDM GPON result discussion that we acquired the pin point issue of long-haul fiber transmission for maximum reach upgradation using hybrid OA performance at sweep value of input OSP 20 dBm. At the sweep of 20dBm for 20 Gbps at 240 Km fiber transmission, we obtained the measured values such as Max.Q-Factor 10.4, Min.Log of BER 1.01e-025 and OSNR range 39.3 to 59.9 dB for 20 Gbps at 240Km as better results compared with all previous experiments.

The various experiments of HBR TDM GPON result analysis have been discussed with the results of Figure 6.3.1 to 6.3.4 and highlighted the maximum capacity of HBR and maximum reach (fiber distance) of TDM GPON. As a result, compared the HBR minimum 2.5 Gbps to maximum 20 Gbps for different fiber distance ranges 50 Km, 75 Km up to 120 Km at fixed fiber dispersion value 16.78 dB/km/nm. All the experiments implemented with two considerations in the TDM GPON architecture deign assumption. First consideration is without Linear OA EDFA and second is with Linear OA EDFA gain 20 dBm. The Time Delay (TD) has been introduced at NRZ signal in the range minimum 10ps and maximum 60ps. Totally, we have attempted six iterations and every iteration difference with 10ps. Similarly, four ONUs very small TDs have been introduced from 5ps to 20ps and every ONU TD is 5ps. In overall, in this TDM GPON architecture total end to end, the TDs have been assumed 20ps to 80ps for fours ONUs and implemented with TDs based sweep iterative analysis. Apart from other results 6.3.1 to 6.3.3 advantages and disadvantages, the experiment 6.3.4 has been supported for justification and validation of HBR capacity and maximum reach of TDM GPON. As per the result from 6.3.4 in specific that we obtained Max. Q-Factor 2.44, Min.Log of BER 0.0069 and output OSNR 37.30dB at 50ps sweep iteration 5. The TDM GPON results from 6.3.4 suggested that the maximum fiber transmission reach through 75Km for 15 Gbps.

Finally, the proposed FSO GPON architecture has been chosen mainly with the transmission design of FSO -OWC link. All the experiments from 6.4.1 to 6.4.3 of FSO GPON have been considered with core performance parameters FSO channel link distance, beam divergence and FSO channel attenuation. In the FSO GPON, we have chosen the FSO link ranges 0-30 Km, beam divergence 2mrad (fixed) and FSO channel attenuation 0 dB as normal condition and varying attenuation 0 to 3 dB as FSO channel atmospheric interference conditions (abnormal conditions). The atmospheric interference occurrence due to many ecological and other climate conditions like heavy rain, high temperature, fog, snow and storm etc., We have implemented the experiments from 6.4.1 to 6.4.3 and found out various measures as per resulted Figures from 6.4.1 to 6.4.3. The critical validation is that compared with FSO Link in normal condition, the abnormal conditions have serious impacts in the signal transmission due to the variations of channel attenuation. As a best critical experiment study from 6.3.4, we have attempted seven sweep iterations from 0 to 0.3 dB/Km (chosen as a difference of 0.5 dB/Km for every iteration). The Input OSP from CW laser sources as fixed 20dBm and also FSO channel Link distance fixed 30Km.

In the experiment 6.4.3, the iteration 2 at 0.05 dB /Km has given much better expected results than iteration 7 at 0.3 dB / Km results for fixed FSO OWC link distance 30Km and HBR at 10 Gbps. The iteration 2 has obtained the measured values of Max. Q-Factor 15.81, Min.Log BER 1.161e-056 and output OSNR 46.56 dB, whereas iteration 7, obtained the low measured values of Max.Q-Factor 4.01, Min.Log of BER 2.91e-005 and OSNR 46.56 dB. The interesting issue has been observed that both iterations 2 and 7, the OSNR values almost same 46.5 dB. Hence, it has been keenly observed that the additive noise (SNR) values are increased due to the variation of attenuation in the abnormal climatic conditions in the FSO GPON optical wireless (OW) – BAN. In overall comparison, TDM GPON method is the best for short fiber distance 50 to 75 Km for 15 to 20 Gbps under the TD of 5 to 20 ps. DWDM GPON method is the best for long haul fiber transmission up to 240 Km with both OAs such as linear EDFA and Non-linear Raman amplifiers for 20 Gbps at maximum input optical power 20 dBm. Compare with fiber channel based GPON methods, FSO GPON OWC (fibreless) method is the best for short distance maximum of 30 Km for above 10 Gbps transmission without interference and it is an alternative fibreless method for short distance HBR transmission. In overall comparison of all the GPON model needs and depends on the transmitter power (input optical power) when raise the long-haul transmission distance. In the same way, all the methods are having their own few disadvantages due to various issues of performance parameters like variations of dispersion, GVD, PMD, dispersion slope in DWDM GPON, beam divergence, attenuation and other interferences in FSO GPON transmission.

8 Conclusion and Recommendations

We conclude with few suggestions in overall to OWW-BAN access smooth HBR transmission though many fiber topological configurations available in ETC. The various non-linear effects SPM, XPM and FWM in CD are the most critical degrading performances both deterministic (discrete) and stochastic (indeterministic / probabilistic) conditions for any HBR long haul transmission. The CD occurrence not only one type of dispersions, it depends upon various properties of fiber dispersion mechanism such as PMD, GVD, WD and coefficients of other inter and intra- dispersion modulation issues. The remedies for minimization of fiber CD effects depend on the designing of suitable linear / non-linear OAs and DC performance and well-prearranged link power design set up with DCF and FBG. The fiber DC depends on the design and analytical calculation of D_{DCF} and S_{DCF} and coefficient analytical calculations.

In this research project the experiment for WDM /DWDM PON has suggested and concluded from the experiment 6.2.10 that the maximum minimized HBR 20 Gbps with fiber maximum reach for 240 Km and minimized CD occurrence by improve of Q-Factor and Min-Log of BER and OSNR using hybrid amplifier. The research project experiment 6.2.10 as a fiber transmission model to support for HBR 10 – 20 Gbps WDM / DWDM GPON using hybrid OAs at input OSP 20 dBm have in smooth operation and it can be recommended as first for the Addis Ababa to Dejen (or reverse route) fiber optic transmission line still with few deep practical and equipment testing analyses to minimize CD occurrences. In specific, the 4 x 4 WDM / DWDM GPON architectures are supporting maximum of 5, 20, 40 and 80 Gbps since each channel of 4x4 WDM / DWDM considered to transport high bandwidth with 1.25, 5, 10 and 20 Gbps.

Once the CD can be minimized by N cascade stage (N= minimum 2, 3,…up to N+1) of hybrid OAs, even it can be recommended and possible to implement DBA scheme to every end user to access HBR 10 Gbps to 20 Gbps without any interference in secured way from Addis Ababa to Bahir Dar fiber route maximum distance 520 Km(from urban-semi urban up to rural). But link power budget and power margin experiment analyses are an essential part before implement the cascade stages OAs. Suppose, the fiber transmission distance below 80 Km and even up to 120 Km fiber transmission route in

Ethiopia, we suggest and recommend the HBR 10 Gbps WDM / DWDM PON as per the research experiment 6.2.7 by optimizing, scaling and increasing the input OSP 5 dBm in optimum way as another recommendation. Ultimately, we suggest and conclude the controlling of CD in WDM / DWDM GPON architecture performance as an important note. It depends on optimizing and estimating every channel optical pulse modulating / transmitting power and energy level by choosing efficient channel spacing of WDM / DWDM channels during HBR long-haul transmission.

Similarly, as in the TDM GPON architecture that we suggest the TDs are more constraint parameter since TDM GPON based on Time -Slot or Time Delay (TS or TD) and also synchronization of source signal or frame format process is important from OLT to ONU. On the basis of proposed works, we suggest the research experiment 6.3.4 for maximum HBR 15 Gbps at 75Km by scaling and optimizing the EDFA gain 20 dB and OSNR 37.30 dB. The research experiment 6.3.4 has suggested and recommend for present and future ETC FTTH applications of Ethiopia, the bandwidth consumers. They can avail maximum DBA 10 Gbps and below up to the range 2.5 Gbps through fiber link distance 75 Km at 50ps NRZ encoding format signal transmission.

Apart from the fiber transmission, as a replacement upcoming BAN technology FSO GPON scheme has many avenues to solve the indoor and outdoor transmission in ETC and other broadband end user access. Most of the rural to urban including Addis Ababa in Ethiopia are severely affected with poor telecommunication signal reception due to abnormal climate conditions in certain periods even day time and up to the months in a year. The research project experiment 6.4.3 has suggested suitable for abnormal climate conditions to access HBR using FSO GPON to the FSO -OWC channel attenuation 0 to 3 dB /km with input OSP 20dBm using EDFA gain 20 dB at fixed distance 30 Km and beam divergence 2mrad. The proposed FSO GPON architecture model and its resulted output can be recommended to implement from Addis Ababa to Debrezeit (Bishaftu) to access maximum of HPR 10 Gbps every end user by optimizing the attention and beam divergence effect during abnormal climate conditions at a distance of 30Km.

In short, this research can be studied in further to solve various issues of CD compensation techniques in non-linear WDM / DWDM GPON long haul fiber routed transmission with different modulators performances for L-Band and compare with C-band. It helps still more to bring the SOF system for smooth operation as well as to upgrade the HBR performance for future needs of ETC. Next, we have to proceed the research experiment study in deep to minimizing ps TD issues in TDM GPON for above 10 Gbps and 75 Km. Finally, expanding the FSO GPON various topologies structural design, FSO channel link distance performance beyond 30 Km at abnormal climate conditions should be for further study for the ETC alternative solution towards cost trade-off and other industrial broadband telecommunication service provider applications in Ethiopia. In this research work we have chosen mainly the NRZ modulation signal format since the study has generally begun with analyses of bandwidth / HBR capacity performance. The CSRZ, DPSK and Duobinary modulation signal formats still support more on high capacity and data rate, power spectral consumption and long-distance optical transmission system with cost effective capability. These comparative modulation signal formats study will be carried as further study in future.

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Approval of Investigators

We hereby declare that the research report entitled

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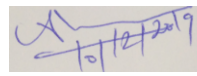
is our original work; all sources are duly acknowledged and the report is compiled by incorporating the necessary comments and suggestions given by the reviewers.

	Name	Signature	Date
Principal Investigator	Mr Anteneh Assefa		
Co- Investigator	Dr Sultan Feisso		
Co- Investigator	Dr Pushparaghavan Annamalai		

Approval of Reviewers

I hereby confirm that (PI)Dr./Mr. __________________________________has accomplished his/her work as per the approved proposal and incorporated all the comments given by the reviewers in his/her terminal report of the project entitled _________ _________________ and hence the report qualifies for submission as standard research output.

	Name	**Signature**	**Date**
Reviewer 1.	________________________________	__________	_________________
Reviewer 2.	________________________________	__________	_________________

Approval: **School Ethical Review Board (School Scientific Committee)**

Name	Signature	Date
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