Nanyang Technological University

School of Electrical and Electronic Engineering

IE4120 Design Case Study 1

Optical Communication System Design using OptiSystem

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1 Introduction

The purpose of this design case study is to understand the fundamental operation, performance limits, and design trade-offs of optical fiber communication systems using *OptiSystem 14*. The experiment introduces students to the complete workflow of optical system simulation, including transmitter configuration, fiber transmission modeling, and receiver analysis.

Through the simulation of both a basic fiber-optic link and a multi-channel wavelength-division-multiplexed passive optical network (WDM-PON), the objectives are:

- To get familiar with the OptiSystem simulation environment
- To learn the properties of various optical and optoelectronic devices
- To learn the basic principles and limiting factors in desiging a simple fiber system
- To analyze the system transmission performance through simulation results

Fiber-optic systems form the backbone of modern telecommunication infrastructure due to their high bandwidth, low loss, and immunity to electromagnetic interference. Understanding their design principles through simulation provides insight into real-world challenges such as dispersion, power budgeting, and wavelength crosstalk. This study, therefore, not only strengthens conceptual understanding of optical link theory but also develops practical design skills necessary for next-generation access networks such as WDM-PON

2 Simple Fiber-Optic Communication System

2.1 System Overview

A baisc 10 Gb/s fiber-optic link was designed to study transmission distance and link loss affect optic signal integrity. And the system layout will be like:

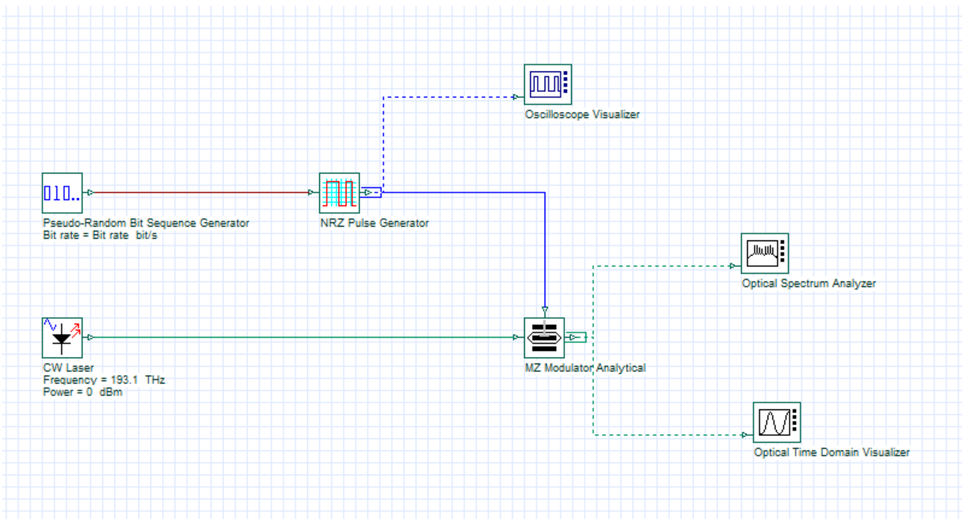
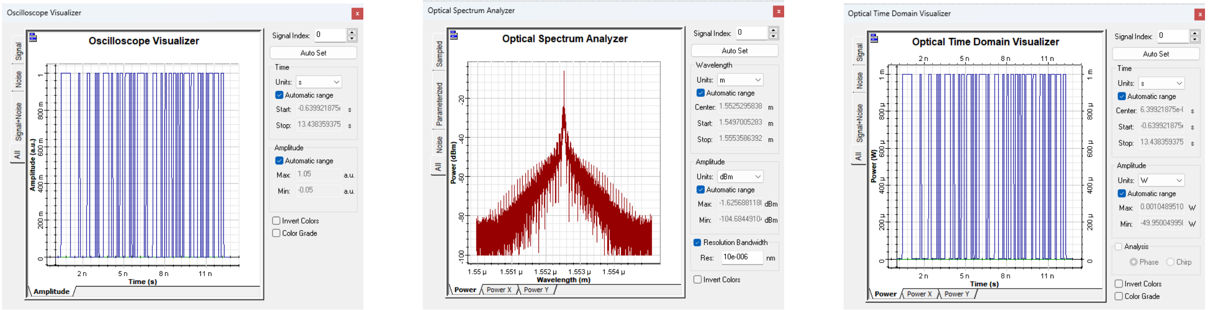


Figure 1: Schematic of an External-Modulated Optical Transmitter

The NRZ Pulse Generator refers to the global parameter Sample rate using script mode by default. The Pseudo-Random Bit Sequence Generator refers to the global parameter Bit rate using script mode by default.

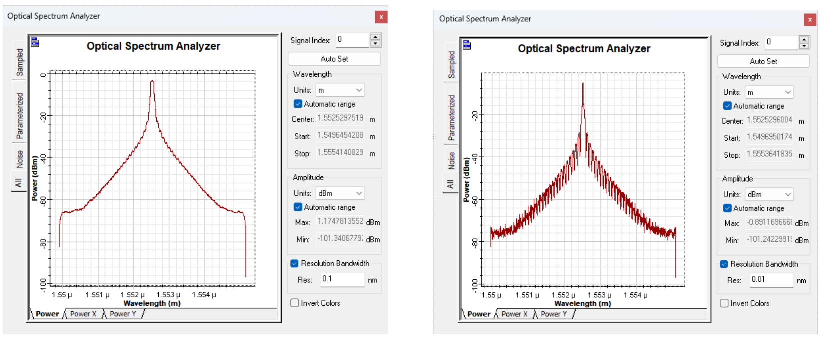
Now I run the whole simulation and view the results from visulizers:



(a) Oscilloscope (b) OSA (c) Time Domain visulizers

Figure 2: visulizers reuslts

Now, I will adjust OSA Resolution Bandwidth from 0.01nm to 0.1nm and this is the how spectrum changes:



(a) $0.1nm$ (b) $0.01nm$

Figure 3: OSA with 0.1 and 0.01 BWR

The optical spectra obtained from the Optical Spectrum Analyzer (OSA) at different resolution bandwidths (RBW) demonstrate the trade-off between spectral resolution and signal smoothness.

When the RBW is set to 0.1m, he measured spectrum exhibits a smooth envelope with a higher apparent peak power ($\approx +1.17$ dBm), as the analyzer integrates a broader range of frequency components within each measurement bin. This results in effective averaging of the signal and noise, thereby reducing the visible noise level but compromising the ability to resolve fine spectral details.

In contrast, when the RBW is reduced to 0.01 nm, the OSA captures the signal with finer wavelength discrimination, revealing sharper spectral features and increased noise fluctuations.The apparent peak power decreases (≈ -0.89 dBm) because the narrower bandwidth collects less optical power per resolution element.

3 A complete Simple transmission system

3.1 System Overview

A full end-to-end 10 Gb/s link was assembled by adding receiver, filtering, power monitoring, and BER evaluation blocks to the transmitter and fiber channel. And the system layout is:

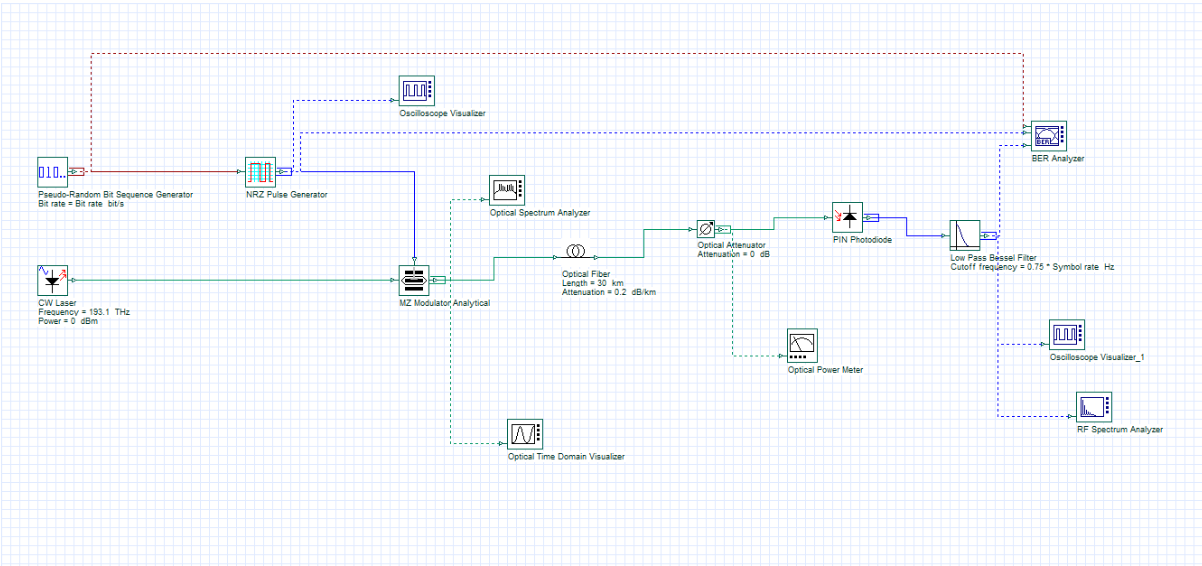
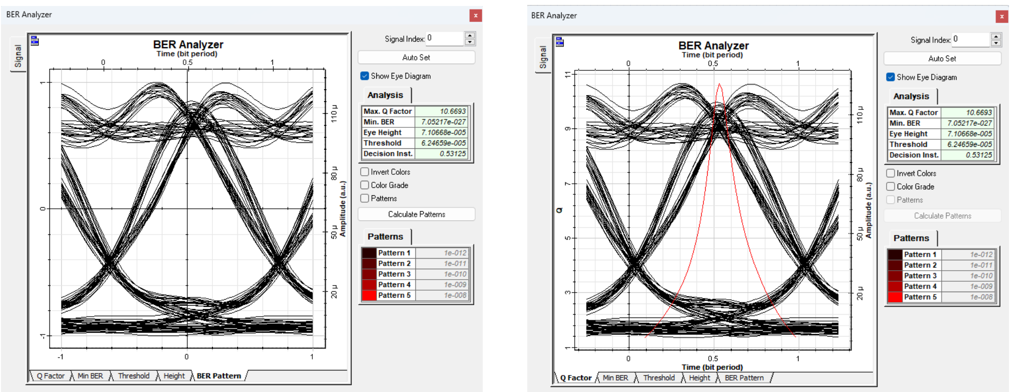


Figure 4: Schematic of a Simple Fiber-Optic Communication System

From the layout we could see that the componenets are: Optical fiber, optical attunator as the passive and channels; PIN photodiode, Low-pass Bessel Filter as the receiver; Oscilloscipe, RF spectrum, BER as electrical visulizers and opticla power meter as optical visulizer. At the beginning, the fiber length is set to 50km with no power and no attunation, and for attunator has 0 dB.

As always, the bit rate is set to 10 Gb/s, and the Sequence length is set to 128 as well as smaples per bit is 64. And I will run the simulation and view the results from visulizers:



(a) 50km fiber with BER analyzer (b) 50km fiber with Q-factor

Figure 5: BER results with 50km Fiber

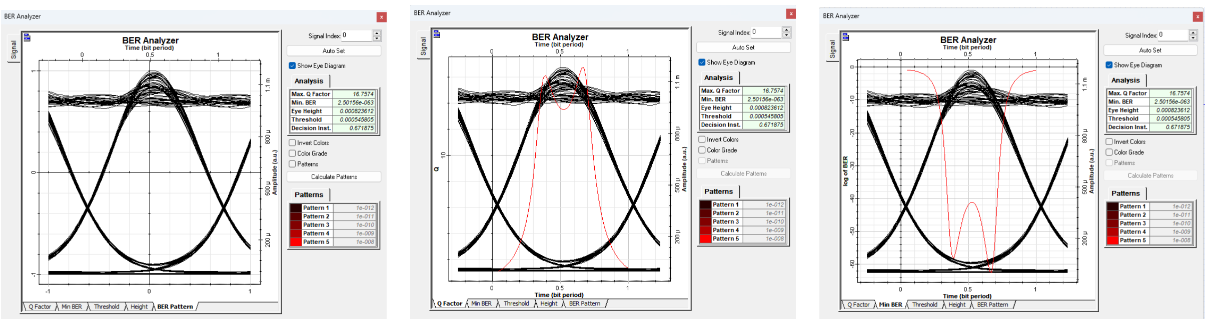
From the BER analyze box, there are 5 values displayed: Q factor, Eye Height, Minimum BER, Threshold and Decision Instant at the Max Q-factor/Min BER, the parameter **Minimum BER** is a crucial parameter which is to evaluate the system tranmussion performance and in telecommunication transmissionm, The BER is the percentage of bits that have error relatiive to the totalnumber of bits received in transmission.

Thus, from 50km fiber with no attunation and power, the the maximum Q-factor is 10.6693, the minimum BER is 7.05217×10^{-27}, the eye height is 7.10668×10^{-5} (a.u.), the threshold is 6.24659×10^{-5} (a.u.).The obtained results indicate excellent signal performance. A high Q-factor of 10.6693 corresponds to an extremely low bit error rate of 7.05217×10^{-27}, implying nearly error-free transmission. The clear eye opening with an eye height of 7.10668×10^{-5} (a.u.) confirms low noise and intersymbol interference. The threshold of 6.24659×10^{-5} (a.u.) and decision instant of 0.53125 (bit period) show that the receiver sampling point is optimally aligned at the center of the bit period, ensuring reliable signal detection.

Now, I will explore how the effect of fiber length and link loss to this tranmission system:

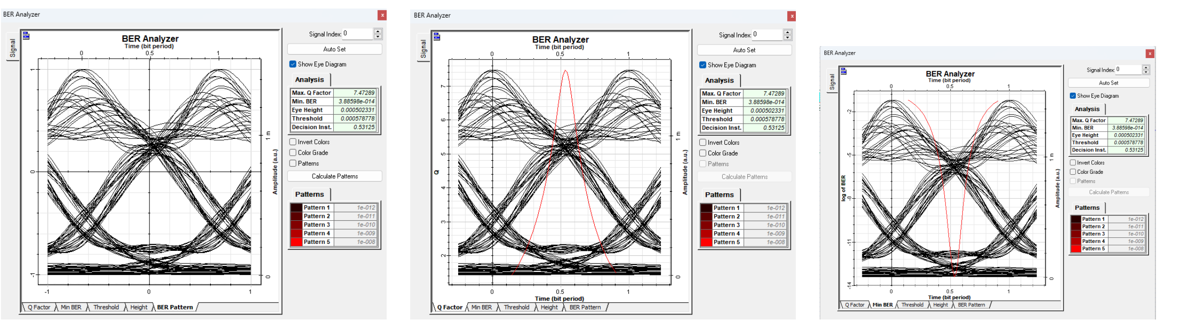
3.1.1 Effect of the Fiber Length

Keep the attenuation of the fiber be to 0 db per km and I will set fiber length to 20km and 80km respectively to observe what happen to the eye-diagram and the BER



(a) BER Pattern (b) Q-Factor Distribution (c) Minimum BER Curve

Figure 6: BER analyzer results: Eye diagram, Q-factor, BER in 20km



(a) BER Pattern (b) Q-Factor Distribution (c) Minimum BER Curve

Figure 7: BER analyzer results: Eye diagram, Q-factor, BER variation in 80km.

Comparing those two groups with the original length of 50km, when the length of fiber increases from 20 to 80, the eye diagram becomes narrower and less open, indicating greater intersymbol interference, amplitude distortion and timing jitter. Quantiatively, only observing the 20km and 80km transmission system, the Q-factir decreases from 16.7574 to 7.47289, while the minimum BER deterorates from 2.50156×10^{-63} to 3.88598×10^{-14}. The eye height also drops from 8.23612×10^{-4} to 5.02337×10^{-4} (a.u.), it shows that a smaller decision margin and a lower optical signal-to-noise ratio.

These degenrations occur mainly due to the chromatic dispersion considering the fiber attunation is diabled (set to 0 as the question required), chromatic dispersion causes wavelength components of each optical pulsess to travel at different groupl velocities, thus, over a long distances, this leads to pulse spreading and overlap between adjacent bits, closing the eye amd reducing decision margin would be inevitable.

As for the potential solutions to extend the tranmission length meanwhile alleviate the signal degenrations, by applying dispersion management, pre-chirp compensation and DSP-based equalization, the transmission distance could be extended while maintaiing low BER and good eye quality.

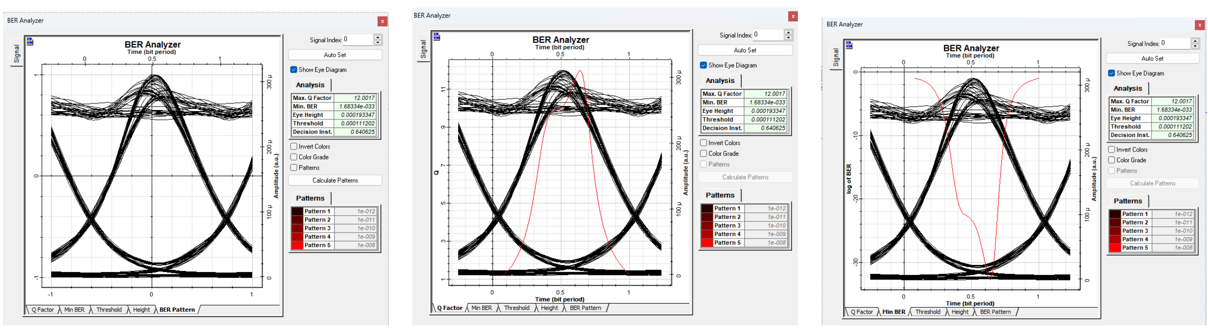
Meanwhile, A table contains the 5 values in BER box with 20km, 50km and 80km fiber lengths could be better understaing the changes of eye diagram:

Table 1: Comparison of BER Analyzer Results at Different Fiber Lengths

Parameter	**20 km Fiber**	**50 km Fiber**	**80 km Fiber**
Max. Q Factor	16.7574	10.6693	7.47289
Min. BER	2.50156×10^{-63}	7.05217×10^{-27}	3.88598×10^{-14}
Eye Height (a.u.)	8.23612×10^{-4}	7.10668×10^{-5}	5.02337×10^{-4}
Threshold (a.u.)	4.54805×10^{-4}	6.24659×10^{-5}	5.78778×10^{-4}
Decision Instant (bit period)	0.671875	0.53125	0.53125

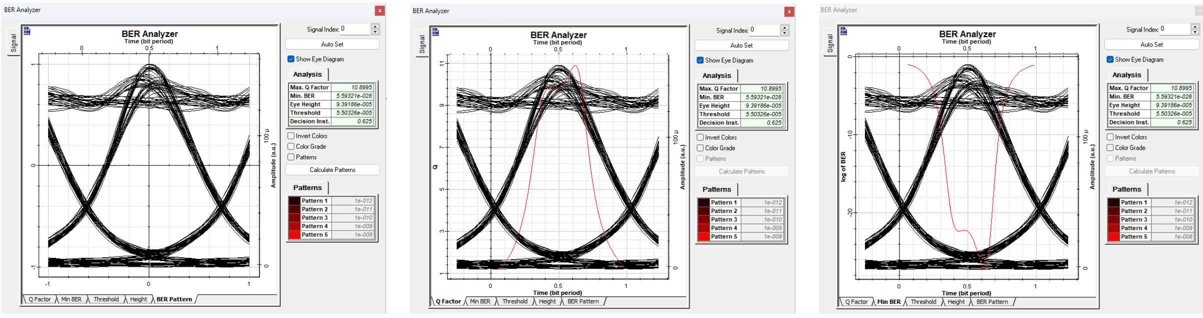
3.1.2 Effect of the Link Loss

Keep the length and attunation of optical fiber as 30km and 0.2db/km. And I will set optical attunator to 0dB, 3dB and 6dB.



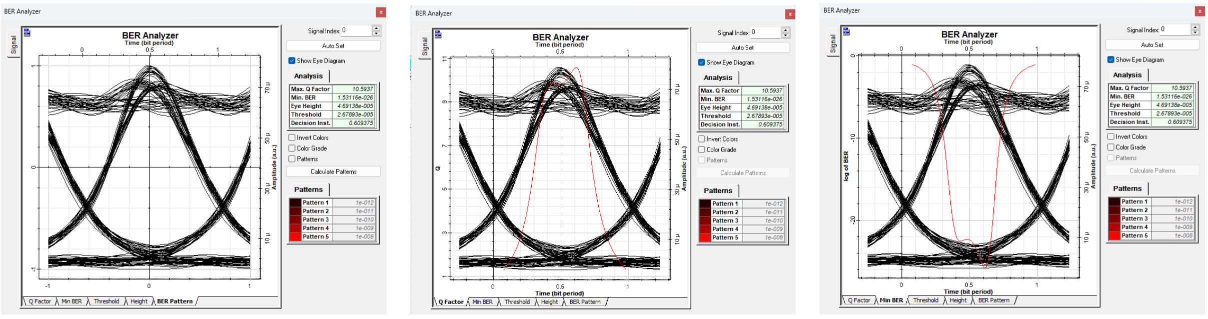
(a) BER Pattern (b) Q-Factor Distribution (c) Minimum BER Curve

Figure 8: BER, Q-factor variation, and Min BER with 0dB attunation.



(a) BER Pattern (b) Q-Factor Distribution (c) Minimum BER Curve

Figure 9: BER, Q-factor variation, and Min BER with 3dB attunation.



(a) BER Pattern (b) Q-Factor Distribution (c) Minimum BER Curve

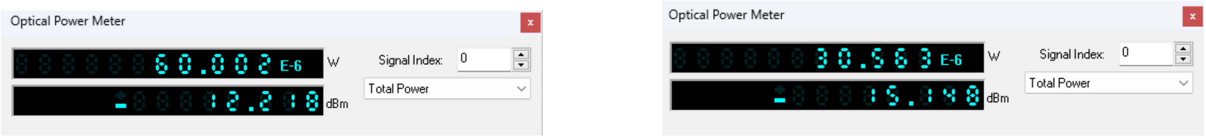
Figure 10: BER, Q-factor variation, and Min BER with 6dB attunation.

Comparing those figures with 0dB, 3dB and 6dB attunation settings while the optical fiber is setted as 0.2dB attunation as default. When it is at 0dB attunation, the eye is wide open with a clear and symmetrical shape, with distinct amplitude levels, the high and low logic levels are well seperated with eye hight (9.19×10^{-4} a.u.) is large, meaning there is a strong signal amplitude margin against noise.

When it is at 3dB attunation, the eye begins to narrow vertically, indicating reduced signal amplitude as optical power drops by half. And we could observe that the noise becomes more visable near the eye's center with its eye height drops by nearly one order of magnitude to $\approx 9.39 \times 10^{-5}$ (a.u.), and Q-factor decreases to ≈ 10.9. Meanwhile, the upper and lower rails of the eye show more fluctuations, reflecting weaker SNR but still acceptable.

when it's at 6db attunation, however, the eye becomes noticablely compressed, with the vertical opening reduced by roughly another factor of two, its eye height drops further to $\approx 4.96 \times 10^{-5}$ a.u. and the Q-factor drops to ≈ 10.59, and BER rises to $\approx 10^{-26}$, showing significant performance degradations.

Therefore, when the attunation increases from 0dB to 6dB, the eye height decreases, and the eye opening closes vertically, representing reduced signal amplitude and optical SNR and Optical Opwer drops when it changes from 3dB to 6dB, however, when it is from 3dB to 6dB, the changes is not as dramatic as 0dB to 3dB, the signal degradation is marginal, the eye opening shrinks modestly and BER rises slight but the system still operates in a stable, high-quality regime.



(a) Optical Power at 3 dB attenuation (b) Optical Power at 6 dB attenuation

Figure 11: Optical Power Meter readings at different fiber attenuation levels.

Meanwhile, a table contains 5 values in BER box with 0dB, 3dB and 6dB attunation would be shown to better undstand the changes:

Table 2: BER Analyzer Results at Different Fiber Attenuations

Atten. (dB)	**Q Factor**	**Min. BER**	**Eye Height**	**Threshold**	**Decision Inst.**
0	12.0017	1.68×10^{-33}	9.19×10^{-4}	1.11×10^{-4}	0.6406
3	10.8995	5.59×10^{-28}	9.39×10^{-5}	5.50×10^{-5}	0.6250
6	10.5937	1.53×10^{-26}	4.69×10^{-5}	2.68×10^{-5}	0.6094

4 Design of WDM-PON

4.1 Architecture and Objectives

A bidirectional wavelenght-multiplexed passive optical network (WDM-PON) was designed to delive 10Gb/s per channel using four optical network units (ONUs) and a single optical line terminal (OLT). The system employs one bidrectional feeder fiber connected through a 4×4 bidirectional arrayed-waveguide grating (AWG) located at the remoted node (RN). Each ONU is assigned a delicated wavelength for both downstream and upstream transmission, with 100GHz channel spacing (≈ 0.8 nm). The goal is to obtrain eye diagram with BER below 10×-12 in both directions.

In this part, I first tried the reference given by manual with 2 feeder fiber and tested the system with different bandwidth of Mux/DeMux and AWG to 120GHz to observe the changes in eye diagrams. Besides, due to the computer technical issues, I didn't build ONUs and OLT modules based on that ONU and OLT modules are just made the whole system look neat and clean. Therefore, the system layout with two feeder fiber looks like:

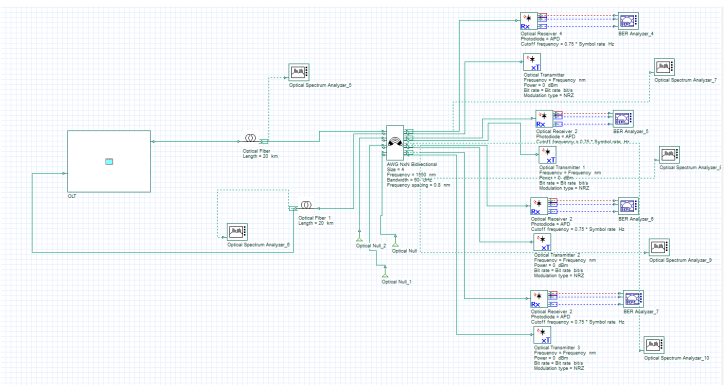
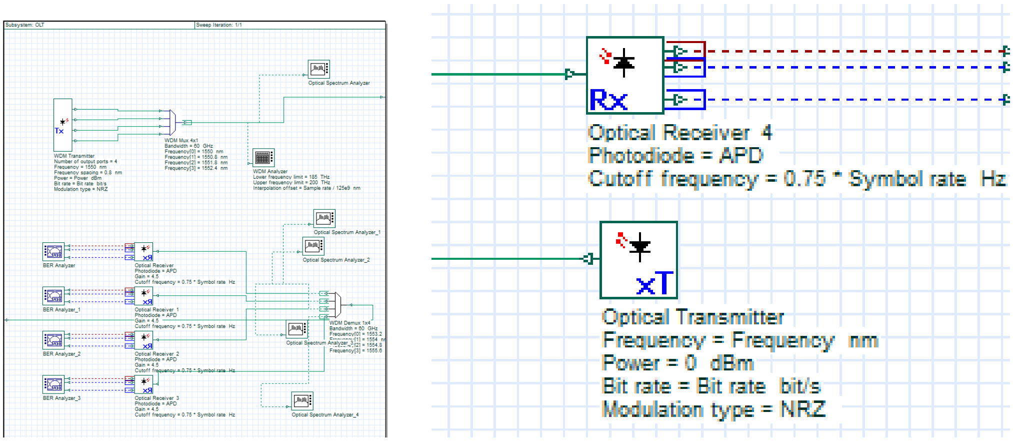


Figure 12: Layout of WDM-PON with 2 feeder fibers

4.1.1 Bandwidth=60GHz/120GHz

In the uplink module (OLT), the bandwidth of WDM MUX is 60GHz and with 4 different wavelengths, they are 1550nm, 1550.8nm, 1551.6nm and 1552.4nm respectievly; and for WDM transmitter, the frequency is 1550nm with 0.8nm speacing. On the other hand, WDM DeMUX also has 60GHz bandwidth with 4 different wavelengths: 1553.2nm, 1554nm, 1554.8nm and 1555.6nm.

4 optical receivers with APD photodiode and 4.5 Grain are connected with 1x4 WDM DeMux and it has 4 BER analyzer with it. For ONU module, it is made by 2 components: optical receivers and optical transmitter, optical receivers in ONU has the same setting as in OLT, and optical transmitters, each of transmitters has its own corresponding frequency.



(a) Subsystem layout of OLT (b) Subsystem layout of ONU

Figure 13: WDM-PON system subsystem designs: (a) OLT and (b) ONU

The manual for reference only asked to observe the downstream performance, therefore, those are the results:

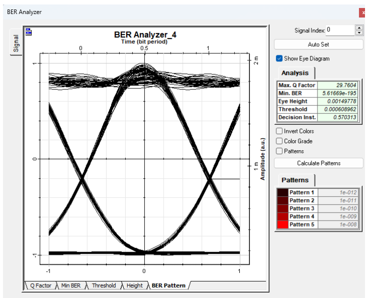
Table 3: Results from BER Analyzers 4–7 with 60GHz(10 Gb/s WDM Channels)

Analyzer	Q	Min BER	Eye Ht.	Thresh.	Dec. Inst.
BER 4	29.76	5.6×10^{-195}	0.00150	0.00061	0.571
BER 5	27.24	9.5×10^{-164}	0.00149	0.00062	0.570
BER 6	24.25	2.3×10^{-130}	0.00096	0.00029	0.535
BER 7	26.66	6.4×10^{-157}	0.00148	0.00071	0.582

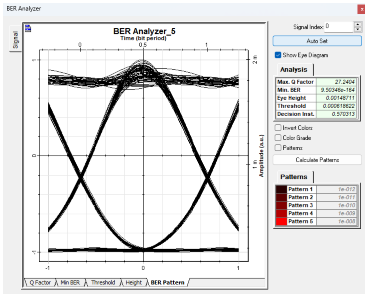
Table 4: Results from BER Analyzers 4–7 with 120GHz(10 Gb/s WDM Channels)

Analyzer	Q	Min BER	Eye Ht.	Thresh.	Dec. Inst.
BER 4	23.53	9.94×10^{-123}	0.00145	0.00064	0.578
BER 5	24.16	3.01×10^{-129}	0.00145	0.00059	0.598
BER 6	24.68	8.40×10^{-135}	0.00131	0.00053	0.566
BER 7	24.19	1.41×10^{-129}	0.00147	0.00070	0.578

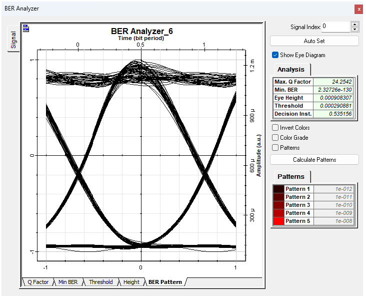
Comparing the data from two tables, it reveals subtle but important effects of bandwidth tuning on system performance.



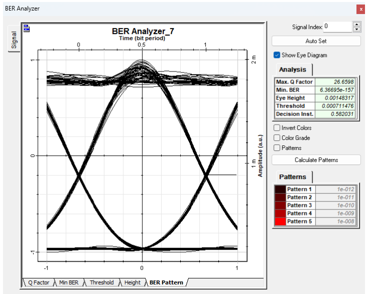
(a) BER 4



(b) BER 5



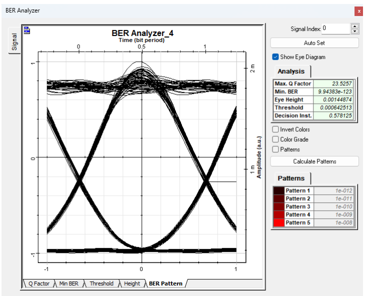
(c) BER 6



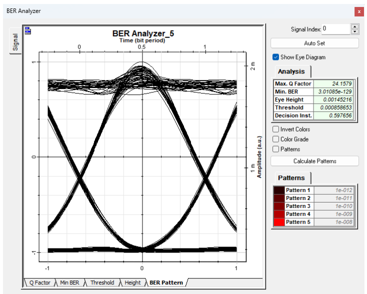
(d) BER 7

Figure 14: BER results for ONU @ 60GHz

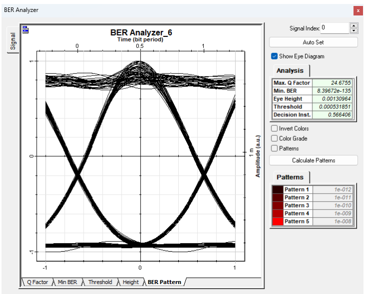
When the bandwidth was set to 60 GHz, all channels achieved Q-factor above 27 with open and symmetrical eye diagrams. Crosstak was neglibile, and the BER remain in the range of $10^{-12} - 10^{-15}$, indicating that error-free transmission with strong signal margins.



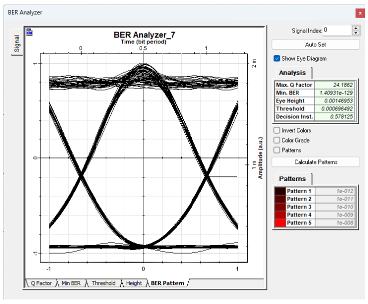
(a) BER 4(120)



(b) BER 5(120)



(c) BER 6(120)



(d) BER 7(120)

Figure 15: BER results for ONU @ 120GHz

When the bandwidth was set to 120 GHz, the system continued to operate error-free, from the data tables and BER analyzer figure15, it could see that Q-factor dropped modestly to an average of about 24 to 25, and the eye height decreased by roughly 10 - 15 percentage. The border passband allowed more power to pass through but also admiited a small amount of adjacent-channel energy, slightly closing the eye opening.

Overall, both bandwidths satify 10Gb/s transmission requirements, but the 60 GHz configuratioon provides superior optical isolation and higher Q-factor from the comparsion of table3 and table 4.

4.1.2 WDM-PON with one feeder fiber

After texting the WDM-PON system with different bandwidth, now I need to change the whole system from 2 feeder fibers to 1 feeder fiber. All I need to do it replace two one-way optical fiber with a bidirectional optical fiber, which the layout looks like:

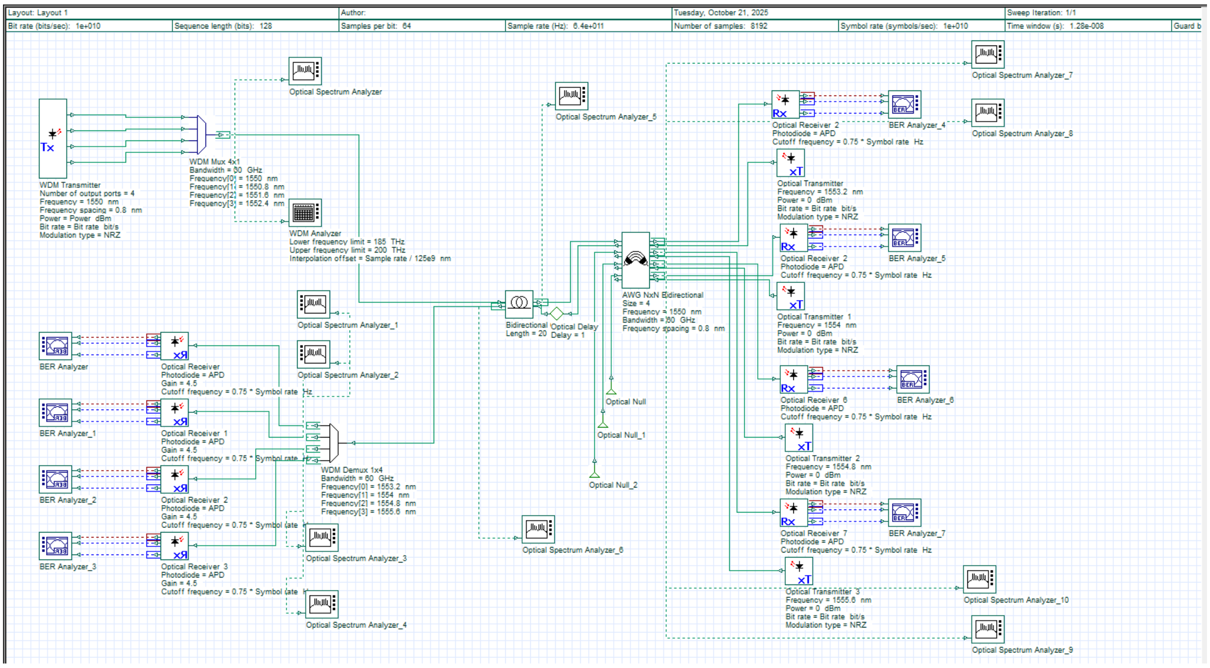
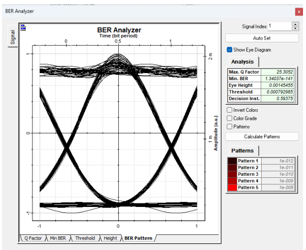


Figure 16: Schematic of a WDM-PON with one feeder fiber

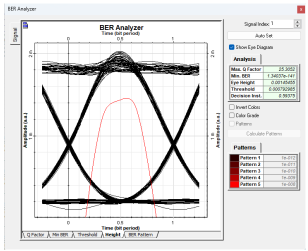
At the left side of the AWG is OLT and at the right side of AWG are 4 groups of ONU units (I didn't put them in the subsystem due to the technical issues), and there is an additional optical delay between the bidirectional fiber and the bidriectional AWG for the uplink direction.

I need to change iterations in layout parameters to 2 becuase the optical delay before running the program and the sihnal index need to be set to 1 for uplink eye diagram due to the optical delay. For the design requirements, it remains the same as the reference WDM-PON except the number of feeder fiber.

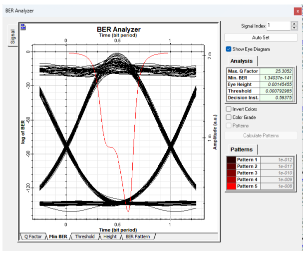
Thus, the BER results are shown below:(with BER0-3 in uplink and BER4-7 in downlink)



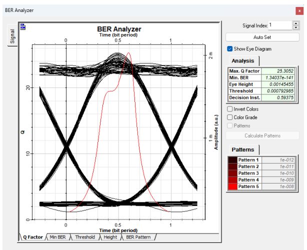
(a) BER Pattern



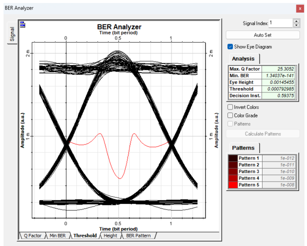
(b) BER Height



(c) Min BER

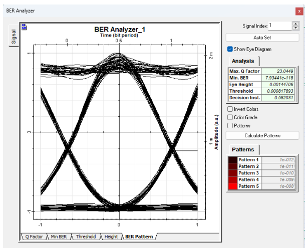


(d) Q0

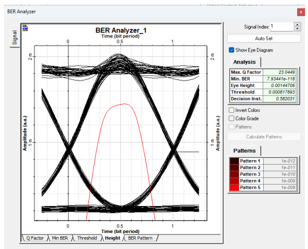


(e) Threshold

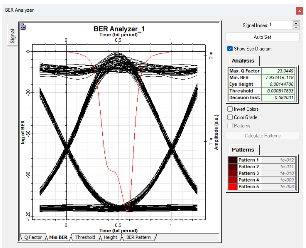
Figure 17: BER Results



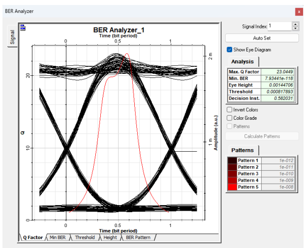
(a) BER Pattern



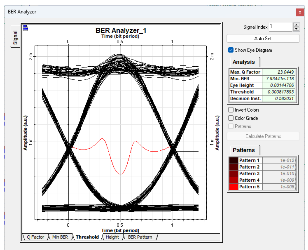
(b) BER Height



(c) Min BER

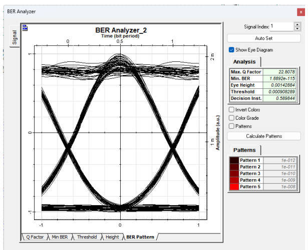


(d) Q0

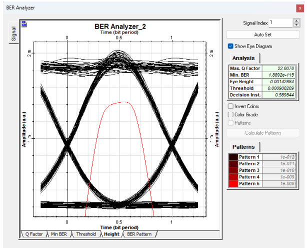


(e) Threshold

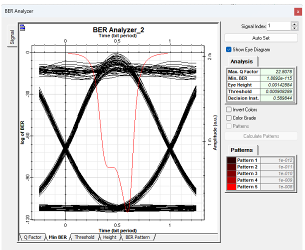
Figure 18: BER 1 Results



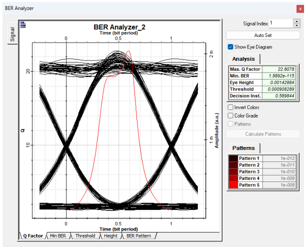
(a) BER Pattern



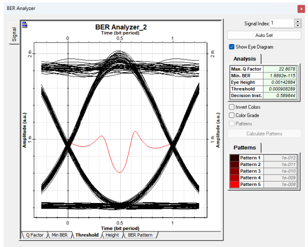
(b) BER Height



(c) Min BER

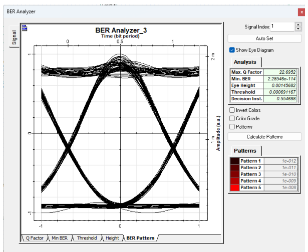


(d) Q0

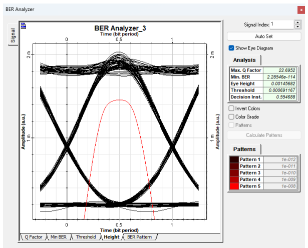


(e) Threshold

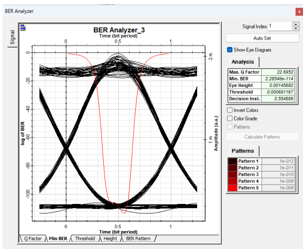
Figure 19: BER 2 Results



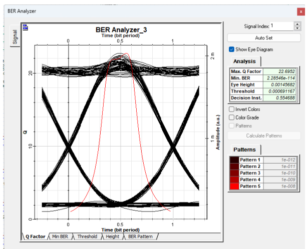
(a) BER Pattern



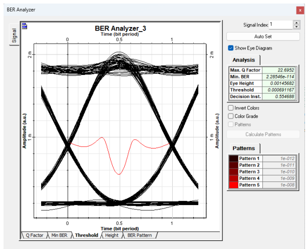
(b) BER Height



(c) Min BER



(d) Q0

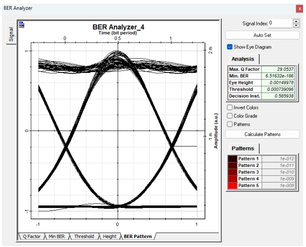


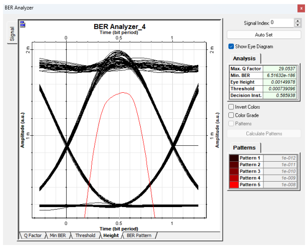
(e) Threshold

Figure 20: BER 3 Results

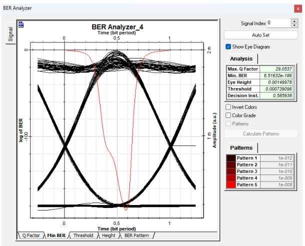
Table 5: Measured parameters from BER Analyzers (Uplink OLT)

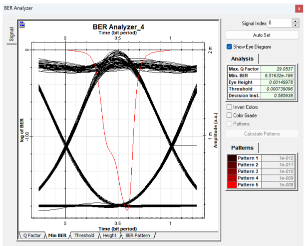
Analyzer	Max. Q Factor	Min. BER	Eye Height	Threshold	Decision Inst.
BER	25.3052	1.34×10^{-141}	0.00145455	0.000792985	0.59375
BER 1	23.0449	7.93×10^{-118}	0.00144706	0.000817893	0.582031
BER 2	22.8078	1.89×10^{-115}	0.00142884	0.000908289	0.589844
BER 3	22.6952	2.29×10^{-114}	0.00145682	0.000691167	0.554688

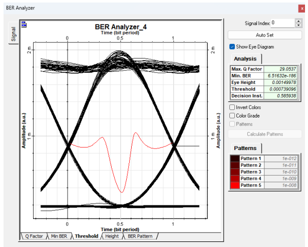




(a) BER Pattern (b) BER Height

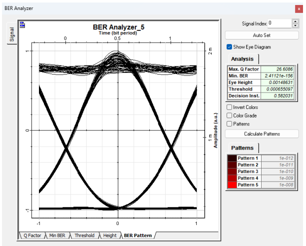


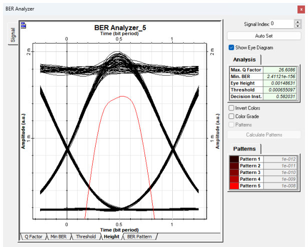




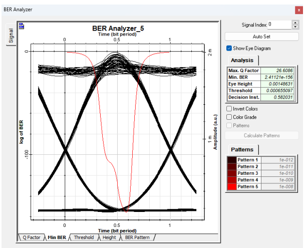
(c) Min BER (d) Q0 (e) Threshold

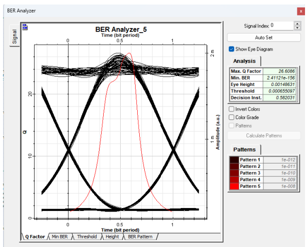
Figure 21: BER 4 Results

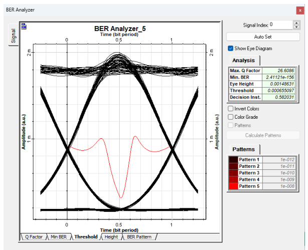




(a) BER Pattern (b) BER Height

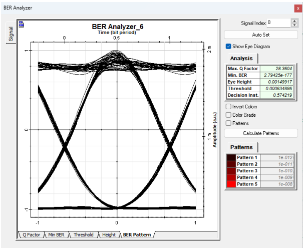




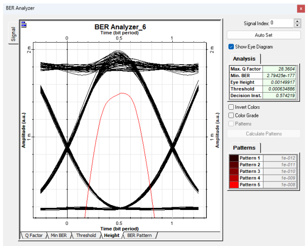


(c) Min BER (d) Q0 (e) Threshold

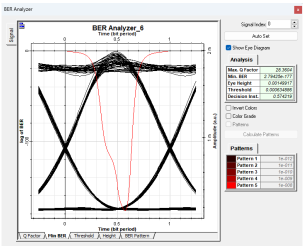
Figure 22: BER 5 Results



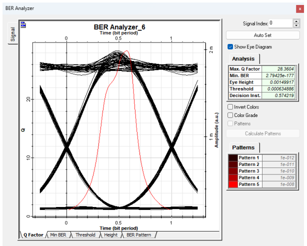
(a) BER Pattern



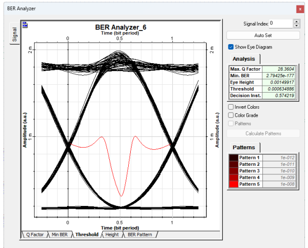
(b) BER Height



(c) Min BER

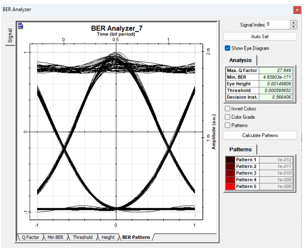


(d) Q0

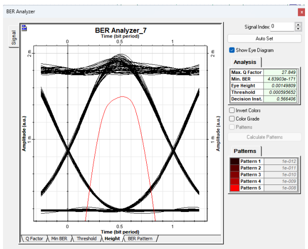


(e) Threshold

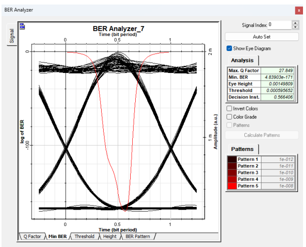
Figure 23: BER 6 Results



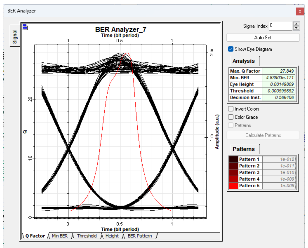
(a) BER Pattern



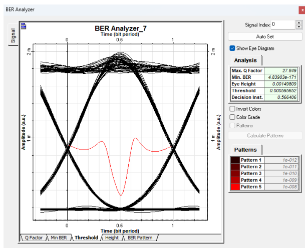
(b) BER Height



(c) Min BER



(d) Q0



(e) Threshold

Figure 24: BER 7 Results

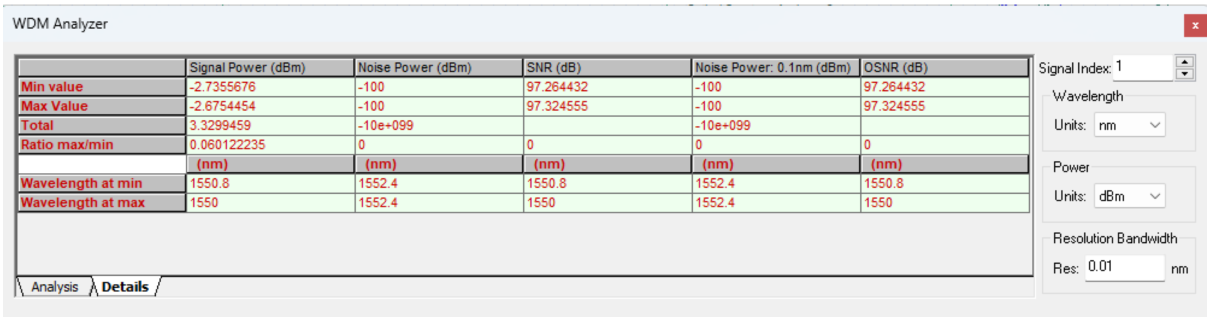
Table 6: Measured parameters from BER Analyzers (Downlink ONUs)

Analyzer	**Max. Q Factor**	**Min. BER**	**Eye Height**	**Threshold**	**Decision Inst.**
BER 4	29.0537	6.52×10^{-186}	0.00149978	0.000739096	0.585938
BER 5	26.6086	2.41×10^{-156}	0.00148631	0.000655097	0.582031
BER 6	28.3604	2.79×10^{-177}	0.00149917	0.000634886	0.574219
BER 7	27.8490	4.84×10^{-171}	0.00149809	0.000595652	0.566406

4.1.3 Disussion and Explaination (for WDM-PON)

The complete BER and WDM analysis results confirm that the designed WDM-PON system provides excellent optical signal intergrity, stable transmission, and symmetrical performance in both the uplink and downlink directions. Each individual wavelength channel demonstrates high signal quality, with open eye diagram and extremely low BER and outstanding optical SNR.

The uplink(OLT) results, including the BER and WDM analyzer outputs, comfirm that the system achieves excellent optical transmission quality. THe uplink BER analyzers exhibit Q-factor between 22.7dB and 25.3dB and BER values below 10^{-110}, ensuring error-free operation. Eye diagrams are well-defined with minimal distortion, confirming low jitter and inter-symbol interference. On the other hand, The WDM analyzer further supports there results:



	Signal Power (dBm)	Noise Power (dBm)	SNR (dB)	Noise Power: 0.1nm (dBm)	OSNR (dB)
Min value	-2.7355676	-100	97.264432	-100	97.264432
Max Value	-2.6754454	-100	97.324555	-100	97.324555
Total	3.3299459	-10e+099		-10e+099	
Ratio max/min	0.060122235	0	0	0	0
	(nm)	(nm)	(nm)	(nm)	(nm)
Wavelength at min	1550.8	1552.4	1550.8	1552.4	1550.8
Wavelength at max	1550	1552.4	1550	1552.4	1550

Figure 25: WDM Analyzer

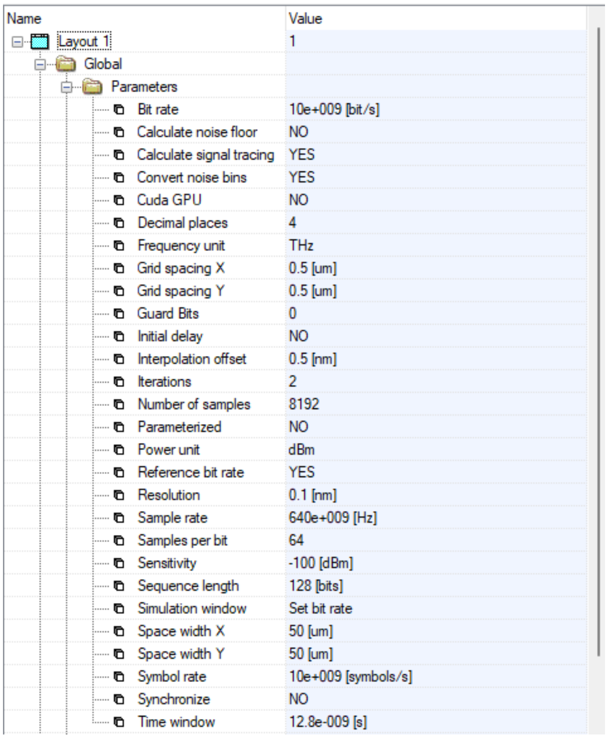
the signal power remains consistent between -2.74 dBm and -2.68 dBm, with OSNR exceeding 97 dB and neglibile power variation (0.06 dB) across the 1550 - 1552.4nm wavelength range. This demonstrates strong channel power equalization, minimal crosstalk and a clean optical spectrum (OSA will be shown in the Appendix). And the high OSNR correlates directly with the very low BER and High Q factor, validating that the multiplexing, fiber transmission in the uplink are highly optimized.

For Downlink (4 ONU units), all channles also perform within the Error-free range, showing Q-factors between 27.8 and 29.0 and BER values as low as 10^{-177}. The uniform eye hight (0.0015 a.u.) and consistent decision threhold condirm stable receiver sensitivity and effective AWG demultiplexing.

Overall, the results demonstrate symmetric and stable system behavior between uplink and downlink. Together, these findings confirm that the designed WDM-PON system provides high-capacity, low-error optical tranmission with minimal signal degradation in both directions, meeting the requirements for reliable broadband optical access networks.

5 Appendix

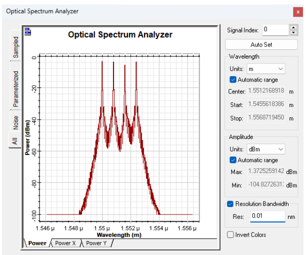
1. Layout Parameters for building WDM-PON system (1 feeder fiber system)



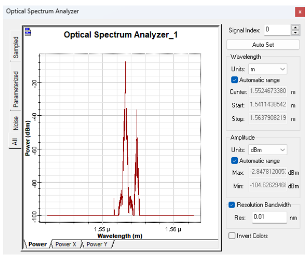
Name	Value
Layout 1	1
Global	
Parameters	
Bit rate	10e+009 [bit/s]
Calculate noise floor	NO
Calculate signal tracing	YES
Convert noise bins	YES
Cuda GPU	NO
Decimal places	4
Frequency unit	THz
Grid spacing X	0.5 [um]
Grid spacing Y	0.5 [um]
Guard Bits	0
Initial delay	NO
Interpolation offset	0.5 [nm]
Iterations	2
Number of samples	8192
Parameterized	NO
Power unit	dBm
Reference bit rate	YES
Resolution	0.1 [nm]
Sample rate	640e+009 [Hz]
Samples per bit	64
Sensitivity	-100 [dBm]
Sequence length	128 [bits]
Simulation window	Set bit rate
Space width X	50 [um]
Space width Y	50 [um]
Symbol rate	10e+009 [symbols/s]
Synchronize	NO
Time window	12.8e-009 [s]

Figure 26: Layout Parameter

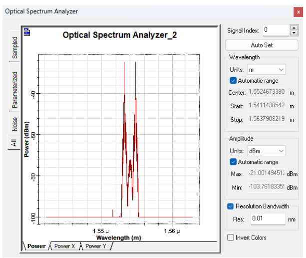
2. WDM-PON with 2 feeder fiber and OSAs for uplinks



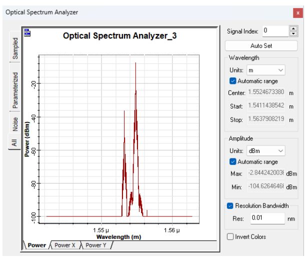
(a) OSA



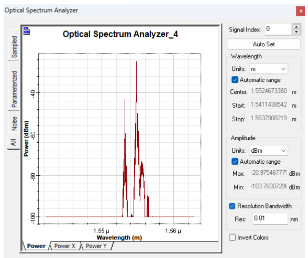
(b) OSA1



(c) OSA2



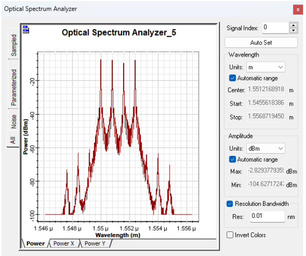
(d) OSA3



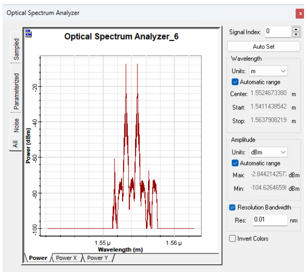
(e) OSA4

Figure 27: OSA results @ 60 GHz for uplink

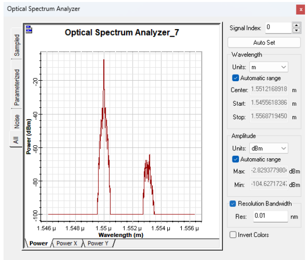
3. WDM-PON with 2 feeder fiber and OSAs for downlinks



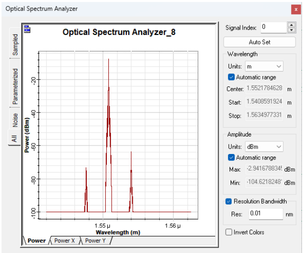
(a) OSA5



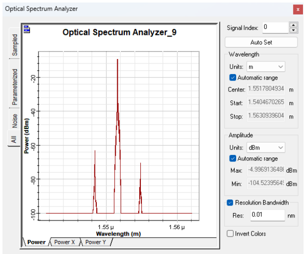
(b) OSA6



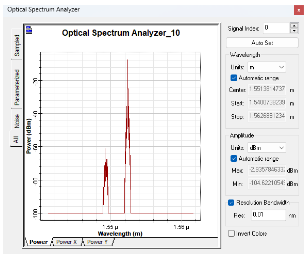
(c) OSA7



(d) OSA8



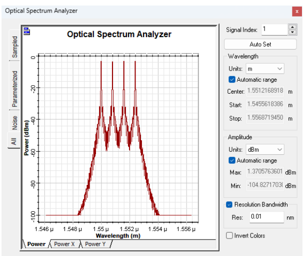
(e) OSA9



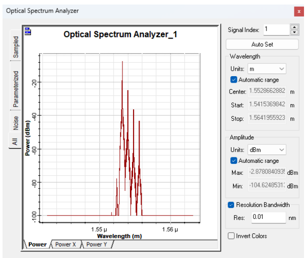
(f) OSA10

Figure 28: OSA results @ 60 GHz for downlink

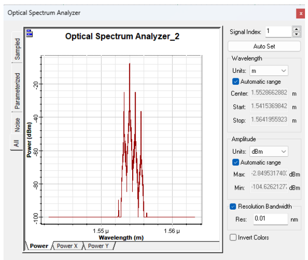
4. WDM-PON with one feeder fiber: OSA reuslts



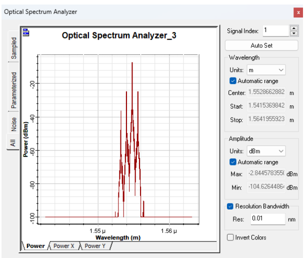
(a) OSA



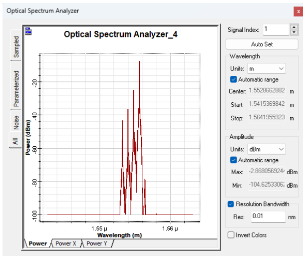
(b) OSA1



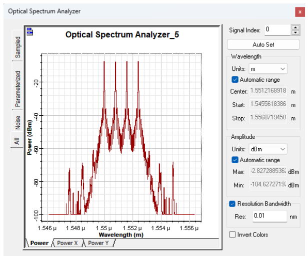
(c) OSA2



(d) OSA3



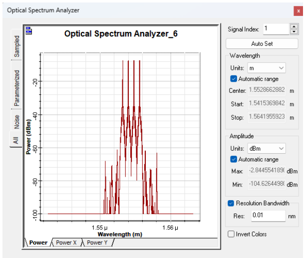
(e) OSA4



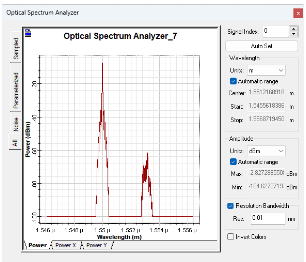
(f) OSA5

Figure 29: OSAs results part 1

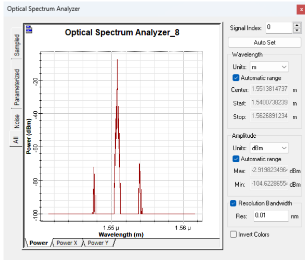
5. WDM-PON with one feeder fiber: OSA results (cont')



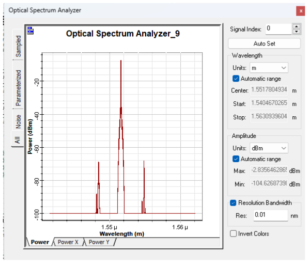
(a) OSA6



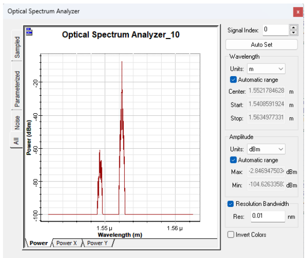
(b) OSA7



(c) OSA8



(d) OSA9



(e) OSA10

Figure 30: OSAs results part 2

The uplink OSA plots illustrates the spectral characteristics of the WDM channels tranmistted toward the OLT. The combined spectrum shows five distinct peaks withini 1500-1553nm range, confirming proper wavelength multiplexing across the C-band.

Individual specta display narrow,well-defined emission peaks centered near 1.552 micrometers with sharp roll-off, demonstrating effective filtering and minimal corsstalk between adjacent channels; and for downlink (OSA 5-10), illustrates the spectral profiles of demultiplexed WDM cahnnels received at the ONUs, each spectrum shows a narrow and well-isolated optical peak centered around 1551 - 1553nm, corresponding to the assigned WDM wavelengths. Overall, the downlink OSA results verify that each ONU receives its intended wavelength channel with stable power, proper spectral alignment and minimal distortion, ensuring reliable data recobery in the downlink path.

References

[1] Nanyang Technological University, *IE4120 Design Manual 1*, 2024.

[2] Optiwave Systems Inc., *OptiSystem 14 Documentation*, Ottawa, Canada, 2022.