EC9100
OPTICAL COMMUNICATIONS
POINT-TO-POINT OPTICAL LINK FOR SMART CONNECTIVITY

SUBMITTED BY:

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Introduction:

As part of the university's Smart Campus Initiative, there is an increasing demand for a robust, high-speed communication infrastructure to enable seamless connectivity between core academic facilities. This assignment presents the design and analysis of a point-to-point optical communication link connecting the Central Data Center to the Engineering Building over a distance of 70 km. The proposed system must sustain a bit rate of 1.25 Gb/s, enabling bandwidth-intensive services such as real-time lab data streaming, cloud-based academic platforms, IoT integration, and AR/VR-enabled remote learning.

To meet these requirements, a directly modulated Fabry-Pérot (FP) laser with 0 dBm output power has been selected as the optical transmitter, and a PIN photodiode serves as the receiver. The link will utilize single-mode fiber (SMF) deployed in 10 km segments, incorporating 2 dB loss per splice/connector, and must achieve a target BER of 10^{-15}, with a 6 dB system margin for reliability.

This assignment aims to guide the design process of the optical link by evaluating system losses, determining link budget, and ensuring that performance specifications are met. Reasonable assumptions and industry-standard parameters will be used, along with references from lecture notes and verified datasheets, to justify design decisions and calculations.

Requirements for the system:

- Distance: 70 km
- Bit Rate: 1.25 Gb/s
- Target BER: 10^{-15}
- System Margin: 6 dB
- Transmission Medium: Single-Mode Fiber (SMF)
- Transmitter: Directly modulated FP Laser, 0 dBm output
- Receiver: PIN Photodiode
- Segment Length: 10 km per splice
- Splice Loss: 2 dB per splice (6 splices)
- Isolator loss: 1 dB

Wavelength Selection:

Selected Wavelength = 1550nm

Due to:

- Lowest fibre attenuation (~0.25 dB/km)
- Low Dispersion: Reduces signal distortion, maintaining clarity over long distances.
- Compatibility with EDFAs (Erbium-Doped Fibre Amplifiers)
- Widely available components and commercial support

Modulation and Line Coding:

Choosing and justifying the modulation and coding scheme:

Selected modulation scheme: Non-Return-to-Zero (NRZ) On-Off Keying (OOK) with 4B5B line coding.

Justification:

- NRZ-OOK is simple and cost-effective
- 4B5B coding avoids long strings of 0s or 1s (helps timing recovery)
- Spectral efficiency: ~1 bit/s/Hz
- Implementation Complexity: Low
- Dispersion Tolerance: Better than RZ

Discuss spectral efficiency, dispersion tolerance, and implementation complexity:

- Spectral Efficiency:
  Spectral efficiency refers to how effectively a given bandwidth is used to transmit data. For OOK modulation, the spectral efficiency is relatively low compared to more complex modulations like QAM. This is because OOK transmits one bit per symbol, making it simple but less efficient in terms of bandwidth usage. However, for the 1.25 Gb/s bit rate and the relatively short distance (70 km), OOK provides an adequate balance of simplicity and performance without the need for complex signal processing.

- Dispersion Tolerance:
  Dispersion tolerance refers to the system's ability to handle signal spreading caused by fiber dispersion, which can distort high-speed signals. OOK is somewhat sensitive to dispersion, especially at high bit rates. However, given the moderate bit rate of 1.25 Gb/s and the 1550 nm wavelength, chromatic dispersion is manageable for distances like 70 km with single-mode fiber. For longer distances, additional

techniques like dispersion compensation may be required, but for this design, the dispersion tolerance is sufficient without needing extra compensation.

- Implementation Complexity:
  Implementation complexity for OOK modulation is low, making it an attractive choice for this design. It requires simple modulation and demodulation processes, ideal for systems with a PIN photodiode receiver. The system does not need advanced signal processing or complex algorithms, making it easier and cheaper to implement compared to more complex modulation schemes like QAM. The simplicity also helps in maintaining system reliability and reducing the chance of error.

Link Power Budget Analysis:

Splice Segments Calculation:

Given:

- Link distance = 70 km
- Splice every 10 km

∴ No of Splices = $\frac{70}{10} - 1 = 6$

Power Loss Calculation:

Component/Source	Loss (dB)
Fibre attenuation (70 km × 0.25 dB/km)	17.5
Splice/Connector Losses (6 × 2 dB)	12.0
System Margin	6.0
Total Link Loss	**35.5** dB

Received Power Estimation:

- Received Power = (0.0 dBm – 35.5 dBm) = -35.5 dBm

Receiver Sensitivity Check:

- Bit Rate = 1.25 Gb/s
  H = 10log10 (1.25 × 109) = 91Db

- Receiver sensitivity estimation:
  PIN Sensitivity = 0dB – (120 – H) = -(120-91) = -29 dBm

Power Margin:

- Power Margin = Received Power − Receiver Sensitivity
  Received Power = -35.5 dBm
  Receiver Sensitivity = -29.0 dBm

- Calculation:
  Power Margin = (−35.5 dBm) − (−29.0 dBm) = (−35.5 dBm + 29.0 dBm) = -6.5dB

Conclusion:

- The power margin is -6.5 dB, which means the received power is 6.5 dB below the required sensitivity of the receiver. This negative margin confirms that the received power is insufficient and that optical amplification (such as an EDFA) is necessary to meet the receiver's sensitivity.

Proposed Solution: Optical Amplification (EDFA):

- To address the issue where the received optical power is below the receiver sensitivity (received power of -35.5 dBm vs. receiver sensitivity of -29.0 dBm), optical amplification is necessary to boost the signal and ensure reliable reception.

Why EDFA?

- The Erbium-Doped Fiber Amplifier (EDFA) is the best solution for this scenario, especially given the 1550 nm wavelength used in your system. EDFAs are widely used in long-distance optical communication for amplifying signals while maintaining the signal in optical form (avoiding the need for electrical conversion).

EDFA Characteristics:

- Gain: EDFAs typically provide a gain of 20-30 dB, which will be sufficient to bring the received power to the required level.

- Wavelength Compatibility: EDFAs operate efficiently around 1550 nm, the selected wavelength for this system.
- Noise Figure: EDFAs have a low noise figure (typically 4-5 dB), meaning they can amplify the signal with minimal added noise, which is crucial for maintaining signal quality over long distances.

Position of EDFA:

- Location: The EDFA should be placed at regular intervals along the link. For a 70 km link, EDFA should be placed at the midpoint of the fiber to compensate for losses from fiber attenuation and connector/splice losses.

EDFA Specifications:

- Wavelength: 1550 nm (for compatibility with fiber's low attenuation at this wavelength).
- Gain: 20-30 dB (to compensate for link losses).
- Noise Figure: 4-5 dB (to minimize additional noise in the system).•
- Output Power: Can typically boost signal to +15 dBm or more, which will be sufficient for this system.

Reasons for EDFA Need:

- Here received power is -35.5 dBm, and the required sensitivity is -29.0 dBm; the EDFA needs to boost the signal by at least 8 dB to meet the receiver's requirements.
- With an EDFA providing a 20-30 dB gain, it will be more than enough to raise the power level above the required -29 dBm sensitivity threshold.

Dispersion Estimation and Management:

Total Dispersion:

- Total Dispersion = 17 ps/nm.km x 70 km = 1190 ps/nm.km

Dispersion Limit:

- Approx max tolerable dispersion for NRZ at 1.25 Gb/s: ~1000–1200 ps/nm. So, it's borderline tolerable.

Recommended Solution:

- Even though the dispersion is below the limit, if further improvement is desired.

- Use a Dispersion Compensating Fibre (DCF) with:
  Compensation of ~–1190 ps/nm
  Placed after the EDFA or near the receiver

- Use EDC (Electronic Dispersion Compensation) at the receiver for cost-effective compensation.

Calculations for Compensation Techniques:

- SMF dispersion: +17 ps/nm·km × 70 km = +1190 ps/nm
- Use DCF with dispersion ≈ –80 ps/nm·km
- Required DCF length ≈ 1190 / 80 = 14.875 km

System Block Diagram:

[PRBS Generator]

→ [NRZ Pulse Generator]

→ [Directly Modulated FP Laser (0 dBm)]

→ [Optical Isolator]

→ [10 km SMF]

→ [Connector/Splice (-2 dB)]

→ [10 km SMF]

→ [Connector/Splice (-2 dB)]

→ [10 km SMF]

→ [Connector/Splice (-2 dB)]

→ [EDFA Amplifier]

→ [Dispersion Compensation Module (DCM)]

→ [10 km SMF]

→ [Connector/Splice (-2 dB)]

→ [10 km SMF]

→ [Connector/Splice (-2 dB)]

→ [10 km SMF]

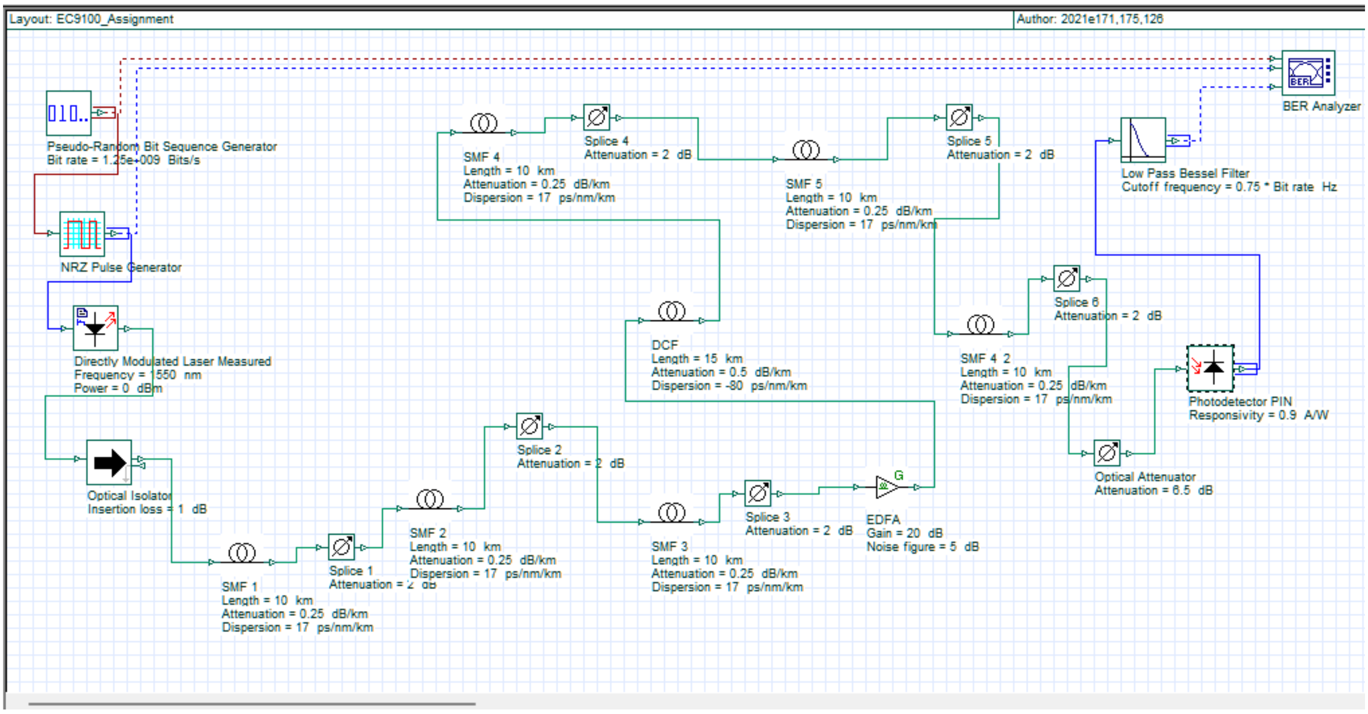
→ [Attenuator (to set power before receiver, -6.5 dB)]

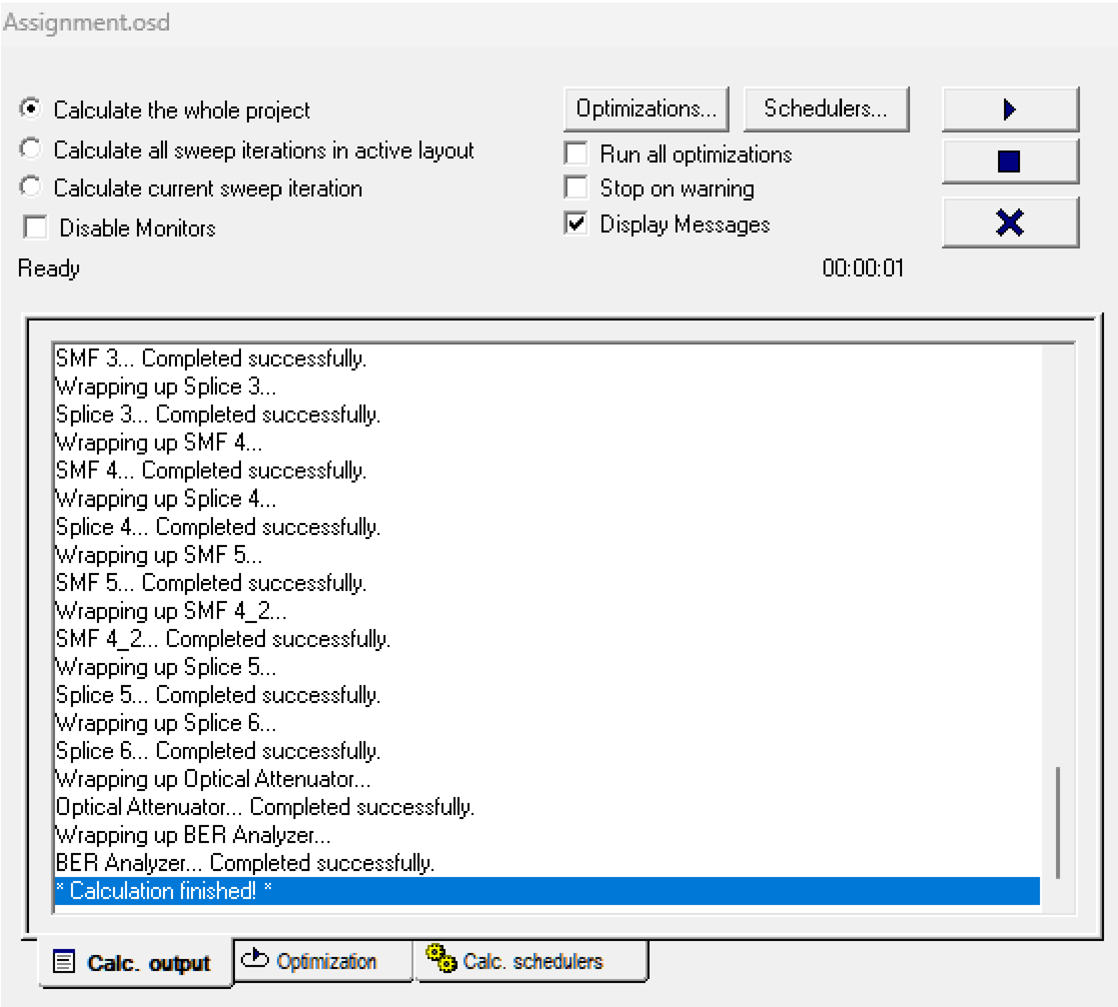
→ [PIN Photodiode Receiver]

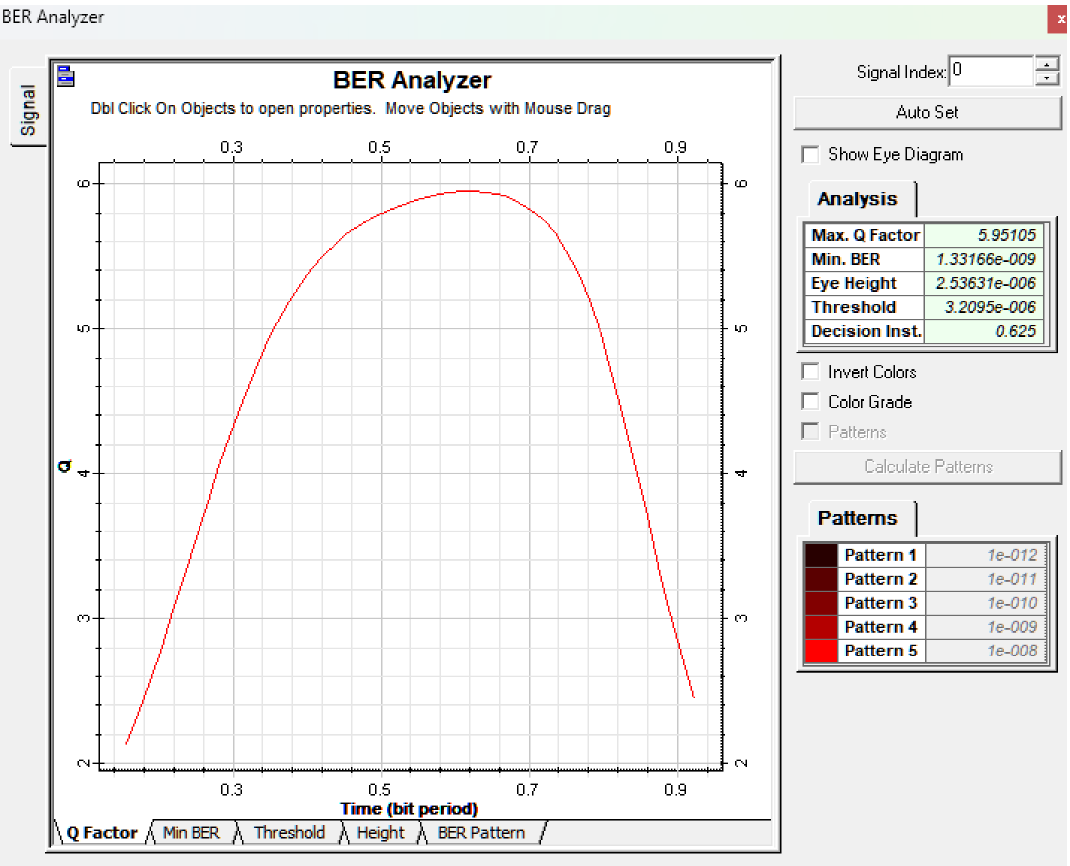
→ [Bessel Filter (Bandwidth limited)]

→ [BER Analyzer]

Simulation and Analysis:




Assignment.osd
Calculate the whole project
Calculate all sweep iterations in active layout
Calculate current sweep iteration
Disable Monitors
Optimizations...
Schedulers...
Run all optimizations
Stop on warning
Display Messages
Ready
00:00:01
SMF 3... Completed successfully.
Wrapping up Splice 3...
Splice 3... Completed successfully.
Wrapping up SMF 4...
SMF 4... Completed successfully.
Wrapping up Splice 4...
Splice 4... Completed successfully.
Wrapping up SMF 5...
SMF 5... Completed successfully.
Wrapping up SMF 4_2...
SMF 4_2... Completed successfully.
Wrapping up Splice 5...
Splice 5... Completed successfully.
Wrapping up Splice 6...
Splice 6... Completed successfully.
Wrapping up Optical Attenuator...
Optical Attenuator... Completed successfully.
Wrapping up BER Analyzer...
BER Analyzer... Completed successfully.
* Calculation finished! *
Calc. output
Optimization
Calc. schedulers


BER Analyzer
Signal
BER Analyzer
Dbl Click On Objects to open properties. Move Objects with Mouse Drag
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0.5
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6
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Time (bit period)
Q Factor
Min BER
Threshold
Height
BER Pattern
Signal Index: 0
Auto Set
Show Eye Diagram
Analysis
Max. Q Factor 5.95105
Min. BER 1.33166e-009
Eye Height 2.53631e-006
Threshold 3.2095e-006
Decision Inst. 0.625
Invert Colors
Color Grade
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Calculate Patterns
Patterns
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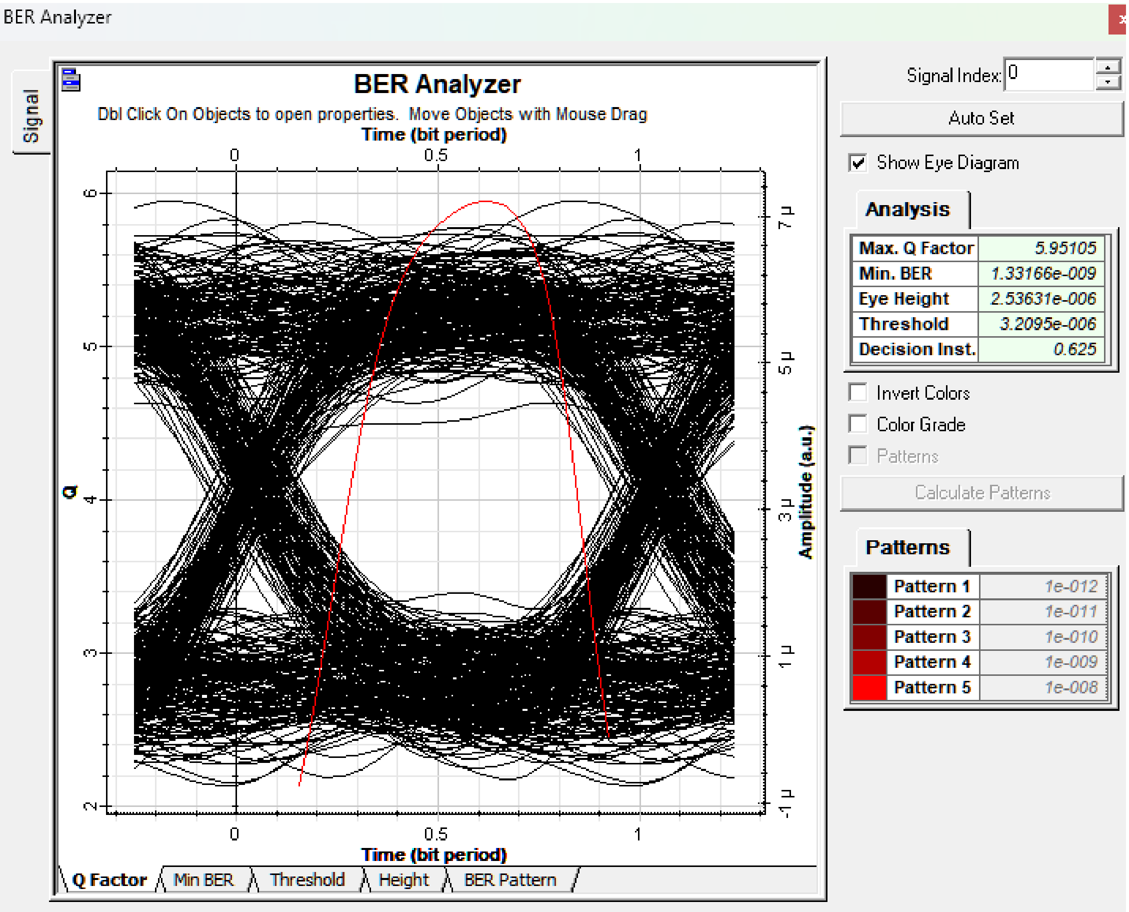
Pattern 2 1e-011
Pattern 3 1e-010
Pattern 4 1e-009
Pattern 5 1e-008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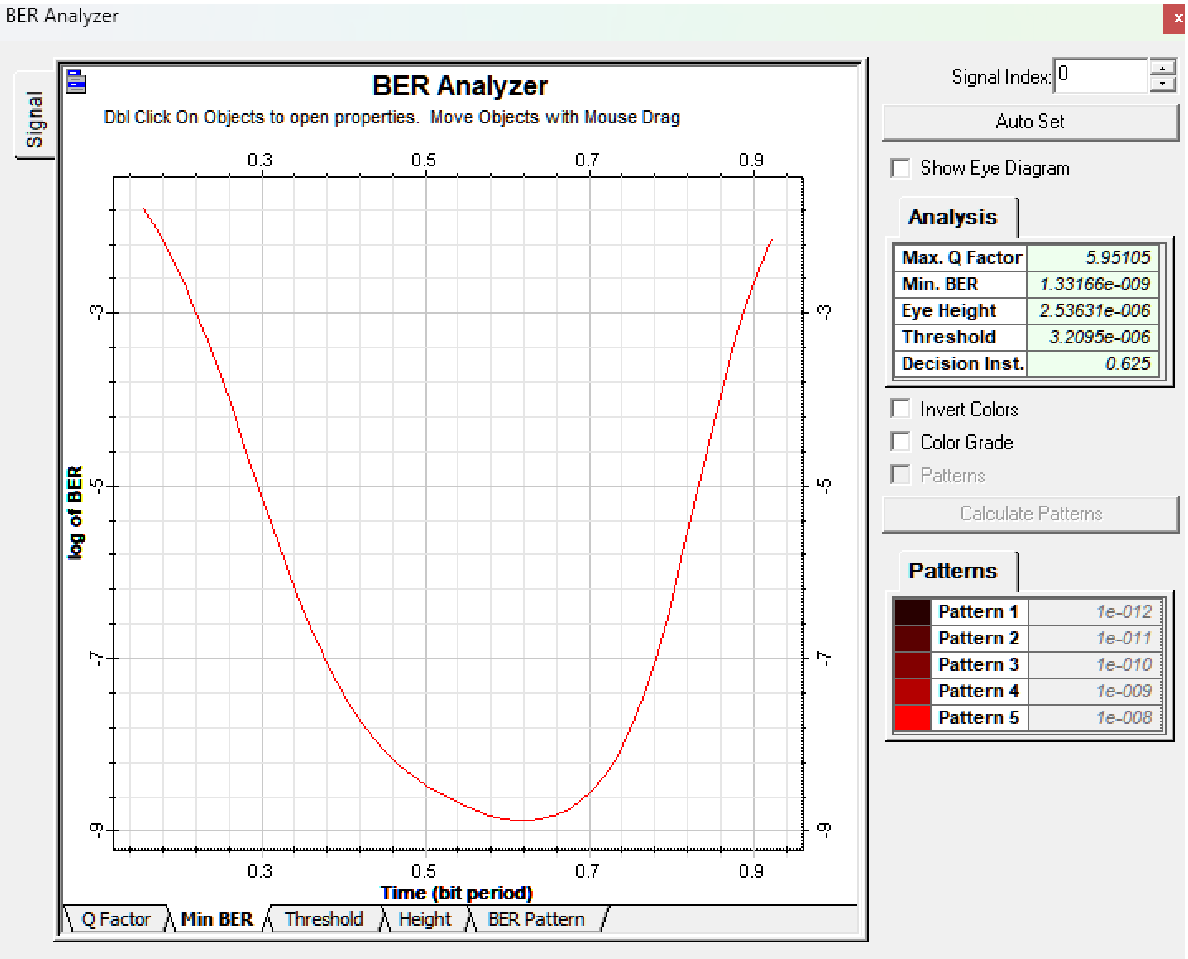
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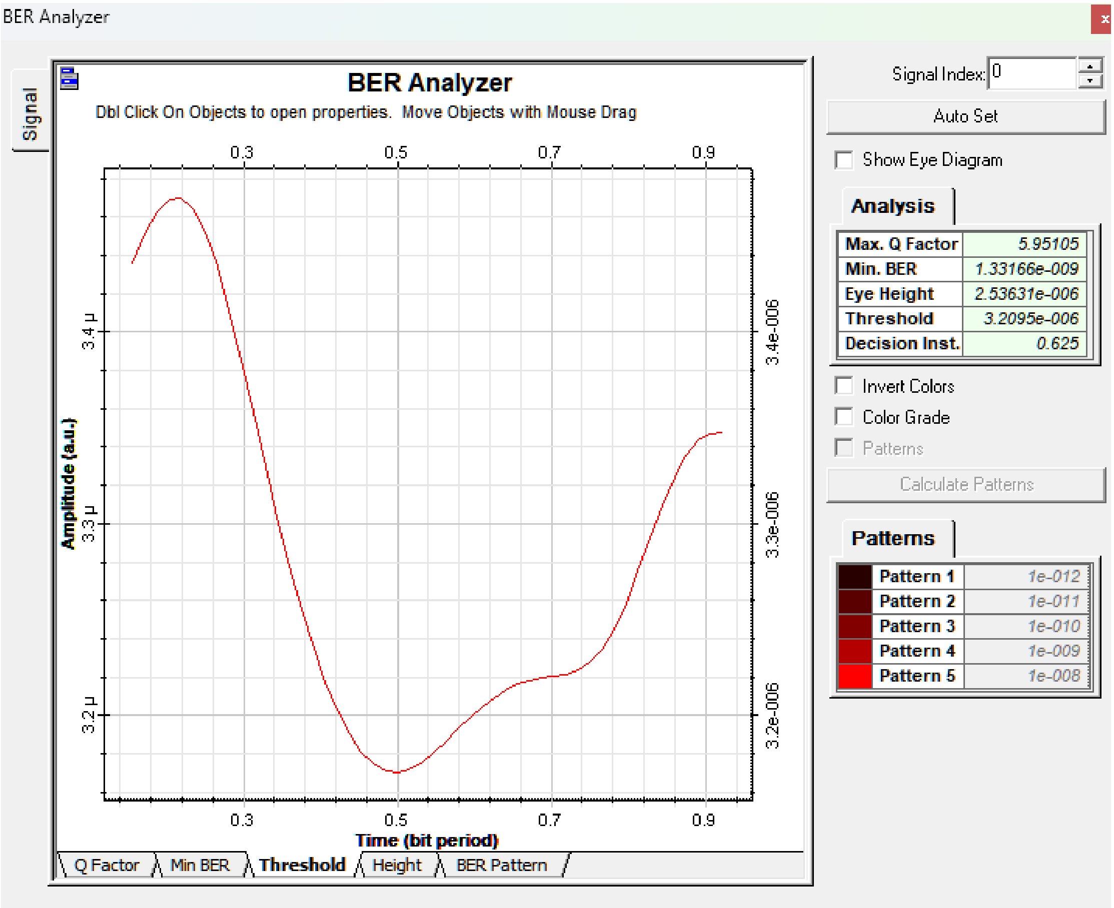
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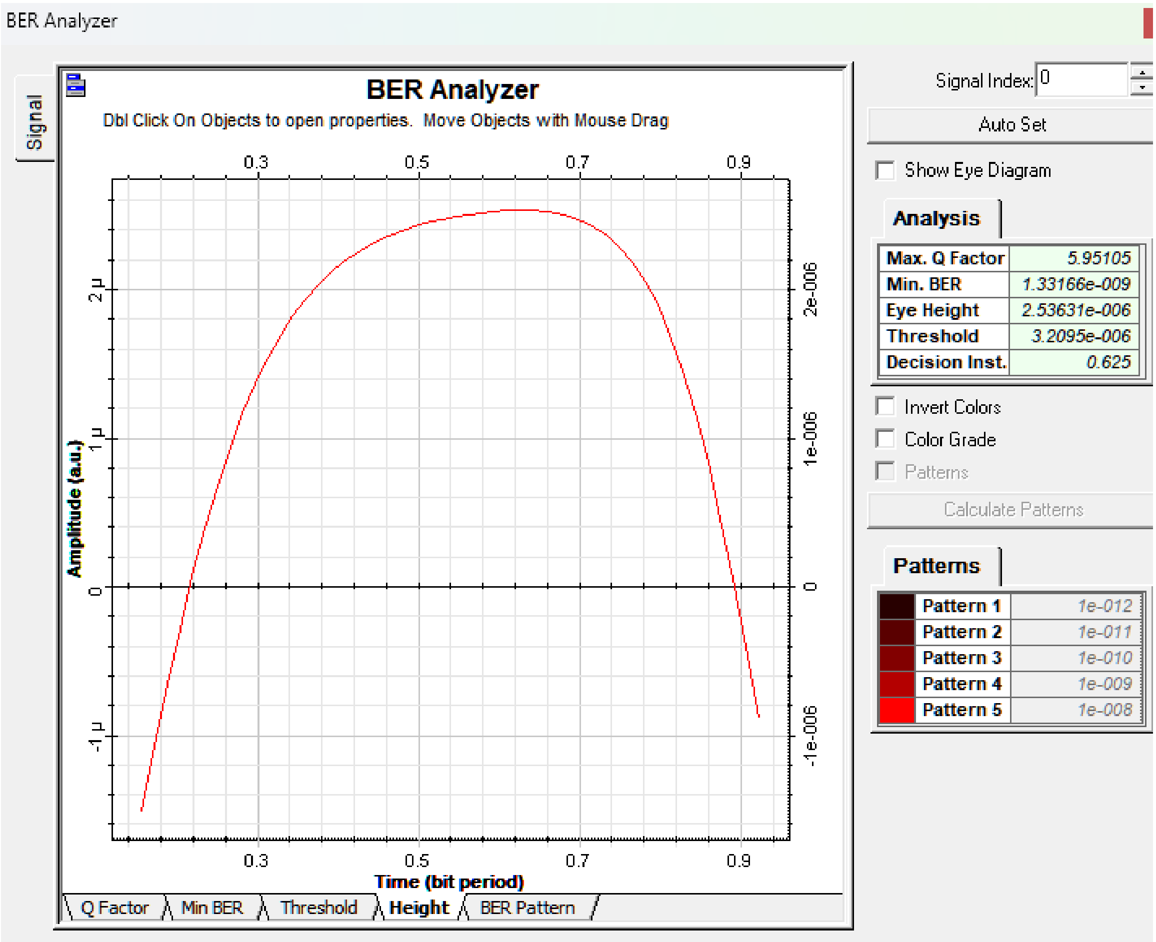
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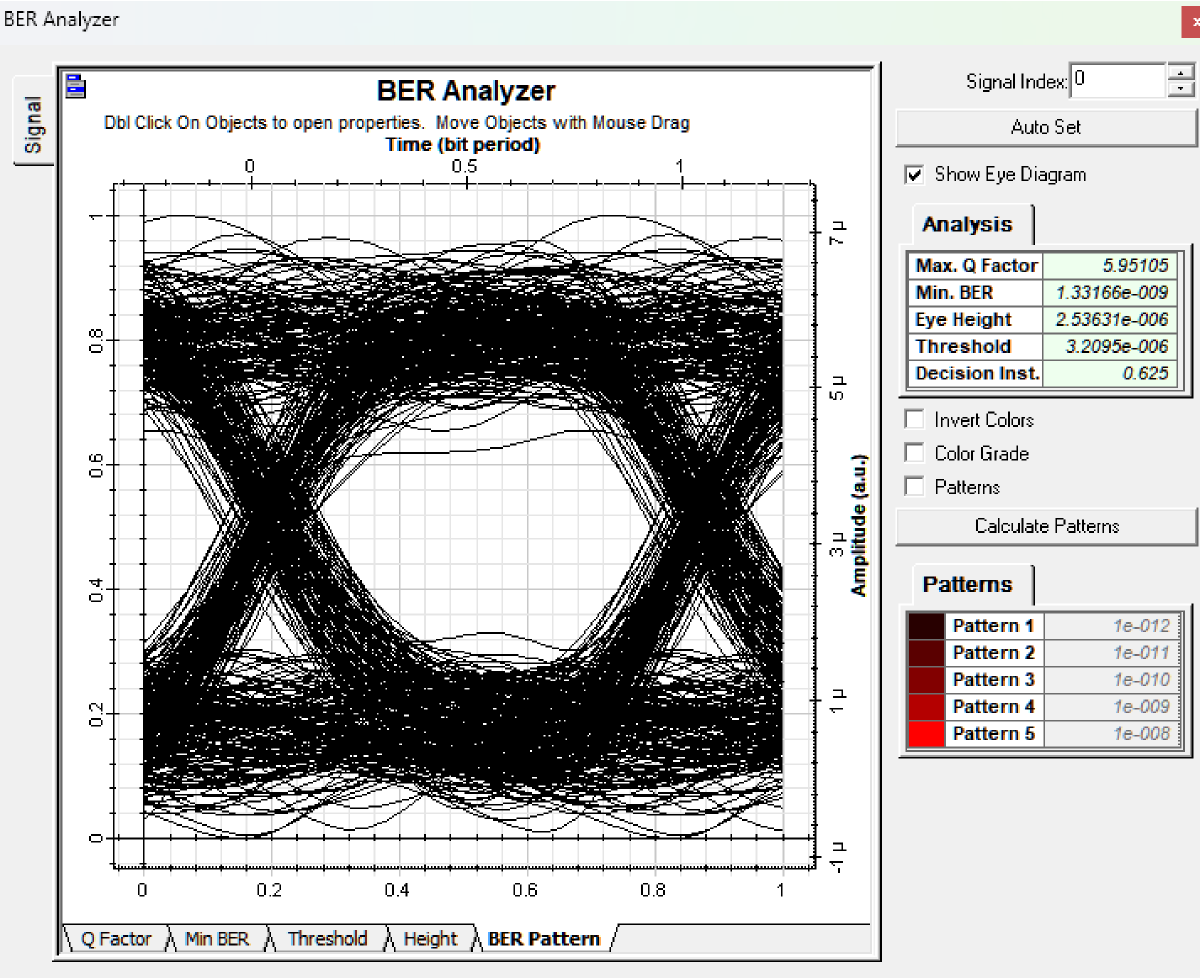

Conclusion:

In this assignment, we designed and analyzed an optical communication link for a Smart Campus Initiative. The system, using single-mode fiber (SMF) over 70 km, was configured with an FP laser transmitter, a PIN photodiode receiver, and Erbium-Doped Fiber Amplifiers (EDFA) for signal boosting.

After calculating the link budget and assessing the received power, it was found that the received power of -35.5 dBm was lower than the required -29 dBm sensitivity. To fix this, EDFA amplification was used, providing the necessary boost to the signal.

We also considered chromatic dispersion, which was found to be manageable, but Dispersion Compensating Fibre (DCF) could be used for further optimization if needed.

By running the simulation and analyzing results like BER, eye diagrams, and received power, we confirmed that the system can work reliably with the proposed components, achieving a low BER and sufficient signal strength for reliable communication.

Contribution:

2021/E/126:

I was responsible for designing the overall point-to-point optical link architecture. I calculated the total link loss due to fiber attenuation and splice/connector losses, and determined the necessary gain for the EDFA amplifier. I also selected the appropriate dispersion compensation method using DCF and ensured that the system met the required BER and system margin specifications. My focus was on ensuring that all physical layer design aspects were optimized for a 70 km high-speed optical link.

2021/E/171:

My main contribution was configuring and setting up the optical communication system in the simulation software. I selected the appropriate components, such as the PRBS generator, NRZ pulse generator, directly modulated FP laser, isolator, SMF segments, and PIN photodetector. I carefully set the key parameters based on datasheets and lecture values to ensure accurate modeling. I also helped test various configurations to achieve optimal signal transmission and system performance.

2021/E/175:

I worked on analyzing the simulation results and documenting the entire project. I observed the BER values, evaluated the eye diagrams, and ensured that the system achieved the target BER of 10^{-15}. I compiled all component parameters into a clear table format, wrote the introduction, and structured the report for clarity and professionalism. Additionally, I proofread all technical content to ensure the report maintained accuracy and coherence.