Optic Communication System Project

8 Channels WDM High Speed Communication System

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Introduction

During our current age, the increasing ability to transmit more information over longer distances more quickly has expanded the boundaries of our technological development in many areas such as data networks, wireless and satellite communications, cable operators, and broadcasters.

All of this has become possible by the use of fiber optics, and as technology demands insist upon improved performance, fiber optics will continue to increase.

In this project, we try to apply all the knowledge we have acquired in Optical Communication Systems course and looked for the most adequate components to respect the specifications listed below.

Specifications

The goal of this project is to design and dimension an optical communication with the following characteristics:

- Unidirectional communication
- 8 DWM channels
- C-band which runs from approximately 1530nm to 1565nm
- Bit rate: 40Gbps per channel
- Link: 500 Km
- Bit Error Rate: BER< 10^{-13} (Q-factor >5) per channel

I. Components

1. Emission

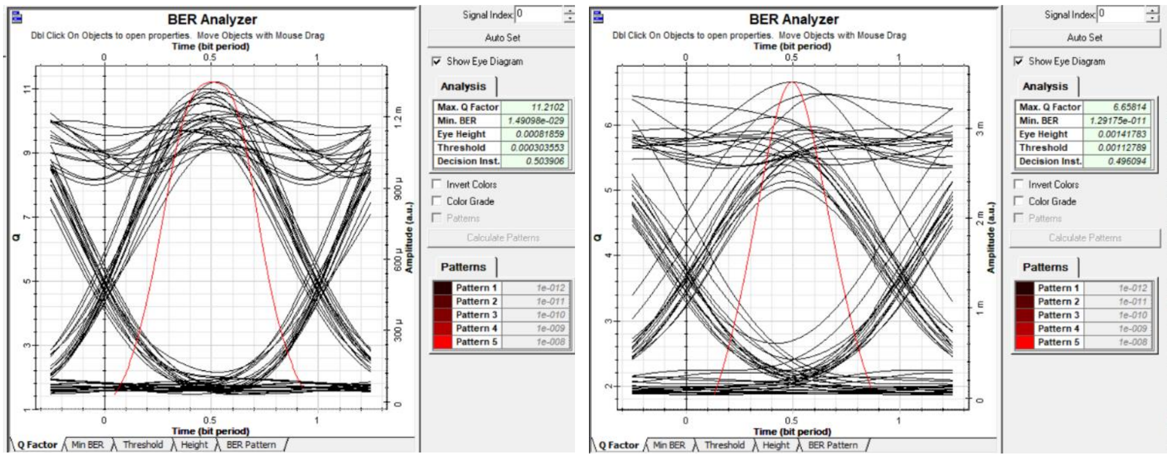
a. Laser source

As an optical source, we have chosen 8 different **LQC1550-05E CW Laser Diodes** operating on frequencies ranging from 193.1 THz to 193.8 THz with an output power of 1.2 mW.

***Figure 1:** LQC1550-05E CW Laser Diode*

b. Source Modulation

We decided to adopt the RZ modulation format because it tolerates nonlinearities when the dispersion in the optic span is compensated.



RZ Modulation

Q-factor =11.2102

NRZ Modulation

Q-factor =6.65814

***Figure 2:** Performance comparison between RZ and NRZ*

To modulate the sequence, we have used the **photline MX1300-LN-40 Mach-Zehnder Modulator**. We have chosen the Mach-Zehnder Modulator because of its low insertion loss of 3.5dB.

Figure 3: Photline MX1300-LN-40 Mach-Zehnder Modulator

c. DWDM 8x1 Multiplexer

In this transmission circuit, we are going to multiplex 8 channels on the C band. We respected the ITU recommendations for DWDM multiplexing using 193.1 THz as a central frequency and a channel spacing of 100GHz (~0.8nm).

To ensure separation between the channels in the frequency domain (linear cross-talk suppression), before multiplexing, each channel is optically filtered with a sixth- order Bessel filter with a bandwidth equal to two times the Bit rate (or 160 GHz).

We have chosen the **OptoSpan DWDM Mux/Demux** for multiplexing because it provides the most robust and low-cost bandwidth upgrade for your current fiber optic communication networks

Figure 4: OptoSpan DWDM Mux/Demux

2. Optic Span

The optic span is made of three cells (repeated using a loop control) each cell covers a distance of 150 km, plus an extra fourth cell, which covers 50 km to have a total of 500km

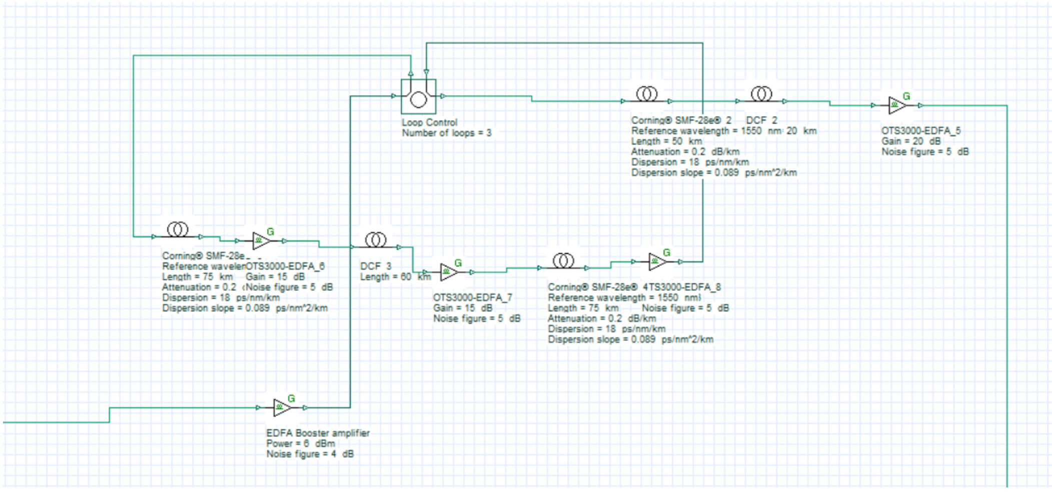


Figure 5: *Optic Span*

a. Optic fiber

The optical fiber used in this project is the **Corning® SMF-28e® Optical fiber.** We have chosen this Optic fiber because it is one of the most used SMF in the world, it is compatible and fully compliant with the recommendation ITU-T G.652.D, and it comes with low linear attenuation (0.19 dB/Km) and low cost (0.18$/m).

As for the Dispersion Compensating Fiber DCF we have chosen **Thorlabs DCF38** it is specifically designed to compensate corning SMF-28e Fiber.

Figure 6: *Corning® SMF-28e® Optical fiber*

Figure 7: *Thorlabs DCF38*

b. EDFA Optic Amplifier:

In order to compensate the losses due to linear attenuation of the fiber and the insertion loss of some components we have chosen the **OTS3000-EDFA** optical amplifier set on Gain control mode, and it provides a constant gain of 15db

***Figure 8**: OTS3000-EDFA*

3. Reception

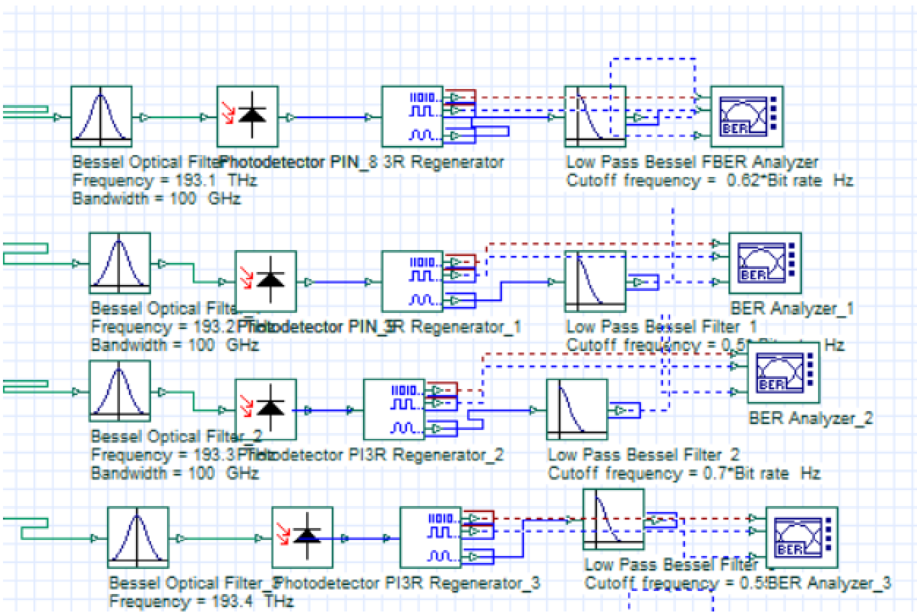


***Figure 9** : WDM Receiver design*

a. Filters:

In order to minimize the signal distortion and inter symbol interference we have used a band pass Bessel optical filter with a cut-off frequency of 100 GHz, and a low pass Bessel electrical filter.

The optical filter we have chosen is **Acphotonics's Band Pass/ Edge Pass Filter**, which operates on the C band and have low insertion loss. As for the electrical filter we have chosen **Thorlabs' Low band Filter**

***Figure 10**:Acphotonics's Band Pass/ Edge Pass Filter*

***Figure 11**: Thorlabs' Low band Filter*

b. PIN photodiode receptor

For the receptor we have chosen an InGaAs PIN Photodiode with reception power $Pr = I_{dark} / R = -67$ dBm

***Figure 12:** High Linearity InGaAs PIN Photodiode*

II. Dimensioning of the optical chain span

1. Solution for compensating the dispersion of the optical fiber:

a. Dispersion scheme:

To compensate the accumulated dispersion in the fiber we have found three different dispersion compensation schemes: pre-, post-, and symmetries compensation scheme.

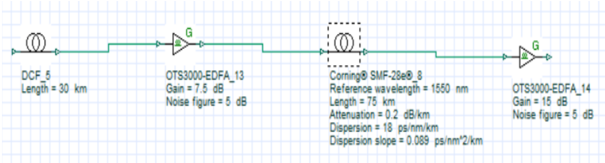


***Figure 13**: Pre-compensation scheme*

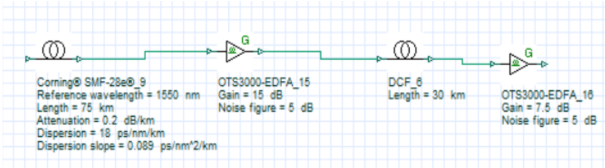


***Figure 14**: Post-compensation scheme*

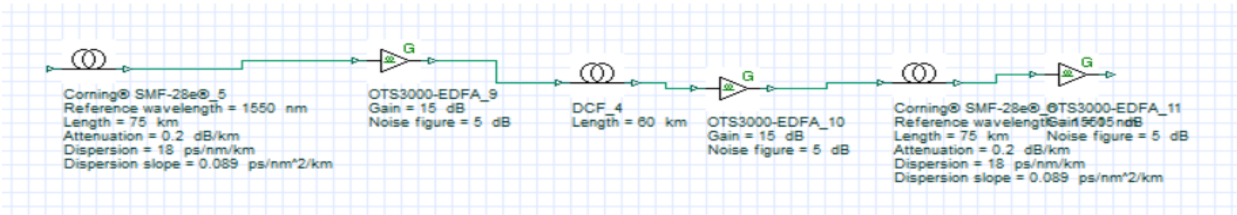
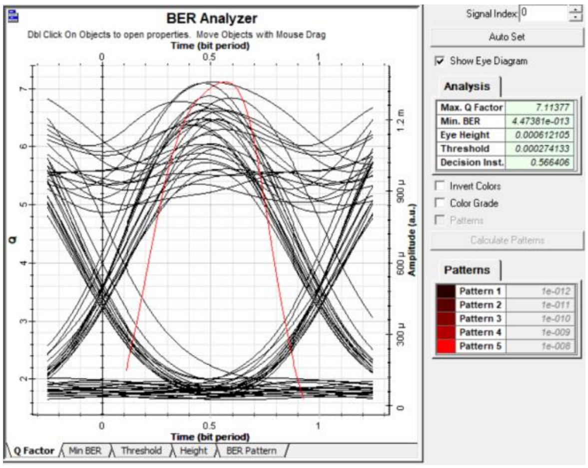
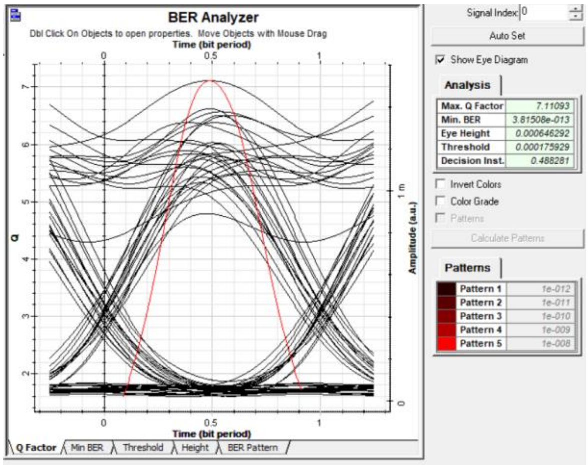


***Figure 15:** Symmetric compensation scheme*

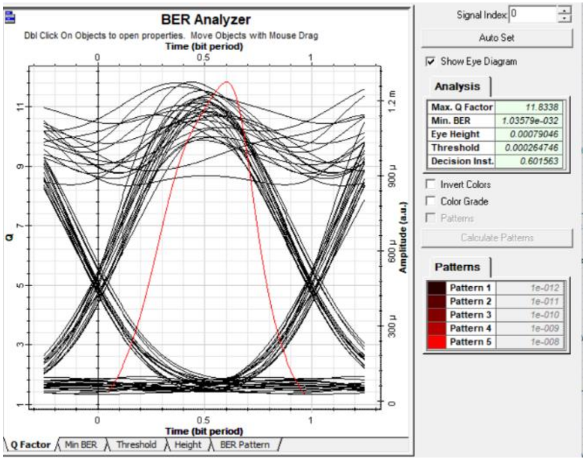
After experimenting all the schemes, we have decided to adopt the symmetric compensation scheme because it gave the best performances.





post-compensation scheme ***pre-compensation scheme***

Q-factor =7.11377 ***Q-factor =7.11093***



symmetric-compensation scheme

Q-factor =11.8338

Figure 16*:Performance comparison between pre-, post-, and symmetric compensation schemes*

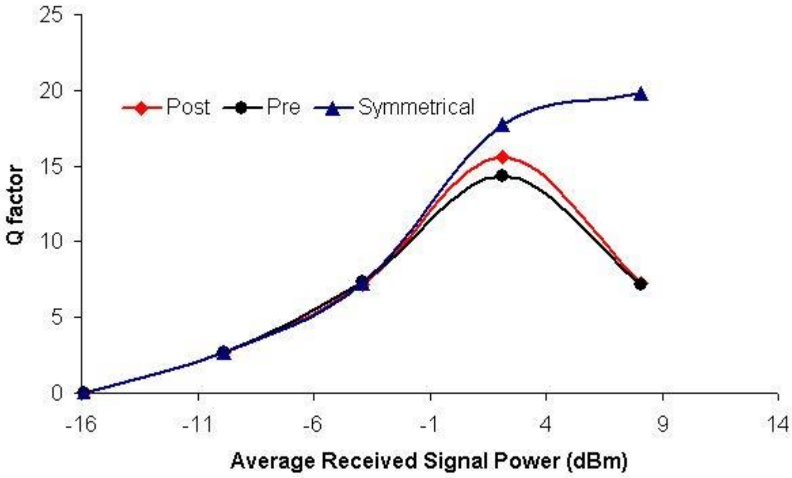


Figure 17*: Q factor verses signal power at 2.5 and 10 Gbps bit rates for pre-, post-, and symmetrical dispersion compensations*

b. Dimensioning the DCF:

We are using a DCF with chromatic dispersion of -45 ps/nm/km, since our cell covers 150 km and our SMF have a chromatic dispersion of 18 ps/nm/km, then we have a total dispersion of 150*18= 2700 ps/nm per cell. To compensate the dispersion we need the length of the DCF to be -2700 /-45= 60 km.

2. Energy Balance:

To ensure good signal quality and to avoid power loss due to attenuation and insertion loss we have decided to add:

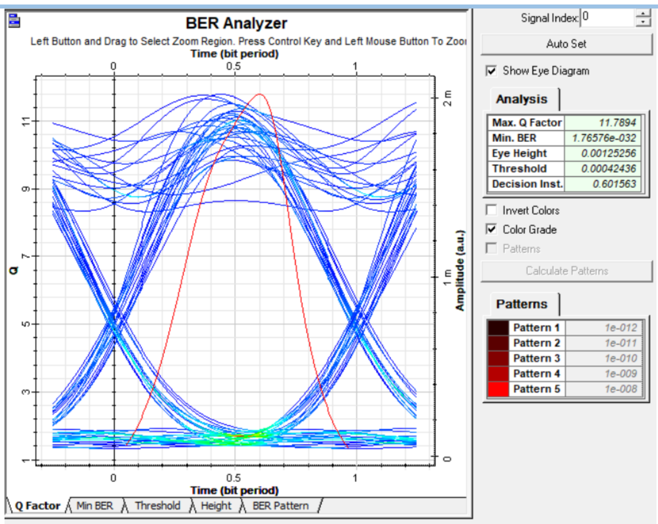
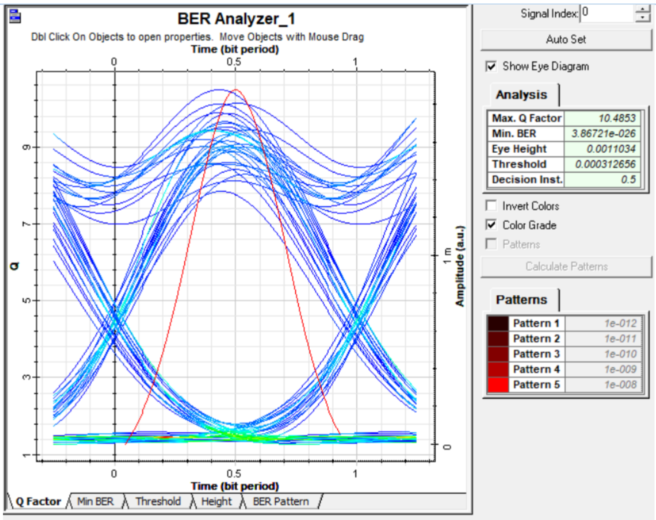
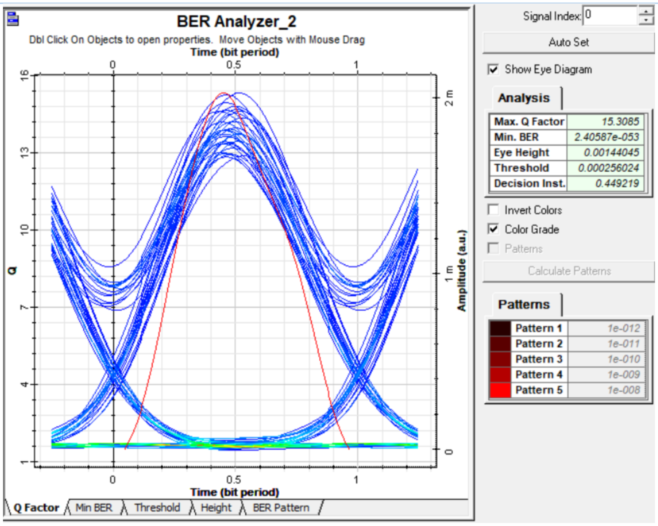
- A pre-amplifier working on power control mode with output power of 6 dB to cover for the losses introduces by the multiplexer (this value is determined experimentally by measuring the power level before and after the multiplexer)
- Three inline amplifiers working on gain control mode per cell (9 in total) with optical gain of 15dB to cover for the attenuation introduced by the two SMF and the DCF (ASMF*L= 0.2*75=15 dB) (A_{DCF}*L=0.25*60=15dB)
- A post amplifier to cover for the losses of the extra 50 km forth cell and for the losses introduced by the demultiplexer.

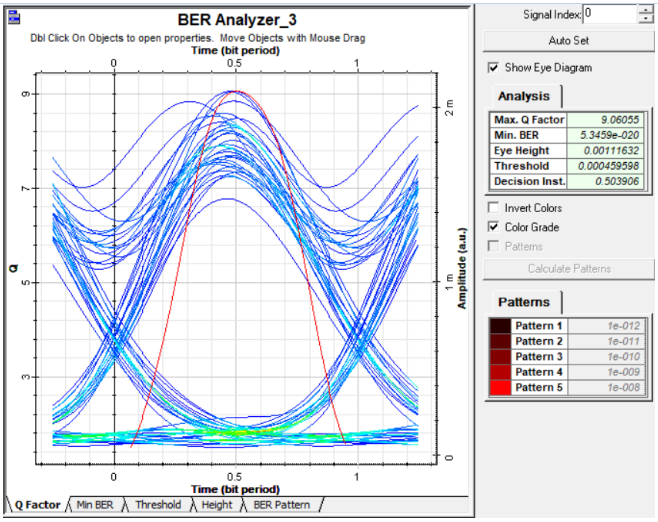
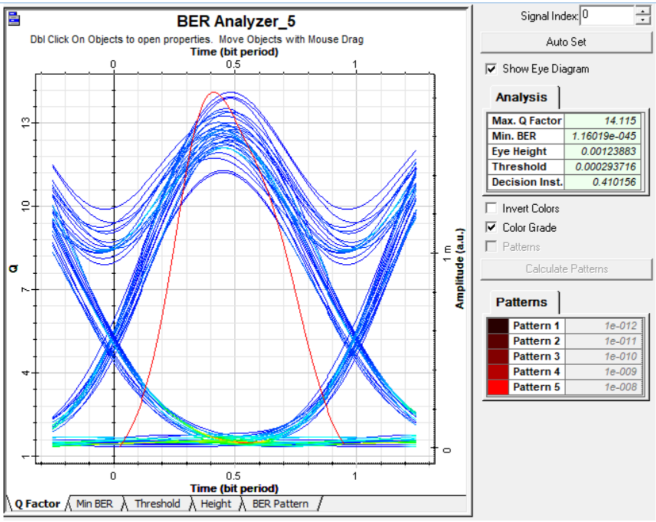
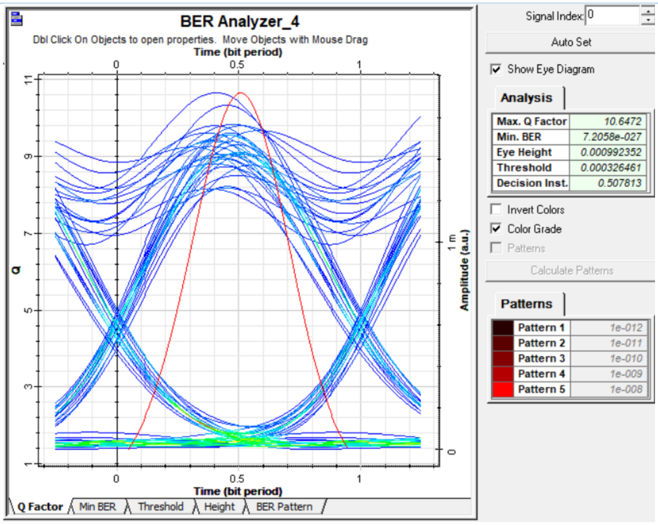
If we establish the Link budget, we find:

$P_e - A_{mux} + P_{pré\text{-}amp} + (-2*A_{SMF}*L_{SMF} - A_{DCF}*L_{DCF} + G_{EDFA}*3)*3 - A_{SMF}*L_{SMF} - A_{DCF}*L_{DCF} + G_{post\text{-}amp} - A_{demux}$ = 0.79-2.5 + 6 +(15*3-60*0.25-2*75*0.2)*3 – 0.2*50-0.25*10+20-2.5= 9.29dBm

$P_r = I_{dark} / R = 0.2*10^{-9}/0.9 = 0.2\ 10^{-9}$ W = -67 dBm < 9.29 dBm

III. Simulation Results

Channel	Eye diagram	Q-factor
1		11.7894
2		10.4853
3		15.3085

4		9.06055
5		14.115
6		10.6472

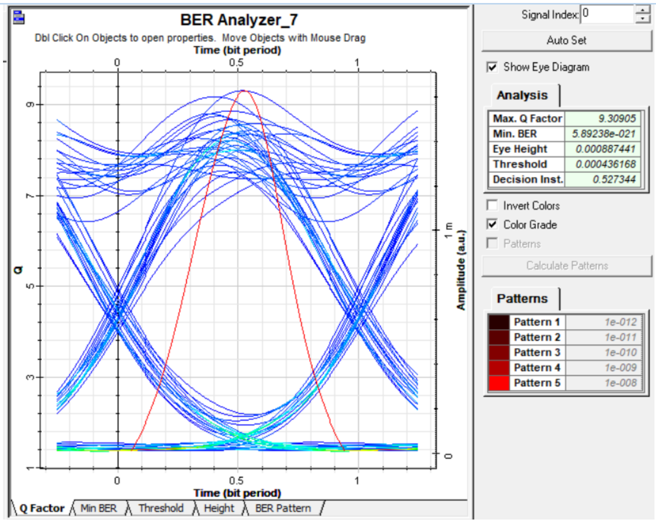
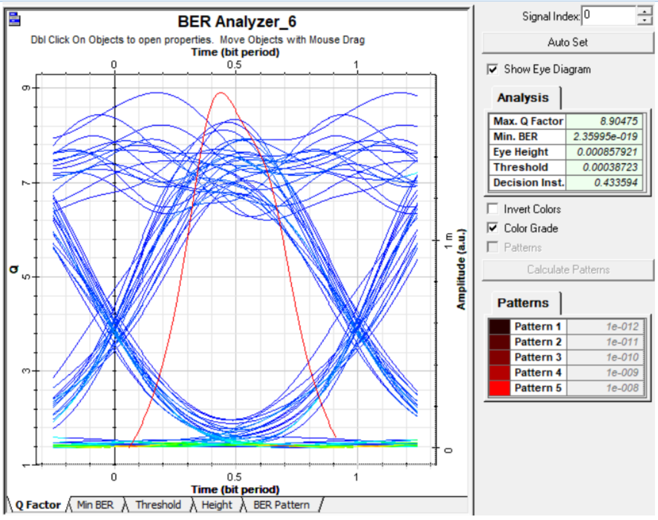
7		9.30905
8		8.90475

***Figure 18**: Simulation results for the different channels*

Conclusion

In conclusion, we tried in this project to apply all the knowledge acquired in the optical communication systems course to design a realistic 40Gbits 500 km 8 channels DWDM transmission chain that provides decent quality (the worst channel has a Q factor that equals 8.9) while respecting the datasheets of the different component.

Annex

- ***LQC1550-05E CW Laser Diode***

Overview

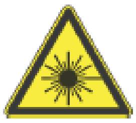
The LQC1550-05E CW Laser Diode Module is an economical choice. It includes the diode and collimating optics in a single case. This Fabry-Perot (FP) 1550 nm Laser Diode Module with a 5 mW CW elliptical beam comes in a self contained module. It requires a 5 VDC external power supply. An LPMS-5-110 or LPMS-5-220 Series Power Supply (not included) must be used with this LD module to meet CDRH requirements by providing an interlock input, key enable switch, delayed start-up, and laser active indicator. Warranty is not applicable when a custom power supply is used to drive the module.

Product Series Overview

Laser Diode Modules, CW

Technical Specs

Type	CW Laser Diode	**Size**	Ø38.1 x 157.5 mm
Center Wavelength	1550 nm	**Noise**	<0.5%
Center Wavelength Tolerance	±20 nm	**Applications**	Spectroscopy, Interferometry, Machine Vision, Marking, Flow Cytometry, Tissue Fluorescence
Output Power	5 mW		
Power Stability	<1% (8 hr.)		
Beam Diameter (1/e^2)	3.42 x 4.11 mm	**Linewidth**	1 nm
Beam Divergence Full Angle	<1.5 x 0.7 mrad	**Power Requirements**	4.8 to 12 VDC
Maximum Operating Current	3000 mA	**Operating Temperature**	0 to 40°C



- ***Photline MX1300-LN-40 Mach-Zehnder Modulator***

MX-LN-40 Performance Highlights

Parameter	Min	Typ	Max	Unit
Operating wavelength	1530	-	1625	nm
Insertion loss	-	3.5	-	dB
Electro-optical bandwidth	28	30	-	GHz
Vπ RF @50 kHz	-	5	-	V

Specifications given at 25 °C, 1550 nm

- ***OptoSpan DWDM Mux/Demux***

Optospan

8 CHANNEL PREMIUM DWDM MUX/DEMUX

DWDM-T08SUL-000

8+1 Channel DWDM (100GHz) Mux/Demux ITU Channels 30-37

OptoSpan DWDM-T08SUL-000 8-Channel DWDM Multiplexer/Demultiplexer is a high performance integrated system that combines eight ITU-T G.694.1 Dense Wavelength-Division Multiplexing (DWDM) wavelengths into a composite signal during transmit. During receive, the system separates a composite signal into eight individual wavelengths.

This dual-fiber low-cost passive MUX/DEMUX offers low insertion loss and high isolation for increased distance and reliability.

FEATURES

- Low Insertion Loss
- High Channel Isolation
- Epoxy-Free Optical Path
- 8 Channels: ITU 30 - 37
- Compatible OptoSpan Transceivers Available
- Passive Devices Require No Power Supply
- Customized WDM Solutions Available

APPLICATIONS

- Metro-Core, Metro-Access and Enterprise Networks
- Enterprises with Fiber Infrastructure
- Networks requiring ATM, Escon, Fibre Channel & Gigabit Ethernet Simultaneously
- Mirroring/Replicating data to Disaster Recovery Sites

REGULATORY COMPLIANCE

- Telcordia GR-1221 and GR-1209
- ITU-T G.694.1

OPTICAL SPECIFICATIONS

Parameter	Typical Value
Operating Wavelength	100 GHZ
Operating Channel	ITU ch30-ch37
Channel Passband	+/- 0.11 nm
Insertion Loss (with connector) in to drop and add to out	Max < 3.4 dB
Insertion Loss (with connector) in to UPG and UPG to out	Max < 2.6 dB
Liks Loss (mux+demux) (with connector) DWDM ports	Max < 4.7 dB
Polarization Dependent Loss	< 0.2 dB

Parameter	Typical Value
Directivity ch port	> 60 dB
Directivity UPG port	> 50 dB
Polarization Mode Dispersion	< 0.1 ps
Maximum Power Handing	500 mW
Operating Temperature	0ºC~70ºC
Storage Temperature	-40ºC~85ºC
Fiber Type	SMF-28e
Pigtail Type	900 um
Connector Type	LC/UPC

- ***Corning® SMF-28e® Optical fiber***

Optical Specifications

Fiber Attenuation

Maximum Attenuation

Wavelength (nm)	Maximum Value* (dB/km)
1310	0.33 – 0.35
1383**	0.31 – 0.35
1550	0.19 – 0.20
1625	0.20 – 0.23

*Maximum specified attenuation value available within the stated ranges.
**Attenuation values at this wavelength represent post-hydrogen aging performance.
Alternate attenuation offerings available upon request.

Attenuation vs. Wavelength

Range (nm)	Ref. λ (nm)	Max. α Difference (dB/km)
1285 – 1330	1310	0.03
1525 – 1575	1550	0.02

The attenuation in a given wavelength range does not exceed the attenuation of the reference wavelength (λ) by more than the value α.

Macrobend Loss

Mandrel Diameter (mm)	Number of Turns	Wavelength (nm)	Induced Attenuation* (dB)
32	1	1550	≤0.05
50	100	1310	≤0.05
50	100	1550	≤0.05
60	100	1625	≤0.05

*The induced attenuation due to fiber wrapped around a mandrel of a specified diameter.

Point Discontinuity

Wavelength (nm)	Point Discontinuity (dB)
1310	≤0.05
1550	≤0.05

Cable Cutoff Wavelength (λ_{ccf})

λ_{ccf} ≤ 1260 nm

Mode-Field Diameter

Wavelength (nm)	MFD (µm)
1310	9.2 ± 0.4
1550	10.4 ± 0.5

Dispersion

Wavelength (nm)	Dispersion Value [ps/(nm•km)]
1550	≤18.0
1625	≤22.0

Zero Dispersion Wavelength (λ_0): 1302 nm ≤ λ_0 ≤ 1322 nm
Zero Dispersion Slope (S_0): ≤ 0.089 ps/(nm²•km)

Polarization Mode Dispersion (PMD)

	Value (ps/√km)
PMD Link Design Value	≤0.06*
Maximum Individual Fiber	≤0.2

* Complies with IEC 60794-3: 2001, Section 5.5, Method 1, (m = 20, Q = 0.01%), September 2001.

The PMD link design value is a term used to describe the PMD of concatenated lengths of fiber (also known as PMD_Q). This value represents a statistical upper limit for total link PMD. Individual PMD values may change when fiber is cabled. Corning's fiber specification supports network design requirements for a 0.20 ps/√km maximum PMD.

Dimensional Specifications

Glass Geometry

Fiber Curl	≥ 4.0 m radius of curvature
Cladding Diameter	125.0 ± 0.7 µm
Core-Clad Concentricity	≤ 0.5 µm
Cladding Non-Circularity	≤ 0.7%

Coating Geometry

Coating Diameter	245 ± 5 µm
Coating-Cladding Concentricity	<12 µm

Environmental Specifications

Environmental Test	Test Condition	Induced Attenuation 1310 nm, 1550 nm & 1625 nm (dB/km)
Temperature Dependence	-60°C to +85°C*	≤0.05
Temperature Humidity Cycling	-10°C to +85°C* up to 98% RH	≤0.05
Water Immersion	23°± 2°C	≤0.05
Heat Aging	85°± 2°C*	≤0.05
Damp Heat	85°C at 85% RH	≤0.05

*Reference temperature = +23°C

Operating Temperature Range: -60°C to +85°C

- ***Thorlabs DCF38***

THORLABS

Dispersion Compensating Fiber

DCF38

Description

Thorlabs' dispersion compensating bare fiber delivers high performance across a broad spectral range in the telecom region. These fibers have both high mechanical reliability and high optical stability. The DCF38 fiber has dispersion designed specifically to match and compensate Corning L1000 or SMF-28e+ fiber.

Specifications

Dispersion Specifications	
Dispersion @ 1550 nm	-49.00 to -30.00 ps/nm*km
Dispersion Slope @ 1550 nm	-0.155 to -0.075 ps/nm^2*km
Typical Effective Area	≥26.8 µm^2
Polarization Mode Dispersion	≤0.05 ps/√km

General Specifications	
Mode Field Diameter @ 1550 nm	5.72 to 6.30 µm
Cladding Diameter	125.0 ± 1.0 µm
Coating Diameter	250 ± 5 µm
Coating-Cladding Concentricity	<12 µm
Core-Clad Concentricity	≤0.5 µm
Cutoff Wavelength	≤1520 nm
Attenuation @ 1550 nm	≤0.265 dB/km
Attenuation Slope from 1530 to 1565 nm	-0.00040 ≤ to ≤ -0.00011 dB/nm*km
Point Discontinuity	≤0.10 dB @ 1550 nm
Optical Return Loss	≥60 dB
Typical Splice Loss @ 1550 nm (Splice DCF38/DCF38)	≤0.15 dB

US, Canada, & South America: +1-973-300-3000 | France: +33 (0) 970 444 844 | Europe: +49 (0) 8131-5956-0 | UK & Ireland: +44 (0)1353-654440
Brazil: +55-16-3413 7062 | Scandinavia: +46-31-733-30-00 | Japan & Asia: +81-3-5979-8889 | China: +86 (0)21-60561122

- *OTS3000-EDFA*

Specifications

Parameters	Unit	OTS3000-BA	OTS3000-LA	OTS3000-PA
Dimension	mm	160×200×21（WxDxH）		
Maximal Power Consumption	W	15		
Input Power	dBm	-15 ~ 8	-30 ~ -5	-30 ~ -5
Gain	dB	15	24	18
Saturated Output Power	dBm	16	13	13
Wavelength Range	nm	1529 ~ 1564		
Flatness	dB	≤ 1.5		
Noise Figure	dB	≤ 5.0		
Input/ Output Pump Leakage	dBm	≤ -40		
Return Loss	dB	≤ -45		
Input/Output Isolation	dB	≥ 30		
Polarization Dependent Gain	dB	≤ 0.3		
Polarization Mode Dispersion	ps	≤ 0.5		
Working Mode		AGC/APC/ACC		
Connector Type		LC/PC		
Operating Temperature	℃	-5 ~ +55		
Storage Temperature	℃	-20 ~ +70		
Relative Humidity		5% ~ 95% (non-condensing)		

Ordering Information: OTS3000-EDFA-A-B-C-D-E

A：Amplifier Type	B：Saturated Output Power	C：Max Gain	D：Input Power Range	E：Connector Type
BA: Power amplifier **LA**: Line amplifier **PA**: Pre-amplifier **X**: Others	**16**: Max +16dBm **13**: Max+13dBm **X**: Others	**G24**: Max 24dB **G18**: Max 18dB **G15**: Max 15dB **X**: Others	**A**：-15 dBm ~ +8 dBm **B**：-30 dBm ~ -5 dBm **X**: Others	**LP**: LC/PC **X**: Others

- ***Acphotonics's Band Pass/ Edge Pass Filter***

acphotonics

RoHS COMPLIANT

Band Pass / Edge Pass Filters

ACP's Micro-Optics WDM utilizes thin film coating technology and proprietary design of non-flux metal bonding micro optics packaging. It provides low insertion loss, high channel isolation, low temperature sensitivity and epoxy free optical path. All AC Photonics' products are Telcordia qualification tested.

PERFORMANCE SPECIFICATIONS

Parameter	Specifications	
	Band Pass	**Edge Pass**
Pass Channel Wavelength Range	1570nm to 1609nm	1528nm to 1565nm
Reflect Channel Wavelength Range	1400nm to 1560nm + 1615nm to 1640nm	1450nm to 1490nm
Insertion Loss	≤ 0.6dB (Max); ≤ 0.4dB(Typ.)	
Insertion Loss Variation	≤ 0.25dB	
Rejection Channel Isolation	≥ 25dB	
Polarization Dependent Loss	≤ 0.10dB	
Return Loss	≥ 50dB	
Optical Power	≤ 500mW	
Operating Temperature	0 to +70°C	
Storage Temperature	-40 to +85°C	
Package Dimensions	Ø5.5 x L34mm (L38 for 900um)	

FEATURES

Wide Operating Wavelength Range
Low Insertion Loss
Flat Spectral Gain
High Stability and Reliability
Epoxy Free Optical Path

APPLICATION

DWDM System

- ***Thorlabs' Low band Filter***

THORLABS

5 kHz Low-Pass Filter

EF114

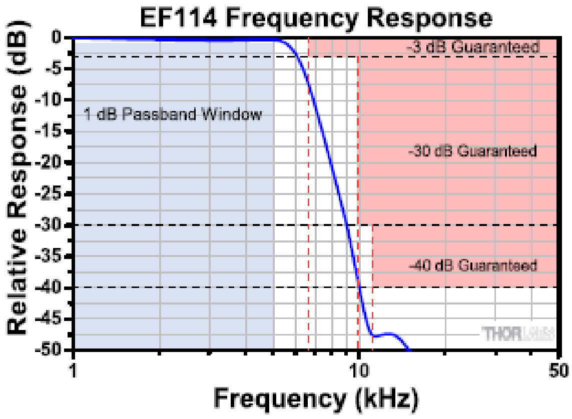
Description

The EF114 Low-Pass Filter employs a 5th order elliptic filter design. The design reduces group delay variation while preserving a practical 5th order rejection skirt. The EF114 is notably designed to terminate into any modern voltage signal transfer system that has a high impedance input, including DAQ systems, laboratory test equipment, and oscilloscopes. This architecture provides the highest signal-to-noise ratio capabilities for $V_{transfer}$ systems.

Specifications

EF114	Value[a]
Passband (1 dB Window)[b]	0 to 5 kHz
3 dB Rejection	> 6.61 kHz
30 dB Rejection	> 9.95 kHz
40 dB Rejection	> 11.14 kHz
Source Impedance (BNC Female)	50 Ω (Typical)
Load Impedance[c] (BNC Female)	≥100 kΩ (Typical)
Input Voltage	±10 V (Max)
Storage Temperature	-20 to +70 °C

a. Values measured at 25 °C.
b. Performance measured to 500 MHz.
c. This filter can be operated with termination resistances below 1 kΩ, however, the passband will narrow at smaller termination resistances and the performance is not guaranteed.



Sample Response Data

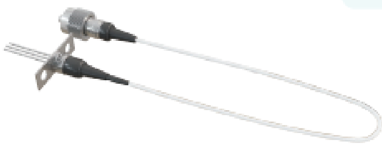
Freq. (kHz)	Rel. Resp. (dB)	Group Delay Variation (µs)
1.00	0.00	0.00
1.10	-0.04	-0.26
1.33	-0.10	-0.67
1.47	-0.15	-0.41
1.61	-0.20	-0.28
2.15	-0.33	0.57
2.60	-0.40	3.50
3.15	-0.44	8.23
3.47	-0.43	12.71
3.82	-0.40	18.66
4.20	-0.35	29.68
4.47	-0.32	39.14
4.67	-0.30	47.23
4.83	-0.31	55.91
4.96	-0.31	63.15
5.00	-0.32	65.48
5.05	-0.33	68.37
5.14	-0.37	74.87
5.23	-0.41	84.77
5.36	-0.55	94.31
5.51	-0.78	104.35
5.60	-1.01	108.61
5.90	-2.07	111.75
6.11	-3.16	103.21
6.55	-6.18	68.17
7.47	-15.04	-5.78

Freq. (kHz)	Rel. Resp. (dB)
9.04	-29.86
9.12	-30.68
9.20	-31.51
9.95	-39.46
10.04	-40.35
10.13	-41.28
10.76	-46.83
11.24	-48.22
12.70	-47.01
14.09	-48.14
16.20	-52.43
18.62	-59.20
21.22	-69.53
24.39	-61.97
28.28	-58.11
32.22	-56.78

Specifications Subject to Change without Notice

June 28, 2016
TTN104221-S01, Rev A

- ***High Liearity InGaAs PIN Photodiode***



High Linearity InGaAs PIN Photodiode

ACP's PTD-HL series InGaAs PIN Photodiode is sensitive at 1310nm and 1550nm bands. It has high linearity and very low second-order inter-modulation distortion (IMD2). Our state-of-the-art planar fabrication techniques lead to high quality and reliability.
All AC Photonics' products are Telcordia qualification tested.

FEATURES

Planar Semiconductor Design & Dielectric Passivation
3-Pin Coaxial Streamline Packaning with Fiber Pigtail
Souperior Noise and Photoelectric Perfomance (High Linearity)
Low Cost

APPLICATION

Optical Communication System
Optical Power monitor
Analog CATV Application, Such as High Frequency (860MHz) CATV receiver
Multi-access Transmitter, etc.

PERFORMANCE SPECIFICATIONS

Parameter	Symbol	Test Conditions	Min.	Typ.	Max.
Operation Wavelength	λ			1000nm - 1650nm	
Dark Current	ID	VR=5V, Ee=0		0.2nA	0.5nA
Responsivity	Re	VR=5V, λ=1310nm	0.85A/W	0.90A/W	
Responsivity	Re	VR=5V, λ=1550nm	0.90A/W	0.95A/W	
Capacitance	c	f=1MHz, case grounded VR=5V, Ee=0,		0.63pF	0.75pF
Operating Voltage	Vopr			-5V	-15V
Second Order Inter-modulation distortion	IMD2	f1=400MHz, P1=-3dBm f2=450.25MHz, P2=-3dBm MI=40%, Pavg=0dBm, Rload=50W IMD2: f1+f2=850.25MHz,VR=12V			
Back Reflection	RL				-40dB
Frequency Responsibility	BW	VR=5V, 50Ω Load with lead, length=6mm, case open	3GHz		

References

- Optiwave
- Wikipedia