100GE 40km SMF PMD

IEEE 802.3ba Task Force

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Chris Cole - Finisar

Pete Anslow - Nortel

Ramon Gutierrez - UNAM

Wenbin Jiang - Huawei

John Johnson - CyOptics

Radha Nagarajan - Infinera

Hirotaka Oomori - Sumitomo

Matt Traverso - Opnext

Supporters

- Ghani Abbas - Ericsson
- Arne Alping – Ericsson
- Ralf-Peter Braun – Deutsche Telekom
- Martin Carroll – Verizon
- Mike Dudek – JDSU
- Jörg-Peter Elbers – Adva
- Joel Goergen – Force10
- John Jaeger – Infinera
- Jack Jewell - JDSU
- Jeff Maki – Juniper Networks
- George Young - AT&T
- Mark Nowell – CISCO
- Gary Nicholl – CISCO
- Shoichi Ogita – Eudyna
- Thomas Paatzsch - Cube Optics
- Shashi Patel – Foundry Networks
- Bill Ryan – Foundry Networks
- Sam Sambasivan – AT&T
- Henk Steenman – AMS-IX
- Eddie Tsumura – ExceLight
- George Young - AT&T
- Ted Woodward – Telcordia

40km SMF Outline

- Status
- Architecture
- LAN WDM Baseline (-10nm) Grid
- 40km Baseline Grid Link and Power Budget

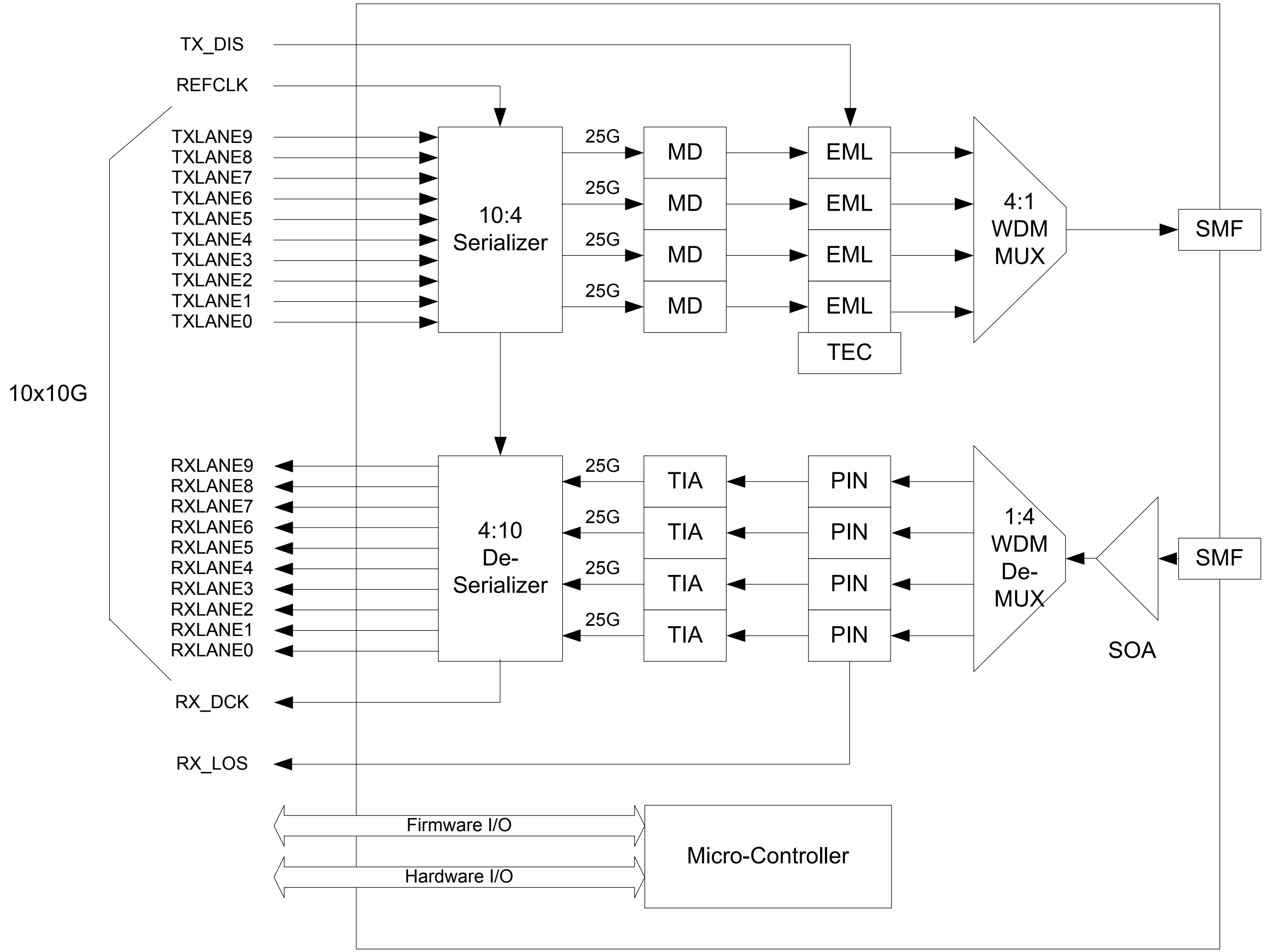
<u>The following appendices have NOT been reviewed by the presentation co-authors (other then the lead author) and supporters, so their co-authorship and support does not necessarily apply to any of the appendices</u>

- Appendix 1: LAN WDM Reference (0nm) Grid and Power Budget
- Appendix 2: LAN WDM -5nm Grid and Power Budget
- Appendix 3: LAN WDM -15nm Grid and Power Budget
- Appendix 4: 1310nm EML 40km SMF Dispersion Tolerance Measurements
- Appendix 5: SOA Overload Performance Simulation

40km SMF Status

- Baseline Approach to 40km SMF reach
  - TX: 4x25G MD-EML → LAN WDM Mux
  - RX: 4x25G PIN-TIA ← LAN WDM DeMux ← SOA
- Technical presentations discussing baseline approach
  - cole_01_1106, cole_02_0107, cole_01_0407, cole_01_0507, cole_01_0907, cole_02_0108
  - traverso_01_0407
  - jiang_01_0507, jiang_01_0907
  - gutierrez_01_0507, gutierrez_01/02/03/04_1107
  - matsumoto_01_1107
  - nagarajan_01_1107
  - johnson_01_0108
  - anslow_01_0308
- Key Issues analyzed
  - Min receiver sensitivity
  - Non-linear effects
  - Overload
  - PMD Penalty

Gen1 40km 4x25G 1310nm Transceiver Architecture



LAN WDM Baseline (-10nm) Grid

- ITU G.694.1 specification
- 800GHz spacing (193.1THz base)
- 4 wavelengths shifted by -10nm from Reference Grid
- Exact wavelength values: 1295.56 1300.05 1304.58 1309.14 nm
- Shorthand wavelength values: 1295, 1300, 1305, 1310 nm
- 2nm window (precise pass-band TBD)
- G.652 A&B 40km SMF worst dispersion and fiber loss
  - Max positive dispersion (1310nm) = 36ps/nm
  - Max negative dispersion (1295nm) = -114ps/nm
  - Max Loss (1310nm) = 16.8dB
  - Max Loss (1295nm) = 17.3dB

40km Baseline Grid Power Budget

25G Link Budget 40km SMF TP2 → TP3 dB	LAN WDM EML chirp α = -0.5 λ = 1295nm ER = 8dB
Fiber Loss (G.652 A&B)	17.3
Connector loss	2.0
Dispersion Penalty	1.5
Other Penalties (TX, PMD)	1.7
Total budget	22.5 dB

25G Pwr. Budget 40km SMF TP2 → TP3 OMA (Average) dBm	LAN WDM EML chirp α = -0.5 λ = 1295nm ER = 8dB
TX Min [Max]	2.6 (1.0) [5.6 (4.0)]
TP2 TX Min [Max] 2.5dB Mux loss	0.1 (-1.5) [4.1 (2.5)]
Link Budget (dB)	22.5 dB
TP3 RX Min	-22.4 (-24.0)
RX Min (with 1dB crosstalk penalty)	-10.2 (-11.8) dBm

- EML chirp range assumption: $-0.5 \leq \alpha \leq 1.0$
- 1.5 dB Dispersion Penalty and 1dB PMD in Other Penalties needs further quantification
- Min attenuation = 0dB assumption subject to verification of SOA WDM overload at low bias
- RX overload, max difference in power between wavelengths, other specs TBD

Appendix 1: LAN WDM Reference (0nm) Grid

- ITU G.694.1 specification
- 800GHz spacing (193.1THz base)
- 4 wavelengths selected for minimum dispersion in 1310nm window
- Exact wavelength values: 1305.72, 1310.28, 1314.88, 1319.51 nm
- Shorthand wavelength values: 1305, 1310, 1315, 1320 nm
- 2nm window
- G.652 A&B 40km SMF worst dispersion and fiber loss
  - Max positive dispersion (1320nm) = 75ps/nm
  - Max negative dispersion (1305nm) = -74ps/nm
  - Max Loss (1320nm) = 17dB
- Reference Grid is used as basis for comparison of alternate grid proposals

40km Reference Grid Power Budget

25G Link Budget 40km SMF TP2 → TP3	LAN WDM EML chirp α = 1.0 λ = 1320nm ER = 8dB
Fiber Loss (G.652 A&B)	17 dB
Connector loss	2.0
Dispersion Penalty	2.0
Other Penalties (TX, PMD)	1.7
Total budget	22.7 dB

25G Pwr. Budget 40km SMF TP2 → TP3 OMA (Average)	LAN WDM EML chirp α = 1.0 λ = 1320nm ER = 8dB
TX Min	2.6 (1.0) dBm
TP2 TX Min 2.5dB Mux loss	0.1 (-1.5)
Link Budget (dB)	22.7 dB
TP3 RX Min	-22.6 (-24.2)
RX Min (with 1dB crosstalk penalty)	-10.2 (-11.8) dBm

Appendix 2: LAN WDM -5nm Grid

- ITU G.694.1 specification
- 800GHz spacing (193.1THz base)
- 4 wavelengths shifted by -5nm from Reference Grid
- Exact wavelength values: 1300.62, 1305.15, 1309.71, 1314.3 nm
- Shorthand wavelength values: 1300, 1305, 1310, 1315 nm
- 2nm window
- G.652 A&B 40km SMF worst dispersion and fiber loss
  - Max positive dispersion (1315nm) = 56ps/nm
  - Max negative dispersion (1300nm) = -92ps/nm
  - Max Loss (1315nm) = 16.6dB
  - Max Loss (1300nm) = 17.1dB

40km -5nm Grid Power Budget

25G Link Budget 40km SMF TP2 → TP3 dB	LAN WDM EML chirp α = -0.5 λ = 1300nm ER = 8dB
Fiber Loss (G.652 A&B)	17.1
Connector loss	2.0
Dispersion Penalty	1.2
Other Penalties (TX, PMD)	1.7
Total budget	22 dB

25G Pwr. Budget 40km SMF TP2 → TP3 OMA (Average) dBm	LAN WDM EML chirp α = -0.5 λ = 1300nm ER = 8dB
TX Min [Max]	2.6 (1.0) [5.6 (4.0)]
TP2 TX Min [Max] 2.5dB Mux loss	0.1 (-1.5) [4.1 (2.5)]
Link Budget (dB)	22 dB
TP3 RX Min	-21.9 (-23.5)
RX Min (with 1dB crosstalk penalty)	-10.2 (-11.8) dBm

- EML chirp assumption: $-0.5 \leq \alpha \leq 1.0$
- 1.2 dB Dispersion Penalty and 1dB PMD in Other Penalties needs further quantification
- EML λ = 1315nm, chirp = 1.0: Dispersion Penalty = 1.5dB, Fiber Loss = 16.6dB

Appendix 3: LAN WDM -15nm Grid

- ITU G.694.1 specification
- 800GHz spacing (193.1THz base)
- 4 wavelengths shifted by -15nm from Reference Grid
- Exact wavelength values: 1290.54, 1295.00, 1299.49, 1304.01 nm
- Shorthand wavelength values: 1290, 1295, 1300, 1305 nm
- 2nm window
- G.652 A&B 40km SMF worst dispersion and fiber loss
  - Max positive dispersion (1305nm) = 19.2ps/nm
  - Max negative dispersion (1290nm) = -134ps/nm
  - Max Loss (1305nm) = 16.9dB
  - Max Loss (1290nm) = 17.6dB

40km -15nm Grid Power Budget

25G Link Budget 40km SMF TP2 → TP3 dB	LAN WDM EML chirp α = -0.5 λ = 1290nm ER = 8dB
Fiber Loss (G.652 A&B)	17.6
Connector loss	2.0
Dispersion Penalty	1.7
Other Penalties (TX, PMD)	1.7
Total budget	23.0 dB

25G Pwr. Budget 40km SMF TP2 → TP3 OMA (Average) dBm	LAN WDM EML chirp α = -0.5 λ = 1290nm ER = 8dB
TX Min [Max]	2.6 (1.0) [5.6 (4.0)]
TP2 TX Min [Max] 2.5dB Mux loss	0.1 (-1.5) [4.1 (2.5)]
Link Budget (dB)	23.0 dB
TP3 RX Min	-22.9 (-24.5)
RX Min (with 1dB crosstalk penalty)	-10.2 (-11.8) dBm

- EML chirp assumption: $-0.5 \leq \alpha \leq 1.0$
- 1.7dB Dispersion Penalty and 1dB PMD in Other Penalties needs further quantification
- EML λ = 1305nm Dispersion Penalty = 0.6dB, Fiber Loss = 16.9dB

Appendix 4: Dispersion Penalty Measurements

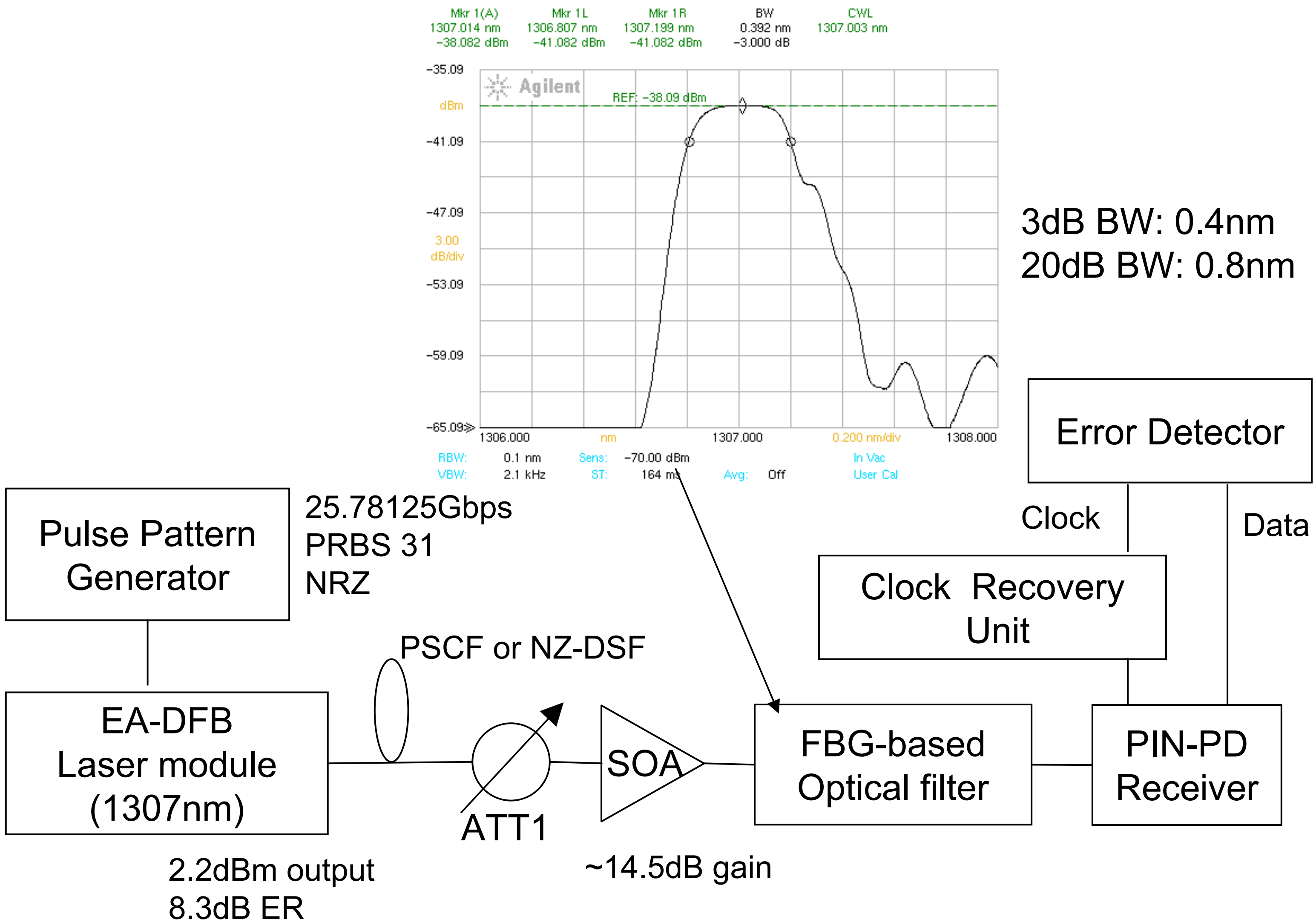
1310nm band EML Dispersion Tolerance Measurement Result over 40km SMF

100GE 40km PMD

Hirotaka Oomori (Sumitomo Electric Industries, Ltd.)

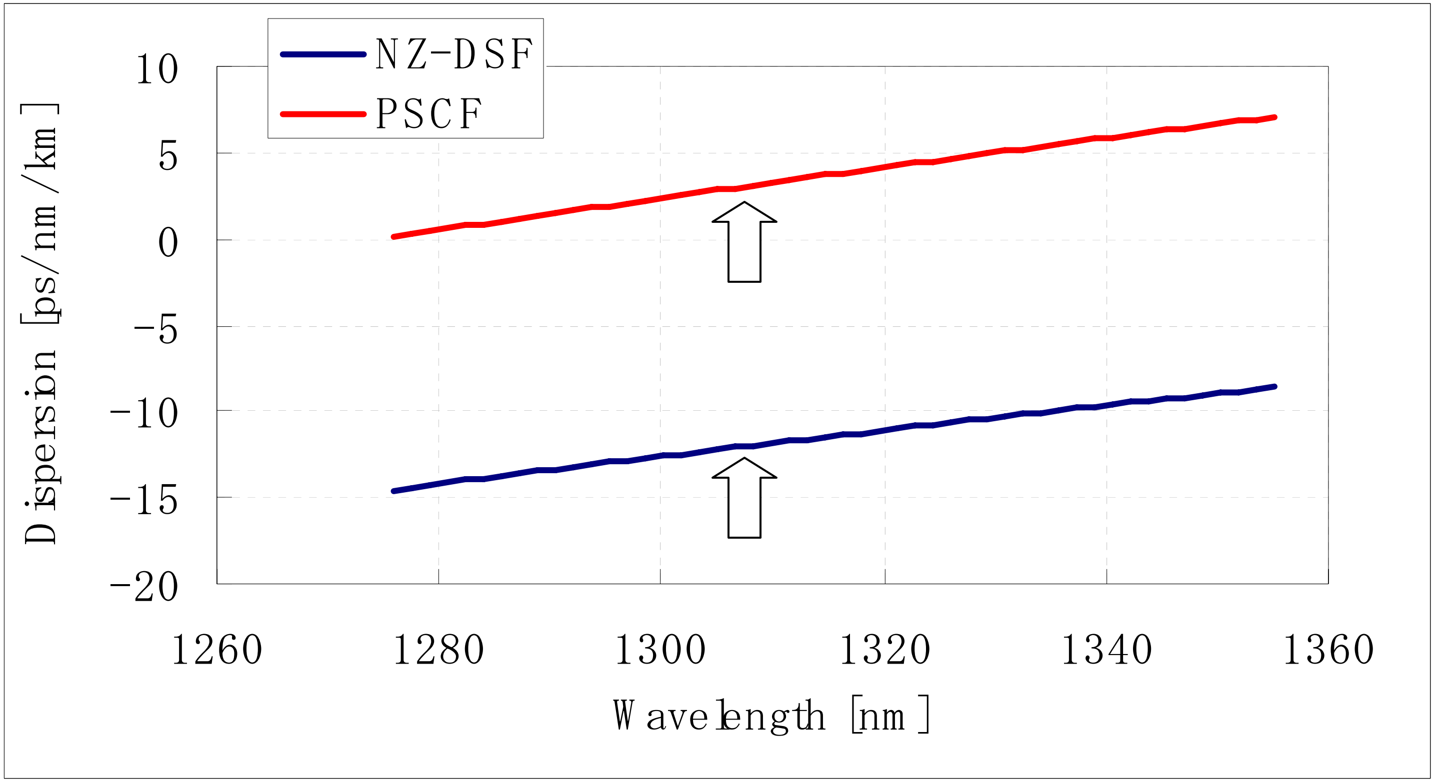
Eddie Tsumura (ExceLight Communications, Inc.)

Test Setup



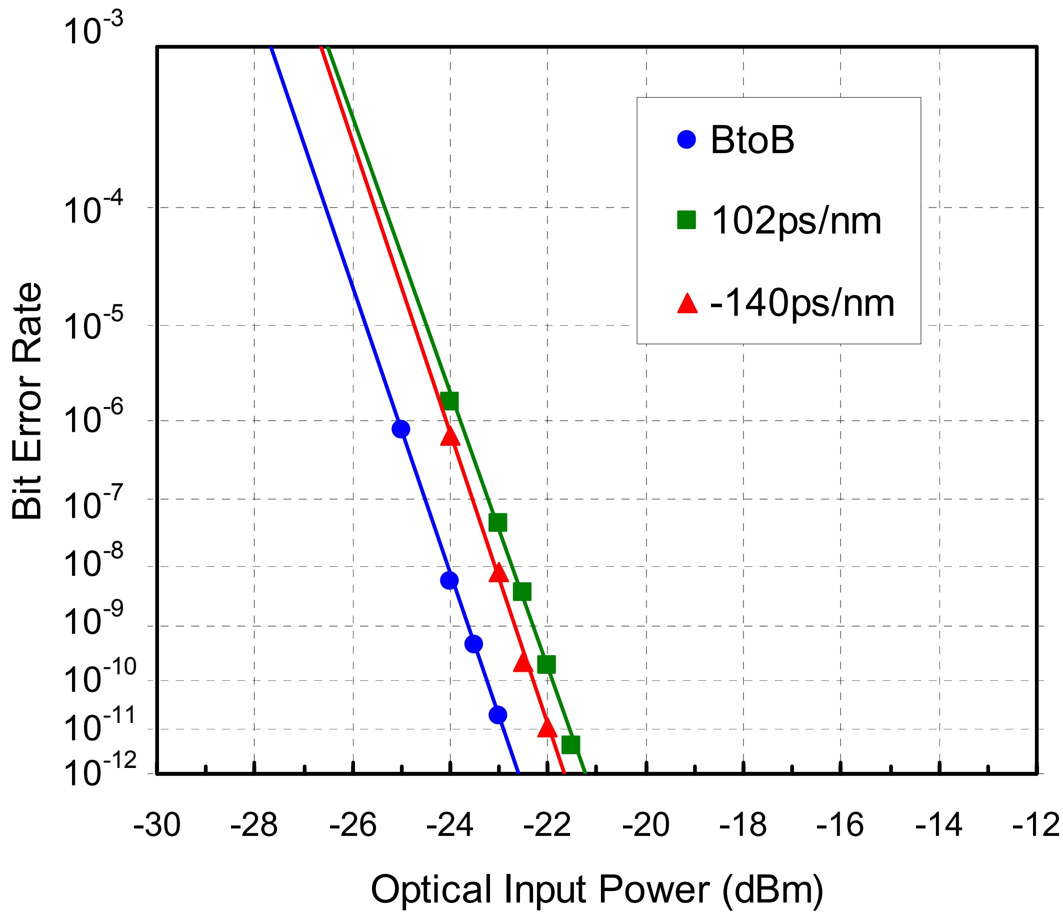
Mkr 1(A)
1307.014 nm
-38.082 dBm
Mkr 1L
1306.807 nm
-41.082 dBm
Mkr 1R
1307.199 nm
-41.082 dBm
BW
0.392 nm
-3.000 dB
CWL
1307.003 nm
Agilent
REF: -38.09 dBm
-35.09
dBm
-41.09
-47.09
3.00
dB/div
-53.09
-59.09
-65.09
1306.000
nm
1307.000
0.200 nm/div
1308.000
RBW: 0.1 nm
VBW: 2.1 kHz
Sens: -70.00 dBm
ST: 164 ms
Avg: Off
In Vac
User Cal
3dB BW: 0.4nm
20dB BW: 0.8nm
Error Detector
Clock
Data
Pulse Pattern Generator
25.78125Gbps
PRBS 31
NRZ
Clock Recovery Unit
PSCF or NZ-DSF
EA-DFB Laser module (1307nm)
ATT1
SOA
FBG-based Optical filter
PIN-PD Receiver
2.2dBm output
8.3dB ER
~14.5dB gain

Dispersion Value of NZ-DSF and PSCF



- NZ-DSF: Non Zero - Dispersion Shifted Fiber
- PSCF: Pure Silica Core Fiber

BER Measurement Result



- 1.4dB penalty @102ps/nm
- 0.9dB penalty @-140ps/nm

Appendix 5: Overload Performance Simulation

Gain-controlled SOA performance

High input power conditions

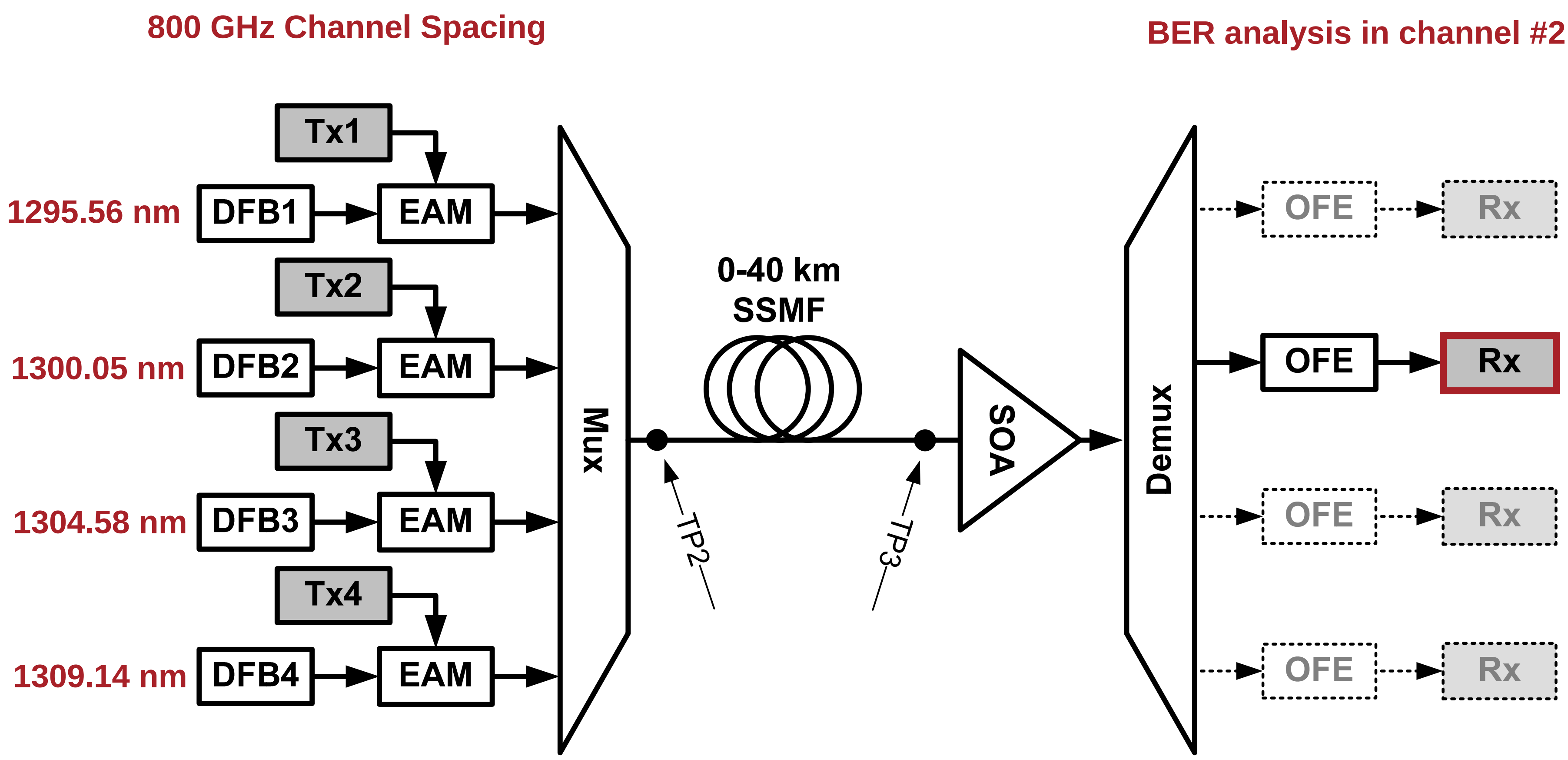
100 GbE 40-km PMD

Ramón Gutiérrez-Castrejón

Universidad Nacional Autonoma de Mexico-UNAM

email: RGutierrezC@ii.unam.mx

Optical Link Setup: 4x25-Gb/s EMLs & SOA Pre-Amp



EML Transmitters Characteristics

For the analysis we have considered:

- Extinction ratio = 8 dB
- Optical signal-to-noise ratio = 40 dB
- High and low EML output powers = +5.6 dBm, +2.6 dBm
- Insertion loss MUX = 2.5 dB
- Insertion loss DEMUX = 5.2 dB

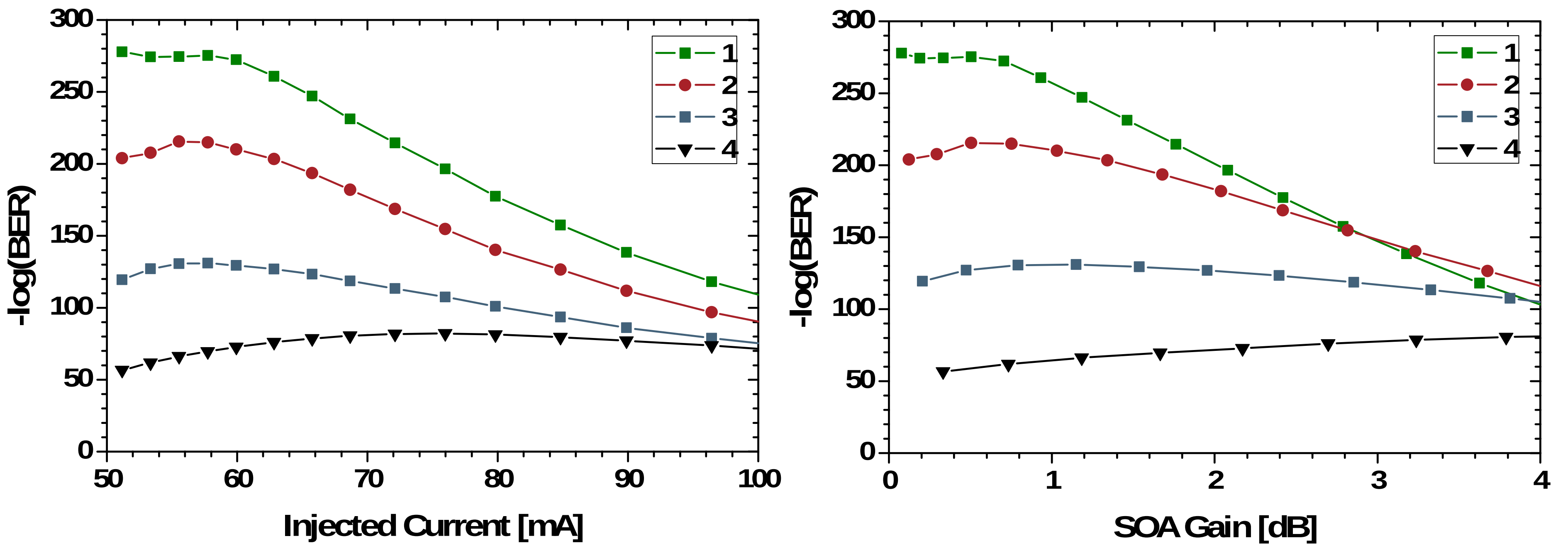
EML Output Power	+5.6 dBm	+2.6 dBm
Per Channel Power at TP2	**+3.1 dBm**	**+0.1 dBm**
Total Power at TP2	**9.1 dBm**	**6.1 dBm**

Simulation Characteristics

- BER vs. SOA injection current analysis
- Current varied in (50 mA ,…,100 mA), corresponding to small-signal gain in (4 dB,…,18 dB). Lower bound determined by SOA model.
- Four fiber lengths analyzed: 0, 0.001, 5 and 10 km
- Fiber Characteristics: losses: 0.45 dB/km (+ 2 dB connector), dispersion coefficient @ 1310 nm: D = -0.20 ps/nm/km, dispersion slope @ 1310 nm: S = 0.090 ps/nm^2/km
- Analysis for
  - <u>High</u> power transmitters: All channels at 5.6 dBm
  - <u>Low</u> power Transmitters: All channels at 2.6 dBm
  - <u>Combined</u> power: All channels at 5.6 dBm, but Tx2** at 2.6 dBm
- Special test bit pattern of 2^10-1 bits. See gutierrez_01_1107.

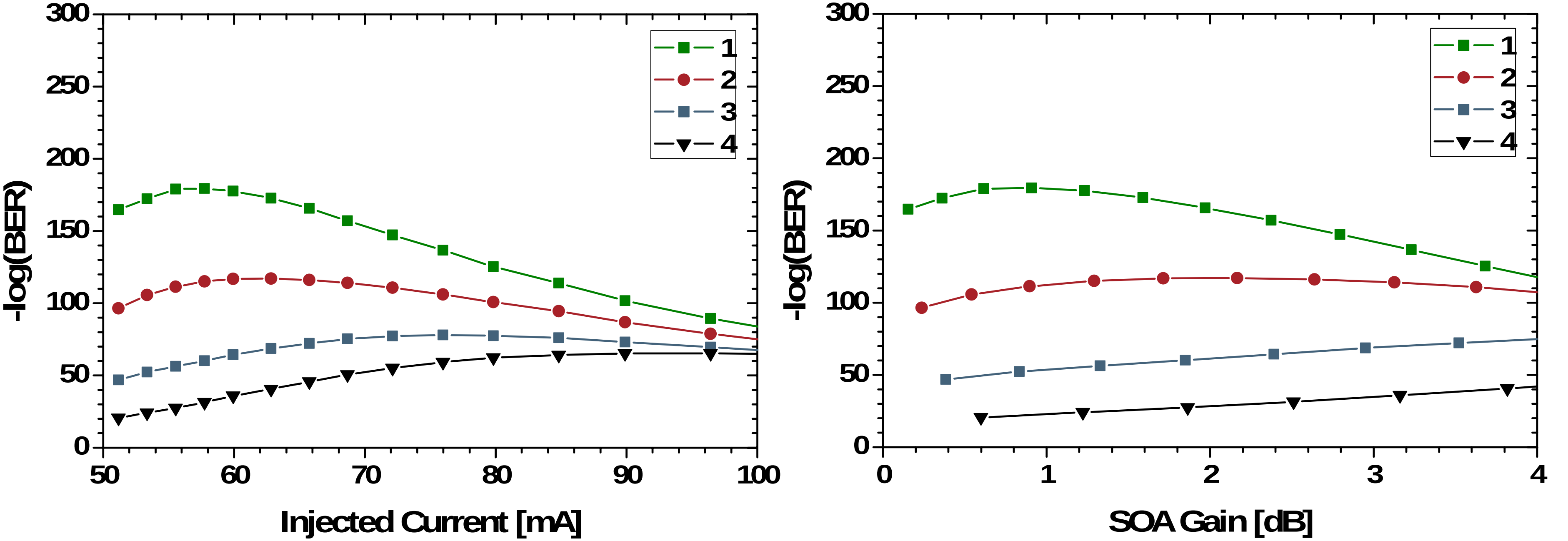
**** Note: BER Performance carried out in Channel 2 (Tx2)**

BER Performance: High Power Transmitter (5.6 dBm)



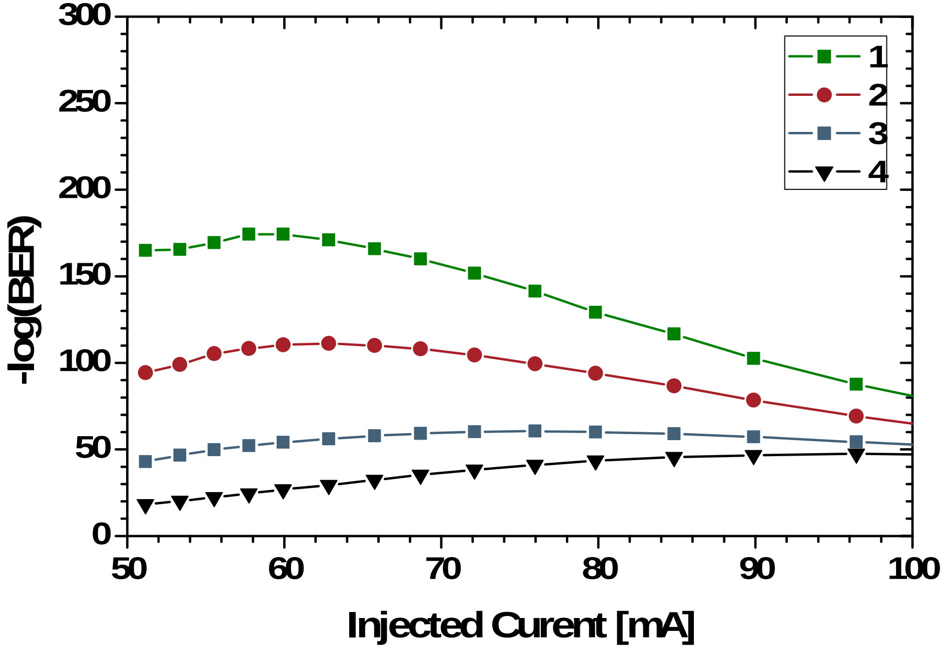
Curve	Fiber Length	Fiber Losses	SOA Input Power (Tot)
1	**0 km**	**0 dB**	**+9.10 dBm**
2	**0.001 km**	**2 dB**	**+7.10 dBm**
3	**5 km**	**4.25 dB**	**+4.85 dBm**
4	**10 km**	**6.50 dB**	**+2.60 dBm**

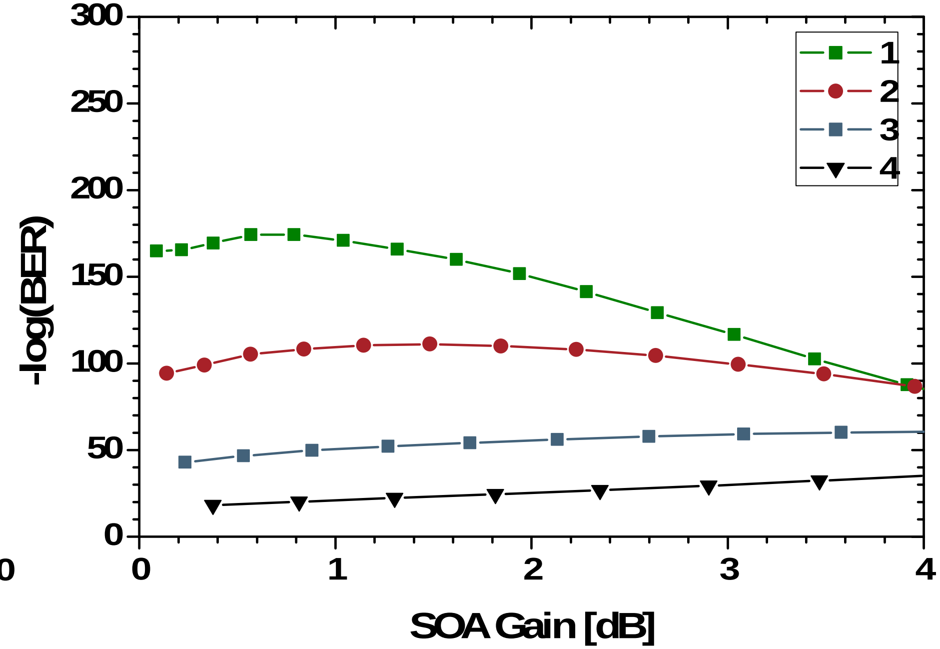
BER Performance: Low Power Transmitter (2.6 dBm)



Curve	Fiber Length	Fiber Losses	SOA Input Power (Tot)
1	0 km	0 dB	+6.10 dBm
2	0.001 km	2 dB	+4.10 dBm
3	5 km	4.25 dB	+1.85 dBm
4	10 km	6.50 dB	-0.40 dBm

BER Performance: High Power w/Low Power @ Tx8





Curve	Fiber Length	Fiber Losses	SOA Input Power (Tot)
1	**0 km**	**0 dB**	**+8.50 dBm**
2	**0.001 km**	**2 dB**	**+6.50 dBm**
3	**5 km**	**4.25 dB**	**+4.25 dBm**
4	**10 km**	**6.50 dB**	**+2.00 dBm**

Appendix 5 Conclusion

- The SOA gain-control scheme exhibits excellent performance for high optical powers
- Good system BER performance for a wide range of current values - no need for highly accurate control
- The SOA gain-control scheme operates correctly even above the transparency point (Gain > 0 dB)
- Single intermediate current value (e.g. 100 mA correspond to 18 dB of small-signal gain) is good enough for fiber lengths ranging from 0 to 10 km and even longer
- Results depends on SOA characteristics
- Measurements required to confirm findings