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40km SMF Outline

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

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

- 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 $\rightarrow$ LAN WDM Mux
  - RX: 4x25G PIN-TIA $\leftarrow$ LAN WDM DeMux $\leftarrow$ 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

10x10G

10:4 Serializer

RX_LANE9
RX_LANE8
RX_LANE7
RX_LANE6
RX_LANE5
RX_LANE4
RX_LANE3
RX_LANE2
RX_LANE1
RX_LANE0

25G 25G 25G

RX_LANE9
RX_LANE8
RX_LANE7
RX_LANE6
RX_LANE5
RX_LANE4
RX_LANE3
RX_LANE2
RX_LANE1
RX_LANE0

25G 25G 25G

TX_LANE9
TX_LANE8
TX_LANE7
TX_LANE6
TX_LANE5
TX_LANE4
TX_LANE3
TX_LANE2
TX_LANE1
TX_LANE0

25G 25G 25G
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

<table>
<thead>
<tr>
<th>40km SMF</th>
<th>TP2 → TP3</th>
<th>dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber Loss (G.652 A&amp;B)</td>
<td>17.3</td>
<td></td>
</tr>
<tr>
<td>Connector loss</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Dispersion Penalty</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>Other Penalties (TX, PMD)</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>Total budget</td>
<td>22.5 dB</td>
<td></td>
</tr>
</tbody>
</table>

#### 25G Pwr. Budget

<table>
<thead>
<tr>
<th>40km SMF</th>
<th>TP2 → TP3</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAN WDM</td>
<td>EML chirp $\alpha = -0.5$</td>
</tr>
<tr>
<td>$\lambda = 1295\text{nm}$</td>
<td></td>
</tr>
<tr>
<td>ER = 8dB</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OMA (Average) dBm</th>
</tr>
</thead>
<tbody>
<tr>
<td>TX Min [Max]</td>
</tr>
<tr>
<td>TP2 TX Min [Max]</td>
</tr>
<tr>
<td>2.5dB Mux loss</td>
</tr>
<tr>
<td>Link Budget (dB)</td>
</tr>
<tr>
<td>TP3 RX Min</td>
</tr>
<tr>
<td>RX Min (with 1dB crosstalk penalty)</td>
</tr>
</tbody>
</table>

| 22.5 dB |
| 0.1 (-1.5) [4.1 (2.5)] |
| 22.5 dB |
| -22.4 (-24.0) |
| -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

<table>
<thead>
<tr>
<th>25G Link Budget 40km SMF TP2 → TP3</th>
<th>25G Pwr. Budget 40km SMF TP2 → TP3 OMA (Average)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LAN WDM</strong>&lt;br&gt;EML chirp ( \alpha = 1.0 )&lt;br&gt;( \lambda = 1320\text{nm} )&lt;br&gt;ER = 8dB</td>
<td><strong>LAN WDM</strong>&lt;br&gt;EML chirp ( \alpha = 1.0 )&lt;br&gt;( \lambda = 1320\text{nm} )&lt;br&gt;ER = 8dB</td>
</tr>
<tr>
<td>Fiber Loss (G.652 A&amp;B)</td>
<td>TX Min</td>
</tr>
<tr>
<td>Connector loss</td>
<td>TP2 TX Min 2.5dB Mux loss</td>
</tr>
<tr>
<td>Dispersion Penalty</td>
<td>Link Budget (dB)</td>
</tr>
<tr>
<td>Other Penalties (TX, PMD)</td>
<td>TP3 RX Min</td>
</tr>
<tr>
<td>Total budget</td>
<td>RX Min (with 1dB crosstalk penalty)</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>25G Link Budget</th>
<th>LAN WDM</th>
<th>25G Pwr. Budget</th>
<th>LAN WDM</th>
</tr>
</thead>
<tbody>
<tr>
<td>40km SMF TP2 → TP3 dB</td>
<td>EML chirp $\alpha = -0.5$ $\lambda = 1300nm$ ER = 8dB</td>
<td>40km SMF TP2 → TP3 OMA (Average) dBm</td>
<td>EML chirp $\alpha = -0.5$ $\lambda = 1300nm$ ER = 8dB</td>
</tr>
<tr>
<td>Fiber Loss (G.652 A&amp;B)</td>
<td>17.1</td>
<td>TX Min [Max]</td>
<td>2.6 (1.0) [5.6 (4.0)]</td>
</tr>
<tr>
<td>Connector loss</td>
<td>2.0</td>
<td>TP2 TX Min [Max] 2.5dB Mux loss</td>
<td>0.1 (-1.5) [4.1 (2.5)]</td>
</tr>
<tr>
<td>Dispersion Penalty</td>
<td>1.2</td>
<td>Link Budget (dB)</td>
<td>22 dB</td>
</tr>
<tr>
<td>Other Penalties (TX, PMD)</td>
<td>1.7</td>
<td>TP3 RX Min</td>
<td>-21.9 (-23.5)</td>
</tr>
<tr>
<td>Total budget</td>
<td>22 dB</td>
<td>RX Min (with 1dB crosstalk penalty)</td>
<td>-10.2 (-11.8) dBm</td>
</tr>
</tbody>
</table>

- 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 $\lambda = 1315nm$, 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

<table>
<thead>
<tr>
<th>25G Link Budget</th>
<th>LAN WDM</th>
<th>25G Pwr. Budget</th>
<th>LAN WDM</th>
</tr>
</thead>
<tbody>
<tr>
<td>40km SMF TP2 → TP3 dB</td>
<td>EML chirp $\alpha = -0.5$ $\lambda = 1290nm$ ER = 8dB</td>
<td>EML chirp $\alpha = -0.5$ $\lambda = 1290nm$ ER = 8dB</td>
<td></td>
</tr>
<tr>
<td>Fiber Loss (G.652 A&amp;B)</td>
<td>17.6 dB</td>
<td>TX Min [Max]</td>
<td>2.6 (1.0) [5.6 (4.0)]</td>
</tr>
<tr>
<td>Connector loss</td>
<td>2.0 dB</td>
<td>TP2 TX Min [Max]</td>
<td>0.1 (-1.5) [4.1 (2.5)]</td>
</tr>
<tr>
<td>Dispersion Penalty</td>
<td>1.7 dB</td>
<td>2.5dB Mux loss</td>
<td>Link Budget (dB) 23.0 dB</td>
</tr>
<tr>
<td>Other Penalties (TX, PMD)</td>
<td>1.7 dB</td>
<td>TP3 RX Min</td>
<td>-22.9 (-24.5)</td>
</tr>
<tr>
<td>Total budget</td>
<td>23.0 dB</td>
<td>RX Min (with 1dB crosstalk penalty)</td>
<td>-10.2 (-11.8) dBm</td>
</tr>
</tbody>
</table>

- EML chirp assumption: $-0.5 \leq \alpha \leq 1.0$
- 1.7dB Dispersion Penalty and 1dB PMD in Other Penalties needs further quantification
- EML $\lambda = 1305nm$ 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

- **Pulse Pattern Generator**
- **EA-DFB Laser module (1307nm)**
  - 2.2dBm output
  - 8.3dB ER
- **FBG-based Optical filter**
- **PIN-PD Receiver**
- **Error Detector**
- **SOA**
- **ATT1**

Graph:
- **3dB BW: 0.4nm**
- **20dB BW: 0.8nm**

Specifications:
- **25.78125Gbps**: PRBS 31 NRZ
- **20dB BW: 0.8nm**
- **~14.5dB gain**
- **~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

e-mail: RGutierrezC@ii.unam.mx
Optical Link Setup: 4x25-Gb/s EMLs & SOA Pre-Amp

800 GHz Channel Spacing

1295.56 nm
DFB1 \rightarrow EAM
Tx1

1300.05 nm
DFB2 \rightarrow EAM
Tx2

1304.58 nm
DFB3 \rightarrow EAM
Tx3

1309.14 nm
DFB4 \rightarrow EAM
Tx4

0-40 km SSMF

BER analysis in channel #2

Demux

Rx

OFE

Rx

OFE

Rx

OFE
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

<table>
<thead>
<tr>
<th>EML Output Power</th>
<th>+5.6 dBm</th>
<th>+2.6 dBm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per Channel Power at TP2</td>
<td>+3.1 dBm</td>
<td>+0.1 dBm</td>
</tr>
<tr>
<td>Total Power at TP2</td>
<td>9.1 dBm</td>
<td>6.1 dBm</td>
</tr>
</tbody>
</table>
Simulation Characteristics

- BER vs. SOA injection current analysis
- Current varied in (50 mA,\ldots,100 mA), corresponding to small-signal gain in (4 dB,\ldots,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/nm²/km

- Analysis for
  - **High** power transmitters: All channels at 5.6 dBm
  - **Low** power Transmitters: All channels at 2.6 dBm
  - **Combined** 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)

<table>
<thead>
<tr>
<th>Curve</th>
<th>Fiber Length</th>
<th>Fiber Losses</th>
<th>SOA Input Power (Tot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 km</td>
<td>0 dB</td>
<td>+9.10 dBm</td>
</tr>
<tr>
<td>2</td>
<td>0.001 km</td>
<td>2 dB</td>
<td>+7.10 dBm</td>
</tr>
<tr>
<td>3</td>
<td>5 km</td>
<td>4.25 dB</td>
<td>+4.85 dBm</td>
</tr>
<tr>
<td>4</td>
<td>10 km</td>
<td>6.50 dB</td>
<td>+2.60 dBm</td>
</tr>
</tbody>
</table>
BER Performance: Low Power Transmitter (2.6 dBm)

Curves:

<table>
<thead>
<tr>
<th>Curve</th>
<th>Fiber Length</th>
<th>Fiber Losses</th>
<th>SOA Input Power (Tot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 km</td>
<td>0 dB</td>
<td>+6.10 dBm</td>
</tr>
<tr>
<td>2</td>
<td>0.001 km</td>
<td>2 dB</td>
<td>+4.10 dBm</td>
</tr>
<tr>
<td>3</td>
<td>5 km</td>
<td>4.25 dB</td>
<td>+1.85 dBm</td>
</tr>
<tr>
<td>4</td>
<td>10 km</td>
<td>6.50 dB</td>
<td>-0.40 dBm</td>
</tr>
</tbody>
</table>

- log(BER) vs. Injected Current [mA]
- log(BER) vs. SOA Gain [dB]
BER Performance: High Power w/Low Power @ Tx8

<table>
<thead>
<tr>
<th>Curve</th>
<th>Fiber Length</th>
<th>Fiber Losses</th>
<th>SOA Input Power (Tot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 km</td>
<td>0 dB</td>
<td>+8.50 dBm</td>
</tr>
<tr>
<td>2</td>
<td>0.001 km</td>
<td>2 dB</td>
<td>+6.50 dBm</td>
</tr>
<tr>
<td>3</td>
<td>5 km</td>
<td>4.25 dB</td>
<td>+4.25 dBm</td>
</tr>
<tr>
<td>4</td>
<td>10 km</td>
<td>6.50 dB</td>
<td>+2.00 dBm</td>
</tr>
</tbody>
</table>
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