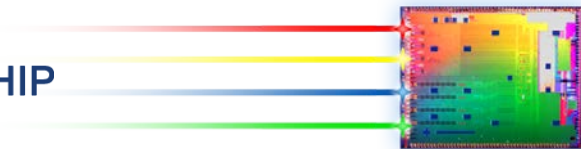


A Review of 400G-PSM4

Brian Welch

FIBER TO THE CHIP



Caveats and Disclaimers

- “400G-PSM4” in this presentation refers to the baseline proposal within welch_3bs_01_0315
- This presentation is a summary/compilation of material from other presentations

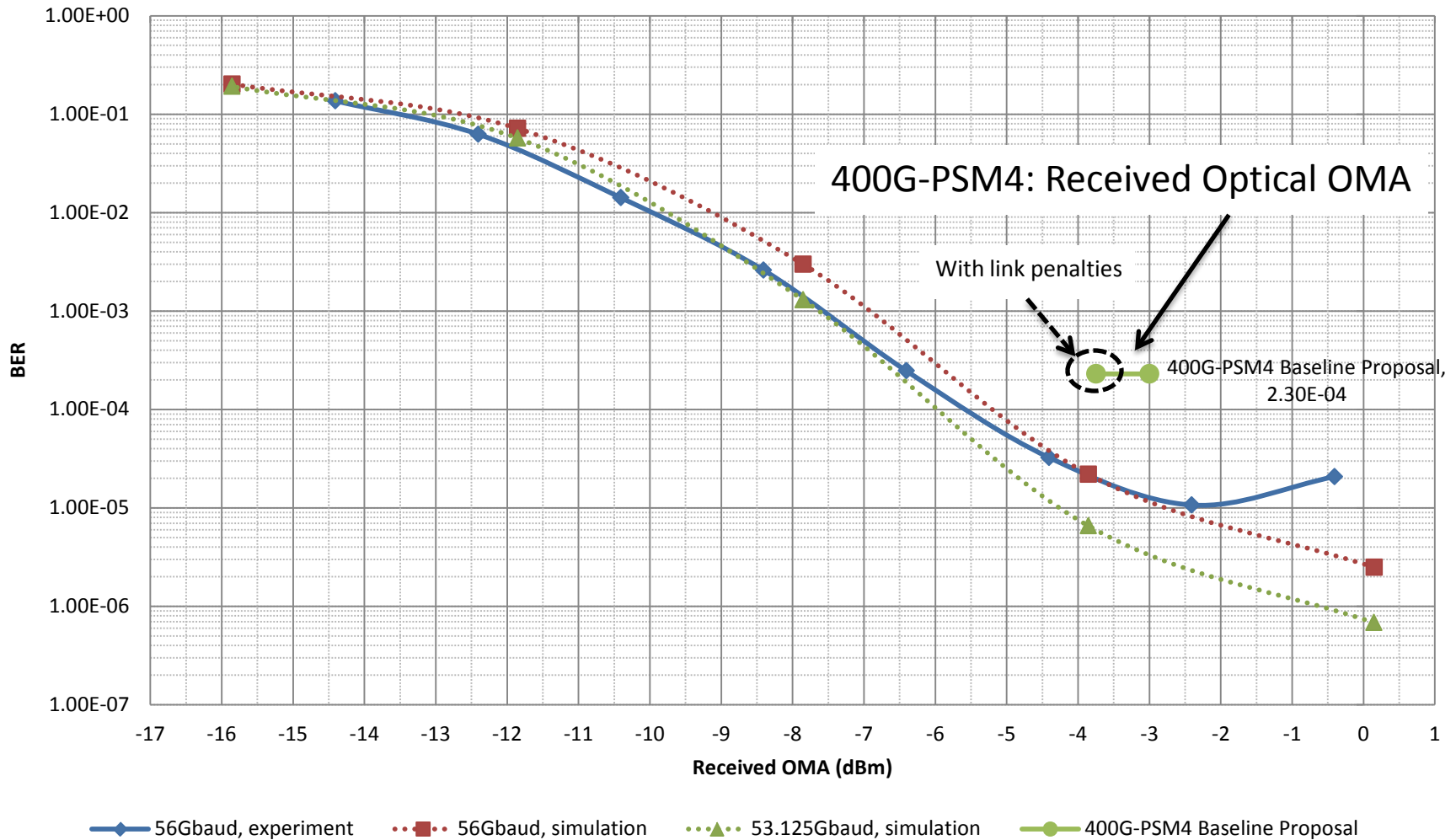
Overview

- Objective and Baseline Proposal
 - Technical Feasibility
 - Economic Feasibility
 - Broad Market Potential
 - Distinct Identity
 - Conclusions
-
- BTI Addressed: RX Technical feasibility on slides 5-7

Objective and Baseline Proposal

- Reach Objective: At least 500m over SMF
- Market Needs:
 - Intra-DC interconnects: Typical reaches 30-500 m
 - Double Link Fiber Plant
 - High volume link: cost/power sensitive
- Baseline Proposal
 - 400G-PSM4: 100G per Fiber over DL-PSM4 fiber plant
 - Welch_3bs_01_0315.pdf

Technical Feasibility: Experimental Results

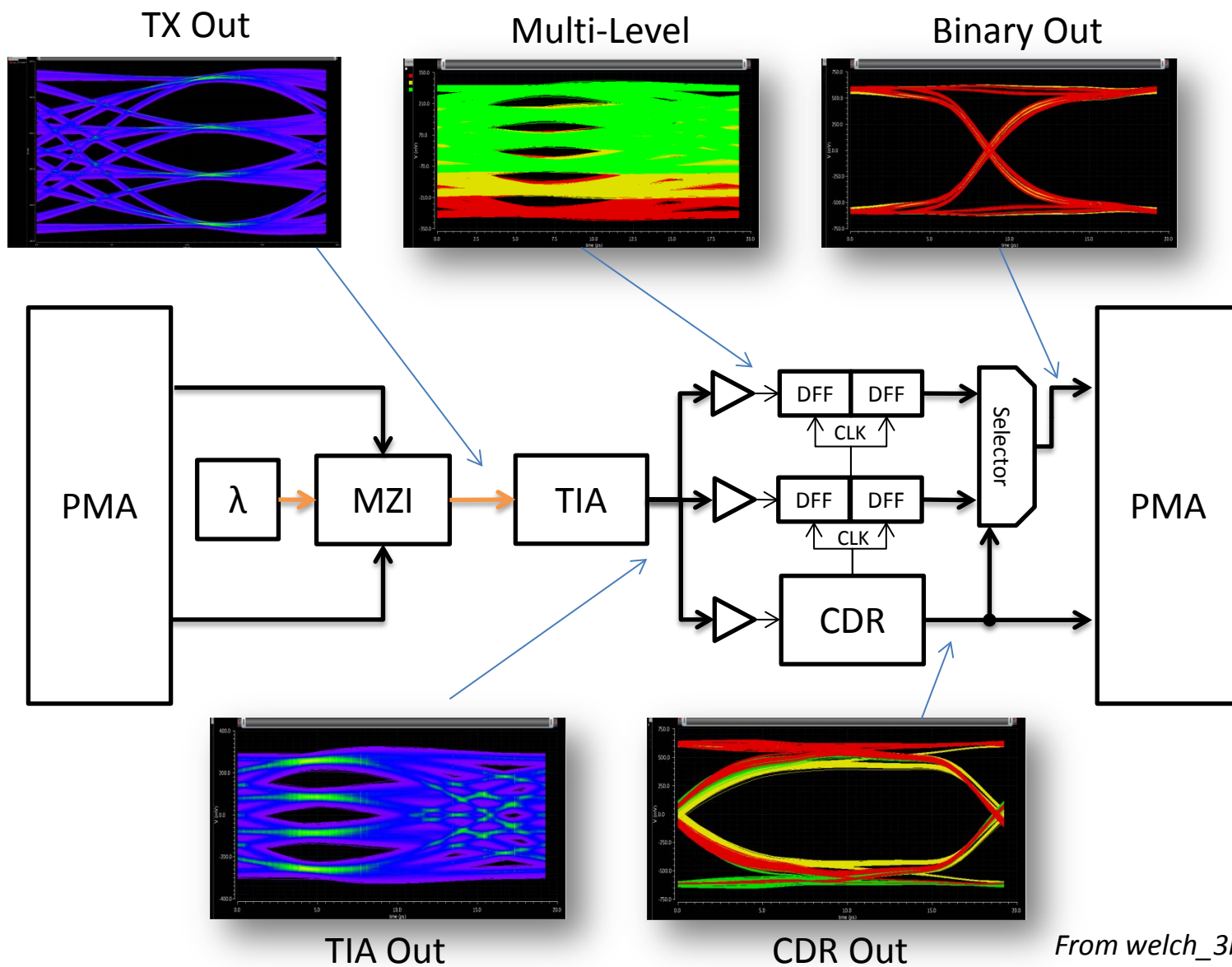


Converted to OMA from way_3bs_01a_0115 with 53.125 Gbaud simulation added.

Technical Feasibility: Experimental Results

- Vs. Measurement of 56 GBD-PAM4
 - Over 1 decade of BER Margin
 - Approximately 2.5 to 3 dB of OMA Margin
- Vs. Simulation of 53.125 GBD-PAM4
 - 1.5 to 2 decades of BER Margin
 - Approximately 3 to 3.5 dB of OMA Margin
- Shown for BER $2.3e-4$ = Correctable to $< 1e-15$
 - Vs. Objective requirement of $< 1e-13$

Technical Feasibility : Design Study (100 Gbps PAM4 link)



From welch_3bs_01b_0914

Technical Feasibility: Power Consumption (500m)

| | 100G-PSM4: 1λx4x25GBD-NRZ | 400G-PSM4: 1λx4x50GBD-PAM4 | 400G-PSM4: 2λx8x25GBD-PAM4 | 400G-PSM4: 2λx8x50GBD-NRZ |
|---------------------------|------------------------------|-------------------------------|-------------------------------|------------------------------|
| Electrical I/O | 500-800 | 2000-3200 | 2000-3200 | 2000-3200 |
| Optical Transmitters (#) | 4 | 4 | 8 | 8 |
| Optical Transmitters (mW) | 500 | 860 | 1160 | 1480 |
| Light Source (#) | 1 | 1 | 2 | 2 |
| Light Source (mW) | 250 | 375 | 562 | 562 |
| Receivers (#) | 4 | 4 | 8 | 8 |
| Receivers (mW) | 300 | 560 | 760 | 920 |
| PAM4 Decoder (#) | 0 | 4 | 8 | 0 |
| PAM4 Decoder (mW) | 0 | 1200 | 1600 | 1200 [†] |
| Auxilliary (mW) | 75 | 150 | 150 | 150 |
| Total (W) | 1.7 – 2.0 | 5.1 – 6.3 | 6.3 – 7.5 | 6.3 – 7.5 |

From welch_3bs_0115b

[†] Designates a 50 Gbaud CDR for NRZ operation

Economic Feasibility: Cost Comparison

| | Module Cost | Cost/Gbps (Normalized) |
|----------------------------|-------------|------------------------|
| 100G-PSM4: 1λx4x25GBD-NRZ | 1 | 1 |
| 400G-PSM4: 1λx4x50GBD-PAM4 | 1.3 – 1.6 | 0.3 - 0.4 |
| 400G-PSM4: 2λx8x25GBD-PAM4 | 3 – 3.6 | 0.8 – 0.9 |
| 400G-PSM4: 2λx8x50GBD-NRZ | 3 – 3.6 | 0.8 – 0.9 |
| 400G-FR4: 4λx4x50GBD-PAM4 | 4.6 – 5.7 | 1.1 – 1.4 |
| 400G-FR8: 8λx8x25GBD-PAM4 | 10 - 12.9 | 2.5 – 3.2 |
| 400G-FR8: 8λx8x50GBD-NRZ | 10 - 12.9 | 2.5 – 3.2 |

400G-PSM4 over 60% lower cost than any other proposal

From *welch_3bs_0115b*

Broad Market Potential

- 400G-PSM4 has the support of 33 people from 20 different companies
- 100G per wavelength solutions have the support of 42 people from 22 different companies
- Support included optical chipset & transceiver providers, host silicon & system providers, system integrators & datacenter operators, and test equipment companies
- 400G-PSM4 has applications beyond 400G Ethernet
 - 4x100G Ethernet and breakout
 - Derivative 1x100G solutions

Distinct Identity

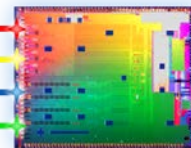
- 400G-PSM4 solutions (four SMF fibers per direction) services reaches between 16 Fiber (per Direction) 400G-SR16 solutions and Duplex SMF solutions.
- 400G-PSM4 solutions services short to medium reaches in “SMF only” data centers
- 400G-PSM4 has lower fiber cost than 400G-SR16, lower transceiver cost than duplex solutions
 - 400G-SR16 transceiver cost currently unknown (to the author)

Summary

- **400G-PSM4 is technically feasible**
 - Contemporary test results show decent margin for 400G-PSM4 baseline proposal
 - Lowest power of 400G SMF proposals
- **400G-PSM4 is economically viable**
 - Over 60% lower cost than any alternate proposal
- **400G-PSM4 has broad market potential**
 - Supported by 33 people from 20 companies representing many different sectors of the optics industry
- **400G-PSM4 has distinct identity**
 - Longer reach, lower fiber count than 400G-SR16
 - Lower cost, lower power than 2km and 10km proposals

Thank You

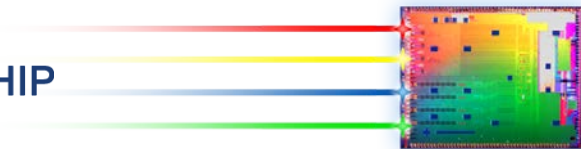
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Appendix

Cost Derivations from
welch_3bs_02_0115b

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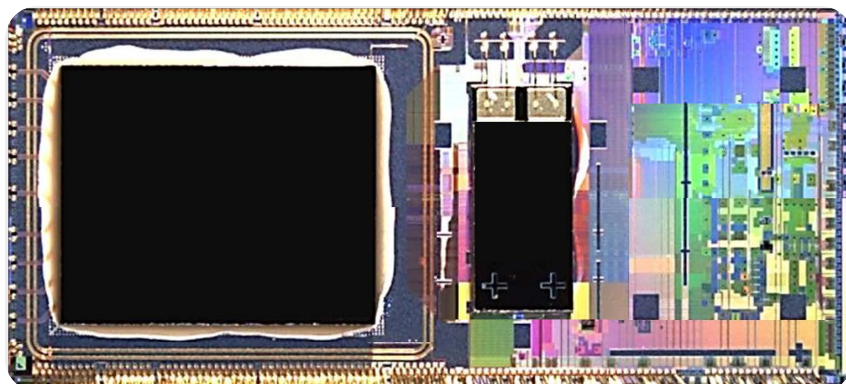


Methodology

- Employs the transceiver cost modeling methodology first employed in `welch_01b_0113_optx.pdf`
 - COGS build up from silicon photonics chipset
- Solutions compared to 100G-PSM4
- Assuming a CDAUI-8 electrical interface for all solutions
- Parametric yield effects not considered

Baseline – 100G-PSM4

Chipset



| | |
|-----------------|--------------------|
| | |
| Photonics IC | 68 mm ² |
| Electronics IC | 17 mm ² |
| Light Source(s) | 1 |
| Chipset COGS | 1 |

Module

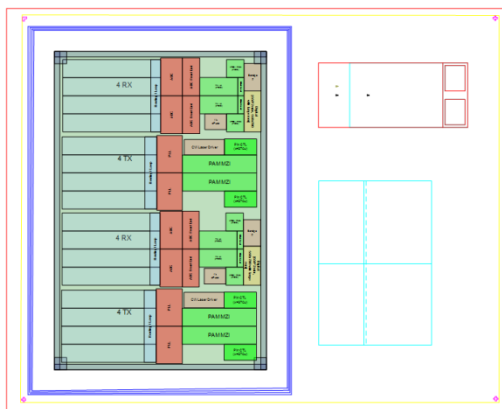


| | |
|--------------------------|-----|
| | |
| Chipset COGS | 1 |
| Optical Attaches | 2 |
| Yield per Attach | 95% |
| Net Yield | 90% |
| Module COGS [†] | 1 |

† Renormalized with packaging and transformation costs applied

400G-PSM4: 1λx4x50GBD-PAM4

Chipset



| | |
|-----------------|------------------------|
| Photronics IC | 102 mm ² |
| Electronics IC | 34 mm ² |
| Light Source(s) | 1 |
| Chipset COGS | 1.5 - 1.7 [‡] |

‡ Range reflects potential for increased light source cost due to more stringent TX specifications

Module



| | |
|--------------------------|------------------------|
| Chipset COGS | 1.5-1.7 |
| Optical Attaches | 2 |
| Yield per Attach | 95% |
| Net Yield | 90% |
| Module COGS [†] | 1.3 – 1.6 [‡] |

† Renormalized with packaging and transformation costs applied

400G-PSM4: 2λx8x25GBD-PAM4

Chipset



| | |
|-------------------|----------------------|
| Photronics IC | 148 mm ² |
| Electronics IC | 40 mm ² |
| Light Source(s) | 2 |
| 8:4 WDM MUX/Demux | 1 |
| Chipset COGS | 2.9-3.4 [‡] |

‡ Range reflects potential for increased light source cost due to more stringent TX specifications

Module

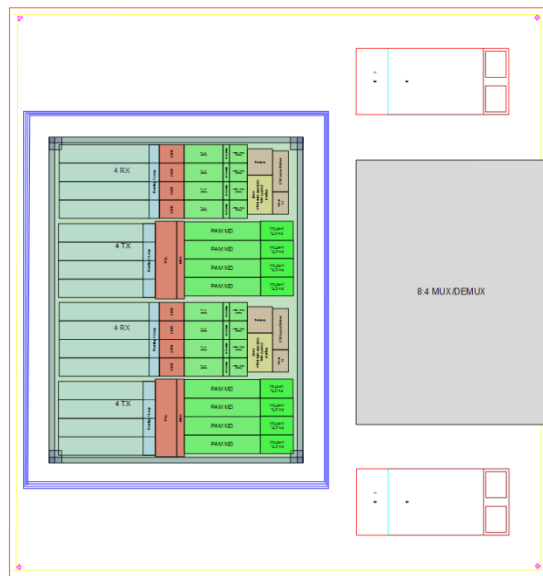


| | |
|--------------------------|----------------------|
| Chipset COGS | 2.9-3.4 |
| Optical Attaches | 3 |
| Yield per Attach | 95% |
| Net Yield | 86% |
| Module COGS [†] | 3 – 3.6 [‡] |

† Renormalized with packaging and transformation costs applied

400G-PSM4: 2λx8x50GBD-NRZ

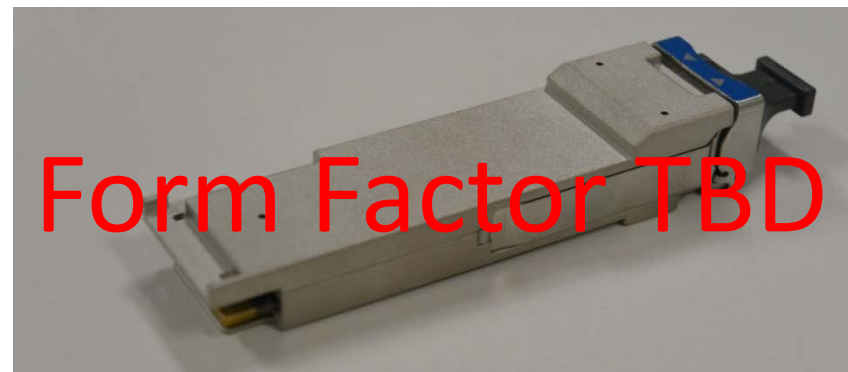
Chipset



| | |
|-------------------|----------------------|
| Photonics IC | 148 mm ² |
| Electronics IC | 40 mm ² |
| Light Source(s) | 2 |
| 8:4 WDM MUX/Demux | 1 |
| Chipset COGS | 2.9-3.4 [‡] |

‡ Range reflects potential for increased light source cost due to more stringent TX specifications

Module



| | |
|--------------------------|----------------------|
| Chipset COGS | 2.9-3.4 |
| Optical Attaches | 3 |
| Yield per Attach | 95% |
| Net Yield | 86% |
| Module COGS [†] | 3 – 3.6 [‡] |

† Renormalized with packaging and transformation costs applied

400G-FR4: 4λx4x50GBD-PAM4

Chipset



| | |
|-------------------|----------------------|
| Photonics IC | 167 mm ² |
| Electronics IC | 34 mm ² |
| Light Source(s) | 4 |
| 4:1 WDM MUX/Demux | 1 |
| Chipset COGS | 3.9-4.9 [‡] |

Module



| | |
|--------------------------|------------------------|
| Chipset COGS | 3.9 – 4.9 |
| Optical Attaches | 5 |
| Yield per Attach | 95% |
| Net Yield | 77% |
| Module COGS [†] | 4.6 – 5.7 [‡] |

[†] Renormalized with packaging and transformation costs applied

400G-FR8: 8λx4x25GBD-PAM4

Chipset



| Chipset | |
|-------------------|---------------------|
| Photonics IC | 218 mm ² |
| Electronics IC | 40 mm ² |
| Light Source(s) | 8 |
| 8:1 WDM MUX/Demux | 1 |
| Chipset COGS | 7-9 [‡] |

| Module | |
|--------------------------|------------------------|
| Chipset COGS | 3.9 – 4.9 |
| Optical Attaches | 9 |
| Yield per Attach | 95% |
| Net Yield | 63% |
| Module COGS [†] | 10 – 12.9 [‡] |

[†] Renormalized with packaging and transformation costs applied

400G-FR8: 8λx4x50GBD-NRZ

Chipset



| Chipset | |
|-------------------|---------------------|
| Photonics IC | 218 mm ² |
| Electronics IC | 40 mm ² |
| Light Source(s) | 8 |
| 8:1 WDM MUX/Demux | 1 |
| Chipset COGS | 7-9 [†] |

| Module | |
|--------------------------|------------------------|
| Chipset COGS | 3.9 – 4.9 |
| Optical Attaches | 9 |
| Yield per Attach | 95% |
| Net Yield | 63% |
| Module COGS [†] | 10 – 12.9 [†] |

[†] Renormalized with packaging and transformation costs applied