400G Optics – Technologies, Timing, and Transceivers

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Caveats and Disclaimers

- **This presentation is** an investigation into three potential solutions for 400G optical transceivers given the current objectives
  - Solutions perceived by the author to have a high probability of technical feasibility
  - Investigations and comparison are using a silicon photonics technology basis
- **This presentation is not** an investigation into all potential solutions for the current objectives
- **This presentation is not** a proposal for any particular solution to satisfy any particular objective
  - Does seek to identify for which objectives the solutions *might* be relative

Agenda

- Reach Objectives
  - 500 m
  - 2 km
  - 10 km
- Market Timing
- Potential Solutions
  - 400G-PSM16 (16x25G)
  - 400G-PSM4 (4x100G)
  - 400G-LR4 (1x400G)
- Comparisons

Reach Objectives

- 500m: Intra-Building
  - Datacenter focused (especially Hyper-Scale DC)
  - Comparable link counts to SR interconnects (similar cost structures desired)
  - Typically pre-terminated fiber plants
  - Approximately 4 dB loss budget
- 2km: Inter-Building
  - Medium reach interconnects
  - Lower link counts than SR interconnects
  - Typically field-terminated fiber plants
  - Approximately 5dB loss budget
- 10km: Inter-Building/Site
  - Long reach 'local' interconnects
  - Low link counts
  - Field-terminated fiber plants
  - Approximately 6dB loss budget

Market Timing

- Initial 400G Standard expected to be ratified in 2017
  - Seven years after 40/100G Ethernet
- First 400G product shipments likely in 2017-2018
  - Native 400G products, not 4x100G solutions
- High volumes of gen 1 400G not likely before 2020

Ethernet Name	Date Initial Standard Ratified
10Mb/s	1983
100Mb/s	1995
Gigabit	1998
10 Gigabit	2002
40 Gigabit	2010
100 Gigabit	2010
400 Gigabit	2017

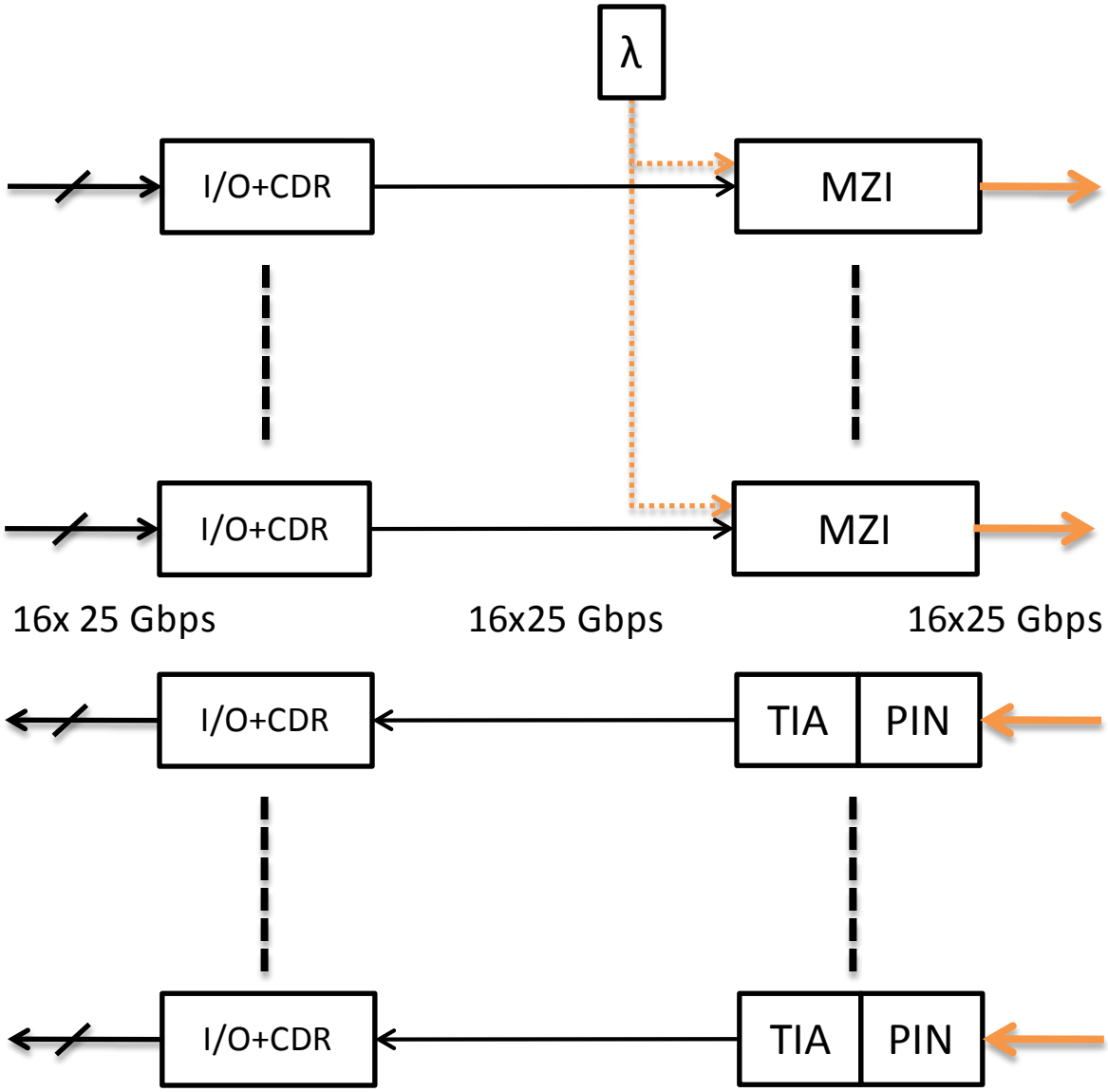
http://www.ethernetalliance.org/subcommittees/roadmapping-subcommittee/

Market Timing

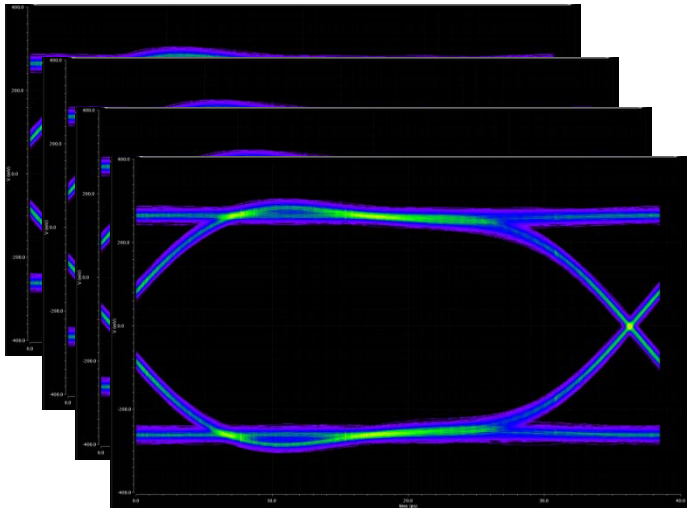
- What solutions will be relevant 6 years from today?
  - 16 Channel Electrical Interface? 8 Channel? 4?
  - 16 Channel Optical Interface? 8 Channel? 4?
  - Predominantly modules? Embedded? Integrated?
- What technologies will those solutions use?
  - 25 Gbaud serial rates? 50 Gbaud? 100?
  - Optical? Electrical?
- Will they be seven years more advanced than 100G?
  - Advanced node in 2010: 45 nm
  - Advanced node in 2014: 20 nm
  - Advanced node in 2017: 16 nm? 10nm?
  - Feature size approximately 1/3rd to 1/4th of 100G contemporary technology?

Potential Solutions

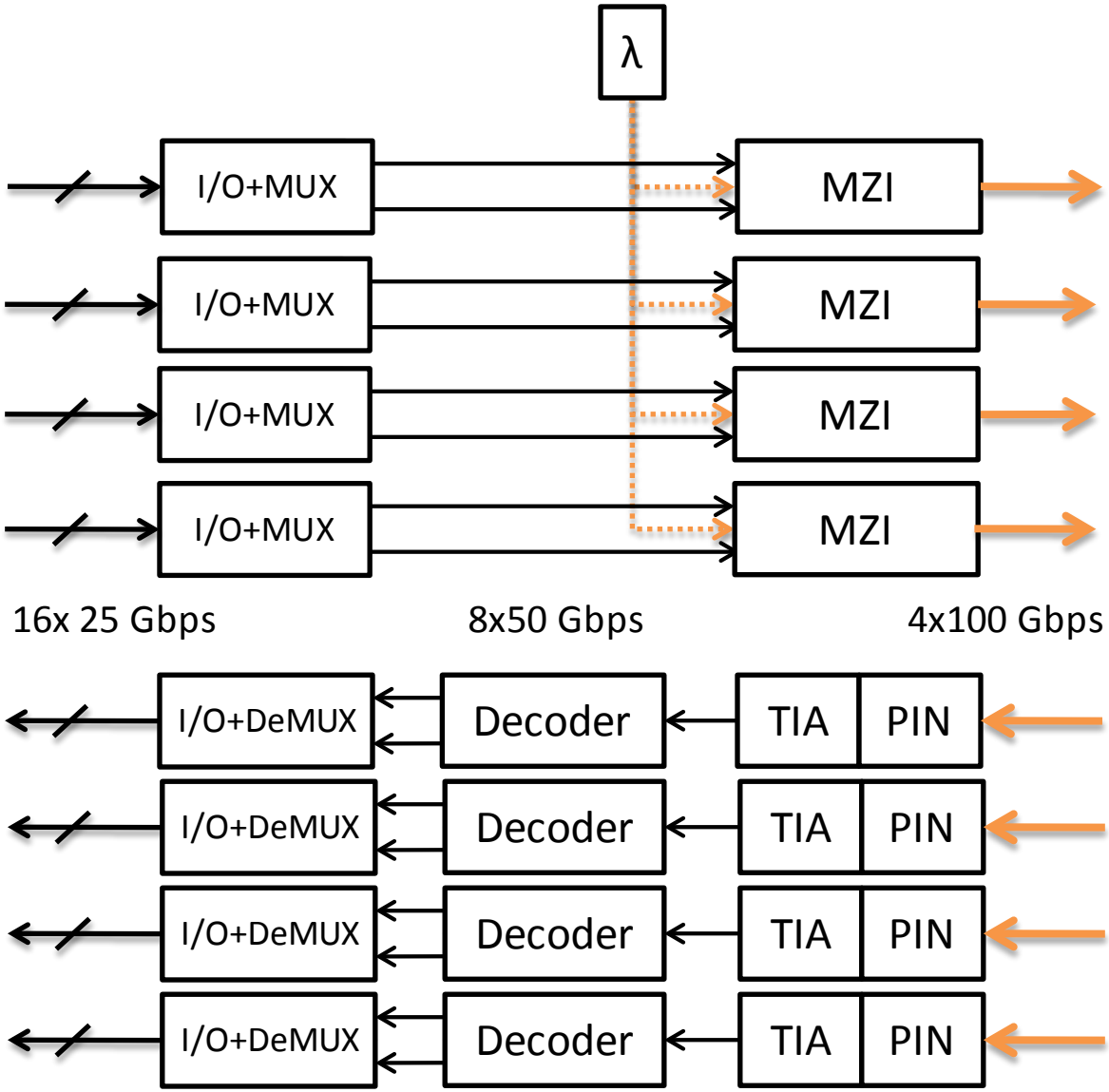
400G-PSM16: Parallel Fiber Only



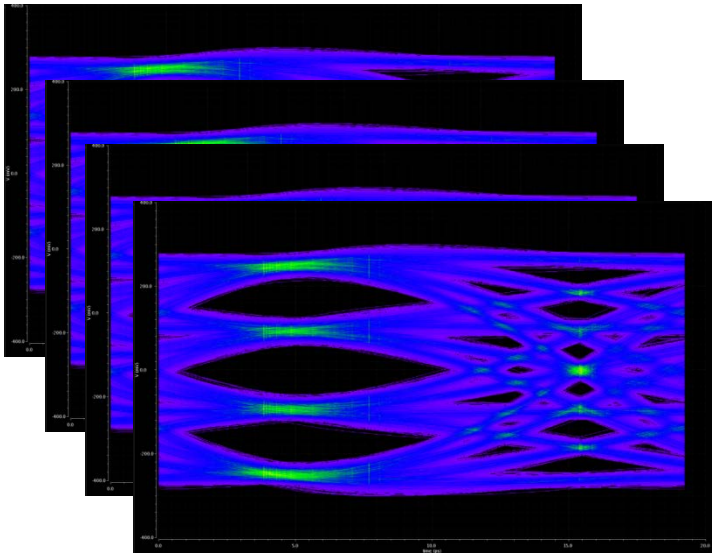
Max: 400G per Laser



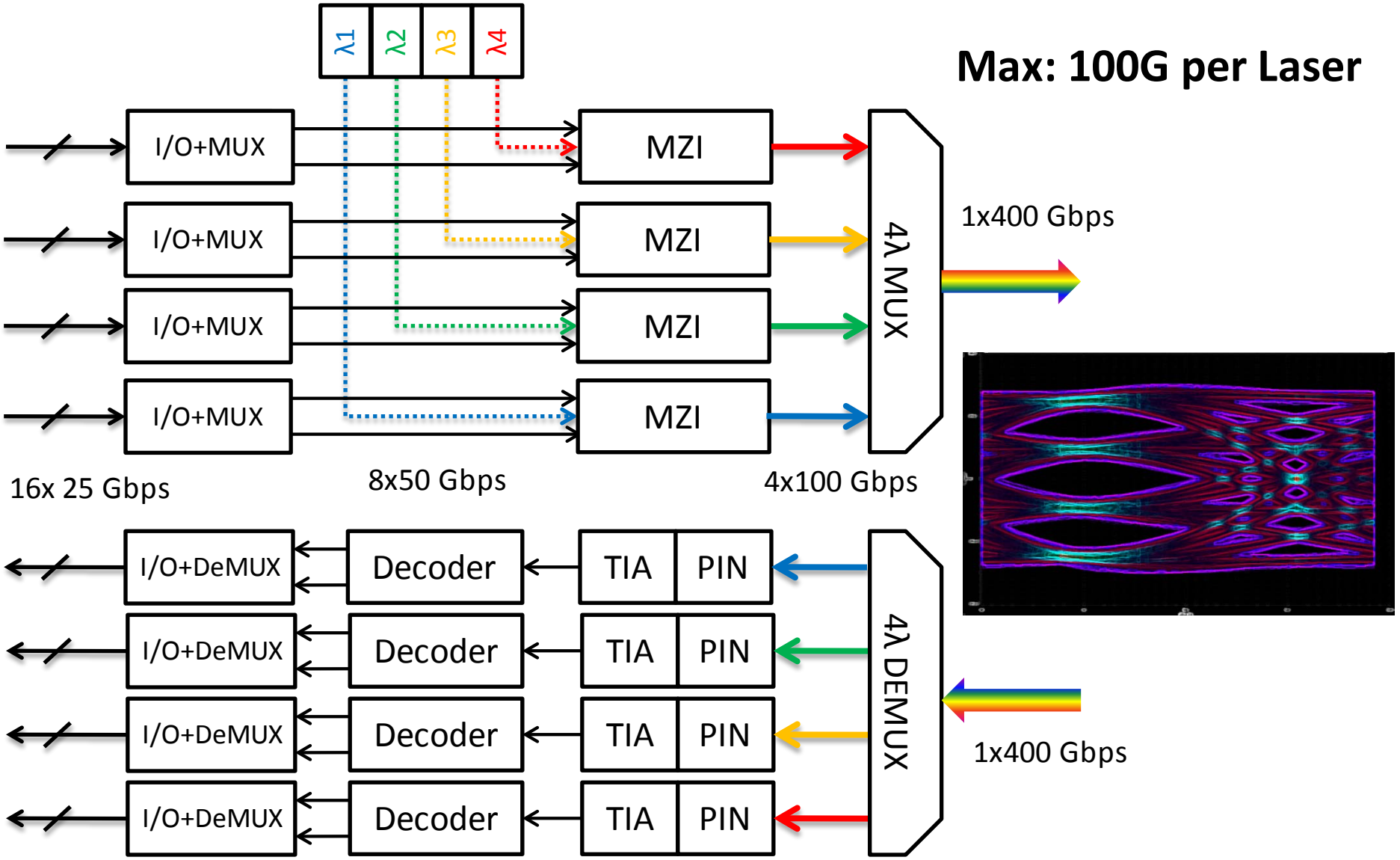
400G-PSM4: Parallel Fiber + PAM4



Max: 400G per Laser



400G-LR4: Duplex Fiber + PAM4 + WDM



Upgrade path from 16x25G electrical interface

- 400G-PSM16 essentially limited to a 16x25G electrical interface
  - 400G-PSM8 could be done for 8x50G electrical interface
- 400G-PSM4 has an easy upgrade path to a 8x50G electrical interface
  - Provided 8x50G is NRZ signaling. Alternate signaling could force the need for additional decode/encode functions in electrical IO
- 400G-LR4 has an easy upgrade path to 8x50G electrical interface
  - Same caveats as 400G-PSM4 upgrade path

Comparisons – Link Budget Delta

Estimated

400G-PSM16

- Higher count connector ~ 0.75 dB (net)
- **Per Lane ~ 0.75 dB**
- 16 lanes ~ 6.2 dB
- **Total ~ 6.95 dB**

400G-PSM4

- PAM4 Encoding Penalty ~ 4.77 dB
- Linearity Penalty ~ 0.3 dB
- MPI & RIN ~ 1.2 dB
- 2 km Penalty ~ 1.75 dB
- TIA Noise penalty ~ 1.5 dB
- **Per Lane ~ 9.52 dB**
- 4 Lanes = 0 dB
- **Total ~ 9.52 dB**

400G-LR4

- PAM4 penalties ~ 6.27 dB
- WDM4 penalty > 5 dB
- 10 km Penalty ~ 2.75 dB
- TIA Noise Penalty ~ 1.5 dB
- **Per Lane > 15.52 dB**
- 1 Lane ~ -6.2 dB
- 4 Lasers ~ 6 dB
- **Total > 15.32 dB**

- *All link budget deltas measured relative to 100G-PSM4*
- *Measures done on a net optical power basis (sum of excess optical power needed across all light sources)*

Comparisons - Power Consumption

Estimated

- Electrical Interface
  - CDAUI16 Assumed ~ 4xCAUI4
  - Gen2 CAUI4 Interface ~ 600-800 mW
  - Gen1 CDAUI16 Interface ~ 2.4 – 3.2 W
- Electrical Components
  - Electrical MUX/DEMUX ~ 35 mW
  - PAM4 Decoder ~ 350 mW
- Optical Components
  - 25Gbaud Transmitter ~ 125 mW†
  - 25Gbuad Receiver ~ 50 mW
  - 50 Gbaud Transmitter ~ 185 mW†
  - 50 Gbaud Receiver ~ 75 mW
  - WDM4 MUX/DEMUX~ 500-1000 mW

- **400G-PSM16**
  - CDAUI16 + 16x25Gbaud Optical
  - **Ptotal ~ 5.2-6 W**
- **400G-PSM4**
  - CDAUI16 + E-Mux + 50Gbaud Optical + ADC
  - **Ptotal ~ 5.4-6.2 W**
- **400G-LR4**
  - CDAUI16 + E-Mux + 50Gbaud Optical + ADC + 4xλ
  - **Ptotal ~ 7.5-9.5 W‡**

† Includes laser power

‡ Includes excess laser power for link budget

Time to Market

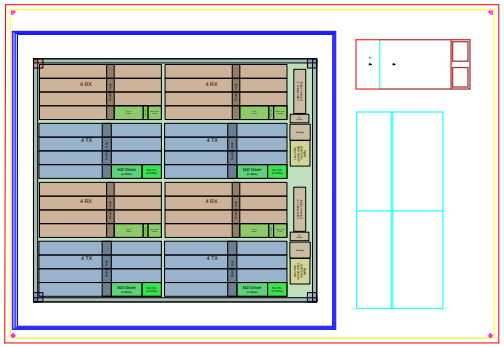
Estimated

- 400G-PSM16: 12-18 Months
  - Essentially 4x100G-PSM4 in single chipset/module
    - No new design features
    - Incremental improvements in CAUI interface (power reduced gen2)
  - Incremental link budget improvements: Low
- 400G-PSM4: 2-3 years
  - 100G-PSM4 +
    - 50Gbaud MZI Driver and TIA
    - PAM4 Decoder
    - Electrical MUX/DEMUX
  - Incremental link budget improvements: Moderate
- 400G-LR4: 3-4 years
  - 100G-PSM4 +
    - 50 Gbaud MZI Driver and TIA
    - PAM4 Decoder
    - Electrical MUX/DEMUX
    - Optical MUX/DEMUX
    - 4λ Integration
  - Incremental link budget improvements: High

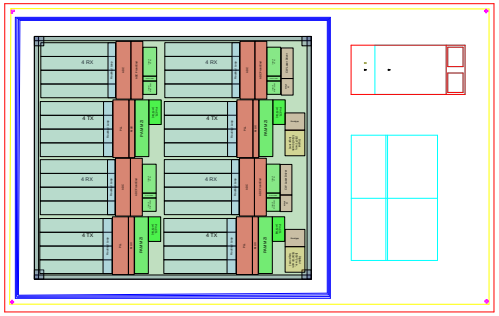
Comparisons - Cost

Estimated

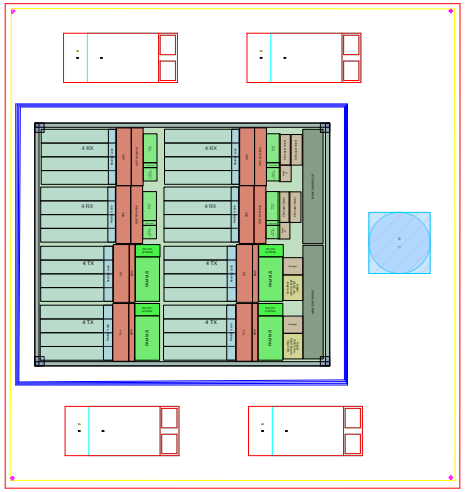
400G-PSM16 Chipset



400G-PSM4 Chipset



400G-LR4 Chipset



Chipset Cost	PSM4	PSM16	4xPAM4-G1	4λxPAM4-G1
Chipset	2	4.11	3.92	11.14

Module Cost	PSM4	PSM16	4xPAM4-G1	4λxPAM4-G1
@ 95% Yield	1	2.05	1.96	8.53

From welch_400_01_1113.pdf

Comparison

Estimated

	100G-PSM4†	400G-PSM16	400G-PSM4	400G-LR4
Time to Market	0	12-18 mo	2-3 yrs	3-4 yrs
Optical Lanes	4	16	4	1
Electrical Lanes Supported	4	16	16,8	16,8
Power	< 3.5 W	< 6 W	~ 6 W	> 7.5 W
Link Budget Delta	0	< 7.0	~ 9.5	> 15.3
Reach > 500m	✓	✓	✓	✓
Reach > 2km	✗	✗	✓	✓
Reach > 10km	✗	✗	✗	✓
Module Cost	1	2.05	1.96	8.53
Link Cost @ 500m		Low	Lowest	Highest
Link Cost @ 2km		High	Lowest	Highest
Link Cost @ 10 km		Highest	Low	Lowest

† *from welch_01_0513_optx.pdf*

Additional Considerations

- Backward Compatibility
  - 400G-PSM4 operating in 100G-PSM4 mode (MZI in NRZ mode)
  - 400G-LR4 operation in 100G-LR4 mode (MZI in NRZ mode)
  - Easy upgrade model from current parallel and duplex fiber plants
- Breakout Potential
  - 400G-PSM16 breakout to 4x100G-PSM4
    - 16x25G Ethernet?
  - 400G-PSM4 breakout to 4x100G Ethernet
    - With single λ 100G companion module

Summary and Conclusions

- Several Options for 400G solutions:
  - Easy: 400G-PSM16
  - Moderate: 400G-PSM4
  - Hard: 400G-LR4
- 400G-PSM4 appears to have the most favorables
  - Longer, but still reasonable, time to market
  - Lowest potential cost
  - Low potential power
- Full duplex solution has the most challenges
  - Longer time to market, but still should intercept volume shipments
  - Higher power, but still should be manageable
  - Considerably higher per unit cost, link cost crossover close to 10 km reach.

Thank You

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