400G-PSM4: Options for 500m Reach Interconnects

Brian Welch

Overview

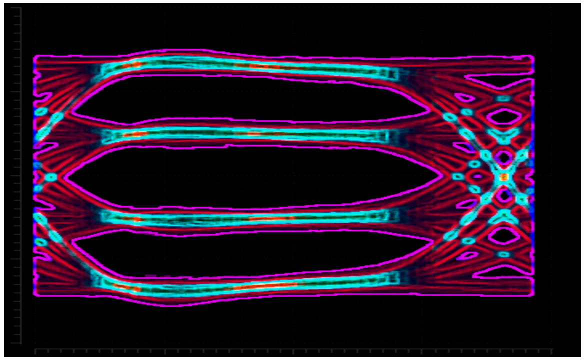
- A comparison of three prospective solutions for 400G interconnects up to 500m
  - 2λx8x25GBaud-PAM4
  - 2λx8x50GBaud-NRZ
  - 1λx4x50GBaud-PAM4

- All prospective solutions use four fibers per direction

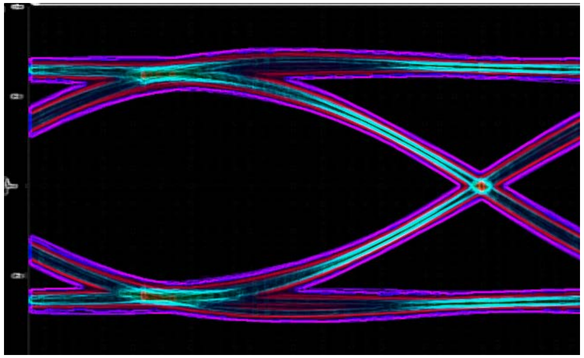
- Presentation compares cost, power, link budget, and risk profiles of different solutions

400G Design Options

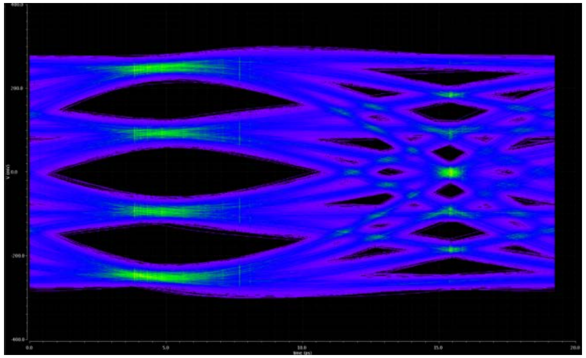
- 2λx8x25GBaud-PAM4
  - Two Wavelength WDM
  - Eight Optical Lanes
  - PAM4 Optical Encoding



- 2λx8x50GBaud-NRZ
  - Two Wavelength WDM
  - Eight Optical Lanes
  - NRZ Optical Encoding

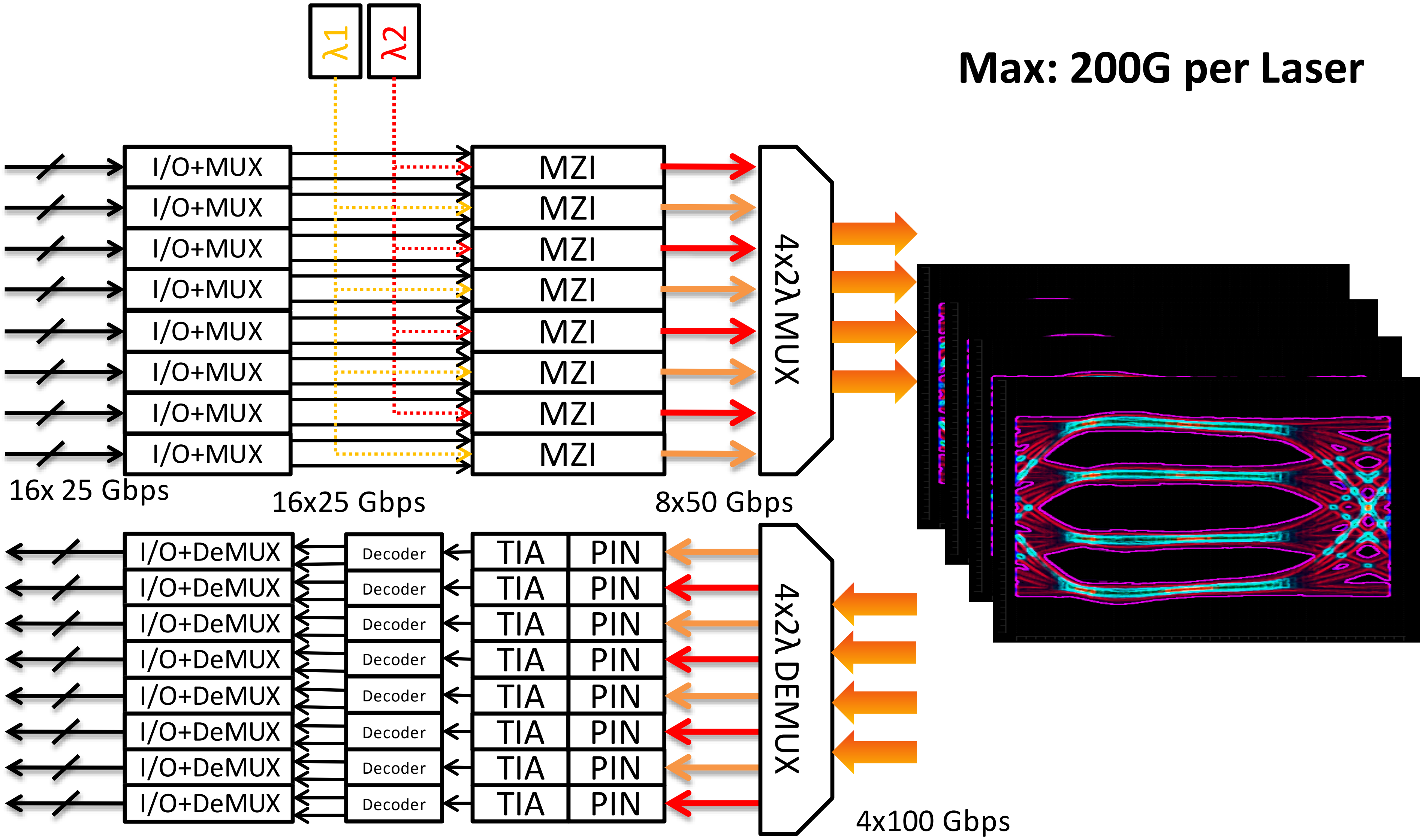


- 1λx4x50GBaud-PAM4
  - Single Wavelength
  - Four Optical Lanes
  - PAM4 Optical Encoding



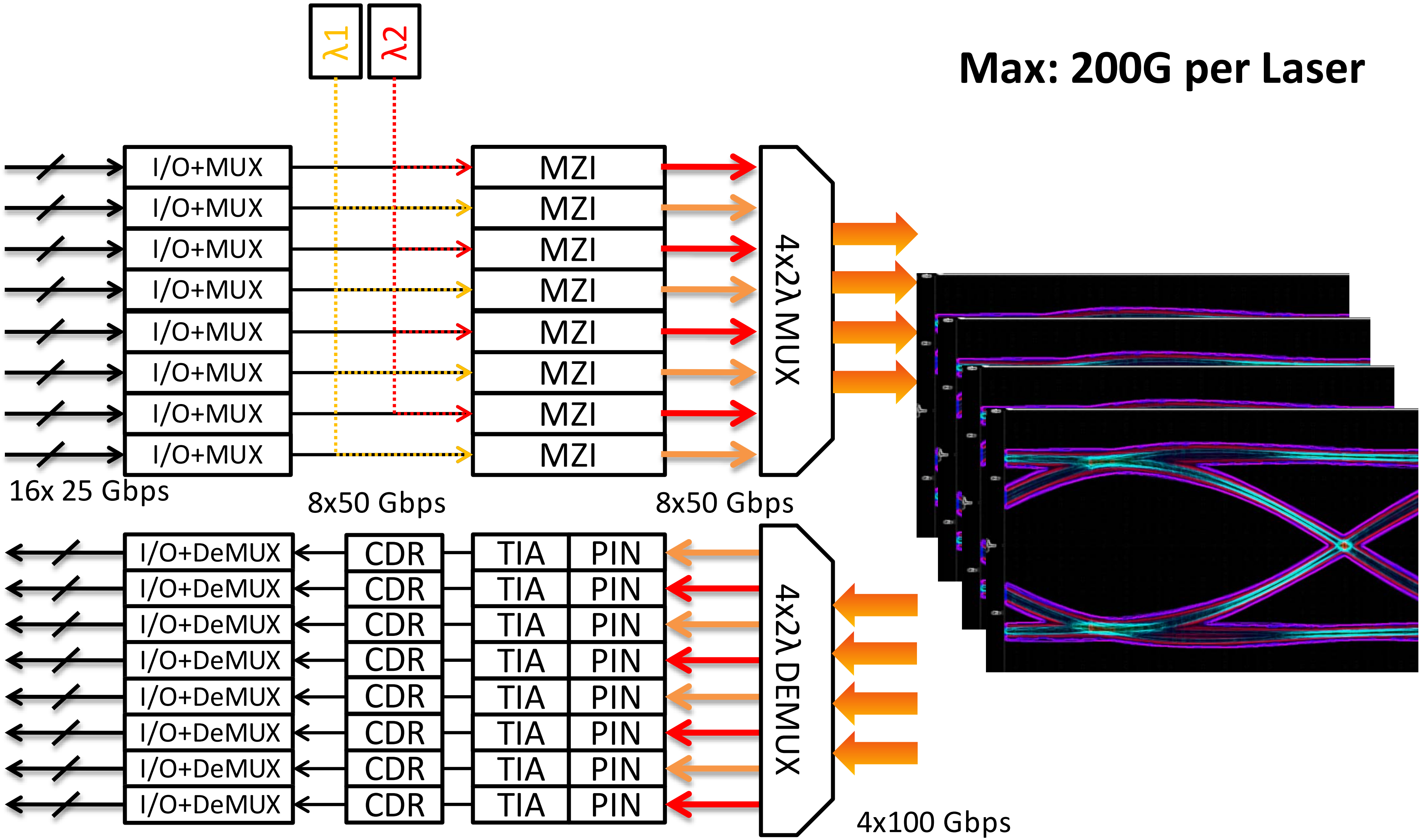
2λx8x25GBaud-PAM4

Max: 200G per Laser



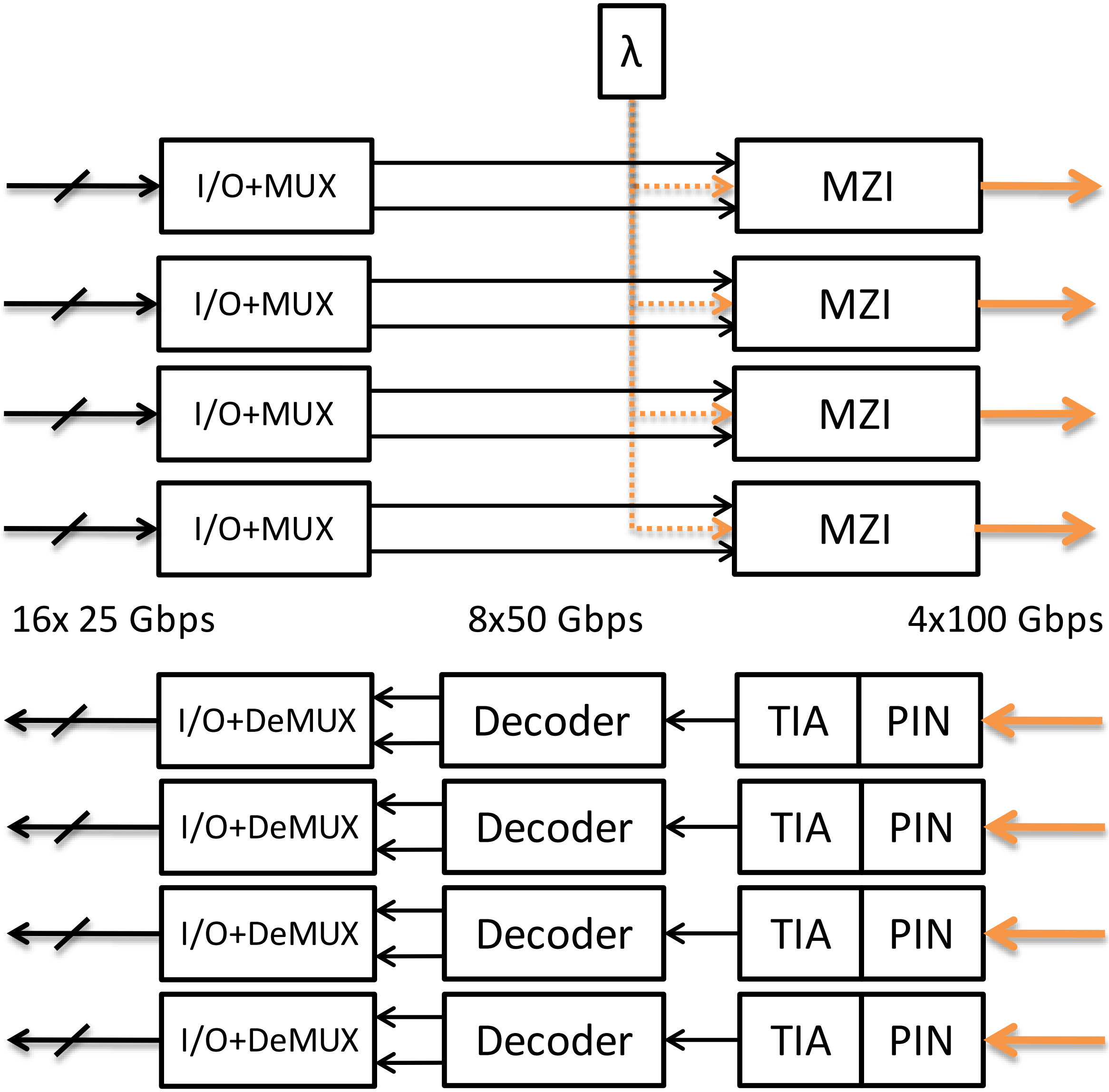
2λx8x50GBaud-NRZ

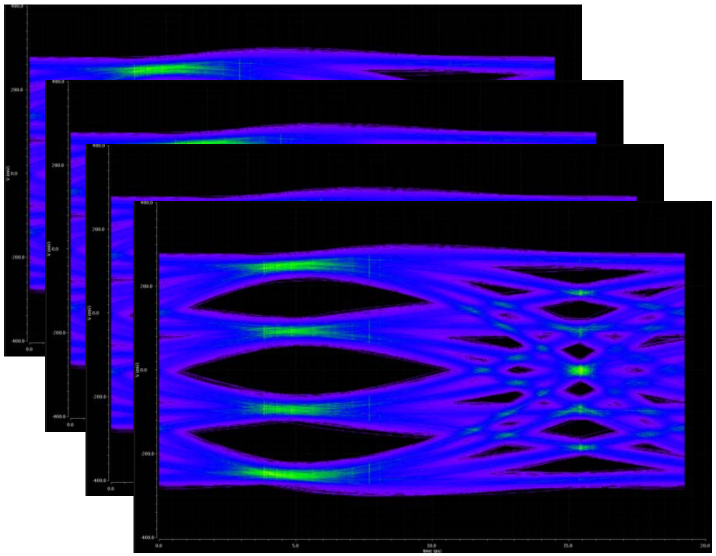
Max: 200G per Laser



1λx4x50GBaud-PAM4

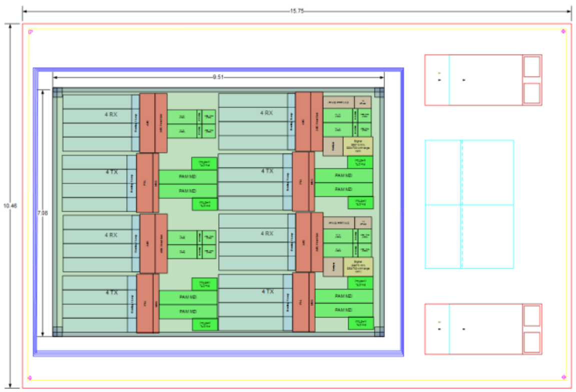
Max: 400G per Laser



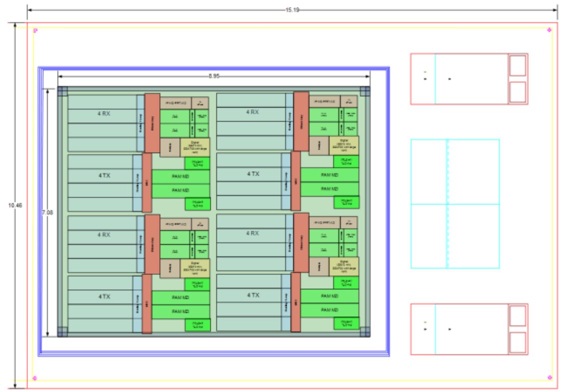


400G Design Options - Cost

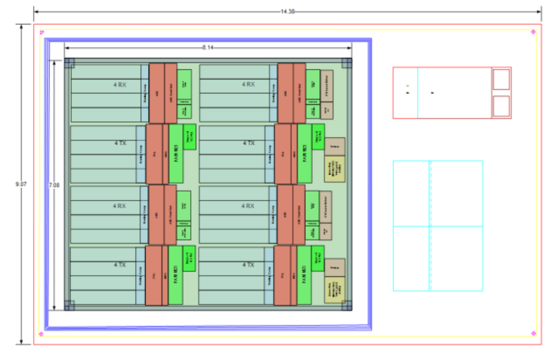
2λx8x25GBaud-PAM4



2λx8x50GBaud-NRZ



1λx4x50GBaud-PAM4



Chipset Cost†	2λx8x25GBaud-PAM4	2λx8x50GBaud-NRZ	1λx4x50GBaud-PAM4
Chipset	5.95	5.82	3.92

Module Cost	2λx8x25GBaud-PAM4	2λx8x50GBaud-NRZ	1λx4x50GBaud-PAM4
@ 95% Yield	1.60	1.56	1.00

Using Methodologies Presented in welch_400_01_1113.pdf

† Chipset Costs Measured Relative to 100G-PSM4

400G – Power

	2λx8x25Gbaud-PAM4	2λx8x50Gbaud-NRZ	1λx4x50Gbaud-PAM4
CDAUI16 Electrical Interface (W)	3.0	3.0	3.0
PAM4 Encoder†			
25G Optical Transmitters (W)	8x0.125 = 1		
50G Optical Transmitters (W)		8x0.185 = 1.48	4x0.815 = 0.74
WDM2 MUX/DEMUX (W)	0.375	0.375	
WDM2 Extra Light Source (W)	0.2	0.2	
25G Optical Recevier (W)	8x0.05 = 0.4		
50G Optical Receiver (W)		8x0.075 = 0.60	4x0.075 = 0.30
25GBaud-PAM4 Decoder (W)	8x0.250=2		
50GBaud-PAM4 Decoder (W)			4x0.35=1.4
50GBaud-NRZ Retimer (W)		8x0.2 = 1.6	
Total	**7**	**7.25**	**5.4**

† PAM4 encoding performed optical by MZI

400G – Link Budget Penalties

	2λx8x25Gbaud-PAM4	2λx8x50Gbaud-NRZ	1λx4x50Gbaud-PAM4
WDM MUX+DEMUX (dB)	4-5	4-5	0
50 Gbaud TIA Noise Penalty (dB)	0	1.5	1.5
PAM4 Encoding Penalty (dB)	4.8	0	4.8
MPI & RIN Penalty (dB)	1.2	0.4	1.2
Linearity Penalty (dB)	0.3	0	0.3
Total Penalty (dB)	**10.3-11.3**	**5.9-6.9**	**7.8**

Link Budget Penalties measured relative to 100G-PSM4

Risk Profiles

Technology Risks

- What technologies are needed to support the different solutions?
- 25GBaud solutions can use 28 nm CMOS technologies
  - Same as used for 100G solutions
- 50GBaud solutions likely to need 20 nm (or below) CMOS technologies
  - 16 nm may be most likely intercept node
- Technology risks are time dependent
  - Decrease as technologies mature

Design Risks

- How much design complexity is inherent in the different solutions?
- NRZ solutions will use the same basic architecture as existing 100G solutions
  - Assuming more advanced CMOS node design risks should be moderate
- PAM4 solutions will need new element vs. existing 100G solutions
  - PAM4 decoder on optical receiver
  - Several suitable architectures, however power/performance tradeoffs may take time
- WDM solutions more complex than parallel 100G solutions
  - Optical control system requirements

400G-PSM4 Scorecard

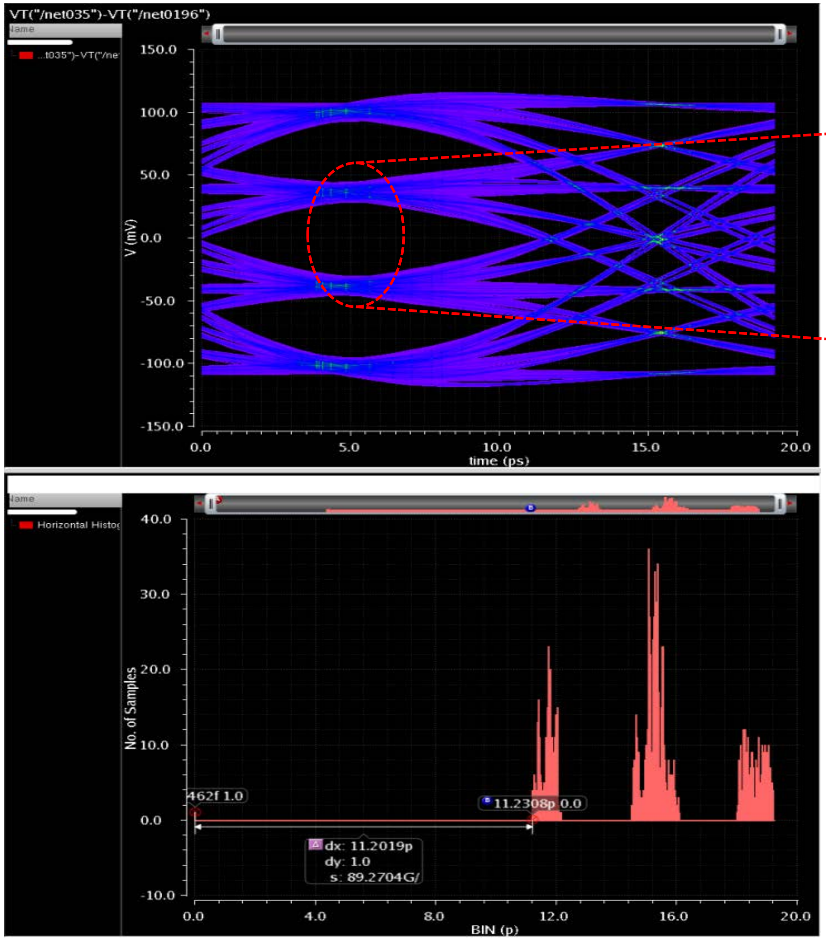
	2λx8x25Gbaud-PAM4	2λx8x50Gbaud-NRZ	1λx4x50Gbaud-PAM4
Module Cost	1.60	1.56	1.00
Module Power	7	7.25	5.4
Link Budget Penalty	10.3-11.3	5.9-6.9	7.8
Max Throughput per Laser (Gbps)	200	200	400
Technology Risk Profile	Low	Moderate	Moderate
Design Risk Profile	High	Low	Moderate
Backward Compatibility (to 100G-PSM4)	Challenging	Challenging	Yes
Forward Scalability Limit	50G Serial	50G Serial	100G Serial
Breakout Potential (to 4x100G)	High	High	High

A PAM4 'Anti-Penalty'

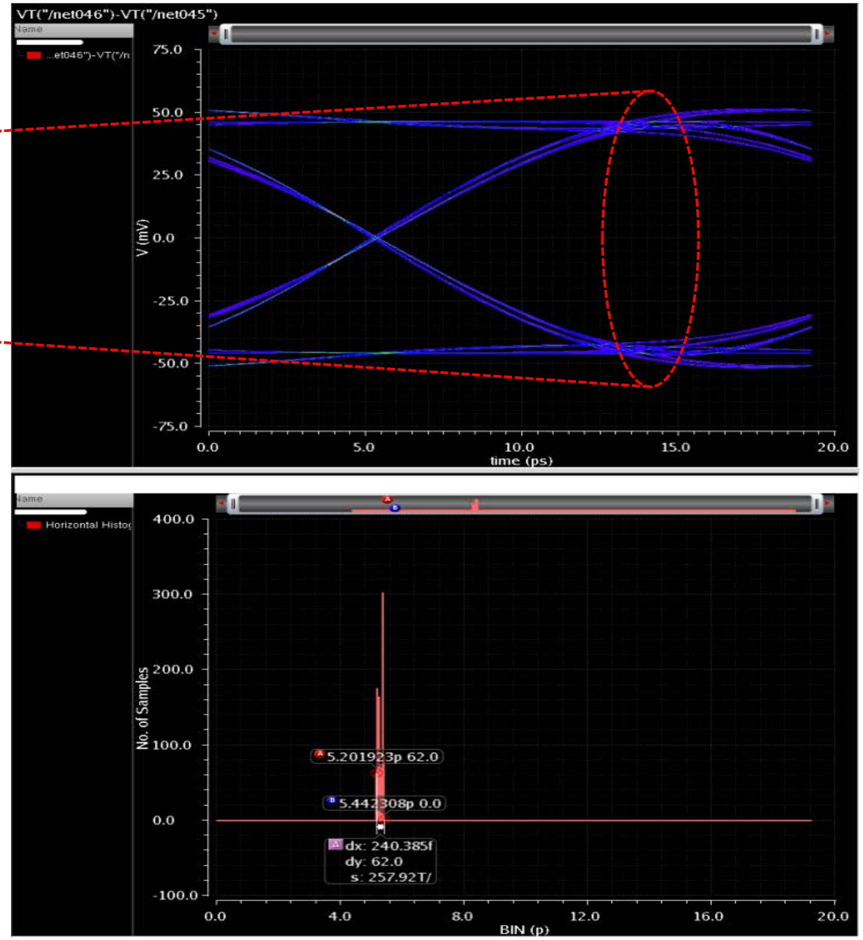
Jitter Composition

Jitter Analyses - DJ

PAM4

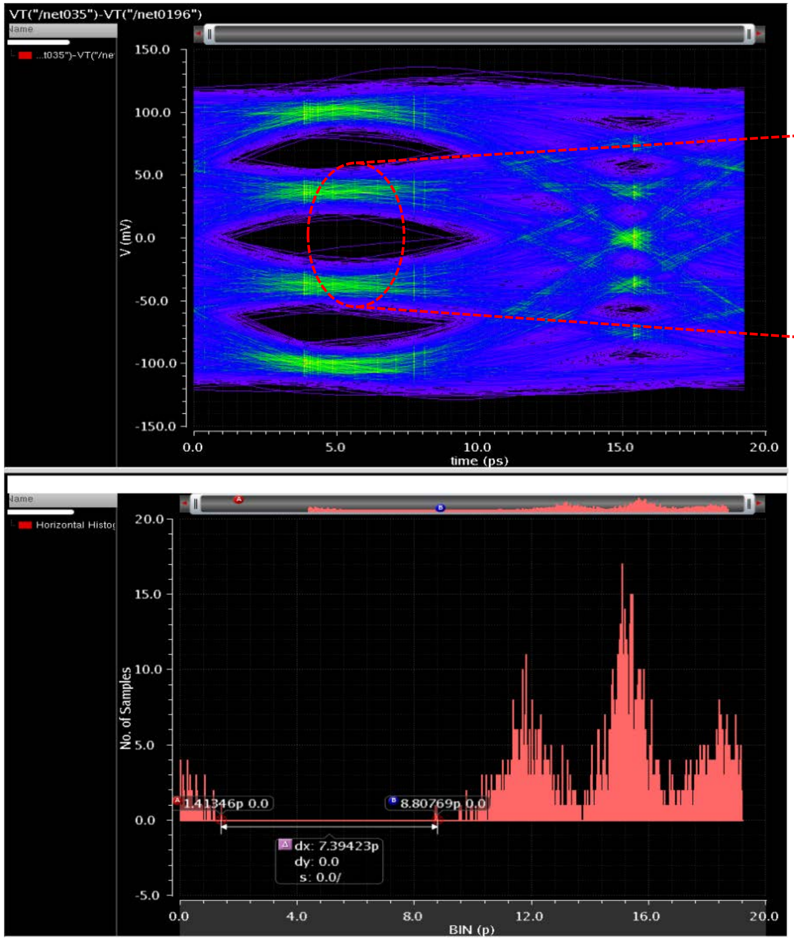


PAM2 (Inner Eye)

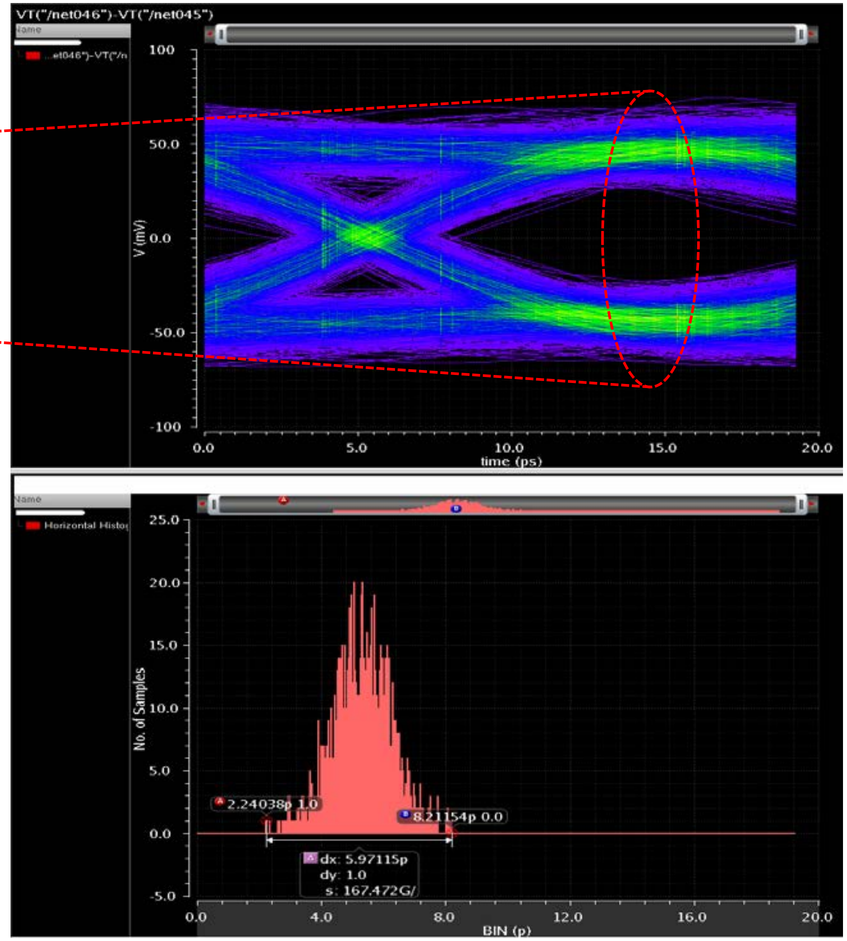


Jitter Analyses - TJ

PAM4



PAM2 (Inner Eye)



Jitter Analyses – Deltas (Comparative Analyses)

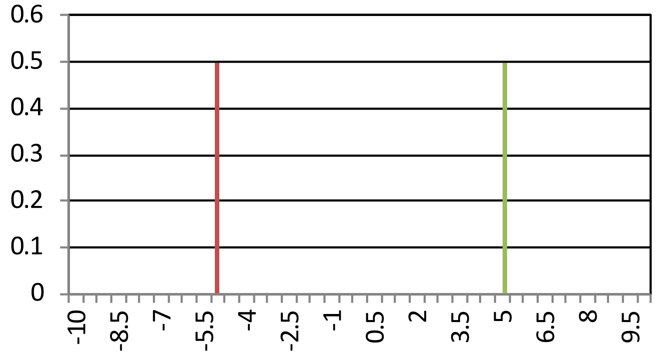
- PAM4 TJ = 12 ps
- PAM4 DJ = 8.2 PS
- Therefore RJ = 3.8 ps

- PAM2 TJ = 5.97 ps
- PAM2 DJ = 0.24 ps
- Therefore RJ = 5.73 ps

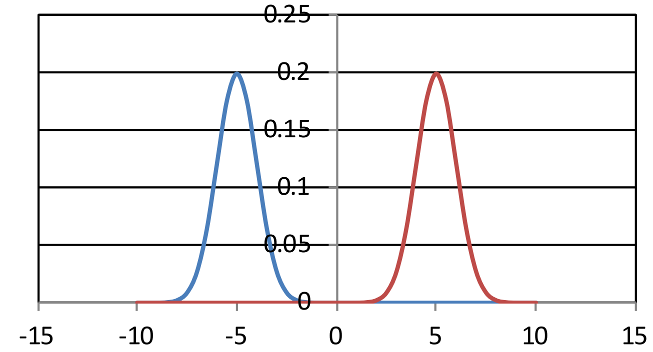
- RJ addition is sub-linear in PAM4
  - Non Dual Dirac Jitter Composition

Jitter Analysis – Dual Dirac vs. PAM4

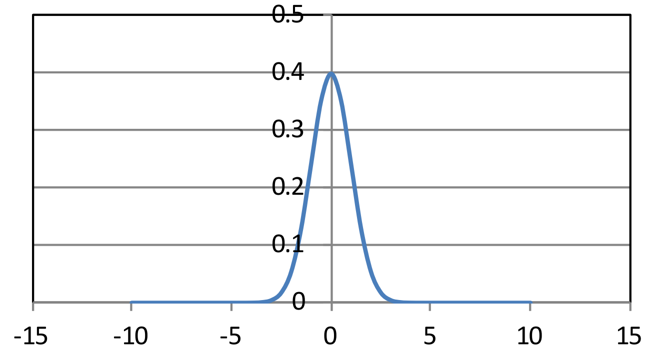
Dual Dirac



Random Jitter

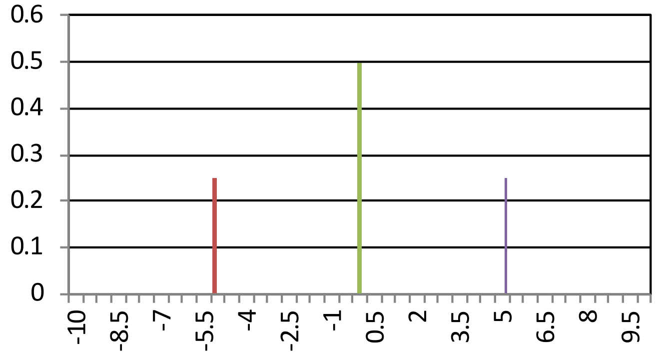


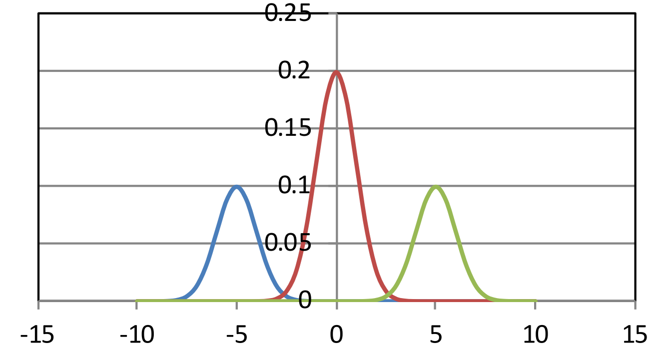
Deterministic Jitter



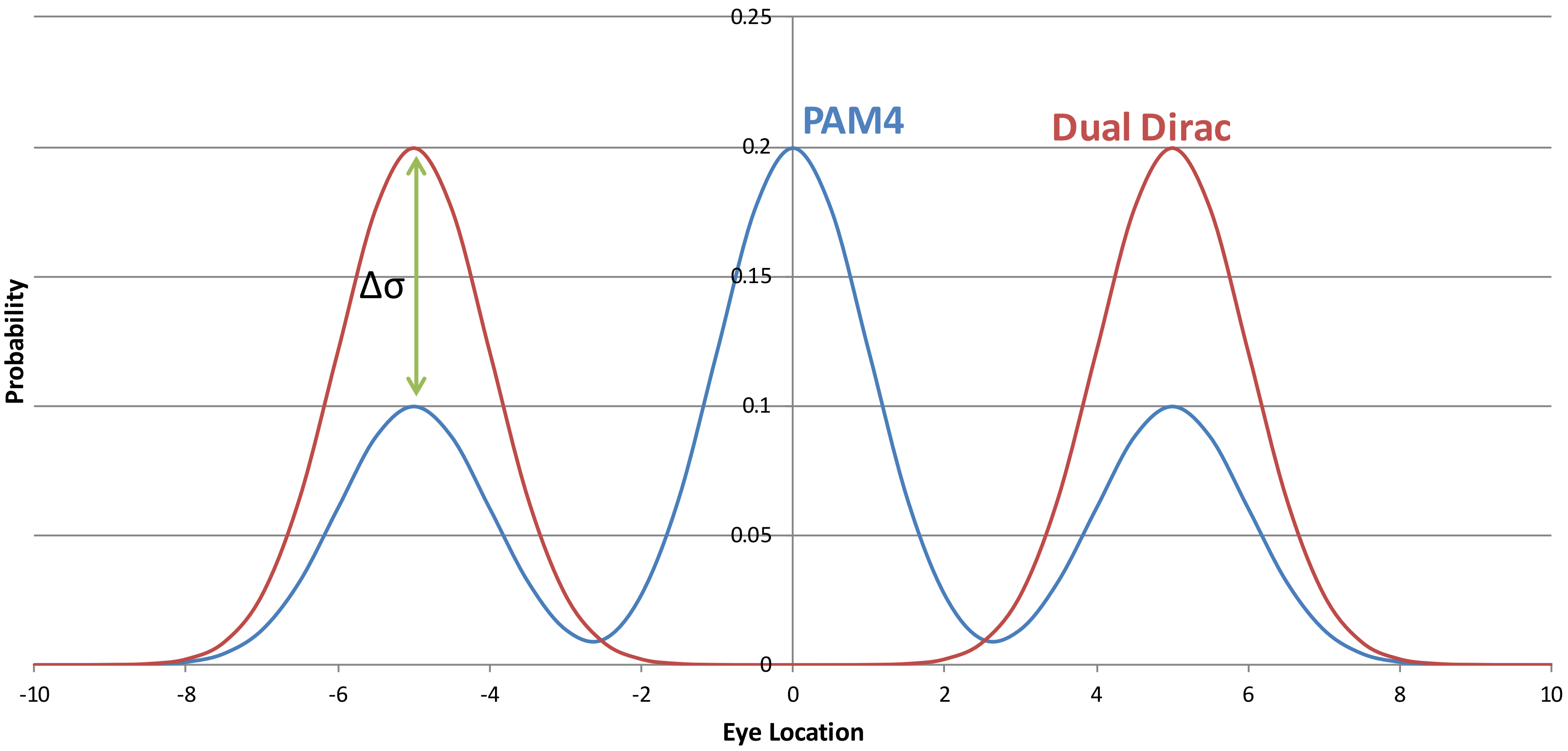
Total Jitter

PAM4





Jitter Analysis – Dual Dirac vs. PAM4



PAM4 has significantly lower jitter probabilities around the outer DJ impulses than a Dual Dirac model would predict

Summary

- Several Options Exist for 400G-PSM4 solutions
  - 2λx8x25Gbaud-PAM4
  - 2λx8x50Gbaud-NRZ
  - 1λx4x100Gbaud-PAM4

- Each solution has strengths and weaknesses
  - 1λx4x50Gbaud-PAM4 seems to have the most positives
    - Lowest potential power and cost
    - Higher technology risk

- PAM4 ‘penalties’ may be less significant than anticipated
  - ‘Anti-penalty’ seems to exist due to non Dual Dirac jitter
    - May be difficult to model empirically

Thank You