Relative Cost Analysis on IM-DD vs Coherent for 800G-LR 10km

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Introduction

- The goal of this presentation is to investigate how to make IM-DD & Coh-lite cost-effectively with lower power consumption for 10km SMF optics.
  - Baseline proposal refer to rodes_3df_01_221012.
- Experimental & simulation analysis show 800G-LR4 is technically feasible in LAN-WDM (e.g. kuschnerov_3df_02_221012).
- Concern on FWM impairment is mitigated effectively using channelized polarization scheme (e.g. liu_3df_01_221012)
- It is beneficial to extend IM-DD to higher data rate and longer reach as much as the industry can do before Coherent replacement.

Outline

- LR4 10km Market Status
- Key 800G technology comparison, assembly and test factor etc providing cost reduction associated with 800G LR4 IM-DD and 800G LR1 Coh-lite technology.
  - With reference to existing 400G LR4 and 400G ZR products
- 800G 10km transceiver relative cost analysis
- Summary

Observation of LR4 10km Market Status

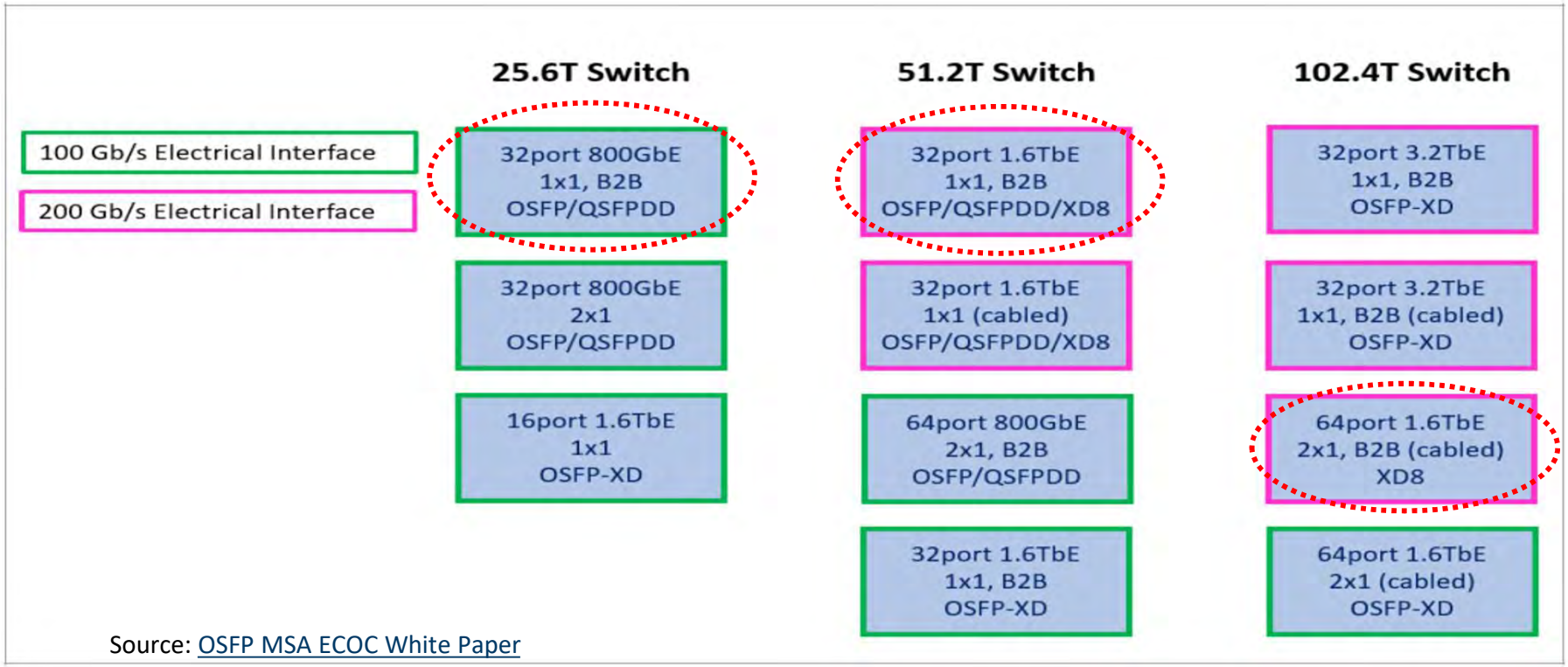
- 100G LR4 is everywhere and its market still growing well.
  - ~2 Million units annually
  - Very diverse application scenarios: switch to router, router to router, co-location connectivity, between campus, wireless transport, etc.
- 200G LR4 show demand for telecom market e.g. in Asia
  - Low volume, to replace CFP2 version.
- 400G-LR4-10 start shipping, but no one ask alone for 400G-LR4-6
  - Complement with 400G LR8 and ER8.
- Commercialization of 800G 2xFR4/LR4 starting qualification
  - 2xFR4/LR4 breakout show more cost effective for 25.6T switch
- There is market interest in 800G LR8.

It is thus worthwhile to consider 800G LR4.

System configurations for next-gen switches

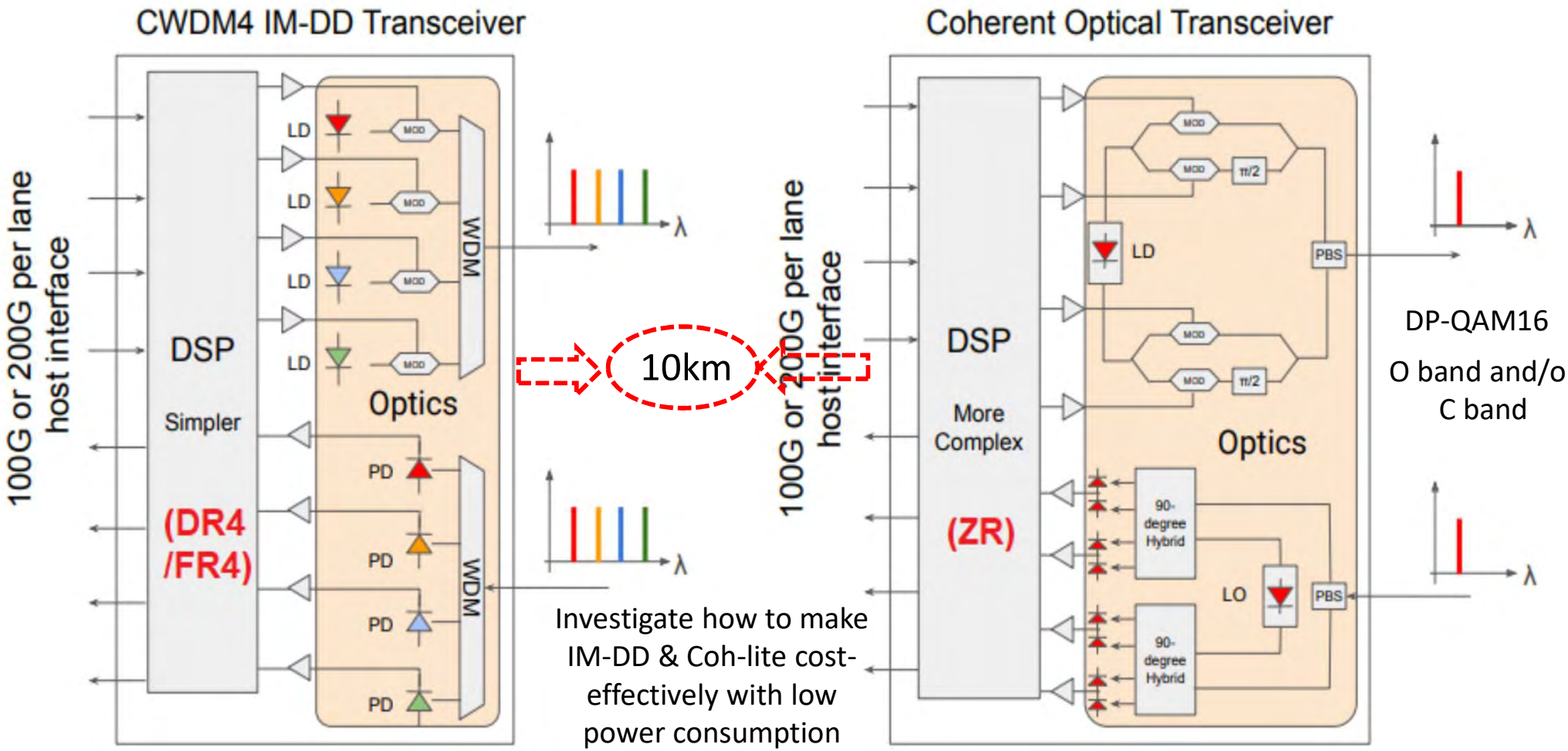
OSFP MSA just completed OSFP1600 specs (Rev.5.0, 10/4/22), supporting 8x200 Gb/s host I/O

- 1U switch with 32 OSFP1600 ports supporting 51.2T throughput
- 2U switch with 64 OSFP1600 ports supporting 102.4T throughput



Source: OSFP MSA ECOC White Paper

800G Transceiver Architectures (IM-DD vs Coherent)



Investigate how to make IM-DD & Coh-lite cost-effectively with low power consumption

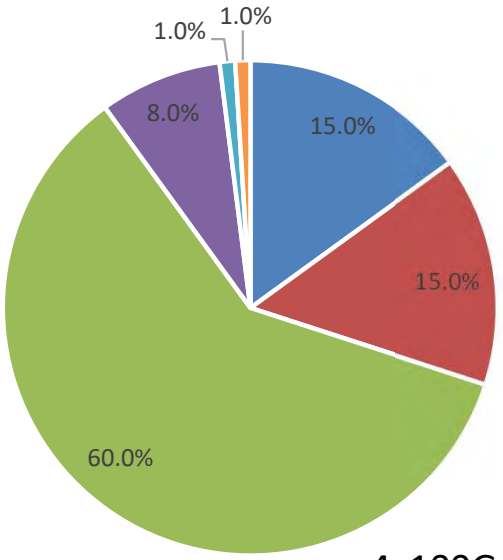
Source: 802.3df (google)

Transceiver Power Consumption (400 vs 800G)

400G & 800G optics modules with the 100 Gb/s electrical/optical lane ecosystem

400G (4x100G) DR4/FR4 at ~8W

Power Consumption Composition Breakdown
HT (70℃)



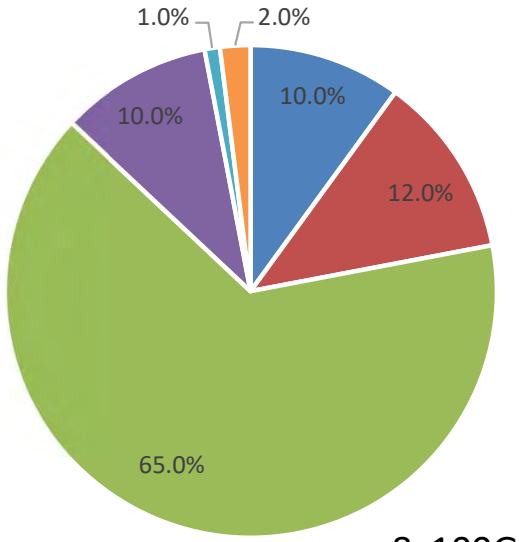
4x100G QDD

TEC Laser DSP TIA MCU Other

Rough estimation with 7nm DSP

800G (8x100G) DR8/2xFR4 at <13~14W

Power Consumption Composition Breakdown
HT (70℃)



8x100G OSFP/QDD

TEC Laser DSP TIA MCU Other

Rough estimation with 5nm DSP

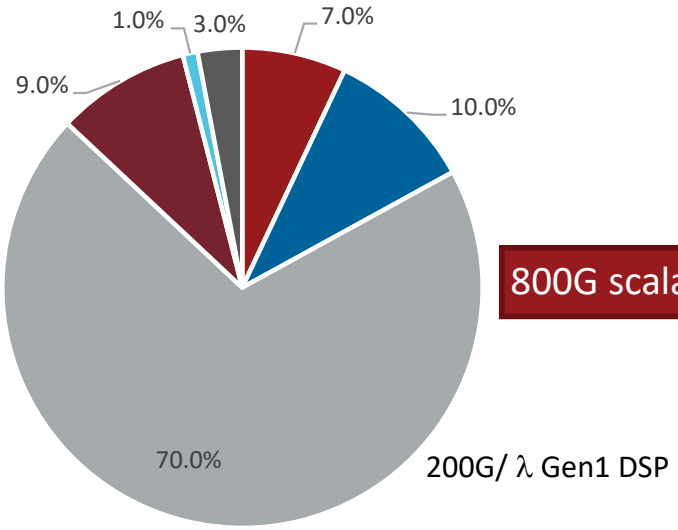
Transceiver Power Consumption (800 vs 1.6T)

Next 800G & 1.6T optics with the 200 Gb/s electrical/optical lane ecosystem

800G DR4/FR4 at ~11~12W

Power Consumption Composition Breakdown

HT (70℃)



200G/ λ Gen1 DSP

4x200G QSFP-DD800

■ TEC ■ Laser ■ DSP ■ TIA ■ MCU ■ Other

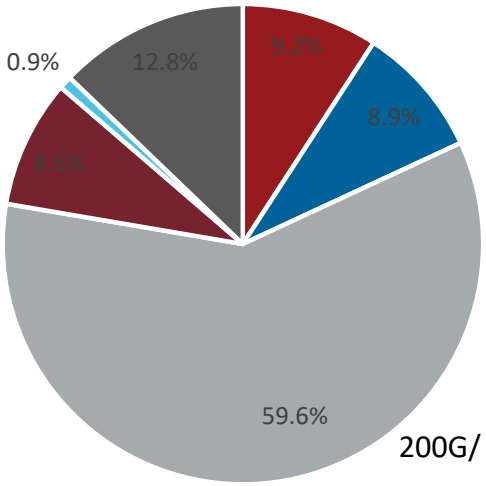
Rough estimation with 5nm DSP

800G scalable to 1.6T

1.6T (8x200G) DR8/2xFR4 at <22W

Power Consumption Composition Breakdown

HT (70℃)



200G/ λ Gen2 DSP

8x200G OSFP1600/QSFP-DD

■ TEC ■ Laser ■ DSP ■ TIA ■ MCU ■ Other

Rough estimation with 3nm DSP

How to optimize cost for 10km Optics (1)

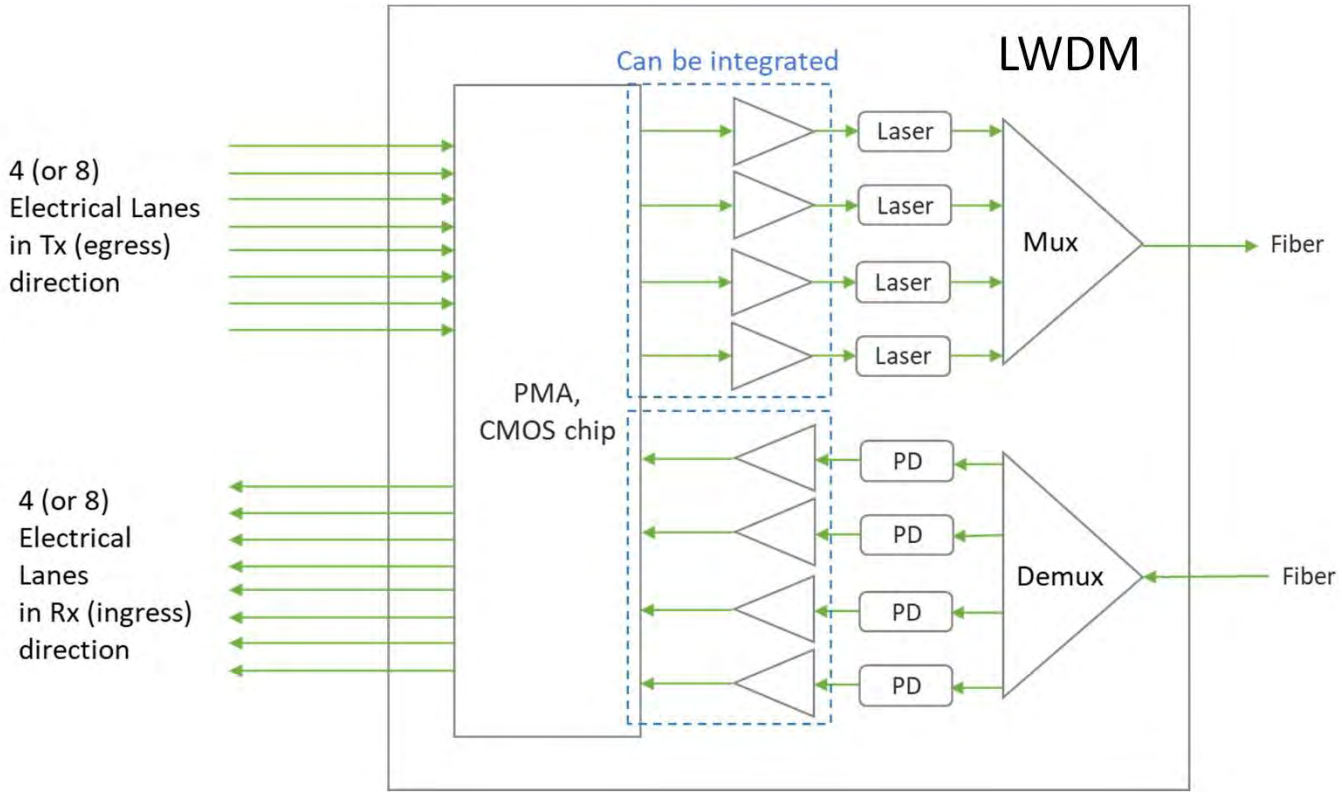
- PAM4 IM-DD for 800G-LR4 could maximize the reuse of 800G DR4/FR4 building blocks.
  - DSP: no purpose built, re-use and leverage what's deployed for DR4 500m and FR4 2km reach solutions
  - 200G PAM4 LWDM optics could be widely deployed for many purposes.
    - New materials like TFLN may come into play.
- 800G LR4 market is still unclear and could be similar to 400G LR4.
  - Claim less hyperscale use case for 10km for intra data center.
  - Some operators like to skip 800G from 400G to 1.6T.

800G LR4 amortizes 100% of the R&D investment for IM-DD with minimum incremental change.

How to optimize cost for 10km Optics (2)

800G LR4 will have the same component structure as 100G LR4 widely deployed today

- Component Structure is the Best Indicator for lower Long-term Cost



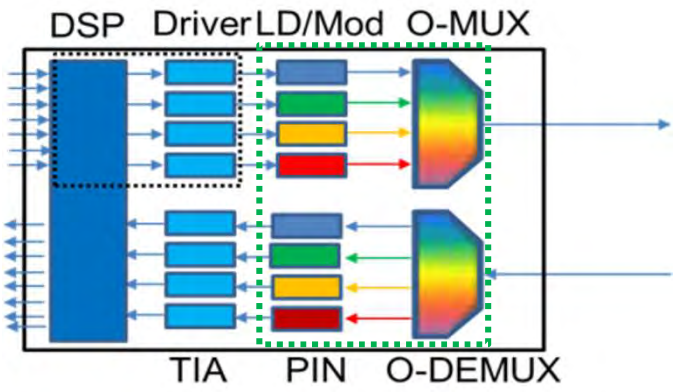
FEC Requirements for 800G LR4 (IM-DD)

- Considering FEC Options for PAM4 IM-DD for 800G-LR4 (patra_3df_01a_2207)

Metric	KP4 RS(544, 514)	RS(576, 514)	KP4 RS(544, 514) + Hamming (128, 120)
Total overhead	Ref (6%)	Ref + 5.8%	Ref + 6.6%
Baud rate for optics	PAM4: 106.25G	PAM4: 112.5G	PAM4: 113.3G
BW requirements	Ref	Ref + 5.8%	Ref + 6.6%
Net Coding Gain – PAM4	7dB	8dB	9.5dB
Latency	52 ASIC clock cycles		52 ASIC clock cycles
FEC power	~200mW		~200mW
Module power	Ref		ref + ~0.5W
FEC threshold	2.4E-4	1.1E-3	4.85E-3
Comments	Leverages existing KP4 FEC, exists in switches, PHY today	Hard decision FEC Slight better flavor of KP4 but with more complexity	Enhanced KP4 FEC with Soft decision. Concatenated FEC proposal for 200G/lane

800G DR4/FR4 vs. LR4 Transceiver Comparison

800G FR4 vs. LR4 configuration



	800G FR4 (4x200G FR4)	800G LR4 (4x200G LR4)
Signaling	PAM4 113.3GBd (IM-DD 4 lanes)	Same
DSP	5nm CMOS	Same
Lasers	4	Same
TX/RX pairs	4	Same
Key opto-components	4x (EML+Ge/Si RX)	Same with polarization manipulation
MUX/DeMUX	1	Same
Wavelength	CWDM	LWDM
Power	~11W	<12W
Reach	<2-3km Limited by dispersion	Up to 10km FWM Mitigation
Form Factor	OSFP/QSFP-DD	Same
Availability	2023	Same

How to optimize cost for 800G-LR1 Coh-lite Optics

- 800G LR1 Implementation Options
  - Wavelength plan: trade offs exist for either O-band or C-band.
    - CD compensation for DSP power consumption
    - Link loss increase by 1.5dB, narrow linewidth consideration for coherent detection
    - Moderate powerful DFBs
      - Consider SOA for O-band lasers, no EDFAs
  - Concatenated FEC for low latency
    - **Consider higher net coding gain (NCG) (21.2% LR1 vs. 16.4% for 800ZR)**
  - Purpose built DSP
    - **Target different silicon from 800ZR**
  - Framing
    - Frame alignment word (FAW) consideration
- Silicon Photonics technology

The 800G LR1 plan does not leverage 800ZR development well for cost effectiveness

FEC Requirements for 800G LR1 (Coh-lite)

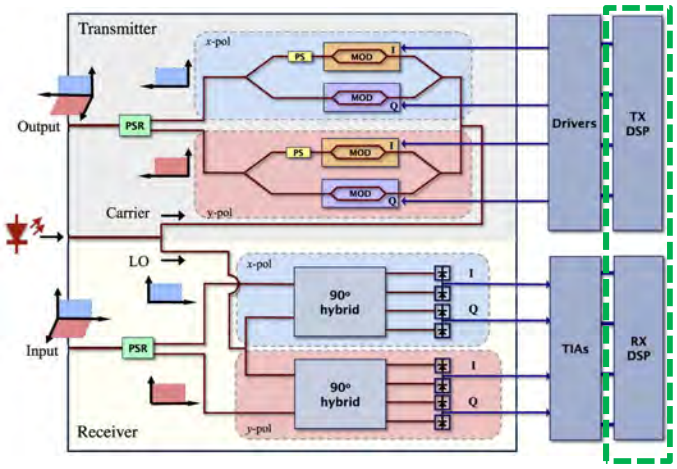
- OIF Q3 selected interleaving FEC and DSP framing schemes, moving ahead with concatenated FEC approach, utilizing P802.3 RS(544,514) FEC as an outer code, and a BCH(126,110) FEC as an inner code, ~123.7GBd (refer to OIF Liaison).

Metric	Unterminated KP4 + convolutional interleaver A + BCH(176,160)	Unterminated KP4 + convolutional interleaver B + BCH(126,110)
Total overhead	16.4%	**21.2%**
Baud rate for optics	118.8GBd	**123.7GBd**
BW requirements	Ref	ref + 4.1%
Net Coding Gain - 16QAM (Chase Decoder)	10.2dB	10.3dB
Latency*	52 ASIC clock cycles	52 ASIC clock cycles
FEC power	~200mW	~200mW
Module power	ref	ref + ~0.5W
FEC threshold	0.85% w/ Chase decoder	1.08% w/ Chase decoder (1.2% w/ proprietary decoder)
Comments	Similar baud rate and frame alignment as 800ZR for streamlined implementation	800G LR1 Coherent choice

**encoder+decoder+interleaver*

800G LR1 vs. 800G ZR Transceiver Comparison

800G ZR vs. LR1 configuration



IC-TROSA

DSP with Client interface

	800G ZR (Coh-Lit, DP-16QAM)	800G LR1 (Coh-Lit, DP-16QAM)
Signaling	DP-16QAM	Same
Baud rate	118.8GBd	**123.7GBd (+5%)**
DSP & FEC	3nm CMOS	Target different silicon and different FEC design
Lasers	1 (high power tunable)	1 (new moderate power)
TX/RX pairs	4	4 (5% higher bandwidth)
Key opto-components	4x (IC-TROSA)	4 (5% higher bandwidth)
Wavelength	Tunable C-band	Fixed O-band or tunable
Power	~22-26W	~20-24W
Reach	80km DWDM (Tunable, Amplified link)	10km (Fixed, non-amplified link)
Form Factor	OSFP/QSFP-DD	Same
Availability	2023-24	2024?

800G LR4 vs. LR1 Transceiver Comparison

	800G LR4 (4x200G LR4)	800G LR1 (Coh-Lit)
Signaling	PAM4 113.3GBd (IM-DD 4 lanes)	DP-16QAM 123.7GBd (Coh-Lite 1 lane)
DSP & FEC	5nm CMOS	3-5nm CMOS with different FEC
Lasers	4 (simpler EMLs)	1 (moderate powerful DFB with narrow linewidth, and wavelength controller)
TX/RX RF pairs	4	4 (higher swing)
Key opto-components	4x (EML+Ge/Si RX)	1x IC-TROSA (SiP or InP)
Wavelength	LWDM	O Band (Fixed)*
Power	<~12W (5nm)	>~20-24W?? (5nm) **
Reach	10km LWDM (FWM Mitigation)	10km O band (Non-amplified Link)
Form Factor	• OSFP/QSFP-DD	• OSFP/QSFP-DD
Availability	2023	2024??

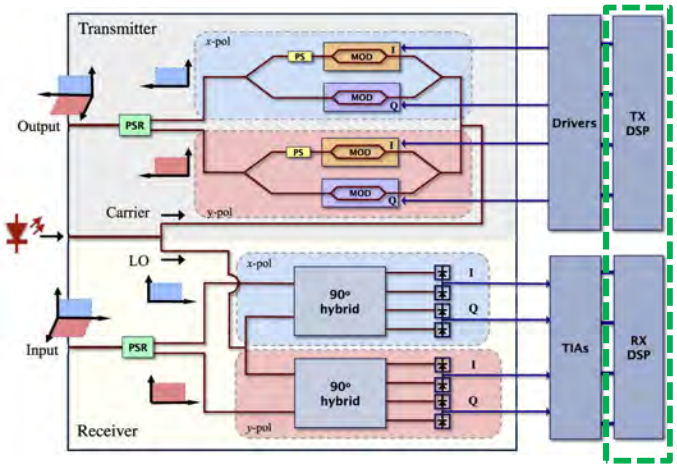
*: C Band may cause more DSP complexity and component costs.

**: Refer to 400ZR 15-20W @ 7nm

400G LR4-10 vs. 400G ZR Transceiver Comparison

- Both 400G LR4-6/10 and 400G ZR are being deployed today

400G ZR vs. LR4-10 configuration



IC-TROSA

DSP with Client interface

	400G LR4-10 (PAM4, IM-DD)	400G ZR (Coherent, DP-16QAM)
Signaling	PAM4	DP-16QAM
Baud rate	56.5625 GBd	59.84375 GBd
DSP & FEC	7nm CMOS	7nm CMOS
Lasers	4	1
TX/RX pairs	4	4
Key opto-components	4x (EML+Ge/Si RX)	4x (IC-TROSA)
Wavelength	CWDM	Fixed or tunable C-band
Power	~8W	~15-20W
Reach	6/10km CWDM (non-amplified link)	40-80km DWDM (non-amplified vs. amp link)
Form Factor	OSFP/QSFP-DD	Same
Availability	In Production	In Production

400G LR4 (IM-DD) vs. 400G-ZR (Coherent) Relative Cost

	400G LR4-10	400G-ZR
DSP & FEC	a	~ 10x a
Lasers	b (EML as reference, take 50% as LD cost)	~ 15x b (tunable lasers)
Modulators	c (EML as reference, take 50% as modulator cost)	~ 10x c
Receiver	d	~ 20x d
Driver EIC	e (integratable with DSP)	~ 5x e
TIA EIC	f	~ 8x f

Note: *The authors are not aware of public sources for the information presented in this chart, and the data presented is therefore based on authors' estimates. Implementers' actual or relative acquisition costs may vary.*

800G LR4 vs. 400G-LR4 Relative Cost

	400G LR4-10	800G-LR4
DSP & FEC	a	~ 1.2x a
Lasers	b (EML as reference, take 50% as LD cost)	~ b
Modulators	c (EML as reference, take 50% as modulator cost)	~ 1.2x c (higher BW)
Receiver	d	~ 1.2x d (higher BW)
Driver EIC	e	~ 1.2x e (higher BW)
TIA EIC	f	~ 1.2x f (higher BW)

Note: *The authors are not aware of public sources for the information presented in this chart, and the data presented is therefore based on authors' estimates. Implementers' actual or relative acquisition costs may vary.*

800G LR1 vs. 400G-ZR Relative Cost

	400G ZR (Coherent)	800G-LR1 (Coherent Lite)
DSP & FEC	a	~ 1.3x a (more advanced CMOS)
Lasers	b (tunable laser)	~ 0.3x b (fixed wave LD)
Modulators	c	~ 1.5x c (higher BW)
Receiver	d	~ 1.5x d (higher BW)
Driver EIC	e	~ 1.5x e (higher BW)
TIA EIC	f	~ 1.5x f (higher BW)

Note: *The authors are not aware of public sources for the information presented in this chart, and the data presented is therefore based on authors' estimates. Implementers' actual or relative acquisition costs may vary.*

800G LR4 vs. LR1 Transceiver Comparison

	800G LR4 (4x200G LR4)	800G LR1 (Coh-Lit)
Signaling	PAM4 113.3GBd (IM-DD 4 lanes)	DP-16QAM 123.7GBd (Coh-Lite 1 lane)
DSP & FEC	5nm CMOS	3-5nm CMOS with different FEC
Lasers	4 (simpler EMLs)	1 (moderate powerful DFB with narrow linewidth, and wavelength controller)
TX/RX RF pairs	4	4 (higher swing)
Key opto-components	4x (EML+Ge/Si RX)	1x IC-TROSA (SiP or InP)
Wavelength	LWDM	O Band* (Fixed)
Power	<~12W (5nm)	>~20-24W?? (5nm)**
Relative cost	'Refer to slides 17-20'	
Reach	10km LWDM (FWM Mitigation)	10km O band (Non-amplified Link)
Form Factor	• OSFP/QSFP-DD	• OSFP/QSFP-DD
Availability	2023	2024??

*: C Band may cause more DSP complexity and component costs.

**: Refer to 400ZR 15-20W @ 7nm

Conclusions

- 800G-LR4 can be supported with PAM4 and direct detection (with effective FWM suppression option)
- 800G LR4 IM-DD for 10 km reach will re-use and leverage a huge base of technologies and components deployed for 500 m and 2 km reach solutions
  - 800G LR4 amortize 100% of the R&D investment with minimum incremental change.
- 800G LR1 Coh-lite requires larger NCG with +5% higher overhead
  - Push optics bandwidth into extreme, rendering little higher optics cost
  - Simpler DSP might not justify to balance the complication of stronger SFEC.
- 800G LR1 Coh-lite may cost higher than 800G ZR
  - Purpose built DSP is assumed
- Conclusion: our technical and cost analysis indicates that the proposed 800G LR4 IM DD for 10km SMF is more cost-effective than the proposed 800G LR1 approach.

800G-LR4 based on IM-DD is thus the promising approach to move forward

Thank you

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