Technical feasibility of the "10km @ 800Gb/s" objective

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Motivation

- In the Chair's report in April, the group has adopted the "10km @ 800Gb/s" objective.
- Two presentations ("Coherent-Lite for beyond 400GbE" and Considerations on the "10km @ 800Gb/s" objective") have been made up to now, to support the "10 km @ 800Gb/s" objective.
- This contribution further discusses the technical feasibility of the **four** options (excluding 2×400b/s Coherent solution), supporting 800Gb/s over a single SMF in each direction with length up to at least 10 km.

- Adopted by B400G SG, Apr 2021
- Approval by 802.3 WG Pending

- Support a MAC data rate of 800 Gb/s
- Support full-duplex operation only
- Preserve the Ethernet frame format utilizing the Ethernet MAC
- Preserve minimum and maximum FrameSize of current IEEE 802.3 standard
- Define a physical layer specification that supports 800 Gb/s operation over 8 pairs of MMF with lengths up to at least 50 m
- Define a physical layer specification that supports 800 Gb/s operation over 8 pairs of MMF with lengths up to at least 100 m
- Define a physical layer specification that supports 800 Gb/s operation over 8 pairs of SMF with lengths up to at least 500 m
- Define a physical layer specification that supports 800 Gb/s operation over 4 pairs of SMF with lengths up to at least 500 m
- Define a physical layer specification that supports 800 Gb/s operation over 4 pairs of SMF with lengths up to at least 2 km
- Define a physical layer specification that supports 800 Gb/s operation over 4 wavelengths over a single SMF in each direction with lengths up to at least 2 km
- Define a physical layer specification that supports 800 Gb/s operation over a single SMF in each direction with lengths up to at least 10 km
- Define a physical layer specification that supports 800 Gb/s operation over a single SMF in each direction with lengths up to at least 40 km

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Why Coherent-Lite?

- Transmission-penalty-free electronic dispersion compensation
  - Remove the CD transmission limit of IM-DD
  - Possibility to use higher-dispersion wavelengths (e.g. C-band)
    - Optical amplification and DWDM enable new architectures
- 10dB better receiver sensitivity
  - Possibility for lower overhead FEC for latency-sensitive applications
- Lower baud-rate optical component enables better future scalability
  - How to scale to 3.2Tb/s modules (16x200G IM-DD or 4x800G Coh-Lite)?
- Robustness against link reflection and multi-path optical interference

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Feasible Schemes for 10km @ 800Gb/s

Scheme	8×100Gb/s Direct Detection	4×200Gb/s Direct Detection	1×800Gb/s Coherent	2×400Gb/s Coherent	4×200G SHD
Wavelength	LWDM	LWDM	Fixed λ (C Band)		CWDM
Laser	8×Cooled DFBs	4×Cooled DFBs	1×Cooled ECL		4×Uncooled DFBs
DAC/ADC pairs	8/8	4/4	4/4		8/8(12)
Symbol Rate	53GBaud	112.5GBaud	116GBaud		60GBaud

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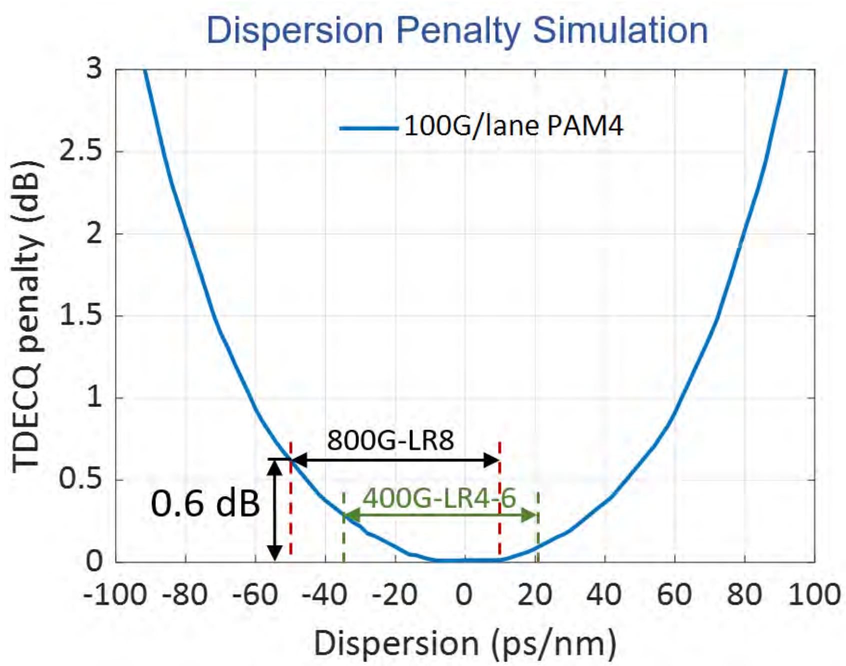
Option 1 for 10km @ 800Gb/s (1/2)

800G-LR8 using 8 wavelengths over a single SMF in each direction with lengths up to at least 10 km:

- Low-cost and energy-efficient IMDD solution, reusing the 50GBaud optics;
- Preferring LWDM over CWDM due to smaller chromatic dispersion for the edging wavelengths at O Band;
- Requiring more power margin to cover the dispersion penalty than 400G-LR4-6.

PMD Type	Grid	Wavelength	Reach	Dispersion
800G-LR8	CWDM8	1271nm, 1291nm, 1311nm, 1331nm, 1351nm, 1371nm, 1391nm, 1411nm.	10km	-59.4 ~ 96.4ps/nm
800G-LR8	**LWDM8**	1273.54nm, 1277.89nm, 1282.26nm, 1286.66nm, 1295.56nm, 1300.05nm, 1304.58nm, 1309.14nm.	10km	-50.8 ~ 9.4ps/nm
400G-LR4-6	CWDM4	1271nm, 1291nm, 1311nm, 1331nm.	**6km**	-35.6~20.1ps/nm



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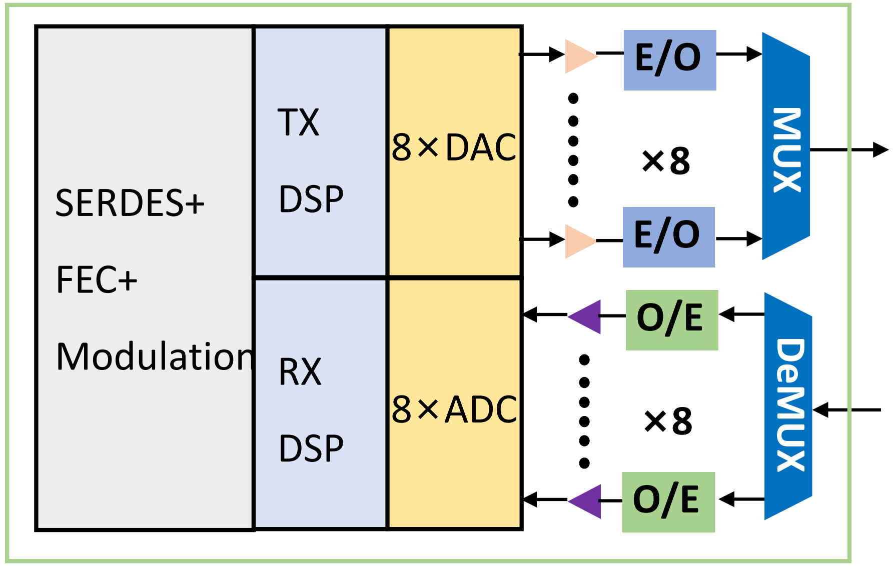
Option 1 for 10km @ 800Gb/s (2/2)

800G-LR8 using 8 wavelengths over a single SMF in each direction with lengths up to at least 10 km:

- Requiring 8×cooled lasers (LWDM8);
- Requiring more power margin to cover the insertion loss of the MUX/DeMUX and the dispersion penalty;
- Challenge of power consumption for QSFP-DD.



Option1: 800G-LR8

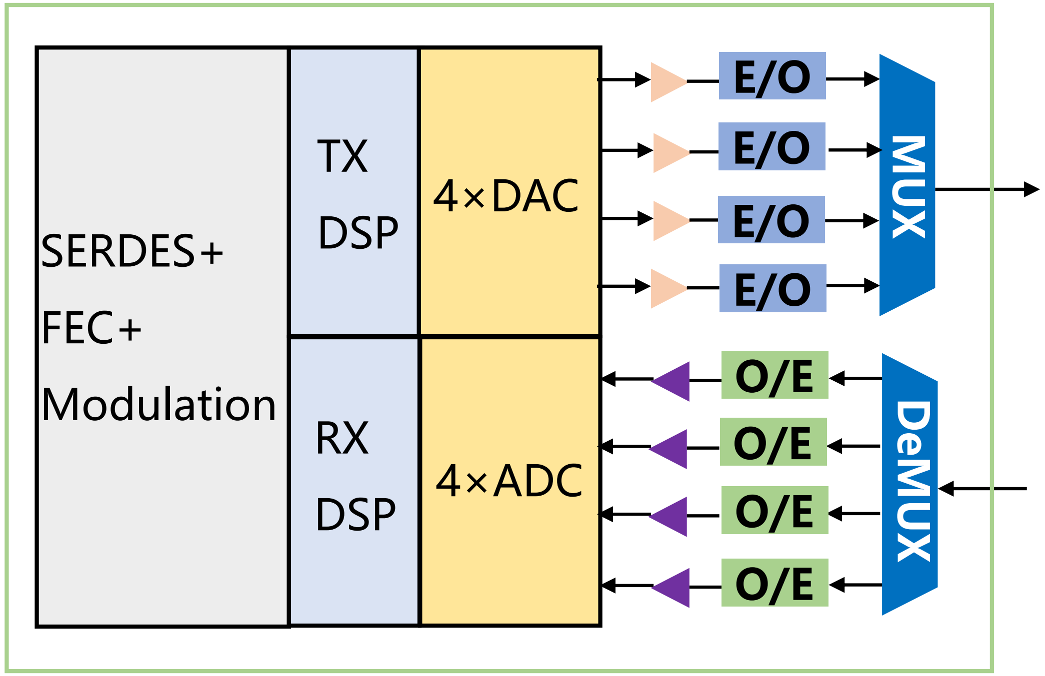
Item	Parameter
Modulation format	PAM4
Symbol rate	53GBaud
The number of DAC/ADC pairs	8/8
The number of lasers/transceivers	8
Wavelength	1273.54nm, 1277.89nm, 1282.26nm, 1286.66nm, 1295.56nm, 1300.05nm, 1304.58nm, 1309.14nm
Dispersion	-50.8 ~ 9.4ps/nm

1. http://100glambda.com/.
2. Shigeru Kanazawa *et al.*, "High Output Power and Compact LAN-WDM EADFB Laser TOSA for 4× 100-Gbit/s/λ 40-km Fiber-Amplifier-Less Transmission," 2020 OFC.

Option 2 for 10km @ 800Gb/s (1/2)

800G-LR4 with 4 wavelengths over a single SMF in each direction with lengths up to at least 10 km:

- Halved number of optoelectronic components but increased bandwidth requirement compared with Option 1;
- LWDM has to be used due to larger chromatic dispersion penalty at higher symbol rate.



Option2: 800G-LR4

Grid	Wavelength	Dispersion
LWDM4	1295.56nm, 1300.05nm, 1304.58nm, 1309.14nm.	-28.4 ~ 9.4ps/nm
CWDM4	1271nm, 1291nm, 1311nm, 1331nm	-59.4 ~ 33.4ps/nm

Item	Parameter
Modulation format	PAM4
Symbol rate	112.5GBaud
The number of DAC/ADC pairs	4/4
The number of lasers/transceivers	4
Wavelength	1295.56nm, 1300.05nm, 1304.58nm, 1309.14nm.

Option 2 for 10km @ 800Gb/s (2/2)

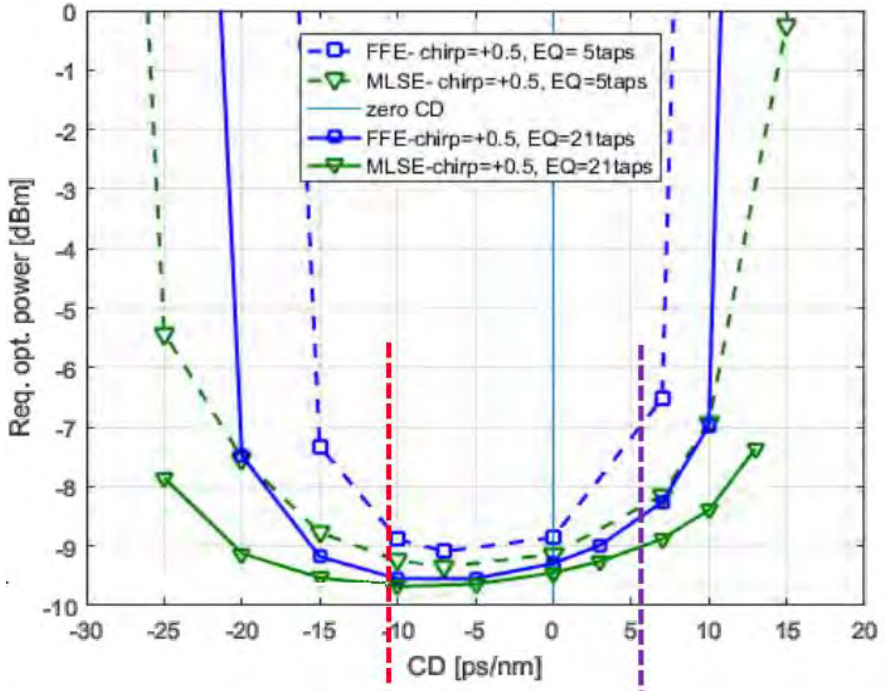
800G-LR4 with 4 wavelengths over a single SMF in each direction with lengths up to at least 10 km:

- The dispersion of 800G-LR4 with LWDM4 is higher than that of 800G-FR4 using CWDM4 with Concatenated FEC (BER threshold of 2e-3), indicating that stronger FEC than KP4 is also needed in 800G-LR4.
- Enhanced DSP (eg. MLSE) is required to reduce the dispersion penalty.

PMD Type	Grid	Wavelength	Reach	Dispersion	FEC
800G-LR4	LWDM4	1295.56nm, 1300.05nm, 1304.58nm, 1309.14nm.	10km	**-28.4 ~ 9.4ps/nm**	≥2e-3
800G-FR4	CWDM4	1271nm, 1291nm, 1311nm, 1331nm	**2km**	-11.9 ~6.7ps/nm	2e-3*

* The FEC of 800G FR4 is referred to 800G Pluggable MSA (https://www.800gmsa.com/)

224Gb/s PAM4 CD tolerance



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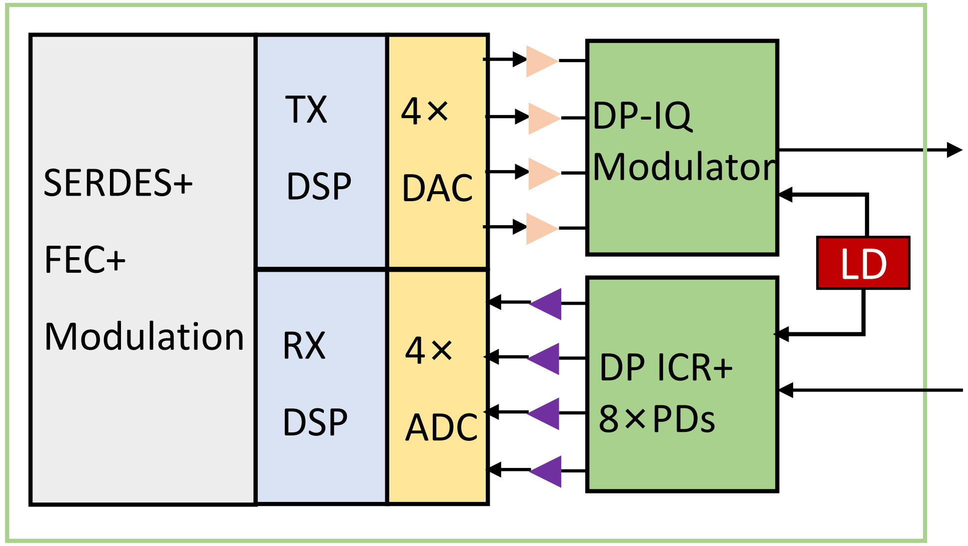
Option 3 for 10km @ 800Gb/s (1/2)

800G-LR1 utilizing single wavelength over a single SMF in each direction with lengths up to at least 10 km:

- Digital coherent detection with 800Gb/s per lane;
- Preferring C band wavelength, due to the relatively low fiber loss and the effective chromatic dispersion compensation by coherent DSP;
- Requiring 100GBaud+ optoelectronic components.



Option3: 800G-LR1

Item	Parameter
Modulation format	DP-16QAM
Symbol rate	116GBaud
The number of DAC/ADC pairs	4/4
The number of lasers/transceivers	1
Wavelength	C band, e.g. 1547.72nm

800LR: https://www.oiforum.com/technical-work/hot-topics/800g-coherent/

Option 3 for 10km @ 800Gb/s (2/2)

Cedric Lam from Google has discussed the technical feasibility of the 800G coherent lite scheme for campus applications in the SG meeting on July 20.

Challenges for Coherent Datacenter Interconnects

- Modulator efficiency (loss and Vpi)
- Modulator Drive
- DSP optimized for <10km datacenter applications

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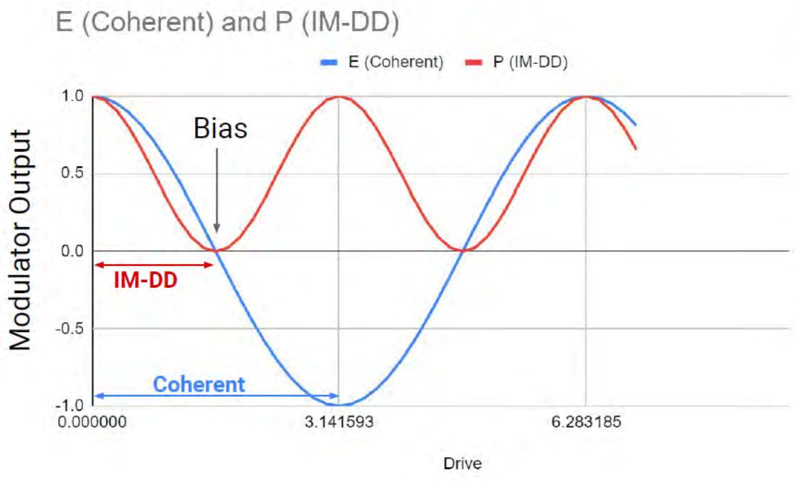
Low-Loss High Efficiency Modulator Needed



- Coherent modulation requires twice drive swing to achieve the same ideal peak power as IM-DD
- Drivers today are designed for IM-DD modulations
- Modulator V-pi is still a challenge (especially for SiPh).
  - Need to develop efficient drivers and efficient modulators.

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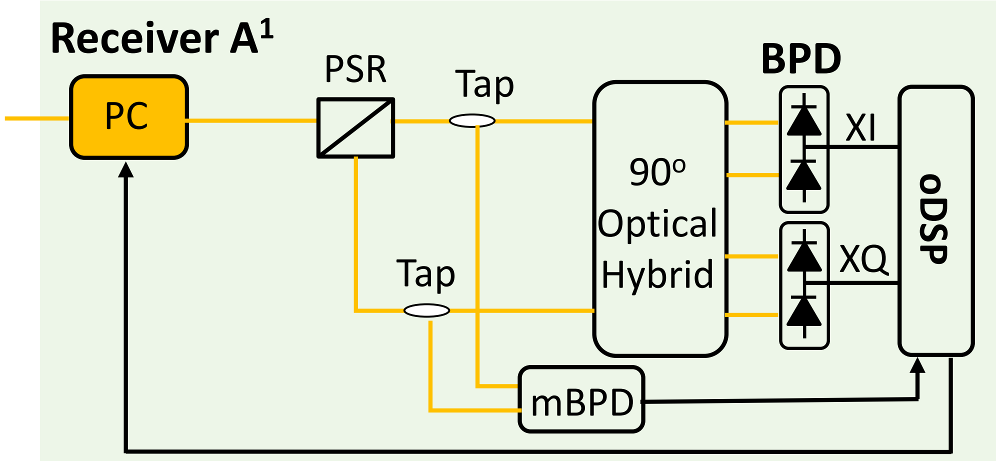
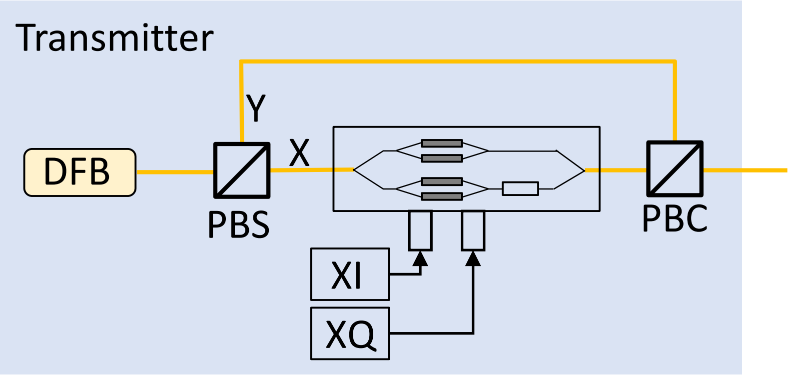
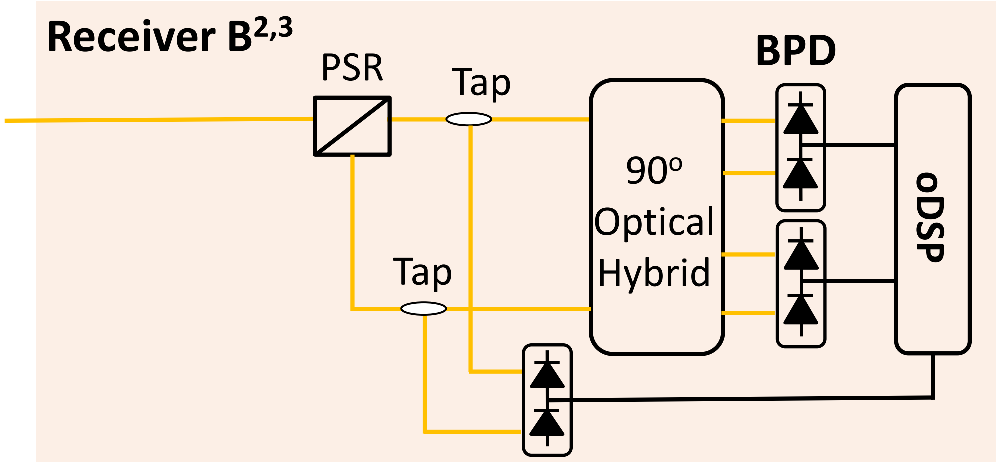
Option 4 for 10km @ 800Gb/s (1/4)

800G-LR4 with 4 wavelengths over a single SMF in each direction with lengths up to at least 10 km:

- Self-homodyne detection (SHD) with 200Gb/s per lane based on the 50GHz optics;
- PC (polarization controller) in receiver A can be integrated with single-polarization ICR；
- Besides receiver B, other types of SVDD receiver structure can also be used.



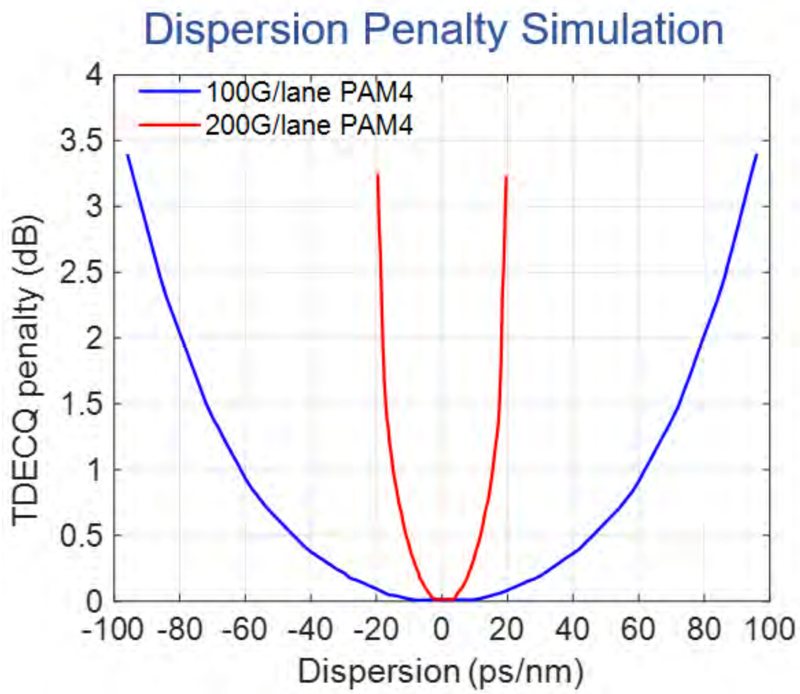




1. Y. Wen *et al.*, Optics Express, 28(15), 21940-21955.
2. W. Shieh *et al.*, APL Photonics 1(4), 040801 .
3. S. Zhang *et al.*, "224-Gb/s 16QAM SV-DD Transmission Using Pilot-Assisted Polarization Recovery with Integrated Receiver," in 2021 OFC, paper W7F.4.

Option 4 for 10km @ 800Gb/s (2/4)

- Traditional IMDD can only recover the intensity information, therefore, suffering from dispersion-induced TDECQ penalty.
- SHD enables full-field recovery, consequently achieving dispersion-penalty-free transmission. The small CD from the edging wavelengths at O Band can be eliminated by simple equalization.
- The SHD Rx DSP bypassing carrier recovery and CD compensation (O Band operation) is simpler than conventional coherent Rx DSP and is comparable with IMDD Rx DSP.



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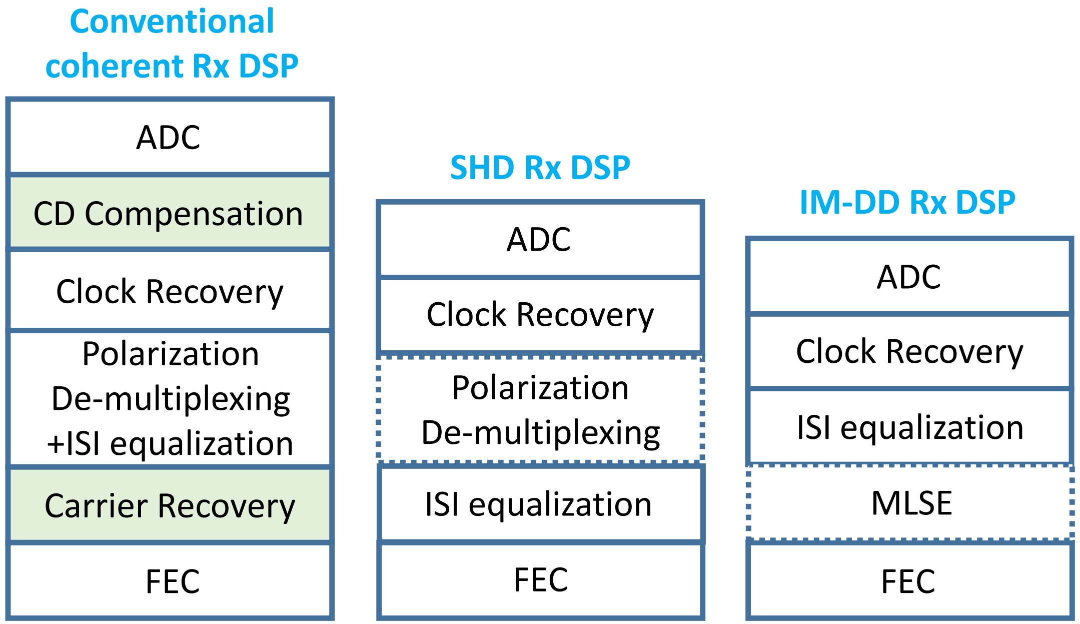
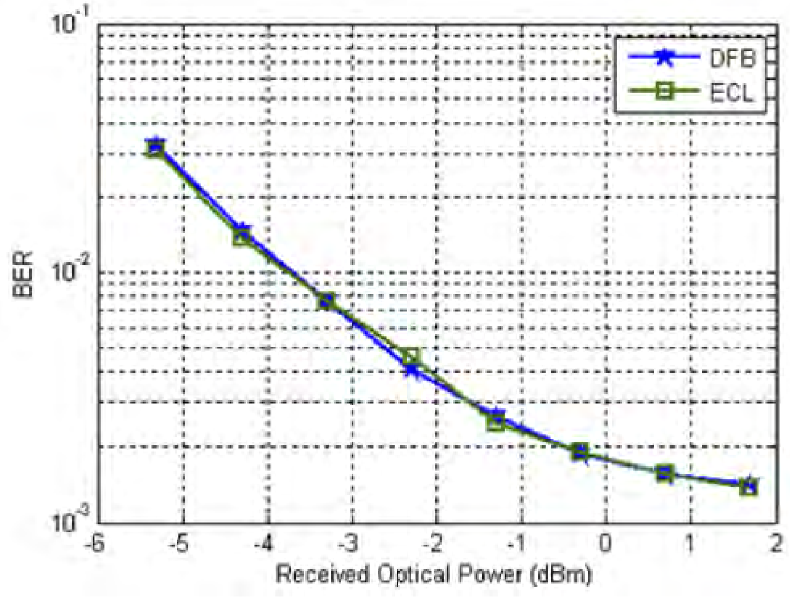


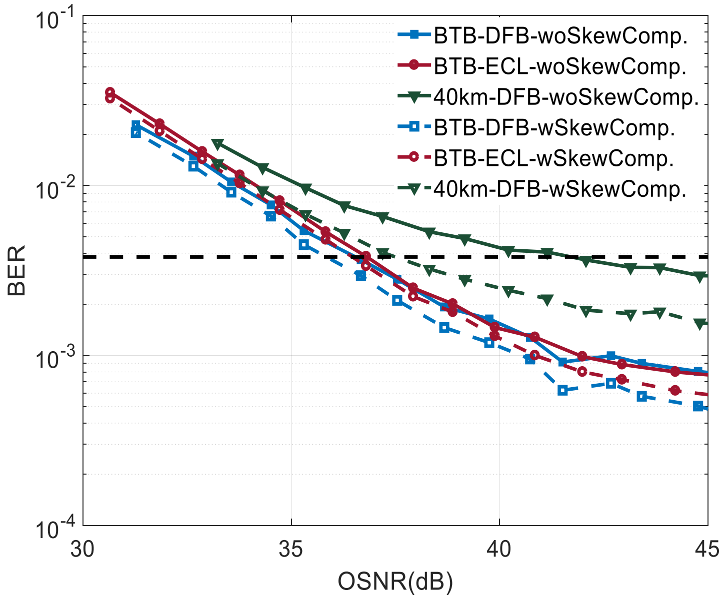
The DSP functions indicated by the dashed boxes are optional, depending on the implementation scenarios.

Option 4 for 10km @ 800Gb/s (3/4)

- Single lane 200Gb/s using the SHD scheme with both receiver types has been experimentally demonstrated in the laboratory.
- The performance in the case of the DFB and ECL are practically the same, demonstrating the large linewidth tolerance of the SHD scheme.
- Using receiver B architecture, 200Gb/s 16QAM signal transmission over 40km has been validated, indicating the feasibility of 10km transmission.



Y. Wen *et al.*, "200G self-homodyne detection with 64QAM by endless optical polarization demultiplexing," *Optics Express*, *28*(15), 21940-21955.

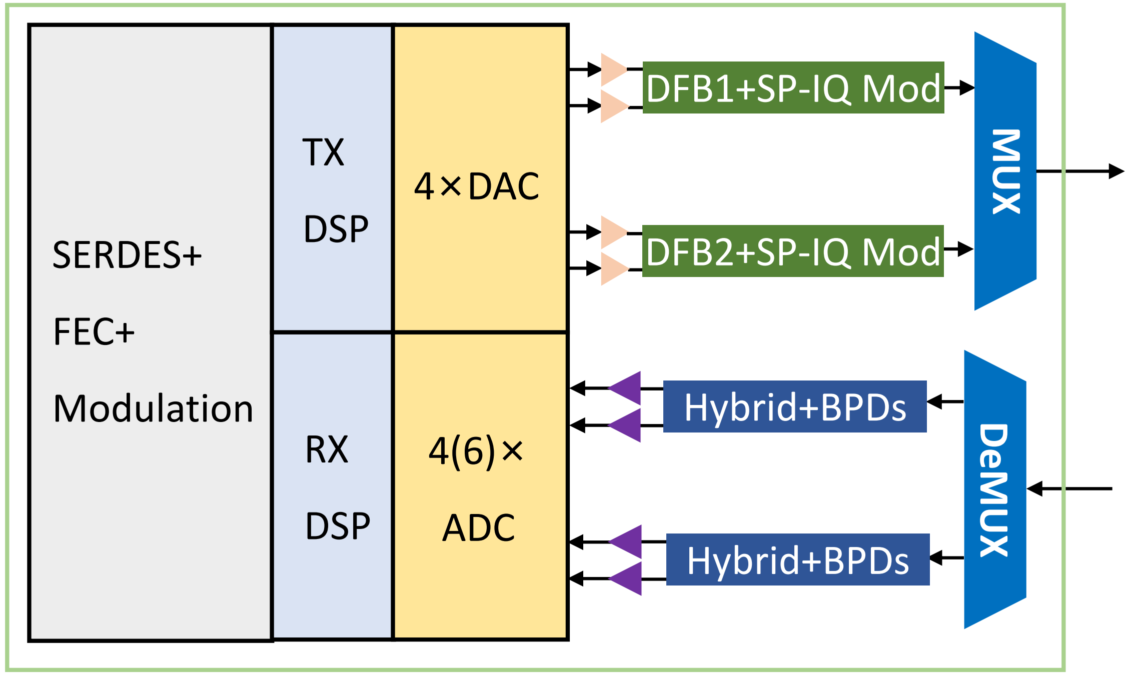


S. Zhang *et al.*, "224-Gb/s 16QAM SV-DD Transmission Using Pilot-Assisted Polarization Recovery with Integrated Receiver," in 2021 OFC, paper W7F.4.

Option 4 for 10km @ 800Gb/s (4/4)

Besides 800G-LR4 with 4 wavelengths using 60Gbaud 16QAM, this scheme can also realize 400G/lane by sharing 100GBaud+ optic components.

- Self-homodyne detection (SHD) with 400Gb/s per lane;
- Reusing two of uncooled DFB lasers (O Band CWDM4) and simple DSP;
- It can been scaled to 1.6TE-LR4 (4×400Gb/s) reusing CWDM4 DFB lasers.



Option 5: 800G-LR2

Item	Parameter 1	Parameter 2
Modulation format	SP-16QAM	SP-16QAM
Symbol rate	60GBaud	116GBaud
The number of DAC/ADC pairs	8/8(12)	4/4(6)
The number of lasers/transceivers	4	2
Wavelength	1271nm, 1291nm, 1311nm, 1331nm	1291nm, 1311nm,

Feasible Schemes for 10km @ 800Gb/s

Scheme	**8×100Gb/s Direct Detection**	**4×200Gb/s Direct Detection**	**1×800Gb/s Coherent**	**2×400Gb/s SHD**
Grid	LWDM	LWDM	Fixed λ (C Band)	CWDM
Laser requirements	8×DML/EML	4×EML	1×narrow linewidth ECL	2×large linewidth DFB
DAC/ADC pairs	8/8	4/4	4/4	4/4(6)
Component bandwidth	>25GHz	>50GHz	>50GHz	>50GHz
DSP Complexity	Low	Middle	High	Middle
Cost	Middle	Low	High	Low

Summary

This contribution discusses several schemes, which are technically feasible for the objective that 800Gb/s over a single SMF in each direction with length up to at least 10 km:

- 800G-LR8 (100G/lane) is feasible for 10 km @ 800Gb/s, leveraging the low dispersion of LWDM.
- By resorting to enhanced DSP and stronger FEC, IMDD using LWDM4 with an increased lane rate of 200Gb/s also enables 800-Gb/s 10-km transmission.
- 800G-LR1 using coherent lite scheme with single lane rate of 800 Gb/s is another option and has been discussing by the industry.
- 800G-LR2 utilizing SHD, two uncooled large-linewidth DFB lasers (400G/lane), and simple DSP can also support this objective.

Thank you.