Co-Packaging Interoperability Demo
OFC 2023

Co-Packaging Interoperability Demonstration

- Co-Packaging Framework Document
- 3.2T Optical Module for Co-Packaging Project
- ELSFP Project
- Electrical Interfaces for Co-Packaging
- Interoperability Demonstrations

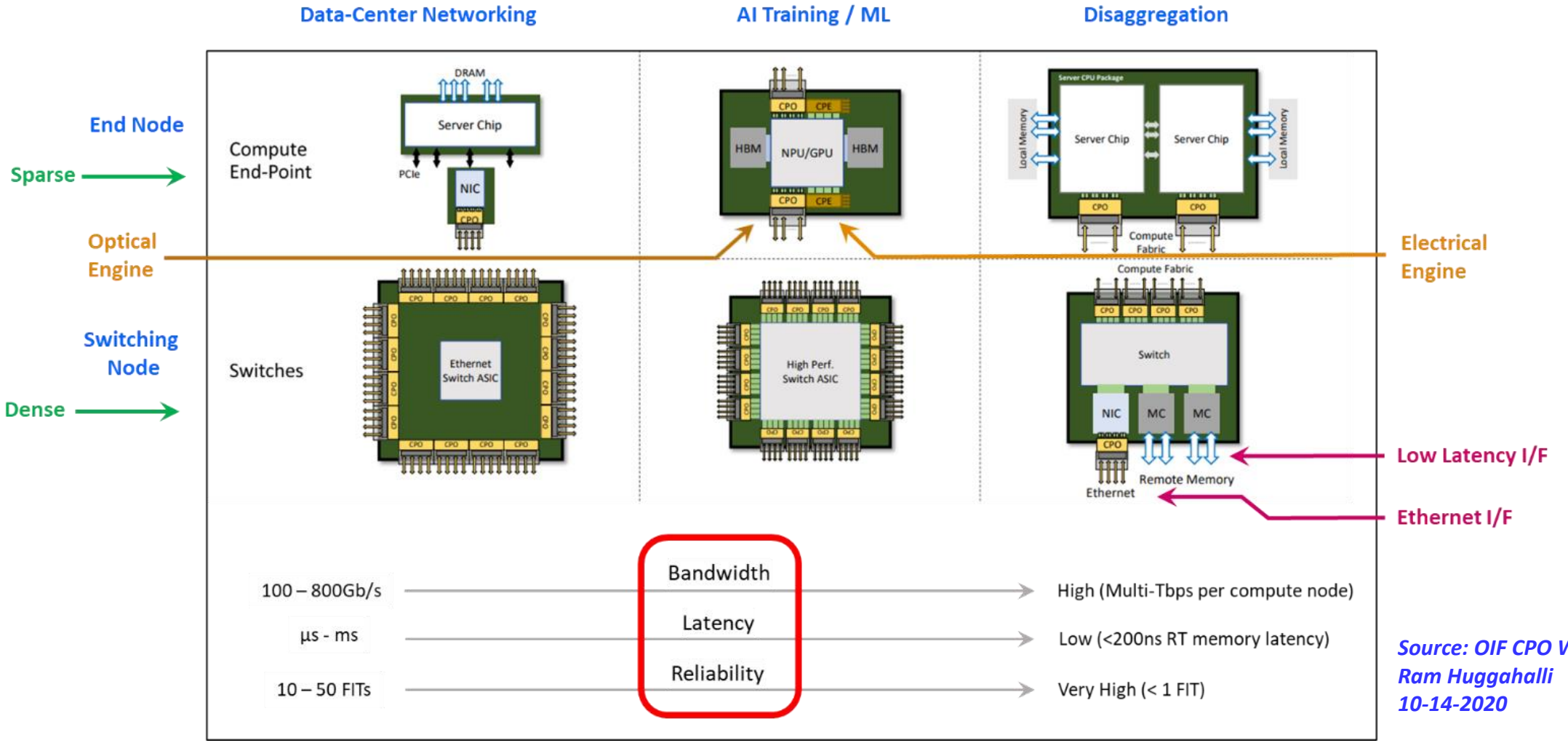
What is a Framework Document?

Framework Project

- A framework project has been a successful vehicle for the OIF.
- It enables the OIF membership to explore next generation industry needs and to forge an industry consensus, particularly with respect to interoperable solutions by:
  - Identifying the various application needs (application spaces)
  - Identifying points where interoperability is important
  - Identifying what kinds of parameters should be interoperable
  - Identifying additional projects which can nail down specifics for interoperability
- It results in a framework document detailing how the OIF can address next generation industry needs through follow on implementation agreements.

Co-Packaging Application Spaces

Framework Project

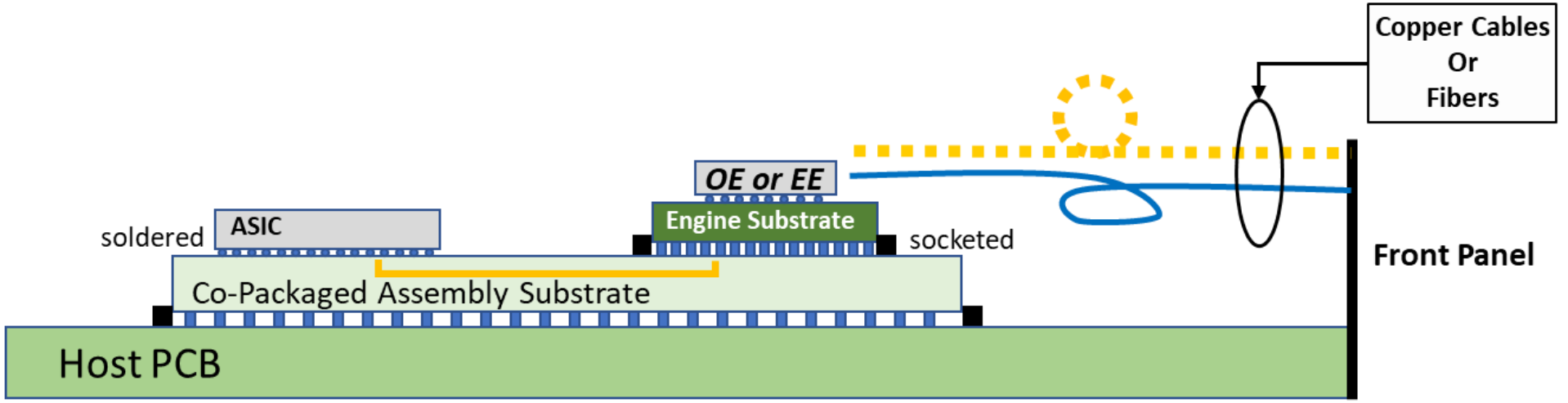


Source: OIF CPO Webinar, Ram Huggahalli 10-14-2020

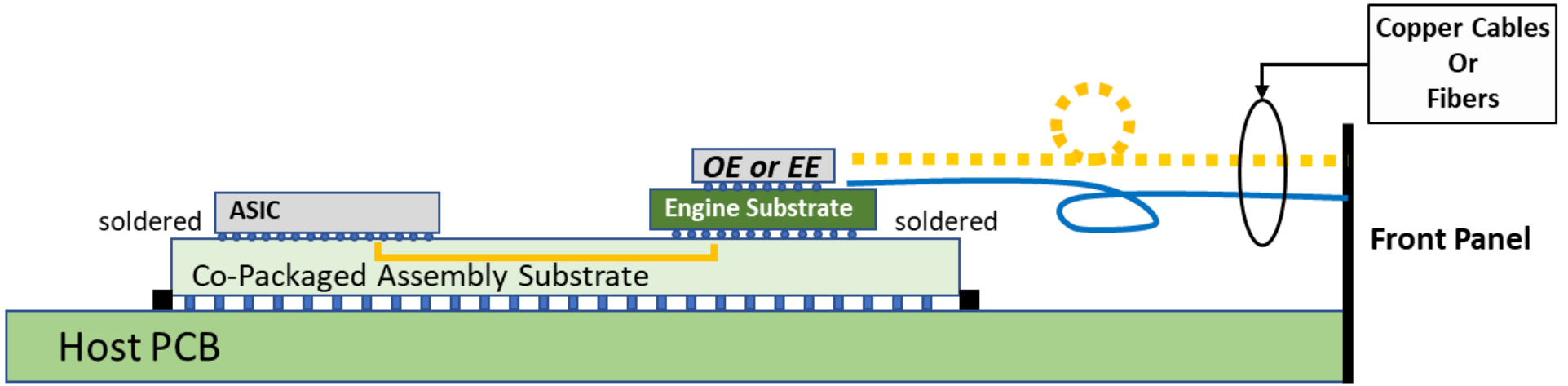
Co-Packaging Architectures (1)

Framework Project

Co-Packaged using socket for engine



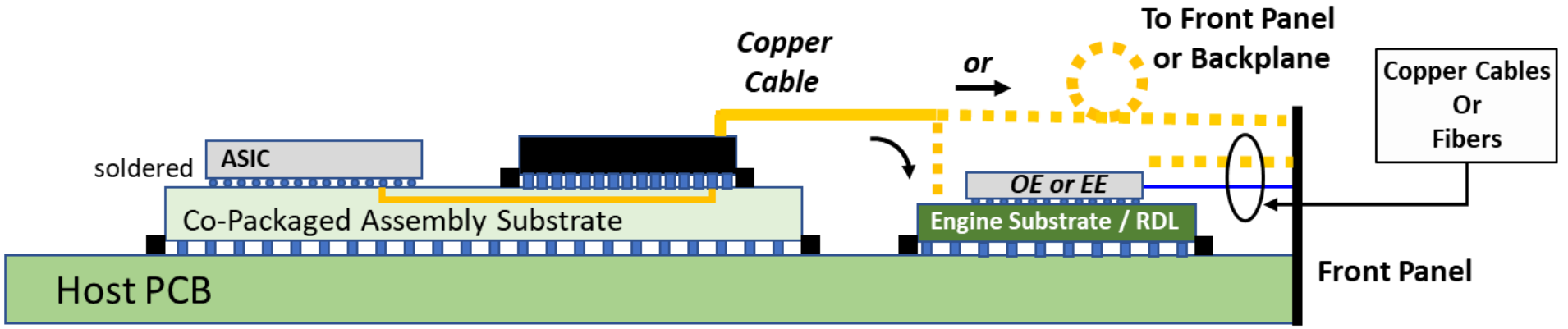
Co-Packaged with soldered engine



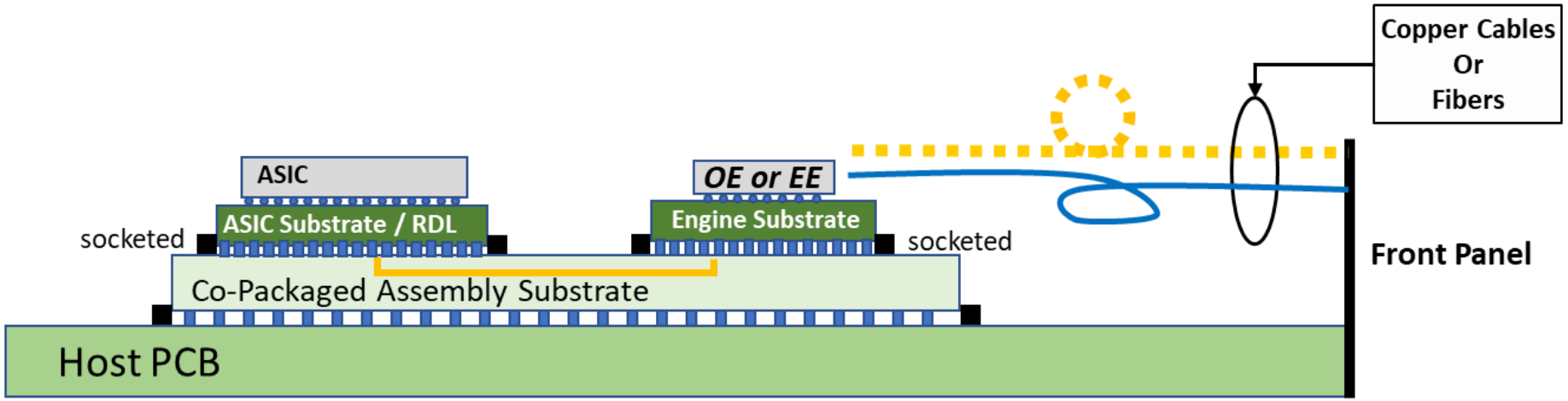
Co-Packaging Architectures (2)

Framework Project

Co-Packaged using copper cable assembly

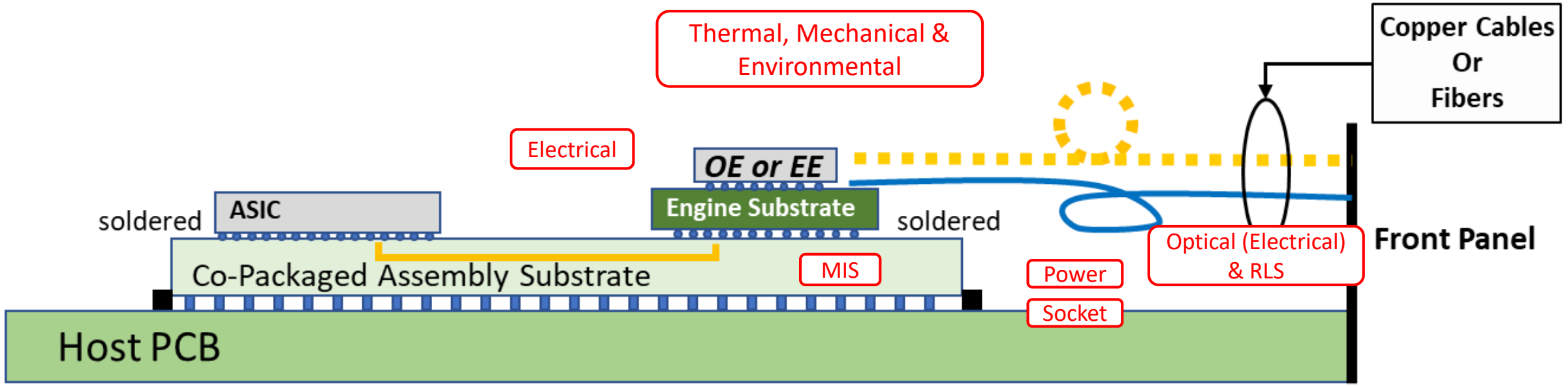


Near-Packaged using socketed engine



Interfaces Studied for Interoperability

Framework Project



Application Example

- **Switch Generation:** 51.2Tb/s
- **Lane Speed:** 106 Gb/s
- **Interface Architecture:** XSR based AUI, 400G-FR4 PMD
- **Motivation:** System power reduction, ecosystem & operational readiness

Reliability and Repairability

Table of Contents (high-level)

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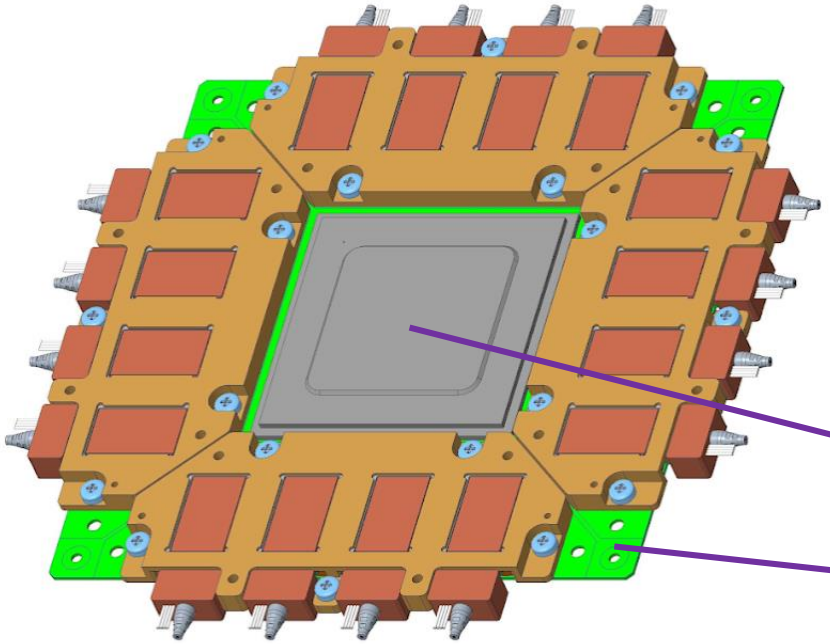
- Interoperability Demonstrations

Overview
3.2T Optical Module

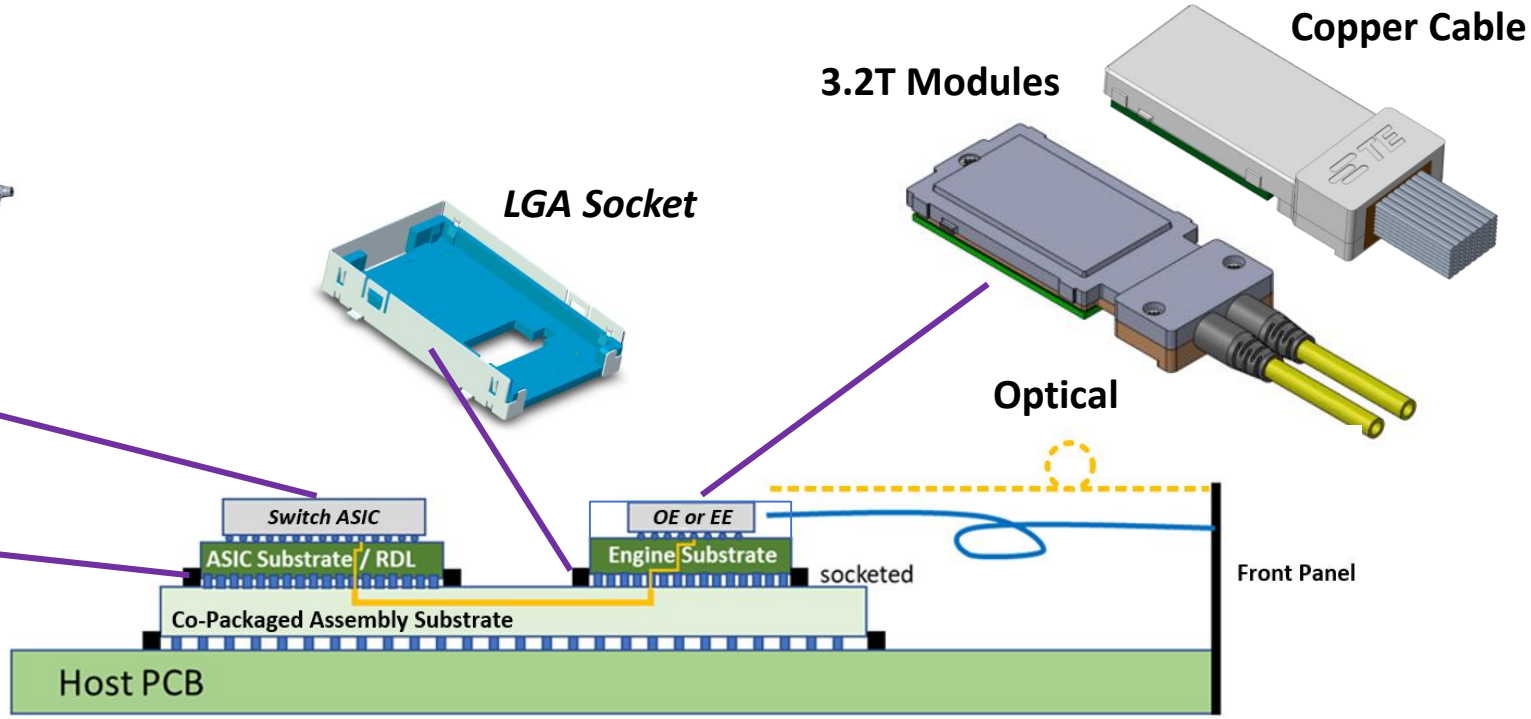
- The OIF started the 3.2T Module Project Feb 2021
  - Project proposed by Facebook (now Meta), Microsoft, Ranovus, Intel, with a large industry backing
- The initial goal was to create:
  - A 3.2T Optical Co-Packaged Module IA for 51T data-center switch applications
- This presentation aims to update the industry on our progress so far…
- Contributions and collaboration from many members are included in here, with sincere appreciation from the Editor

Example System Attachment
3.2T Optical Module

- 16 x 3.2T Modules = 51.2T Switch Capacity



Co-Packaged Assembly Substrate (Interposer)

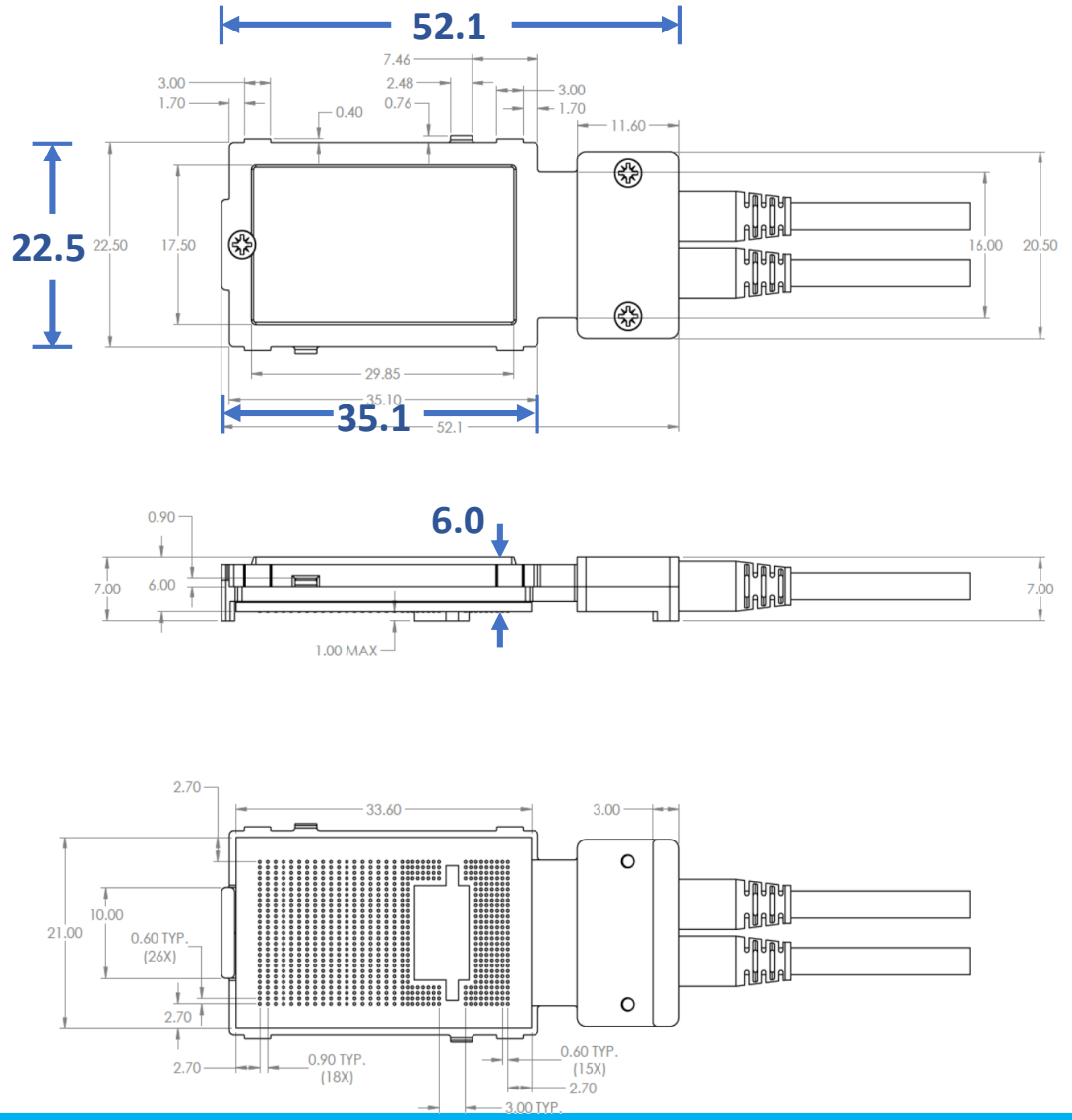


Channel components cross-section

3.2T Module Dimensions

3.2T Optical Module

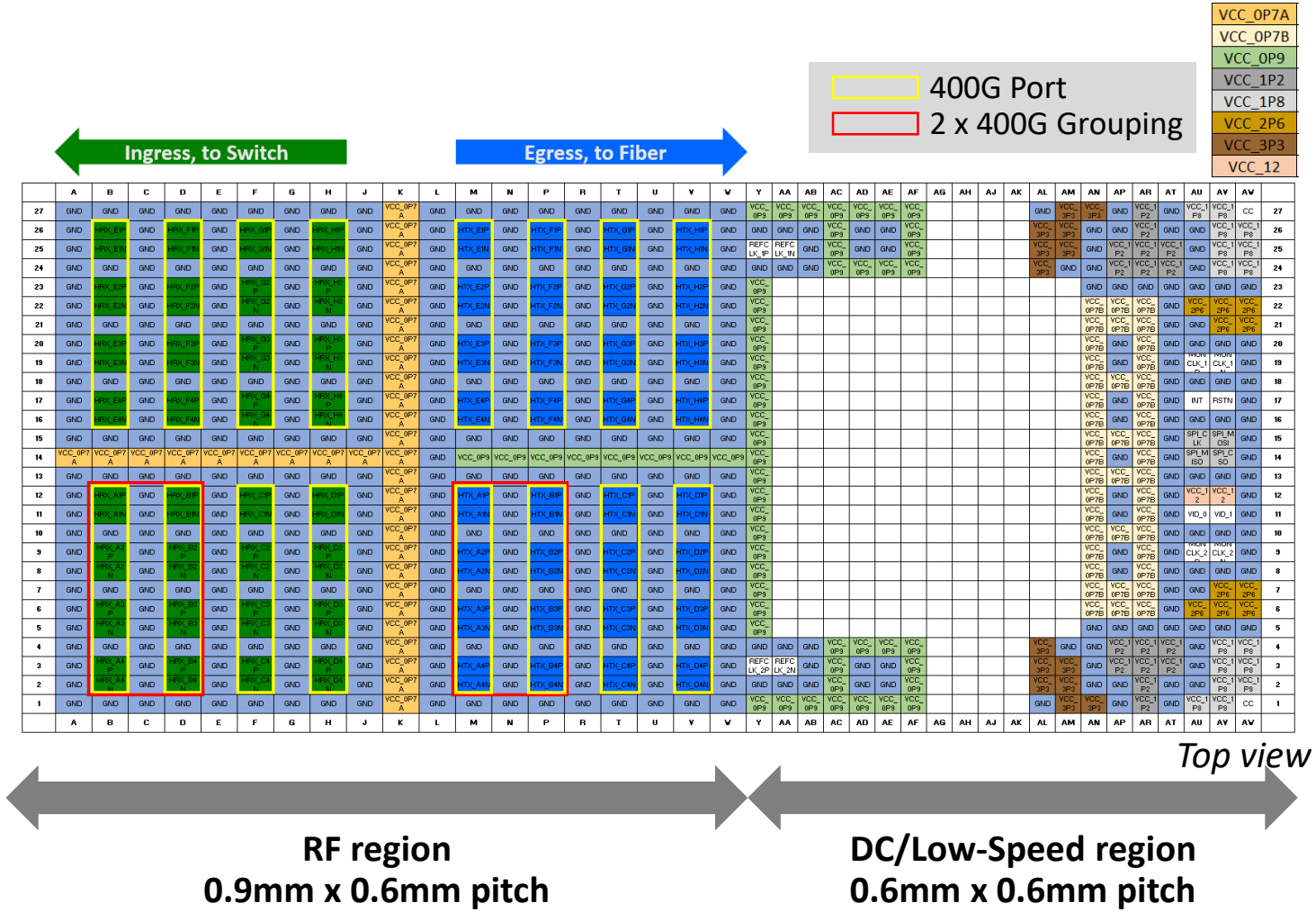
- 32 x 112G XSR to Standard Optics:
  - 8 x 400G DR4
  - 8 x 400G FR4 (incl. 200G mode)
- Copper Cable Assembly compatible
- Power capability:
  - 56W (Internal Laser option)
  - 48W (External Laser option)



LGA Pin Map

3.2T Optical Module

- Supply rails:
  12V, 3.3V, 2.6V, 1.8V, 1.2V, 0.9V, 0.7V
- Comms Electrical: 1.2V SPI
- Comms protocol: CMIS
- 400G and 800G (2x400G) port grouping defined
  - *For low power modes and 2x400G-FR4 cable assignment*

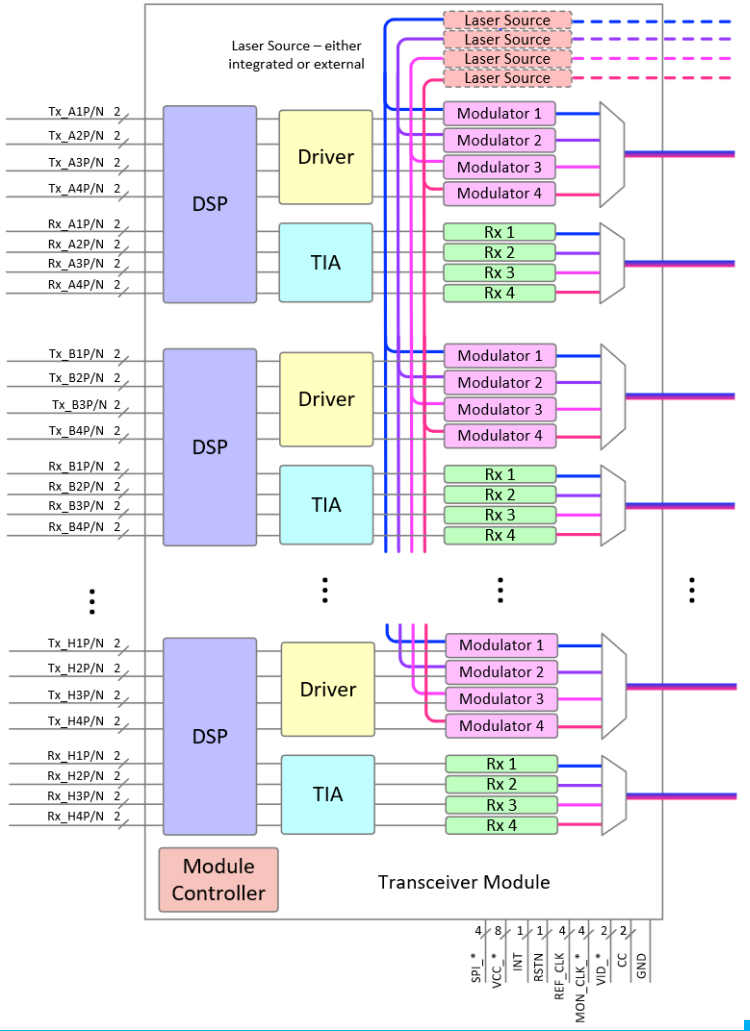


3.2T Optical Module Functionality

3.2T Optical Module

- FR Module example ->

- *How does this all fit in?*
  - *3D integration*
  - *Die/functionality integration*
    - *Optics (Laser + Modulator + PD)*
    - *EIC (Driver/TIA/Control)*



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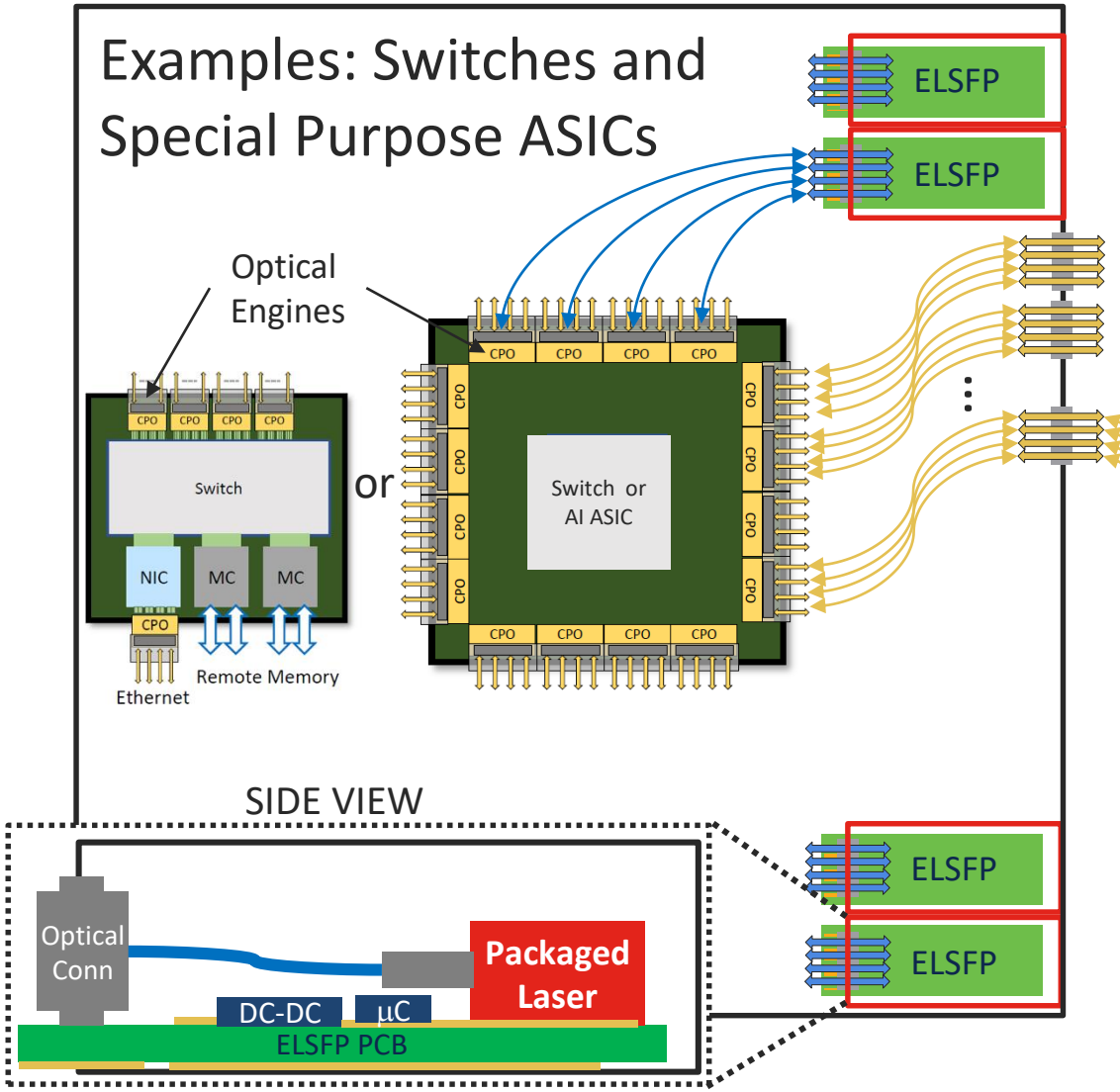
Why ELSFP?

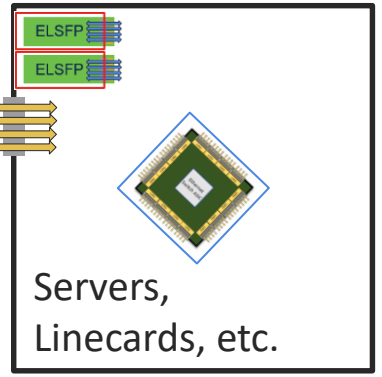
ELSFP Project

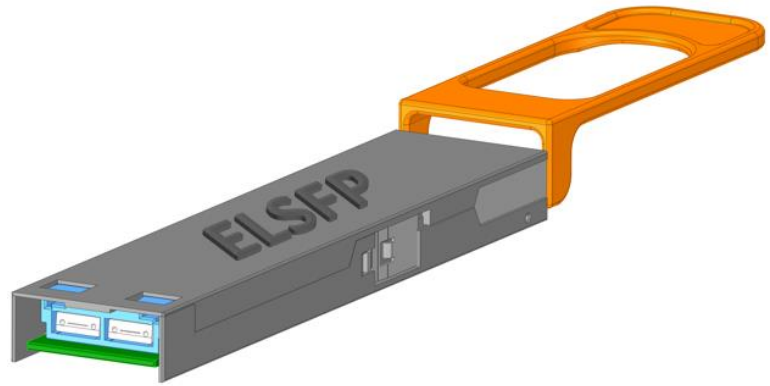
- OIF defining common External Laser Pluggable
- Industry need for co-packaged and near-packaged systems
  - Systems need faceplate density
  - External laser modules need common specification for economies of scale
- Form factor to span multiple system generations
  - Plan for optical & thermal scaling

External Laser Small Form Factor Pluggable (ELSFP)



- ELSFPs provide CW laser power for optical engines (OEs).
- Decreases thermal power density in the system
- Each large system will likely need multiple (i.e. 8 or 16) ELSFPs
- The light from a given ELSFP can feed more than a single OE.
- A pluggable form factor helps to ensure total system reliability and a "hot swap" replacement if a single laser or ELSFP module fails.
- Eye safety is achieved by a blind mate optical connector internal to the system.





Initial Technical Concept

ELSFP Project

Density

- Blind mate pluggable
- Width similar to OSFP (16 modules wide with standard management I/O)

Commonality

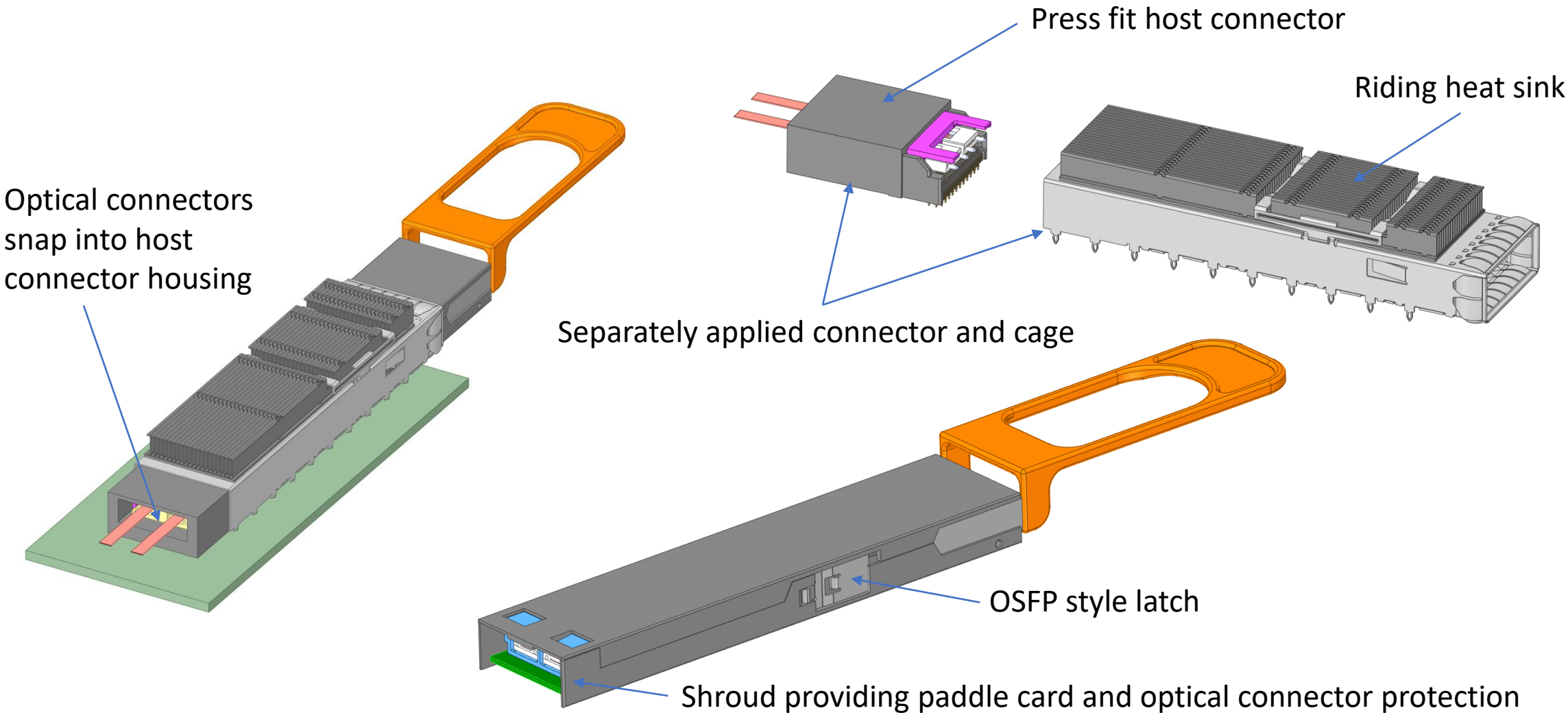
- Industry standard 3.3V Supply
- CMIS (Common Management Interface Specification)

Scaling

- Optical Power Classes
- Thermal Power Classes
- Belly-to-belly configurations
- Riding heat sink for system flexibility
- 2 “MT like” ferrules for future proofing
  - Support for 8 PM fibers per MT
  - Support for multiple OE modules

Single Port ELSFP Design

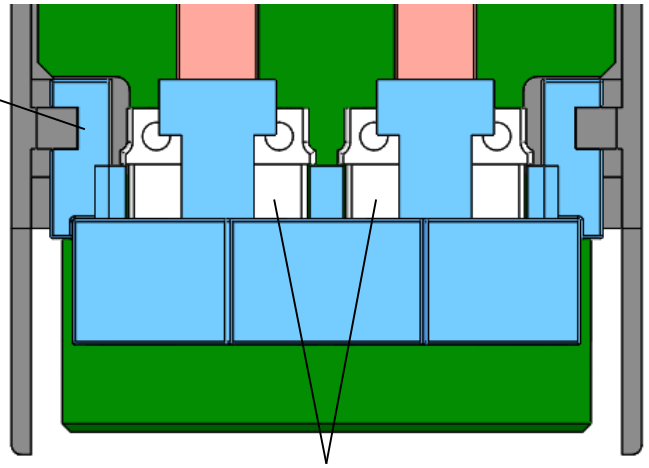
ELSFP Project



ELSFP Module-Side Optical Connector

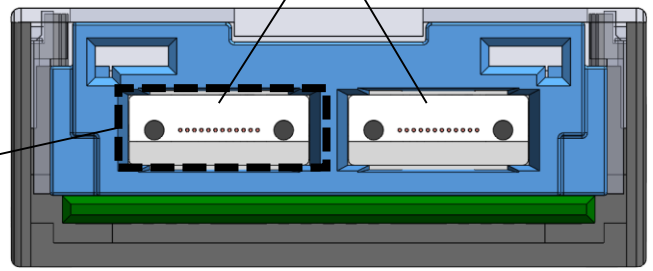
ELSFP Project

Connector-to-Module Attachment (Optional)

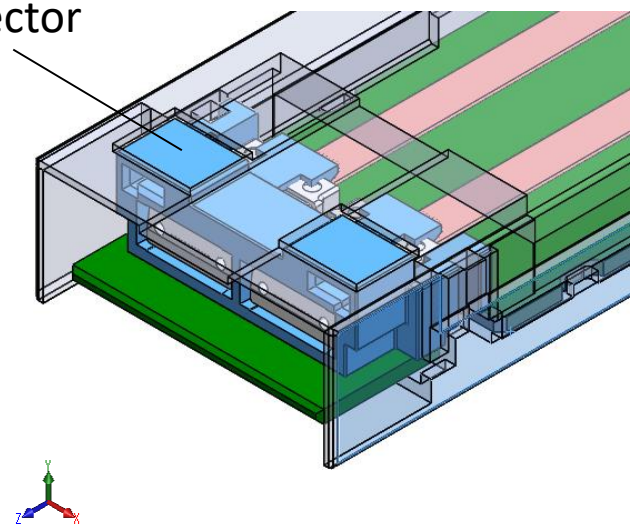


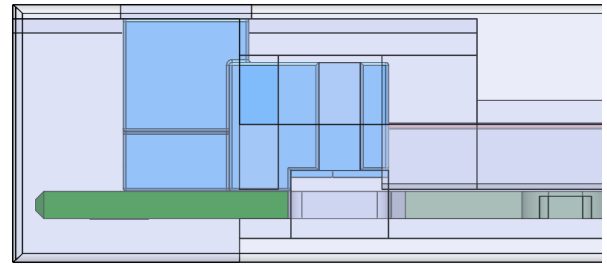
1 or 2 MT-like Ferrules

Optional 2nd MT-like Ferrule



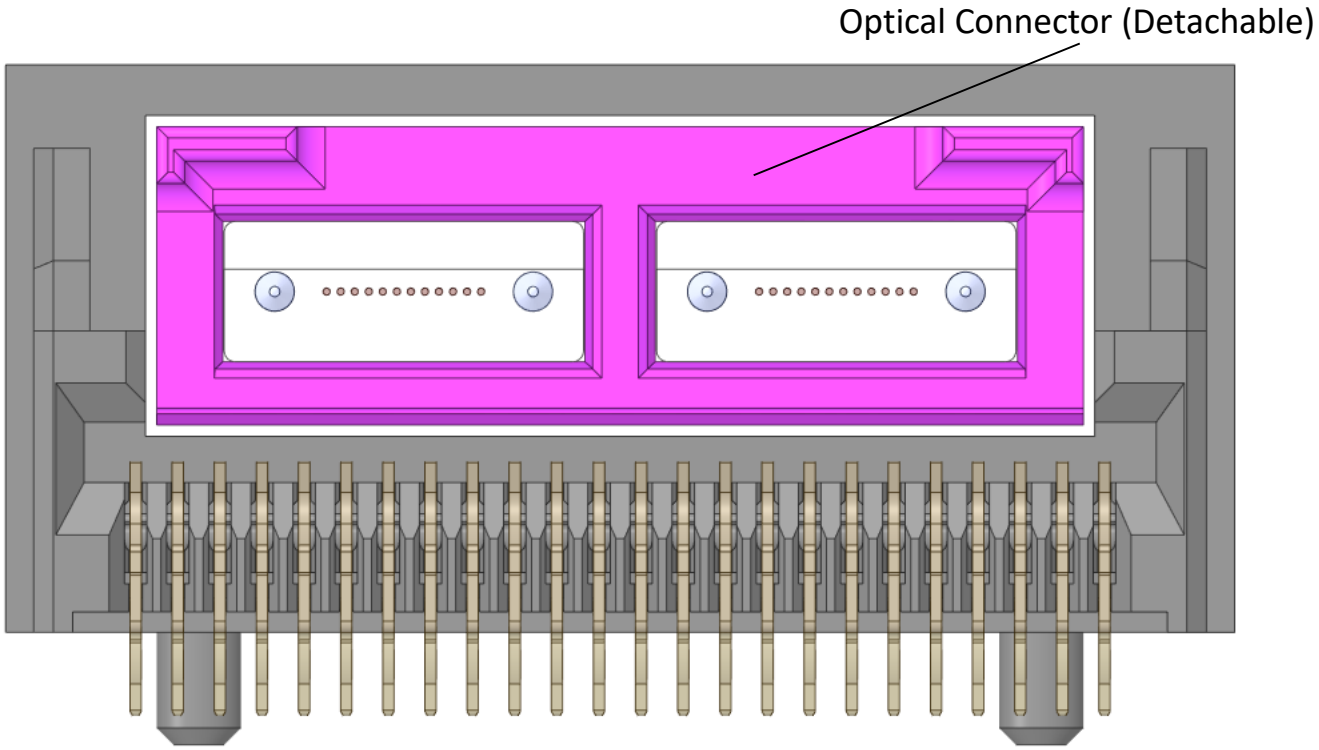
Robust anchoring for optical connector





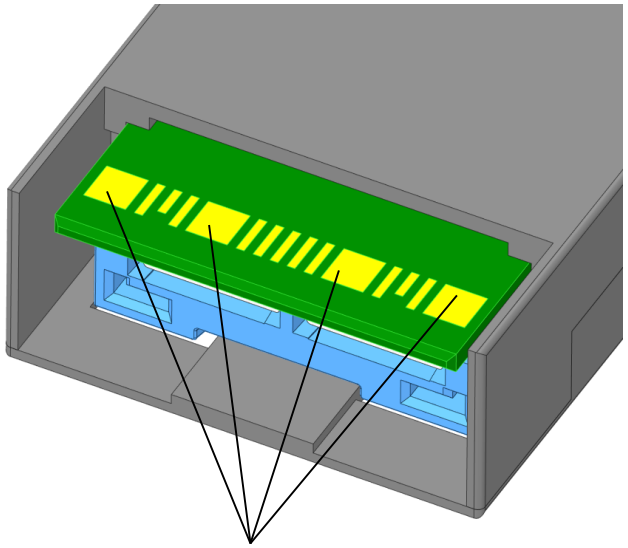
ELSFP Electro-Optical Connector

ELSFP Project



Host side Electro-Optical Connector

Module Bottom side Electrical Contacts



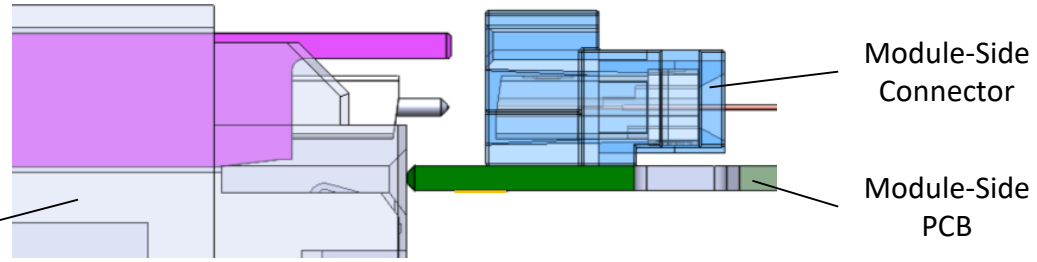
Sufficient power and ground to support **30W**

Additional pins for control/management, laser safety (i.e. presence pin), and spares for future proofing
Optical connector sub-assembly (pink) is separable from the board mounted electrical connector sub assembly

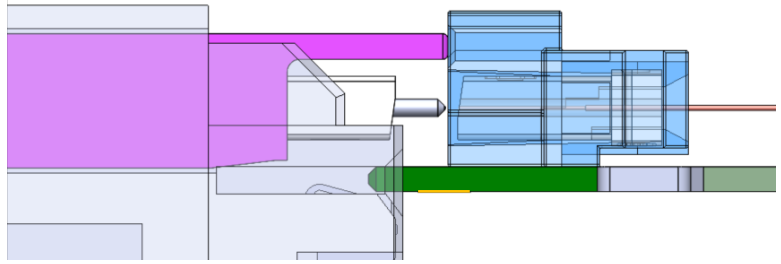
ELSFP Mating Sequence

ELSFP Project

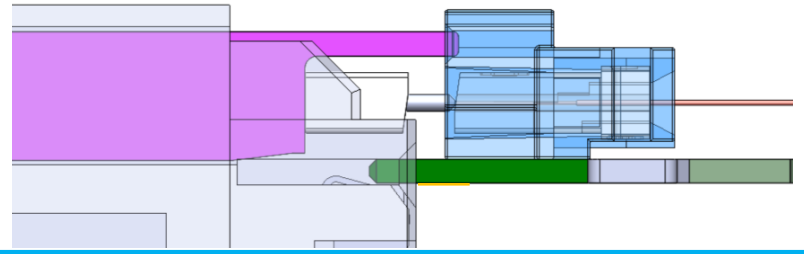
STEP 1: Coarse alignment (PCB-to-host receptacle)



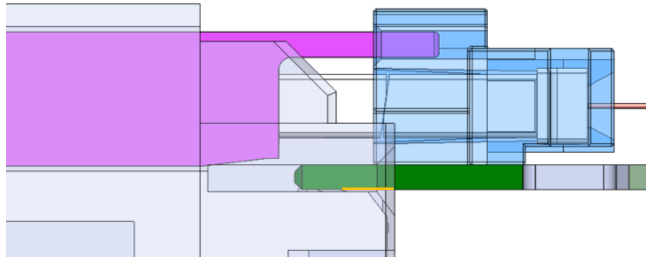
STEP 2: Coarse alignment (Optical coarse alignment pins)



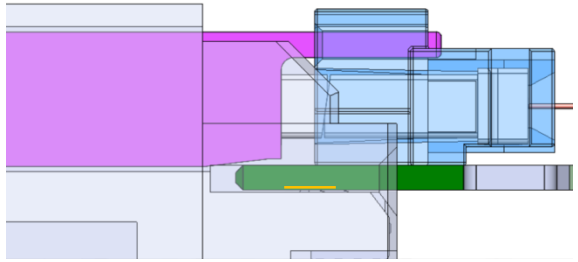
STEP 3: Fine alignment (ferrule guide pins)



STEP 4: Ferrule end-faces in contact



STEP 5: Electrical contact (presence pin)



- Host side optical connector sub assembly has float to enable fine optical alignment.
- PCB and optical coarse alignment pins mate prior to fine alignment of optical ferrule guide pins .
- Ferrule end-faces to contact prior to electrical contact.

ELSFP Optical Power Classes

ELSFP Project

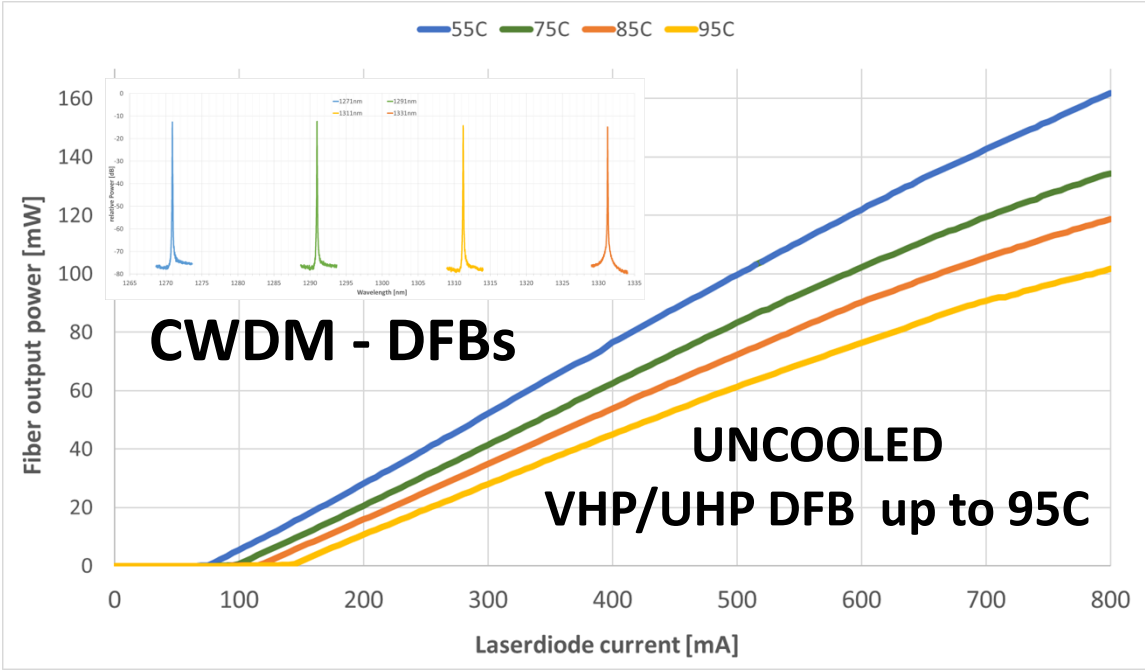
ELSFP Optical Power Classes	Power/λ/Core +/- 1.5dB
Super Low Power - SLP	2dBm
Ultra Low Power - ULP	5dBm
Very Low Power - VLP	8dBm
Low Power - LP	11dBm
Medium Power - MP	14dBm
High Power - HP	17dBm
Very High Power - VHP	20dBm
Ultra High Power - UHP	23dBm
Super High Power - SHP	26dBm

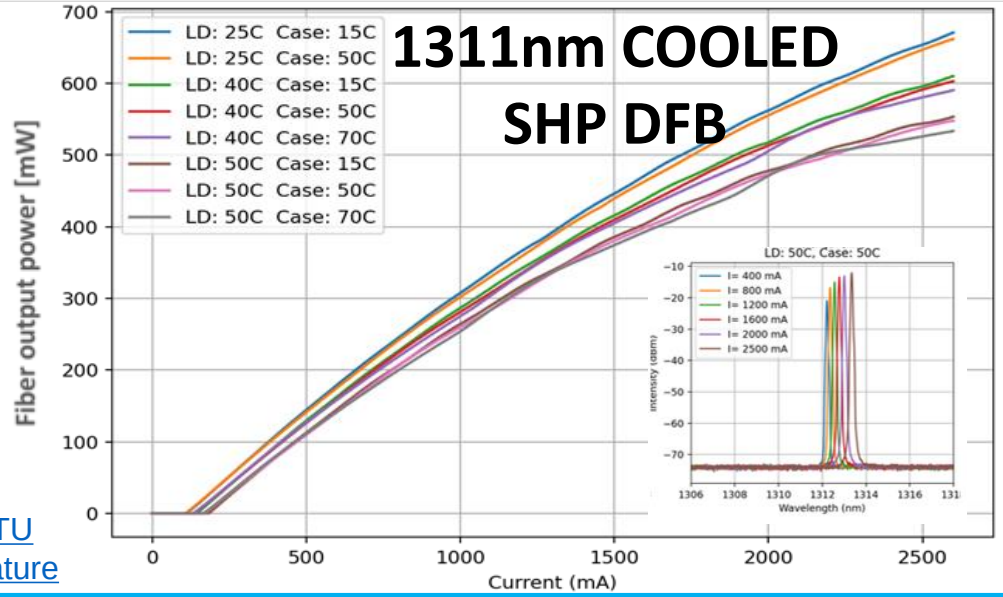
Combs

Single-Channel

Multi-Channel

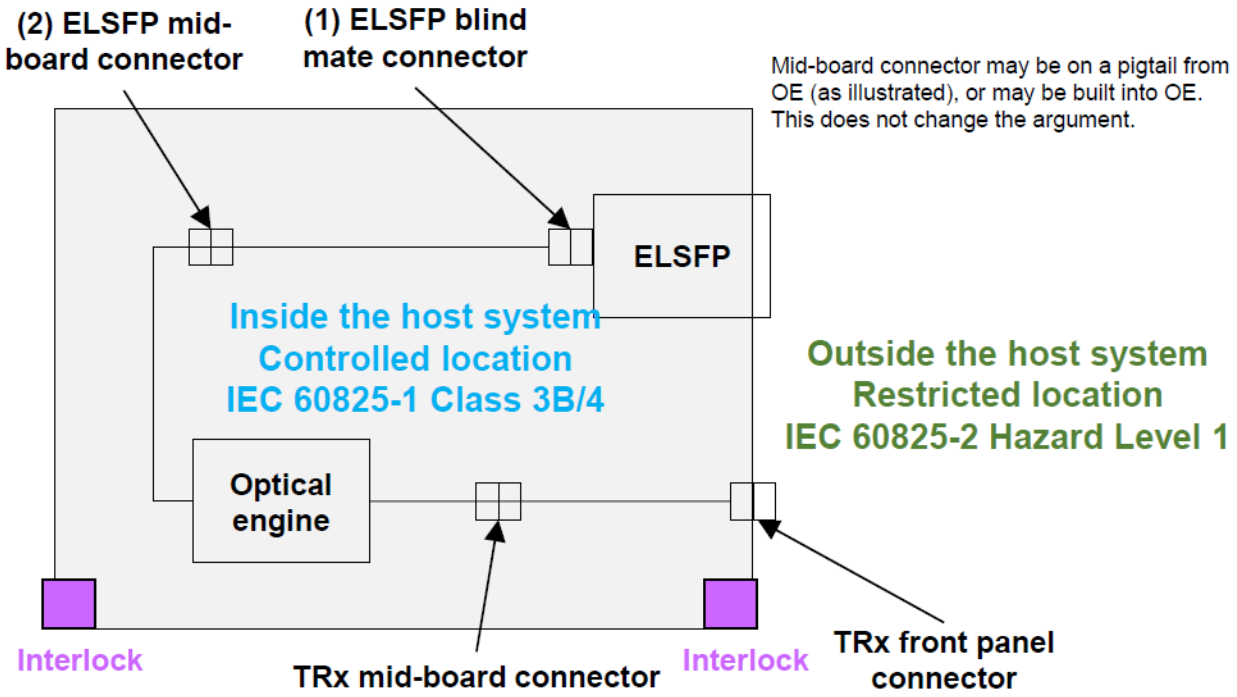
*Naming convention inspired by ITU Radio Frequency Band Nomenclature





Eye Safety
ELSFP Project

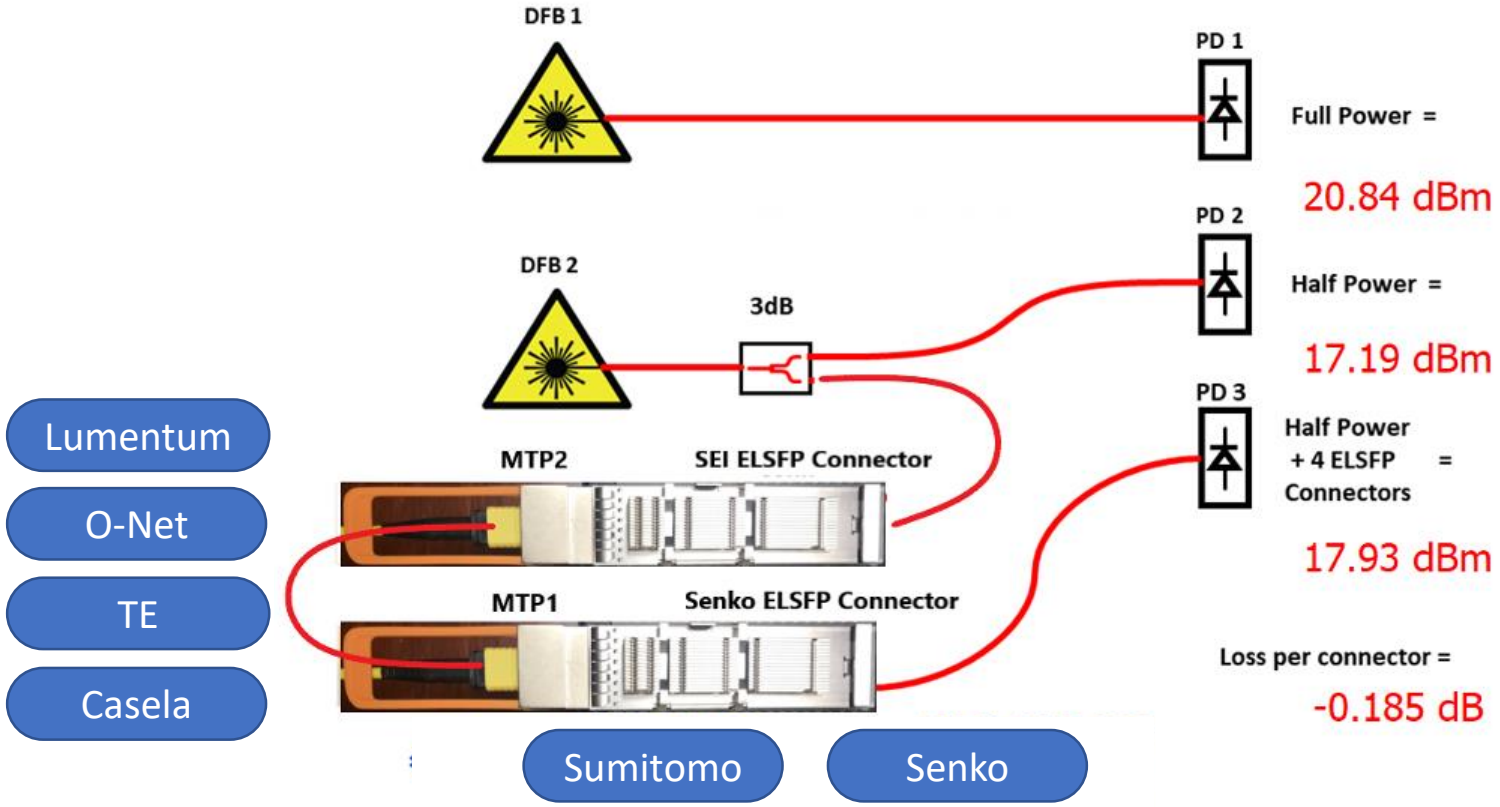
ELSFP's blind mate optical connector paired with a system interlock enables a safer co-packaged system implementation for users.



Similar to EDFAs with powerful CW lasers, Class 3B and 4 lasers can be used inside ELSFP and systems can be deployed in unrestricted locations.

ELSFP Pass Through Module with Blind Mate Connector

Group 1	Group 2
☐ CH 1	☐ CH 5
☐ CH 2	☐ CH 6
☐ CH 3	☐ CH 7
☐ CH 4	☐ CH 8
Group 3	**Group 4**
☐ CH 9	☐ CH 13
☐ CH 10	☐ CH 14
☐ CH 11	☐ CH 15
☐ CH 12	☐ CH 16



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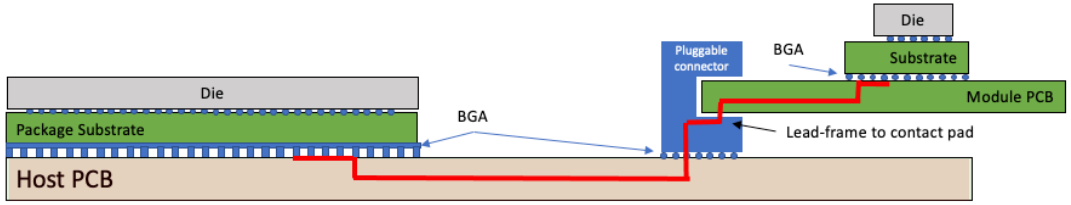
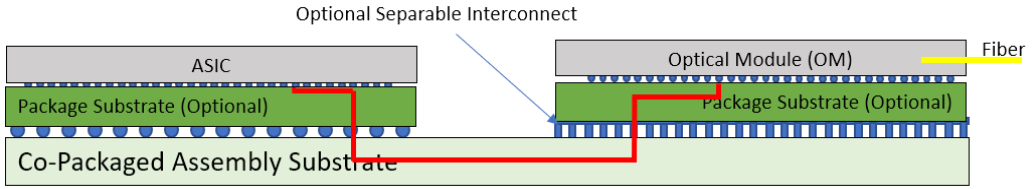
CEI – An Essential Building Block for Co-packaging

Pluggable Module Channel Example Illustration



- Channel loss: 16dB ball to ball (22-24dB bump to bump)
- Typical pluggable connectors: IL of ~1dB with RL of -10dB @26.5GHz

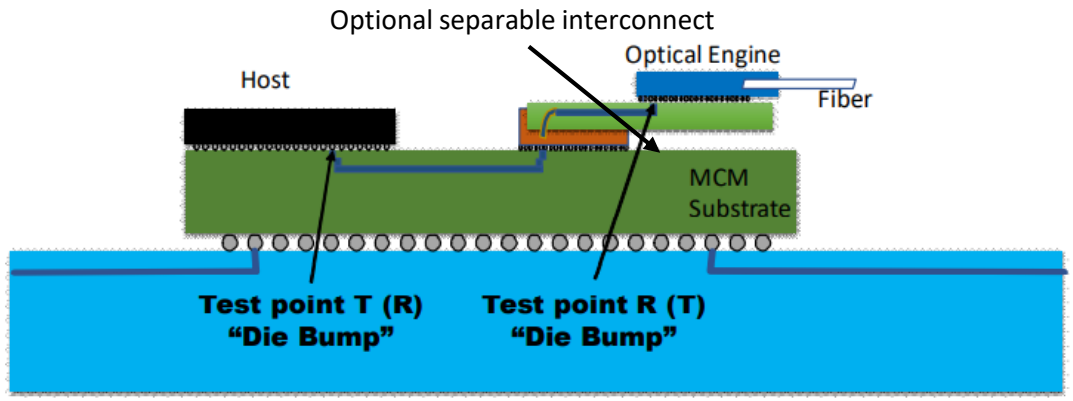
CPO/NPO Channel Example Illustration



- Channel loss: CPO – 10dB bump to bump; NPO – 13dB bump to bump
- Optional separable interconnect performance example: LGA socket: IL of ~0.05dB with RL of -40dB @26.5GHz (*oif2020.341.01, Nathan Tracy*)
- Avoids/reduces major discontinuities.
- Optical modules are not end user pluggable.

- Significant power saving opportunity over VSR to be captured.
- A broad interoperable ecosystem is the key to success and can only be achieved through standardization.

CEI-112G-XSR-PAM4 for Co-packaging



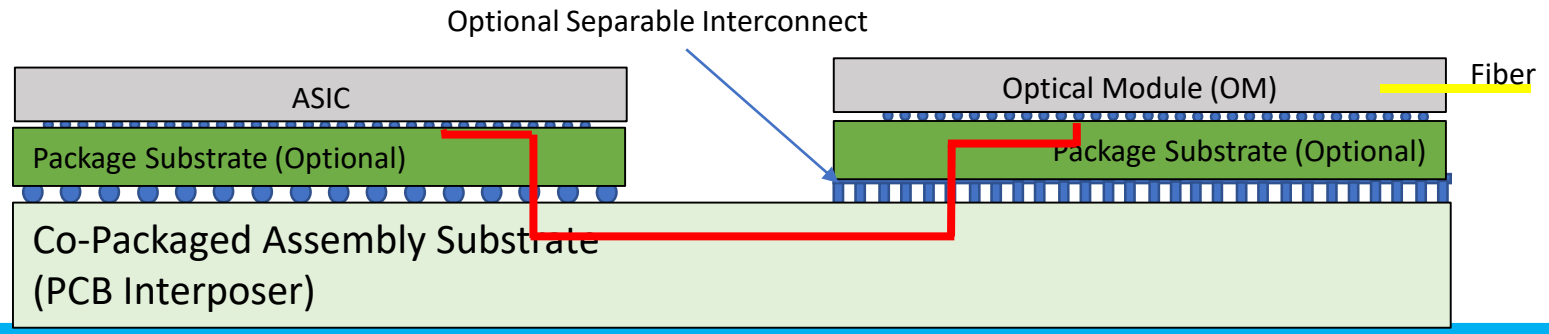
Category	IL at Nyquist (Max, dB)	BER (Max)
CAT1	**10**	**1e-6**
CAT2	10	1e-8
CAT3	8	1e-9

- Baud rates supported: 36 Gsyms/s to 58 Gsyms/s
- Based on loss and jitter budgets between TX and RX using copper signal traces in a SIP(System in a Package) to enable low power consumption
- Three channel categories are defined, allowing optimization for various applications.
- Timeline
  - Project started in April 2018.
  - Draft specification is becoming technically stable. Few pending items to be addressed.

CEI-112G-XSR+ -PAM4 for Near Packaging

- The emergence of Near Package Optics (NPO) Architecture
  - Co-packaging requires significant package substrate size increase and technology advancement, which adds risk to goals of availability, cost and multi-vendor support.
  - Instead of a monolithic package approach, Near Packaging relies on advanced PCB technology for dense high-speed routing without significant power penalty.
  - Near Packaging architecture takes advantage of existing technologies and more robustly enables an open ecosystem implementation.
- Additional margin also strengthens a broader supply base for co-packaging implementation and adoption.

- Baud rates supported: 36 Gsyms/s to 58 Gsyms/s
  - Optimize for Ethernet rate @ 106.25Gbps – the key application for CPO/NPO
  - Insertion loss < 13dB @ 26.5625GHz Nyquist bump to bump with up to 1 separable interconnect.
- Enable the lowest practical energy consumption (pJ/b) implementation.
- Leverage specification methodology and other work from existing CEI 112 projects.



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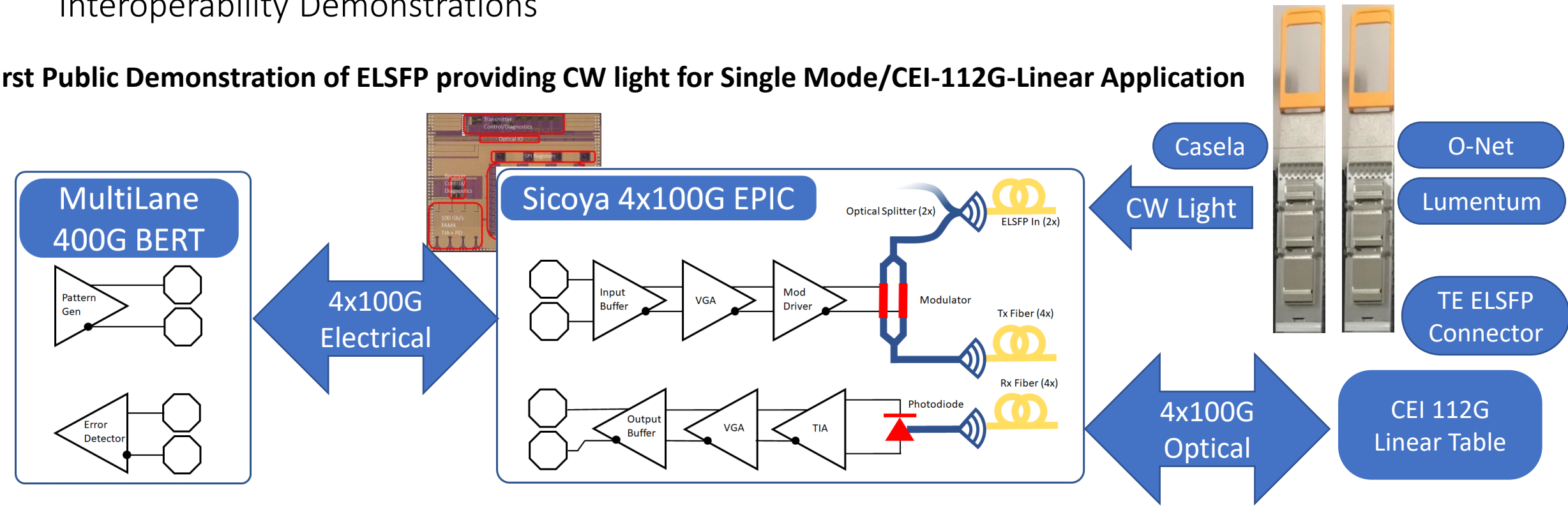
Joint Co-Packaging ELSFP & CEI Linear Interface

Interoperability Demonstrations

First Public Demonstration of ELSFP providing CW light for Single Mode/CEI-112G-Linear Application



Tx Optical Path: ELSFP → PM Fiber → 1:2 Optical Splitter → MZ Modulator → SM Fiber → CEI Linear Table

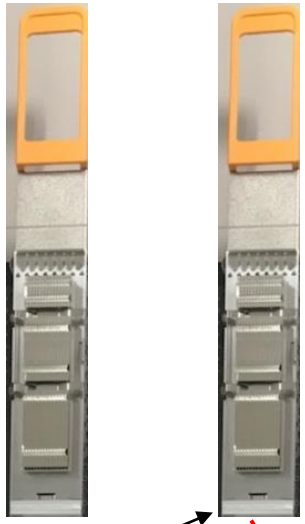
Tx Data Path: 100G PAM4 BERT → 10dB Loss → Linear MZ Driver → MZ Modulator

Rx Data Path: CEI Linear Table → SMF → Photodiode/Linear TIA → 10dB Loss → 100G PAM4 Error Detector

Joint Co-Packaging ELSFP & CEI Linear Interface

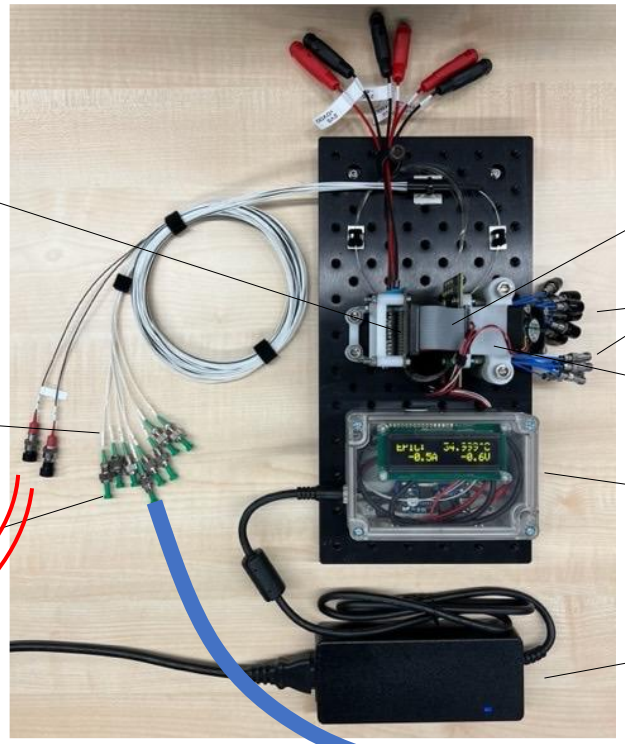
Interoperability Demonstrations

Uncooled ELSFP
Casela; O-net
Lumentum DFB Laser



TE Connectivity ELSFP
connector and cage

CEI
Sicoya



Supply and Communication Board

2x ext. Laser input PM FC/APC

8x IO FC/APC

Sicoya 4x100G PAM4 Silicon Photonics with Monolithically Integrated Driver and TIA Evaluation Board

RF Connector

TEC Cooler Block

TEC Controller

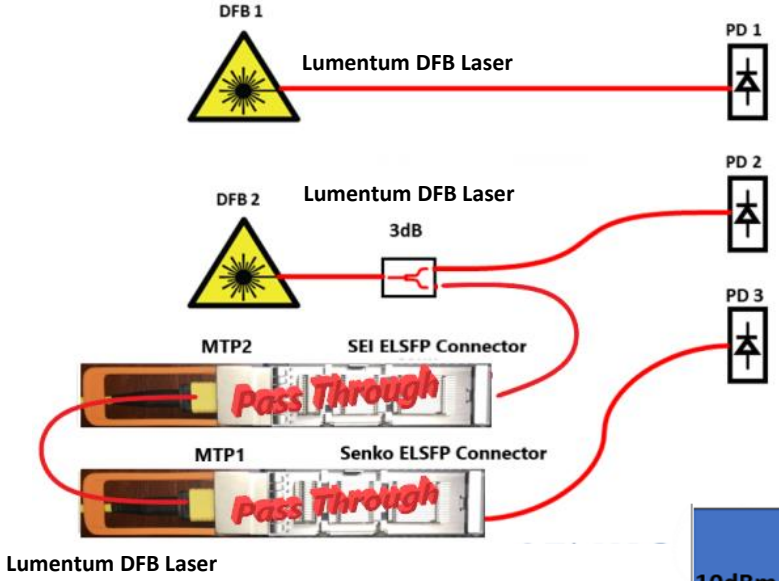
12V / 6.67A Power Supply

4x100G Optical

CEI 112G Linear Table

Active ELSFP & Blind Mate Interoperability

Interoperability Demonstrations



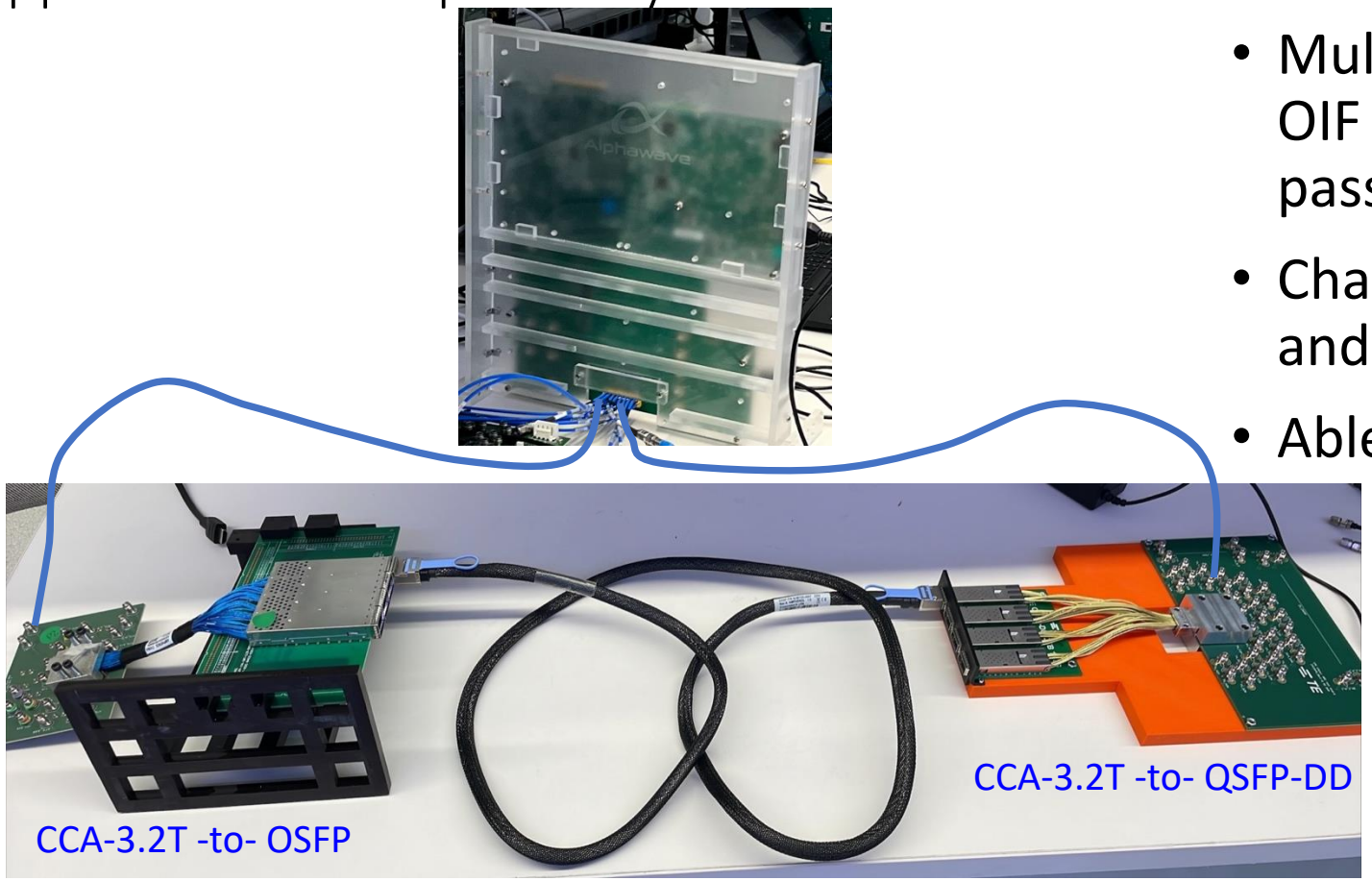
- First public demonstration of uncooled ELSFP:
- Active Modules (Casela, O-net)
- 2x (8) PMF MT Blind-mate Connector
- CWDM DFB lasers >100mW ex fiber

24 dBm ELSFP Connector loss measurements:

ELSFP Passive Demo Unit Optical Connection (4 MT Mating Pairs) Validation Test Results										
		CH1-CH8	CH2-CH7	CH3-CH6	CH4-CH5	CH5-CH4	CH6-CH3	CH7-CH2	CH8-CH1	Ave
10dBm Input Power Tested at O-net	Pin (dBm)	10	10	10	10	10	10	10	10	
	Pout(dBm)	7.86	7.96	7.98	7.8	7.92	6.78	7.96	8.64	
	Total Loss (dB)	-2.14	-2.04	-2.02	-2.2	-2.08	-3.22	-2.04	-1.36	
	Loss per MT Pair(dB)	-0.54	-0.51	-0.51	-0.55	-0.52	-0.81	-0.51	-0.34	-0.53
24dBm Input Power Tested at Lumentum	Pin (dBm)	24.07	24.07	24.07	24.07	24.07	24.07	24.07	24.07	
	Pout(dBm)	20.29	21.24	21.76	22.41	20.83	22.17	21.79	22.36	
	Total Loss (dB)	-3.77	-2.83	-2.30	-1.66	-3.24	-1.89	-2.28	-1.71	
	Loss per MT Pair(dB)	-0.94	-0.71	-0.58	-0.41	-0.81	-0.47	-0.57	-0.43	-0.61

3.2T Co-Package Copper Cable Demo

Copper Cable Interoperability Demonstrations



OSFP800 -to QSFP-DD800 DAC 1.5m

- Multi-vendor demonstration of the OIF 3.2T Module implemented using passive copper
- Channel components sum to ~30dB and demonstrated 112G-LR silicon
- Able to achieve better than 2E-9 BER

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OIF
CELEBRATING
25 YEARS

Wednesday March 8th

"Bringing Order to Chaos – OIF"
3pm-4pm in Theater 3

Moderator: **Stephen Hardy**, *Lightwave*
Panelists:
Karl Gass, OIF PLL WG Optical Vice Chair
Vladimir Kozlov, LightCounting
Sterling Perrin, Heavy Reading;
Nathan Tracy, OIF MA&E Co-Chair PLL, TE Connectivity
Alan Weckel, 650 Group

Celebration Reception
4pm-5pm
Booth #5101