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Integrated Photonic Systems Roadmap

On-Board Optical Interconnection
A Joint Development Project Consortium

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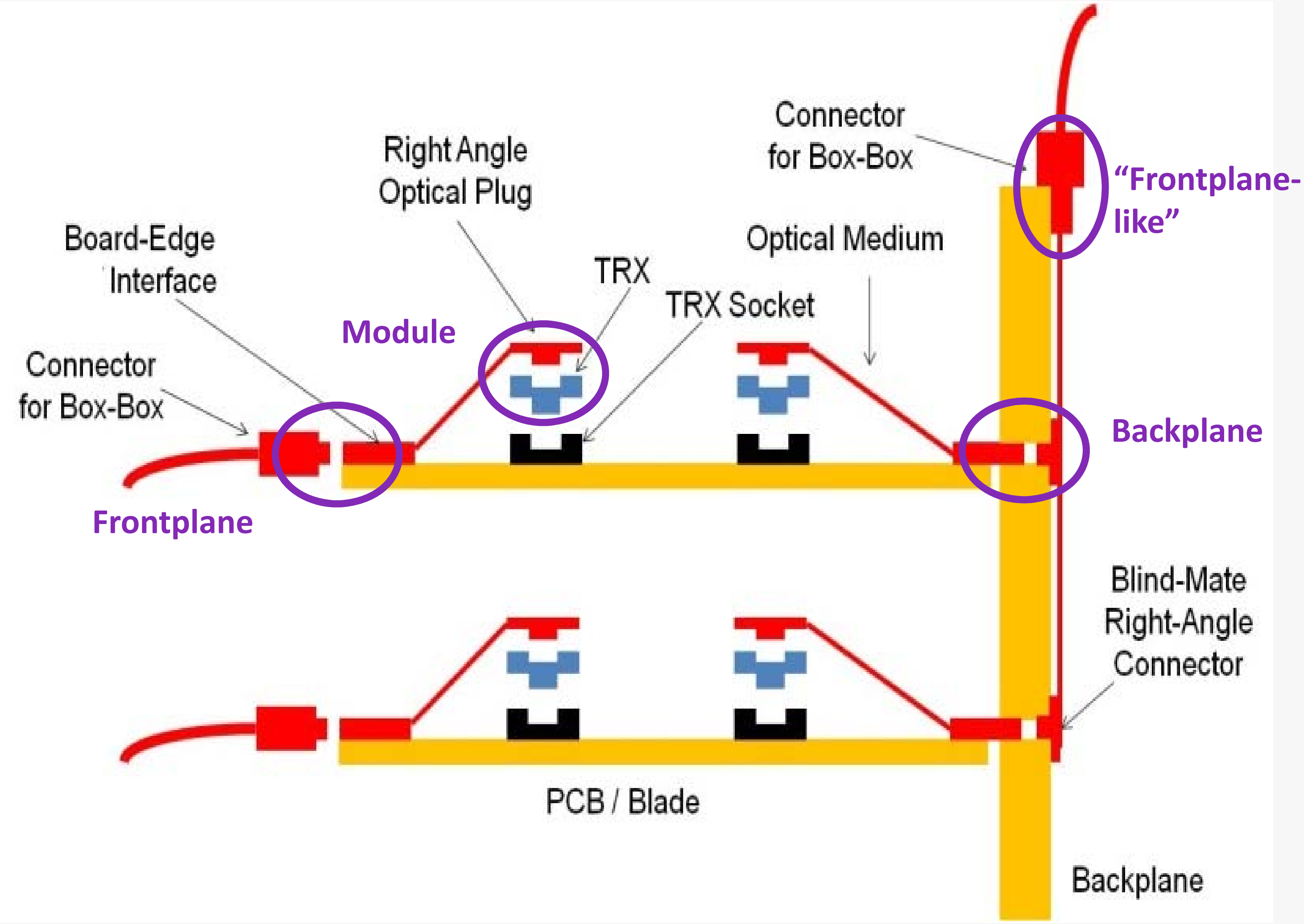
Driving Photonics Manufacturing

Presentation Outline

- Executive Summary
- Issues in Board-Level Optical Interconnect
- Origin of the Project Proposal
- Project SOW and Deliverables
- Project Participation & Anticipated Benefits

Generic Board-Level Interconnection System



Executive Summary

- A proposal is now being written for a project to build and characterize a board-level interconnect system based on silicon photonic (SiPh) modules & single-mode (SM) expanded-beam connectors.
- The goal is to identify gaps in technologies needed for cost-effective volume deployment of SiPh board-level interconnect.
- Potential participants are being recruited to contribute to the detailed proposal, which is due by December 1st.
- This project is intended to first Phase of a longer, more comprehensive project that will ultimately build demonstration vehicles for optical coupling to SiPh chips and PCB-embedded waveguides in later Phases.

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Issues in Board-Level Optical Interconnect

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Board-Level Optical Interconnection-- Scope

Board-level optical interconnections are those where light is transported within the "geographical bounds" of a Printed Circuit Board/Blade (= inside board perimeter).

This includes Optical:

- Module-to-module connections on a single PCB
- Module-to-board-edge connections on the PCB (for frontplane/backplane connections), ultimately connecting optically to other boards in the same or other chassis.

We will exclude optical connections inside the optical module/package, which are part of the (related) packaging technology.

We will exclude electrical connections at the board edge to an off-board transceiver (e.g. Active Optical Cables), since the connector requirements may differ.

Why Transition to Optical Interconnect On-Board?

- Bandwidth density– especially important on high-port-count switch boards
  - Board edge space is limited
  - Air circulation must be maintained for cooling
  - Fiber connector pitch is one advantage…WDM is a huge advantage.
- Potential for lower power dissipation than copper
  - Copper power loss increases rapidly with BW
  - Power is key to cost component of operating of large data centers
- Lower crosstalk than copper
- Avoid length-dependent signal impairments characteristic of copper
  - Optical link impairments are “distance agnostic” at these short lengths

Why NOT Transition to Optical Interconnect <u>On-Board</u>?

- Cost of components (TRX, optical connectors…)
- Chicken-and-Egg” cost/volume scenario for components.
- Cost/benefit ratio when viewed as complete “ecosystem”
- Precision required in optical connector components
- Labor-intensive PCB assembly process (plug-in modules; route & connect cables)
- Increased level of labor skill for installation and maintenance
- Reliability and maintenance concerns
- Potential disruption of PCB supply chain (especially PCB-embedded waveguides)
- SiPh operates at 1300 or 1550nm; polymer waveguide loss is high.
- Inertia, fear of unknown consequences, risk-value tradeoff…..

Limitation of Scope: Exclude Multi-Mode Systems

Vertical-Cavity Surface-Emitting-Laser (VCSEL) Based MM Systems

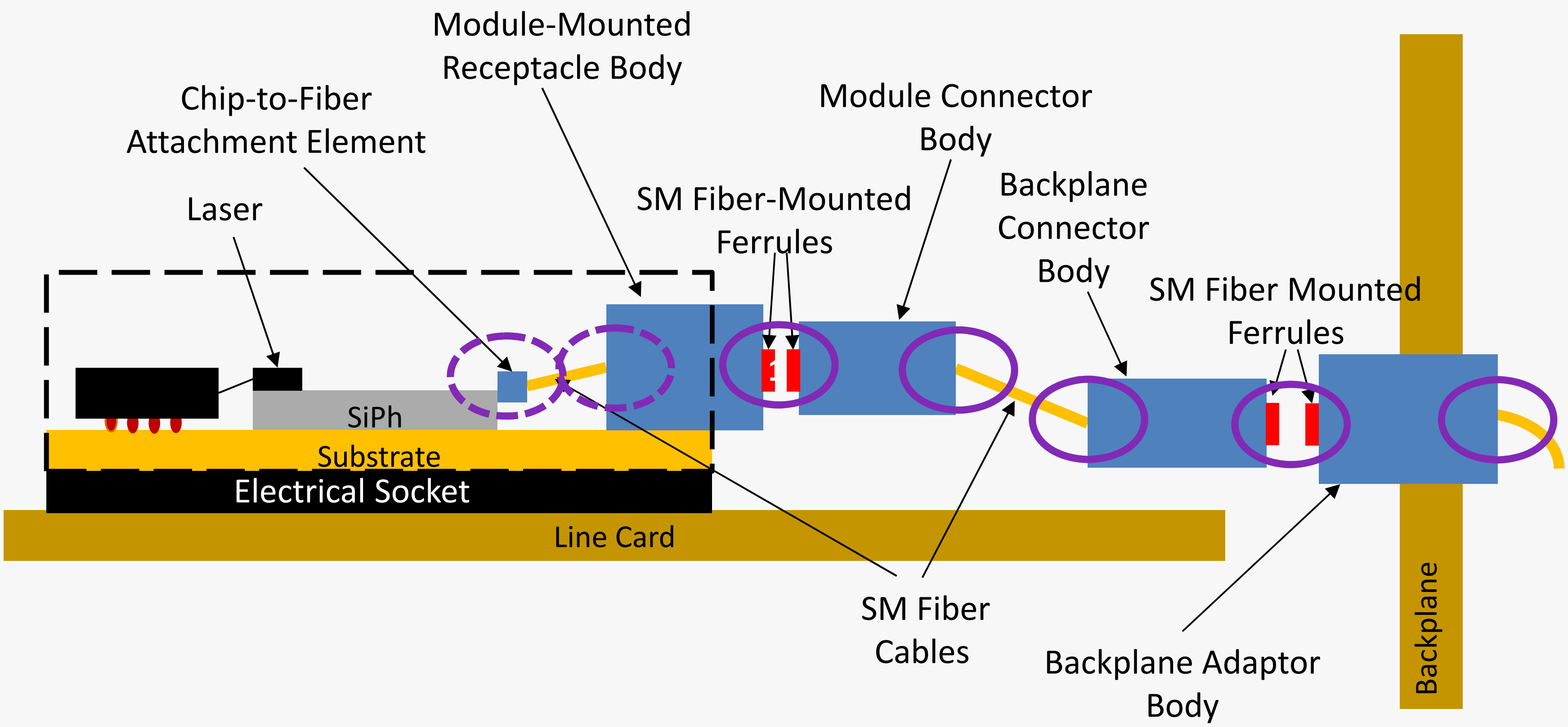
- TRX packaging is simpler.
  - Relaxed alignment tolerances
  - VCSEL emission region easily located
  - Better match to fiber than are high Δn SiPh waveguides.
- Connectors are easier (at least mechanical tolerances)

Do we really need SM on board? YES, if we assume:

- SiPh will deliver the lowest-cost transceivers per functionality.
- SiPh will scale in bandwidth & density more readily than VCSELs (WDM)
- We need high-bandwidth optical connections to distant chassis.

Electrically-Pluggable Module, with Fly-Over Optical Fiber Cables

There are more on-board interconnects inside the package.



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Electrically-Pluggable Module, with Fly-Over Optical Fiber Cables

Advantages

- Can use existing cables and connectors.
- Can use either optically connectorized or pigtailed (cheaper) modules.
- Use electrically connectorized modules, so modules don't need reflow compatibility.
- Replacement of connectorized modules is simplified.
- Separates electrical from optical alignments.

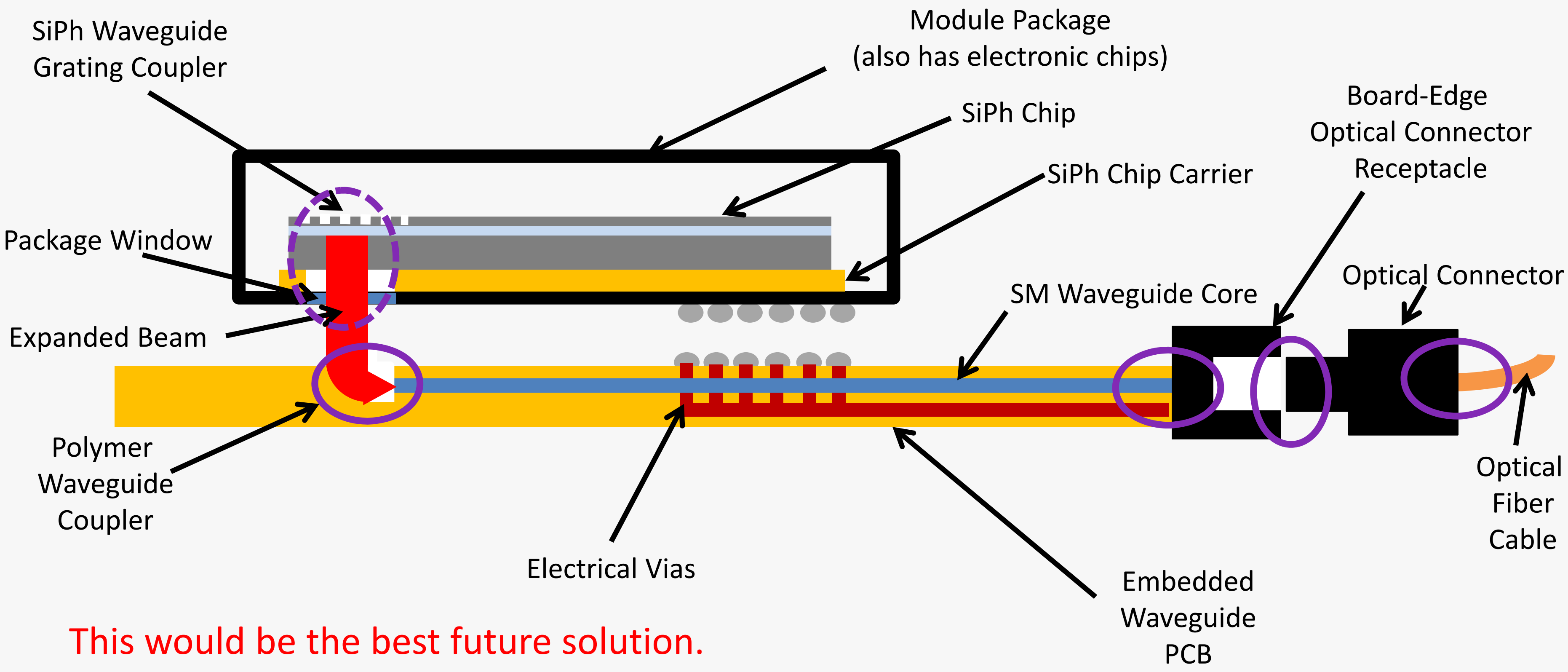
Disadvantages

- Adds manual process of electrically plugging modules to PCB assembly.
- Adds manual process of mating optical cable connectors to mid-board modules.
- Adds manual process of routing cables to board-edge connector.
- Adds manual process of installing optical board-edge connector.
- Complex inventory of cable lengths expected.
- Cable management may result in reliability issues (mechanical snag)

What's Missing?

- Low-enough-cost components & processes.

Silicon Photonics Device Package Reflowed on PCB with Embedded Waveguides



This would be the best future solution.

Silicon Photonics Device Package
Reflowed on PCB with Embedded Waveguides

Advantages

- Final PCB assembly process flow can be similar to today's standard process.
- Minimizes board assembly labor.

Disadvantages

- Module failures = blade failures
- PCB fab process maximally disrupted.

What's Missing?

- Requires new waveguide materials with low absorption loss at ~1310 and ~1550 nm
- Requires new PCB fabrication processes to integrate waveguides into PCBs
- Requires PCB optical backplane/frontplane connectors, and termination processes.
- Requires new, reflow-compatible optical modules.
- Requires new, reflow-compatible optical interface from package to PCB-embedded waveguides; must accept PCB assembly tolerances.
- Requires improvements in optical module reliability?

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Origin of the Project Proposal

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How to Take the First Step?

- AIM MIT Meeting, June 2016
  - TL Smith Board Level Interconnect Overview
  - J. MacWilliams Connector TWG
    - “Low-Hanging Fruit” Challenge
    - Meaningful project for 18 month timeframe
    - Proposed SiPh, expanded-beam connector demo
- AIM Academy Webinar, October 2016
  - TL Smith & J. MacWilliams program overview
- IPSR Weekly Project Planning Webmeetings
  - Scope of Phase I narrowed: no chip connection
  - Phase II and Phase III objectives drafted.
    - Phase II = chip connection technology demo
    - Phase III = PCB embedded waveguide technology demo

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Phase I Project:
Statement of Work & Deliverables

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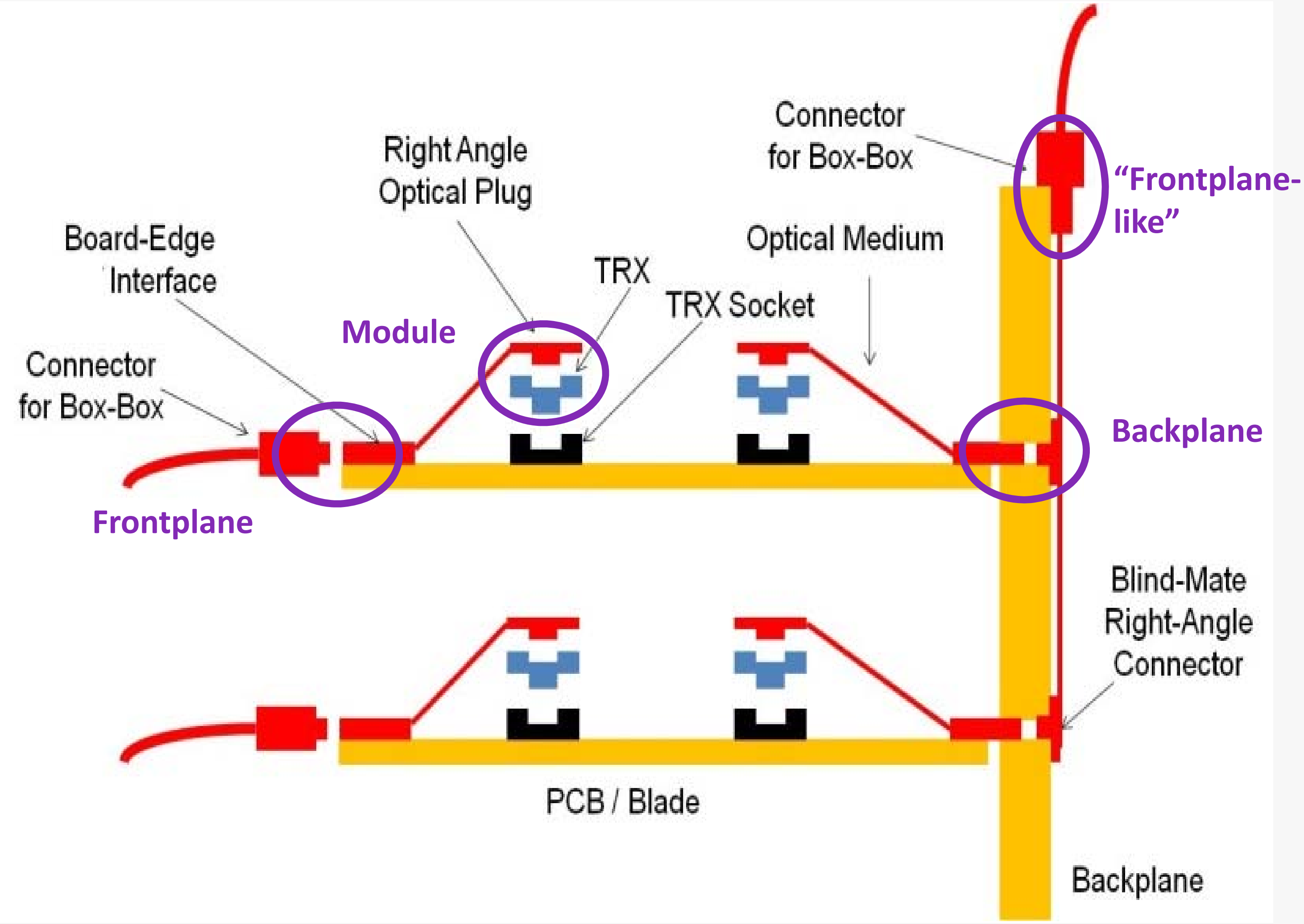
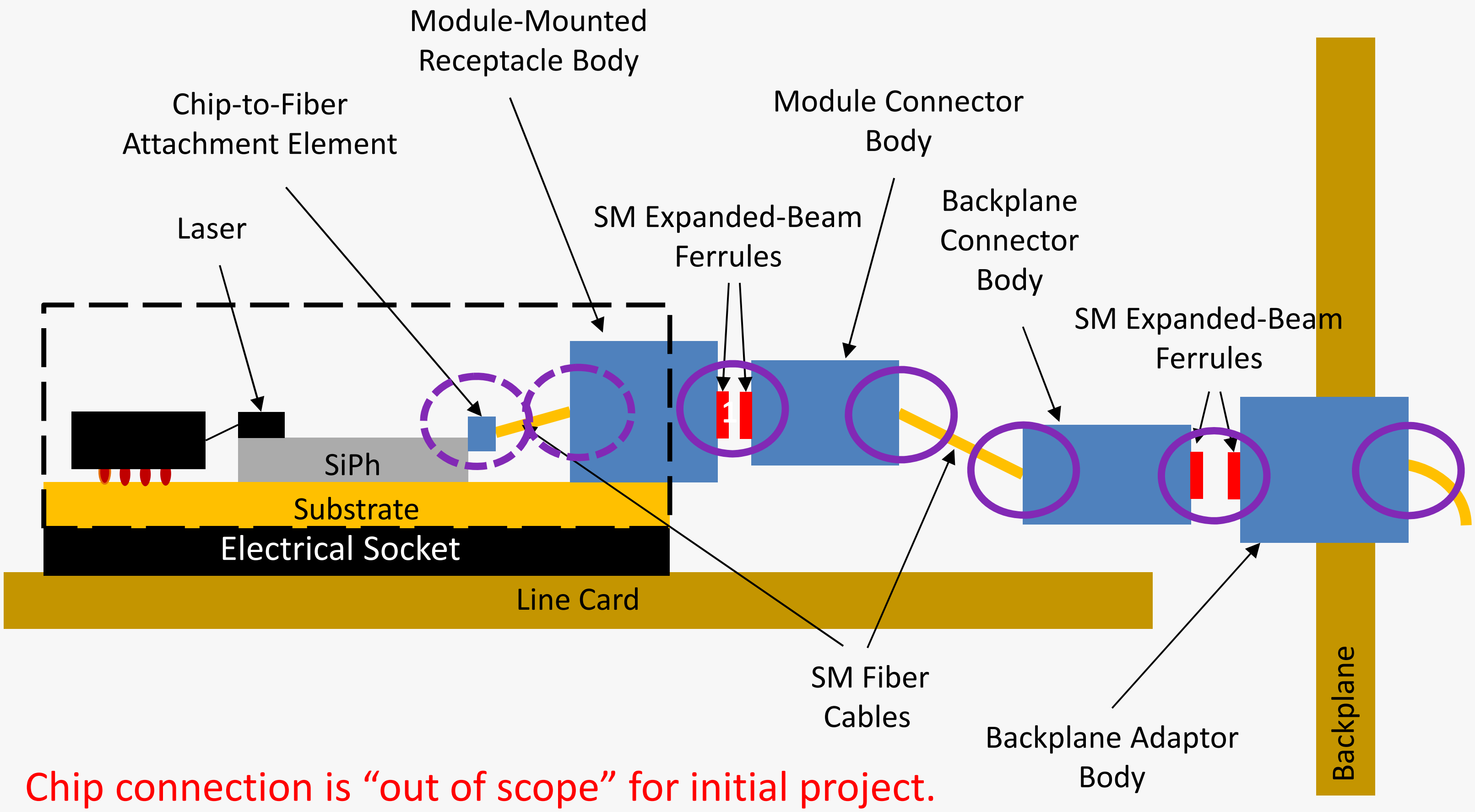
Phase I Statement of Work (1)

- Build demonstration system:
  - – 25 Gbps/channel SiPh optical transceivers
  - – SM expanded-beam connectors
  - – Backplane and Frontplane hardware

Proposed Phase I Demo System



Phase I Demo System Connector Interface Detail



Chip connection is “out of scope” for initial project.

Phase I Statement of Work (2)

- Characterize Components & System
  - Connector loss
  - Wavelength dependent connector loss
  - Polarization-dependent connector loss
  - Connector return loss
  - Connector re-mating loss variations
  - Temperature & Humidity effects (Telcordia GR-1435 U.E.)
  - Dust contamination connector loss variation
  - Bit Error Rate vs connector number & loss.
  - System cost estimates.

Phase I Deliverables

- Document Findings
  - System performance issues identified.
  - Component readiness assessed.
  - Gaps identified.
  - Product needs identified.
  - Timing of SiPh expanded beam system anticipated.
- Publish results.
  - Details TBD by participants
- Formulate and Initiate Phases II and III

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Detailed Phase I Statement of Work

- The detailed statement of work will be refined by potential project participants by the proposal due date, December 1.
- The SOW will be dependent on the interests and capabilities of the participants.
- Participants are expected to contribute components and services free of charge to the Project, for the mutual benefit of all.

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Project Participation & Anticipated Benefits

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Anticipated Benefits of the IPSR Project

- **Quantify performance of SiPh-based on-board interconnect.**
  - Understand BER vs data rate with n-connector daisy chains.
  - Understand power dissipation trade-offs
  - Understand compatibility with Telcordia GR-1435, IEC-60529, IP5X/IP6X
  - Understand relative issues in SiPh vs VCSEL implementations

- **Understanding design tradeoff in SiPh-based on-board interconnect system.**
  - Understand impact of EB connectors on power budget.
  - Understand impact of molded plastic optics at ~ 1550 nm WDM wavelengths
  - Understand impact of EB connectors on temp, humidity, vibration stability
  - Understand impact of EB connectors on dust tolerance.
  - Understand cost benefit of relaxed mechanical tolerances of EB connectors
  - Improve understanding of pigtailed vs connectorized module trade-offs.
  - Improve understanding of fly-over vs PCB-embedded optical media trade-offs.

More Anticipated Benefits of the IPSR Project

- **Identification of component developments needed to fill gaps.**
  - Are connectors currently under development adequate?
  - Are existing cable routing techniques adequate for dense board implementation?
  - Do SiPh transceivers have adequate power for use with multiple connectors?

- **Improve industry & public understanding of SiPh benefits, issues, and timing**.
  - Publish data on the first interconnect system test with SM EB connectors.

- **Potential acceleration of market for associated SiPh transceivers, connector components, and fiber cables.**
  - Overcome implementation hesitancy due to reliability concerns.
  - Identify missing parts of the SiPh commercialization "ecosystem"
  - Motivate industrial development of missing infrastructure.

Contributions Needed from Participants

- SiPh TRx modules, with SM fiber interfaces
- Developmental SM expanded beam connectors.
- Developmental connector bodies for backplane and frontplane.
- PCB and backplane assembly
- Connector termination services
- System test capabilities
- Environmental test capabilities.

Types of Organizations to Participate

- Connector & cable suppliers
- SiPh transceiver suppliers
- System integrators, including:
  - Server manufacturers
  - Telecom switch manufacturers
  - Supercomputer manufacturers
- PCB suppliers
- Electronic assembly houses.

Current Project Proposal Participants

- 3M-Terry Smith (Proposal Co-Leader)
- 3MTS- Bill Bottoms
- Corning- Alan Evans
- Celestica-Tatiana Berdinskikh
- Macom-Rich Grzybowski
- Molex-Tom Marrapode
- Promex Industries-Dick Otte
- US Conec- Darrell Childers
- US Competitors-John MacWilliams (Proposal Co-Leader)

Schedule for SOW

- October 20: AIM Webinar Presentation on Project
- Oct 31 & Nov.1: This Presentation, and Connector TWG
- November 1 to December 1: Proposal Preparation
- December 1: Full Proposal (SOW) Submission

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Thank You!

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