IPSR
Integrated Photonic Systems Roadmap

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IPSR BOARD-LEVEL INTERCONNECT PROJECT PROPOSAL

Executive Summary

The purpose of the Board-Level Optical Interconnect Project is to build and test demonstration prototypes of board-level interconnect systems based on single-mode (SM) fiber, expanded-beam optical coupling, and silicon photonics transceivers. This activity will allow evaluation of existing and developing components, and thereby identify gaps in the technologies needed for practical implementation. These gaps, once identified, can be addressed via subsequent AIM or industrial programs.

The program will be structured in 3 Phases, the first Phase addressing optical media based on SM fiber and expanded-beam connectors, and the second and third phases addressing chip-to-connector coupling and printed-circuit-embedded waveguides, respectively.

The first Phase, detailed below, is anticipated to last 18 months, and will leverage component and labor resources donated to the program by the program participants. Timing, resources and the Statement of Work (SOW) for the second and third phases will be defined during/after execution of the first Phase.

With the successful initiation of Phase I of the Board-Level Optical Interconnect Project, IPSR will be reaching beyond the roadmapping process to pursue hardware projects through its TWG fora. These projects will address key strategic challenges on the roadmap for implementation of photonics technology.

Technology and Industry Background

Fiber Optics traditionally has been best suited for telecom outside plant and inside plant network cabling. With the advent of 'Big Data', including the development of large data centers, each comprising thousands of servers, the need for faster circuitry has materialized. As circuit speeds exceed 25-40G, fiber optics has begun to be employed to connect server racks, switches and routers in both public and private data centers. The market for these and other applications, including stand-alone, mid-range, enterprise servers and scientific computers, exceeds $50B not including infrastructure costs. The Big Data portion of this market is growing $\geq$ 20%/year.

Beyond 40G, and certainly beyond 100G, photonic circuitry and data communications will be required both internal and external to equipment, replacing many copper interconnects and cables at the board level. These will be deployed at IO ports, as well as rack-to-rack, top-of-rack and in network pipelines that can exceed 1Tbps.

Many of the components and supply chains needed for wide implementation of board-level optical interconnect are not yet fully developed. The number of domestic fiber optic connector companies is small with fewer than five major suppliers, and the technology has a steep learning curve. System packaging work-arounds include the use of discrete photonic components and cables, while the ultimate goal has to be one of integrating photonic silicon from the device outward in order to reduce cost and accept high-speed signals beyond 40G. The focal point of this development will be mid-board logic modules with integrated optical transceivers optical interconnect media such as fibers or embedded waveguides. In many cases, the challenge is one of extending existing technology in a way that is cost-effective for high-port-count and short-distance connections. Single mode connectors and cables are in use, but not yet cost-effective in these applications, while other product technologies will require new developments. In most cases developments are a matter of matching market needs with development and tooling costs for future high volume manufacturing (HVM).

In a few cases more basic RDE is needed to overcome technology roadblocks. One key need is for better technology for single-mode interconnects closest to the chip. Coupling light from a SiPh waveguide to a conventional optical fiber requires a low-loss transition from the submicron optical mode dimensions of the on-chip/in-package embedded silicon or glass waveguides, to out-of-package 10 micron round optical fiber waveguides. Key to low loss performance is technology for aligning the optical components to sub-micron tolerances in a cost-effective, manufacturable process.

Another key need is improved, low-loss yet inexpensive optical ferrule technology, to enable the needed mate/de-mate function of connectors coupling fiber-to-fiber or fiber-to-chip. This connector area represents an important opportunity for the U.S. to improve its international competitiveness in fiber optics. The small number of domestic fiber optic connector manufacturers is worrisome, but manageable with an existing global supply chain. But, as of mid-2016, the majority of fiber optic connectors (60%) are assembled in China.

Multimode expanded beam ferrule technology for multi-mode (MM) fiber has been developed and is currently in production by such vendors as US Conec and Molex. However, at present there is no commercially-available expanded-beam SM ferrule. US Conec's stated goal is to develop a single mode expanded beam Prizm™ MT ferrule in 18 months; this will be compatible with their MXC connector products.

Project Definition Process

At the MIT AIM meeting in June of 2016, Dr. Terry Smith (3M Company) presented an overview of the potential approaches to board-level optical interconnect using silicon photonics (SiPh) modules, discussing the relative merits and challenges associated with them. At the same meeting, Terry, along with John MacWilliams (US Competitors, LLC) led a connector TWG breakout session with the challenge to define a project with the goal of a prototype interconnect demonstration within 18 months. Out of the discussion, the idea of proposing to build a prototype board-level demonstration system complete with SiPh modules, single-mode (SM) fiber cables, expanded beam SM connectors arose. This system was chosen because it was felt to be the most practical near-term implementation of SiPh-based interconnect at the board level. This is because expanded beam connectors are believed to capable of offering adequate performance, but at a reduced manufacturing cost due to the relaxed mechanical tolerances provided by the expanded-beam connectors. Additionally, expanded beam connectors offer better resistance to dust, making them more robust and reliable in a realistic system environment. The proposed project scope was initially defined to include development of SM expanded beam connectors for frontplane, backplane and module connections, as well as the associated fiber cables. Sources of connectors, cables, and modules would be required.

At the AIM Academy October webinar Terry Smith and John McWilliams presented a seminar related to this proposal. This led to subsequent discussions on the scope of the proposal. It was decided to limit the scope of the first project to demonstration of the SM expanded-beam connector system, using readily-available modules with any type of optical interface (either connector or pigtailed). This would provide better control for more accurate understanding of connector impacts on system performance.

With the reduction in scope of the Phase I board-level interconnect project to a connector focus, it was also decided to tentatively plan two future follow-on projects, consistent with the expected technology evolution roadmap. These were:

- Phase 2 Project—Demonstration of technology for coupling the SiPh chip waveguides to the module connector interface.

- Phase 3 Project—Demonstration of technology for waveguides embedded in the PCB, with appropriate module-to-board coupling technology.

Further definition of the SOW for Phase I of the Board-Level Optical Interconnection Project will be a goal of the IPSR/AIM Fall meeting (Oct 31 and Nov 1 at MIT). An overview of the proposed program (Phase I), and the needed resources will be given, in order to recruit more participants. In the Connector

TWG break-out session, further definition of the prototype system, the project participants, and the SOW for the final proposal (due December 1) will be pursued.

Project Deliverables

The goal of Phase I will be to build and operate a board-level interconnect system based on expanded-beam SM connectors. The system will be operated at 25Gbps/channel, and parameters such as loss, return loss, polarization-dependent loss, and signal integrity will be determined as affected by the number and types of expanded-beam connectors in the optical path. Additionally, system response during standard environmental tests, such as Telcordia GR-1435, will be assessed. Impact of the use of the expanded beam, rather than conventional SM connectors, on system economics will be modeled.

Specific component and system characterizations to be performed include:

- Connector loss.
- Wavelength dependence of connector loss.
- Connector return loss.
- Connector polarization-dependent loss.
- Connector re-mating loss variation.
- Dust contamination induced connector loss (test TBD).
- Telcordia GR-1435 Uncontrolled Environment Thermal Aging, Humidity Aging, Thermal Cycling, and Humidity/Condensation Cycling testing.
- Signal Bit Error Rate vs connector number and loss (25 Gbps/channel).
- Estimated system implementation cost.

Additional testing may be included at the option of the participating organizations. Results of all testing will be made available in a Project Final Report.

Project Participants

Successful completion of the Phase I project will require participation by organizations that can provide the needed parts and processes. It is envisioned that the participants will form a mini-consortium to execute the program. Participant contributions to the program will be in the form of donated resources, for the common goal of understanding the practicality of the expanded-beam interconnect system.

Contributions needed from participants for a successful program include:

- Silicon photonics modules, with SM fiber interfaces.
- Developmental expanded-beam ferrules.
- Developmental connector bodies for backplane and frontplane.
- PCB and backplane prototype assembly.
- Connector termination services.
- System test capabilities.
- Environmental test capabilities.

As a result of these needs, organizations being sought for participation include SiPh transceiver manufacturers, connector suppliers, system integrators such as server or telecom switch providers, and equipment assemblers.

Organizations which have expressed early interest in participating in Phase I to date, and which are involved in refining the SOW include:

- Celestica
- Corning
- MaCom
- Molex
- Promex Industries
- US Conec

Discussions are currently underway with several other organizations that are interested in joining the project.