Optical PCBs with Embedded Waveguides for Next Generation High Speed Applications

[Joint Development TTM, FCI/Amphenol and Ericsson]

Background

To meet the increasing bandwidth demands in future communication systems, higher data rates and higher channel densities are required. For electrical interconnects, scaling is limited due to fundamental obstacles such as loss, crosstalk, and reflection resulting in limited channel length and packaging density. Besides fundamental challenges, there is a significant increase in cost and power consumption to achieve 100 Gb/s operation and beyond.

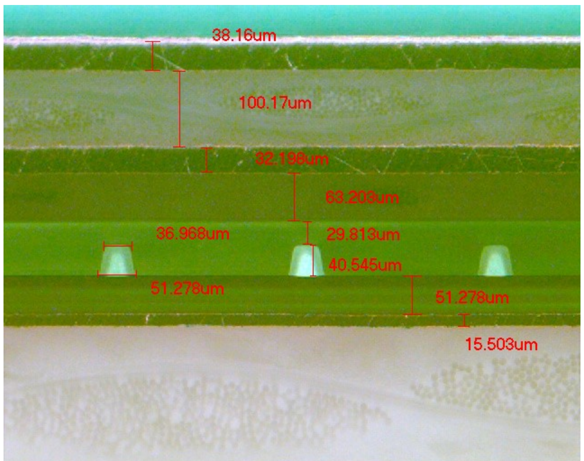
Industry is exploring optical waveguides as a potential option for on-board interconnects. The advantages with optical solutions are that they will increase the packaging density and reduce the link length that high-speed electrical signals have to travel in PCB which enables use of conventional low cost PCB materials and easier designs for routing of the signals.

Scope and Achievements

In joint development during 2014-16 by TTM, FCI and Ericsson teams developed technologies to support advanced PCBs with optical interconnects based on embedded waveguides and the supporting connectors. The prototype reported at ECOC [1] showed first-time ever an end-to-end optical link demonstrator built by industrial partners using embedded polymer waveguides and 90° out-of-plane connector in common PCB test platform with board embedded optical transceivers. The demonstrator PCB contained totally 96 optical channels with up to 2.4Tb/s capacity.

The demonstrator PCB constructed of 6 electrical layers and one embedded optical signal layer. The optical layer was buried between electrical layers in a conventional PCB stack forming optical/electrical hybrid construction (Fig.1). The O/E PCB was fabricated using TTM's proprietary fabrication process. In the process, each optical layer (cladding/core/cladding) is passed through subsequent process cycles to form higher index core trace patterns fully surrounded by lower index optical material. After waveguide fabrication, the optical layers are laminated into PCB stack using standard press-lamination process. Subsequent process steps after stacking optical and electrical layers in the board stack-up include drilling, metallization, curing and cleaning cycles to finalize the PCB with electrical and optical functions. For cost-effectiveness, TTM has scaled up the optical PCB fabrication to support standard form factor production panel sizes e.g. 16”x18”, 16”x20” and 18”x24”. Furthermore, the optical layer can be built on standard loss laminate providing a cost effective hybrid high speed alternative.

The waveguides in the demonstrator were designed with nominal 50 µm core size and 250 µm spacing to match OM3/OM4 fiber ribbons from/to the engines. Bandwidth density (Gb/s/mm) on board can be scaled further by increasing optical channel density and/or engine data rate. The bandwidth density shown in PCB demonstrator resulted 100Gbps/mm (4ch/mm, 250um channel spacing @25Gb/s). However, cross-sectional bandwidth (CSBW) capacity can be further scaled up to 400Gbps/mm (16ch/mm, 62.5um channel spacing, @25Gb/s) or to 800Gbps/mm (16ch/mm, 62.5um channel spacing, @50Gb/s) resulting tenfold improvement in bandwidth capacity per cross-section area and real estate usage vs. electrical designs. This minimizes real estate allocated for optical traces in the board.

a)


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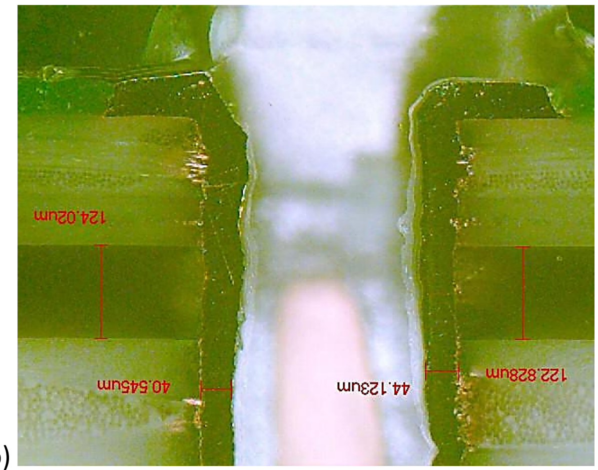
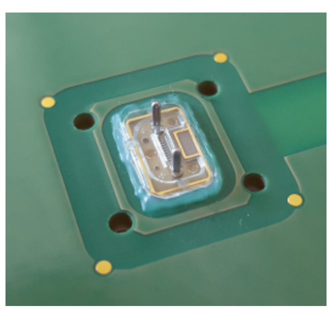


Figure 1 (a): Cross-section of O/E PCB showing electrical and optical layers (b) close view to optical layer

Robust low-loss optical coupling is critical to realize practical optical link on O/E PCB. Some solutions are already presented, e.g. to use a dual-lens systems or to embed a parabolic mirror in the O/E PCB4. The optical coupling in our demonstrator from the optical engine to the embedded waveguides was succeeded over an optical coupling unit with micro lenses on top and bottom side. (Fig.2). Optical connector with 90° light coupler was assembled both ends of the waveguide links. Optical interface is milled to provide holes, slots and cavities for coupler and MT ferrules. A critical parameter during fabrication was, among others, to place the coupling unit in a correct position versus the embedded waveguides due to required accuracy and small dimensional tolerances.

(a)


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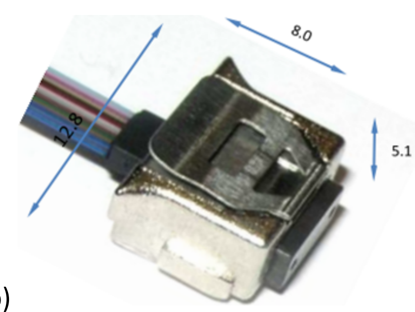

Figure 2. (a) Coupling unit assembled on optical PCB, (b) small size MT-ferrule based connector

For the data transmission two optical engines were assembled in the middle section of the demonstrator board. Fiber ribbons were used to connect each waveguide test channel. For electrical I/O six MXP connectors from Huber-Suhner were used. The OBTs are controlled through the I2C interface. The assembled O/E-PCB with test cables is shown in Fig.3, the testing scheme is detailed in Fig.4.

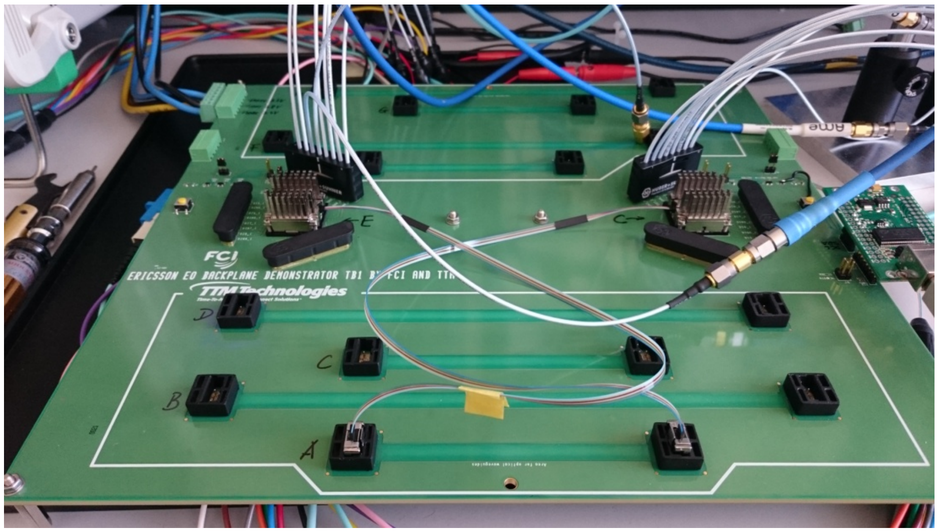

Figure 3. Fully equipped demonstrator with embedded waveguides and two on-board optical transceivers.

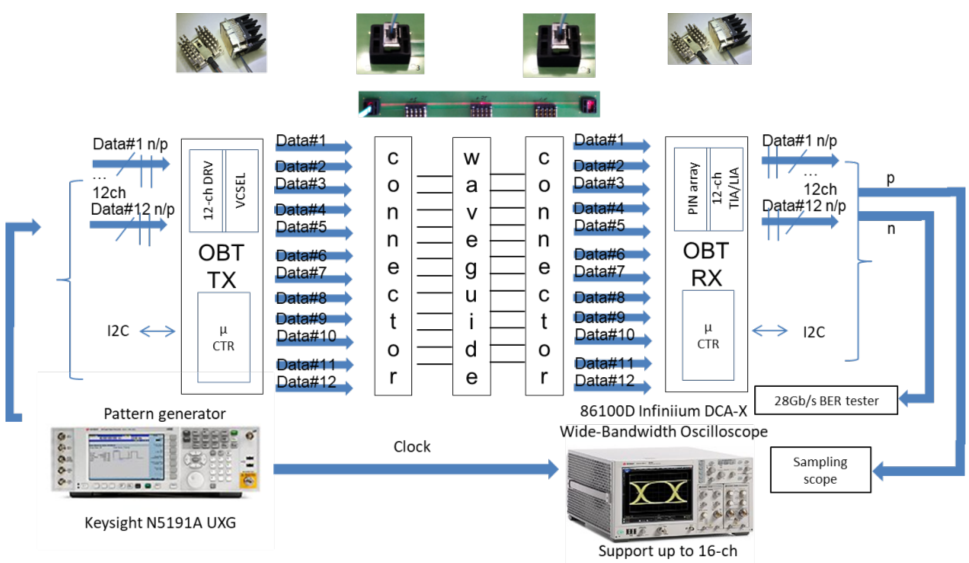

Figure 4. On-Board Link Evaluation Testing Scheme

Summary

- Embedded optical links in PCB showcased in common base with OBTs

- Eight sections of embedded polymer waveguides in arrays of 12 with a length up to 20cm
- Small form factor MT-type optical connector with support housing for connection to CU
- 8 x 300Gbps (2.4Tbps) optical links with waveguides
- Insertion loss for different link parts
    - Link loss (CNN-WG-connector) 7-8 dB (4"/10cm); 9-10 dB (8"/20cm)
    - Waveguide loss <0.1 dB/cm (min); 0.1dB/cm (ave)
    - Coupling loss: < 2.5 dB/ connector (min); 3dB (ave)
- Traffic tests
    - 10Gbps: PRBS31 traffic from external optical TX without errors
    - 20Gbps: FCI O-BT 300Gbps LEAP: Good eye (Mask: IEEE 100GBASE-SR4) PRBS31 traffic without errors
- Characterization: Eye diagrams and extracting, Rise/fall times, Jitter, Mask testing and ER for the optical one, BER testing, Link budget
- Technical documentation: Design reference, technical specification, capability matrix, electrical model, qualification report, SI report

Further Information

[1] M. Immonen, R. Zhang, M. Press, H. Tang, W. Lei, J Wu, H. J. Yan, L. Xiu Zhu, M. Serbay, "End-to-end Optical 25Gb/s Link Demonstrator with Embedded Waveguides, 90°Out-of-Plane Connector and On-board Optical Transceivers" in Proc. of ECOC, Düsseldorf, Germany, 2016

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