An Optical Backplane Connection System With Pluggable Active Board Interfaces

Notices

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Issue 2.0 | October, 2007

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Introduction

The increasing physical constraints associated with copper transmission lines on printed circuit boards (PCB’s) in high speed electronic systems has spawned research over the past 10 years into optical waveguides supported on PCBs [1]. Optical waveguides are not subject to the same stringent physical limitations on signal speed and density as electronic transmission lines. Optical PCB technology will be applied on backplanes in high speed systems, where the first communication bottlenecks are expected to occur [2]. One of the greatest challenges to the commercialisation of optical PCB technology has been the difficulty of aligning components to conventional optical waveguide structures in order to establish and maintain an optical connection. This relates in particular to the ability to dock and undock daughtercards directly to and from an optical backplane.

Prior research into the problem of coupling to an optical backplane has centred on the use of intermediary optical interfaces on the backplane to deflect optical signals by 90° into and out of the waveguides. The applications commonly considered have been passive optical backplane connection schemes supporting parallel fibre-optic components such as optical fibre ribbons.

In this paper we propose an optical backplane connection scheme whereby active parallel optical devices can be connected directly to the optical backplane waveguides in a pluggable fashion. In order to minimise the cost of the optical interconnect, the transceiver and the connector are part of the same unit and intermediary optical interfaces on the backplane are omitted.

We address the challenges inherent to implementing a pluggable daughtercard connection to an optical backplane and present a solution based on a prototype system comprising a passive optical PCB, two daughter cards, parallel optical transceivers and pluggable connectors.

An experimental evaluation is thereby included, wherein 10.3 Gbps optical signals of 850 nm wavelength are conveyed between two daughter cards across a polymer waveguide-based optical PCB by means of the proposed connection scheme.

Application Model

In a conventional system, a backplane and a daughtercard are arranged in a mutually orthogonal configuration. If the backplane is a passive optical PCB, then photonic transmit and receive devices will be required on the daughtercard to support and maintain an optical data communication structure (Fig 1).

In a cost-effective system, these devices would most likely comprise PIN photodiodes and 850 nm VCSELs. Upon direct assembly, the optical emitting and receiving areas of these devices would lie in parallel to the plane of the PCB, thereby allowing an optical channel to be sustained orthogonally to the daughtercard. In consequence, such a channel could be conveyed by an optical waveguide, to which a photonic interface may be drawn into physical engagement (Fig 2).

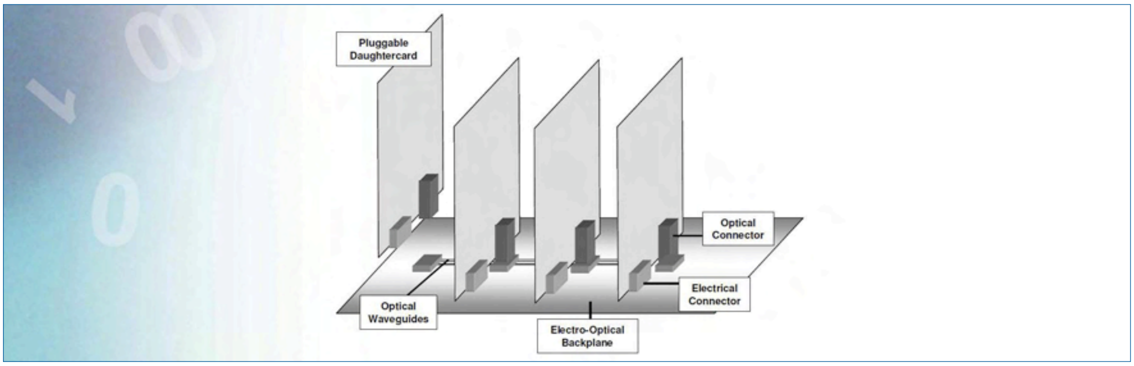

Figure 1: Conventional optical backplane system

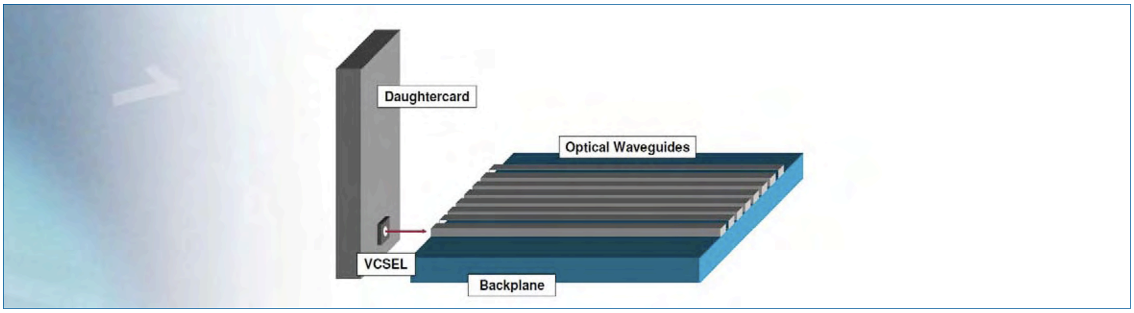

Figure 2: Relative orientations of daughtercard VCSEL to backplane waveguides

Such a butt-coupling scheme would eliminate the need for intermediary optical interfaces on the backplane, such as 45° optical deflection structures, and thus minimise the number of interfaces incurring optical losses as well as additional assembly costs.

Proposed Coupling Method

It has been shown that an interconnect approach based upon direct butt-coupling to multimode polymer waveguides would be subject to lateral input misalignment tolerances in the order of the waveguide aperture size itself [3]. Given the dimensions and layout densities inherent to conventional parallel multimode waveguide interfaces, such as Multi-Terminal (MT) parallel optics, the interface between the daughtercard and optical backplane would be subject to high alignment tolerances (less than +/-25 μm for 50 μm waveguide).

These tolerances would have to be met continuously throughout the connection cycle and would therefore require that the interface remain immune to movements arising between the daughtercard and backplane as a result of system vibrations, air-flow and PCB deformation. The interface would also require a level of detachment mechanical (guide-rails) or electrical (power connectors), as these are generally subject to far wider assembly tolerances than could be assembly on all backplane interface components would be prohibitively high.

In order to address these challenges, a method is proposed whereby the optical interface on the daughtercard is housed on a platform, which is separated from the supporting daughtercard by a mechanically flexible bridge.

The platform is complemented by mechanical features which will engage with compliant structures on the optical PCB allowing the optical interface to be drawn into physical alignment with the waveguide interface on the optical PCB. Finally, a mechanical mechanism would be required to raise and lower the optical interface platform.

The method comprises a two stage engagement process: a first stage of coarse alignment whereby the daughtercard is inserted into the backplane in the conventional manner providing the necessary electrical and mechanical connections, and a second stage of fine alignment whereby the optical connection is asserted as described. from other non-optical backplane interface components, accommodated optically. The cost of widespread precision. In this manner, the requirement for precision assembly is restricted to the optical interface platform on the daughtercard and the compliant receptacle on the optical backplane.

Design Outline and Discussion

We sought to test this method by designing and constructing a pluggable optical PCB connector module incorporating a quad parallel optical transceiver and cam lever mechanism. In order to evaluate both the connector principle and its application to high speed optical signal insertion and extraction from an optical PCB, the transceiver was designed to accommodate 10 Gbps traffic per channel.

In addition, we designed a complete optical backplane test system and demonstrate both a pluggable connection and high speed signal transfer across an optical backplane.

Photonic Interface Design

The photonic interface comprises a section of a parallel optical transceiver supported on the daughtercard, which forms the physical connection with the optical PCB. The active transmit and receive elements – VCSEL die array and PIN photodiode die array – are bonded directly to the PCB over appropriate thermal distribution structures (Fig. 3).

VCSELs were chosen on the basis of cost, suitability of emission orientation and characterisation with respect to polymer waveguide communication [4].

In selecting an appropriate surface to mate physically with the waveguide interface, we initially considered a geometric microlens array; however the ability to collimate the divergent output of a VCSEL into a waveguide at close proximity would have exceeded available manufacturing tolerances and introduced undesirable Fresnel losses. We then determined that a gradient index microlens array (GRIN lens) would be suitable as it could be calibrated to image the output from the VCSEL onto the point of intersection with the waveguide [5]. Likewise the lens could image the output of the waveguide onto the active area of the PIN photodiode. The GRIN lens array and support structure (Fig. 4) serve both to protect the fragile die underneath and to counter the optical

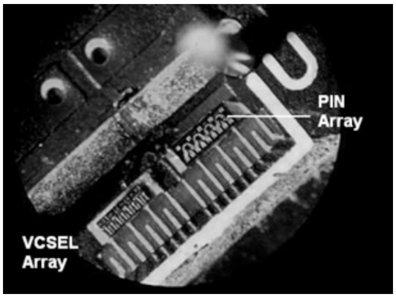

Figure 3: Attachment of VCSEL array and PIN array to PCB

divergence from the VCSELs and the waveguides. In addition, the planar ingress / egress surfaces of the GRIN lenses make them suitable for butt-coupling to flat surfaces.

The prototype transceiver employs a quad array of 850 nm VCSELs with an active area of 7 µm diameter and an emission divergence angle of 20°, which is reproduced by the imaging GRIN lens, yielding an effective N.A. of 0.173. In addition, the PIN photodiodes used in the transceiver contain active areas of 70 µm diameter.

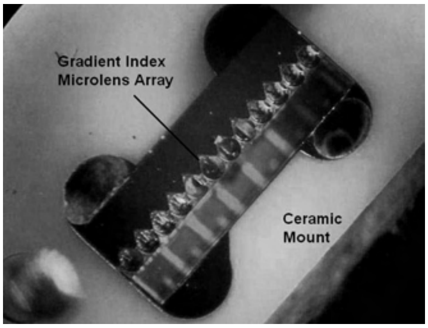

Figure 4: Gradient Index microlens array and support structure

Mechanical Registration Interface

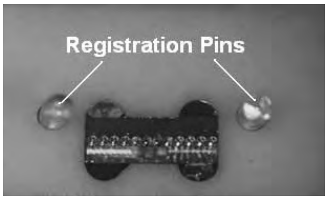

Figure 5: Opto-mechanical registration interface

The photonic interface is complemented by salient mechanical structures (Fig. 5), the purpose of which is to engage with a compliant receptacle on the optical PCB and draw the image points of the GRIN lens array into precise alignment with the waveguides.

On the prototype, the mechanical alignment structures and their layout with respect to the photonic array are based on an existing parallel optical interface convention, namely the Multi-Terminal (MT) style interconnect (Fig. 6a), thus supporting stand-alone testability of the photonic interface itself using MT fibre-optic patch-cords (Fig. 6b).

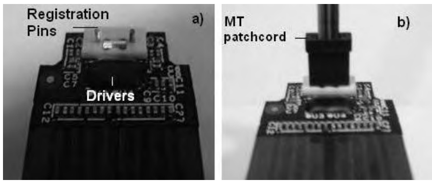

Figure 6: a) Optical interface platform
b) Transceiver evaluation using MT patch-cord

Optical Waveguide Design and Composition

The optical waveguide parameters for the experimental evaluation of the proposed interface and coupling method were designed to be compliant with the photonic interface. Concordantly, the waveguide interface on the optical PCB can also be tested with MT patch-cords.

Each testbed comprises a straight row of 12 parallel multimode waveguides with a centre to centre pitch of 250 µm and waveguide cross-section of 70 µm x 70 µm (Fig. 7).

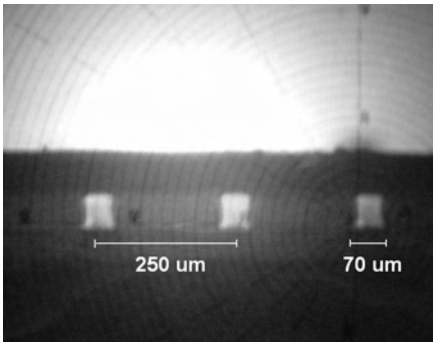

Figure 7: Optical waveguide interface

Prior research into optical inter-mode dispersion in polymer optical waveguides over varied sizes has yielded favourable results for this size of cross-section [6]. The testbed extends over a distance of 10 cm from one point of interface at one end of the PCB to the other point of interface at the other end.

The waveguide core and cladding were composed of a cross-linked polymer acrylate which is deposited on an FR4 base and patterned lithographically [7].

The refractive indices of the polymer core and cladding layers were 1.556 and 1.5264 respectively, thus yielding a N.A. of 0.302 for the waveguide.

As the waveguide N.A. is larger than that of the imaged VCSEL, good power coupling is ensured between the active optical transmitter on the daughtercard and the recipient waveguide on the backplane.

Prototype Transceiver Circuit

The optical transceiver circuit (Fig. 8) is constructed on flexible laminate PCB; the sections housing the photonic interface and the daughtercard connector are supplemented with rigid FR4 layers, while the bridge between these sections is exposed and flexible.

This arrangement serves the critical purpose of ensuring that the rigid platform supporting the photonic interface is free-floating with respect to the daughtercard. This allows the photonic interface to be manipulated into precise alignment with the optical waveguides irrespective of the relatively coarse alignment of the daughtercard.

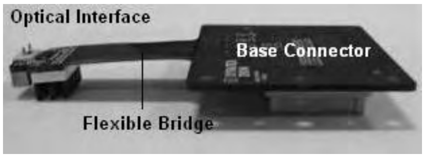

Figure 8: Parallel optical transceiver circuit

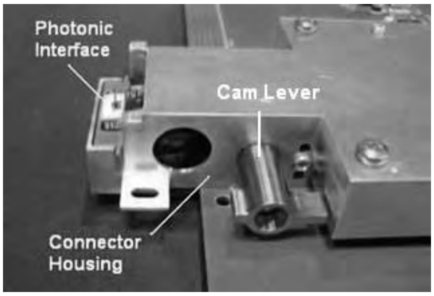

Figure 9: Cam-based optical backplane connector mechanism

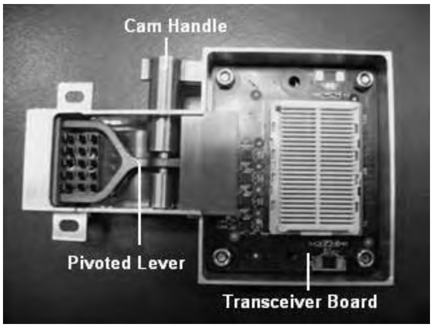

Figure 10: Pluggable connector mechanism (underside)

Pluggable Connection Mechanism

The connector mechanism (Fig. 9) serves two key functions:

1. Retraction of the photonic interface to protect the salient mechanical alignment structures during the daughtercard insertion and retraction process
2. Elevation of the photonic interface into engagement with compliant receptacle on optical PCB.

The parallel optical transceiver is housed within a mechanical casing incorporating a pivoted lever (Fig. 10), which is driven by the cam handle. The pivoted lever is bifurcated to provide a balanced tension to the photonic interface section of the transceiver PCB. Thus, by operating the cam handle, the photonic interface can be retracted and elevated as required.

The connector assembly (including the transceiver board) is electronically plugged to the daughtercard and fastened at the screw points. The daughtercard is guided within the chassis along standard guide rails to the point of engagement with both the optical backplane and a separate electrical backplane. At the first level of optical engagement, guide features on the connector housing bring the photonic interface into coarse alignment with the compliant receptacle. At the second level of engagement, the cam handle is activated and the photonic interface elevated, such that the MT alignment pins on the interface are made to mate with the MT slots on the compliant receptacle, thus forcing the photonic array into a precise butt-coupled arrangement with the waveguide array on the backplane. All precision assembly on the design is thus restricted to the photonic interface and the compliant receptacle.

Demonstration Assembly

An assembly was constructed to demonstrate the proposed optical backplane connection system (Fig. 11). The assembly is comprised of two line-cards each housing the prototype active connector modules, thus supporting

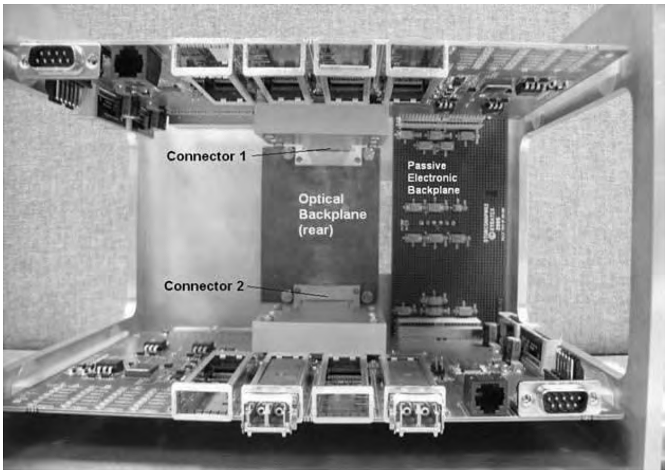

Figure 11: Demonstration assembly for pluggable optical backplane connection system

a pluggable connection to the optical PCB which bounds the line-cards. The function of the line-cards is to route high speed traffic from an external source - such as a network analyser - to the prototype transceiver and vice versa.

In addition a separate electrical backplane is provided to supply power to both line cards. All elements are supported in an aluminium chassis.

Experimental Characterisation

Parallel Optical Transceiver Evaluation

The optical transceiver was driven with a 10 GbE LAN bit pattern at 10.3 Gbps and mated to a MT patchcord with 62.5µm fibre fan-out, allowing direct characterization of the transmitted output from each channel in terms of jitter and output power (Fig. 6b). The VCSELs were driven with bias and modulation currents of 11.91 mA and 9.8 mA respectively. The measurements were consistent showing an average jitter of 31.2 ps (0.32 UI, Unit Interval expressed as a fraction of the bit period) and an average optical power of 0.43 mW.

Connector Interface Characterisation

The transceiver connector was docked to the optical PCB and a MT patchcord to the egress waveguides at the other end. The extracted data-stream was characterized after passage through the butt-coupled connection and polymer waveguides. We carried out a comparative assessment on how the preparation of the optical PCB interface surface affects both interface scattering losses and high-speed signal integrity in terms of jitter. We considered 3 preparations: a) diced (worst case), b) diced and polished and c) diced with isapropanol applied to reduce the effect of surface, taking the average over the four waveguide channels under test. The results are shown in Table 1.

Case	Waveguide Preparation	Total Jitter / ps	Relative Loss / dB
Fig. 11 a)	*No Waveguide (Reference)*	32.9	0
Fig. 11 b)	*Isapropanol*	34.9	4.5
Fig. 11 c)	*Diced and Polished*	54.3	6.9
Fig. 11 d)	*Diced*	86.4	7.9

Table 1: Waveguide transmission characterisation

This evaluation allows the trade-off space between cost of waveguide interface preparation vs quality of signal output to be explored. The optical signal waveforms for the four cases outlined in Table 1 are shown in Fig. 12.

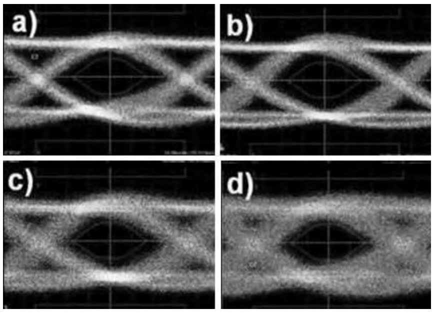

Figure 12: Eye diagrams for 10.3 Gbps optical transmission characterisation

Loop-back Transmission Test

In the final round of testing, both daughtercards were connected to the optical backplane. A 10 GbE LAN bit pattern was generated by an external traffic generator and transferred to one daughtercard, converted to an optical signal by the transceiver and launched into the optical waveguides of the backplane by the connector. After propagation through the waveguide, the signal was then retrieved by the second transceiver through its connection to the backplane and transferred out through the second daughtercard to a traffic analyser. Repeated four hour soak test cycles consistently showed unimpaired traffic throughput in the loop-back configuration described. In accordance with 10 GbE LAN specifications, the BER limit of 10^{-12} was satisfied throughout the test cycle.

Conclusion

In this paper we have outlined a novel optical backplane connection system and have demonstrated its successful implementation with respect to high speed data transfer across multimode polymer waveguides. We have developed and characterised a complete optical backplane and daughtercard system based on the direct coupling of active devices to an optical PCB and have subsequently demonstrated a viable approach toward the application of pluggable optical backplane interconnects.

Further Work

Currently the direct connection to the exposed waveguide interface results in considerable optical loss and scattering. Future designs will have to address this by attaching a permanent optical coupling element over the waveguides.

In addition, alternative structures for the high precision mechanical coupling should be explored. The MT compliant features deployed in the current prototype were chosen for convenience, however structures more suited to the rigours and tolerances of the opto-mechanical engagement process should be devised.

Acknowledgements

We would like to acknowledge the assistance of David Selviah, Ioannis Papakonstantinou and Guoyu Yu of the Optical Systems and Devices group at University College London who characterised the tolerances inherent to multimode polymer waveguides.

We would also like to acknowledge Professor Frank Tooley and Dr Navin Suyal for their assistance on matters of optical PCB fabrication.

In addition, we acknowledge Torsten Possner of GrinTech GmbH for his competent advice regarding GRIN microlens assemblies.

Finally we would like to acknowledge the UK Department for Trade and Industry and the UK Engineering and Physical Sciences Research Council for funding this work as part of the Storlite project.

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