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NEMI Cost Analysis: Optical Versus Copper Backplanes

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Abstract

The 2002 International Electronics Manufacturing Initiative (iNEMI) Optoelectronics roadmap anticipated a cross-over in cost-performance whereby a system using optical transmission of high speed signals would have lower overall “cost” than a pure electrical system of equivalent function. In 2003, iNEMI formed a task group to investigate this cross-over point via cost modeling analysis. The activities to date have been to adapt and verify an existing cost model for copper-based PCBs and develop an electrical backplane technology roadmap to 40 GHz, with logical combinations of bus type, connectors and signal conditioning chip sets. We are currently reviewing the relevant optical technologies, including optical fiber, fiber flex or embedded polymer waveguide, optical connectors and transceivers to develop the equivalent optical roadmap. This presentation will be a work-in-progress report on the iNEMI project activities with the goal of developing cost and performance models to compare different designs of electrical and optical backplanes.

Introduction

While electronics continually advances in the face of increased performance requirements, the industry is debating the limits of the electron (1). Starting with high-end telecom systems as one frontier pushing the bandwidth limits of copper, this iNEMI team has focused on the backplane – the crossroads for signals being switched between an array of daughter cards. The maximum capability of the backplane determines the performance of the system, in this case measured as high as about ten gigabits per second (Gbps) of switching capacity. Within today’s backplane, we see layers of copper, whose characteristics mostly determine how many Gbps we can switch.

“Going faster” in a copper backplane entails any combination of the following:

- Making the copper thicker
- Making the dielectric layer thinner
- Using dielectrics with lower loss tangents
- Adding more signal layers
- Minimizing the signal length
- Maximizing distance between signals
- Making the board larger (wider and longer) to handle more signals per layer

Meanwhile, we observe that a single optical fiber has a far higher transfer rate in Gbps than a whole copper backplane. Why not make the backplane out of fiber? Today, some backplanes have a surface layer of fiber, so that is certainly possible (2). But these fibers provide point-to-point connections, not true bus-based backplane performance. Further, the cost can be enormous, since each fiber end needs to be connected to a unique optical module, or spliced to another fiber, entailing assembly time and module costs.

But, there are other ways to carry photons. Optical waveguide research holds the promise of electronic-like circuit board structures, complete with optical vias, patternable signal layers, bus architecture, and simple assembly methods (3). However, this technology leap requires complementary developments, including new connectors (optical), optical modules with laser and detector arrays that align with optical vias, and turning light at a 90-degree angle. Most of these technology hurdles have been proven in the lab at this time. Whether they can be commercialized depends on a number of factors, including the following:

- Market need for optical performance levels
- Manufacturability
- Reliability
- Connector cost
- Assembly cost
- Optical PCB cost

The iNEMI optical PCB cost modeling project is focusing on this last issue, as an extension of prior iNEMI project work (4). It's a "what-if" analysis: "What if there's a market need? Before we go testing reliability and working out the manufacturing scale-up issues, we need to know the cost relationship."

To this end, the iNEMI team has developed a copper-based backplane cost model as a starting point. The team has validated the model with two medium-sized US PCB companies familiar with the backplane business, along with two North American telecommunication system OEMs who routinely purchase backplanes (5).

The original iNEMI cost comparison goal was to show a cost-performance crossover point, highlighting where optical PCBs would be more cost effective than copper, such as the conceptual graph in Figure 1.

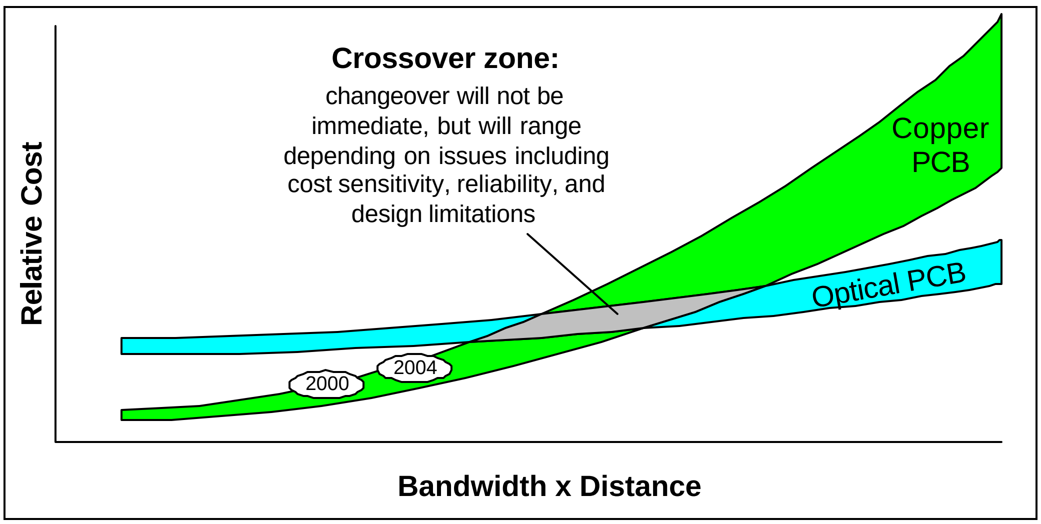

Figure 1 - The iNEMI Cost Modeling Goal is to find the Crossover Point between Copper and Optical PCBs

However, these comparisons to optical PCBs are not yet undertaken. Mainly, the iNEMI team has realized that there will be other differences between copper and optical systems besides the circuit boards (i.e., daughter card construction as optoelectronic or just electronic, connector types, assembly techniques, and so on). As a result, the team will evaluate the cost of whole systems: one with a copper backplane versus one with an optoelectronic backplane. Further, this comparison will be conducted for 3-4 telecom systems with varying performance levels, in other words "black box" rough designs for today's and tomorrow's telecom systems.

This paper, the second in a series of reports on the progress of this iNEMI team (5), reviews the optical PCB technologies under consideration for future analysis.

Optoelectronic Circuit Board Challenges

Accommodating two systems on one circuit board presents unique challenges, as shown in Figure 2. The electrical and optical layers must be integrated into a single laminated unit. The waveguide layers can be fabricated from either plastic or glass, and can be either on the top surface or embedded within the PCB. Particularly challenging, though, is getting the optical signal out of the circuit board, since turning light 90° can cause significant losses. Through the PCB edge, there's no need to bend the light through a right angle vertically, so edge connectors, if feasible given the system design, would be preferable. For surface modules and components, connection to the optical waveguide layer requires reflecting light 90°

vertically, via a mirror. With light, the alignment of transmitters, waveguides, and receivers becomes a critical factor in whether a system works properly. So, the PCB and surface and edge components need to either (1) meet precision manufacturing dimensions, or (2) be adjustable dimensionally during assembly.

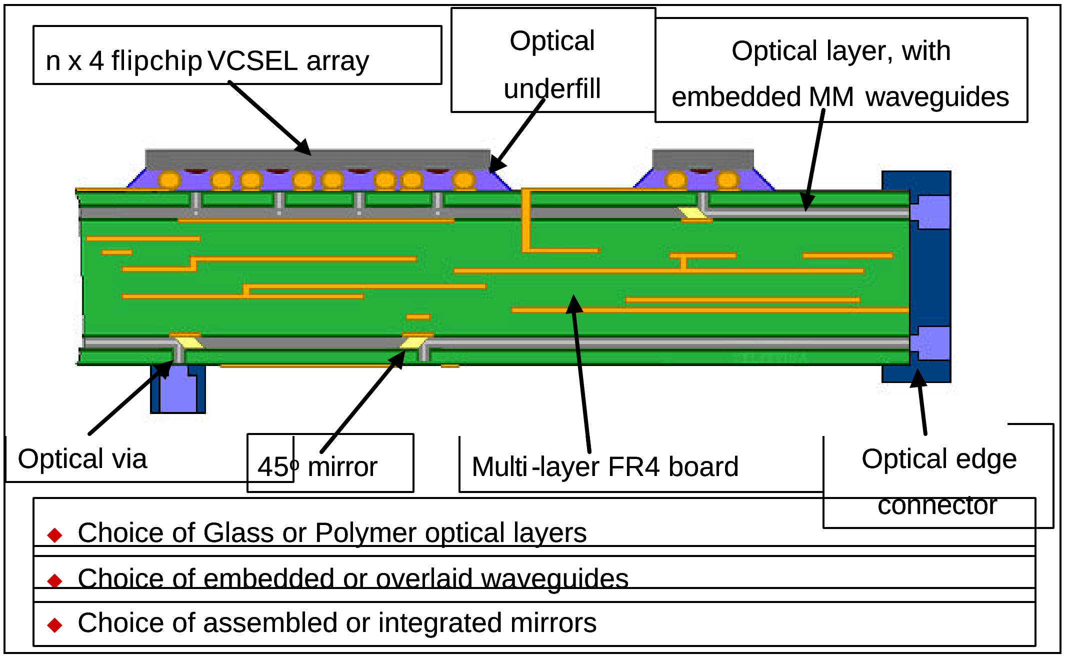

Figure 2 - Challenges of Optoelectronic Circuit Boards

Optical Technologies for Printed Circuit Boards

Tables 1 and 2 provide a detailed breakdown of optical technologies, including both waveguides and fiber. Table 1 shows the overall capabilities of each, while Table 2 focuses on performance details.

General Optical Technology Characteristics

As listed in Table 1, the various optical technologies can be categorized by (1) coupling methods, or how they integrate with optical signals a system, (2) the applications where they are best suited or have found commercial success, (3) the companies or organizations who own intellectual property or are practicing the technology, and (4) the maturity level of the technology, whether still in R&D or in full-scale production.

Table 1 - Optical Waveguide and Fiber Technologies – Overview

	Coupling Methods (3)	Applications	Producer	Status
Optical Waveguides				
Polymer				
Deposited	Fiber + Free Space	Backplanes, General interconnect		R&D
Photoimaged	Direct fiber/component, I/O mirror arrays, Array connectors, single/stacked layers	Stand alone flex or board/substrate interconnects-chip, component, functions, links, fully connectorized, stacked or single layer.	Optical CrossLinks	Custom Prototying & Production
Embossed				
Press	Fiber + Surface (4)	WDM, Splitters, Couplers, ADM	OptoFoil - Fraunhofer Institute	Production
Roll	Fiber + Surface (4)	Ribbon Cables, Backplanes	3M, Promerus	Production
Trench & Fill	Fiber + Surface	DWDM, VOA, ADM, Splitters, Couplers	Shipley, DuPont Photonics, NTT, Neophotonics	R&D
Micromolded	Fiber/F.S./Surface (4)	Light Pipes, Backplanes, Passive Interconnect	Promerus	Production
Molded	Fiber + Free Space	Light Pipes, Backplanes		?
Inorganic				
Silica on Silicon	Fiber end	DWDM, ADM, AWG	Neophotonics, Symmorphics	Production
Polysilicon	Fiber end	Chip Switches, Modulators	Intel	Research
Hybrids (6)	Fiber end	VOA, ADM	Lightwave Microsystems, Neophotonics	Production
Optical Fiber				
Embedded Fiber				
Glass	Fiber + Surface	Backplanes, Lightpipes	Hitachi Chemical (Wire Wrap)	R&D
Polymer	Fiber + Surface	Backplanes, Lightpipes	Northrup-Grunman	R&D

Optical Technology Details

As listed in Table 2, the performance capability and rough cost of the optical technologies ranges widely. By column, (1) Field Size refers to the format for creating the waveguides, whether on a large panel, wafer, or something in between. (2) Attenuation describes the light absorption for each of the materials implemented, for two different wavelengths; (3) WG (waveguide) Type means whether the technology could be embedded as a layer within a PCB, or whether it would be limited to the surface (rib); (4) Mode structure refers to whether the technology can carry one wavelength at a time or multiple wavelengths; (5) Waveguide pitch documents the ballpark lower limit on feature size as reported by the producer or by technologists; (6) NRE (nonrecurring engineering) cost per layer refers to the mask cost or other engineering required for patterning each layer of the waveguide. For wafer processing, this would be the lithography mask. For embossing, this would reflect the cost of the unique embossing tool; (7) Cost per square foot per layer attempts to capture the fabrication cost of each layer, including materials, equipment, labor, and tooling. The sources for these costs include the publicly known costs for common processes such as wafer processing, the producer of a technology, or from cost models.

Table 2 - Optical Waveguide and Fiber Technologies – Details

	Field Size in.	Attenuation, dB/cm 830 nm	1550 nm	WG Type	Mode Structure	Waveguide Pitch (2)	NRE Cost $/Layer (5)	Cost $/ft^2/Layer (5)
Optical Waveguides								
Polymer								
Deposited	12 X 18	0.1	0.5	Rib	Multimode	Coarse	1K	5 - 10
Photoimaged	12 X 18, 13" reel to reel	0.08	0.7	Rib & Embedded	Single Mode & Multimode	Hyperfine	100 to~2500	30-50
Embossed								
Press	Wafer (1)	0.1	0.1	Embedded	Single/Multi	Fine	10K	1,500
Roll	36 X 36	0.1	0.3	Rib & Embedded	Single/Multi	Fine	20K	5 - 10
Trench & Fill	Wafer	0.1	0.1	Embedded	Single/Multi	Fine	10K	1,500
Micromolded	36 X 36	0.1	0.3	Rib & Embedded	Single/Multi	Fine	12K	10
Molded	24 X 24	0.1	0.5	Rib	Multimode	Coarse	>50K	5
Inorganic								
Silica on Silicon	Wafer	< 0.1	< 0.1	Rib & Embedded	Single/Multi	Fine	10K	1,500
Polysilicon	Wafer	?	?	Embedded	Single Mode	Fine	15K	3000
Hybrids (6)	Wafer	< 0.1	< 0.1	Rib & Embedded	Single	Fine	15K	1,700
Optical Fiber								
Embedded Fiber								
Glass	18 X 24	< 0.1	< 0.1	Embedded	Single/Multi	Coarse	5K	50
Polymer	18 X 24	< 0.1	< 0.1	Embedded	Multimode	Coarse	5K	30

Notes:

1 Press embossing requires high pressure, thus field size is limited to small (4 - 5 in.) wafers.
2 Hyperfine pitch - Line and space 10:1; Fine pitch - Line and space 1:1; Medium pitch - Line and space 1:5; Coarse pitch - Line and space >1:10.
3 Ability to fabricate micro lenses during waveguide fabrication process without a separate alignment allows low cost F.S. (free space) coupling.
4 Grating fabrication in the same process step as waveguide formation without a separate alignment.
5 Assumes commercial volumes and 200 mm wafer size.
6 Hybrid systems use inorganic waveguides for transmission and use polymers localized for specific functions (i.e. switching).

Future Work

The iNEMI team is currently evaluating the system costs of various "black box designs," for both electronic and optoelectronic circuit board implementations. The team is gathering information on system design, optoelectronics assembly, and connector costs. The forum is open to new members who have data that can make the comparison more accurate.

Summary

The iNEMI optical backplane cost modeling team has developed the framework for comparing optical PCBs to today's copper PCBs. PCB fabricators and OEM users have validated the copper case output costs, ensuring the model is within 10% of their internal cost models.

References

(1) Bogatin, Eric, "Has the Copper Interconnect Hit Its Speed Limit?" Printed Circuit Design & Manufacture, Vol 21, No 1, January 2004, p 24.

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(3) Chiarotto, Nancy, "Embedded Waveguides: Current Status and Challenges," 14th Annual International Electronics Packaging Symposium, September 23-25, 2003, Binghamton University, Binghamton, NY.

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(5) Singer, Adam et al, "NEMI Cost Analysis: Optical Versus Copper Backplanes," Proceedings of APEX 2004, March 2004.