Multi Fiber Connector Technologies

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Abstract: This paper describes the advancement of high density optical interconnect components which is enabling high bandwidth, low cost, single-mode and multimode optical communication between IC's for on-card, optical backplane and chassis to chassis applications.
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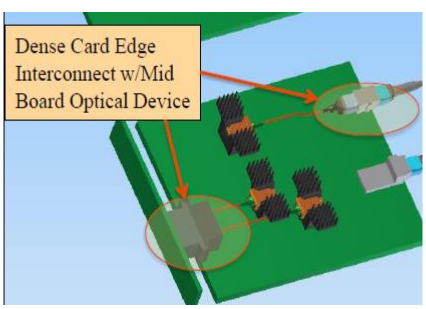
1. Introduction

Bandwidth, cost, density, and power requirements are driving evolution in system equipment design resulting in optical links within the rack at reaches traditionally served by copper. Data rates per channel are rapidly migrating to 25Gb/s and beyond. Compact 850 nm VCSEL based parallel optic modules are readily available and currently being designed into next generation data center networking architectures. In addition, optically enabled silicon IC devices are emerging which are enabling low cost single-mode Tx/Rx modules offering optimal link length flexibility at costs comparable to multi-mode links. Recent silicon photonic OE conversion technology has demonstrated MM transmission at 25Gb/s utilizing for over 800 meters with 1310nm lasers in conjunction with new 1310 optimized high bandwidth optical fiber [1]. Furthermore, advanced multiplexing techniques in both single mode and multimode protocols are emerging to support cost effective links carrying 100Gb/s and more on a single optical fiber [2].

This next-generation high speed link development activity has resulted in architectures demanding Mid-PCB mounted versions of these multi-channel Tx/Rx modules directly adjacent to the computing IC. Placing the OE conversion in the middle of the PCB next to the ASIC rather than at the traditional edge mounted location for pluggable Tx/Rx modules (e.g., SFP, QSFP) offers multiple advantages:

1. Preservation of card edge real estate: Dense, passive interconnects at the edge of the PCB take a fraction of the space required by the pluggable OE device. Figure 1 compares card-edge bandwidth density of card edge pluggable Tx/Rx devices to mid board mounted Tx/Rx devices with an aggregation of high density connectors at the card edge



Mid Board Mounted Tx/Rx

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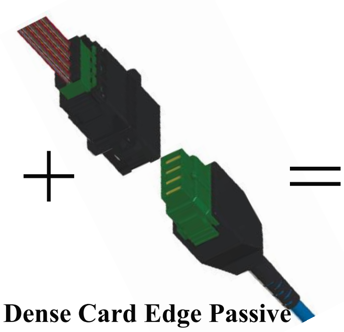

Dense Card Edge Passive Interconnect

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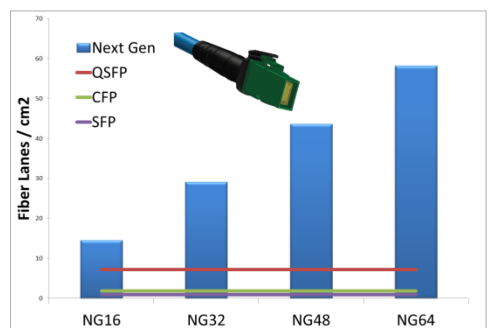

Channel density comparison between next gen high density connectors and edge mounted optics

Figure 1: Channel Density at the card edge with embedded optics

2. Signal Integrity: Minimizing high speed transmission over copper traces results in minimal signal degradation through the electronics signaling. [3]
3. Thermal management: OE/EO conversion concentrated at the edge of the PCB complicates thermal transfer out of the system for high bandwidth architectures by creating an unbalanced thermal profile across the PCB. On the contrary, placement of the Tx/Rx devices in the middle of the PCB offers maximum flexibility for forced air convection and liquid cooling approaches.

This migration of next generation system designs with mid-PCB mounted OE/EO conversion is driving requirements for new optimized optical fiber demarcation points at either the front panel faceplate of the PCB or in the rear of the PCB. If the fiber demarcation point is in the rear of the PCB, the optical connectors may need to be mated 'blindly' and coexist with the electrical backplane or mid-plane.

2. Conventional Multi-Fiber Interconnects

Traditional MT rectangular ferrules are the most commonly used multi-fiber interconnect. Traditional MTs are designed around maintaining physical contact of the polished fiber tips for stable optical performance. This physical contact requires very tightly controlled termination, polishing and metrology procedures which increase the cost of traditional multi-fiber interconnects. In addition to maintaining physical contact, each fiber tip in the ferrule must be kept pristine to ensure the signal is not attenuated through contamination blockage or loss of z-axis alignment (i.e., physical contact). Figure 2 illustrates the primary attributes impacting the performance of traditional MT based multi-fiber connectors: component precision, polished endface geometry and the ability to maintain physical contact via ferrule spring loads, and fiber tip quality or cleanliness [4].

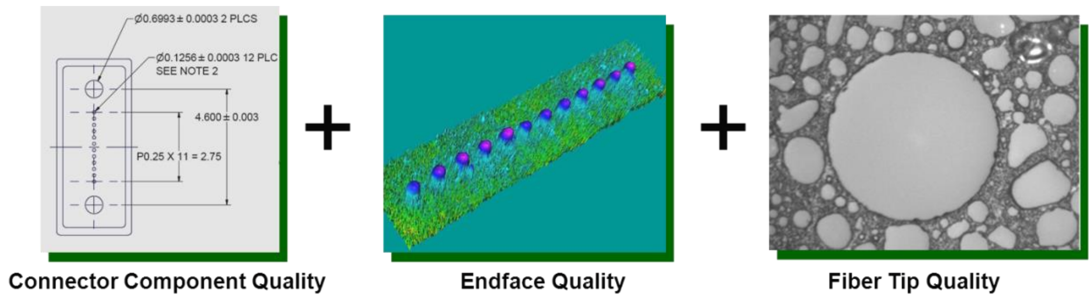

Figure 2: Factors impacting performance of traditional MT physical contact ferrules

In order to maintain fiber tip contact on MT ferrules, the working normal force between ferrule mating planes is standardized for the number of fibers in the ferrule. For 12 fibers or less, the nominal force between ferrules is 9.8N. The nominal ferrule mating force for more than 12 fibers and up to 24 fibers is 22N. For ferrule densities requiring greater than two rows of fiber arrays, obtaining and maintaining physical contact of the fiber tips becomes unobtainable with state of the art polishing and termination technology.

3. Expanded Beam Interconnects

While traditional, physical contact MT ferrules are suitable for demanding low-loss, high performance applications, they are not optimized for short reach optical backplane and point to point applications. This has resulted in focused development activity on next generation optical backplane interconnects. A free space, expanded beam, collimated optical interconnect eliminates the need for fiber tip physical contact, which in turn, reduces the overall cost of multi-fiber optical cable assembly manufacturing. Light emitted by the fiber diverges from the fiber tip through the optical polymer to the lens. Over this distance, the beam diverges based on the NA of the fiber and the index of the polymer. The beam exiting the lens is nearly collimated. The same lens on the receiving ferrule focuses the light onto the fiber core. A cross section of the mated ferrule and ray trace schematic is shown in Figure 3. The ferrule design presented in this investigation is made with one, molded, monolithic component combining micro holes and lenses and expands the beam to a collimated spot over 3X the fiber core diameter [5]. The collimated free space transmission is also tolerant to z-axis alignment and reduces the need for high mating forces and costly polished end face topologies associated with physical contact connectors. Furthermore, the impact of debris occluding the power and causing z-axis separation is significantly reduced due to the expanded beam at the mating interface.

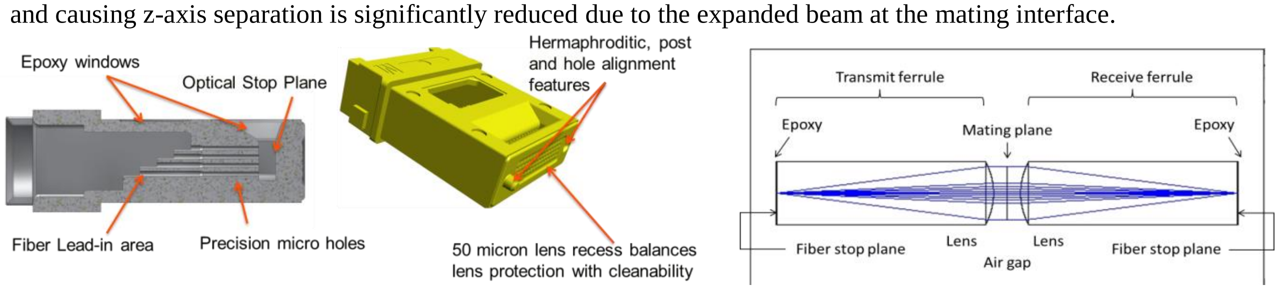

Figure 3. Expanded Beam, Free-Space, Lensed, Multi-Fiber Ferrule

3. Expanded Beam Interconnects for Optical Backplanes

The optical backplane could be stored in varying locations of a rack scale design. If the optical backplane is located in rear or middle of the rack scale design, a blind mate of the optical ferrules is required. Two primary challenges associated with blind mating optical interconnects are the impact of debris and the aggregation of high mating forces typically associated with physical contact optical interconnects. Cleaning traditional, bulkhead optical connectors in the field is a normal and accepted practice to ensure minimal insertion loss; however, accessibility to the daughter card or backplane mounted ferrules can greatly complicate removal of debris in a blind mate configuration. Debris insensitivity of expanded beam connectors minimizes the need for accessing and cleaning those ferrules. In addition to debris insensitivity, the forces required to mate expanded beam ferrules is a fraction of the force required for physical contact ferrules. As previously noted, the current state of the art polishing for traditional MTs can only support up to 24 fibers of physical contact with higher forces required at higher fiber counts. Conversely, the expanded beam ferrule discussed in this paper supports up to 64 fibers while maintaining a low mating force of 3N. Figure 4 highlights minimal impact of contaminated SM expanded beam ferrules along with the industry standard endface quality requirements for traditional connectors [6]. In addition, figure 4 illustrates potential 25Gb/s aggregated bandwidth throughput at different mating forces for traditional and expanded beam ferrules.

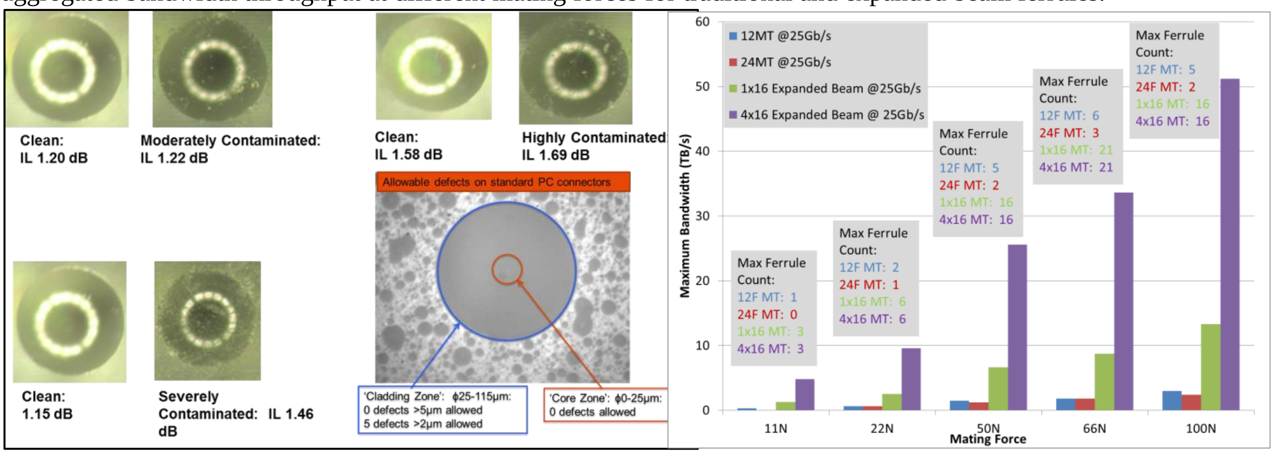

Figure 4: Expanded Beam Interconnects Reduce Impact of Debris and Mating Force Requirements

4. Expanded Beam Backplane Interconnect Empirical Results

A ray-tracing, Monte Carlo simulation model was initially established to predict loss of the expanded beam ferrules for optical backplane applications with predicted tolerance values. Initial random inter-mate insertion losses for multimode applications were modeled to be 1.2dB maximum and 2.0dB maximum for single mode applications without an anti-reflective treatment on the lens surface [5,6]. Anti-reflective treatment on the lens surface can yield an improvement of 0.35-0.5dB depending on the material properties of the ferrule and the anti-reflective performance. Multimode expanded beam ferrules are now in volume production. As part of the validation of the theoretical models, Figure 5 illustrates current inter-lot insertion loss production data on four row (4x16) multi-mode ferrules with no anti-reflective treatment on the lenses. This data indicates that initial predicted tolerance values are being exceeded and paves the way for even lower loss expanded beam connections.

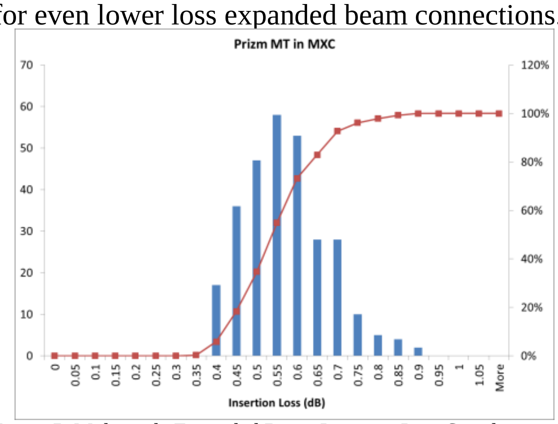

Figure 5. Multimode Expanded Beam Insertion Loss Simulation results

5. References

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