Miniature Detachable Photonic Turn Connector for Optical Module Interface

Darrell Childers, Eric Childers, Joe Graham, Mike Hughes, Dirk Schoellner, Alan Ugolini
US Conec, Ltd.
1138 25th Street SE; Hickory, NC 28603-2306
Phone: 828/323-8883 Website: www.usconec.com
alanugolini@usconec.com

Abstract

Miniature embedded parallel optic modules are newly available and currently being designed into system equipment solutions to address the expanding requirement for very dense I/O bandwidth. These embedded miniature parallel optic modules greatly improve component densities by significantly reducing the board level footprint requirements of traditional parallel optic modules such as SNAP12 [1], POP4, QSFP [2] and the recent CXP specification [3]. Implementation of these small form factor modules facilitates the ability to pack more processing power onto the physical board, thereby conserving valuable space and power in data centers [4]. These mid-board mounted miniature modules enable the use of high density optical connectors, such as 24 and 48-fiber MPO type connectors at the card edge. These high density optical connectors significantly improve the interconnection density and operational function at the card edge over traditional front panel mounted parallel optics. Fiber optic jumper cables are used to provide the optical interface between the miniature embedded parallel optic modules and the high density optical connector at the card edge. Application issues to this enhanced embedded parallel optic system exist when the optical interface into the module does not equally facilitate the system value achieved by the miniature module and high density card edge connector. To complement the benefits offered by implementation of a miniature optical module, an equally innovative and economical module connector interface is required. This module connector must enhance the functionality of providing the optical jumper interface between the module and high density connector at the card edge. The design solution presented herein is a low cost, low profile connector system that provides a reliable, consistent, and repeatable mating interface to the miniature optical module. It achieves the design and performance requirements needed to effectively implement these new high density parallel optic systems.

1. Introduction

Communication networks depend on the ability of the infrastructure to sustain reasonable and reliable bandwidth. As the need for bandwidth increases, so must the bandwidth density at the card-edge [4][5]. Original GBIC type transceivers were capable of sustaining asynchronous I/O at 1Gb/s while using approximately 1 square inch of front panel surface area. For data communication line cards, the cost for card-edge surface area (card-edge real estate) is fixed by the physical size of the line card and the overall cost of the line card itself. Increasing the size of the line card only increases the overall cost of the device such that there is a trade-off between card-edge real estate versus line card cost [4]. To improve the overall value of the card-edge real estate, higher bandwidth density must be achieved. This paper describes a parallel optical module, connector, jumper and card-edge solution. The emphasis of this paper is on the optical turning connector.

An optical module consists of driving electronics, a source and/or detector, and a passive alignment mechanism for coupling into the transmission media [6]. Commercially available single channel TOSA/ROSA modules can transmit up to 10Gb/s [7]. For higher bandwidth, either Wavelength Division Multiplexing (WDM) or Spatial Division Multiplexing (SDM) methods are used. WDM is the process where multiple data streams are sent over the same fiber simultaneously using separate source wavelengths for each data stream [8]. Special filters called Bragg gratings are used to separate each channel from the data flow. Each filter is tuned to match the wavelength of the corresponding data stream launch. The need for specially tuned sources and filters makes WDM solutions more expensive than other solutions.

For at least 10 years, spatial division multiplexing (SDM), aka parallel optics, has been the lower cost solution for short reach LAN, SAN and LSI applications up to 300m [9][10][11]. The monolithic nature of parallel optics blends nicely with the manufacturing processes for VCSEL and detector arrays. Passive alignment is added to the module to facilitate the use of MPO style connectors. The passive alignment mechanism is either actively or optically aligned to the substrate. Once aligned, it is permanently mounted to the substrate.

The transceiver module may be mounted at the card-edge or mid-board. When mounted at the card-edge, the transmission media is connected directly to the module with the optical axis perpendicular to the card-edge. There are two primary issues. The first problem is heat dissipation when a series of transceivers are mounted in close proximity at the card-edge. Without proper cooling, the line card will most likely fail catastrophically. Another problem with close proximity card-edge mounting is signal integrity. EMF shielding at the card edge hinders air movement which in turn aggravates the heat issue mentioned earlier. Also, added EMF shielding causes the transceiver to occupy more card-edge real estate, lowering the bandwidth density.

As an alternative to card-edge implementation, the mid-board configuration places the transceiver at a convenient location somewhere on the line card away from the card-edge. A short optical link extends the module to the card-edge for connection to the external network media. Therefore, only an optical adapter is located at the card-edge. For current MPO technology, a maximum of 72 channels may be connected through a single MPO adapter, which takes up approximately ½ square inch of card-edge real estate. EMF shielding for mid-board installations is less stringent around the transceiver itself since it is away from the card-edge and is encased by the overall line card shielding. Since the transceiver may be placed anywhere on the line card, it is conceivable to spread the heat load across the majority of the line-card making it easier to manage heat dissipation. However, the mid-board configuration presents two new issues to deal with. First, is cable routing.

In a simple example, the transceivers may be linearly offset from the card-edge in the direction of the optic axis. This scenario allows for a simple straight ribbon fiber jumper to link the transceiver to the card-edge adapter. However, in practice it is more likely that the transceiver may be transversely offset and rotated relative to the card-edge adapter. This precludes ribbon fiber cable from being used on the line card except in special circumstances. The industry has addressed this issue with loose tube fiber, round cable jumper assemblies [12]. Round cable jumpers do not suffer preferential bend issues, which make them ideal for mid-board mounted line-card transceiver solutions.

The second issue with mid-board configurations is the amount of line card real estate used by the footprint of the MPO connector used to offload the IO to the card-edge.

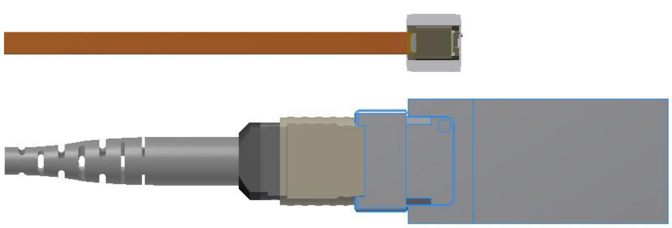

Figure 1: Footprint Comparison

As shown in figure 1 above, the footprint of the MPO connector mounted mid-plane is more than twice the foot print of the same connector at the card-edge. The transceiver takes up the same amount of real estate in the middle of the line card as it does at the card-edge. However, the MPO connector and bend limiting hardware connected to the transceiver in the mid-board configuration takes up real estate on the line card itself.

A new type of transceiver and connector system was developed to decrease the overall transceiver/connector foot print to allow for higher bandwidth density within the line card. The transceiver is subject of other technical and commercial papers. This paper focuses on the design of the connector, which serves as the optical interface between the transceiver module and the fiber jumper leading to the card-edge. This connector was developed so as to not add to the overall footprint of the transceiver on the line card. Also, the ribbon layering feature allows for more dense population of transceivers on the line-card. Finally, by increasing the bandwidth density per line card, the total size of the equivalent solution is reduced. The overall effect is to reduce system acquisition and operation costs, while satisfying the need for a stable and reliable communication infrastructure.

2. Design Theory

A multi-fiber ferrule and accompanying connector hardware have been designed as a miniature optical module interface that facilitates perpendicular mating to the printed circuit board. The connector provides passive alignment to the optical module and incorporates novel retention features for multiple matings. Precision alignment to the parallel optic device is accomplished by use of molded alignment posts within the connector ferrule and corresponding alignment holes at the module interface, as shown in Figure 2. Precision and repeatable alignment between the parallel optics module and the optical fiber is necessary to create a low cost commercially viable product. The ferrule is a molded component, with a monolithic array of microholes that accepts a ribbonized array of cleaved fibers and directs them toward individual aspheric total internal reflection (TIR) lenses. Each TIR lens redirects the light path approximately 90º to the fiber axis. The lenses do not transmit light through the lens, rather it reflects internally due to the index difference between the ferrule polymer and air. When used with a transmit module, each connector lens converts collimated light into converging light with an acceptance angle less than that of the

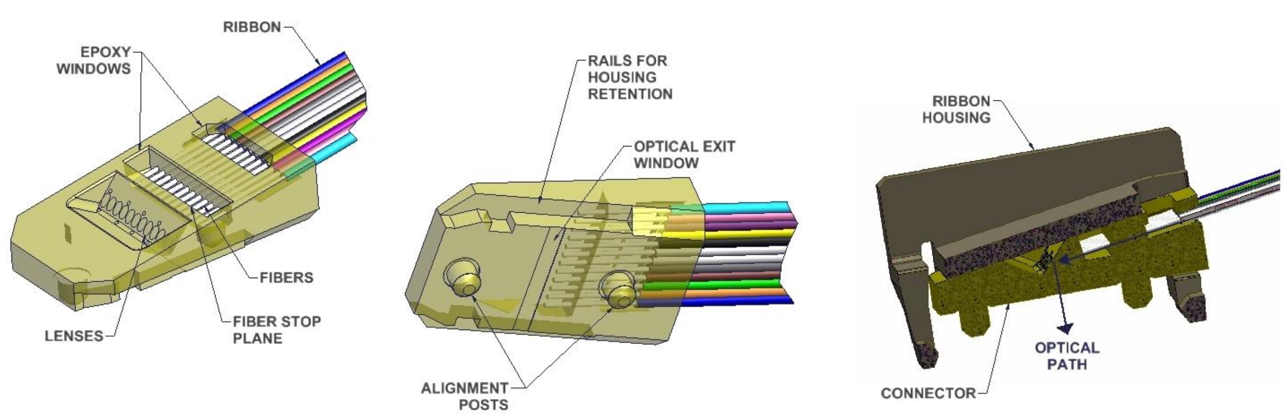

Figure 2: Connector Ferrule and Housing

fiber and beam waist smaller than the fiber core diameter. When used with a receive module, each lens converts diverging light from the fiber into nearly collimated light emitting from the bottom of the connector. The number of components necessary to manufacture various cable assemblies is minimized by the inherent bidirectional nature of the connector. Any jumper can be used with either a transmit or receive module, thereby lowering the total solution cost.

The exit window of the ferrule, located on the bottom surface between the alignment posts, is a narrow optical window through which the light beams transmit into and out of the connector. It is recessed from the mating plane to protect the window from damage.

The connector is attached to the miniature optical module through the Module Optical Interface (MOI) which is aligned and permanently attached to the module transmitter or detector array allowing for passive alignment of the connector. A secondary optic is embedded in the MOI to relay light through the system. In a transmit configuration, the output from each transmitter is collimated by the MOI so that it is focused by the connector TIR optic for coupling into a multimode fiber. In a receive configuration the nearly collimated output from the ferrule is focused by the secondary optic onto the detector (see Figure 3).

The microholes that capture and position the optical fibers are aligned to both the lens axis as well as the alignment posts located on the bottom of the part, so that the fibers are repeatable and reliably located to the device connection. The smooth wall located in front of the microholes acts as a stop plane for the fiber array, which guarantees that the fibers are always positioned correctly at the focal point of the lenses. The two openings towards the rear of the ferrule are for index-matching epoxy to securely bond the fiber array in place. By using an epoxy that matches the index of the polymer to the fiber, back-reflections from the fibers are minimized and effects of the fiber endfaces are eliminated. Since both the location and dimension of each microhole is controlled precisely, the fibers are always positioned at the optimal launch and receive location for the lens to perform correctly.

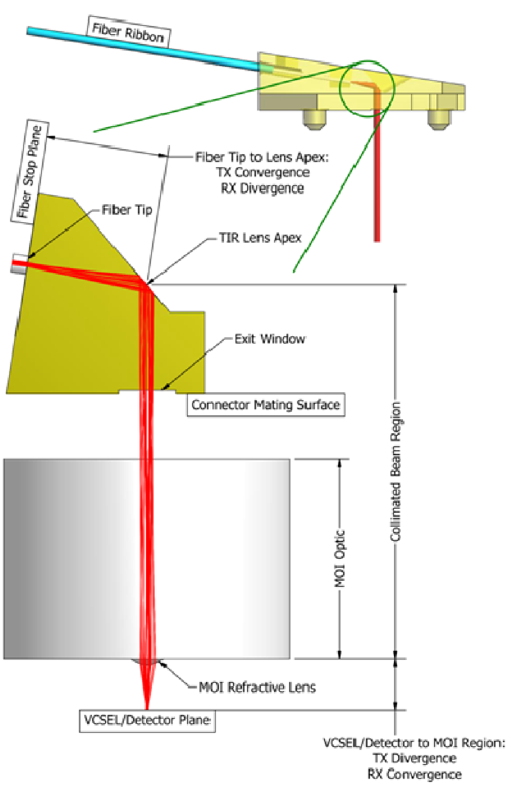

Figure 3: Ray Trace Schematic

A connector housing has been designed to protect the lenses, while providing a reliable, consistent and repeatable, mating interface to the MOI. The connector housing snaps directly onto the ferrule and covers the lens array face. The housing has latches that hold the connector to the MOI. The housing is retained on the connector using the rails that are located along the bottom of the connector, adjacent to the alignment posts. Once the housing has been snapped on to the connector, it provides gross alignment to the MOI and holds the connector in place. Tolerances have been designed into the housing and connector rails, such that the ferrule is allowed float laterally, while maintaining vertical position after mating to the MOI. This float permits the precision alignment posts and MOI alignment holes to control the optical path alignment without over-constraining the connection.

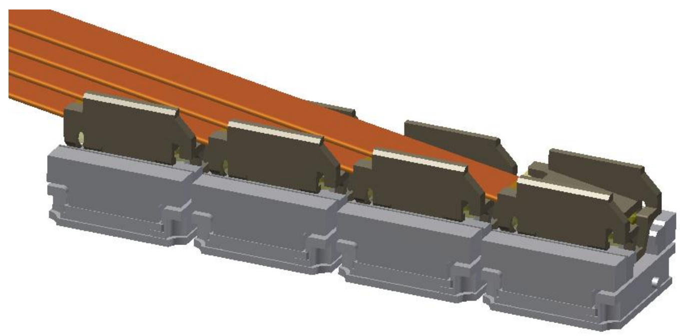

Figure 4: Stacked Ribbon High Density Transceivers

Several different connector housing designs have been developed to support various fiber cable connection configurations. The ribbon housing option, as shown in Figure 4, is available for connectors that using standard ribbon fibers from a variety of cable manufacturers. A set of stacked ribbons with staggered connector terminations maximized transceiver density while minimizing the footprint on the line card. The ribbon housing options cradles, routes and protects the ribbons toward the card-edge.

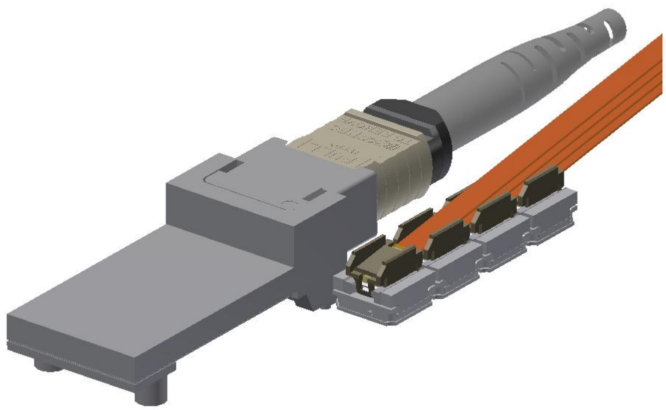

Figure 5: Single Traditional Transceiver vs. Multiple High Density Stacked Ribbon Transceivers

For applications that require enhanced non-preferential bend cable routing and improved fiber mechanical protection, a round jacketed cable housing that provides fiber strain relief has also been developed. It performs the same latching and sealing functions as the ribbon housing, while also crimping directly to the fiber jacket to provide tension relief and improved mechanical cable performance, as shown in Figure 6. This option facilitates the most flexibility for transceiver location on the line card.

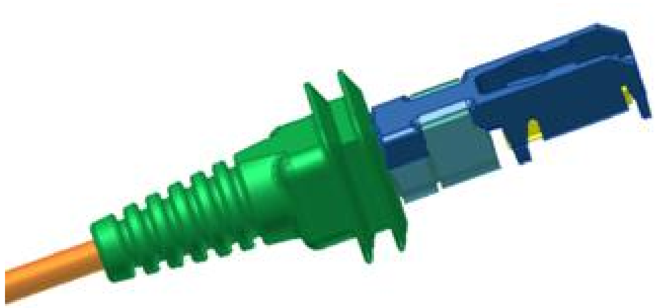

Figure 6: Module Connector for Jacketed Optical Cable

3. Assembly and Testing

In order to reduce the costs associated with standard multi-fiber connectors; this new connector design completely eliminates the need for connector polishing and traditional termination procedures. The following is a summary of the assembly and testing procedures.

When using standard multimode ribbon fiber, the ribbon fiber is stripped and subsequently cleaved 2.75 mm beyond the end of the ribbon matrix. While traditional mechanical cleavers can be used, use of a laser cleaving process has been implemented and shown significant benefits. Laser cleaving can be implemented easily in high volume, and reduces the processing time considerably. Laser cleaving eliminates the possibility of fiber cracking or chipping, and generates a slightly rounded fiber endface, without affecting the performance of the fiber. In addition, laser cleaving generates a highly controlled cleave length. As compared to the flat fiber tips generated with a mechanical cleave, the rounded fiber tips reduce the amount of debris generated during fiber insertion through the ferrule's microholes.

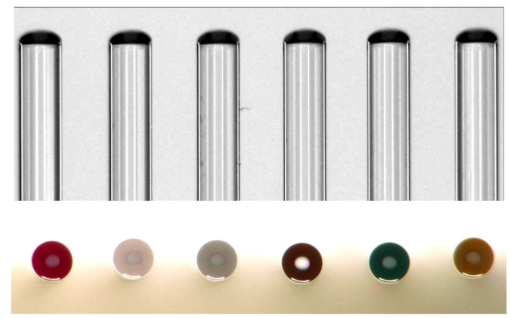

Figure 8: Image of Laser Cleaved Fiber Profile and Endface

Figure 7 shows the endface scan of a typical laser cleaved fiber. The horizontal profile through the center of the fiber is shown in Figure 8, and the improved fiber radius is visible. The laser cleaving process is capable of consistent and coplanar cleave, which leads to consistent light launch conditions across the lens array during corrector operation. After laser or mechanical cleaving, the cleaved fiber array is inserted into the ferrule microholes. A visible or UV light-curable index matched epoxy is then injected into both epoxy openings, and the fiber is pushed into its final resting place against the stop plane. Applying the epoxy first ensures that the index-matching epoxy coats the fiber endfaces and eliminates air pockets between the fibers and the stop plane.

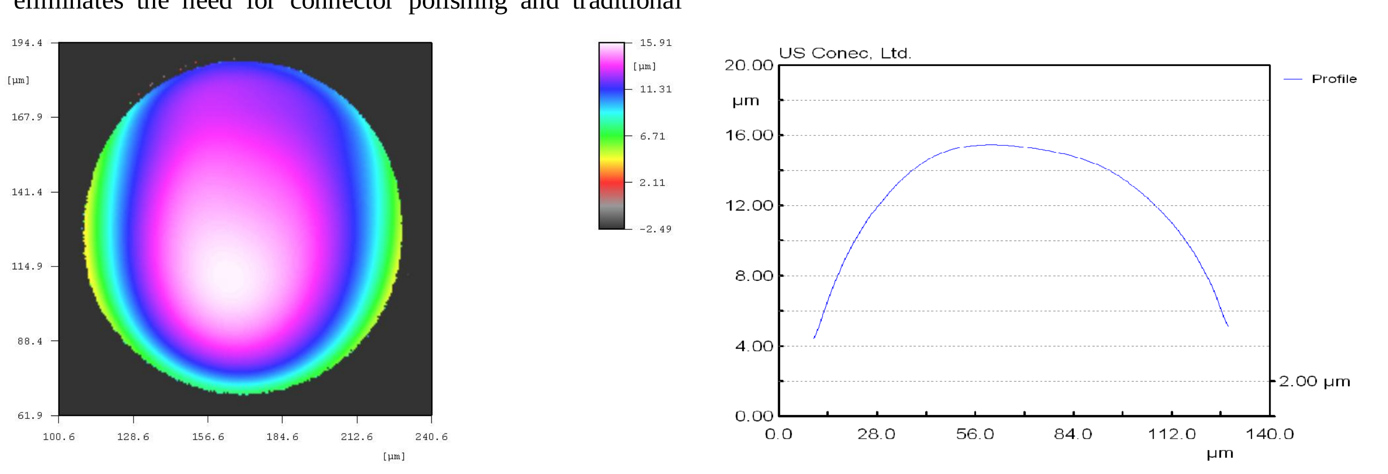

Figure 7: Endface Topology of Laser Cleaved Fibers

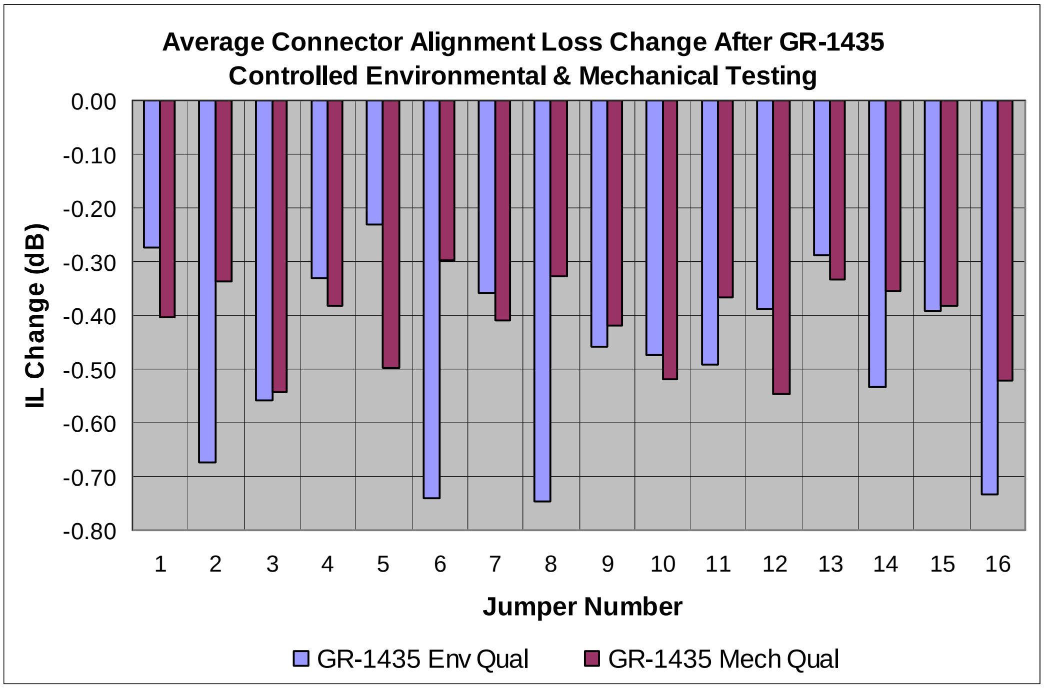

Figure 9: Average Connector Values for Both Environmental and Mechanical Testing

The assembly is then cured using an appropriate UV or visible light source, followed by installation of the connector housing. The entire cleave, termination, and cure process can easily be completed in approximately one minute, greatly reducing the time involved in standard fiber termination and polishing.

The connector is tested in a manner similar to standard fiber connector testing; conventional back reflection and insertion loss test equipment is used to characterize the connector performance. Unlike standard multifiber connectors however, this new photonic turn connector system is designed to mate to a transceiver module only rather than to another connector. Therefore, specific testing protocols and benchmarks have been established that correlate to the final predictive behavior of the connector when mated to the transceiver.

Final cable assembly evaluation consists of three simple functional tests to verify performance. First, the quality of the interface from the cleaved fiber endface to the ferrule stop plane is verified by inspecting this region carefully for backreflections. By terminating the exit window of the ferrule with an index matched fluid or elastomer, any return loss peaks can be assumed to occur at the fiber to stop plane interface. While the connector has an exposed air to plastic interface at the exit window under normal operating conditions, eliminating this interface reflection during back reflection testing allows for any air pockets in the light path or delamination of epoxy from the fiber stop window to be easily detected. Second, the total amount of light that is successfully turned by the TIR lens towards the bottom of the connector is tested by placing the ferrule's optical exit window in front of an insertion loss test system detector while launching light into the fiber terminated end of the connector. This "throughput loss" test would include any losses from the connector on the other end of the cable assembly, which is typically an MT based multifiber connector. Lastly, the test system is then referenced, so that the photonic turn connector performance can be tested independent of the impact of the MT connection. Alignment of the beams is evaluated with an aperture plate that consists of two alignment holes and a series of twelve precise apertures centered between the two alignment holes. The aperture plate is mounted onto the connector using the

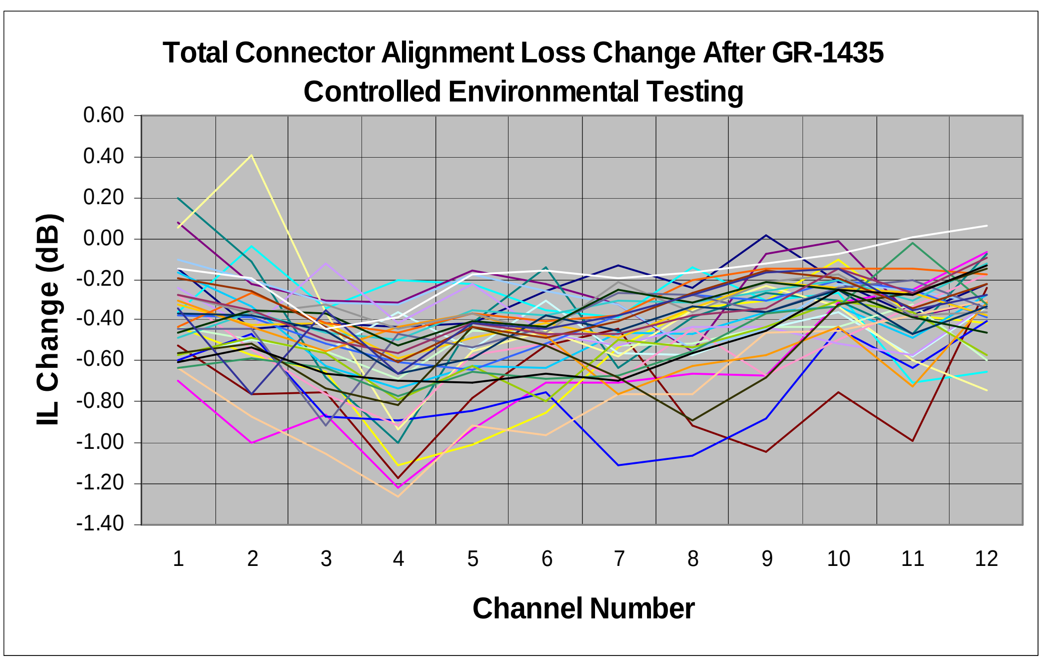

Figure 10: Controlled Environmental Testing Results

matched alignment posts and holes, which positions the twelve apertures directly below the ferrule's optical exit window, precisely where the light beams should exit. The size of the apertures has been designed to deliberately truncate the light beam to increase the sensitivity of the test. This "alignment loss" test with the aperture plate is used to identify potential anomalies, including debris in the light path, true position of the fiber array relative to the lens array, lens shape, true position of the alignment posts relative to the lens array, and any debris or damage on the ferrule lenses. The alignment loss correlates to the link performance but is not indicative of the actual insertion loss between the connector and transceiver. Correlation between the alignment loss values and the final connector/module performance has been established and will be used by cable assembly manufacturers and equipment makers. Finally, the throughput loss and alignment loss can be summed to generate a final benchmark value of the entire fiber optic cable assembly, referred to as the "total loss" of the connector.

4. Results

The connector system has gone through numerous performance evaluations based on industry standards, such as Telcordia GR-1435-CORE Issue 2 controlled environment. The testing methodology must be changed slightly from traditional fiber optic connectors due to the fact that this particular system was not designed for connector to connector applications. The connector has passed a close approximation of the GR-1435 controlled environment test procedure, as well as additional environmental testing, such as the GR-1435 uncontrolled environment thermal aging test and a thermal shock test involving five cycles from 60ºC/95%RH to -40ºC with one minute dwells. Figures 9 and 10 are a summary of environmental and mechanical qualification data. The average connector alignment loss change after environmental and mechanical testing is shown on the left and the total alignment loss change for each connector after environmental testing is shown on the right. All data presented is the change in alignment loss after the complete series of tests for either environmental or mechanical.

5. Summary

In order to meet the requirement for lower overall cost, higher density I/O interconnects, miniature embedded parallel optic modules are being designed into system equipment. These modules mounted mid-board enable usage of passive high density optical connectors at the card edge. Optical jumpers provide the interface between the mid-board mounted module and the high density connector on the card edge. These optical jumpers are terminated on one end with the high density card edge connector and a module interface connector on the other. It is of importance to the feasibility of this next generation solution that the module interface connector exhibit features and performance to facilitate and compliment the value of the entire parallel optic solution. A new multi-fiber, top attached optical connector that incorporates TIR lenses has been developed as an interface into these new modules. Connector components have been minimized and the termination process simplified resulting in a low cost interconnect. Innovative design features enable the connector solution to meet the application's mechanical and optical performance requirements.

Expanding applications for this photonic turn connector may include connector to connector use in all optical backplanes or low profile front card edge connections. Next generation designs may include multi-row fiber ferrules to facilitate ultra-high density interconnects and transceivers. While the connector has passed controlled environment testing, future applications may require uncontrolled environment testing. New applications for this connector will undoubtedly drive new testing methodologies and procedures.

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