Next generation, high density, low cost, multimode optical backplane interconnect

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ABSTRACT

This paper describes the development, termination and performance of next generation optical backplane interconnect components. This low cost, dense optical interconnect technology combined with recent advances in 10G/lane and beyond, miniature imbedded Tx/Rx devices is driving bandwidth density to unprecedented levels.

A monolithic, multi-fiber ferule with integrated collimating lenses was designed with the same overall footprint as a traditional MT-type, multi-fiber rectangular ferrule. The new optical ferrule was designed with precision micro holes for alignment to the lens array allowing for incorporation of multiple rows of fibers into single ferrule unit. The design supports up to four rows with as many as 16 fibers per row for a total potential lane count of up to 64 within in a single ferrule.

A low cost termination is achieved by securing precision-cleaved fiber arrays into the rear of the ferrule with a quick-cure, index matched, UV light activated epoxy. The elimination of a polished fiber array greatly reduces the cost and complexity associated with physical contact based multi-fiber interconnects. With the same overall footprint as an MT ferrule, the new, lens-based ferrule can be used in conjunction with MPO and other MT based connectors. However, by eliminating the need for physical contact via the use of collimated light beams, the connection force per ferrule required is greatly reduced, paving the way for high ferrule counts and mass insertion of dense optical backplanes.

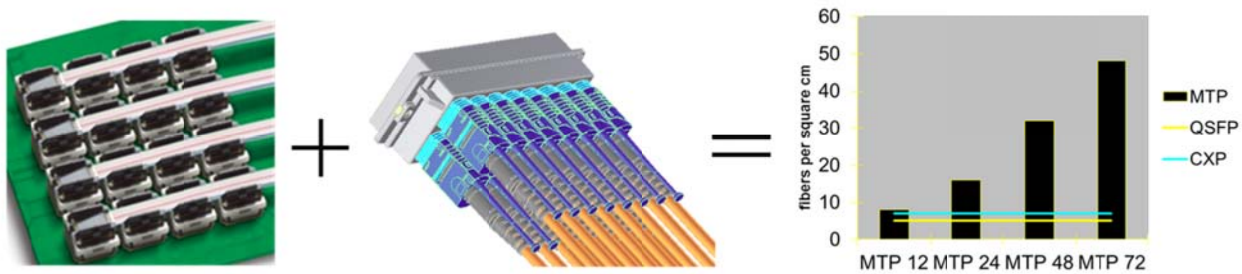
Mated pairs of the new ferrule were tested for insertion loss with the substitution method and all channels were <1dB.

Keywords: Multi-fiber, MT, expanded beam, backplane, connector, ferrule, MPO, lens, parallel

1. Background: Embedded Parallel Optic Active Devices + High Fiber Count Interconnects

Bandwidth demand, multi-core processor computing capacity, cost, density, and power requirements are driving optics into shorter and shorter distance chip to chip communication links. Backplanes for HPC, server, switching and routing equipment applications are migrating from electrical to optical signal transmission. VCSEL speeds of 10G are now common with standardization activity for 25G VCSEL links already in process.

Today, low-cost miniature 850 um VCSEL parallel optic embedded modules are available and being installed into many equipment solutions for a variety of computing and networking applications. These next-generation, parallel optic modules have been released in footprints as low as 8.2mm X 7.8m [1]. Embedding the optical device in the center of the card offers many advantages over traditional card edge mounted pluggable or AOC devices: First, the bandwidth density obtained by aggregating multiple embedded optics at the card edge via dense multi-channel optical interconnects eclipses the density obtained by state of the art edge mounted optics. The chart in figure 1 illustrates the lane density as a function of equipment bulkhead area when embedded optics are combined with the dense MTP® brand MPO connector format. In addition, by aggregating the Tx/Rx modules close to the ASIC, the high speed transmission over copper PCB traces is minimized, signal integrity is enhanced, and the path to VCSEL transmission >10Gb/s is greatly simplified. Furthermore, heat dissipation becomes more easily managed with laser devices evenly dispersed throughout the card as opposed to aggregated at the edge of the card.



Example miniature embedded Tx/Rx device: Avago MicroPod®

Example dense card edge connector Package: MTP® Brand MPO

Channel density comparison between high fiber count MTP connectors and edge mounted CXP /QSFP parallel optics

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

Architectures which utilize multiple embedded parallel optic modules facilitate the need for dense optical interconnect technology at the card edge demarcation point. Currently, this parallel optic demarcation occurs via multi-fiber bulkhead feed through or blind-mateable connectors which utilize traditional MT ferrules for the precision alignment.

These traditional multi-fiber ferrules are designed to support physical contact of the fiber tips and low losses for structured cabling and longer distance applications. The following sections will provide an overview of traditional multi-fiber ferrules, expanded beam connectors, the integration of lens arrays into the new, monolithic ferrule design in addition to experimental results for the new interconnect and future activities.

2. Traditional Monolithic Multi-Fiber Ferrules:

Multi-fiber ferrules commonly referred to as the “MT ferrule” or “rectangular ferrule” were originally developed by NTT Laboratories for use in subscriber network lines in an outside plant environment. The ferrules were initially molded out of a thermosetting epoxy material but migrated to a more environmentally stable thermoplastic material as precision molding technologies advanced. Due to the need for dimensional stability in the extreme operating environment, the ferrules are molded with a very high content of glass filler. In fact, the glass filler content can range from 60-80% by mass of the ferrule. Figure 2 highlights the glass filler appearance of a polished MT ferrule endface.

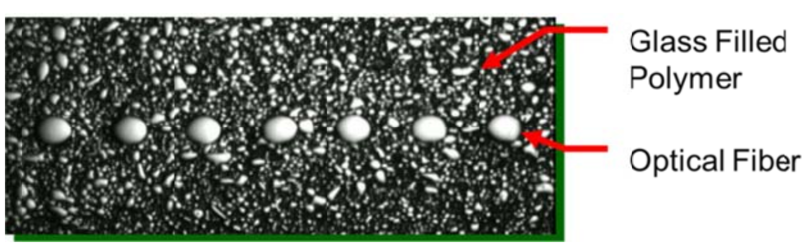


Figure 2: Traditional MT Ferrule endface appearance

Today’s most common applications for multi-fiber connectors are structured cabling and external equipment interface for data centers and central offices which require very low insertion and return losses. Figure 3 shows insertion loss results for a random intermate of 24 fiber, low-loss, multi-mode MT Elite® ferrule.

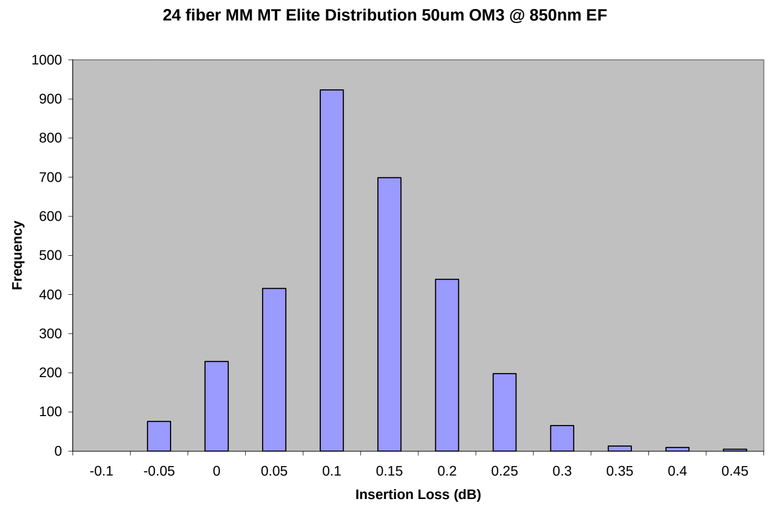


Figure 3: Empirical data: 24F, Low-Loss MPO random intermate distribution @ 850nm; 50um, Encircled Flux launch conditions per IEC 61280-4-1

In order to obtain a low, stable, insertion loss, the glass fiber tip mated pairs must come into physical contact with each other. This physical contact requires very tightly controlled termination, polishing and metrology procedures which work to drive 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 4 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, and fiber tip quality or cleanliness.

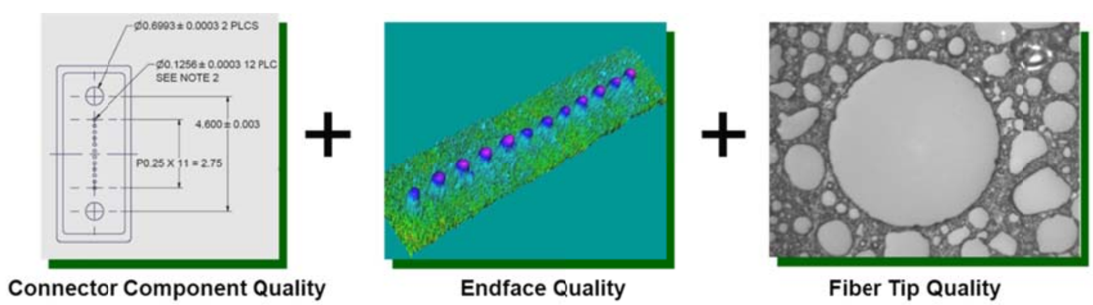


Figure 4: Factors impacting performance of traditional MT physical contact ferrules

For interconnect densities beyond 24F, obtaining and maintaining physical contact of the fiber tips becomes unobtainable with state of the art polishing and termination technology. As a result, the mated fiber tip interface of high fiber count ferrules (>24 fiber) becomes unstable which can result in optical interference and amplifying return loss values higher than a simple unmated connector will generate (i.e., unstable RL values can oscillate and peak at values below 10dB.)

While traditional, physical contact MT ferrules are suitable for demanding low-loss, high performance applications, they are not optimized for short reach, cost sensitive optical backplane applications. In addition, because the bandwidth densities needed for emerging high end optical backplanes require more than 24 channels, fiber physical contact is not a viable option. This has resulted in focused US Conec development activity on next generation optical backplane interconnects described in the following sections.

3. Non-Physical Contact Connectors: Expanded Beam

Expanded beam connectors are a subset of free-space optical interconnects. The "space" between the connectors must have a different index from the lens media for refraction to occur. Because of this fundamental rule, expanded beam connectors do not touch within the lens aperture. Use of expanded beam technology eliminates the need for fiber tip physical contact which ultimately reduces the overall cost of multi-fiber optical cable assembly manufacturing.

As shown in Figure 5, light emitted by the fiber diverges from the fiber tip through a homogenous optical medial to the refractive boundary of a lens. Over this distance, the beam diverges based on the NA of the fiber. The lens has an aspheric prescription to account for various modes of the beam. The resultant beam has a characteristic beam waist at the mating plane between the connectors. Beyond the mating plane, the beam begins to diverge in the far field region of propagation, which is collected by the second optic where the beam converges to the receiving fiber tip.

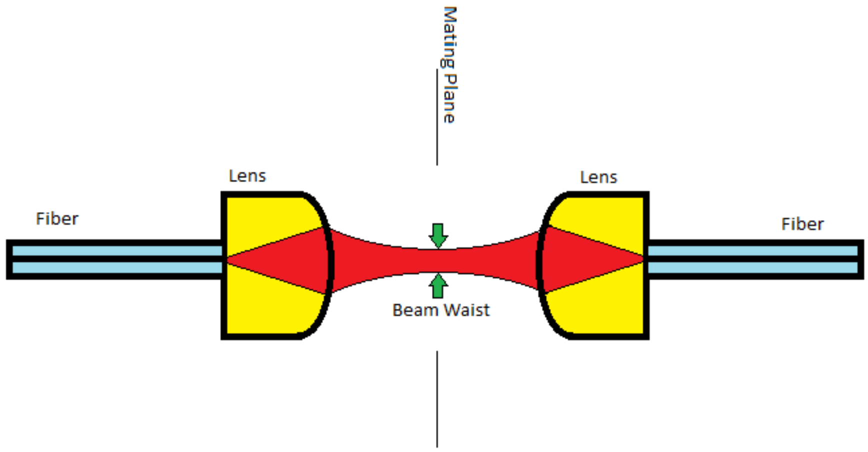


Figure 5: Expanded Beam Connectors

One of the advantages of an expanded beam connection is the lower sensitivity to debris as compared to a traditional fiber to fiber interface. Flux is the measure of radiation through an area for a specified amount of time[9]. In optics, the base units for flux are Watts/meter2. A 50µm diameter core fiber has an area of 2 x 103 µm2, while an expanded beam described here has a diameter of 180um with a corresponding 2.5 x 104 µm2 area. Consider a 16µm diameter dust particle that has landed on the tip of a connector with a uniform power distribution across the emission area. This dust particle has a cross-sectional area of 2 x 102 µm2. For a traditional MT ferrule connector, this would account for blocking 10% of the light transmission. The effect of the blocked light would be nearly 0.5dB of insertion loss between the mated MT pair. For an example expanded beam connector, the effect of the same particle reduces to 0.8% light blockage, corresponding 0.035dB.

Another key advantage of the expanded beam connector is the reduced alignment precision required along the fiber axis (Z axis). Perfect collimation of the emitted beam eliminates all sensitivity of the lens-to-lens distance on insertion loss. As shown in Figure 6, the spot size would remain the same regardless of the z-axis gap.

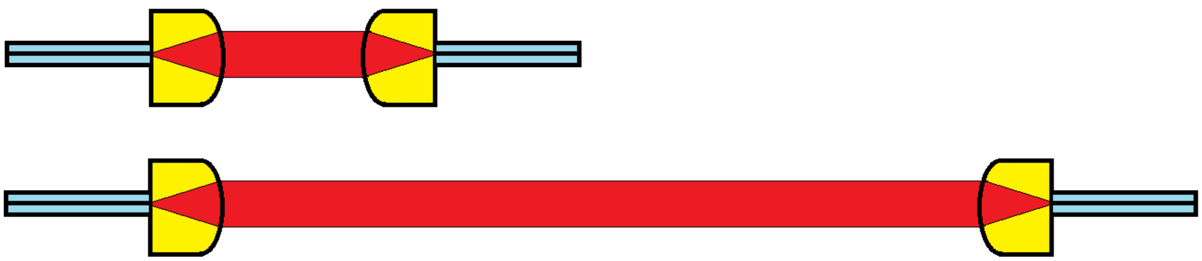


Figure 6: Insensitivity to Z-axis gap for the Ideally Collimated Lensed Connector

In reality, the emitted beam is not perfectly collimated, but has a far field NA of 0.0060 for the first millimeter of travel, based on RMS radius modeling of the spot size at 0 and 1mm. Beyond 1mm, the NA continues to increase to a limit of 0.026, which is almost an order of magnitude less than current multi-mode fibers. According to Figure 7, the coupling efficiency is relatively unaffected by the lens-to-lens air gap over the first millimeter. After 1.5mm, the sensitivity increases, but shows that even up to 2mm the change in insertion loss is just above the noise level of most commercial test systems.

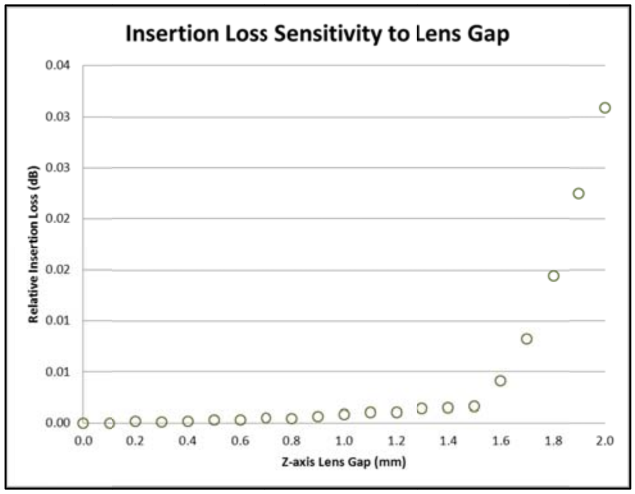


Figure 7: Connector Sensitivity

Combining the relaxed Z-axis alignment precision required for collimated, expanded beam connectors with multi-fiber connectors, the precision and costs associated with maintaining physical contact across one or more fiber arrays of connectors is greatly reduced.

4. Initial Integration of collimating lenses in the PRIZM® LightTurn®

US Conec has previously developed and released a monolithic, collimating multi-fiber ferrule designed as an active device interface that facilitates perpendicular mating to the printed circuit board. This interconnect, known as the PRIZM® LightTurn® connector, provides passive alignment to the transceiver and incorporates novel retention features for multiple re-mattings. Precision alignment to the parallel optic device is accomplished by use of molded alignment posts within the ferrule and corresponding alignment holes at the transceiver interface. The PRIZM® LightTurn® ferrule is the first ever single molded component combining an array of precision micro holes with an array of collimating lenses.

The ferrule accepts cleaved fibers and utilizes a total internal reflection (TIR) lens design to turn the light 90º, eliminating the need for connector polishing. The ferrule has several major component features, as shown in Figure 8. The array of aspheric, asymmetric TIR lenses redirects the light path at approximately 90º to the fiber axis. The lens array provides for bi-directional light transmission, but functions differently depending on the direction. The light path is collimated when exiting the ferrule. The same ferrule lens array, upon receiving the conditioned collimated light from the parallel optic module, focuses the light onto the fiber tips. Use of collimated light entering and exiting the ferrule reduces the alignment tolerance requirements and the effects of debris on the optical exit window. The micro holes 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 micro holes 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. An optically smooth exit window is molded into the bottom of the ferrule between the alignment posts to allow the light to enter and exit the ferrule with minimal distortion. The two openings towards the rear of the ferrule are for index-matching epoxy to securely bond the fiber array in place. The connector housing has been designed to protect the lenses and provide a reliable, consistent, repeatable, mating interface to the optical module. It snaps directly onto the ferrule and covers the lens array face, while also providing latches that hold the connector to the mating surface. The housing provides gross alignment and holds the connector in place, while allowing the ferrule to float laterally. This float permits the precision alignment posts and transceiver alignment holes to control the optical path alignment without over-constraining the connection.

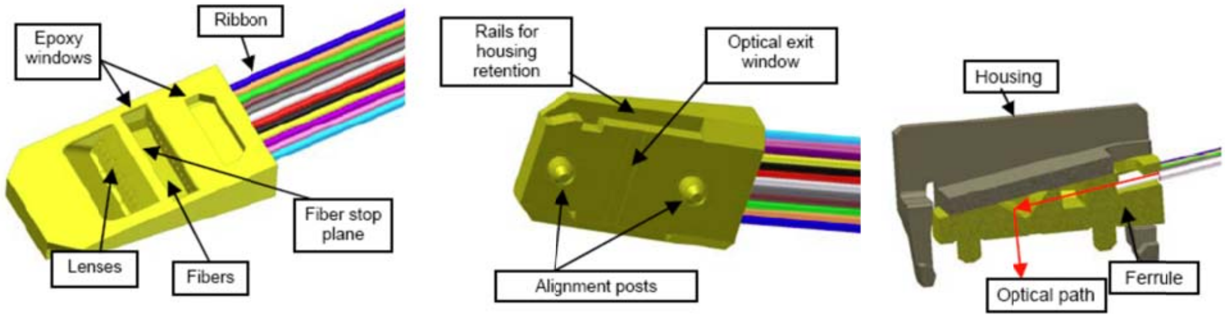


Figure 8: Previous Monolithic Collimating Array Ferrule with Micro holes

To reduce the cost associated with standard multi-fiber connectors, this new connector design completely eliminates the need for connector polishing and traditional heat-cure epoxies. The following is a summary of the assembly and testing procedures:

Standard multimode 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 is recommended due to the resulting rounded fiber tips and clean endface along with a highly controlled cleave length. As compared to the fiber tips generated with a mechanical cleave, the rounded fiber tips reduce the amount of debris generated during fiber insertion. The cleaved fiber array is then inserted into the ferrule micro holes. A visible or UV light-curable index matched epoxy is then inserted into both epoxy openings, and the fiber is pushed into its final resting place against the stop plane. Inserting the epoxy first ensures that the index-matching epoxy coats the fiber endfaces and eliminates air pockets between the fibers and the stop plane. The assembly is then cured using a 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.

5. US Conec PRIZM MT™ Design Overview

US Conec has expanded on the success of the PRIZM® LightTurn® collimating array to Tx/Rx interconnect with development of the PRIZM MT™, fiber to fiber interconnect ferrule for card-edge applications.

The PRIZM MT™ was designed with the same low-cost, no polish termination methodology developed for the PRIZM® LightTurn® connector. By utilizing a similar dual window design, a cleave-only fiber array is aligned to an optical stop plane and bonded into the ferrule via an index matched light cure or thermal cure epoxy. Utilization of micro-holes for precision alignment allow for scaling to multiple rows in the same monolithic ferrule in a manner similar to multi-row traditional MT ferrules.

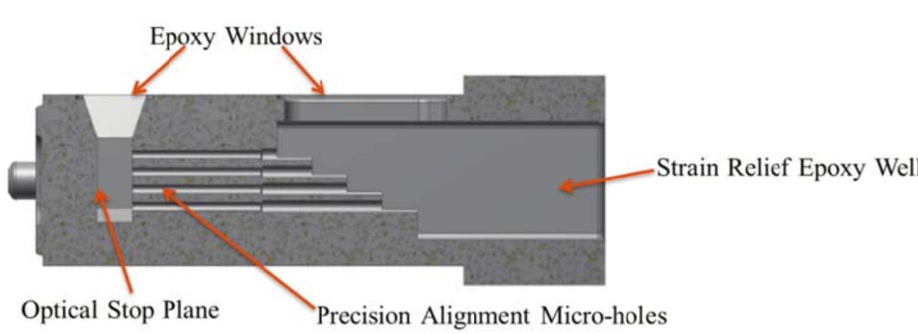


Figure 9: PRIZM MT™ cross section

The PRIZM MT™ was designed with the same outer length, width, height and shoulder footprint as a traditional, physical contact MT ferrule. This aspect of the ferrule design allows for use with existing MT based connector solutions like the MTP® brand MPO connector or other ganged MT ferrule based connector solutions. Similarly, any future optical backplane interconnect architectures using PRIZM MT® technology have the versatility to switch to tradition physical contact MT ferrules for applications requiring lower insertion losses, longer reaches and reduced back reflections.

The PRIZM MT™ ferrule was designed to be used with or without traditional MT guidepins. With two through holes in the ferrule, traditional alignment guidepins and a subsequent guide pin holder/keeper can be used for existing connector designs. However, by capitalizing on the molded-in, precision alignment post technology established with the PRIZM® LightTurn® ferrule, a hermaphroditic design with a single precision alignment post and precision alignment hole eliminate the need for the guide pin sub-assembly. Figure X illustrates the molded alignment post design of the PRIZM MT™ compared to the MT ferrule which contains two guide holes and two separate guide pins.

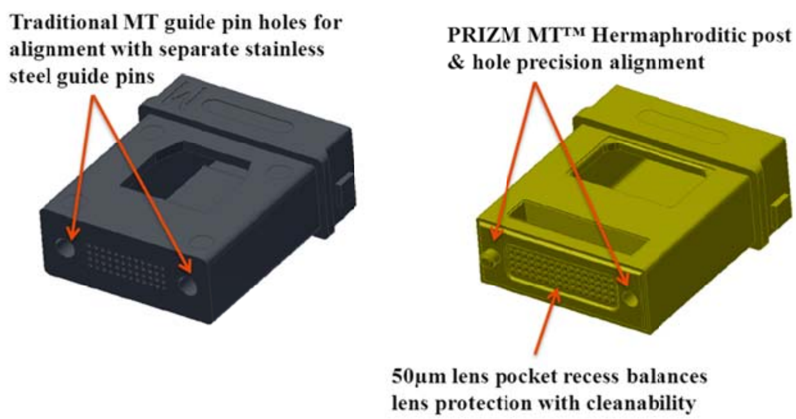


Figure 10: PRIZM MT™ Designed with same external footprint as traditional MT ferrule

Furthermore, the PRIZM MT™ was designed with an alternative interface footprint which will support up to 16 rows of fibers. By increasing the alignment hole/pin pitch to 5.2mm and changing the nominal alignment post size to 550 microns, four additional fibers with a 250 micron pitch can be added to the traditional maximum 12 fiber row footprint associated with MT ferrules.

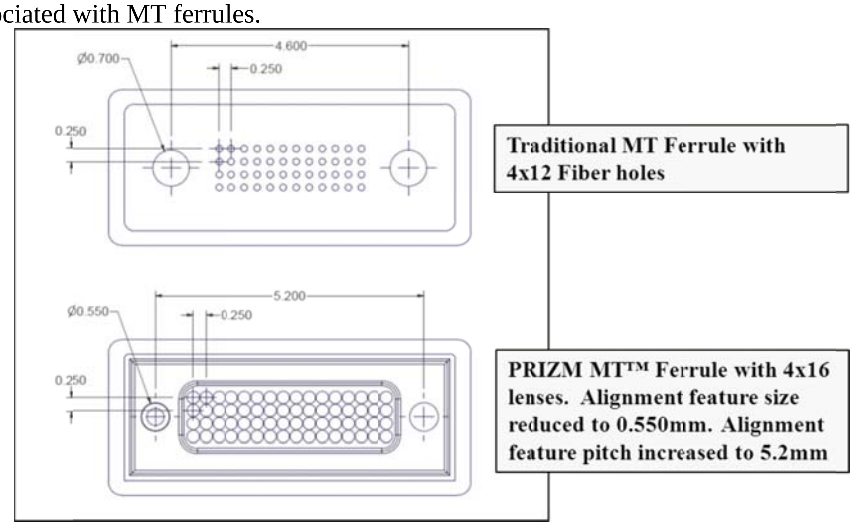


Figure 11: PRIZM MT™ endface expandable to rows of 16

As described in the section on expanded beam technology, the impact of contamination on the lensed endface is much less severe when compared to traditional fiber connectors. However, minimizing contamination and providing the ability to clean the connector endface when it is contaminated have been considered with the ferrule design. The PRIZM MT® ferrule endface was designed to protect the optical transmission area by sealing off the lens array features on the mated ferrule pair. In addition, the lens array was only slightly recessed below the contact surface of the ferrule providing access to the lenses with an industry normal contact based field or factory cleaning tool.

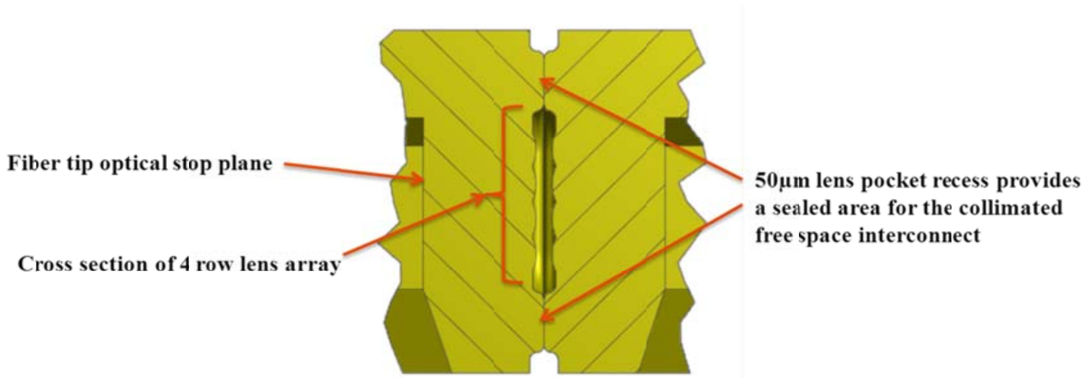


Figure 12: Cross-section of PRIZM MT™ mated pair

The features of the PRIZM MT™ offer an optimized interconnect solution for high density, low-cost, MM, VCSEL based card to card or optical backplane interconnect applications.

6. Empirical results

The PRIZM MT™ ferrule is tested in a manner similar to standard fiber connector testing which uses conventional return loss and insertion loss test equipment. Unlike standard multi-fiber connectors however, this new lens ferrule is designed to mate to another lens ferrule rather than to a standard ferrule with fiber to fiber contact. Therefore, unique testing procedures are necessary to utilize traditional fiber based test equipment.

Final cable assembly evaluation consists of two functional tests to verify performance. First, the insertion loss is measured as shown in Figure 13 starting with an encircled flux (EF) compliant standard MT launch lead per IEC 61280-4-1. A hybrid jumper with a standard MT ferrule on one end and a PRIZM MT™ on the other end is coupled to the source while a reference power level is measured from the PRIZM MT™. Next, a jumper with a PRIZM MT™ ferrule on each end is coupled to the previously referenced PRIZM MT™ ferrule. The opposite end is placed in front of the detector and the insertion loss is measured. The measured insertion loss represents the light lost in coupling light from the referenced lens ferrule into the device under test plus the loss within the lens ferrule adjacent to the detector.

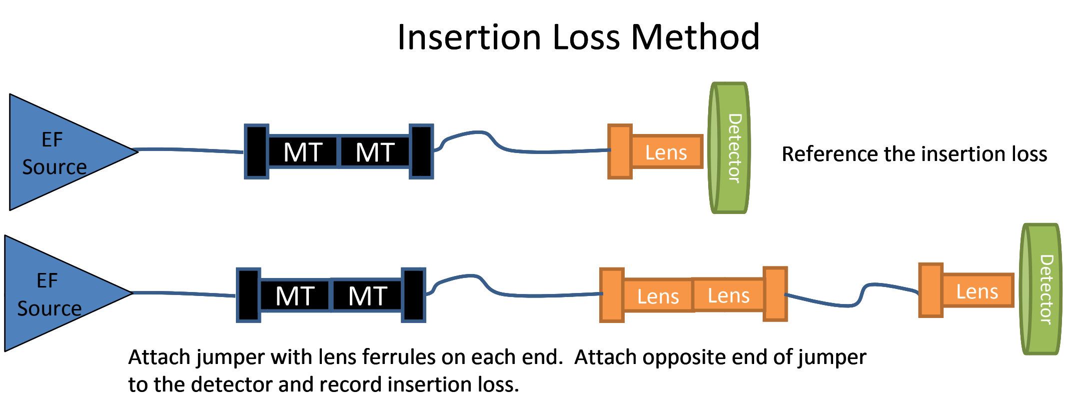


Figure 13 Insertion Loss Method

Second, the quality of the area between the cleaved fiber endface and the ferrule stop plane is determined by measuring the return loss of the ferrule. Unlike traditional, physical contact MT ferrules, the return loss at the lens to lens expanded beam interface is simply determined by the physical geometry of the lens. This gives the PRIZM MT™ a significant advantage over multi-row, high fiber count MT ferrules where reliable physical contact is unachievable. The value of the return loss measurement for the completed assembly is simply to verify that the termination was properly completed and that the fiber tips were correctly coupled to the stop plane within the ferrule. If the area between the fiber tips and stop plane contains voids or debris, poor return loss values of <20dB will be observed.

The insertion loss testing consisted of an intermate study using 22 randomly inter-mated lensed ferrule pairs. The results of the insertion loss testing are shown in Figure 14.

The return loss results for each of the 240 mated fiber pairs were between 22 and 25dB.

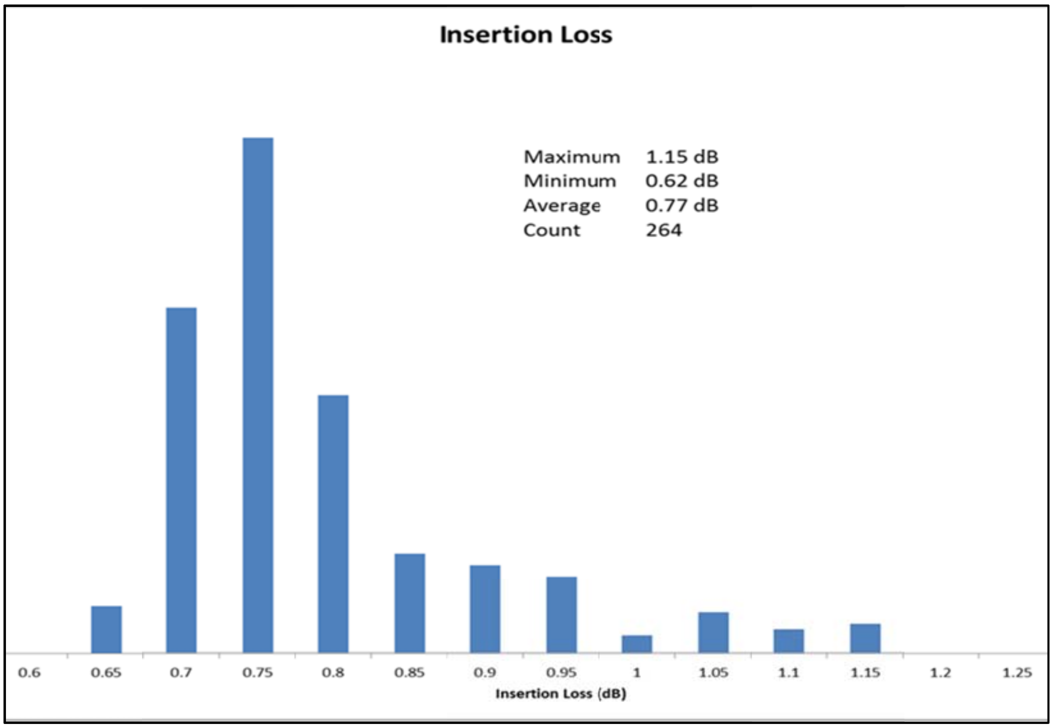


Figure 14: Insertion Loss results from random intermate testing of the PRIZM MT™ Ferrule

The low cost termination methodology combined with tolerant Z-axis alignment provide stable insertion loss and return loss performance for high fiber count, short reach, multimode applications.

7. Future Work

The next step for this interconnects technology is completion of industry standard environmental testing to ensure reliability in various operating environments. Successful testing already completed with the PRIZM® LightTurn® connector suggest that the PRIZM MT™ will be compatible with TIA 568 Commercial Building and Cabling applications as well as qualification regimens established by Telcordia for public network environments. Testing compatibility of the ferrule with new and existing MT ferrule based connector platforms will be completed in 2012.

Upon establishment of a successful industry optical backplane interconnect, US Conec will introduce this technology to IEC SC 86B to standardize the mechanical interface optical interface of the PRIZM MT™.

8. References

[1] Fields, Mitch., "Optical Interconnects for Chip-to-Chip Communications", ECOC 2010, Turin, Italy.

[2] Gurreri, M., Kevern, J., Kadar-Kallen, M., Castagna, L., Childers, D., Hughes, M., "Multi-Fiber, MT Ferrule Endface Fiber Tip Displacement Model for Physical Contact Interconnects", OFC 2007, Anaheim, CA.

[3] Fields, Mitch, "Transceivers and Optical Engines for Computer and Datacenter Interconnects," OFC/NFOEC 2010 Special Symposia,

[4] Shintaku, T., Nagase, R., Sugita, E., "Connection Mechanism of Physical-Contact Optical Fiber Connectors with Spherical Convex Polished Ends", Applied Optics, Vol. 30, No. 36, pp. 5260 – 5265, (Optical Society of America 1991).

[5] Deeg, E. W., "Effect of Elastic Properties of Ferrule Materials on Fiber-Optic Physical Contact (PC) Connection", AMP Journal of Technology, Vol. 1: 25-31, (1991).

[6] Deeg, E. W., "New Algorithms for Calculating Hertizian Stresses, Deformations, and Contact Zone Parameters", AMP Journal of Technology, Vol. 2, pp. 14-24, (1992).

[7] Reith, L. A., Grimado, P. B., and Brickel, "Effect of Ferrule-Endface Geometry on Connector Intermateability", in Technical Proceedings, NFOEC 1995, Vol. 4, (1995).

[8] Knecht, D., Luther, J., Pyatt, J., and Ugolini, A., "Recent Advances in MT Ferrule Processing and MTP Hardware Design", in Technical Proceedings, OFC, (Optical Society of America, 2005)

[9] Born, M., Wolf. E., Principles of Optics, 7th (expanded) ed., Cambridge University Press, United Kingdom, 1999