Single-Mode Expanded Beam MT Connector with Angled Lens Array for Improved Optical Performance

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Abstract *A single-mode 16 fiber expanded beam ferrule compatible with standard MT based connectors designed to meet data center optical link requirements is demonstrated. Optical performance including environmental exposure and durability testing is summarized, providing empirical confirmation of the optical design.*

Introduction

Hyperscale data center growth over the last decade has generated a need for longer reach fiber link solutions inside and between the larger data center buildings, requiring high density single-mode connections at data racks, switch faceplates and backplanes. These high density connections are typically difficult to access, require high levels of expertise for installation and are prone to debris induced link failures. The single-mode expanded beam MT ferrule described in this paper was developed to address this application.

Design

The low loss single-mode expanded beam ferrule is monolithic in design. Relying on proven design features used in millions of MT [1] and lensed MT ferrules [2] already implemented in the field, this ferrule utilizes guide holes and metal guide pins to align the mating ferrules, as is visible in Fig. 1. The guide pin pitch matches the pitch of 16 fiber MT ferrules currently in use today resulting in compatibility with existing connector components and accessories. Since the ferrule has the standard MT footprint, it can be used in MT based connector systems like MPO and MXC [3].

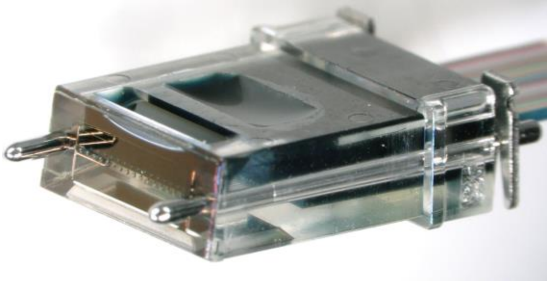

Fig. 1: Single-mode lensed MT ferrule

The configuration shown in this paper is one row of 16 channels, but the ferrule has been designed to be adaptable to smaller pitch fiber for up to 24 channels and multiple rows. Since the ferrule is compatible with the MXC connector interface, low spring forces can be used to mate the ferrules together. A spring force of 3 to 5 N complements high density ganged backplane applications. Since the ferrule is built on the existing MT and lensed MT history and technology, standardized termination processes and fiber preparations are utilized. The ferrule features a recessed lens cavity surrounded on all sides by the mating plane of the ferrule. This continuous mating perimeter provides protection for the lenses in the un-mated state and a barrier to the ingress of dust and debris when mated.

Theory

The lensed ferrule is designed to achieve ≤ 0.7 dB insertion loss and ≥ 55 dB return loss. As with most lensed ferrules, the tip of the fiber is inside the ferrule near the lens that collimates the expanded beam. As shown in Fig. 2, some notable characteristics of the design are a fiber cleaved at an angle, a thin layer of adhesive, an angled surface where light enters the ferrule material, and a lens surface that is tilted relative to the optical axis. Reflections are present at three interfaces: fiber/adhesive, adhesive/ferrule, and lens/air. Each of these are addressed to achieve a return loss greater than 55 dB.

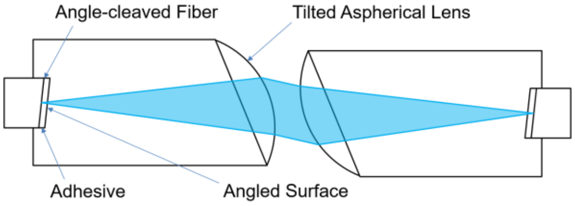

Fig. 2: Optical design schematic

The return losses for the fiber/adhesive and adhesive/lens interfaces are determined by evaluating the overlap integral [4] between the fiber mode and the tilted reflected mode. The tilt angle of the reflected mode is twice the angle of the interface. The fiber mode is calculated using the weakly guiding approximation [5]. The total reflected power, in the coherent case considered here, depends on the phase relation between the two reflections; the reported values assume the reflections add in phase, which is the worst-case scenario. Note that the calculations described above are for one fiber/adhesive/ferrule interface, one half of the mated pair, and do not include the reflection at the lens/air interface.

Since the refractive indices of the ferrule, adhesive, and fiber cannot all match exactly, an angle is needed on the fiber tip and at the entry surface of the ferrule. Using the technique above, the return loss is calculated as a function of fiber and entry angles as well as the index of the adhesive at the two surfaces. From Fig. 3, it is evident that both angles play a large role in determining ferrule return loss performance, therefore a fiber cleave angle of 7° and an entry angle of 6° were selected.

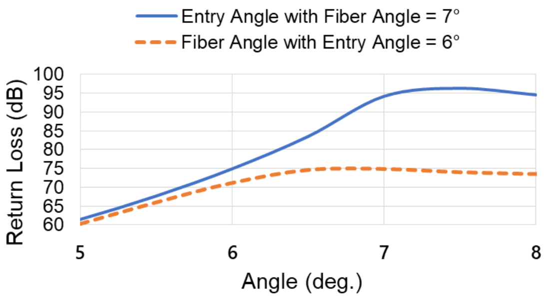

Fig. 3: Return Loss as a function of the entry angle or of the fiber angle, with adhesive refractive index = 1.55

As the data shown in Fig. 3 assumed a fixed refractive index for the adhesive, calculations were performed to ensure that adhesive index variation would not unduly impact ferrule performance. Figure 4 demonstrates that varying the adhesive refractive index from 1.5 to 1.6 does not degrade the return loss performance of the ferrule when used with the design selected above.

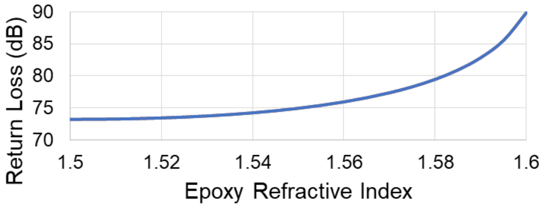

Fig. 4: Return loss as a function of adhesive refractive index assuming a fiber cleave angle of 7° and an entry angle of 6°.

In addition to the considerations presented above, the contribution of the lens/air interface has to be considered. As shown in Fig. 2, the lens surface is tilted relative to the optical axis, however this attribute alone is insufficient. To reduce the lens/air Fresnel reflection, an anti-reflection coating is added to the lens surface. Assuming a 0.3% reflectance, the return loss of the lens/air interface is 80 dB for the current design. In a hypothetical design with a non-tilted lens and the same size of collimated beam, the return loss of the lens surface is only 47 dB.

The expanded beam diameter is 60 µm, comparable to the core diameter of a multi-mode fiber. The choice of beam diameter is driven by several factors including the sensitivities to ferrule-to-ferrule offset and tilt shown in Fig. 5. The ferrule lens is twice the diameter of the beam to prevent any beam clipping.

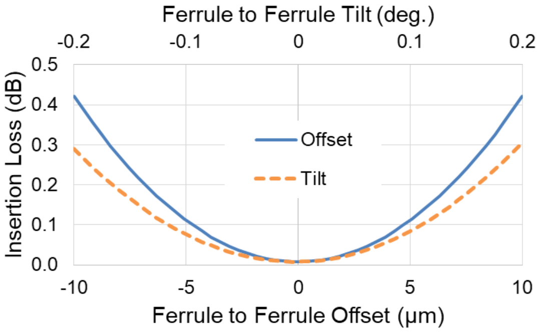

Fig. 5: Sensitivity of the insertion loss performance of a mated ferrule pair to ferrule-to-ferrule offset and tilt.

Optical modeling software was used to calculate the coupling between a pair of ferrules with the fiber and adhesive parameters discussed above. As the lensed ferrule is predicated on popular previous MT and lensed MT ferrule designs, achievable molding and termination tolerances are well understood. Tolerances on the fiber positions and angles are comparable to those of a single-mode MT ferrule; the connector is more tolerant of lateral misalignment and less tolerant of angular misalignment (see Fig. 5). A Monte Carlo simulation was run to estimate the insertion loss performance. Figure 6 shows the distribution of insertion loss; 97% of the insertion losses are under 0.7dB.

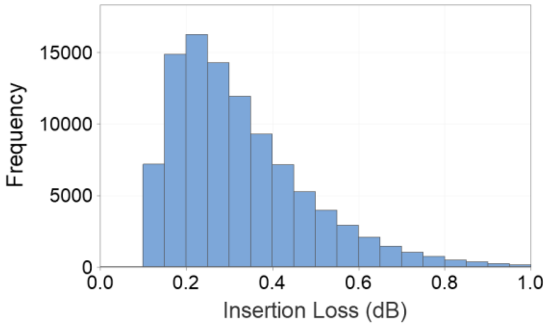

Fig. 6: Monte Carlo simulation of the ferrule insertion loss with 100,000 points, assuming molding and termination tolerances similar to standard ferrules.

Performance

The single-mode expanded beam ferrule is terminated using traditional MT and expanded beam MT termination techniques. Standard 16-fiber ribbon arrays are stripped and then laser cleaved to create the proper optical endface prior to insertion into the ferrule [2]. The fiber array is then inserted into the ferrule with adhesive, and cured. To verify the optical design, ten ferrules were randomly selected from a large molding run of ferrules and terminated with standard single-mode fiber, with MPO hardware on the non-DUT ends. The ferrules were held inside standard MXC hardware for ease of mating during testing.

The MXC encased ferrules were then intermated. Insertion loss and return loss were measured for each permutation, generating 1,440 insertion loss measurements. As shown in the histograms in Fig. 7, 99.8% of the channels have an insertion loss less than 0.7 dB with an average insertion loss of 0.45 dB and a standard deviation of 0.06 dB. The return loss meets the projected ≥ 55 dB specification on average, but some channels fall below this limit. Inspection with an optical frequency domain reflectometer shows that the low return loss is due to reflections near the tip of the fiber, and not at the lens surface. As the ferrule is still in development, the low return loss events are being addressed as the termination and laser cleaving processes are refined.

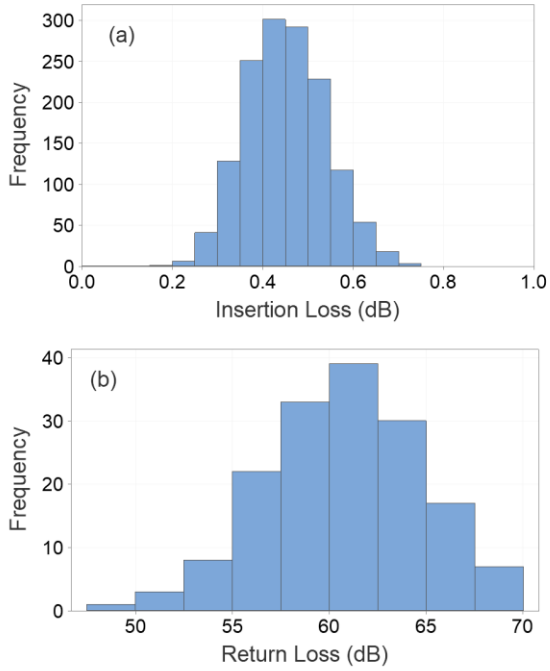

Fig. 7: Intermate a) insertion loss and b) return loss for unmated ferrules in MXC connectors.

The durability and repeatability of the ferrule and connector was tested in a single-port blind mate MXC connector package, as it is expected that this connector will often be used in back-plane applications where blind mating is needed. The ferrules were each mated 100 times with insertion loss measured after each mate for the first 50 mates, and then at 10 mate intervals for a total of 55 sets of data. Change in insertion loss during the durability test is shown in Fig. 8; the standard deviation per channel average is 0.013 dB with the single worst channel having a standard deviation of 0.034 dB. The ferrules were not cleaned during the testing and no deterioration of the ferrules was observed at the end of the test.

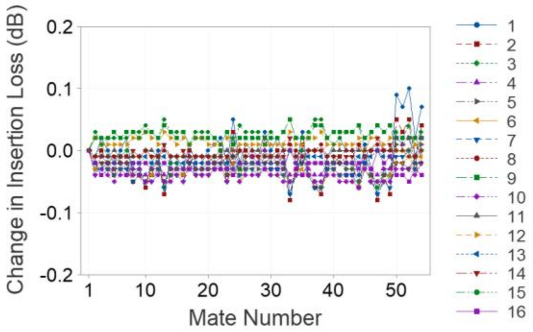

Fig. 8: Insertion loss change during a durability test.

Environmental Testing

Samples were exposed to Telcordia GR-1435 [6] controlled and uncontrolled environmental thermal aging, humidity aging, and thermal cycling serially for three days each test. The test conditions and results are summarized in Tab. 1. The maximum change in insertion loss is 0.18 dB for all tests, well within the 0.3 dB allowable change.

Tab. 1: Maximum change during environmental exposure.

Test	Max IL Delta 1310/1550 nm (dB)
Thermal Aging: 60°C	0.10 / 0.09
Humidity Aging: 40°C/95%RH	0.12 / 0.09
Thermal Cycling: -10-60°C	0.10 / 0.10
Thermal Aging: 85°C	0.12 / 0.17
Humidity Aging: 75°C/95%RH	0.15 / 0.14
Thermal Cycling: -40-75°C	0.16 / 0.18

Conclusion/Summary

A novel design for a monolithic, single-mode, expanded beam ferrule with low insertion loss, <0.7dB, high return loss, >55dB, has been successfully demonstrated. Data has been presented showing capability of performance via insertion loss intermateability, durability and GR-1435 controlled environment testing. Future work will include further improvements to insertion loss and return loss as well as demonstration of the advantages of the ferrule with regard to debris sensitivity, durability and reduced mating forces.

References

[1] T. Satake, S. Nagasawa, M. Hughes, and S. Lutz, "MPO-type single-mode multi-fiber connector: Low-loss and high-return-loss intermateability of APC-MPO connectors," *Optical Fiber Technology*, vol. 17, no. 1, pp. 17-30, 2011. DOI: 10.1016/j.yofte.2010.09.004

[2] D. Childers, E. Childers, J. Graham, M. Hughes, "Next-generation, high-density, low-cost, multimode optical backplane interconnect," *Proceedings of the SPIE 8267, Optoelectronic Interconnects XII, 82670O*, vol. 8267, International Society for Optics and Photonics, 2012, DOI: 10.1117/12.909688

[3] OSFP (Octal Small Form Factor Pluggable) Multi-Source Agreement, "Rev 4.1: Specification for OSFP Octal Small Form Factor Pluggable Module," 2 August 2021, https://osfpmsa.org/specification.html, accessed on 25 April 2022.

[4] D. Marcuse, "Loss analysis of single-mode fiber splices," *Bell System Technical Journal*, vol. 56, no. 5, pp. 703-718, 1970, DOI: 10.1002/j.1538-7305.1977.tb00534.x.

[5] D. Gloge, "Weakly Guiding Fibers," *Applied Optics*, no. 10, pp. 2252-2258, 1971, DOI: 10.1364/AO.10.002252

[6] Telcordia, "GR-1435-CORE Generic Requirements for Multi-Fiber Optical Connectors," issue no. 02, May 2008, https://telecom-info.njdepot.ericsson.net/site-cgi/ido/docs.cgi?ID=SEARCH&DOCUMENT=GR-1435, accessed on 25 April 2022.