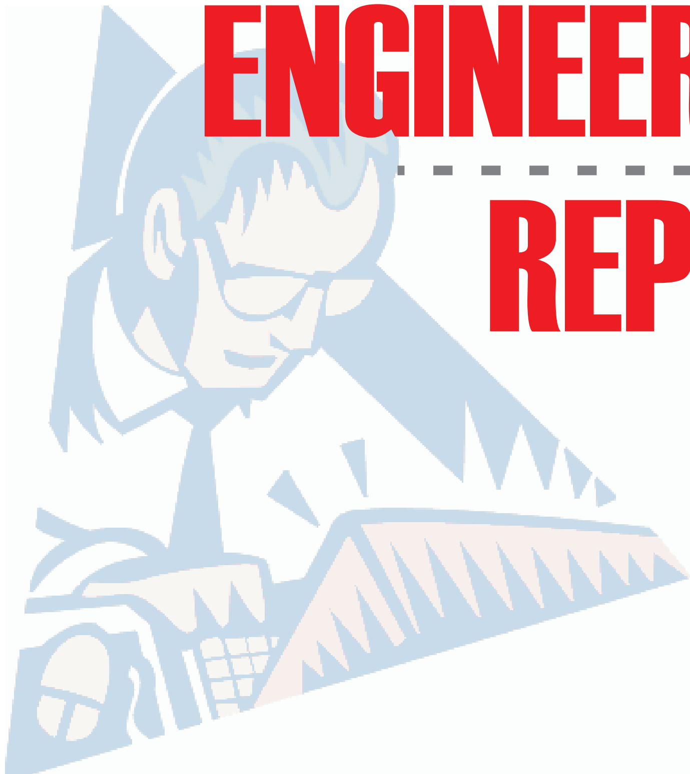
ENGINEERING REPORT



SFF Optical Transceiver
LC vs. MT-RJ
Geometric Comparison

METHODE ELECTRONICS, INC.

Optoelectronic Products

1.0 INTRODUCTION – The need for higher density

As fiber optic networking companies make the transition to the 21st century, a need for increased bandwidth and density has arisen. Much of this demand for higher density comes from the growth of the Internet. However, growth in other communications markets served by the fiber optics industry is also driving this demand.

Internet Protocol packet traffic is often transported via Ethernet or ATM in the Local Area Network (LAN) and SONET or SDH globally. An increase in the number of SONET/SDH lines being switched in the public network Central Office is one of the applications driving this demand for higher density optical interconnects. Data centers which warehouse information and archive records have their own specialized Storage Area Network SAN architecture for transferring large files efficiently. Fibre Channel and ESCON networks which serve the data center are rapidly increasing in number and size. All of the above mentioned applications require higher density connectors and transceivers for patch panels, switch, server, and hub connections.

2.0 PASSIVE CONNECTIVITY – LC and MT connector systems

Two popular high density fiber optic connector systems have emerged which have broad support from OEMs and system integrators. These two connectors are known in the industry as the LC and the MT-RJ. Originally conceived to answer the need for smaller passive optical connections, these connectors are now being adopted by transceiver manufacturers for their active optical interfaces.

2.1 The LC Connector

The LC connector was originally developed at Lucent technologies as a new higher density replacement for the very successful SC connector. As such, the LC has goals of high performance and universal applicability within the SONET/SDH and BellCore compliant public network. Additionally, the connector must meet the low cost targets of the burgeoning data communications market. These datacom connections are often less than 500 meters in length and regularly demand telecommunications grade performance at Local Area Network prices. The Electronic Industry Association/Telecommunication Industry Association (EIA/TIA) has published a standard for the LC connector. Refer to EIA/TIA document number EIA/TIA-604-10. The LC is a single fiber connector which utilizes the traditional cylindrical ferrule and split sleeve coupling approach. Therefore it addresses the need for high density configurable systems such as in patch panels and switches. It is available with a duplex collar which adapts it well for bidirectional optical interfaces.

2.2 The MT Connector

The MT connector was conceived and developed as a multi-fiber array connector with up to 12 fiber positions by Nippon Telephone and Telegraph (NTT). The initial purpose was to reduce the difficulty in pulling large bundles of connectorized fiber through a plenum or ductwork. By reducing the size of the connector bundle dramatically, the MT array connector addressed this problem. The MT is also well suited as a connector for multi-fiber ribbon cable. The MT is a multi fiber rectangular ferrule with two locating pins on the plug, and two corresponding bores on the mating connector. It has been proposed as a telecommunications connector, but lacks the configurability required for patch panel and switch applications. The MT-RJ single mode fiber ferrules require an extreme degree of precision. In array and ribbon fiber terminations, it allows the user to terminate up to 12 fibers simultaneously, thereby realizing a projected savings in labor and material costs. These are the basic advantages of an array connector over a single fiber connector. Of course, yields on multi-fiber array connectors most likely will be reduced. It should also be noted there are other multi-fiber array connectors besides the MT which have their own performance enhancing features such as the MAC, MP, and MPX connector systems.

3.0 TRANSCEIVER CONNECTORS – LC and MT-RJ

The ad hoc industry Multi Sourcing Agreement (MSA) committee has developed an interchangeable footprint for a Small Form Factor (SFF) transceiver supporting LC and MT-RJ optical connectors. This committee includes substantially all of today's optical transceiver manufacturers. This ad hoc standard enable OEMs to concentrate resources on switch and NIC developments. Depending on which connector or transceiver manufacturer is able to meet the customer targets for performance, price and delivery, the selection of a vendor can be postponed until the last moment. Decision regarding vendor and connector style can be easily reversed without significant impact.

3.1 The MT-RJ transceiver

The evolution of the MT into the MT-RJ has been undertaken by AMP and HP in the U.S. market. The MT-RJ is targeted at the Original Equipment Manufacturers (OEMs) of LAN Network Interface Cards (NICs) and switches. It retains the rectangular ferrule, locating pins and precision mating bores. The MT-RJ specifies only two fiber positions, however. The EIA/TIA has also published a normative reference document controlling the MT-RJ. Refer to EIA/TIA-604-12. The MT-RJ has been incorporated into transceiver designs for multimode fiber LED 1300nm 10/100 Ethernet, ATM OC-3 and FDDI. It is currently being developed by TyCo and Agilent, the successors to AMP and HP respectively, into laser based transceiver designs for multimode 850nm Gigabit Ethernet and Fibre Channel at 1.25 Gbps. The MT-RJ has had the benefit of a considerable marketing effort to place it first in the minds of many engineers and buyers.

3.2 The LC transceiver

The LC has recently been developed as a transceiver connector by Lucent, Methode, OCP, HP, and Finisar. Both multimode 850nm and single mode 1300nm and 1550nm laser based versions are available. The 1300nm multimode LED market is being addressed by Methode's MCM Division which has an LC optical transceiver in a miniature transceiver compatible with the RJ copper jack footprint and body style. With an installed base of several million connectors, the LC has gained tremendous momentum in recent months. Much of this opportunity is due to customer disappointment with the lack of MT-RJ transceiver availability. The LC is emerging as the connector of choice for many OEM's Small Form Factor (SFF) transceivers. This is especially true at Gigabit rates.

4.0 RATIONALE – LC vs. MT-RJ manufacturing tolerances

This study will make a comparison of the differences in the LC and MT-RJ connector geometry. Methode is not a proponent of either connector system over the other in any general sense. However, there are certain issues of simple geometry which make the LC more manufacturable. When we use the word manufacturable in this context, we are referring to the capability for the precision molding and machining or grinding operations necessary to produce the optical performance required. The associated costs in time and materials as well as yield of these operations must be considered.

Methode presently offers both LC and MT-RJ connectors for passive optical interconnect applications. Our desire was to be able to support our customers with the new Small Form Factor transceivers as rapidly as possible. We also had the goal of providing single mode product at the earliest date possible. In choosing the LC for our first SFF optical transceiver products, we have done thorough analyses of our internal capabilities to mold precision receptacle bores. We also assessed our abilities to machine and grind precision outside diameters on the LC ferrule as well as the locating pins on the MT-RJ. The third key parameter controlling connector performance and yield is the positional tolerance.

In the LC, this positional tolerance is reflected in the concentricity requirement for the fiber opening in the connector ferrule. In the MT-RJ, it is the positional accuracy and manufacturing tolerance on the locating pin dimension as well as the two fiber openings in the rectangular ferrule. Because these three dimensional parameters are essential in determining optical performance, and since the manufacturing capability supports both connector geometries, we have assumed equal tolerances in the analysis of both connectors except as noted in the text. We have also based our analysis only on the mated assembly. This study does not deal with the difficult problem of the steel locating pins on the MT-RJ mating with a cylindrical bore in a plastic ferrule. Such issues of material deformation are beyond the scope of this paper.

5.0 Geometric Analysis – multimode transceivers

5.1 LC Multimode

Figure 1 shows a simplified sketch of the mating parts of an LC connector. Section lines A-A split the ferrule and precision receiving bore longitudinally. Figure 2 displays the sectioned mated ferrule/bore. The case of a multimode ferrule and receptacle bore is shown in this figure. Figure 2 defines the parameter φ, which is the angular displacement of the ferrule to the precision molded receptacle bore. This angle is defined by the gap shown in Detail A in figure 2 and assumes maximum angular displacement due to a minimum ferrule outside diameter and maximum bore inside diameter. Both the ferrule and the receptacle bore are assumed to be molded parts for the purposes of this analysis with the tolerance range on both 3µm. The angle computed of .085 degrees does not predict any significant loss due to the Numerical Aperture of a multimode fiber.

Therefore, the lateral displacement of the ferrule tip in the precision bore is the single dominating concern. Detail A is exploded in Figure 3. These two figures together explain the conclusions drawn from Figure 4, which illustrates the maximum displacement from the center of the ferrule to the center of the receptacle bore. Figure 4 is the transverse section B-B. The maximum displacement of 4.4µm is the sum of the concentricity with one half the difference between the receptacle maximum O.D. and the ferrule minimum I.D. In a multimode fiber connector, this degree of offset predicts a maximum loss on the order of approximately .5dB for 50/125µm fiber and .4dB for a 62.5/125µm multimode fiber.

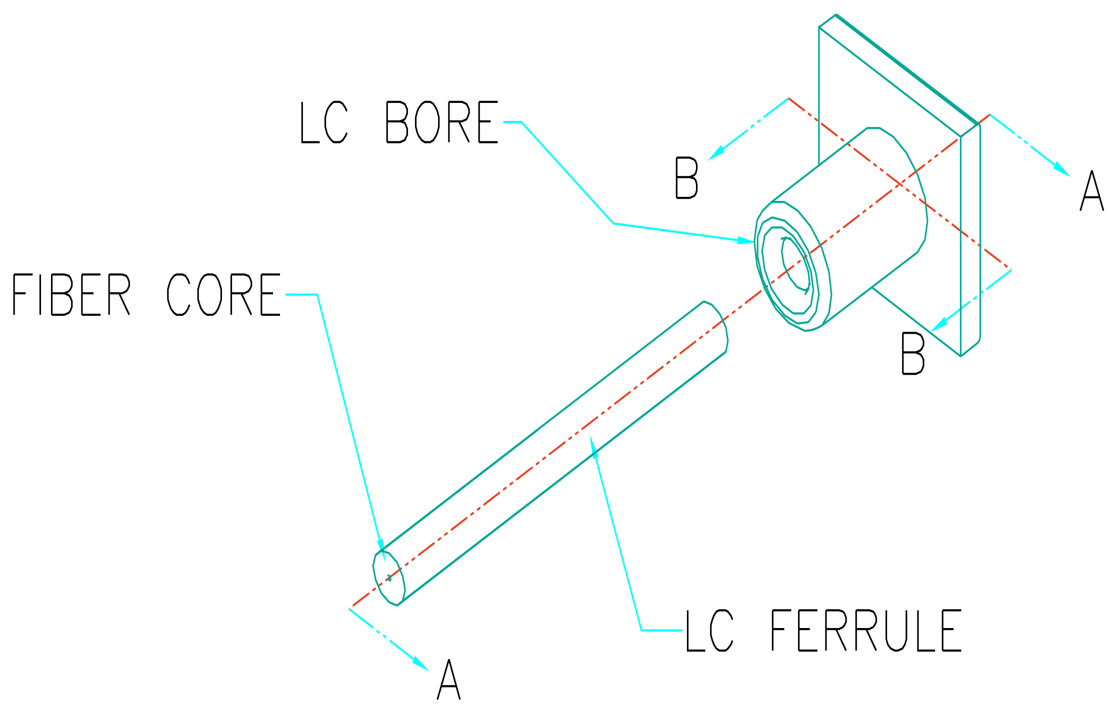


Figure 1: LC mating components

TOLERANCE ASSUMPTIONS			
	ITEM	**DIMENSION**	**TOL. RANGE**
LC	MOLDED BORE ID	1.2505-1.2535	0.003
	FERRULE OD	1.2475-1.2505	0.003
	CONCENTRICITY	◎ .0014	0.0014
MT-RJ	MOLDED BORE ID	0.700-0.703	0.003
	PIN OD	0.697-0.699	0.002
	POSITIONING	0.748-0.752	0.004

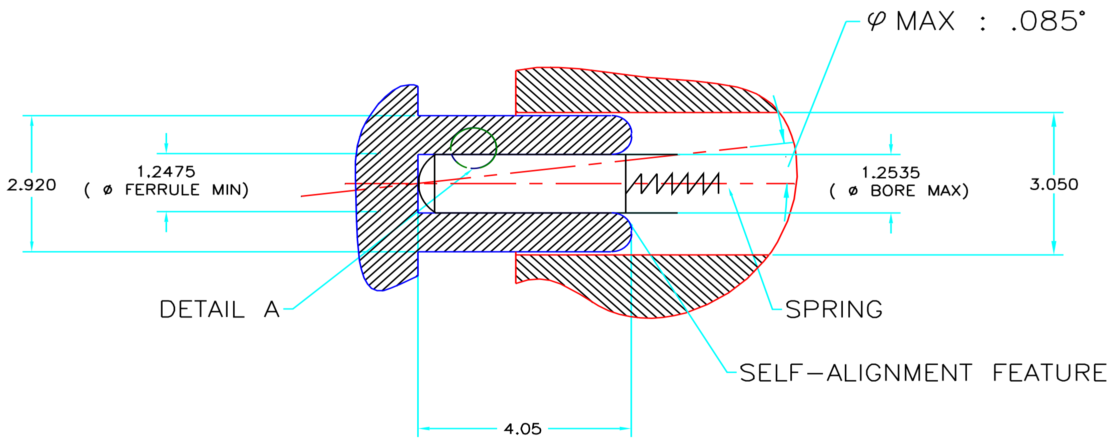


Figure 2: Section A-A. Angular displacement for multimode LC Ferrule/Molded Bore -- maximum displacement

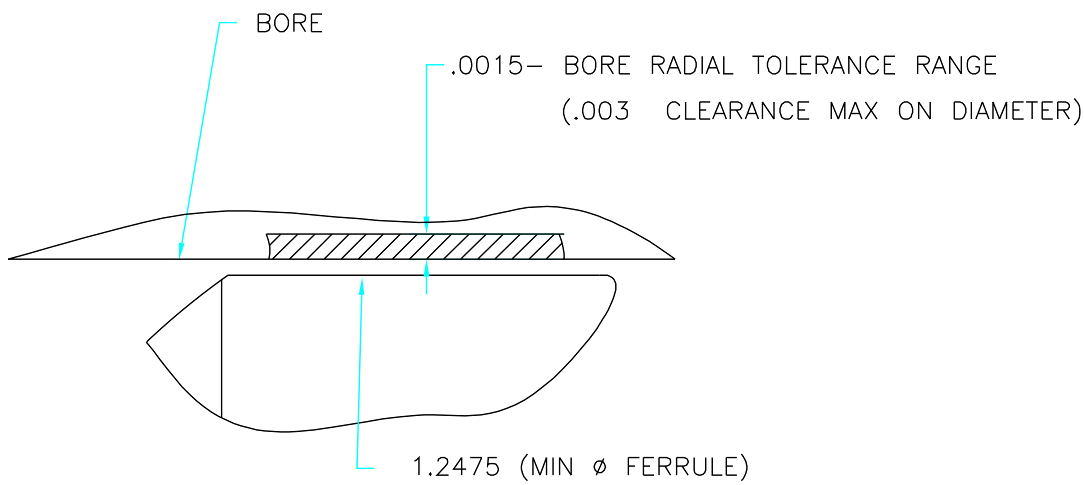


Figure 3: Detail A. Multimode Bore/Ferrule dimensional clearance

TOLERANCE ASSUMPTIONS			
	ITEM	**DIMENSION**	**TOL. RANGE**
LC	MOLDED BORE ID	1.2505-1.2535	0.003
	FERRULE OD	1.2475-1.2505	0.003
	CONCENTRICITY	◎ .0014	0.0014
MT-RJ	MOLDED BORE ID	0.700-0.703	0.003
	PIN OD	0.697-0.699	0.002
	POSITIONING	0.748-0.752	0.004

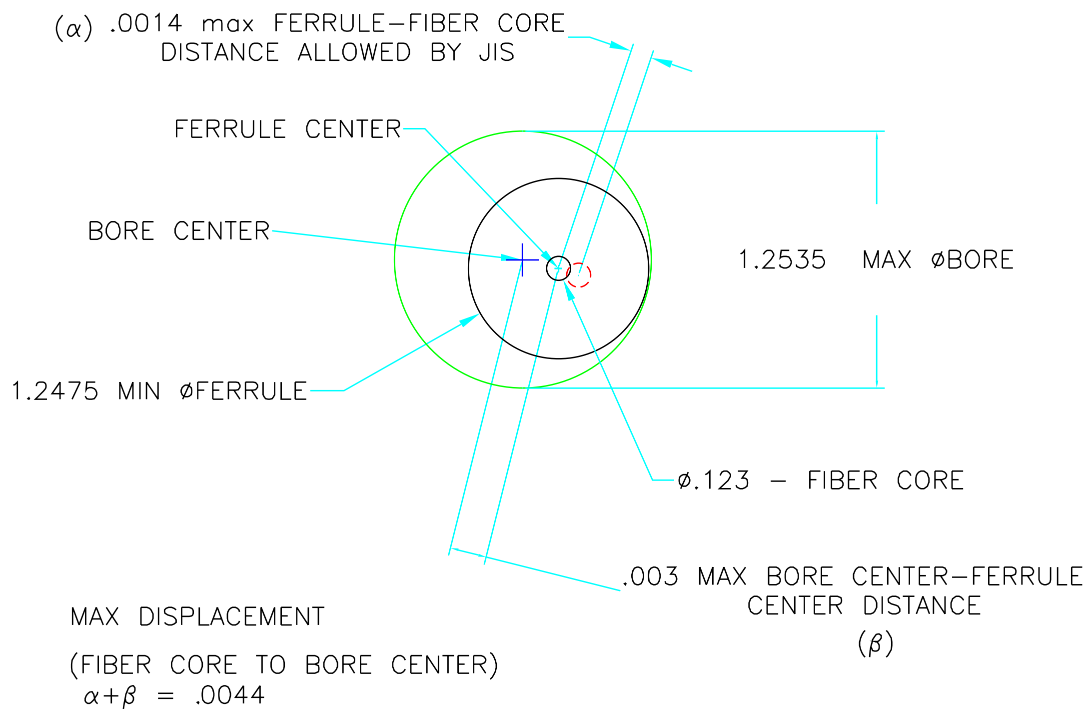


Figure 4: Section B-B. Maximum displacement present in the multimode Fiber Core/Bore intermate

5.2 MT-RJ multimode

The mating components of the MT-RJ are shown in Figure 5. The cross section C-C is shown in Figure 6. The worst case lateral displacement will be the only case dealt with here. Any angular displacements in the MT-RJ will result in air gaps. Air gaps between butt-coupled fibers as in the MT-RJ connector result in significant losses and reflections. The reflections caused by such an air gap may create instabilities in the laser cavity due to the optical feedback. This effect would be most dramatic in a single mode laser applications.

The worst case plug-to-receptacle lateral shift in the C-C plane is occasioned by minimum locating pin diameters on the plug together with a maximum bore diameters on the mating receptacle. The difference is .703 - .697 = .006mm. One half this value will be the maximum plug-receptacle lateral shift, or 3µm. In addition, there is the allowable positional offset of the fiber openings in the plug and receptacle bodies. From center, the maximum allowable distance to a fiber is .376mm. The minimum allowable distance is .374. This difference adds an additional .002mm. The total fiber-fiber displacement is therefore 5µm for the MT-RJ multimode. This number compares favorably with the LC multimode, but neglects a number of difficulties. One is the difficulty in maintaining a positional tolerance of +/- 1µm over a 375µm distance from centerline for the fiber openings. This represents a .25% positional tolerance which is very difficult to achieve in plastic. The tolerance range assumed for the MT-RJ plastic molded receptacle bore is 3µm. This is the same number assumed for the LC multimode analysis. The pin diameter tolerance of 2µm is taken directly from the EIA/TIA specification. The positional tolerance of +/-2µm for the positional tolerance of each of the fiber openings is the most optimistic projection for precision molding capability.

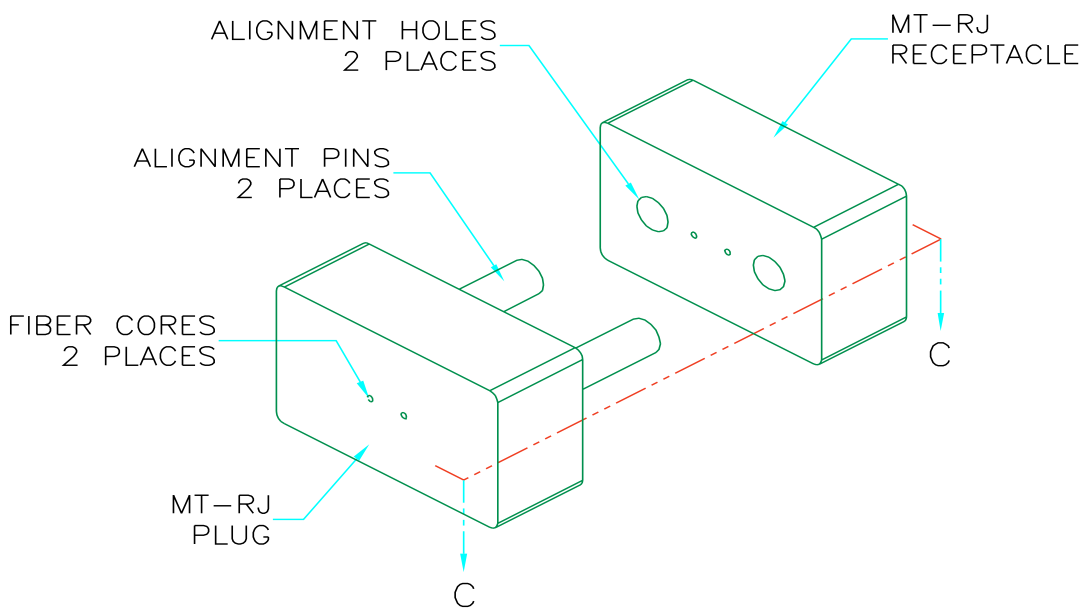


Figure 5: MT-RJ mating components

TOLERANCE ASSUMPTIONS			
	ITEM	DIMENSION	TOL. RANGE
LC	MOLDED BORE ID	1.2505-1.2535	0.003
	FERRULE OD	1.2475-1.2505	0.003
	CONCENTRICITY	◎ .0014	0.0014
MT-RJ	MOLDED BORE ID	0.700-0.703	0.003
	PIN OD	0.697-0.699	0.002
	POSITIONING	0.748-0.752	0.004

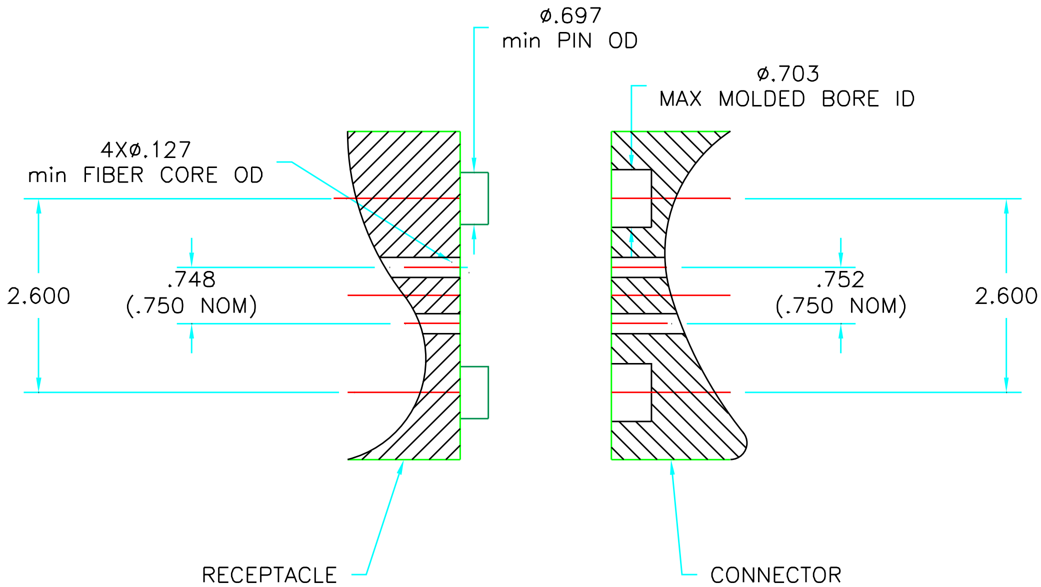


Figure 6: Section C-C forMultimode MT-RJ intermate--maximum displacement

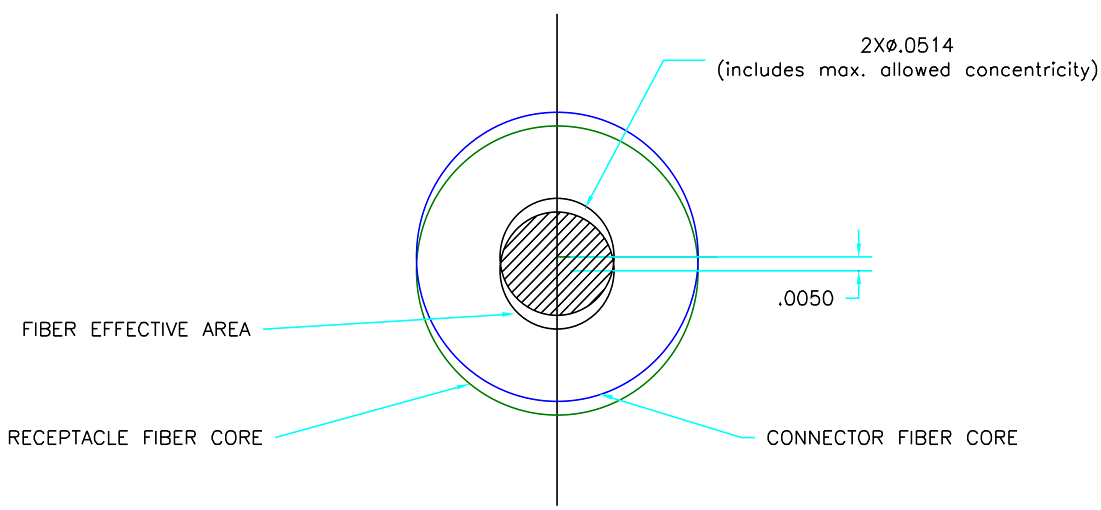


Figure 7: Fibre Core displacement in multimode MT-RJ

5.3 LC single mode

In the LC single mode application, the ferrule is a ceramic material. The Zirconia or Alumina ferrules can be ground and polished to a high degree of accuracy due to their circular symmetry using state of the art rotating machinery. Additionally, solid cylindrical precision bores may be I.D. ground and polished by similar machinery. Methode single mode transceivers in some cases employ a dynamically sized split sleeve approach which reduces cost yet maintains a high degree of precision. Solid ceramic precision bores are still preferred in BellCor or harsh environment applications.

These advantages in techniques and materials provide a major increase in precision for the circularly symmetric mating geometry of the LC in single mode transceivers. Therefore, the ferrule O.D. may be controlled in a range of 1.4mm. The split bore I.D. may be sized within 1.5mm. Refer to the table in Figure 8 for a summary of the tolerances assumed for the LC single mode analysis. These increases in precision feed into the same equation used for the LC multimode analysis.

Figure 9 shows the maximum radial displacement at .00145 as a result of the increased precision available via the processes and materials described above. The results of Figure 9 plus the concentricity tolerance give the total worst case radial displacement for the LC single mode case at .00285 as shown in Figure 10. Figure 10 is the mating plane section B-B as shown in Figure 1 for the LC connector assembly. A radial offset of 2.85mm as in our worst case analysis predicts a maximum loss of 1.4dB for 9mm single mode fiber.

TOLERANCE ASSUMPTIONS			
	ITEM	**DIMENSION**	**TOL. RANGE**
LC	MOLDED BORE ID	1.2497-1.2512	0.0015
	FERRULE OD	1.2483-1.2497	0.0014
	CONCENTRICITY	◎ .0014	0.0014
MT-RJ	MOLDED BORE ID	0.700-0.703	0.003
	PIN OD	0.698-0.699	0.001
	POSITIONING	0.748-0.752	0.004

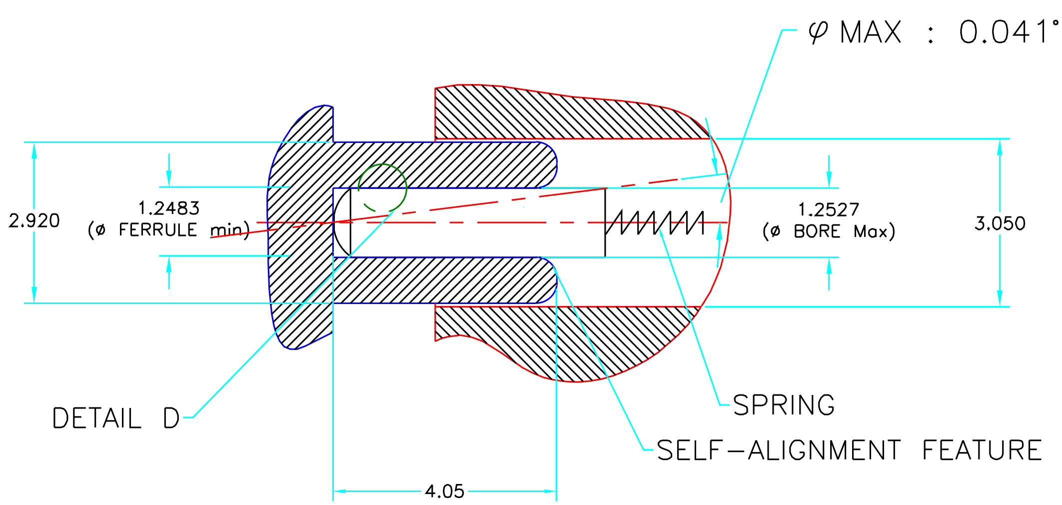


Figure 8: Angular displacement for single mode LC Ferrule/Ceramic Bore--maximum displacement

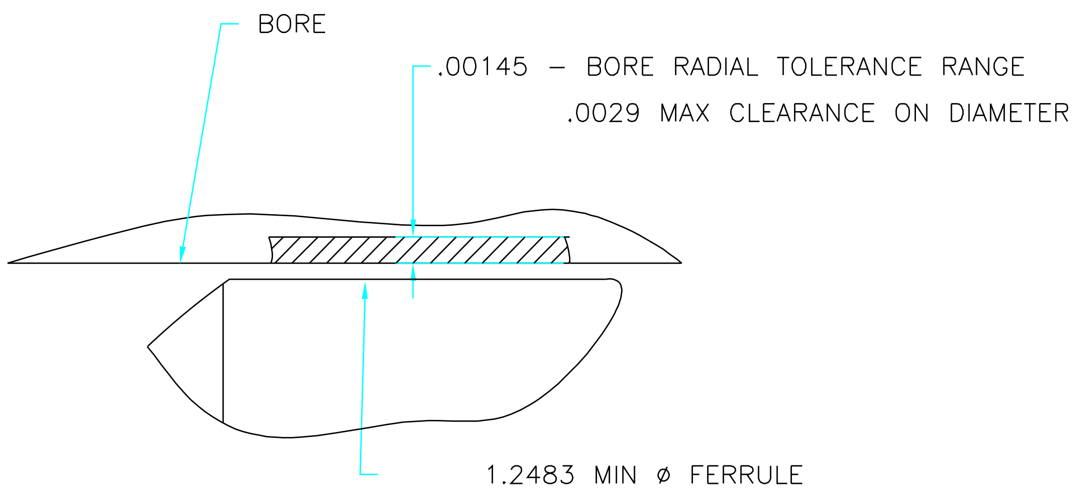


Figure 9: Detail D. Single mode Bore/Ferrule dimensional clearance

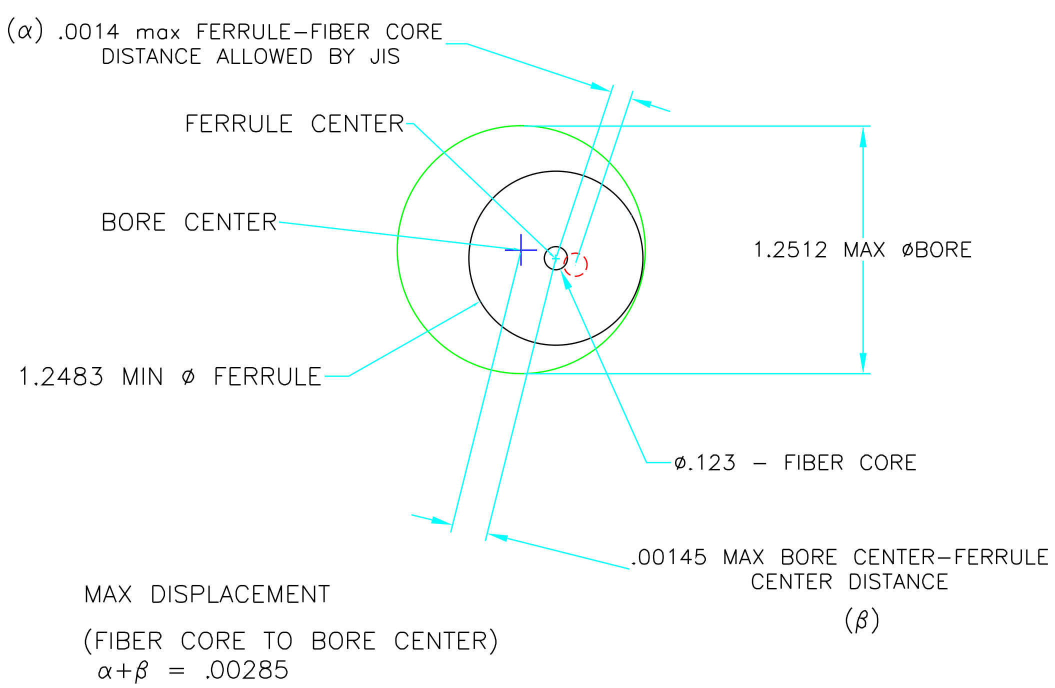


Figure 10: Section B-B. Maximum displacement present in the single mode Fiber Core/Bore intermate

5.4 MT-RJ single mode

For the MT-RJ single mode case, there are fewer enhancements to precision which can be brought to bear. The locating pin diameters have been increased in precision from the .002mm range in the multimode to .001mm in the single mode case. This change can be seen in the table in Figure 11 which shows section C-C of the MT-RJ connector assembly of figure 5. However, unless the ferrule material is changed, the molded plug and receptacle precision cannot be arbitrarily raised. In the MT array connector, Silicon V-groove technology has been used to produce high precision array connectors with some success. However, etch rates and material properties and orientation must be accurately controlled to realize the high precision achievable photolithographically with single crystal semiconductor grade Silicon. Also, the cost of this large area Silicon chip and its processing become prohibitive when only two fibers will be connected, as in the MT-RJ.

The properties of the single crystal Silicon which yield the higher precision are also responsible for some mechanical drawbacks. Single crystal semiconductor grade Silicon is brittle, and often cracks under the applied pressure of connector mating. Additionally, the Silicon chip must be insert molded with the steel locating pins at a high temperature. Coefficients of thermal expansion and contraction are not well enough matched between the Silicon, steel, and plastic to give the yields necessary for high rate manufacturing.

Therefore, in Figure 12 we have been able to reduce the maximum lateral displacement for the MT-RJ to 4.5µm. However, this creates a major problem in single mode fiber where the core diameter is only 9µm total. The loss predicted for this magnitude of fiber-fiber offset is in excess of 4dB.

TOLERANCE ASSUMPTIONS			
	ITEM	**DIMENSION**	**TOL. RANGE**
LC	MOLDED BORE ID	1.2497-1.2512	0.0015
	FERRULE OD	1.2483-1.2497	0.0014
	CONCENTRICITY	◎ .0014	0.0014
MT-RJ	MOLDED BORE ID	0.700-0.703	0.003
	PIN OD	0.698-0.699	0.001
	POSITIONING	0.748-0.752	0.004

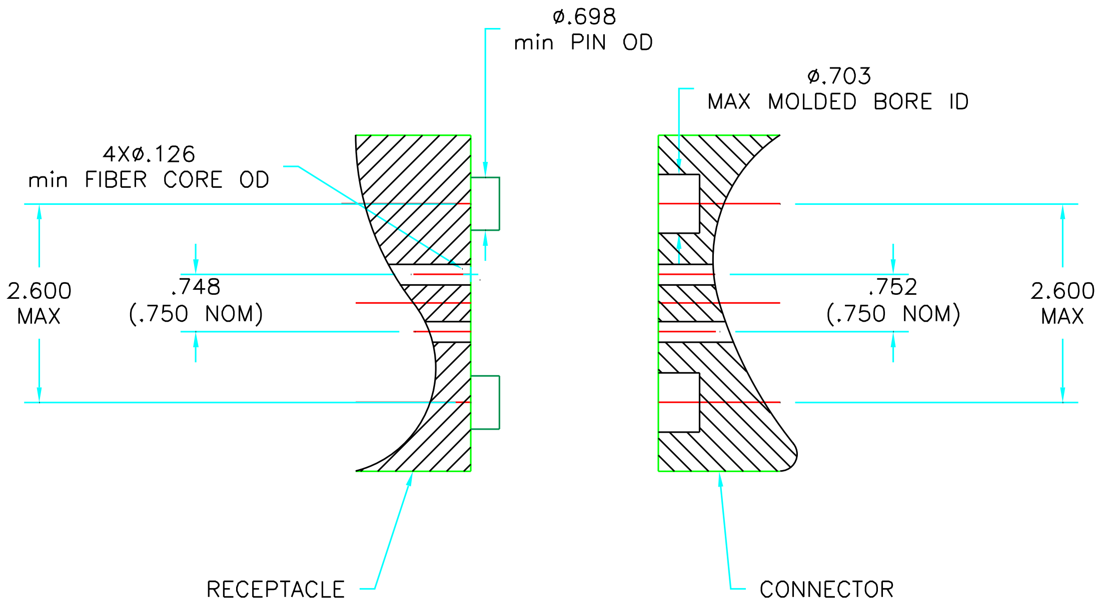


Figure 11: Section C-C for Single mode MT-RJ intermate--maximum displacement

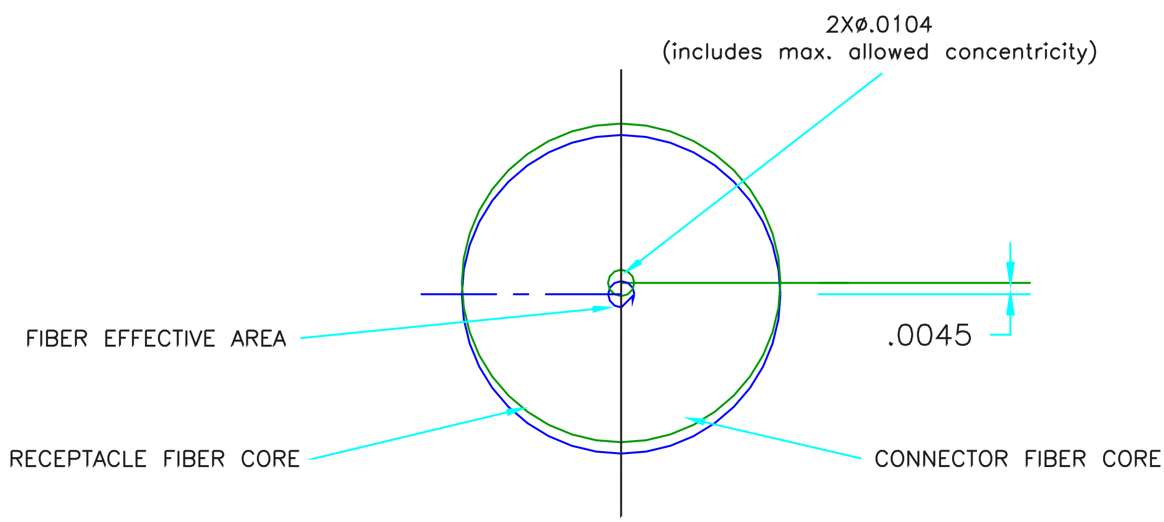


Figure 12: Fibre Core displacement in single mode MT-RJ

6.0 CONCLUSIONS

As shown in our tolerance analysis, the cylindrical geometry of the LC affords it a number of advantages which figure more heavily in the single mode analysis. However, the advantages of the LC are not limited to the single mode case. As noted earlier, this analysis does not include a study of the plastic deformations which may occur when an MT-RJ plug steel pin is mated with the MT-RJ receptacle plastic bores. The mechanics of mating and demating of the LC are also favorable when contrasted with the MT-RJ.

The uniform cross section of an LC plastic molded ferrule mitigates the issue of shrinkage and sinking which contribute to positional errors in multimode ferrules. The uniform cross section of the precision molded bores is also a positive for the LC. The LC connector receptacle relies on a lens and free space coupling. This eliminates the variable losses associated with air gaps which can be induced with paraxial loading in the case of the MT-RJ.

The MT-RJ does have some advantages. It may have a slightly lower bill of materials. It will fit into a somewhat smaller panel opening. This may have consequences of reducing the EMI signature of MT-RJ based transceivers.

However, this potential advantage may quickly evaporate if the MT-RJ yields are not as high as the LC. Experience teaches us the cost associated with the complexity and the precision requirements of the manufacturing process and the cost of yield losses often dominate the equation for the final cost of a connector.

High precision single mode connections are much easier to achieve and maintain in production for the LC geometry. This result is obvious by inspection for a trained fiber connection professional. These are some of the technical and manufacturing reasons why the LC connector has recently begun to outpace the superior marketing of the MT-RJ.

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