Cost & Performance Comparison
Butt Coupled vs. Expanded Beam (Lensed) Connectors

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Multi Gigabit Automotive Optical PHY Study Group
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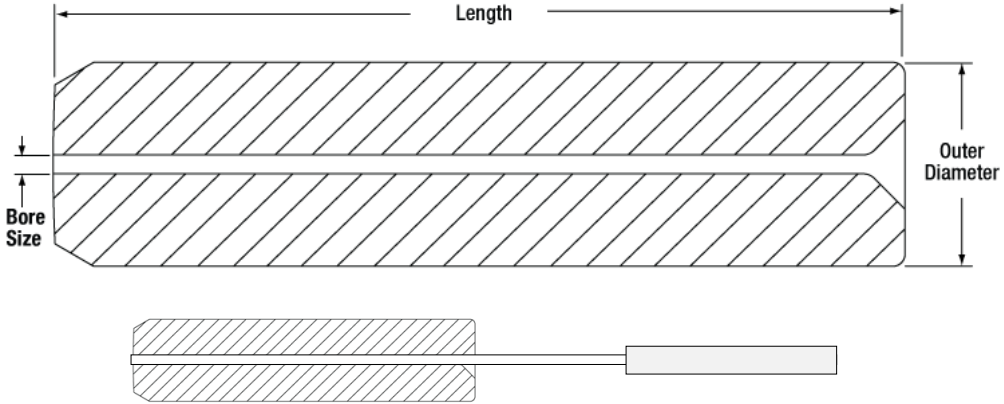
Common Physical Contact (PC) optical connectors

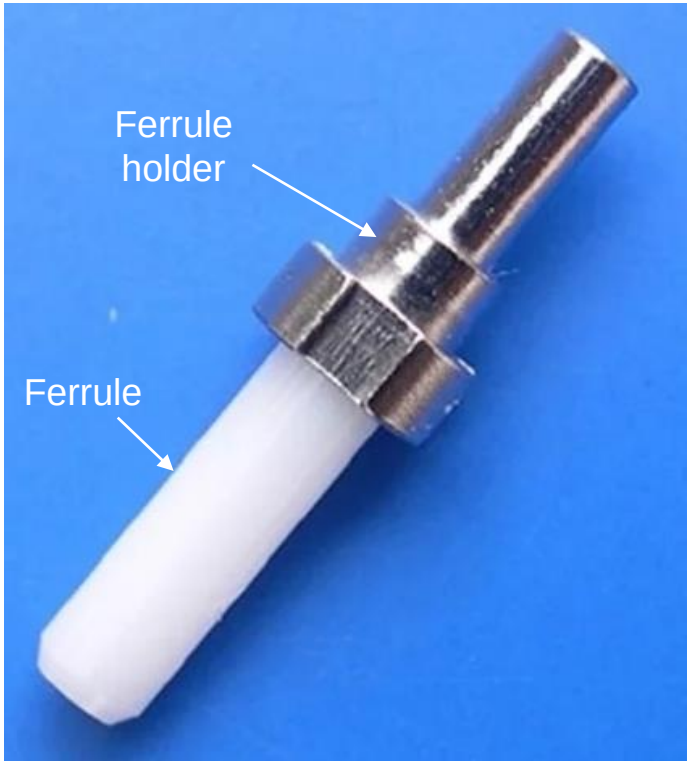
LC Connector

SC Connector

Connector ferrule critical dimensions



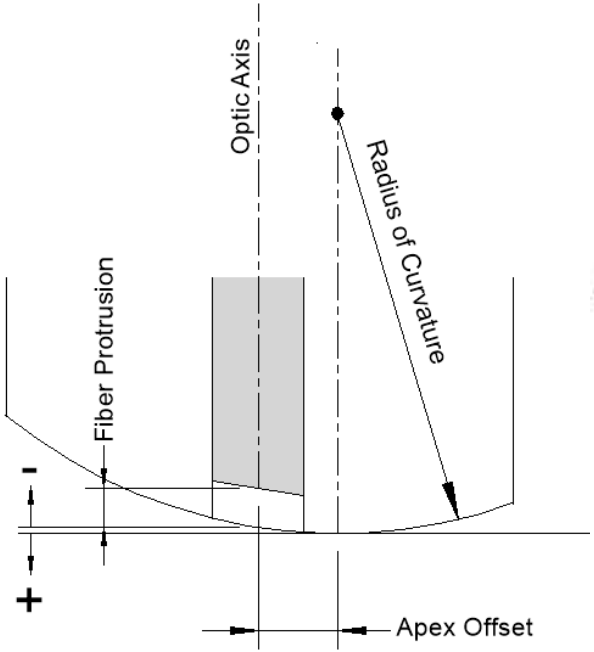
1. Ferrule outside diameter
2. Ferrule inside diameter
3. Circularity
4. Bore concentricity
5. Bore angular offset



Standards specified end face geometry

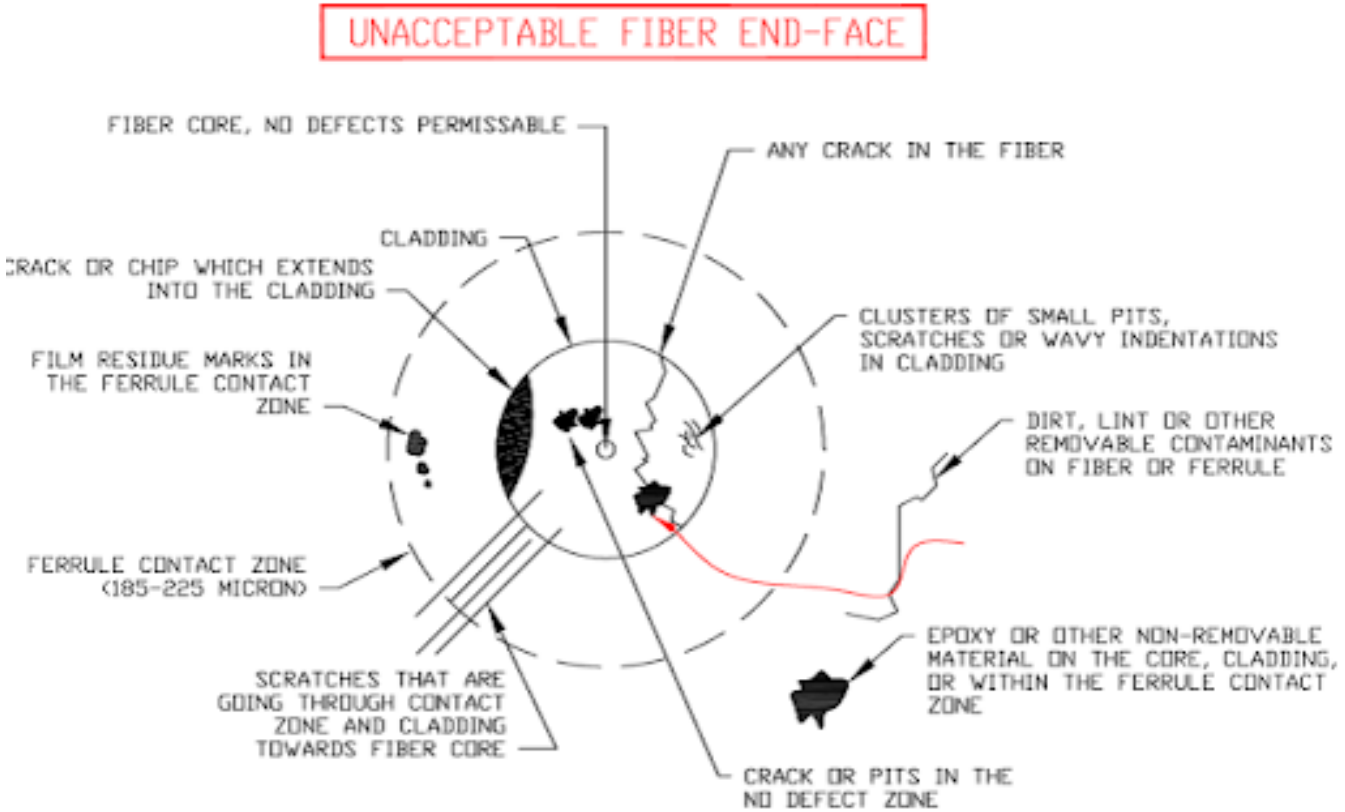
Critical specifications

1. Radius of curvature
2. Apex offset
3. Protrusion
4. Scratches
5. Cracks
6. Pits

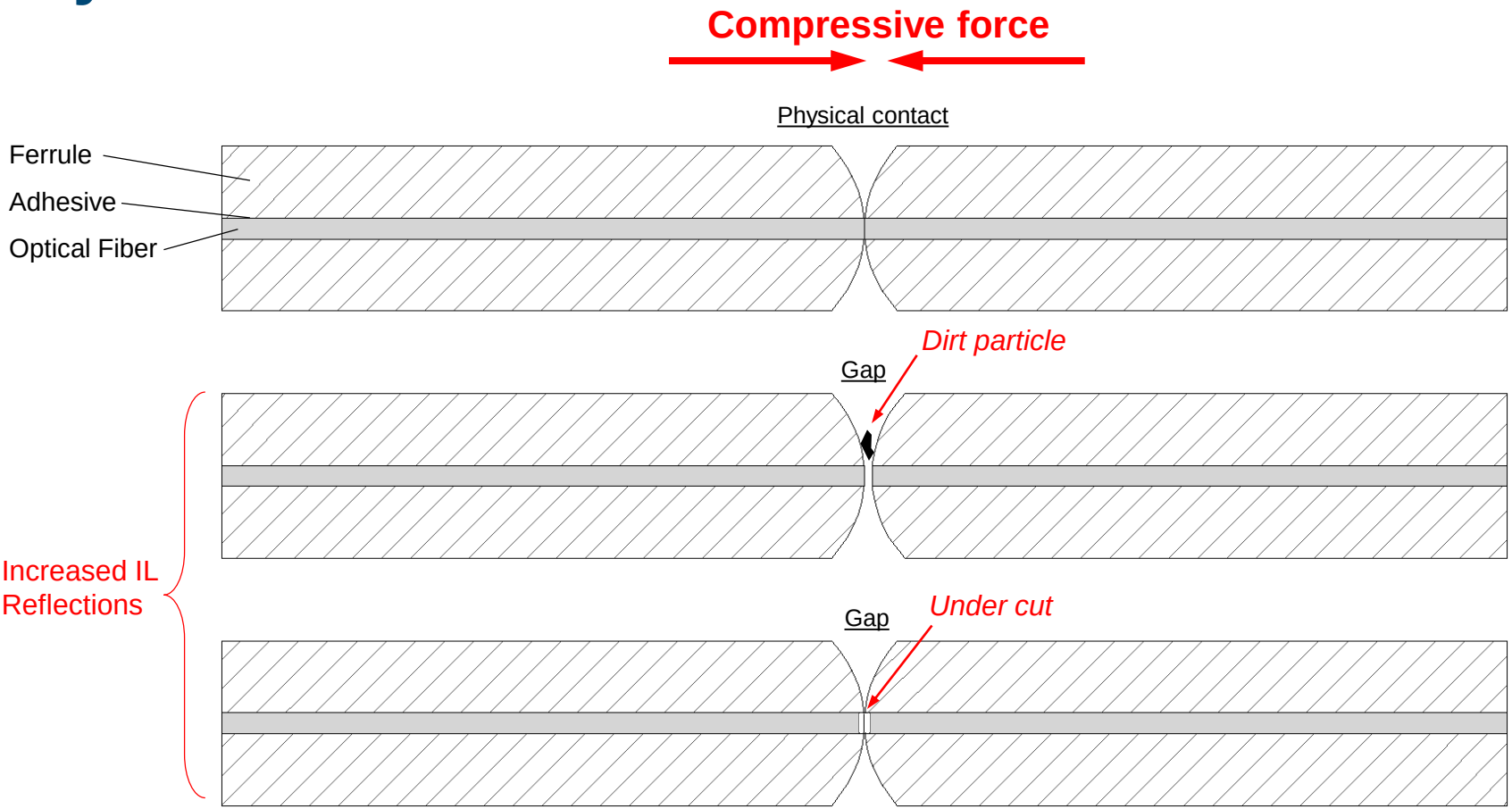


Polishing

Critical end-face quality parameters – Inspection



Physical contact



Expanded Beam Connectors (EBC)

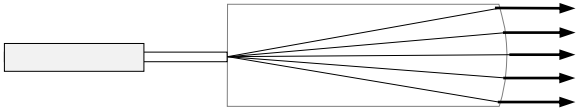
Benefits

1. Non-physical contact
2. Large beam size – less susceptible to dirt
3. No polishing required
4. Ease of cleaning

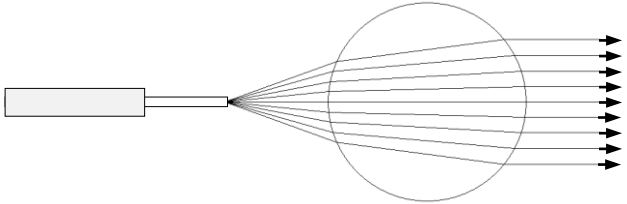
Disadvantage

1. Higher IL compared to PC

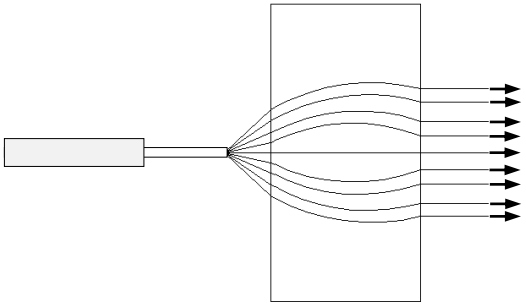
Planar-Convex Lens (C-Lens)



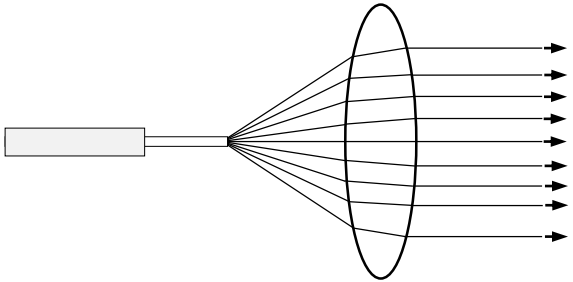
Ball Lens



GRIN Lens

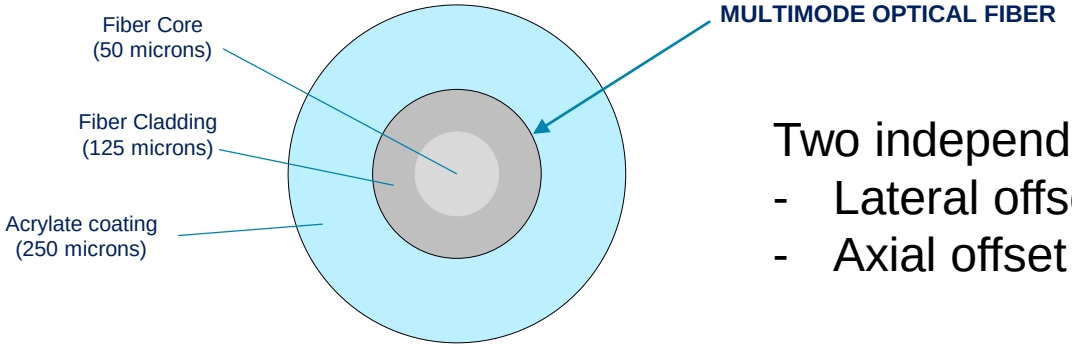


Ordinary Lens



Insertion Loss (IL) measurements

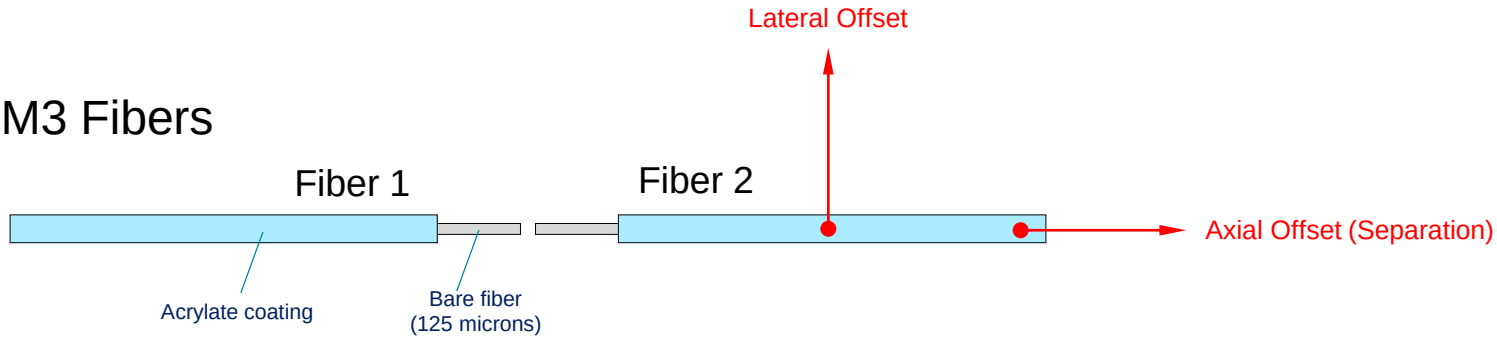
Butt Coupling Insertion Loss



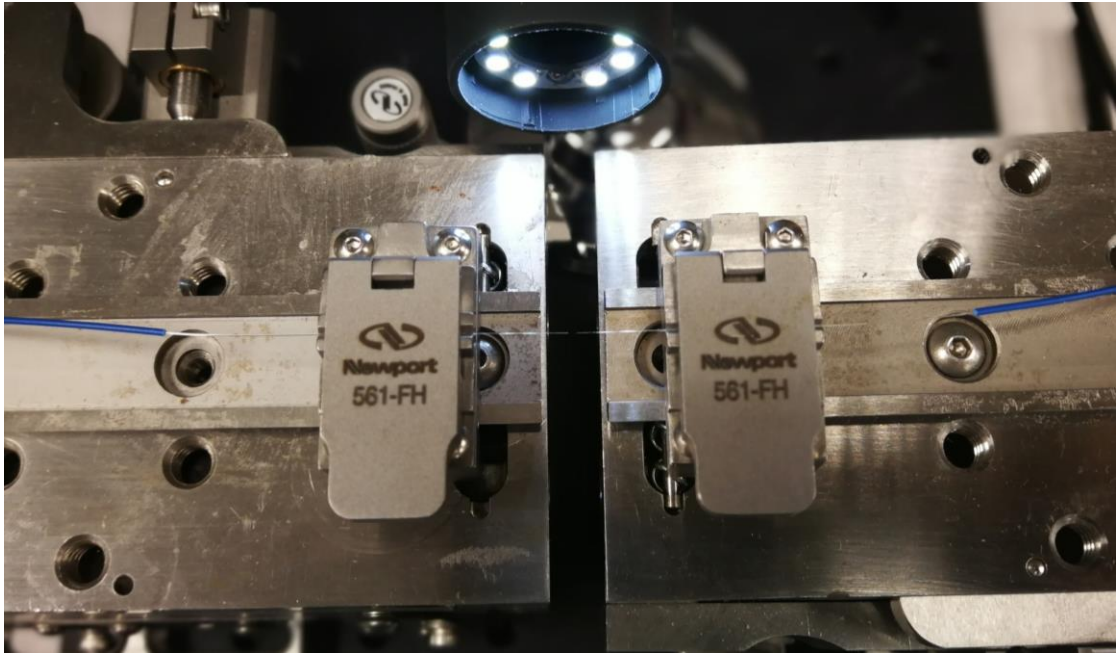
Bare MMF

Two independent displacements
- Lateral offset
- Axial offset

Two OM3 Fibers



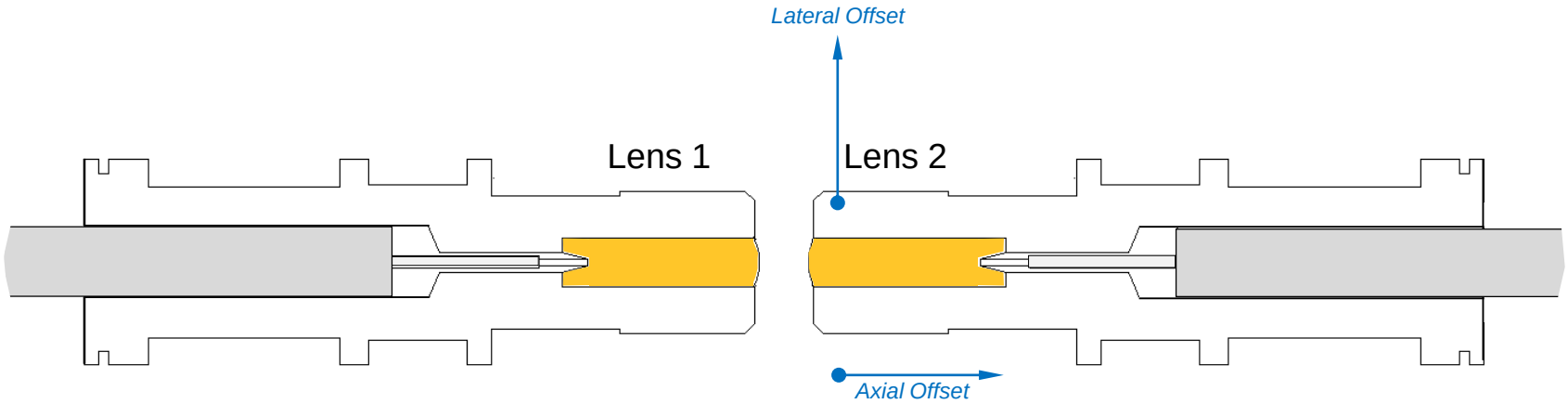
Experimental setup – bare fibers



No axial gap
Minimum loss 0.9dB

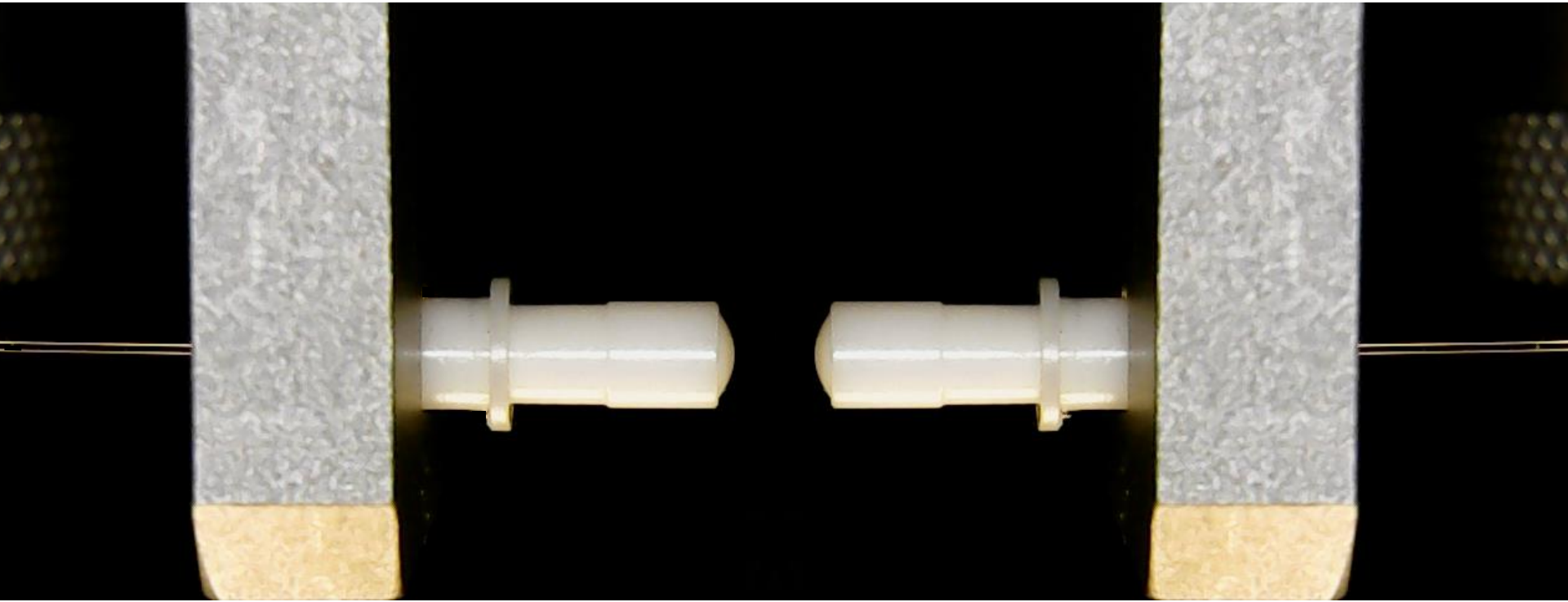
Axial gap 500um
loss 10.2dB

Expanded Beam IL measurements

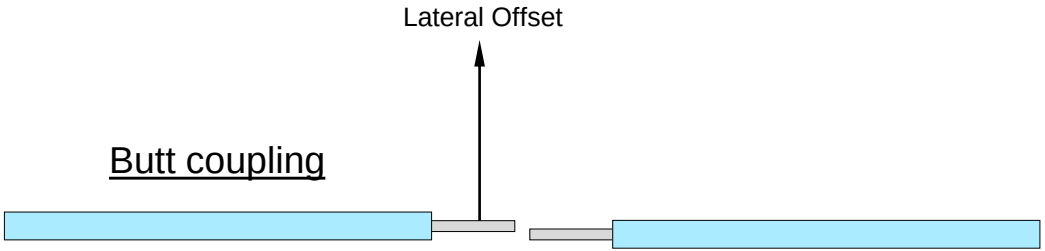


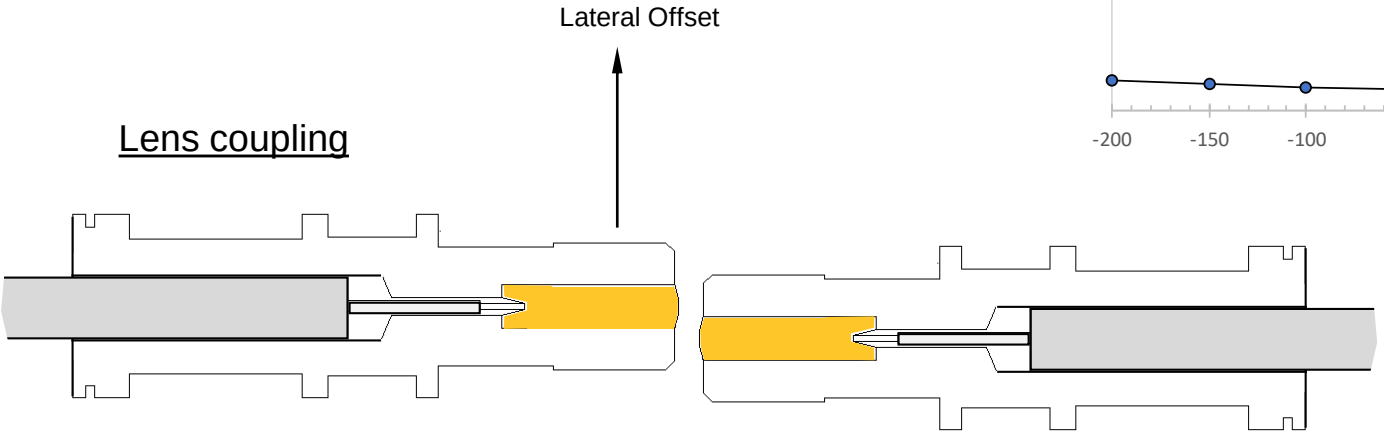
- Used equivalent commercial glass C-Lenses
- Micro-molding targeted for low cost lenses
- No Anti-Reflection (AR) coating for low cost (0.5 dB penalty)

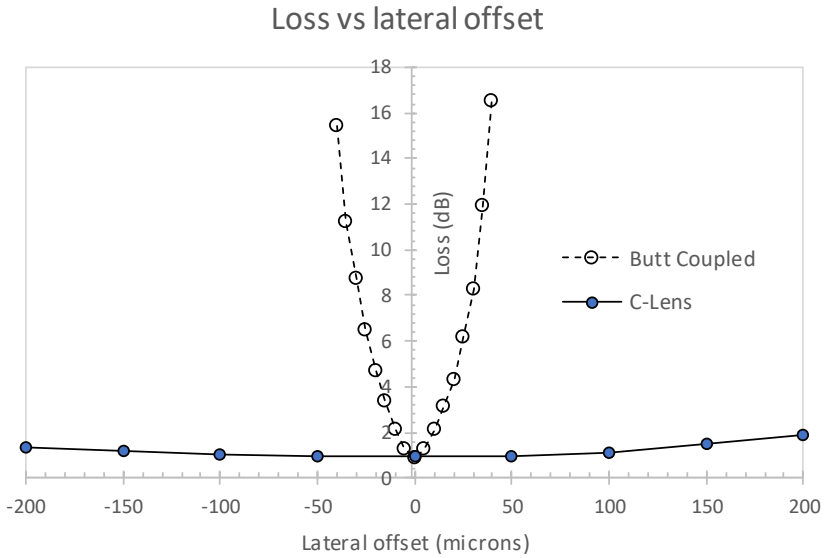
Expanded beam measurement setup



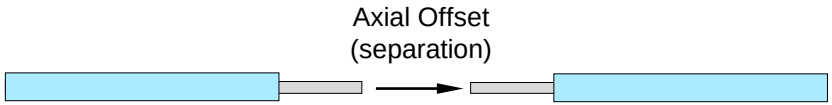
Lateral offset IL measurement results

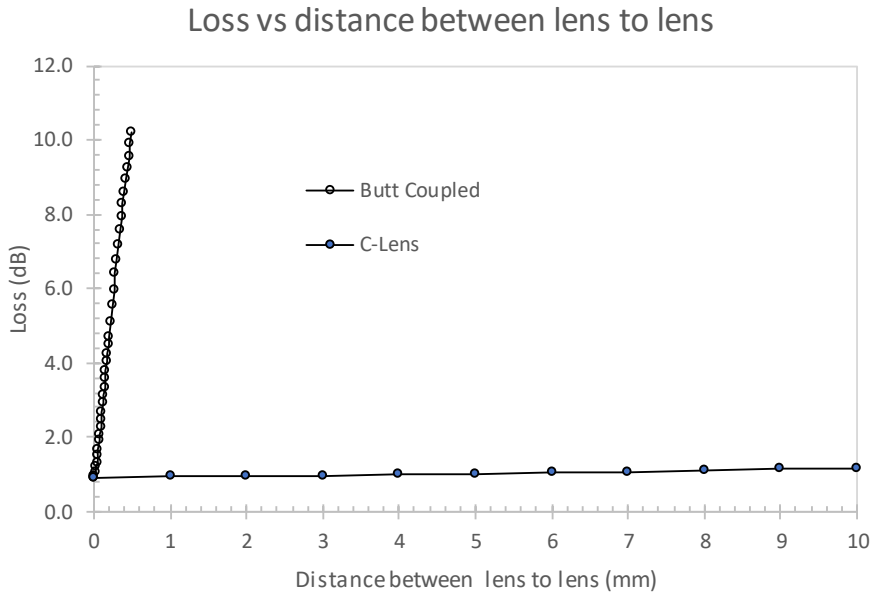


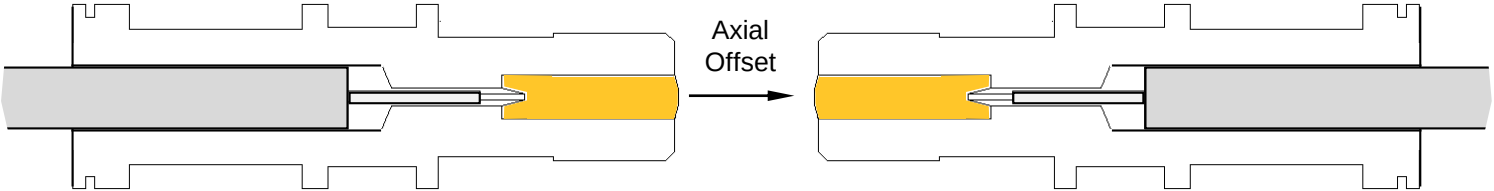




Axial offset IL measurement results



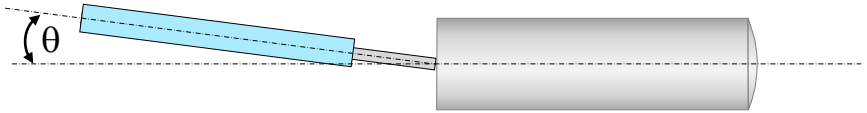


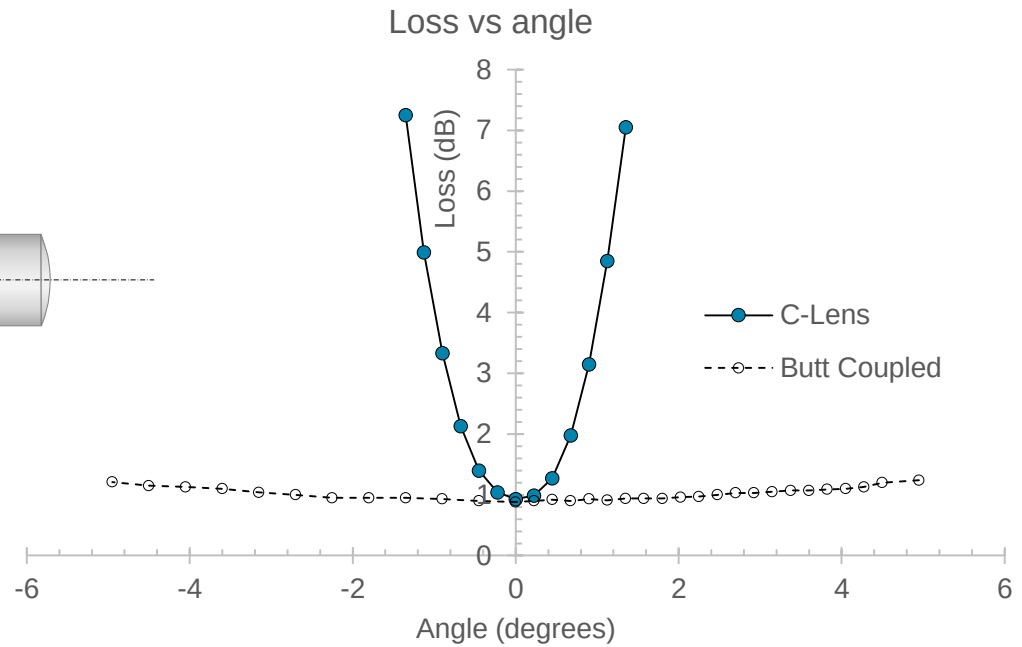


Expanded beam alignment tolerance trade-off

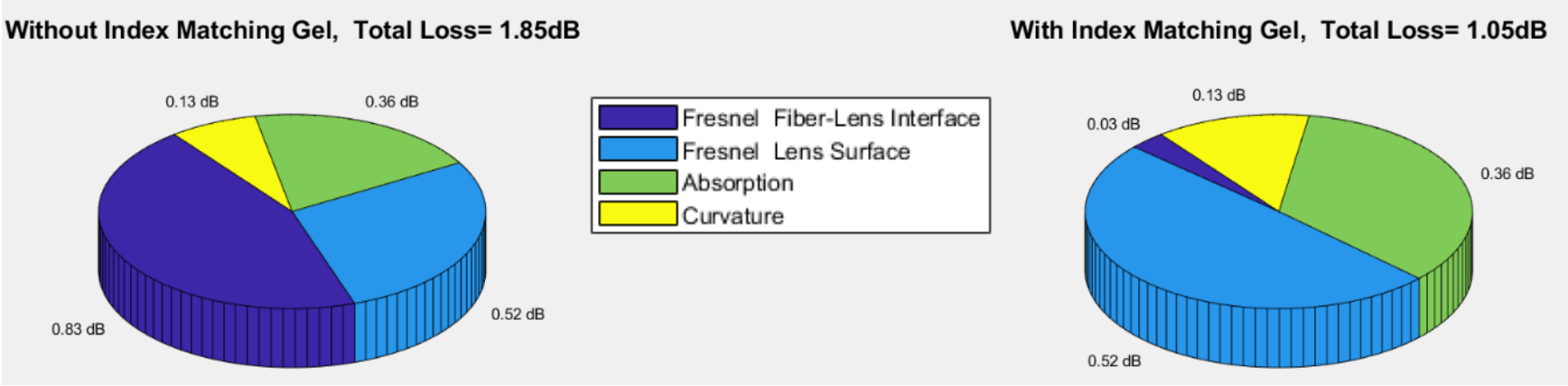
- Angular displacements

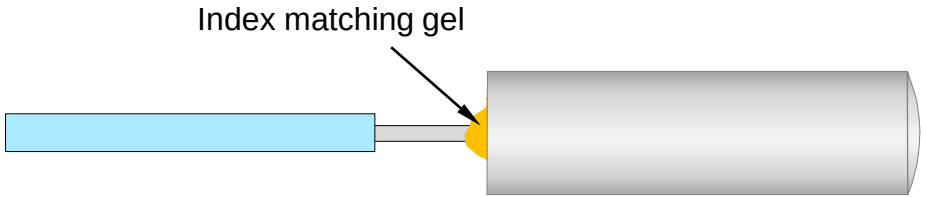
Angular misalignments





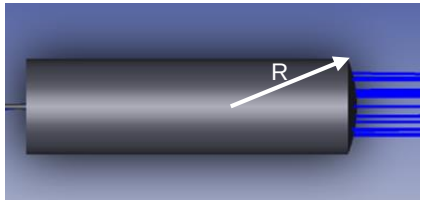
Modeled Insertion Loss – Polymer Lens

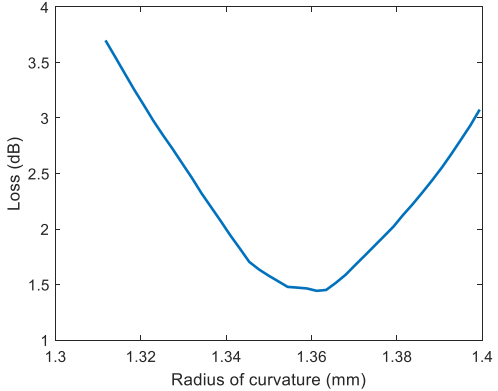




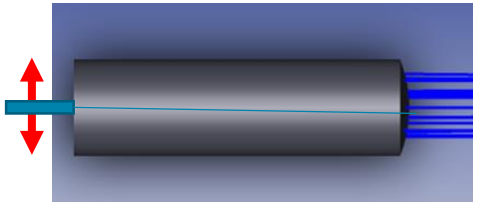
Modeled Insertion Loss Sensitivity

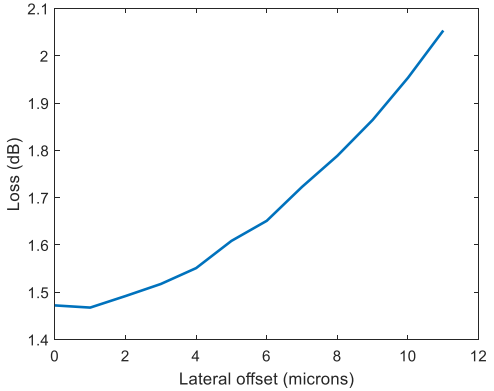
1. Radius of Curvature tolerances for additional losses of 0.3 dB = +/- 15 microns





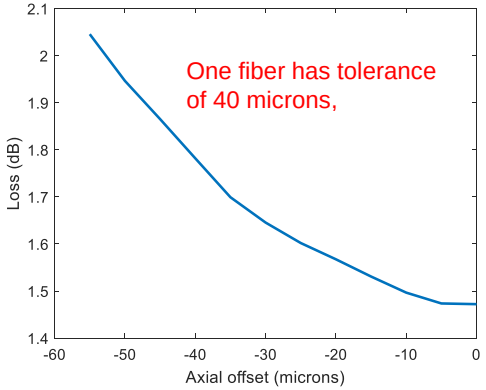
2. Lateral Offset for additional losses of 0.3 dB = +/- 8 microns, assuming +/- 4 microns per fiber (transmit and receive)





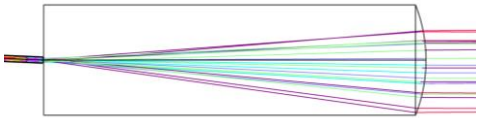
Modeled Insertion Loss Sensitivity continued

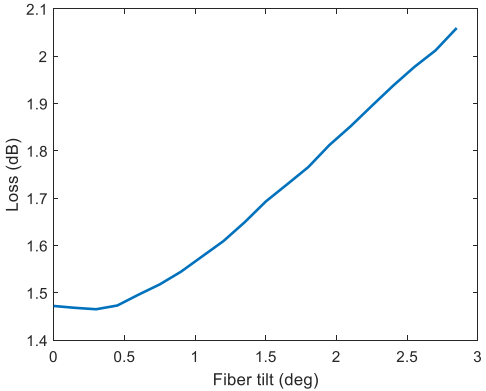
3. Longitudinal Offset per fiber for additional losses of 0.3 dB = +/-40 microns, assuming +/-20 microns for each fiber (TX, RX). One fiber has tolerance of 40 microns.



4. Angular misalignment between lenses for additional losses of 0.3 dB = +/- 0.9 degrees.

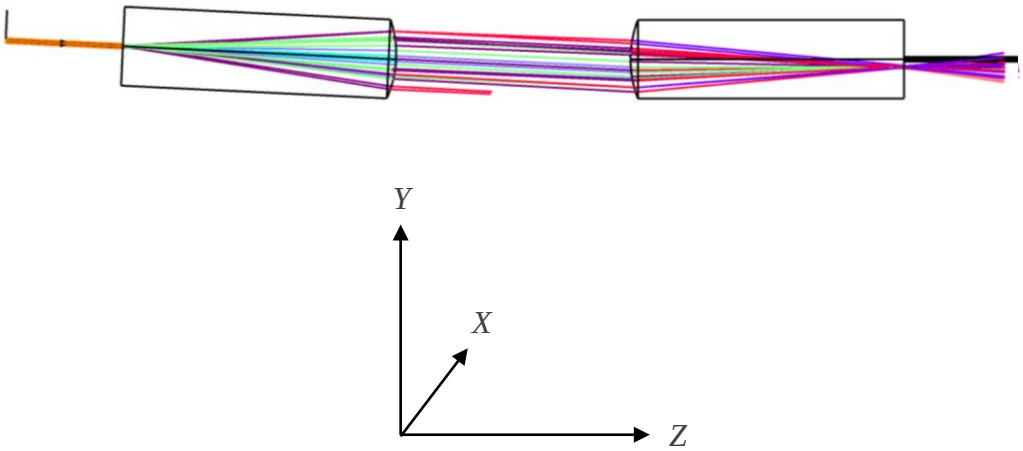
Note that tolerances +/- 0.5 degrees do not increase loss so +/-0.5 deg. it can be used independently

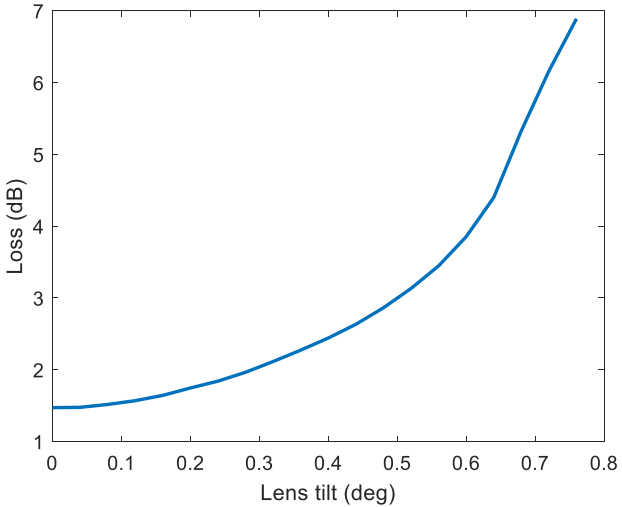




Modeled Loss vs angle (for 3 mm separation)

5. Angular misalignment between lenses for additional losses of 0.3 dB = +/- 0.22 degrees
   Total, +/- 0.11 degree relative to z axis
   = +/- 0.06 degrees for less than 0.1 dB





Commercial Expanded Beam Lens

C-Lens (Planner-Convex lens)

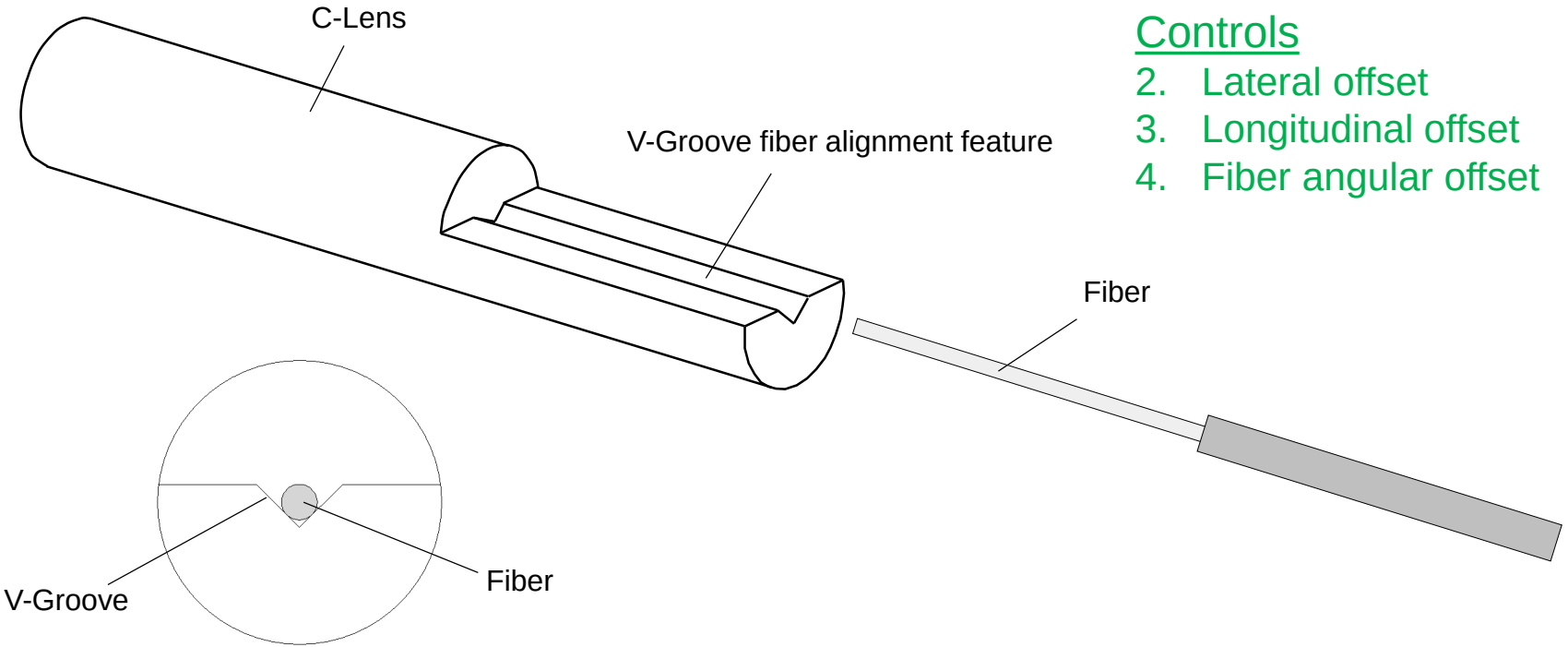
Standard C-Lens

REDESIGNED FOR LOW COST

1. **Molded Polymer material**
2. **Critical dimensions controlled by lens & mold design**
   - Includes a fiber alignment feature

Alternative C-Lens design

C-Lens designed to minimize angular displacement

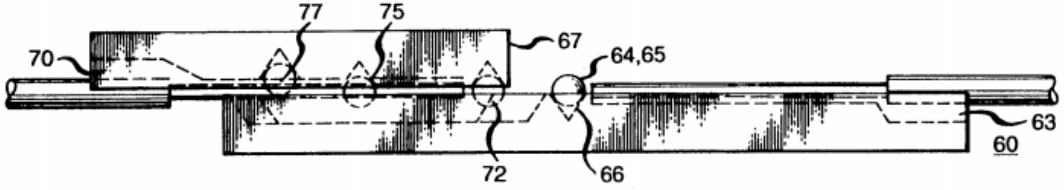


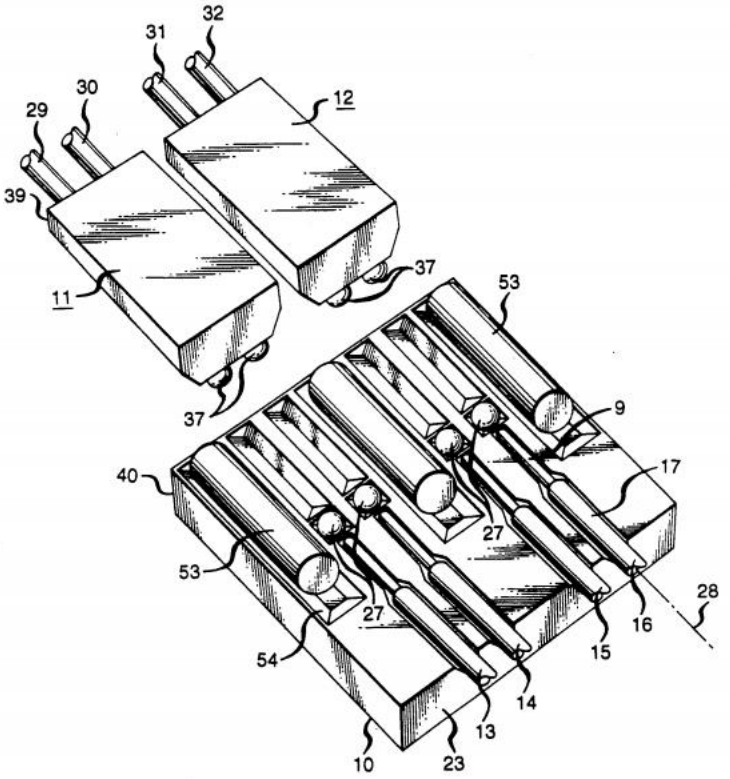
Controls

2. Lateral offset
3. Longitudinal offset
4. Fiber angular offset

USAF F-22 Raptor & F-35 Lightning

Ball lens multi-fiber connector

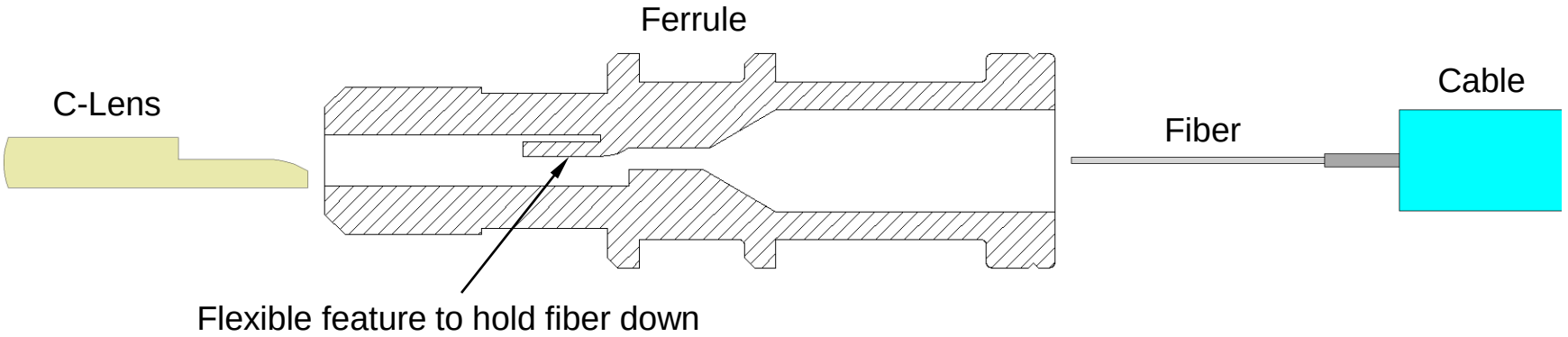


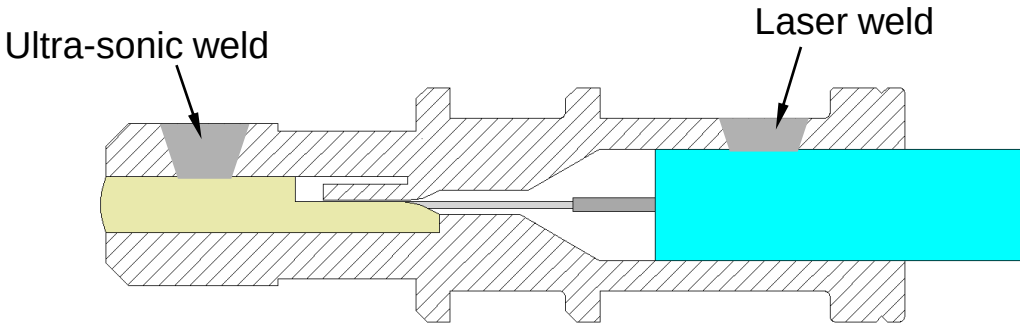


TESTING

- Monitored IL under adverse conditions
  - Shock & Vibration
- No performance impact due to
  - Salt Fog
  - Sand & Dust
  - Thermal Shock
  - Temperature excursions

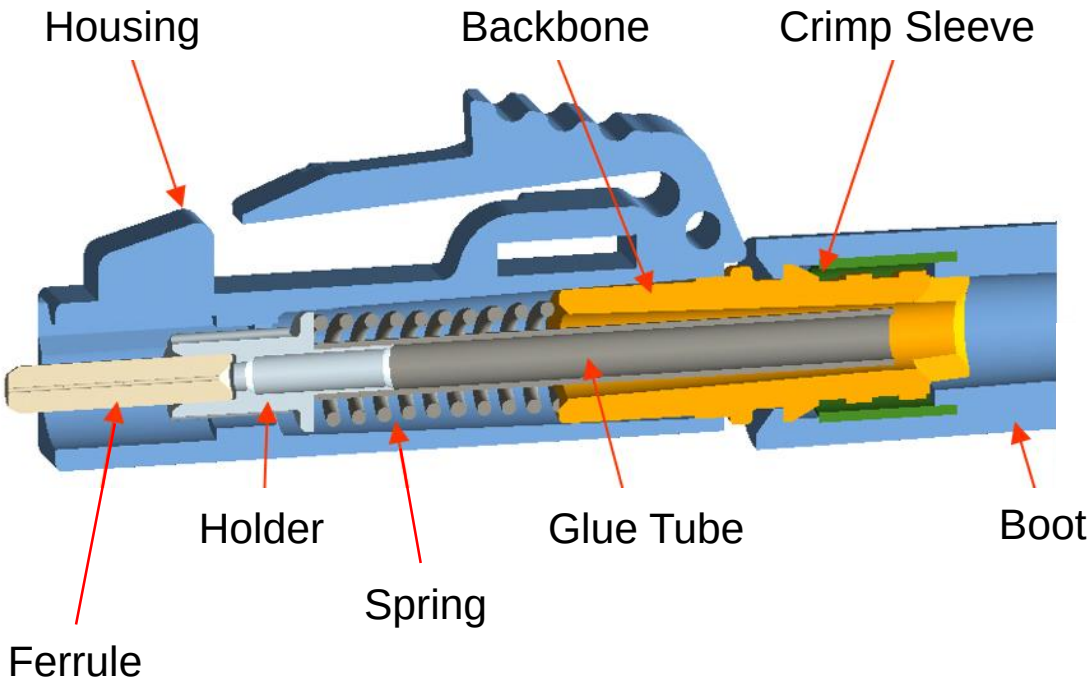
MMF MOST Expanded Beam Connector



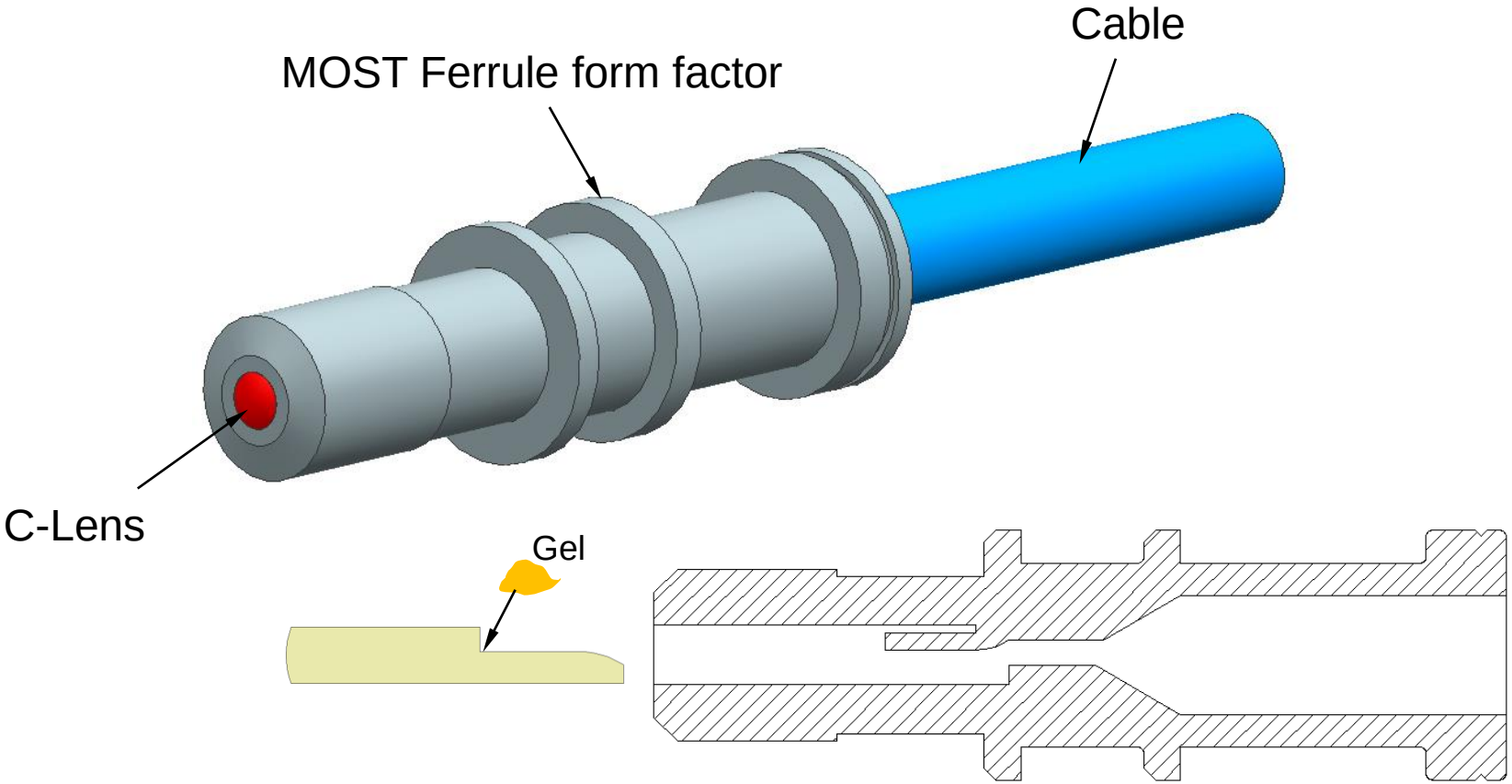


Relative Cost

Panduit LC Connector components

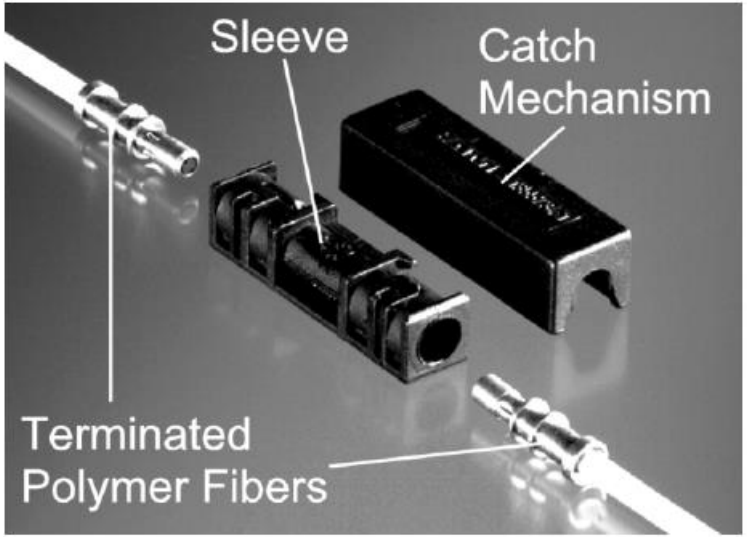


Expanded beam connector



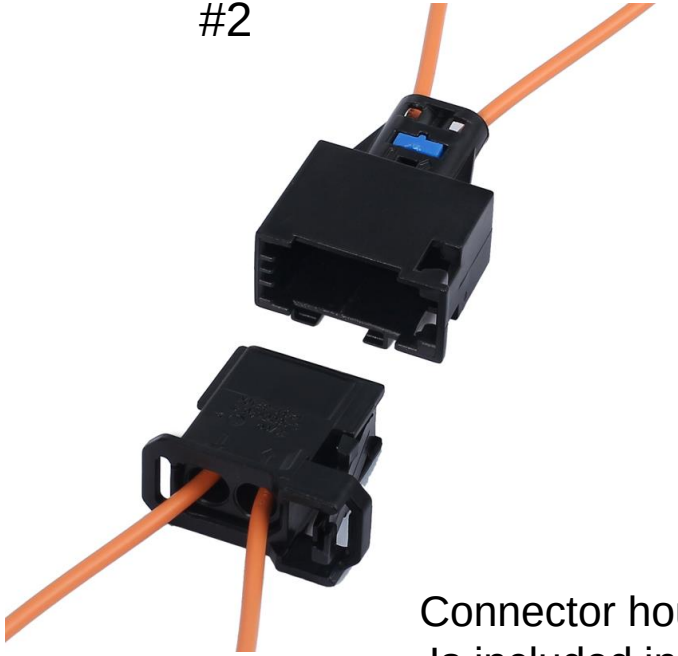
Scenarios

#1



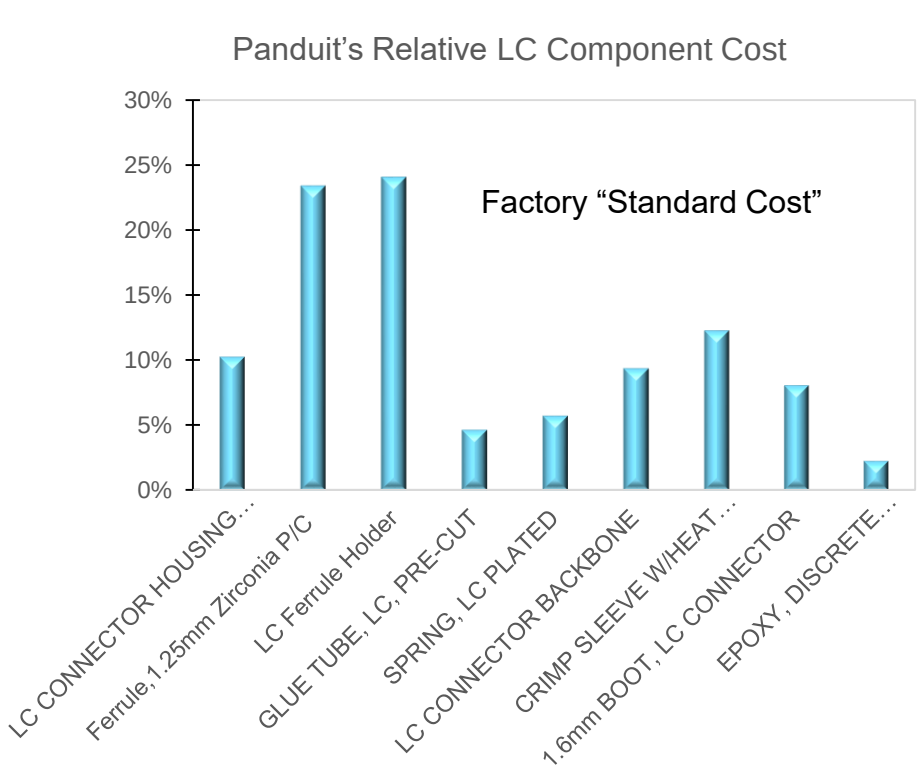
Inline adapter not included in connector cost

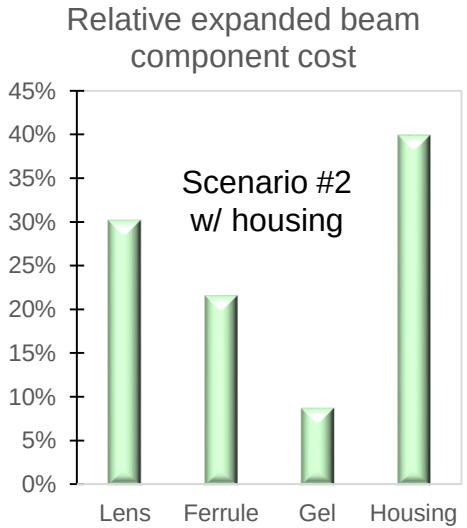
#2



Connector housing Is included in cost

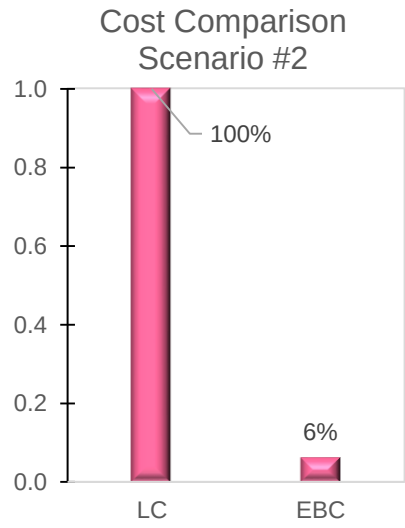
Relative connector cost comparison
– *Excluding assembly & polishing*





Total component cost = 0.14x

- EBC Housing = LC simplex housing
- No polishing required
- Fewer components
- Less assembly steps



For Scenario #1

- No housing
- EBC = 4%

Summary

- **Expanded beam connectors are the best option for automotive applications**
  - Lower cost than physical contact connectors
    - EBC components are 4% to 10% the cost of the LC components
    - No polishing required (expensive)
  - High tolerance to dirt particles
  - Ease of cleaning
  - Low sensitivity to shock and vibrations
- **A target loss of 1.5 dB is a good starting point for a IEEE proposal**
- **Tolerances were computed to allow for extra losses on the order of 0.3 dB**
  - Radius of Curvature: ± 15 microns
  - Lateral offset of fiber to Lens: ± 4 microns
  - Axial offset of fiber to lens: ± 20 microns
  - Tilt fiber relative to lens: ± 0.9 degrees relative to z axis,
    - Up to ± 0.5 degrees do not increase losses
  - Tilt between lenses: ± 0.11 degrees relative to z axis
  - Lateral offset: ± 37.5 microns relative to z axis
    - Up to to ± 10 microns with very low increase in losses

Questions