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Review of Fiber Optic Connector Technology

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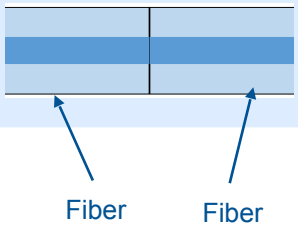
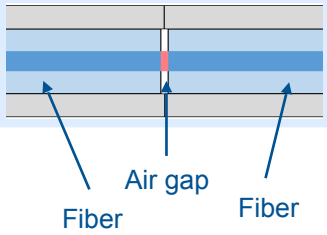
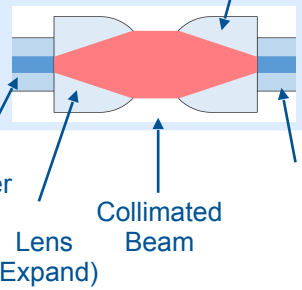
February 9, 2021

Motivation

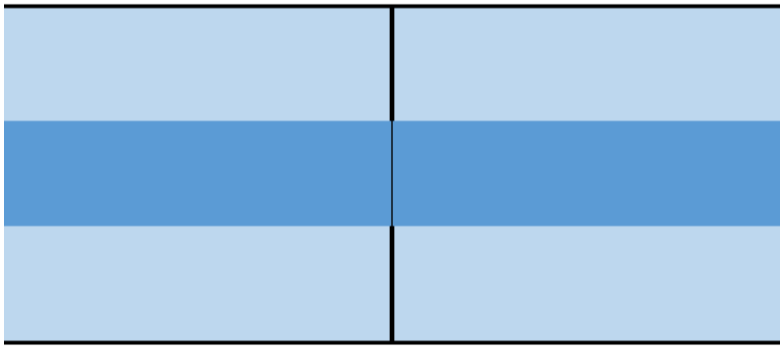
- IEEE 802.3cz is considering different fiber optic connector technologies for automotive applications
  - A contribution suggesting an expanded beam design has been reviewed by 802.3cz
    - https://grouper.ieee.org/groups/802/3/cz/public/9_jun_2020/pimpinella_3cz_01a_0620.pdf
  - Other connector designs have also been discussed
    - Physical contact connectors
    - Airgap connectors
  - A contribution on contamination was also reviewed by 802.3cz
    - https://grouper.ieee.org/groups/802/3/cz/public/jan_2021/fukuoka_3cz_01_0121_connector_dust.pdf
- This contribution is intended to compare the different technologies

Overview of key technologies

Characteristic	Physical contact	Narrow Air gap	Expanded beam
Picture of principle			

What is a Physical Contact connector?

- Traditional ferrule which is polished
  - Very high volume in service
  - Very low loss
  - High return loss
  - No coatings or post processing required
- Con: Higher sensitivity to contamination
- Neutral: Plethora of designs, utilizes standard ferrule, wide availability
- Our view – most mature technology; can be low cost; proven in high volume and harsh environment applications

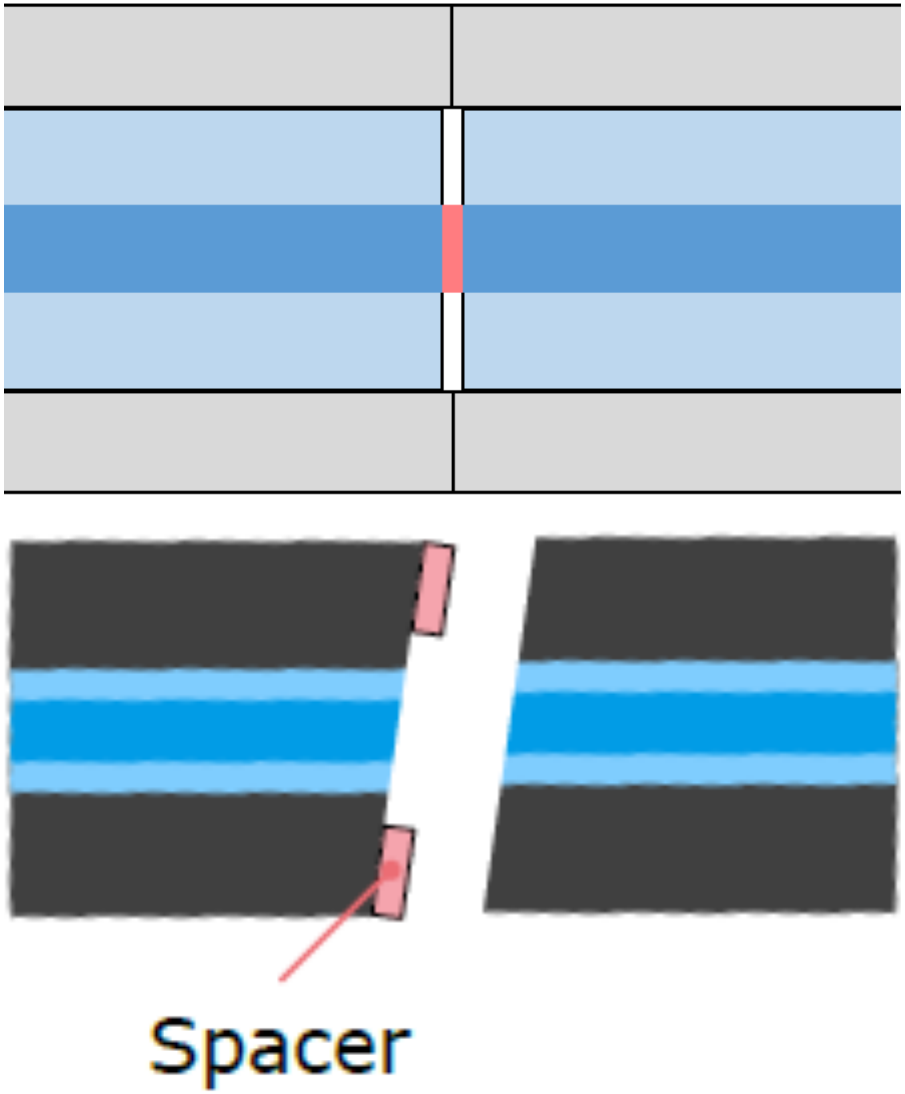


Observations - Physical Contact connectors

- Physical contact (PC) connectors represent the vast majority of fiber optic connectors deployed today
- It is a mature technology with a wide range of non-proprietary solutions and interoperable vendors and could be relevant for automotive applications
- PC also enables the best possible optical performance for most applications, although it can require care for deployment in the field
- The mating pressure of the PC connector prevents ingress of contaminants in the optical path while the connector is mated
- The PC connector has an advantage for liquid contamination
  - See reference to SPIE paper in back
- To help minimize these trade-offs, the industry has adopted standardized processes to polish, clean, and inspect PC connectors.

What is an Airgap connector?

- Process
  - Similar to Physical Contact with a “traditional ferrule” which is polished
  - Second polish step (or design) to create a step in connector end-face such that core/ cladding will have an airgap
  - Finally the connector end-faces are AR coated post polishing
- Compatibility with PC connectors is questionable
- Pro: Offers some improvement to debris sensitivity by reducing non-occlusion related losses (end face debris outside core)
- Con: Requires AR coating to achieve IL and RL comparable to PC connector
- Our view – good solution for low volume applications where high numbers of repeated matings are required (example test equipment interface)

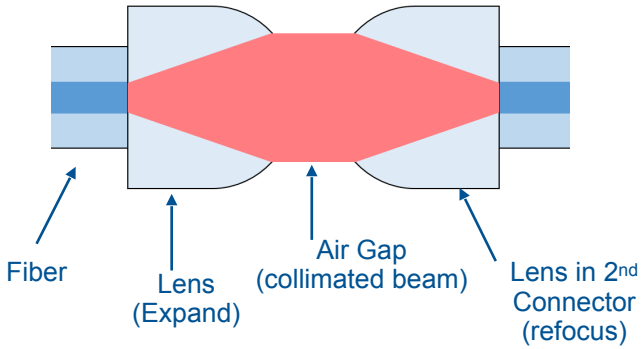


Observations - Airgap connectors

- Emerging technology that may be relevant to automotive applications
- Sealing may be necessary to prevent contamination entering the optical path while the connector is in the mated state
- Airgap connectors are typically proprietary designs from a few connector manufacturers

What is an Expanded Beam connector?

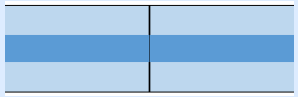
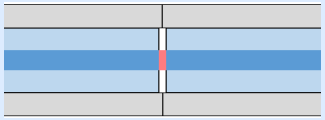
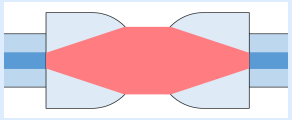
- Process
  - Lens coupled to a fiber
  - Index-matching gel typically required between fiber and lens body
  - AR coating on lens may be required
  - No polish required, only a laser cleave
- Pro: Offers reduced sensitivity to solid contamination
- Con: Not compatible with traditional PC connectors
- Our view – potential solution for in-vehicle applications



Observations - Expanded Beam connectors

- Various EB designs are used extensively in the military/aerospace industry
- In recent years, EB variants have been considered for other applications, e.g. data centers
- Sealing may be necessary to prevent contamination entering the optical path while the connector is in the mated state
- A mature industry but still largely proprietary and volumes are dwarfed by PC connectors

Summary of key technologies

Characteristic	Physical contact	Air gap	Expanded beam
Picture of principle			
Availability	Available in SM and MM	Available in SM and MM	MM available SM growing
Suppliers	Many vendors	A few vendors	Several vendors
Sensitivity to dust	High	High on fiber core Low/Med on other regions	Low
Sensitivity to liquid & condensing fluid in optical path	Low	Medium	Medium/High
Number of elements in optical path	2 (fiber/fiber)	5 (fiber/ARC/air/ARC/fiber)	9 (fiber/gel/lens/ARC/air/ ARC/lens/gel/fiber)
Required alignment accuracy	High	High	High for fibers to lenses and angle between lenses Low for lateral misalignment of lenses and axial distance of lenses
Compatibility with conventional PC	-	Questionable	No
Insertion loss (MM)	0.3 - 0.75 dB	0.3 - 0.75 dB with ARC	0.3 -1.0 dB with ARC
Return loss (MM)	Non-angled: 20 dB Angled: 45 dB	Angled: 45 dB with ARC	28 dB with ARC

Other topics needing consideration

- What connector configuration is needed?
  - Simplex, duplex, or multi-fiber?
  - Optical only or hybrid (optical + electrical)?
- What connector housing design is needed?
  - To meet the environmental requirements
  - To meet the mechanical requirements
  - To meet contamination requirements
    - Liquid ingress
    - Solvents
    - Dust
- Further discussion of the housing design is needed
  - For example: are shutters required? is sealing is required?

Testing of Fiber Optic Connectors for Automotive

- Specifiers should consider using existing industry standards to define use qualification requirements
  - IEC and ISO
- These standards serve as a good reference point, even if the user or OEM chooses to change the test and/or severity for their specific application
- Tests should include optical, mechanical, environmental and solvent resistance

Importance of connector cleanliness

- Regardless of the connector technology, cleanliness of the connector end face is critical to having a good link
  - See reference to SPIE paper in back
- Solid or liquid contamination at any connectivity point of an optical link may cause reduced performance or connector damage
- The industry has adopted standardized processes to polish, clean, and inspect fiber optic connectors
  - IEC 61300-3-35 standard outlines the pass/fail threshold level for the visual requirements for the end face quality
- There also have been several studies of contamination effects by iNEMI on PC and EB connectors

Cleaning methods and tools

- Removing contaminants from optical fiber and bulk heads without damaging the fiber requires special optical cleaning tools
- Many types of cleaning tools exist
  - Pen Cleaners
  - Cartridge Cleaners
  - Lint Free Wipes
  - Lint Free Swab
  - Adhesive-Backed Cleaner
  - Compressed Air
- Most cleaning tools can be used dry or “wet” with a specific detergent fluid
  - Dry cleaning is the most common and fastest cleaning method
  - In situations when contamination on connectors is unable to be cleared by dry cleaning alone, wet cleaning may be necessary

References

- Consortium For On-Board Optics Optical Connectivity Options for 400 Gbps and Higher On-Board Optics
  - COBO Connectivity Options for 400G+ OBO Application Note

- Geoff M. Proudley, Henry J. White, "Contamination effects in single-mode optical fiber connectors," Proc. SPIE 8720, Photonic Applications for Aerospace, Commercial, and Harsh Environments IV, 87200W (31 May2013); doi: 10.1117/12.2018074

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