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# Technical Feasibility of Glass Optical Fibers for Automotive Ethernet

PRESENTED BY:
G. Mabud Choudhury, OFS
mchoudhury@ofsoptics.com
John S. Abbott, Corning Incorporated
jabbottis@corning.com
John Earnhardt, OFS
jearnhardt@ofsoptics.com
Masato Shiino, Furukawa Electric Co. Ltd.
masato.shiino@furukawaelectric.com

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# Agenda

- Introduction
- Glass optical multimode fiber links for Enterprise and Data Center networks
- Glass optical fiber in harsh environment applications
  - Distributed Temperature Sensing
  - Aerospace/Avionics
- Technical feasibility for Automotive environments based on glass, optical multimode fiber for IEEE
- Photonics in Automotive
- ISO and IEC standardization for Automotive
- Summary and future work

## Corning, OFS, Furukawa Electric Group Experience

- Corning, OFS, and Furukawa have experience both in applying optical fiber with industrialized coating and cabling in harsh environments, as well as experience with the automotive industry in other areas.

- See backup slides for more information on experience.

## Introduction

- The IEEE 802.3 Ethernet standards group has two current projects P802.3cy and P802.3cz looking at standards for higher data rate Ethernet in vehicles. P802.3cy is looking at "electrical/copper" standards, and P802.3cz is looking at "optical/fiber" standards.

- The IEEE P802.3cz Multi-Gigabit Optical Automotive Ethernet Task Force is looking at data rates of 2.5, 5, 10, 25, 50 Gb/s (up to 50 Gb/s per lane) over distances of 15m-40m in vehicles.

- As the data rates increase, optical links have transitioned from LEDs to high-speed vertical-cavity surface-emitting lasers (VCSELs) which were first seen in CD-players but are now ubiquitous.

- This presentation will focus on the technical feasibility of glass optical multimode fibers (MMF, OM3 type) whose specifications are optimized to work with high speed VCSELs

- OM3 fiber is available with industrialized coating and cabling suitable for automotive.

# Automotive Ethernet – IEEE 802.3 Standards, Task Forces (TF)

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| IEEE Standard/TF | Name | Start Date | Completion Date | Speed | Cabling | Inline Connectors | Reach |
|---|---|---|---|---|---|---|---|
| IEEE Std 802.3bp™-2016 | 1000BASE-T1 | 3/2012 | 6/2016 | 1 Gb/s | Cu | 4 | 15 m, 40 m |
| IEEE Std 802.3bw™-2015 | 100BASE-T1 | 3/2014 | 10/2015 | 100 Mb/s | Cu | 4 | 15m |
| IEEE Std 802.3bv™-2017 | 1000BASE-RH | 3/2014 | 2/2017 | 1 Gb/s | POF | 4, 0 | 15m, 40 m |
| IEEE Std 802.3cg™-2019 | 10BASE-T1S / -TL | 7/2016 | 11/2019 | 10 Mb/s | Cu | 4, 8 nodes, 10 | 15 m, 25 m, 1 km |
| IEEE Std 802.3ch™-2020 | 2.5/5/10G BASE-T1 | 11/2016 | 6/2020 | 2.5, 5, 10 Gb/s | Cu | 4 | 15 m |
| P802.3cy TF | | 3/2019 | 06 - 09 2023* | 25, 50, 100 Gb/s 1, 2, 4 lanes | Cu | 2 | 11 m |
| P802.3cz TF | | 7/2019 | 07/2023* | 2.5, 5, 10, 25 Gb/s 50 Gb/s | Optical | 4 2 | 40 m 15 m |

*Target completion date for standard based on project timeline

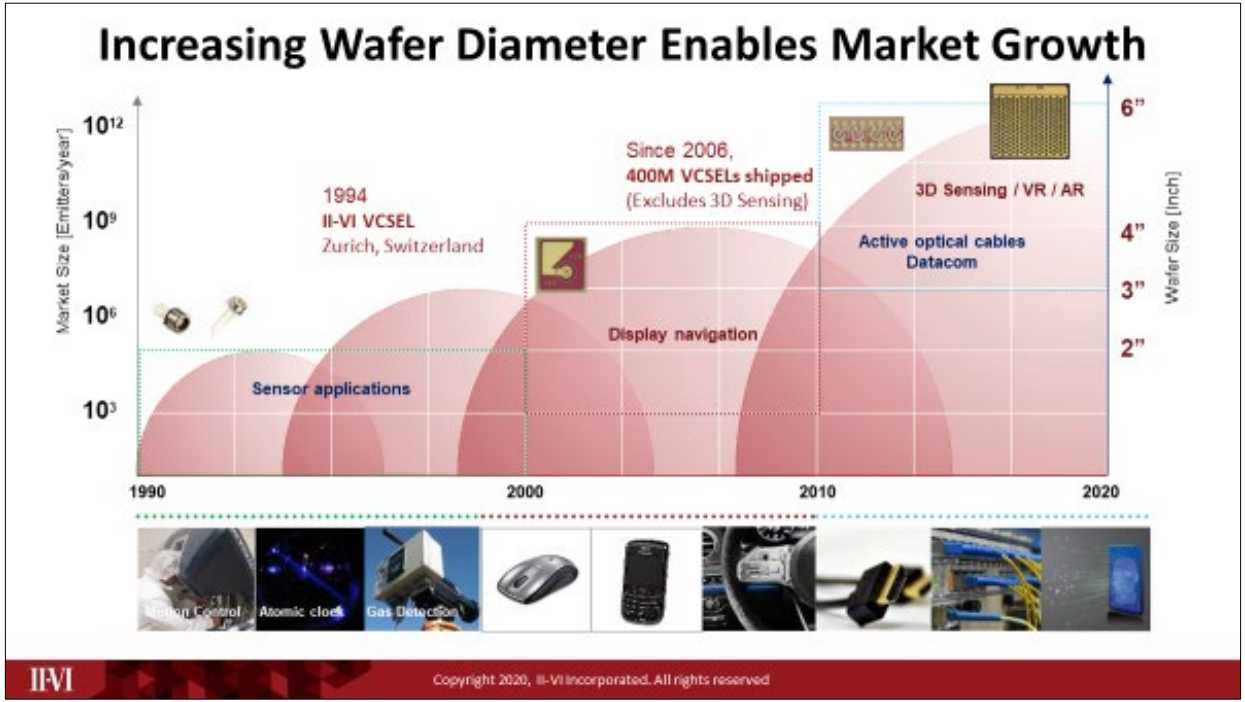
## Multimode Fiber (MMF), OM3

- Multimode fiber (MMF) is a type of glass optical fiber mostly used for communication over shorter distances at higher data rates (typically > 1 Gb/s).
- In multimode fiber, light is carried over a number of different paths, or modes.
- Laser optimized multimode fiber (LOMMF) is specifically optimized to work with relatively low-cost, high data rate, vertical-cavity surface-emitting lasers (VCSELs).
- OM3 is a type of LOMMF (types are differentiated by bandwidth).
- OM3 is 50/125 µm (core/cladding diameters) graded-index, glass optical laser optimized multimode fiber.

| *(described in the industry using primarily the **ISO/IEC 11801** designations)* | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Industry Standards | | | | | Attenuation - Typical Cabled Max. (dB/km) | | Bandwidth (MHz-km) Overfilled Launch (OMBc) | | Bandwidth (MHz-km) Effective Modal Bandwidth (EMB) (also known as Laser BW) | |
| Fiber Type | ISO/IEC 11801-1 Nov. 2017 | IEC 60793-2-10 May 2019 | TIA-568.3 2021 draft | TIA/EIA 492AAAF April 2020 | ITU-T Dec. 2008 | 850nm | 1300nm | 850nm | 1300nm | 850nm | 953nm |
| 62.5/125 | ~~OM1~~ | A1-OM1 | ~~TIA-492AAAF (A1-OM1)~~ | A1-OM1 | — | 3.5 | 1.5 | 200 | 500 | — | — |
| 50/125 | ~~OM2~~ | A1-OM2 | ~~TIA-492AAAF (A1-OM2)~~ | A1-OM2 | G.651.1 | 3.5 | 1.5 | 500 | 500 | — | — |
| 50/125 | OM3 | A1-OM3 | TIA 492AAAF (A1-OM3) | A1-OM3 | — | 3.0[2] | 1.5 | 1500 | 500 | 2000 | — |
| 50/125 | OM4 | A1-OM4 | TIA 492AAAF (A1-OM4) | A1-OM4 | — | 3.0[2] | 1.5 | 3500 | 500 | 4700 | — |
| 50/125 | OM5 | A1-OM5 | TIA 492AAAF (A1-OM5) | A1-OM5 | — | 3.0 | 1.5 | 3500 | 500 | 4700 | 2470 |

# VCSELs – Growing Volume & Markets

- Economic feasibility of VCSEL-MMF links based on high volume, low-cost, high data rate VCSELs




Source: II-VI. Used with permission from II-VI

# VCSEL-MMF Links for Enterprise & Data Center Applications

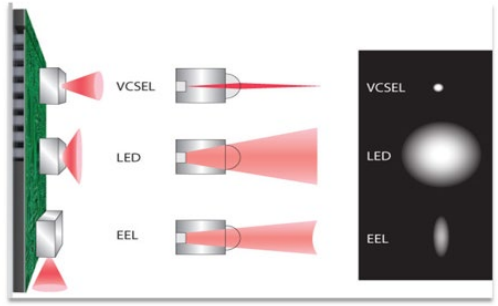
*20+ years of 10+ Gb/s Multimode Fiber in Data Centers*

- VCSELs:
  - **Low cost**, manufacturability, integration, reliability, testability, scalability, packaging, custom packaging, **low power**
- MMF:
  - **Larger core size decreases alignment costs, leading to lower cost connectivity solutions** relative to SMF
  - **Higher resilience to contamination**. Higher usability relative to SMF
  - Higher fiber cost, but **lower link cost**
- High volume, reliable, interoperable, commercially successful solutions
- Established short reach solution for high-speed networks over the past 20 years

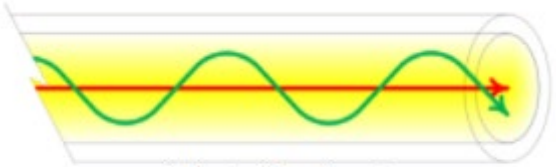
High data rate
Low cost

Low data rate

High data rate



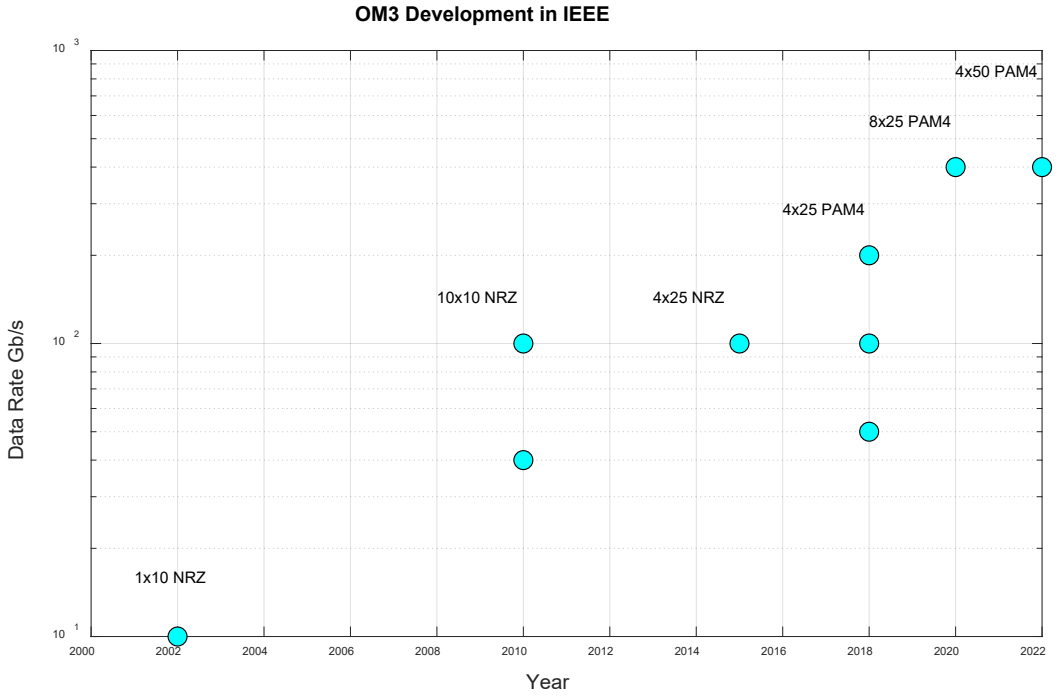

Source: II-VI/Finisar




Source: OFS

# 20+ years of 10+ Gb/s Multimode Fiber in Data Centers

- The 50μm OM3 multimode fiber was developed in 2002 in concert with the development of 10Gb/s VCSELs as a low- cost solution for data centers.
- The fiber has continued to be used at higher data rates and incorporated into IEEE standards for the last 20 years.
- 50G PAM4, 100 Gb/s per lane
- Millions of kms of OM3/OM4 fiber have been deployed in data centers in many millions of links.



# Glass Fiber in Multiple Markets with Challenging Environments

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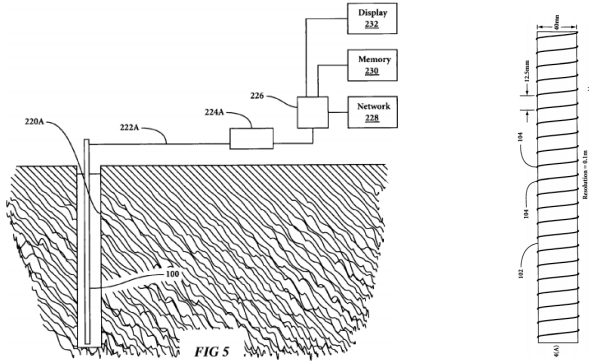
# Cabling for Harsh Environment: Distributed Temperature Sensing

- Multimode Fibers are used in the oil and gas industry as distributed temperature sensors enabling scientists and engineers to map out temperatures under the earth.
- The fibers are protected by special cabling which can withstand the harsh environment including temperatures of 200+º C (references below).
- References:
  - Smolen and van de Spek, “Distributed Temperature Sensing: A DTS Primer for Oil and Gas Production”, 2003
    - http://drilling.posccaesar.org/export/385/projects/DailyProductionReport_1.0/XML/Version1.0/WITSML131/doc/Shell_DTS_Primer.pdf
  - Fenta, Potter, and Szanyi, “Fibre Optic Methods of Prospecting: A Comprehensive and Modern Branch of Geophysics”, *Surveys in Geophysics* (2021)
    - Open Access: https://link.springer.com/article/10.1007/s10712-021-09634-8
- The high-temperature MMF cabling for sensing can be tailored for the automotive environment. Lower cost based on higher volume of automotive market.

DATA PROCESSING

Backscattered light


Source: https://www.corning.com/catalog/coc/documents/articles/distributed-sensing-cable-in-industrial-environments.pdf




Source: Brian et al., US2012/0010846 A1 Jan 12, 2012

# Proven Performance and Reliability In Transportation
# Fiber Optics in Aerospace

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- First used in rigorous military applications – more than 25 years
- Data backbone on F-16, F-18 variants, F-22, and Joint Strike Fighter (JSF)
- Retrofit in various airframe upgrades: C-130 Hercules
- Initial commercial uses in non mission critical applications: e.g. in-flight entertainment
- Proven success is generating further commercial implementation
- Military and commercial are adopting higher data rates, pushing toward higher bandwidth multimode fibers (e.g., OM3 and OM4)
- Multi-fiber cables also in active development

# Aerospace Requirements - Similar to Automotive

*Wide temperature range and robust mechanical performance*

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**High reliability and long lifetime**
- 20+ years

**Wide operating temperature range**
- -55º C to +125º C for commercial aerospace, higher for military

**Tight bends and repeated flexing**
- 9 mm bend radius

**Installation stresses**

**Crush/clamping stresses**
- Resistance to microbending losses as well as mechanical damage

**Chemical resistance as a cable**
- Various oils, fuels, fluids, salt spray, etc.

**Flammability**
- FAA, SAE, and OEM specific tests

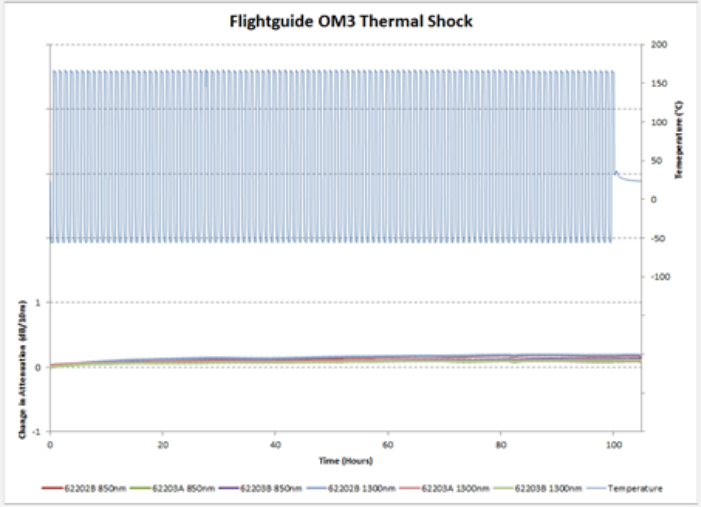
**Smoke and Toxicity Issues**
- Low Smoke Zero Halogen an issue for applications in passenger areas

# Thermal testing of Avionics Cable

*Shock at -55º C to +165º C*

## Thermal Shock

This test was performed in accordance with FOTP-3. The temperature extremes were -55°C to +165°C. One hundred cycles were performed with a 0.5 hour dwell at each temperature extreme. The sample lengths were 10 meters. Optical performance was monitored at both 850nm and 1300nm. Max attenuation change <0.20 dB




| Permanent Change in Attenuation (dB/10m) after Test | | | | | |
|---|---|---|---|---|---|
| 62202B 850nm | 62203A 850nm | 62203B 850nm | 62202B 1300nm | 62203A 1300nm | 62203B 1300nm |
| **0.17** | **0.09** | **0.13** | **0.19** | **0.09** | **0.11** |

# Thermal testing of Avionics Cable

*Cycling at -55⁰ C to +165⁰ C*

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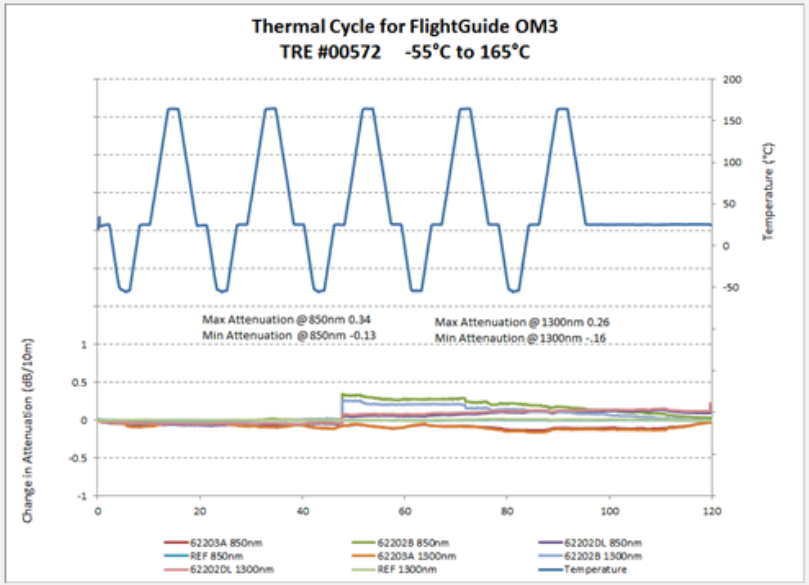
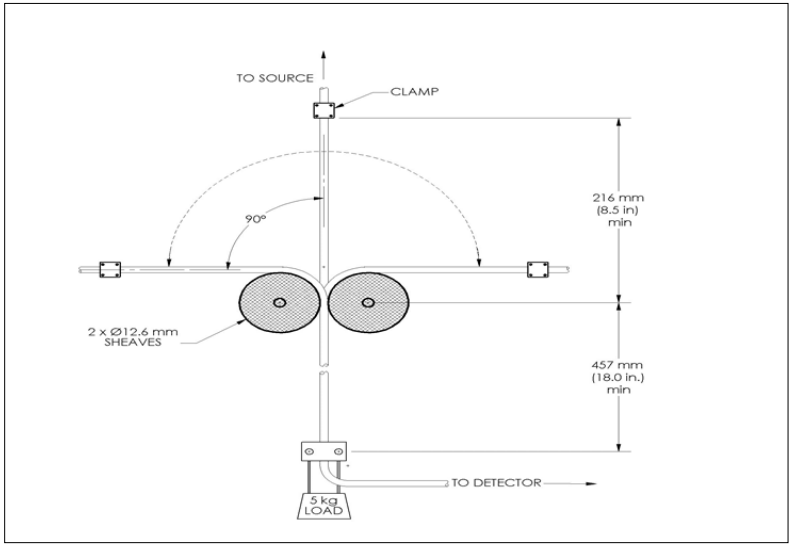
## Thermal Cycling

This test was performed in accordance with FOTP-3. The temperature extremes were -55°C to +165°C for a total of 5 cycles. The dwell time at ambient and each temperature extreme was 1 hour. The sample lengths were 10 meters. Optical performance was monitored at both 850nm and 1300nm. Max attenuation change <0.35 dB



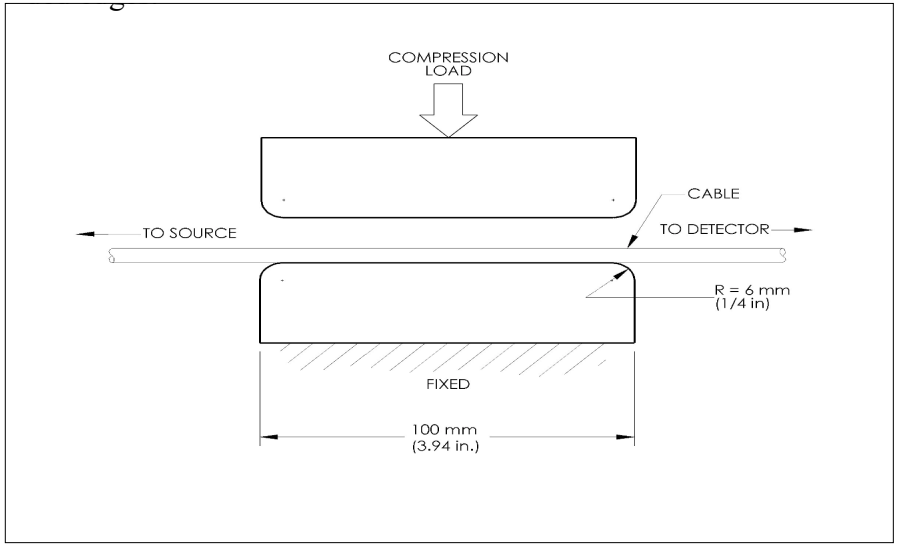
# Avionics Fiber Optic Qualification

*Selected Mechanical Tests at 850 & 1300 nm*




## Cyclic Flex

- 10k cycles
- Max attenuation change <0.4 dB

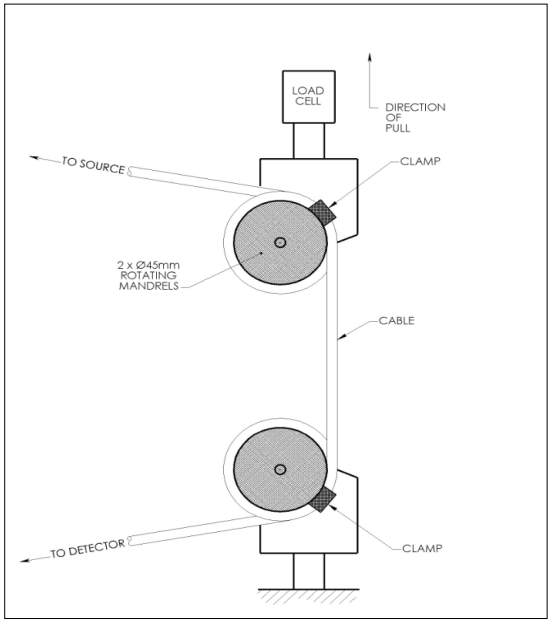



## Compression

- Max load reached 4500 lbs
- Max attenuation change <0.15 dB

# Avionics Fiber Optic Qualification

*Selected Mechanical Tests at 850 & 1300 nm*



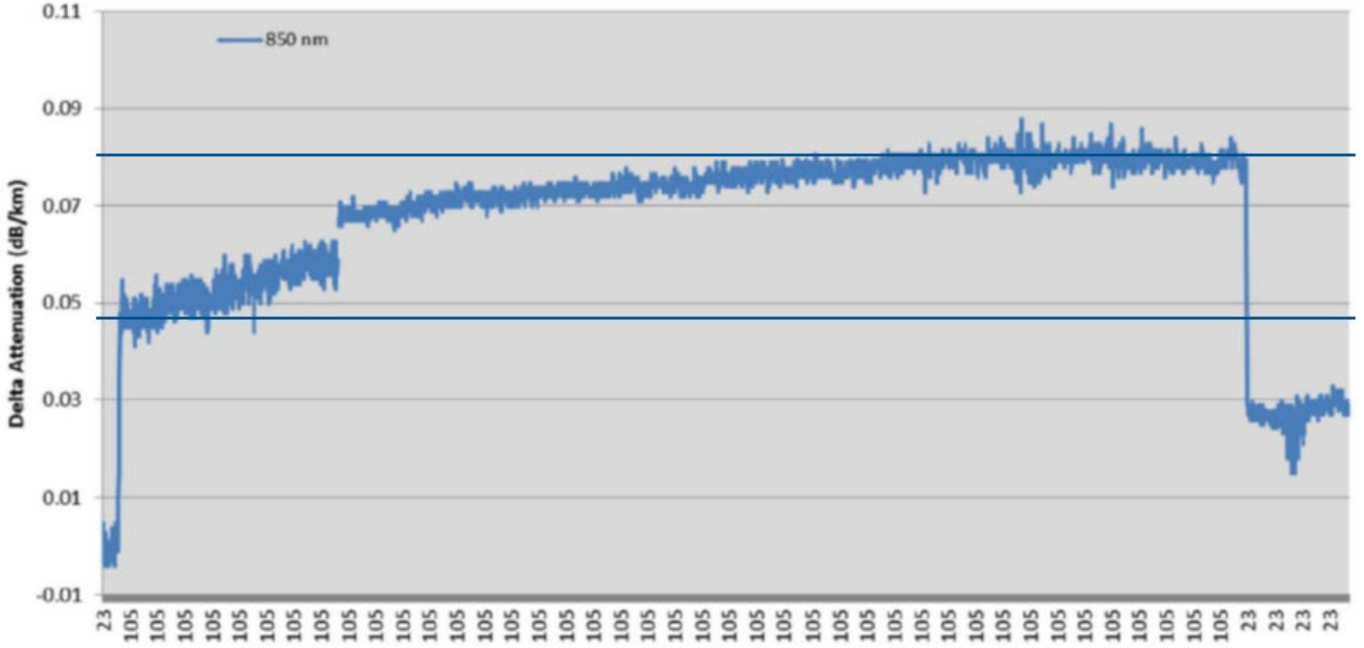

## Tensile loading and bending

Max load to 600N, 45 mm diameter

Max attenuation change <0.05 dB

# Testing Specifically for Automotive Temperatures

Test at Corning of OM3 fiber for 3000 hours at 105º C.
Less than 0.04dB variation in attenuation



# 25 Gb/s Transmission over Harsh Environment Multimode Fiber

*Technical Feasibility (Corning Fiber)*

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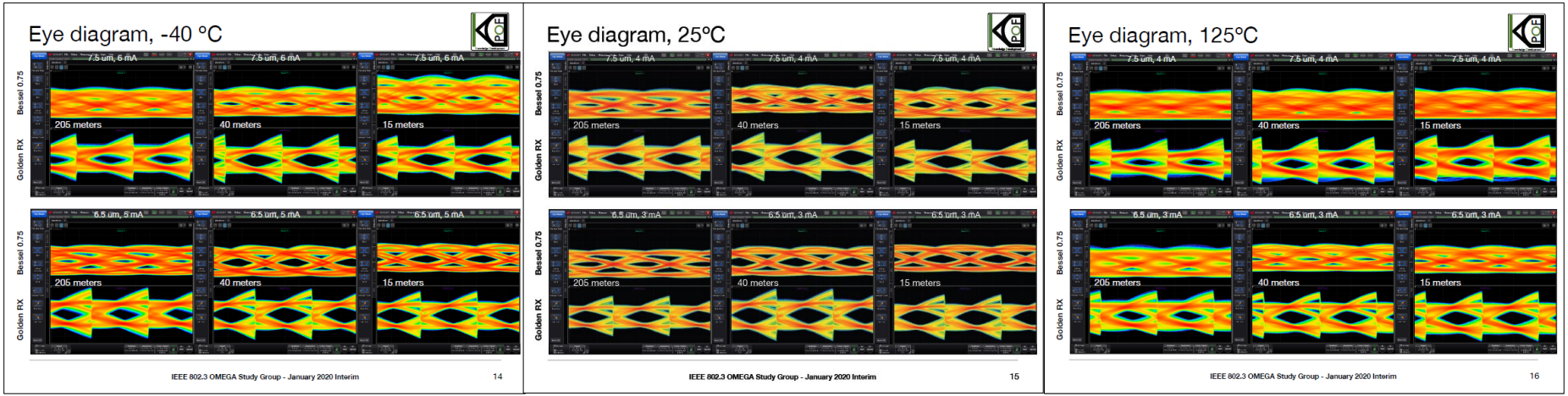
Corning MM50BI-XMT-H (GI glass fiber OM3)
15 m, 40 m, and 205 m
TRUMPF VCSEL-ULM850-25-TT-V03

Open eye at much longer distances than required at -40, +125




Source: https://www.ieee802.org/3/OMEGA/public/jan_2020/perezaranda_OMEGA_02_0120_25G_Corning_fiber.pdf
Acknowledgment:: Rubén Pérez-Aranda (KDPOF)

Lower diagrams after planned signal processing

# 25 Gb/s Transmission over Harsh Environment Multimode Fiber

*Technical Feasibility (OFS fiber)*

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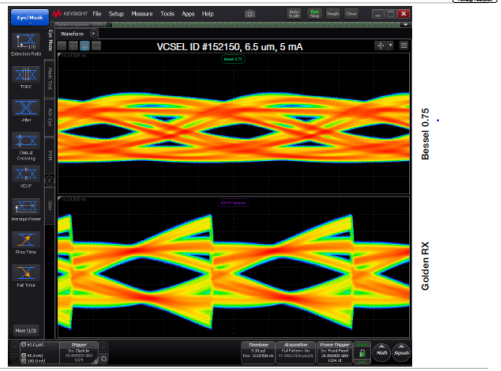
## OFS C24712, FlightLinx® 50 µm OM3 Optical Cable, 100 m
## TRUMPF VCSEL-ULM850-25-TT-V03

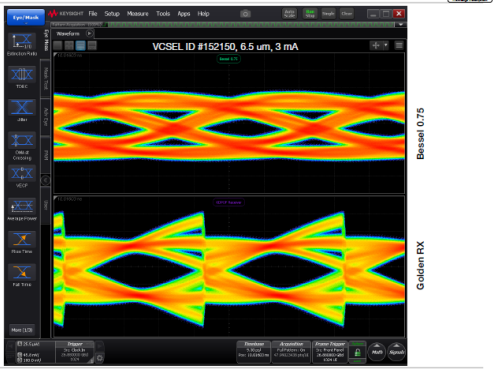
Open eye at much longer distances than required at -40, +125

Eye diagram, -40 °C, 100 m



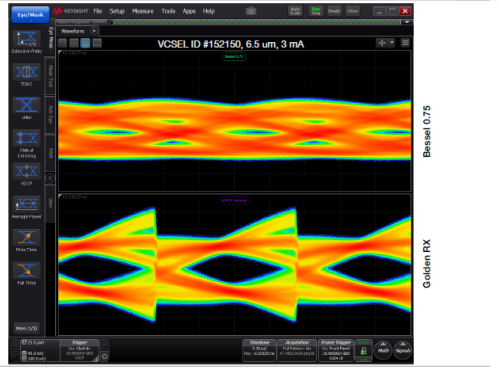

IEEE 802.3 OMEGA Study Group - January 2020 Interim 12

Eye diagram, 25°C, 100 m




IEEE 802.3 OMEGA Study Group - January 2020 Interim 13

Eye diagram, 125°C, 100 m

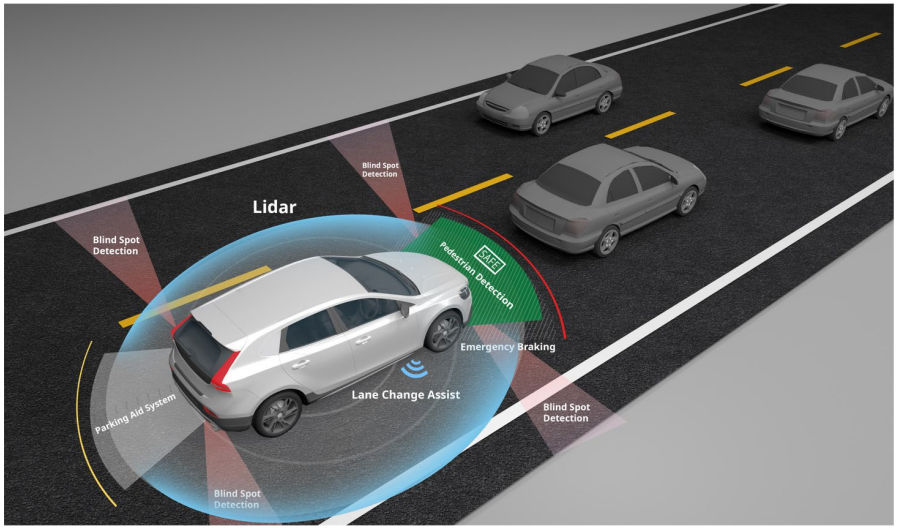



IEEE 802.3 OMEGA Study Group - January 2020 Interim 14

Source: https://www.ieee802.org/3/OMEGA/public/jan_2020/perezaranda_OMEGA_03_0120_25G_OFS_fiber.pdf
Acknowledgment:: Rubén Pérez-Aranda (KDPOF)

Lower diagrams after planned signal processing

# Get ready for Photonics in Automotive




Source: Adobe Stock (licensed)

- Many companies working on LiDAR systems
- Some system architectures utilize optical fibers and VCSELs
- 3D sensing and automotive volumes drives economic feasibility
- LiDAR systems are now undergoing integration and qualification

# ISO standardization trends

ISO/TC22 Road vehicles

TC : 252

SC31 Data communication

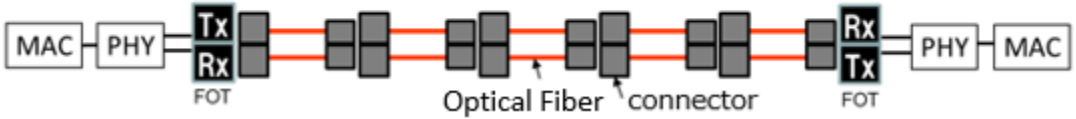
**WG3**
In-vehicle networks

**ISO SC31: Data Communication** (System)

SC32 Electrical & electronic components & general system aspects

**WG10**
Optical components and test methods

**ISO SC32: Hardware** (Harness, Module, connector)




Source: https://www.iso.org/technical-committees.html

# ISO 24581

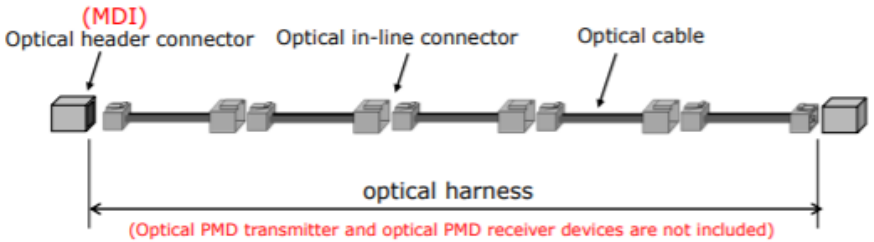
*General requirements and test methods of in-vehicle optical harnesses for up to 100Gbit/s communication*

## New Activity: ISO/PWI 24581

TC22/SC32/WG10 is now starting for the standardization of optical fiber harness for future (higher speed) automotive application.

**Title:**

**General requirements and test methods of in-vehicle optical harnesses for up to 100Gbit/s communication**

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Connect with Innovation

-6-

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Source: https://www.ieee802.org/3/cz/public/15_dec_2020/fukuoka_3cz_01a_151220_ISO24581.pdf

# Multi-Gig Optical Automotive Ethernet and IEC

- IEEE currently references IEC standards in all Ethernet Standards
  - The Automotive application is unique and one that IEC will address
- Initial progress
  - TC 86  Fibre optics Technical Committee
    - Established a liaison with IEEE 802.3 and IEEE 802.3cz with Vince Ferretti as liaison
  - SC86A will consider
    - High temperature fiber standards
    - New cable designs specific to automotive
  - SC86B will consider
    - New service environment definitions for automotive
    - New connector designs specific to automotive
  - SC86C will consider
    - Transmitters - VCSELs and Silicon Photonics
    - High temperature VCSEL reliability
    - Harness test standards

Source: Steve Swanson, Corning/US Delegate

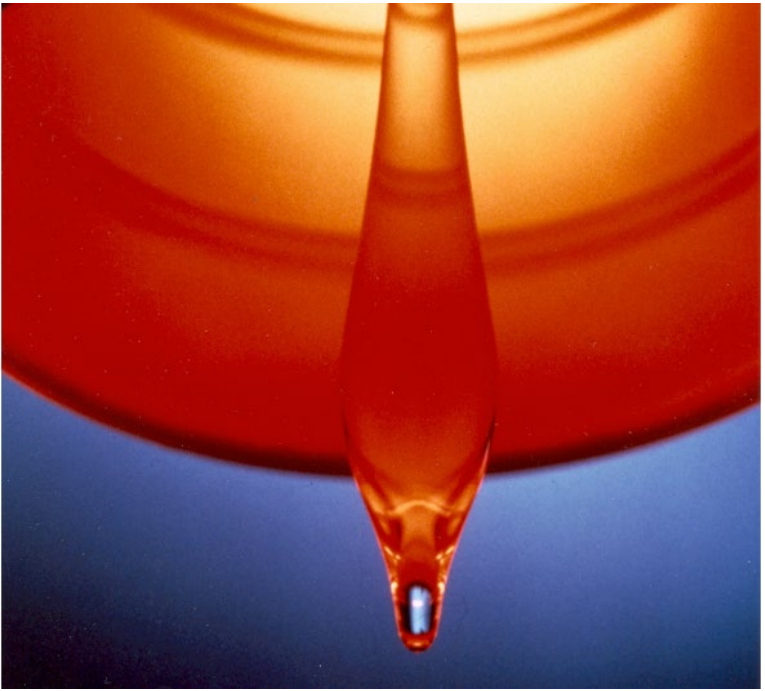
# Summary and Future Work

- It was shown that there is technical feasibility and reliability of glass optical fiber for in-vehicle communication based on:
  - A 20+ year foundation of reliability and commercialization of VCSEL-MMF short-reach, high data rate links for data centers.
  - The extensive use of glass optical fibers in multiple harsh environment applications, some more severe environments than automotive.
  - Testing of high temperature OM3 to automotive temperature requirements. Data transmission testing of VCSEL-OM3 links to automotive temperature range.
- The high volumes associated with applications such as 3D sensing and with automotive drive the economic feasibility of VCSEL-OM3 links.
- Future work:
  - IEEE P802.3cz contributions to progress the standard.
  - Develop ISO and IEC glass optical fiber, cable, harness standards for automotive.
  - Test to ISO TC22/SC32/WG10 and IEC 86 specifications for fiber, cable, harness.
  - Test to any OEM-specific requirements for glass optical fiber, cabling, harness.

# Thank You!

# Backup Slides

# Experience with Specialty Optical Fiber



Both OFS and Corning make specialty optical fiber with fiber, coating, and cabling designed for stringent requirements including high temperature applications.

Coating and fiber cabling rated up to 180+º C.

Protection against changes in attenuation and strength.

Application to vehicle harnesses requires applying these technologies to low-cost, high-reliability solutions meeting automotive requirements.

# Experience with Automotive Harnesses & Cabling

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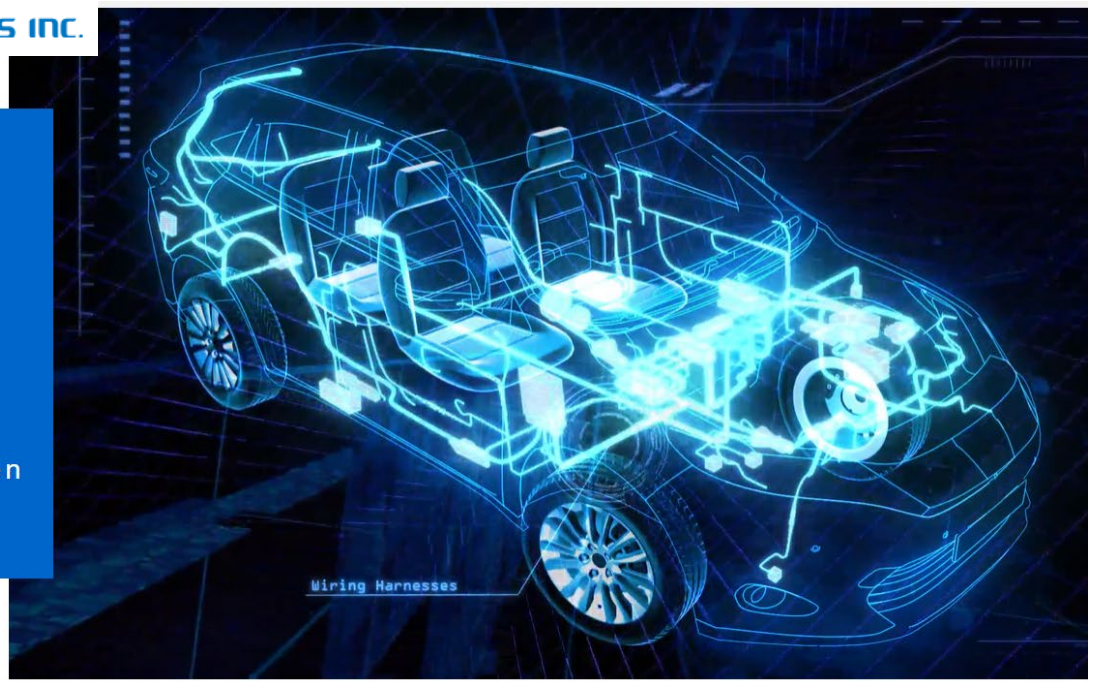
FAS FURUKAWA AUTOMOTIVE SYSTEMS INC.

FURUKAWA ELECTRIC GROUP

Communication Technology between

Driver + Vehicle

Technologies to Enhance Communication Between People and Cars



# IEEE P802.3cz plans to use OM3 fiber for 2.5 to 50 Gb/s Ethernet

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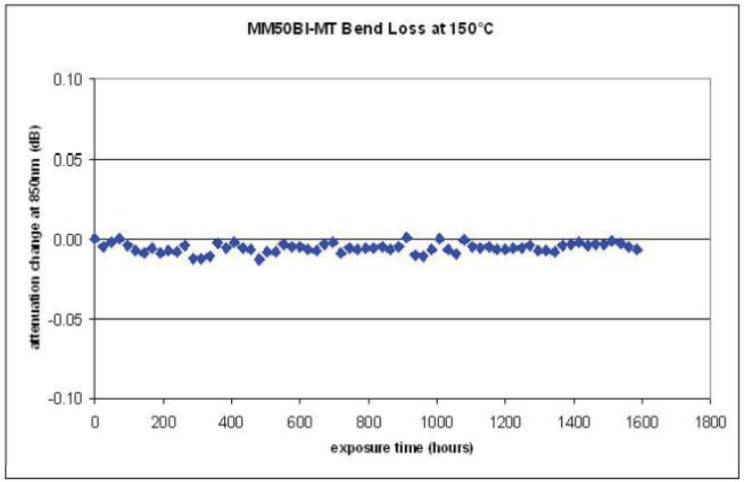
## Bending @ Temperature




**Aged Bend Loss At 150°C, MM50BI-MT (1,600 hours)**

MM50BI-MT fiber was exposed to 150°C continuously. Fiber was deployed in a single turn on a 7.5mm radius mandrel.

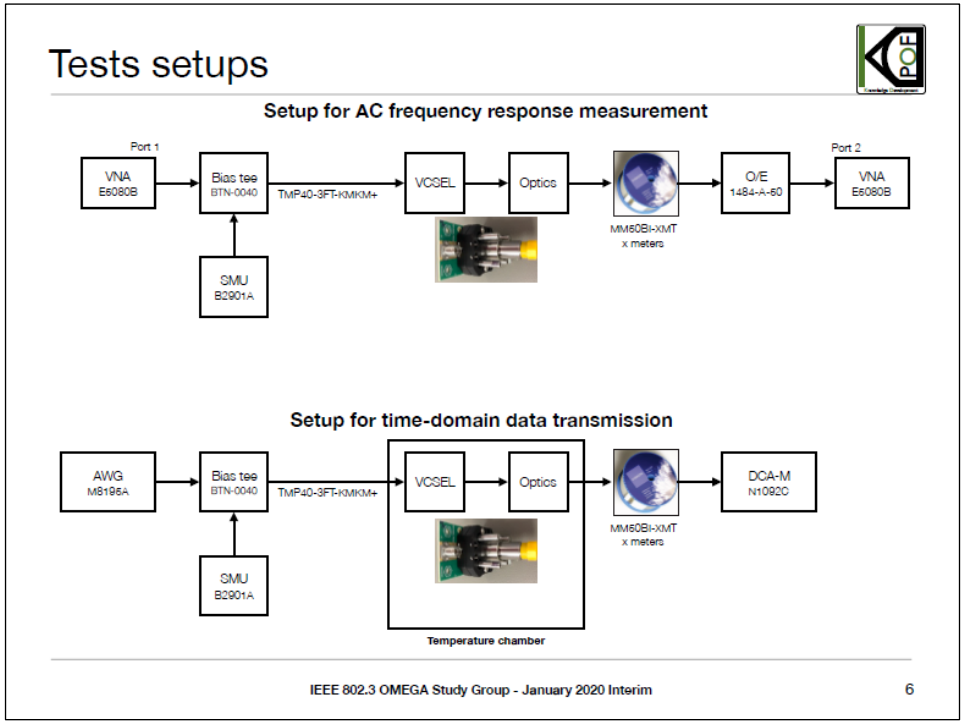
## Corning® Specialty Optical Fiber Suite

| Glass Type | | | Coating Type (Hermetic Coatings available on all fibers) | | |
|---|---|---|---|---|---|
| | | | Standard Acrylate | Mid Temp Acrylate | |
| | | Max Operating Temp (°C) | 85°C | 150°C | 180°C |
| Standard | | Single-mode (Ge-doped core) | SMFHA | SM-MT<br>SMH-MT | SM-XMT<br>SMH-XMT |
| | | Multimode Graded Index (Ge-doped core) | MMFHA | MM50-MT<br>MM50H-MT | MM50-XMT<br>MM50H-XMT |
| Bend Insensitive ClearCurve® | | Single-Mode Min Bend Radius = 5mm | SMBIH-5-A | SMBI-5-MT<br>SMBIH-5-MT | SMBI-5-XMT<br>SMBIH-5-XMT |
| | | Single-Mode Min Bend Radius = 7.5mm | SMBIH-7.5-A | SMBI-7.5-MT<br>SMBIH-7.5-MT | SMBI-7.5-XMT<br>SMBIH-7.5-XMT |
| | | Single-Mode Min Bend Radius = 10mm | SMBIH-10-A | SMBI-10-MT<br>SMBIH-10-MT | SMBI-10-XMT<br>SMBIH-10-XMT |
| | | Multimode Graded Index Min Bend Radius = 7.5mm | MM50BIH-A | MM50BI-OM2-MT<br>MM50BIH-OM2-MT | MM50BI-OM2-XMT<br>MM50BIH-OM2-XMT |
| | | Multimode Graded Index Min Bend Radius = 5mm | NA | MM80BI-MT<br>MM80BIH-MT | MM80BI-XMT<br>MM80BIH-XMT |
| Higher Band Width | | Multimode OM3 | NA | MM50BI-OM3-MT<br>MM50BIH-OM3-MT | MM50BI-OM3-XMT<br>MM50BIH-OM3-XMT |
| | | Multimode OM4 | NA | MM50BI-OM4-MT<br>MM50BIH-OM4-MT | MM50BI-OM4-XMT<br>MM50BIH-OM4-XMT |
| MM | | 62.5µm Multimode | NA | MM62.5-MT<br>MM62.5H-MT | MM62.5-XMT<br>MM62.5H-XMT |
| Other | | High Index, Polarization Maintaining, other | AVAILABLE: Inquire for Details | | |

Source: https://www.corning.com/microsites/coc/oem/documents/specialty-fiber/Corning-Specialty-Fiber-Product-Information-Sheets-111913.pdf

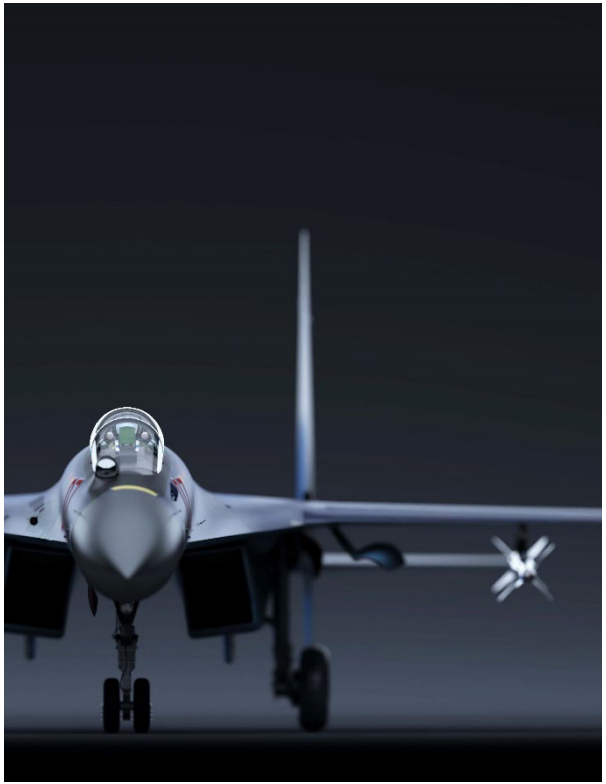
# VCSEL-MMF Link Test Automotive Temperatures

*Corning MM50BI-XMT-H (GI glass fiber OM3), TRUMPF VCSEL*




Source: https://www.ieee802.org/3/OMEGA/public/jan_2020/perezaranda_OMEGA_02_0120_25G_Corning_fiber.pdf

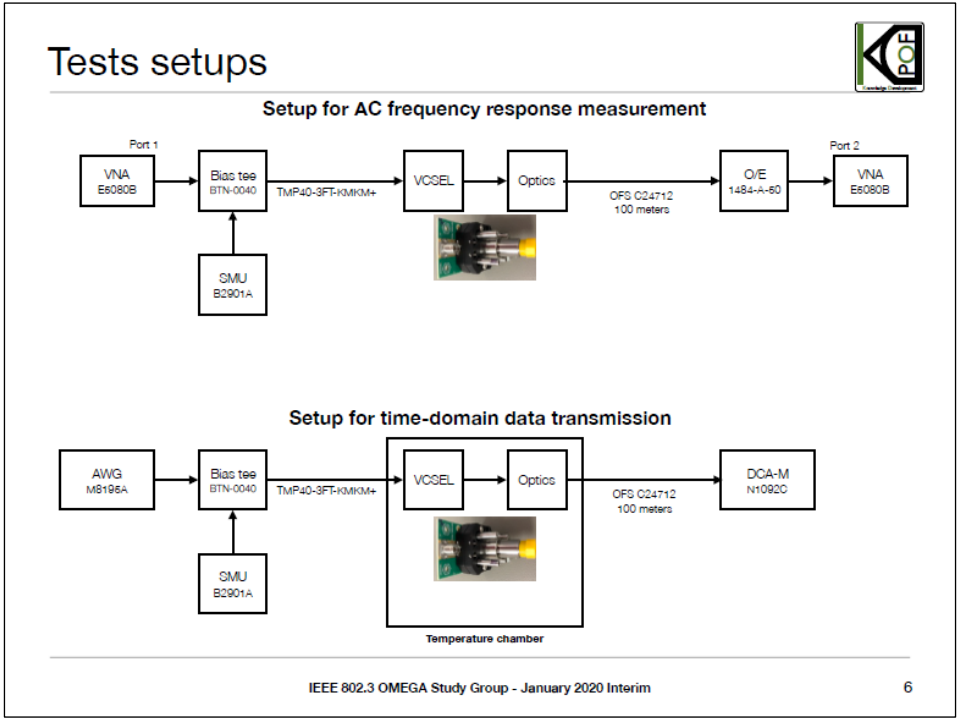
# Optical Fiber Solutions for Avionics



- OFS Optical Fiber Solutions for Avionics:
  - Multi-Fiber Cable with Rollable Ribbon
  - High-Temp Graded Index 50 µm (OM4) Bend Optimized Optical Fiber
  - FlightLinx® PLUS Fiber Optic Cable with High-Temp Optical Fibers (62.5, SM, Graded Index 50 µm (OM4))
  - µLinx® Fiber Optic Cable with High-Temp Graded Index 50 µm (OM4) Bend Optimized Optical Fiber

# VCSEL-MMF Link Test Automotive Temperatures

*OFS FlightLinx 50 µm OM3, TRUMPF VCSEL*




Source: https://www.ieee802.org/3/OMEGA/public/jan_2020/perezaranda_OMEGA_03_0120_25G_OFS_fiber.pdf