Advanced Multigigabit Glass Optical Fiber Automotive Ethernet Link and Test Solutions

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CORNING

KEYSIGHT TECHNOLOGIES

Applying Modern Glass Optical Fiber Technologies to Automotive On-Board Networks

- Emerging Automotive applications can derive significant benefit from the latest glass optical fiber technologies
- As glass fiber and automotive experts engage, we find common topics where modern fiber attributes are unclear or misunderstood
- We will address several of them today:
  1. **B**andwidth: Is high bandwidth glass fiber needed in cars?
  2. **F**it: Are there unique optical link features that address challenges?
  3. **A**ffordability: Are "exotic" glass fiber networks scalable and affordable?
  4. **S**uitability: Can glass fiber thrive in the automotive environment?
  5. **T**est Standards: Are there test procedures & equipment available?
- **Answer:** Modern glass optical fiber technologies are highly suitable for Automotive Networks

Three powerful design trends are increasing vehicle data rates, and the industry is developing standards to enable them

In-vehicle Infotainment & Experience

e.g: 8K display uncompressed data rate: 48 to 143 Gb/s

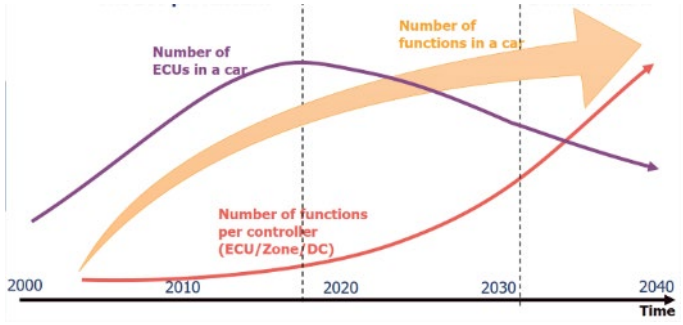
Driver Assistance & Autonomous driving

(Increasing # of sensors)

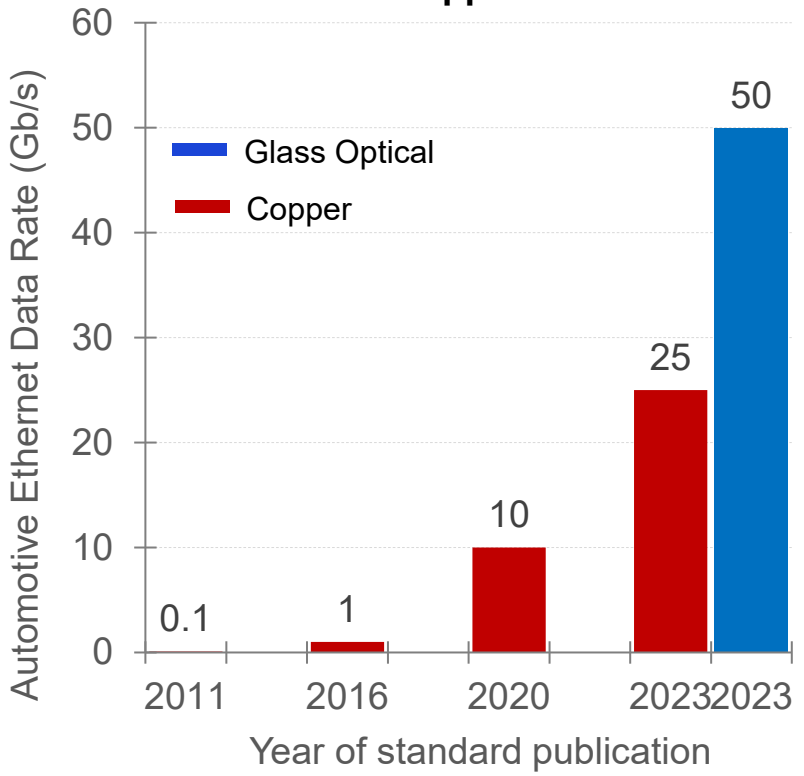
Autonomy> Sensor	L1 Active Safety	L2 Lane	L2+ Multi Lane	L3 Traffic & Hwy Pilot	L4 / L5 Robotaxi
# of Sensors	7	9	15	18	23
Data (Gb/s)	~4	~6	~14	~15	~23

Software Defined Vehicles

(ECU consolidation)



Evolution of IEEE Ethernet Standards for Automotive Applications



Source: LiDAR for Automotive 2023 Report, Yole Group

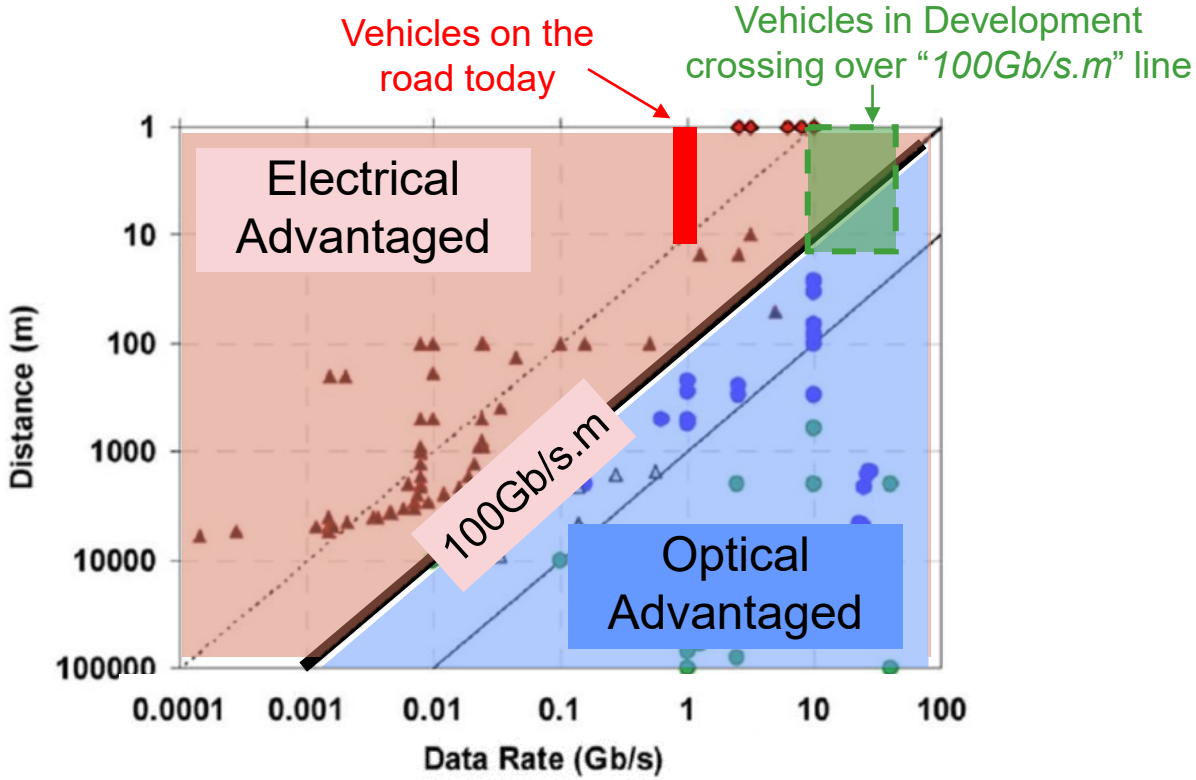
Resulting Data Rate x Distance product will exceed 100Gb/s.m ...a common optical technology transition point

Current known data rate needs in Automotive application are reaching 100Gbps.m threshold

Sensor	Data Rate (~2030)	Distance (m)	Data x Distance (Gbps.m)
Cameras	10G+	5 – 15	>50 to >150
Radars	10-20Gbps	5 – 15	50 to 300
Displays (4k, 60fps)	10Gbps	5 – 15	50 to 150
Backbone	50G+	5 – 15	>250 to >750

Source: IEEE802.3 Task Group meeting presentations

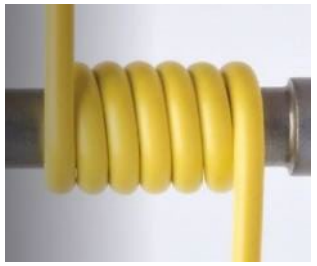
Techno-Economic factors typically favor optical adoption at Data rate x Distance of ≥100Gb/s.m



Source: A. V. Krishnamoorthy et al., "Progress in Low-Power Switched Optical Interconnects," IEEE J. Select. Topics Quantum Electron., vol. 17, no. 2, pp. 357–376, Mar. 2011

1. In-car network links are evolving to require bandwidth x distance product exceeding 100 Gb/s.m

Glass optical connectivity solutions offer other benefits for emerging Automotive challenges



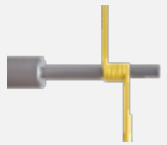
Emerging Automotive Challenge	Optical Link Attribute Fit
• Hardware ready for future upgrades • Same media for 1Gb/s - 200Gb/s	High bandwidth (≥ 200Gb/s @10m on OM3)
• Weight reduction • Compact ECUs	Light weight & Small Footprint
• Harness routing design flexibility • New sensor locations on the vehicle	Tight bends and millions of cycles
• Faster development cycle • Lower qualification costs	Inherently EMI robustness simplifies design
• Greater sustainability	6x lower carbon footprint[1] (vs. twisted pair)

2. Optical link attributes may enable simpler solutions and more flexibility for automotive systems

1. https://europacable.eu/wp-content/uploads/2022/07/Europacable-Whitepaper-on-Energy-Efficiency-of-Fiber-networks-05-July-2022.pdf

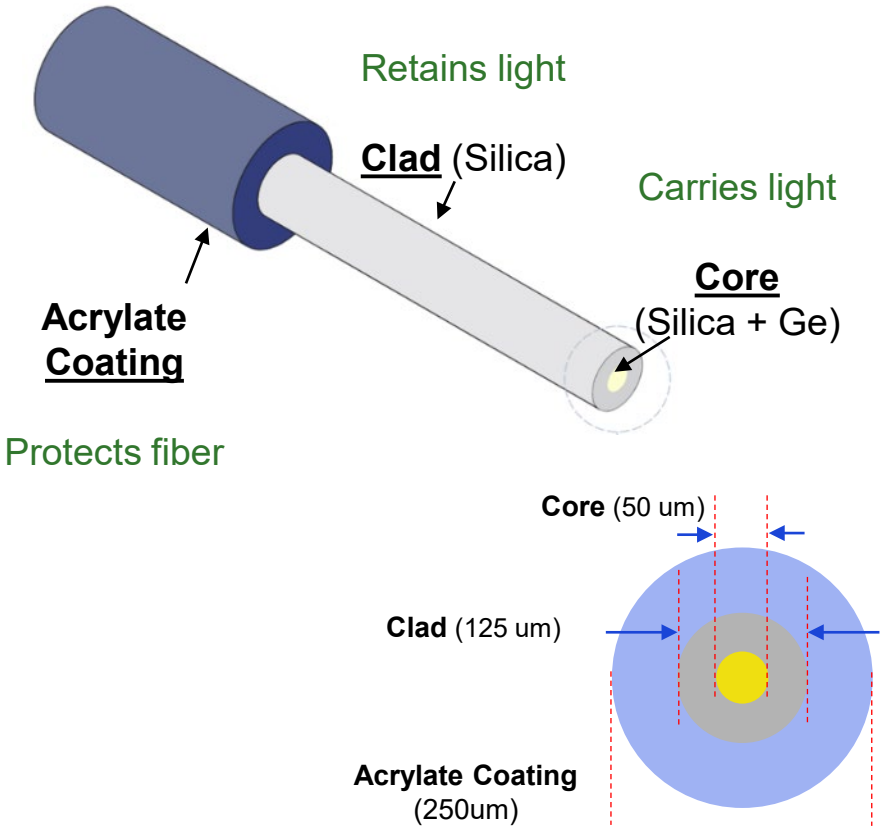
Affordability

Over the last 50 years Glass Optical Fiber Technology has become an affordable, simple, and reliable high-volume solution for muti-gigabit networks in many industries

	1960s	1970s	1980s	1990s	2000s	2010s	2020s	FUTURE
Optical Technology Breakthrough	Invention of Laser → Made optical communication possible	 Invention of low loss glass fiber → Triggered long distance communication	 Zirconia ferrules for optical connectors → Reduced connectivity cost	 In-field connection w/o fusion splicing → Accelerated penetration	 Bend insensitive fiber → Enabled hard to reach installations	 Pre-connectorized cables → Simplified installation	 High density connectors → Reduced installed space	
Application Evolution			Transcontinental Communication	Continental & Metro Networks	Enterprise & Data Center Networks		Access & Fiber To The Home	Hyperscale Data Centers
Ave. Link Length			**1000s of km**	**100s of km**	**kms**	**100s of meters**		**10s of meters**

Standard glass optical fiber leverages decades of innovation to benefit Automotive market

OM3 Multimode glass optical fiber

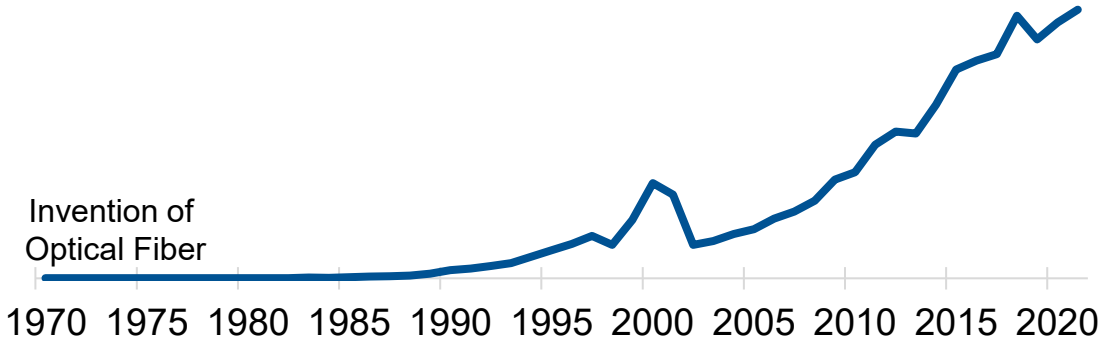


- *Standardized* (2003)
- *Large Bandwidth:* 200Gb/s over 10m
- *Bend Insensitive*: ≤ 0.1dB (two turns @ 15mm bend radius)
- *Multiple suppliers*: Asia, Europe & Americas
- *Large volumes:* Sold several million kms annually
- *Specified* in IEEE 802.3cz

~11lb Bowling ball hanging from 125um multimode glass optical fiber

Optical components and link costs continue to decline

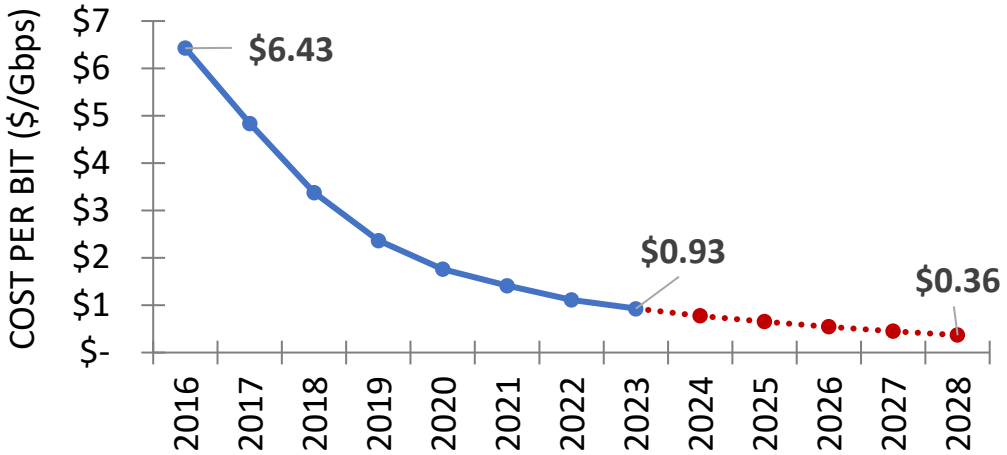
Glass Fiber Volume Since Inception



Source: Corning Inc

- Large Install Base:
  - >6B km of optical fiber deployed since inception
- Large Annual Capacity:
  - >500M km/yr ➔ 5B cars*
- Favorable Economics:
  - >40X price decline since inception

Cost ($/bit) of Ethernet Optical Transceivers



Decrease in $/Gbps				
Industry	**2016**	**2023**	**2028**	**2016-2028 (CADR)**
All Ethernet	$ 6.43	$ 0.93	$ 0.36	~21%

Source: LightCounting Optical Components Market Forecast, April 2023

3. Glass optical fiber technology has scaled, is mature and affordable today

** 10m/link & 10links/car*

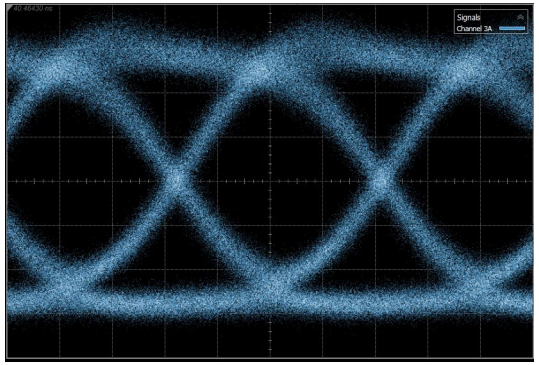
Glass optical fiber-based connectivity solutions can meet stringent Automotive requirements

IEEE 802.3cz Link Attributes

- 2.5Gbps – 50Gbps
- 40m (max) and 4 in-lines connectors (max)
- Max 2dB per connector

40m glass optical cable with 4 inline connectors

Eye diagram, 25Gb/s NRZ, RT



Measured IL = 0.93dB

~90% Available Link Loss Budget

(per channel insertion loss spec of 8.5 dB (25Gbase-AU))

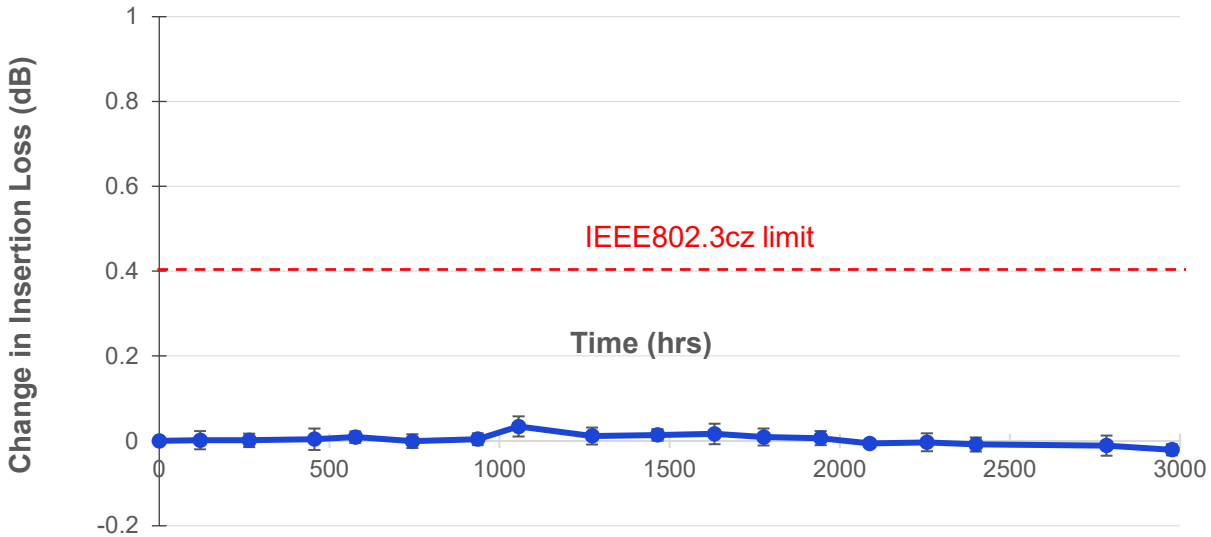
USCAR Requirements

- Temperature: -40°C to +125°C
- Mechanical: Random Vibration and Shock
- Chemical: Several chemicals
- Combination of multiple variables

Glass optical cables are stable at high temperature up to 3000hrs @ 150°C

Glass optical fibers and cables inside thermal aging chamber

In situ Insertion Loss:
< 0.05dB change after 3000hrs at 150°C



Note: Corning also tested temperature & humidity cycling per USCAR-2 (40 cycles, 400 hours, -40°C to +150°C) showing <0.05dB change

Glass optical cables are stable to chemicals with no visible degradation after exposure and static mandrel wrap

Chemical Exposure

	Chemical	Exposure
1	Gasoline	60 mins @ 23°C
2	Battery alkaline	1 min @ 23°C
3	Mineral hydraulic oil	60 mins @ 85°C
4	Diesel	60 mins @ 23°C
5	Brake fluid	60 mins @ 85°C
6	Window washer fluid	60 mins @ 50°C
7	Transmission fluid	60 mins @ 85°C
8	Battery Acid	1 min @ 25°C
9	Lubrication fluid	60 mins @ 85°C
10	Antifreeze fluid	1 min @ 23°C

+

Static Mandrel Wrap, 9mm diameter[1], 2 Months

No visible degradation

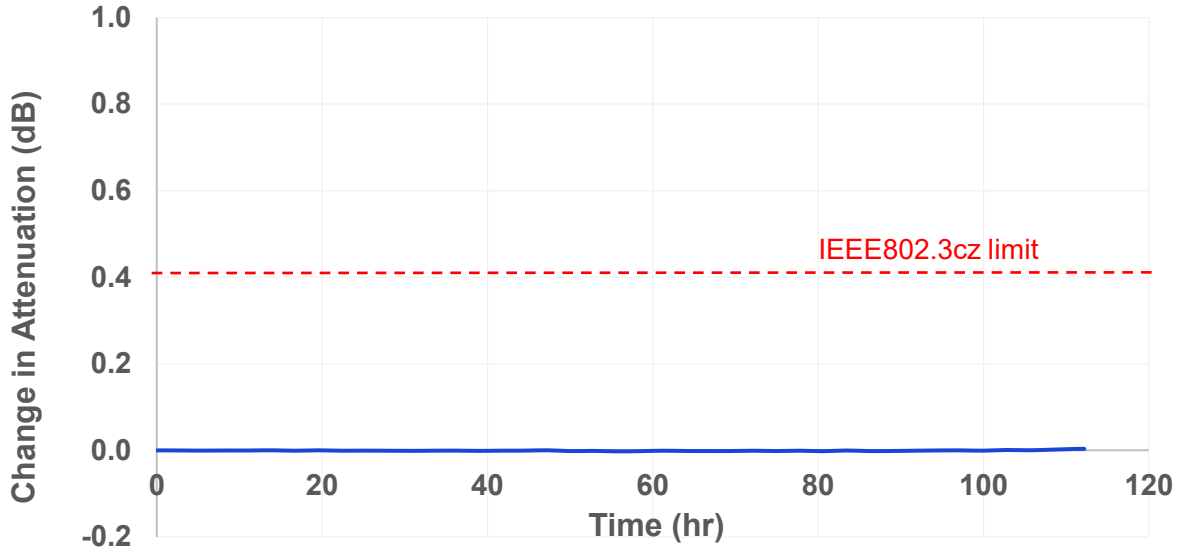
(No cracking, swelling or discoloration)

[1] *Not a measure of long term reliability. See cable spec.*

Glass optical connectors are stable in random vibration per USCAR-2 with no change in attenuation

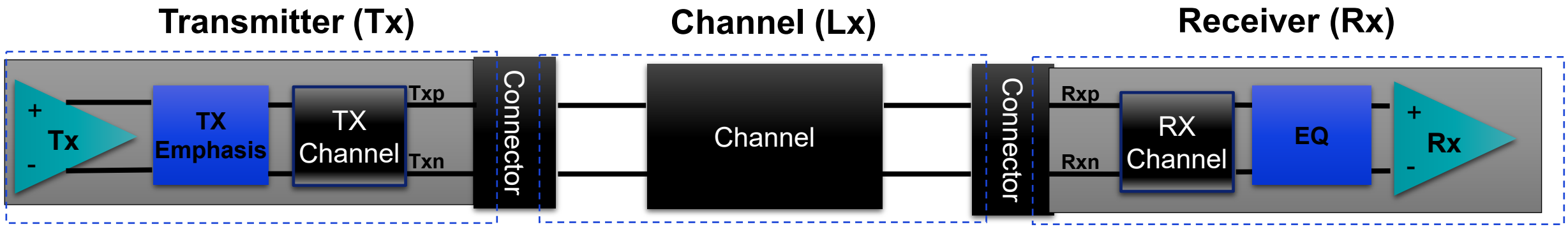
Connector in vibration (random) testing

In situ insertion loss:
No notable change in attenuation after "random vibration" testing per USCAR-2



4. Optical fibers, cables, & connectors meet automotive requirements for durability and handleability

Typical Optical PHY Test System



Real-time Scope

Equivalent-time Sampling Scope + CRU

Network Analyzer (PNA, ENA)

TDR/TDT (DCA)

Bit Error Ratio Tester (BERT) with Pattern Generator (PG)
Optical Reference Transmitter for stressed signal generation
Oscilloscope to calibrate stressed eye signal

An optical-input sampling scope with 4th order Bessel Thomson response + CRU is the choice of scope type for P802.3cz.

IEEE 802.3cz PMD test patterns and parameters

- **TDFOM** (Transmitter and Distortion Figure Of Merit)[1] is a new measurement to evaluate the performance of optical transmitter and to guarantee Interoperability of transmitters.

- For Tx test, the scope should provide the measurements required to perform the test parameters.

- For Rx test, stressed receiver sensitivity measurement validates receiver PHY's ability to work in noisy vehicle environment.

Note[1]: specified in the clause 166.6.4.8 of IEEE std 802.3cz-2023

Test patterns for Tx and Rx test

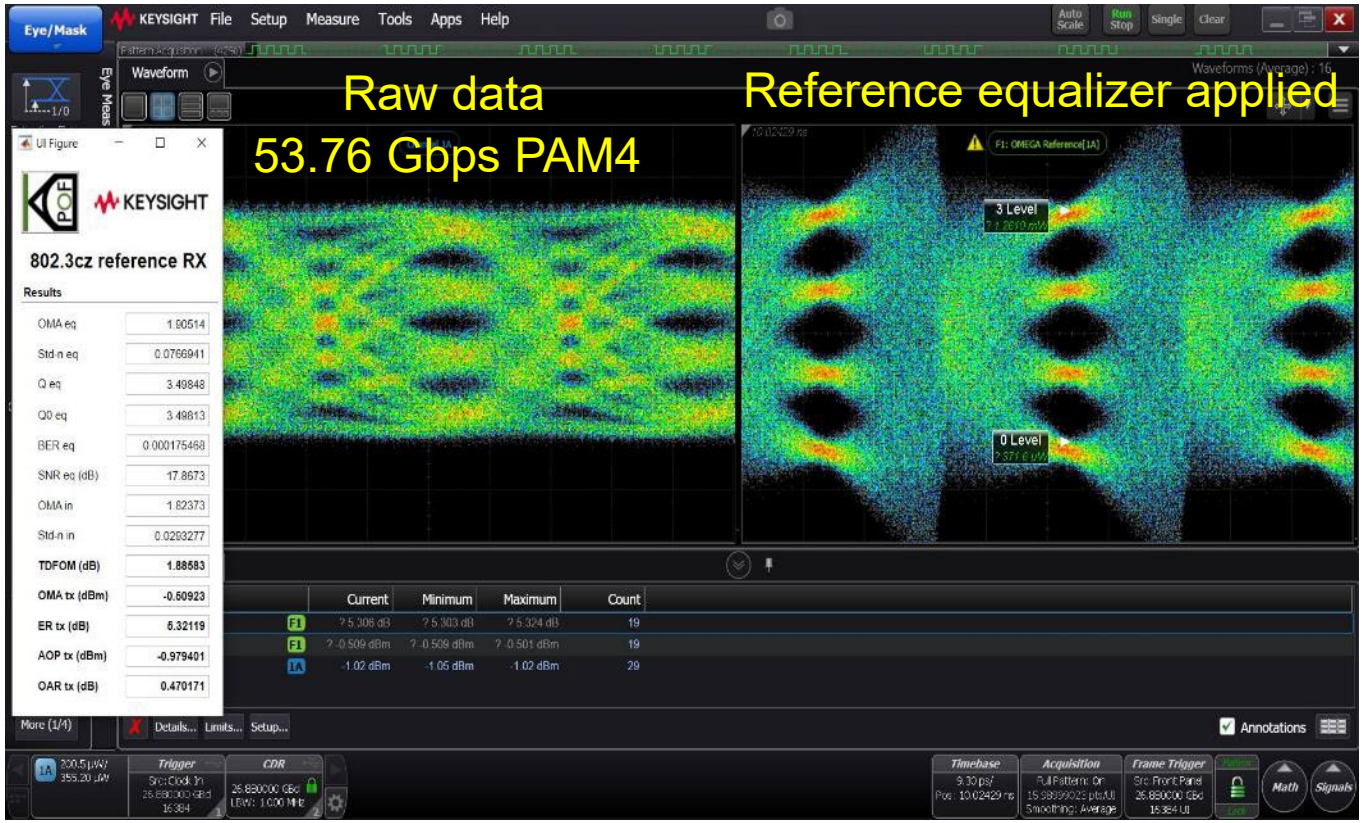
	Pattern	Pattern description	Defined in
Tx	1	SSQWP square wave (n_{sq} {+1}, n_{sq} {-1})	166.5.2
	2	FSQWP square wave (1 {+1}, 1 {-1})	166.5.3
	3	SSPR-NRZ	166.5.4
	4	SSPR-PAM4	166.5.5
Rx	5	Pattern for stressed receiver sensitivity measurement	166.5.6

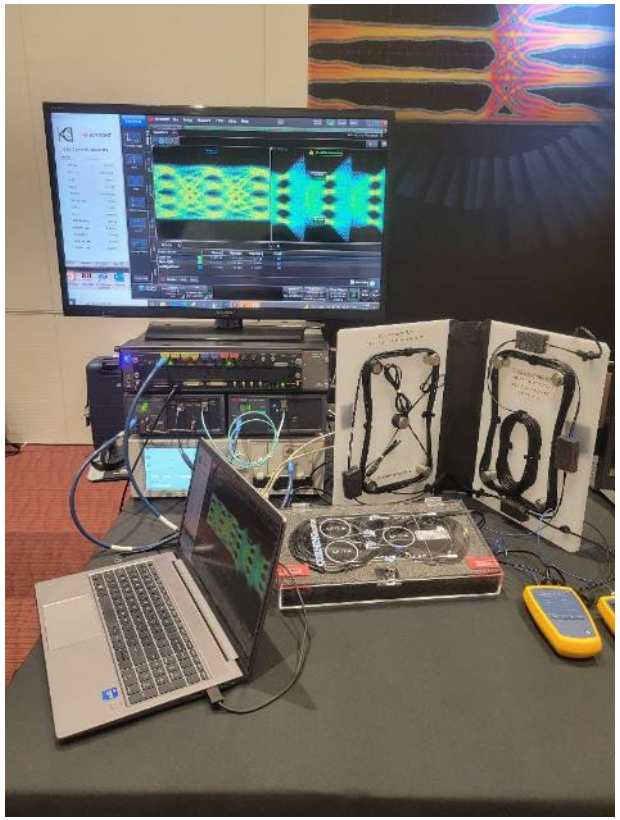
Test parameters for NRZ (for 2.5G – 25G)

	Parameter	Pattern	Related subclause
Tx	Center wavelength and RMS spectral width	3, or valid BASE-AU signal	166.7.2
	Average optical power	3, or valid BASE-AU signal	166.7.3
	Outer Optical Modulation Amplitude (OMA_{outer})	1 or 3	166.7.4
	Transmitter and distortion figure of merit (TDFOM)	3	166.7.8
	Extinction ratio	1 or 3	166.7.5
	$RIN_{12}OMA$	1	166.7.6
	Uncorrelated random jitter (t_J)	1or 2	166.7.7
Rx	Stressed receiver conformance test signal calibration (STDFOM and ER)	3	166.7.10.2
	Stressed receiver conformance test signal calibration (RIN and random jitter)	1	166.7.10.2
	Stressed receiver sensitivity	5	166.7.10.3

Note: Similar test parameters exist for PAM4 50G

Measurement systems and test results





Optical automotive ethernet “proof of concept” measurement on automotive grade 40m long OM3 multi-mode fiber optical cable with 4 inline connectors demonstrated at IEEE Tech Days event in Yokohama 2022

5. Test procedures and Equipment for Optical Automotive applications exist

Conclusion

Automotive industry can benefit from leveraging decades of technology innovations in Glass optical connectivity

- Automotive applications have evolved and can now derive significant benefit from glass optical fiber technologies

- We have shown:

  1. **B**andwidth: Automotive applications benefit from fiber's Bandwidth
  2. **F**it**:** Glass Optical links are Fit to address several other Automotive challenges
  3. **A**ffordability: Glass fiber technology is mature and Affordable
  4. **S**uitability: Glass fiber is Suitable for use in the car
  5. **T**est Standards**:** Test procedures and equipment exist

- Now is the time to start developing expertise to find the right applications for this technology

Optical connectors are suitable for the automotive environment