DIGITAL WE DAYS 2023

OPTICAL MULTI-GIGABIT LINKS FOR AUTOMOTIVE

Partnered with KDPOF

WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

TODAY'S SPEAKERS

PRESENTATION
Óscar Ciordia
Marketing and Sales Director

MODERATION
Markus Eberle
Marketing Department

INFORMATION ABOUT THE WEBINAR

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Duration of the presentation	30 Min
Q&A:	10 – 15 Min

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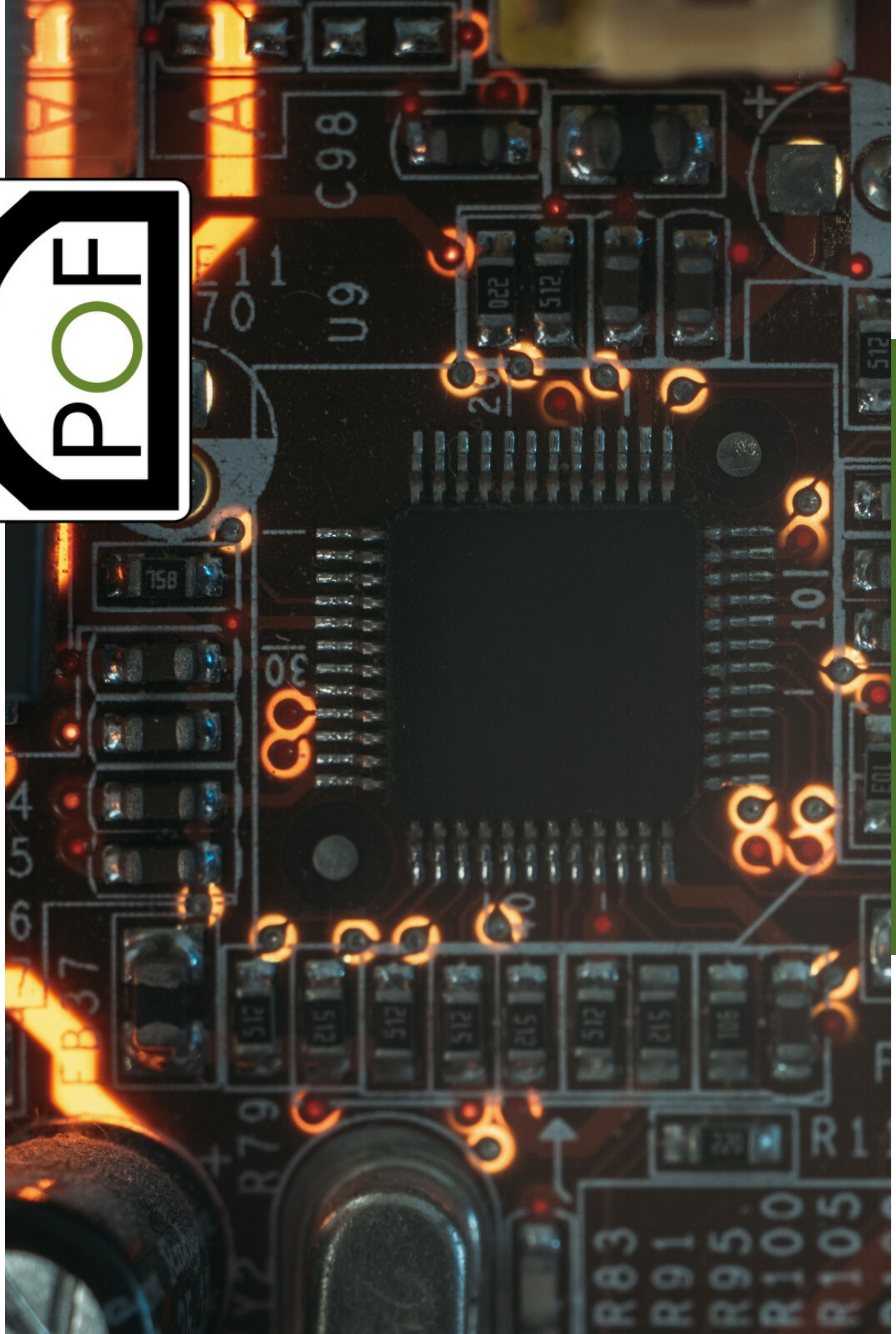

Automotive Optical Multi-gigabit

October 2023

www.kdpof.com

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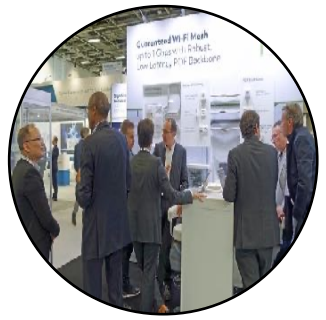


COMPANY OVERVIEW

Founded	Location	Employees	Business model
2010	Madrid	40 FTE including 15 IC designers	Fabless ASSP vendor

COMPANY OVERVIEW

- Head Quarters
  - Madrid (Spain)
- Other locations
  - France
  - Valencia (Spain)
- Commercial offices
  - Sweden
  - Germany
  - Japan
  - Korea
  - GC

BUSINESS AT A GLANCE

In-house capabilities

- Digital, AMS, Optoelectronics and optics design
- IC & photonics characterisation, automotive qualification, failure analysis

Patents granted

- Transceiver EP74397 EP98515 EP80387
- TIA EP105112
- LED Driver EP105113

Associations

JasPar
OPEN ALLIANCE

Standards

ETSI World Class Standards
ISO 9001
IEEE

KDPOF actively participated
in standardization process

TECHNOLOGY

Key products

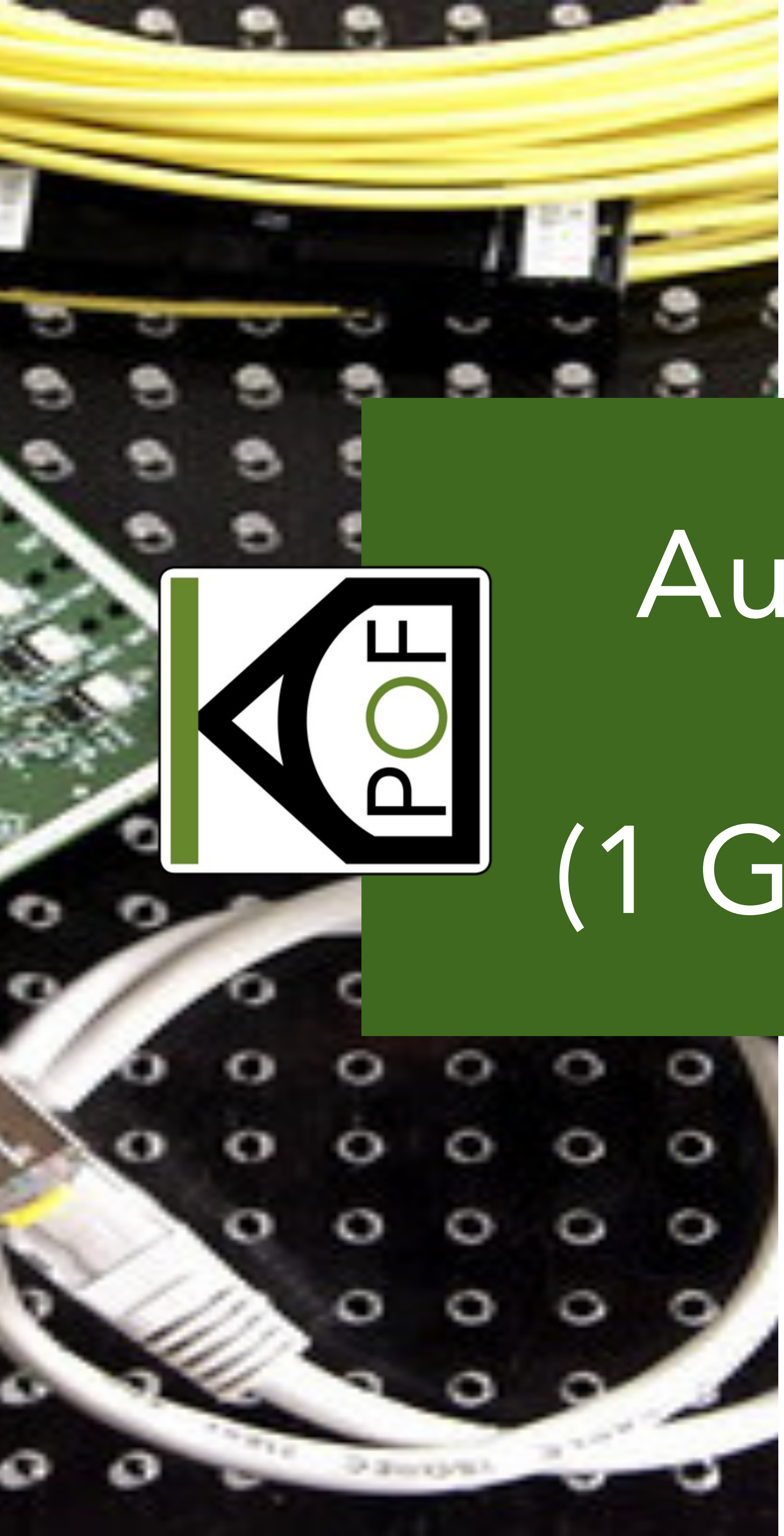
- Transceiver
- Transimpedance Amplifier (TIA)
- LED Driver
- FOT (optical front end)

Supply chain

- Wafer fabrication with TSMC and XFAB
- Packaging and testing with ASE

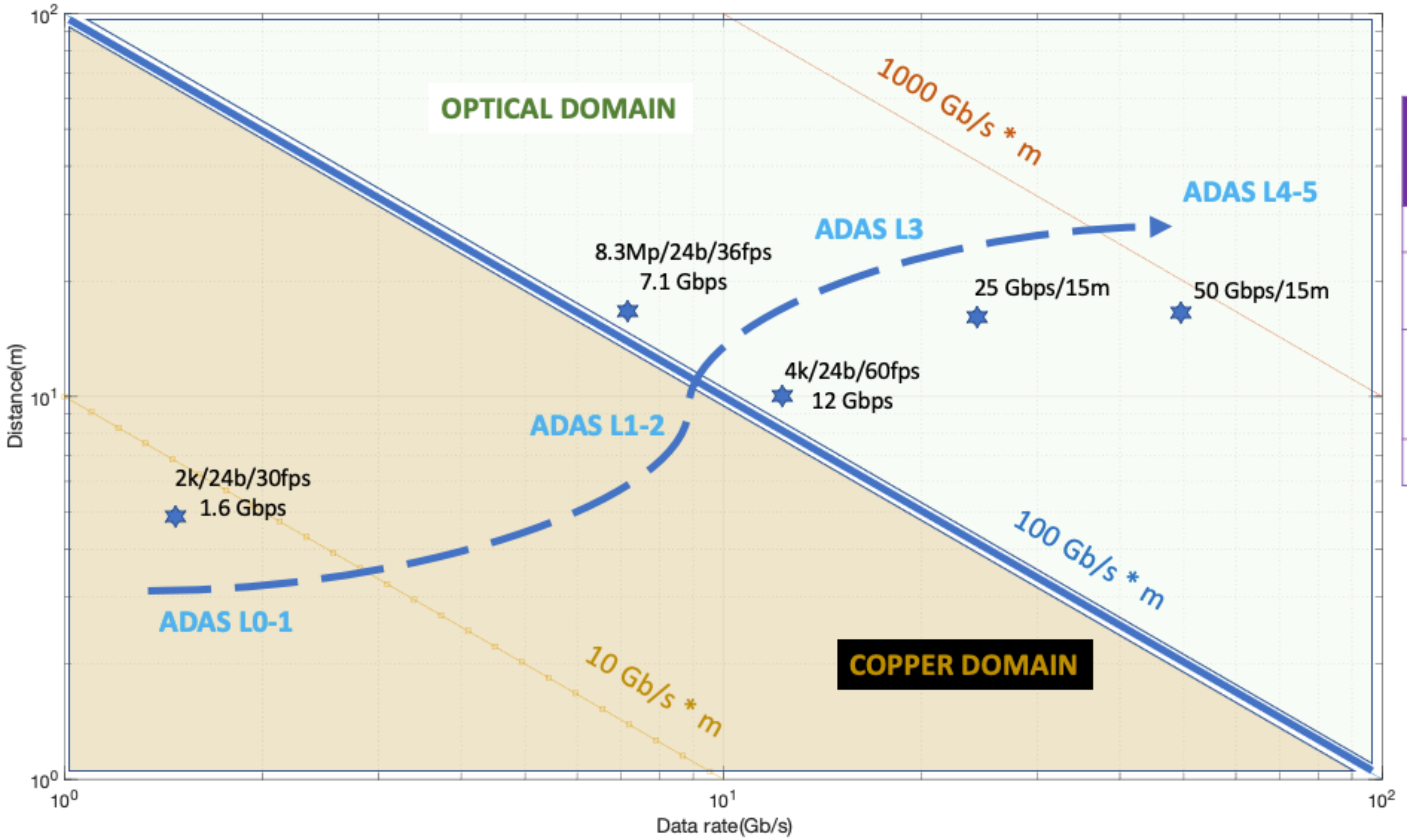
End markets

- Main focus Automotive
- Applications in Home and Industrial



Automotive Optical Multi-gigabit (1 Gb/s up to 50 Gb/s)

KDPOF VIEW: History shows copper links migrate into optical as needs grow



- 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+	10-15	>100
Radars	10-20Gbps	5 - 10	50 - 200
Displays (4k, 60fps)	10Gbps	5 – 10	50 - 100
Backbone	50G+	5	>250

Source: IEEE802.3cz Task Group meeting presentations

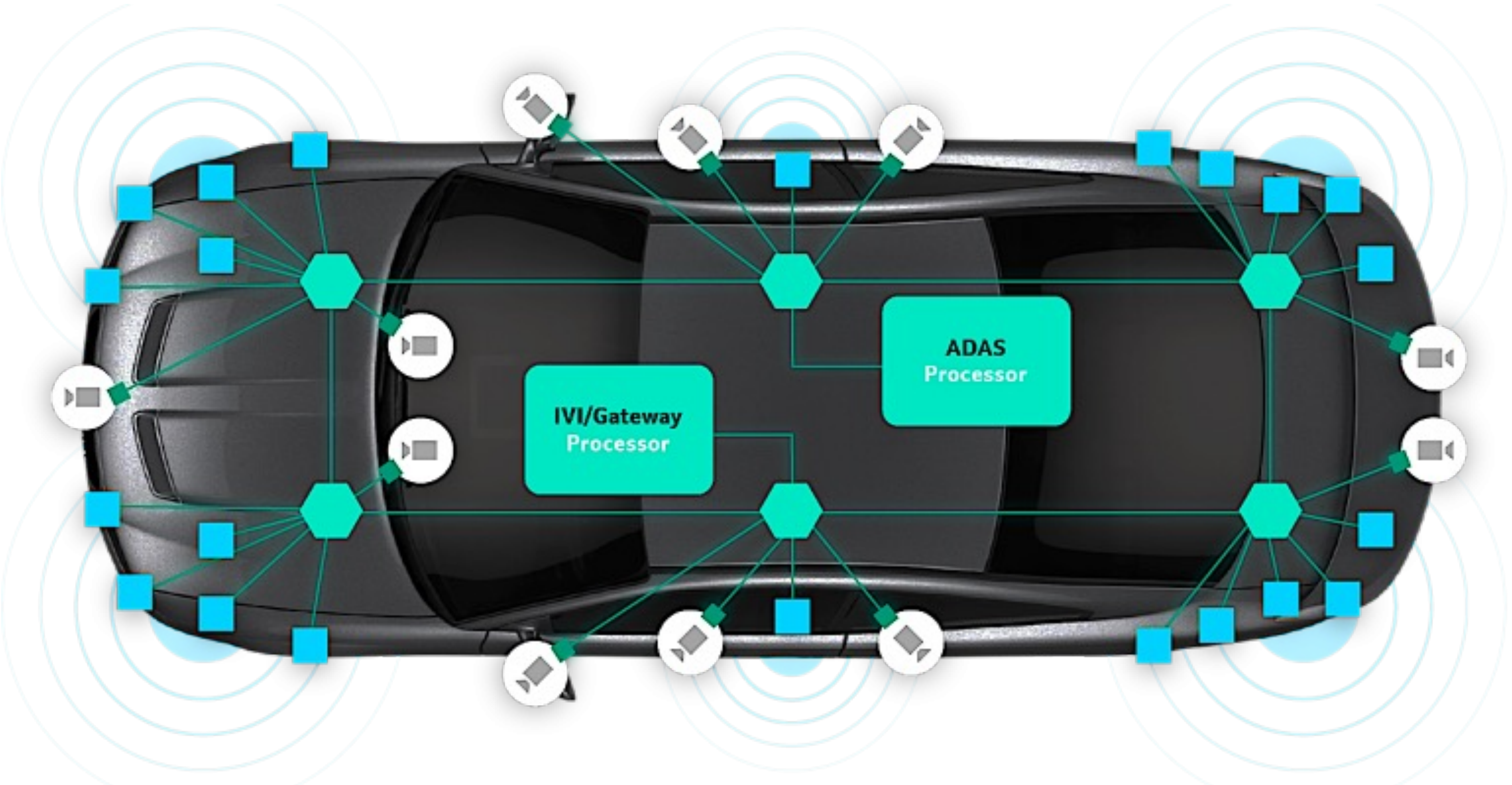
Elaborated from : A. V. Krishnamoorthy et al., "Progress in Low-Power Switched Optical Interconnects," IEEE J. Select. Topics Quantum Electron., vol. 17, no. 2, pp. 357–376, Mar. 2011

COPPER TRANSMISSION CAN EVOLVE, BUT NOT WITHOUT SIGNIFICANT CHALLENGES

Technical Approach	Associated issues
Add more (parallel) lanes	• Cost and weight of cables • Connection size increase • Decreased mechanical flexibility
Larger conductors (& shielding)	
Increase DSP complexity (equalization, FEC, etc.)	• Higher power consumption • Increased latency
Higher signal amplitude	• Higher power consumption • Increased EMC issues

* Source: Corning Inc.

Data links support autonomous and electric vehicles

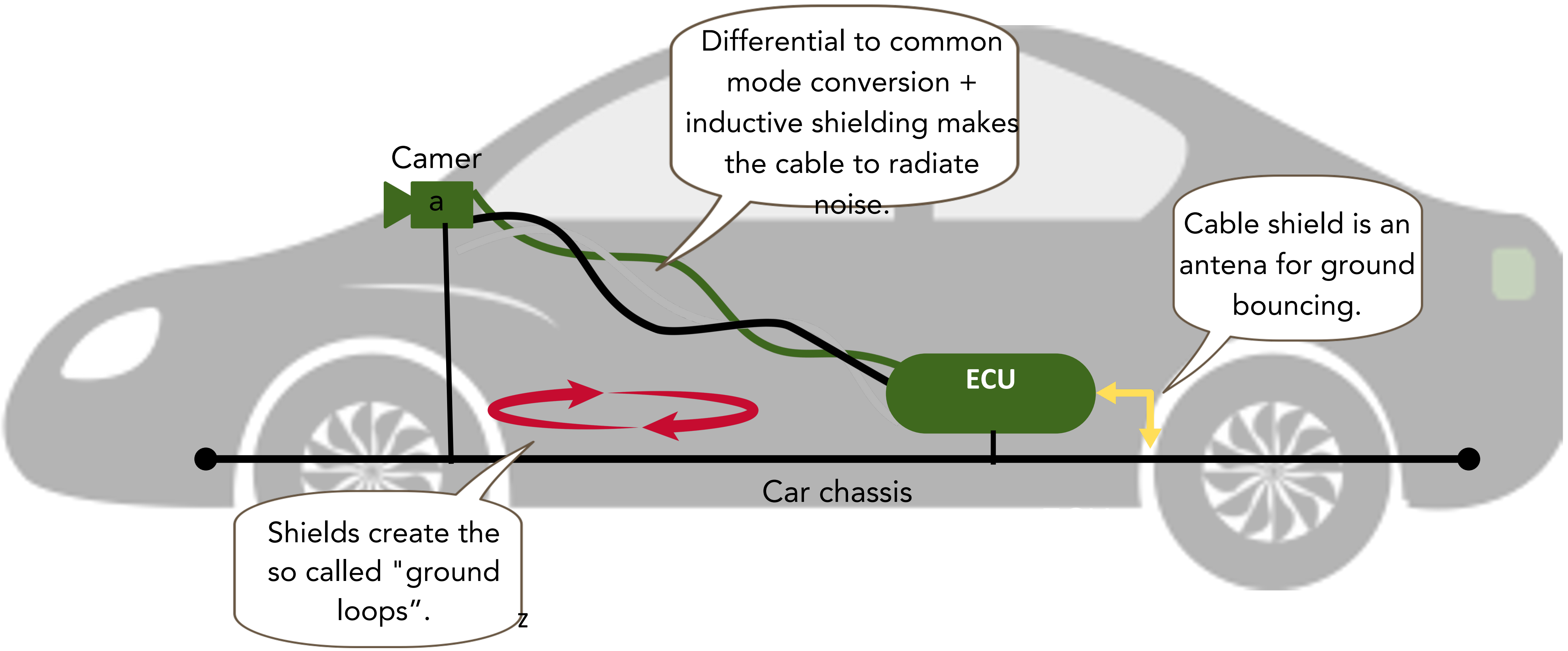


https://www.designnews.com/automotive-engineering/why-cars-are-migrating-zonal-electric-architecture

Exponential increase of the electronics complexity and speed

- Connected cars
- Electrical and autonomous vehicles
- High-speed cameras and sensors (radar, lidar…)
- Centralized high performance computing units processing all raw data
- Zonal architecture, sensor fussion
- Black-boxes

Copper-based data-links do not scale



- **Attenuation /bandwidth** — Attenuation increases at high frequencies
- **EMC problems** — The higher the communication speed, the worse is the problem
- **Electrical noise** — Mainly in EVs
- **Galvanic Isolation** — Battery and engines operate at up to 800V and also connected to the 12V of the car

Automotive requirements for any link technology

Reliability

- <10 FIT over 15 years of life-time

Qualification plan

- According to the new **AEC-Q102-003** standard

  Operation ambient temperature (grade 2): **-40 °C ~ +105 °C**

Feedback from Tier1

- IC (package, pitch, SMD…)
- Connector housing (two-step assembly, waterproof, environmental...)
- Connector-IC mating (manufacture & assembly tolerances)

Cable and connector performance

- Bending: permanent, instant, dynamic, micro-bending
- Vibration, shock test, mechanical loads
- Chemical loads

Link budget

- Optical parameters (emission profile, wavelength, spectral width, AOP…)
- Electrical parameters (electrical model, linearity, bandwidth…)

  Performance: **40 m – 4 IC**

Ethernet has a new standard that complies with requirements

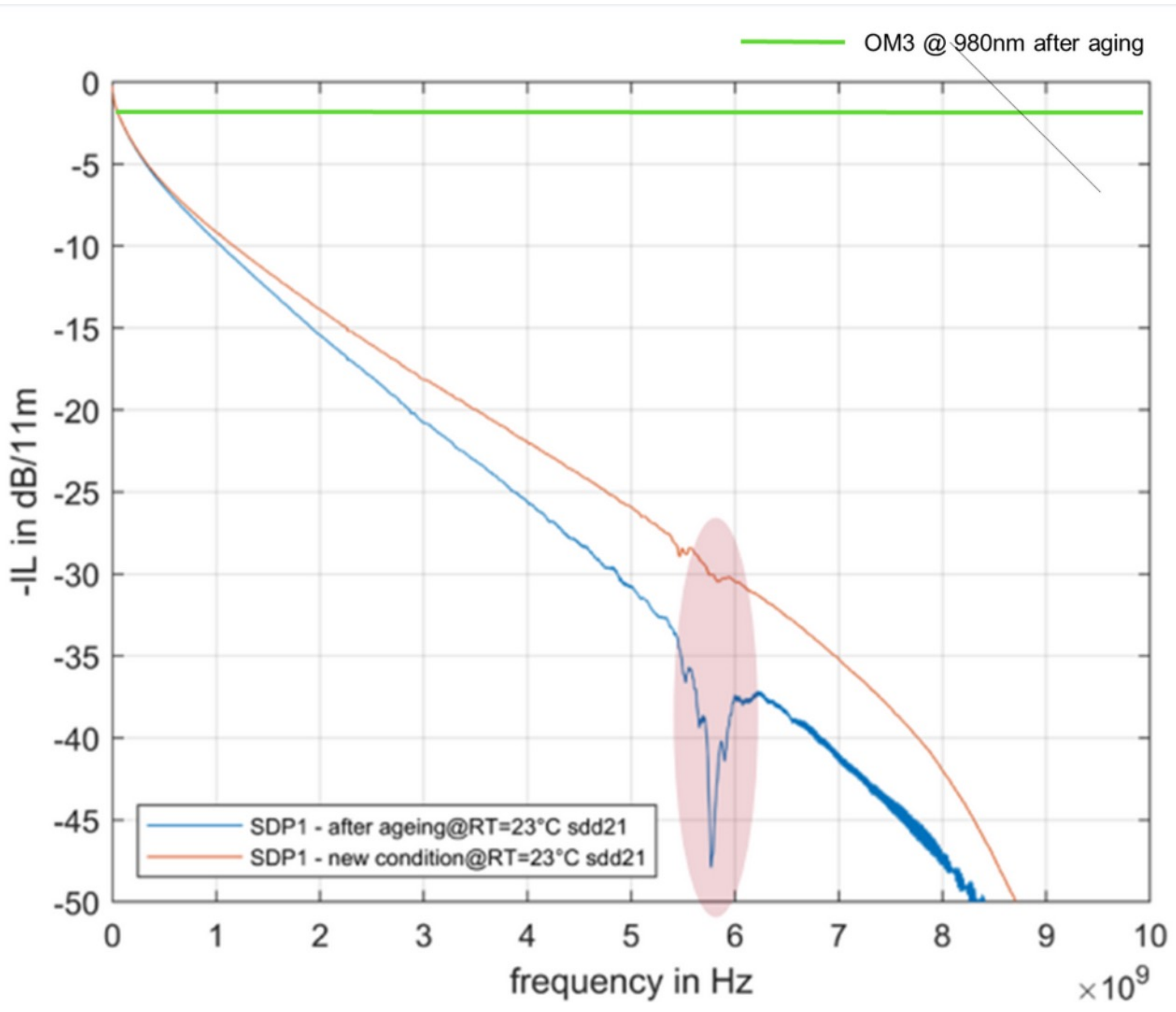
IEEE Std 802.3cz

- Published in **2023**

- Ethernet PHYs specification targeted for Automotive application
  - Support of data rates of **2.5, 5, 10, 25 and 50 Gb/s** (single lane)
  - Support for implementations qualified AEC-Q100 grade 2 (operation T_J & T_{BS} **-40°C to 125°C**)
  - Support of max reach of **40 meter** (cars, buses, trucks)
  - Support for low-cost, small-size, auto-grade optical connectors (up to **4 inline connections**) and cables
  - Support for advance **diagnosis**, **wake-up & sleep** functions, **dependability** function with **OAM** channel
  - Support for Energy Efficient Ethernet (**EEE**) for big power saving in low traffic conditions, asymmetric rate use cases

- Leverage mature components from other industries: **OM3, VCSELs and photo-diodes**

Optical: simplicity makes it the optimal solution



https://grouper.ieee.org/groups/802/3/cy/public/adhoc/koeppendoerfer_3cy_01_10_28_20.pdf

Optical transceiver does NOT have to compensate:

- High attenuation vs frequency
- Ageing

Optical transceiver's electronics are much simpler

- **Smaller silicon area**
- **Shorter latency**
- **Lower power consumption**
- **Cheaper**

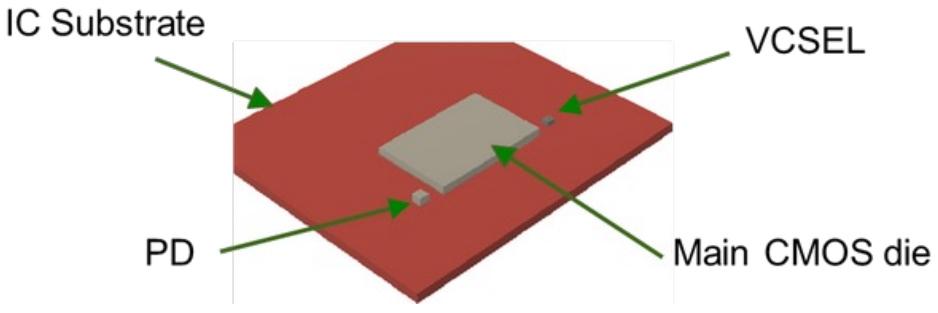
Optical vs Copper tranceiver comparison

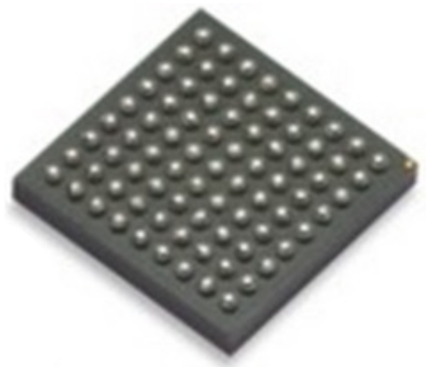
	Optical PHY	Copper PHY
Single-lane max. rate	**50 Gb/s** according to 802.3cz. **100 Gb/s** feasible	**25 Gb/s** according to 802.3cy.
Supported max channel length	**> 40 meters** for at least up to 50 Gb/s	**< 11 meters**
Supported # inline connections	**At least 4** for rates <= 25 Gb/s. **At least 2** for rates >= 50 Gb/s	**Max. 2** for rates >= 2.5 Gb/s
Scalability	**Same cables and connectors** for rates between 1G and 100 Gb/s	**Cable and connector categories depend on data-rate**
Equalizer complexity	FFE + DFE: **< 10 taps** total	**100's of taps** needed
Echo cancelling	**No**	**100's of taps** needed
FEC complexity	RS-FEC (544,522), GF(2^{10}). Complexity FOM = m·(n-k) = **220**	<=10Gb/s: RS (360,326), GF(2^{10}). FOM = m·(n-k) = **340** (> +50%) 25Gb/s: RS-FEC (936,846), GF(2^{10}). FOM = m·(n-k) = **900** (> x4.5)
Block inter-leaver for impulse noise	**No**	**x4** necessary for 10 Gb/s. **x8** be necessary for 25 Gb/s. Complexity scales quadratically with data-rate
Latency	10GBASE-AU is **1.1 us** 25GBASE-AU is **0.45 us** 50GBASE-AU is **0.23 us**	10GBASE-T1 with 4x interleaved is **2.0 us** (+80%) 25GBASE-T1 with 8x interleaved is **4.1 us** (x9)
Start-up time	< 100 ms (shorter in optical as no master/slave config is needed)	< 100 ms
Modulation complexity	**NRZ** for <= 25 Gb/s. Low linearity analog circuits. Low ENOB A/D. **PAM4** for 50 Gb/s	**PAM4** for <= 25 Gb/s. High linearity and resolution D/A & A/D
Power consumption	**Lower**, based on complexity	**Higher**, based on complexity
Connectors cost	**Lower**: simple housing + ferrules	**Higher**: metal shielding
PCB integration	PHY IC placed **close to the ECU edge** PHY IC in the **middle of the ECU close to uP/GPU/sensor/switch** Port PCB area: ~ **22 x 16 mm²**	PHY IC needs to be placed **close to the ECU edge**, close to MDI with **critical layout** Port PCB area: **~50 x 20 mm²**
BOM	PDN passives, optical connector	PDN, EMI filter, ESD protection, CMC, DC block electrical connection
EMC cost	**Much lower**	**Very high**: most problems come up at vehicle level

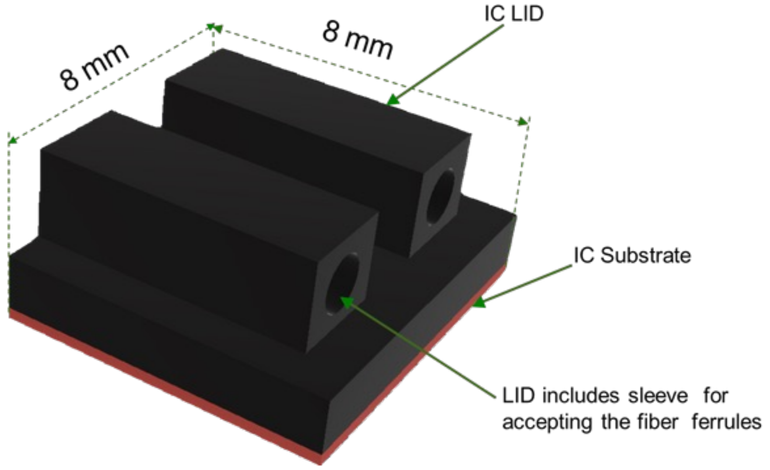
Packaging for the optical transceiver

IC Stand-alone transceiver with full integration of electronics over a common substrate with photonics (PD & VCSEL), and a lid integrating optics for optical coupling and alignment with fiber ferrules and EMC shielding.

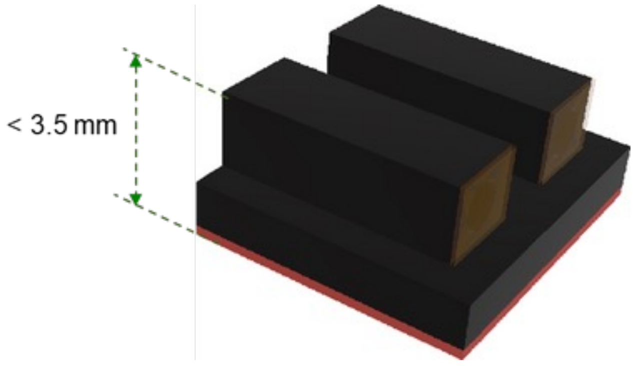
The component will support standard reflow assembly process.





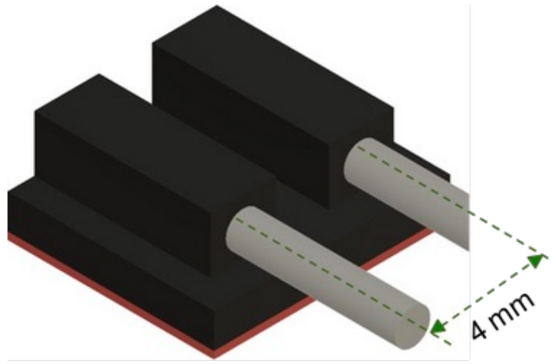


IC with kapton tape to cover the two sleeve holes

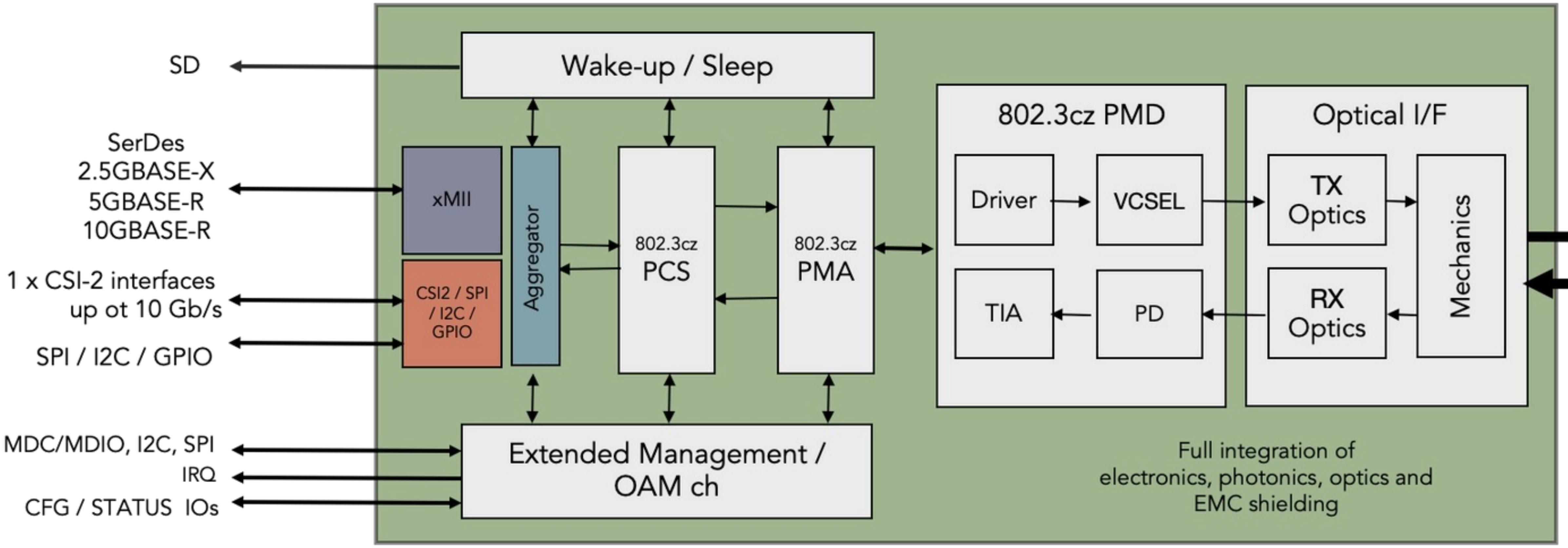


IC with fiber ferrules inserted on the sleeves.

This is done after package is mounted on the PCB



2-to-1 CSI-2 / SerDes / Optical PHY MUX



Ethernet mode:

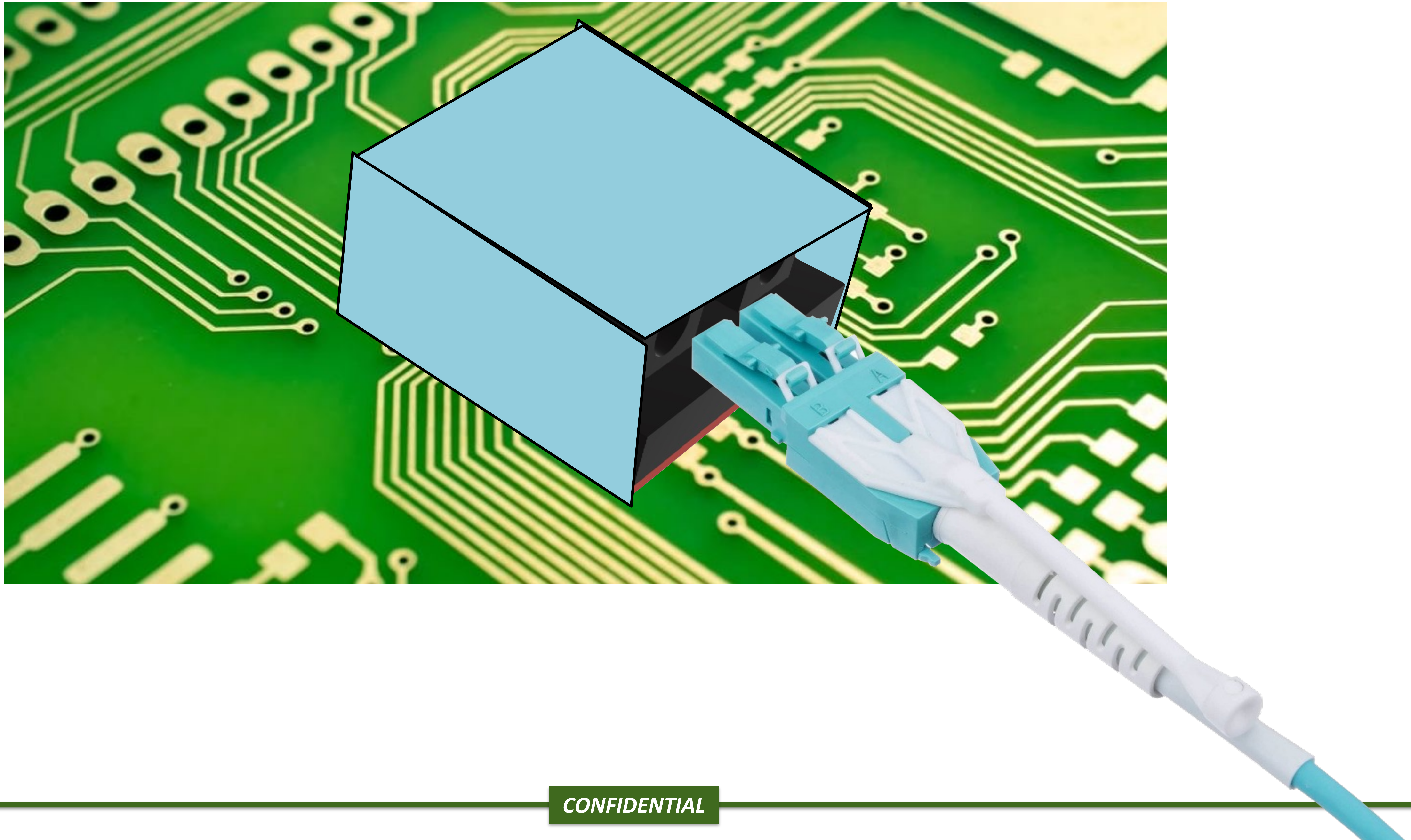
- Duplex OM3
- Symmetric data-rate

CSI-2 mode:

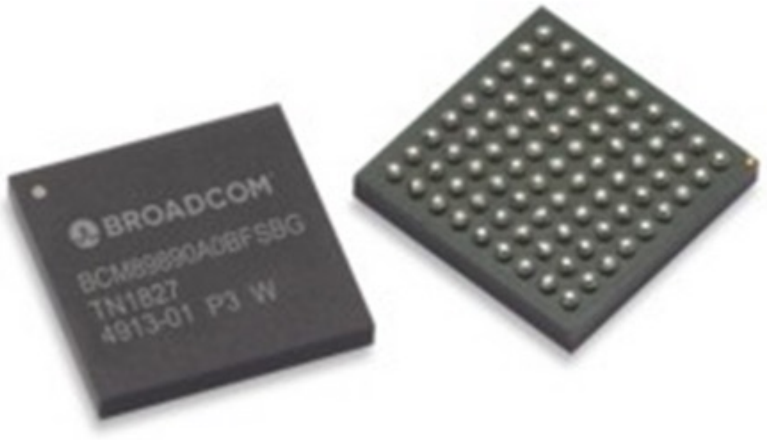
- Duplex OM3
- **Asymmetric** data-rate
- n Gb/s sensor to ECU
- 100 Mb/s ECU to sensor

- The IC is configured for ECU or sensor operation

KD7251 + header assembly (concept)

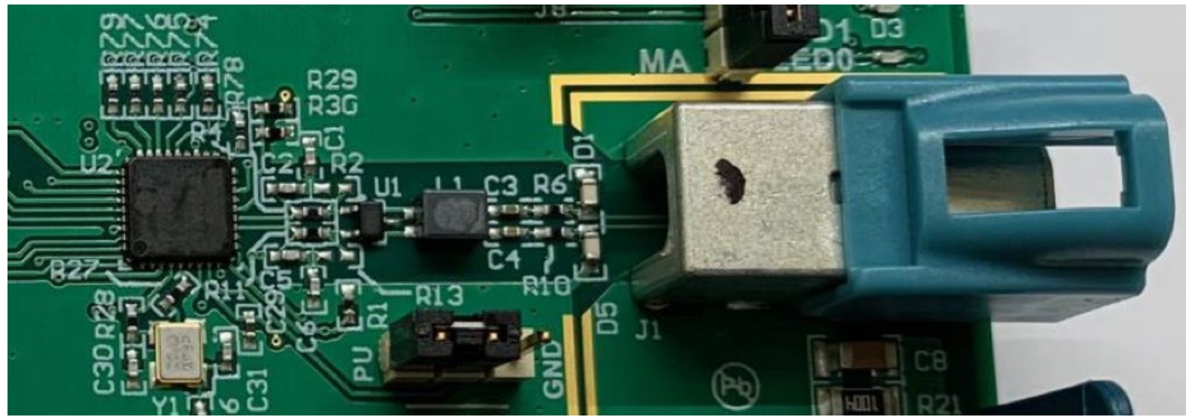


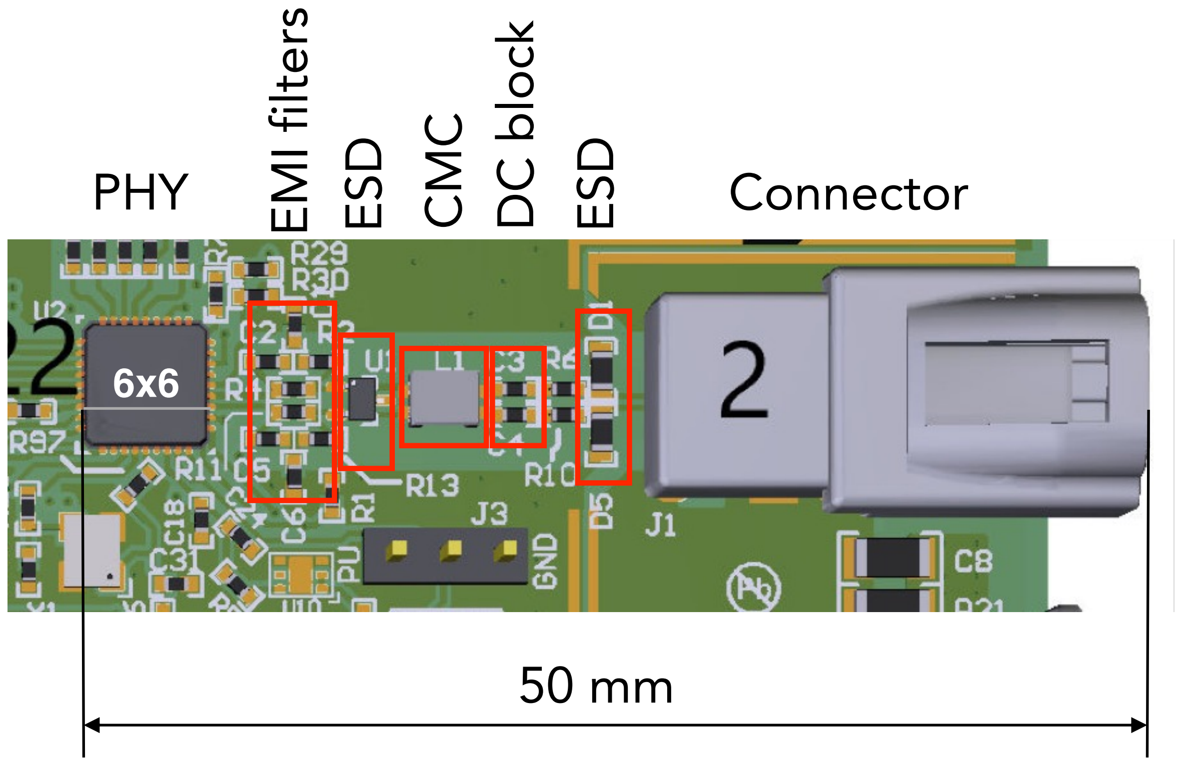
Port size comparison



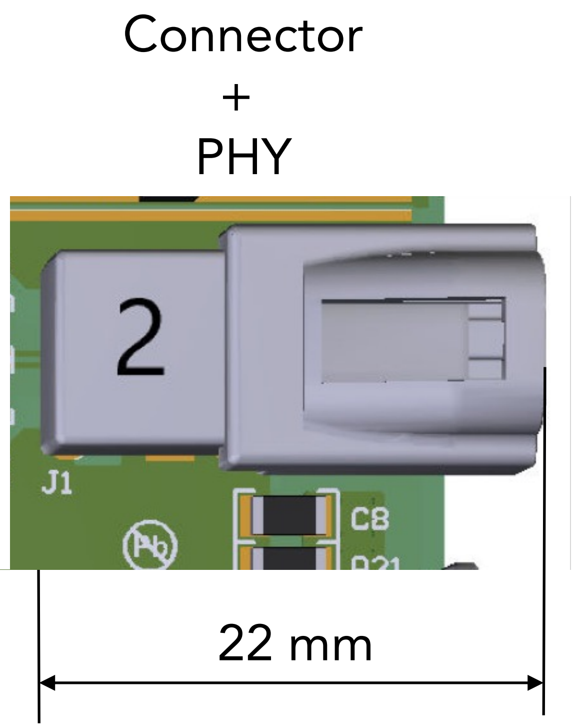
BCM89890, 8x8 mm, BGA-81

1000BASE-T1 port (TI)





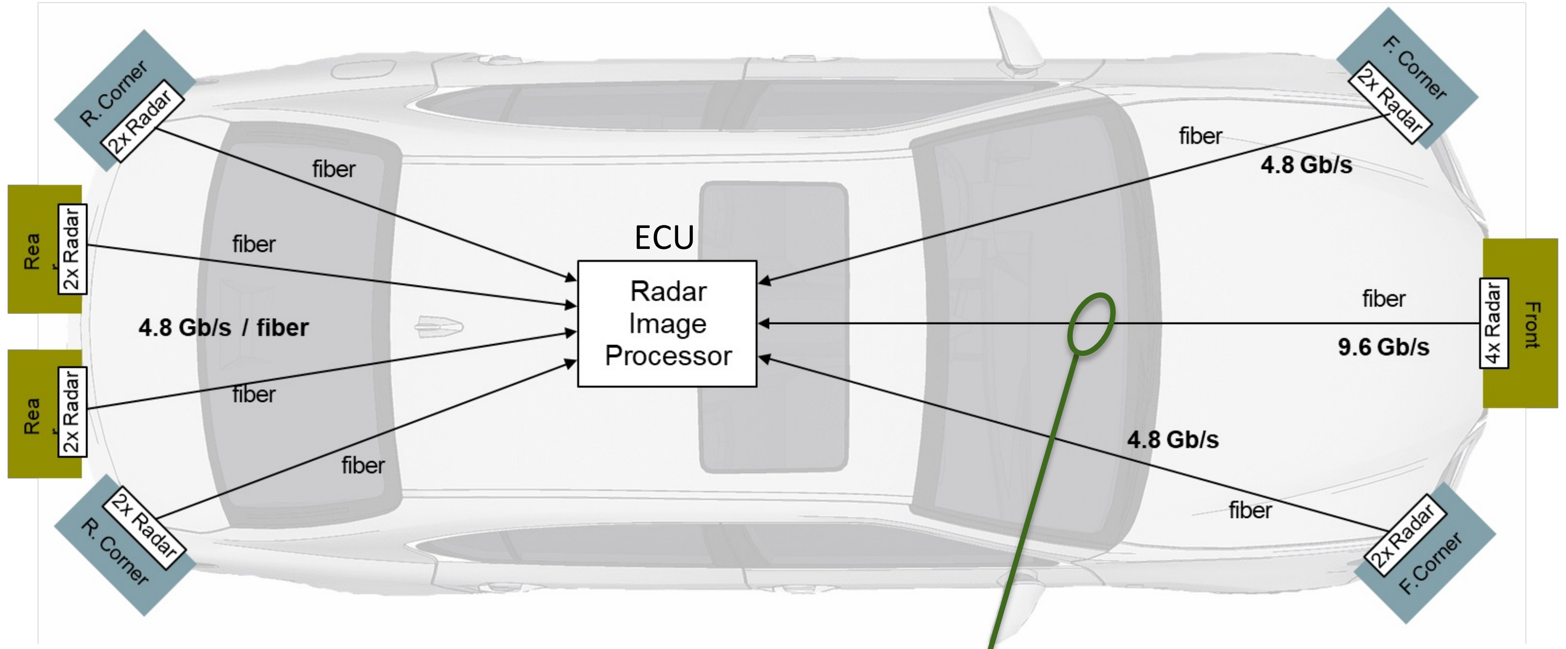
10GBASE-AU port (KD)

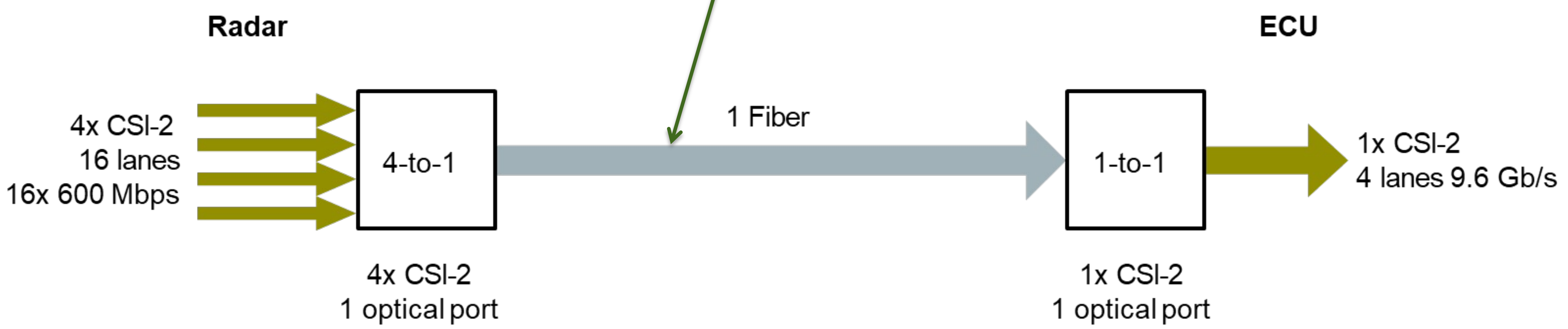


Camera and radar solution

- MIPI operation:
  - CSI-2 to CSI-2
  - CSI-2 to Ethernet with IEEE 1722/MIPI encapsulation
- I2C, SPI and GPIO support over IEEE 1722
- Multiple CSI-2 channels over a single duplex fibre
- Asymmetric optical operation:
  - Up to 12.5 Gb/s downstream
  - 1 Gb/s upstream
- 90º or 180º connectors
- Power supply over hybrid connectors and cables already prototyped
- Several TIER-1 and OEM interested; PoC available

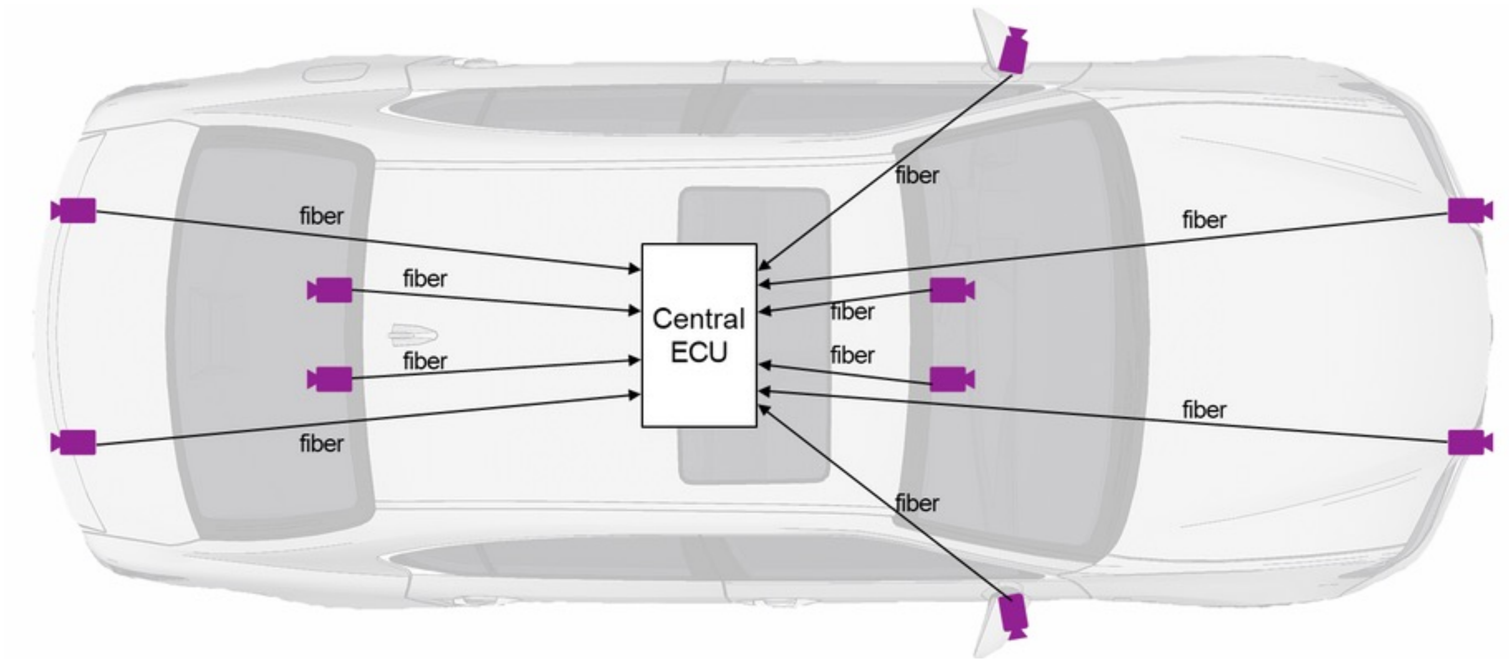
Satellite radar PoC



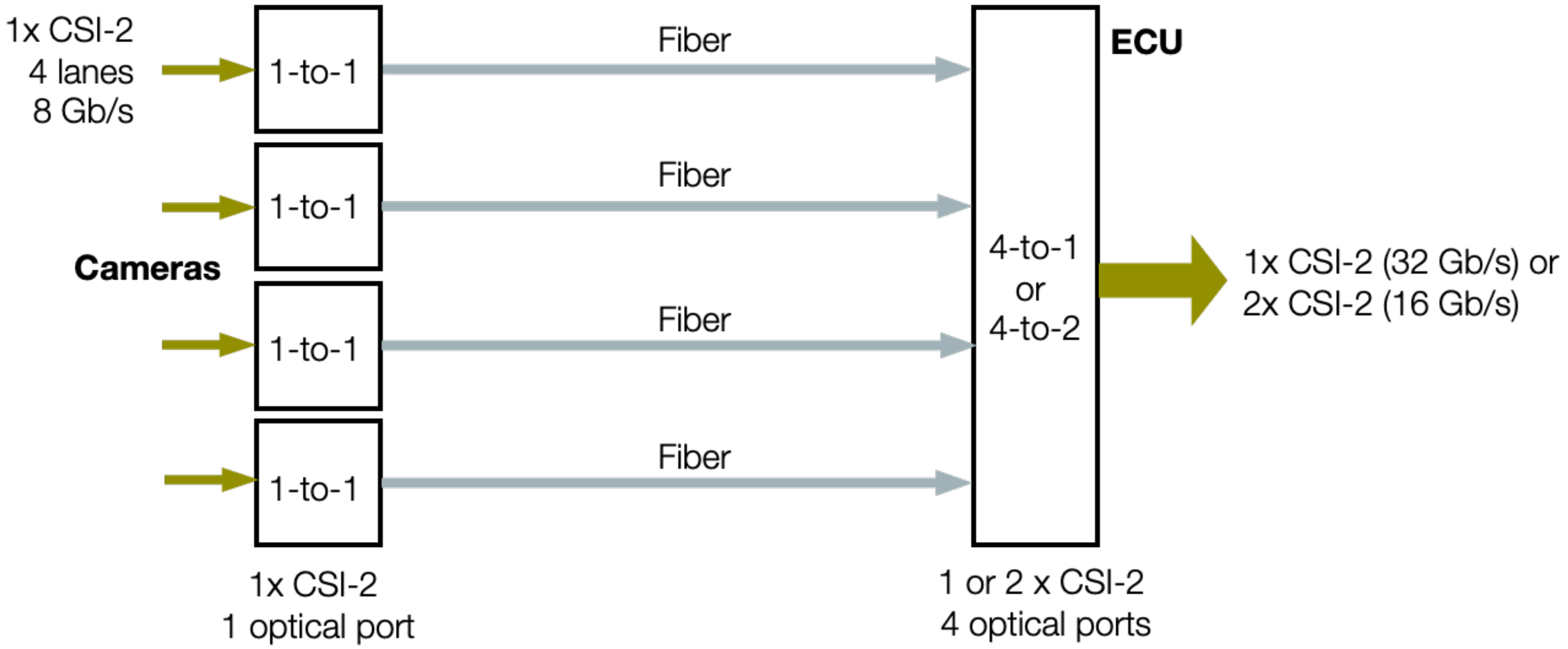


- 2 or 4 FMCW radar transceivers per sensor ECU (e.g. AWR2243)
- 4-lane CSI-2 port per transceiver, 600 Mb/s per lane
- Data-rates:
  - 2 x 4 x 600 = 4800 Mb/s (rear sensors and front corners)
  - 4 x 4 x 600 = 9600 Mb/s (front sensor)
- Radar application is intensive in number of lanes and ports to get aggregated rate

Camera PoC

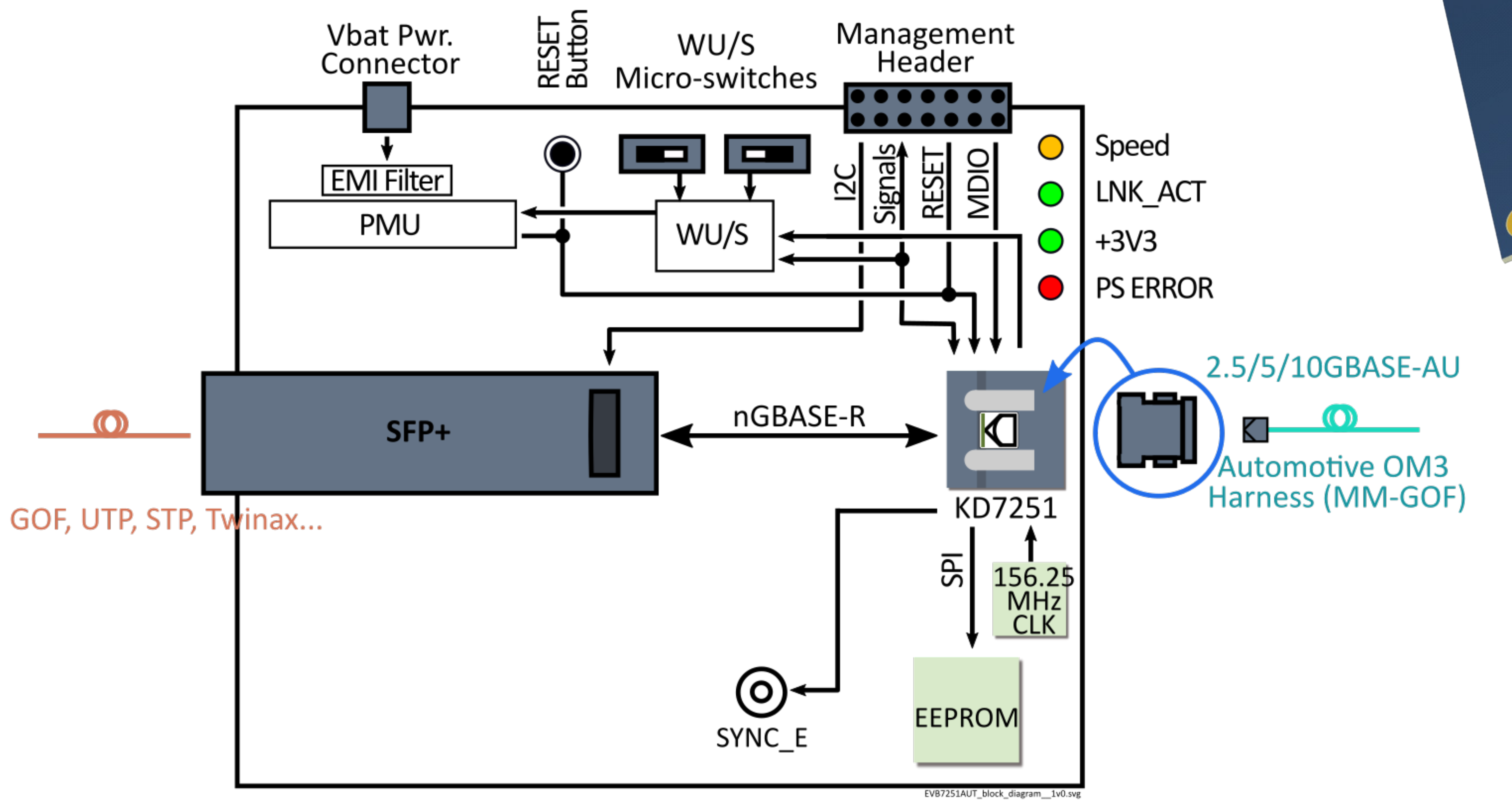


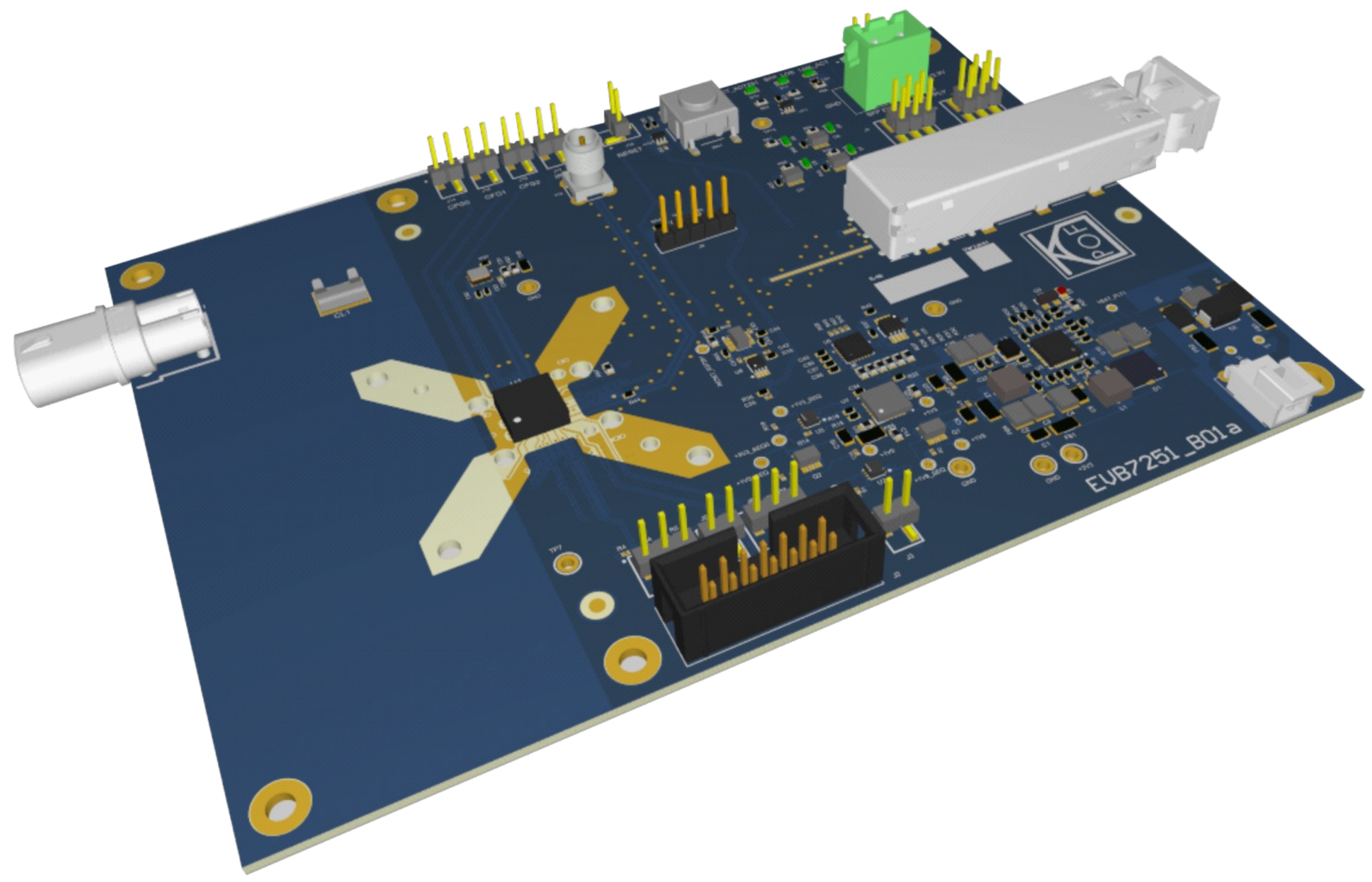
- Up to 10 cameras in high-end platforms with raw-data transmission
- Most of the cameras are ~3 Gb/s, some of them are ~8 Gb/s
- # CSI-2 ports per SOC limited, max 4 (e.g. Xavier, Renesas): virtual CSI-2 channels over single CSI-2 port are used
  - Dual and quad deserializers are currently used with coax and A-PHY



- Camera application is intensive in rate per lane with low number of lanes and ports

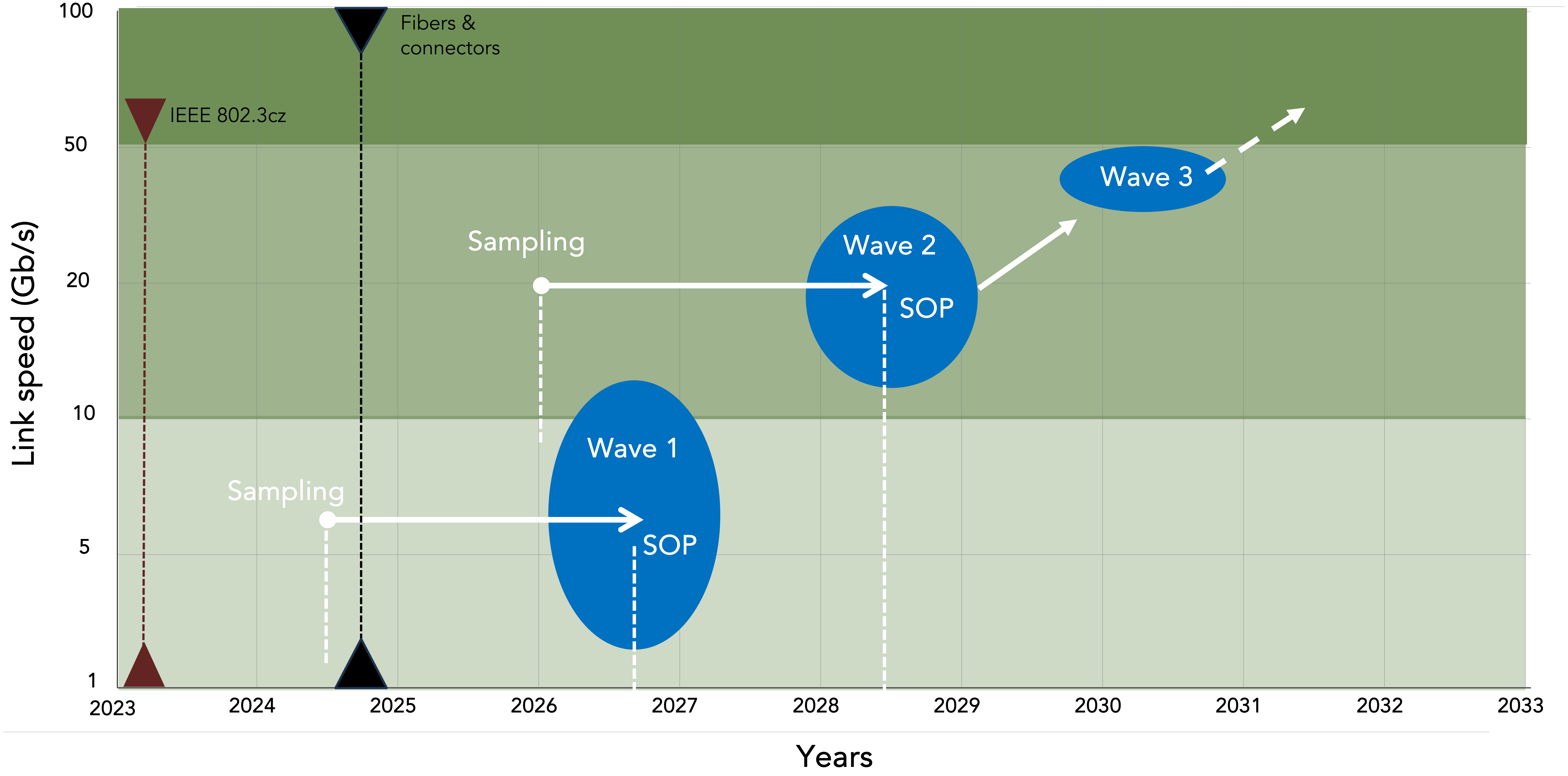
KD7251 eval-board





Availability September 2023

Optical Multi-gigabit Road Map



Ecosystem

- PHY vendors — KDPOF, BROADCOM, ?
- Connector and cables — MD ELEKTRONIK, CORNING, YAZAKI, SUMITOMO ELECTRIC WIRING SYSTEMS
- Test tools — AUKUA SYSTEMS, KEYSIGHT, VECTOR
- Test houses — GRL
- Interested TIER-1 and OEMs (Some with actual projects) — ZF, BOSCH, cruise, HYUNDAI, TESLA, BMW, gm, Lucid, NIO, VOLVO

www.kdpof.com

Thank you!

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Questions

& Answers

We are here for you now!
Ask us directly via our chat or via E-Mail.

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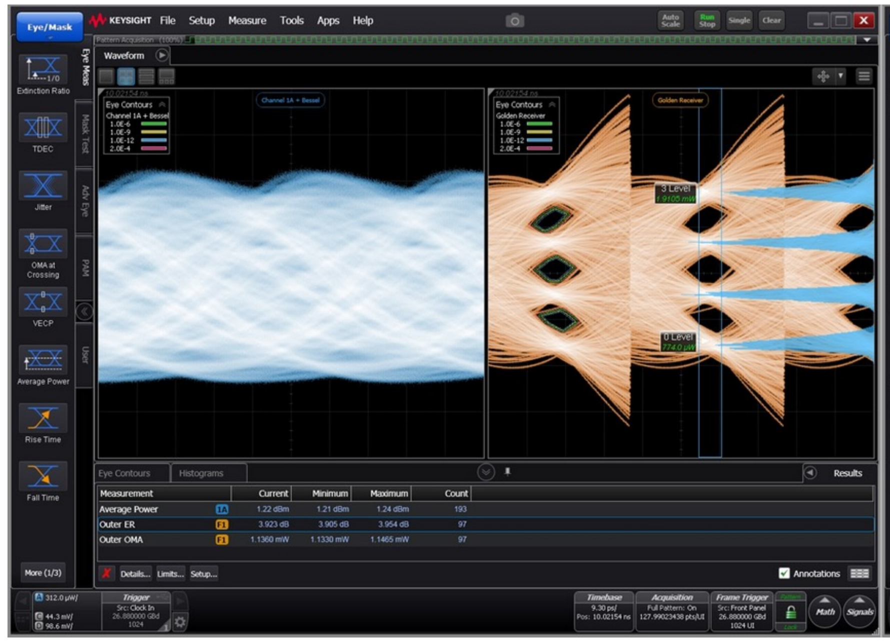
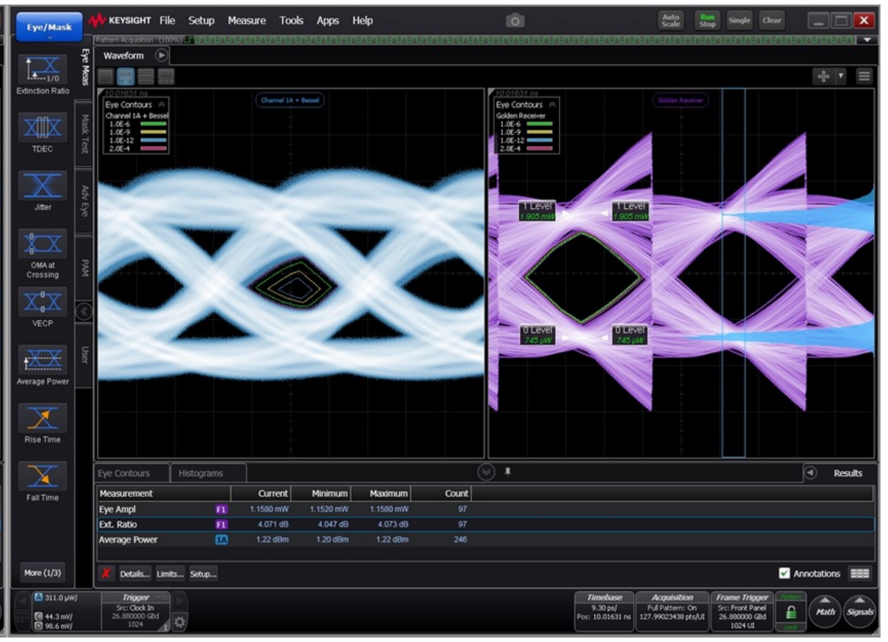
Backup slides

KDPOF advanced digital signal processing

980nm, ER 4dB, 125°C, 40m OM3

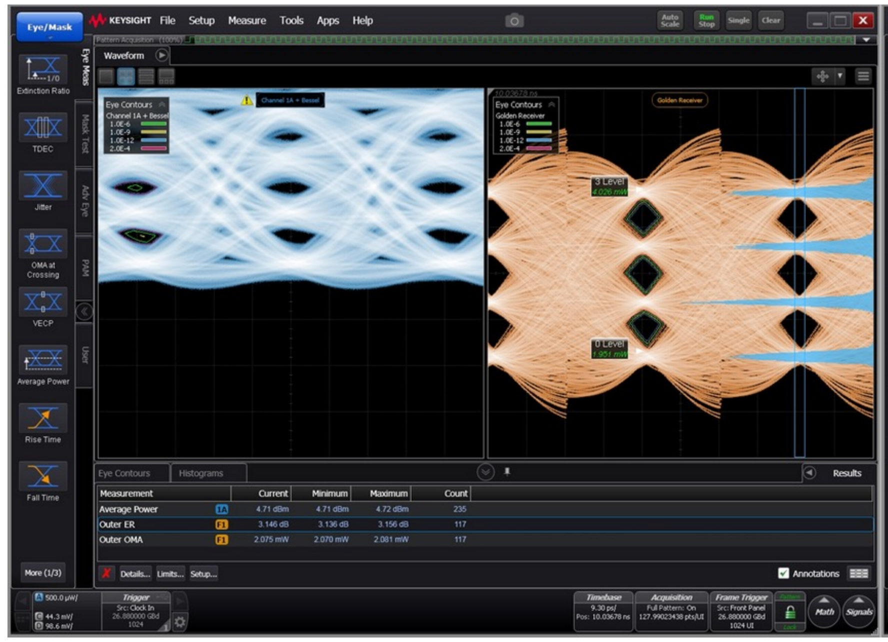


53.76 Gb/s
PAM4

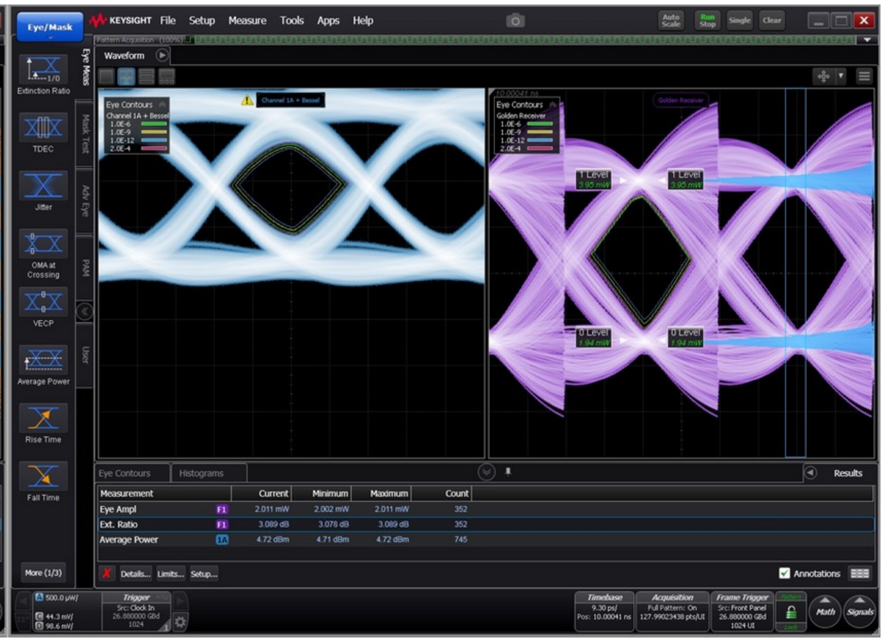


26.88 Gb/s
NRZ

980nm, ER 3dB, -40°C, 40m OM3



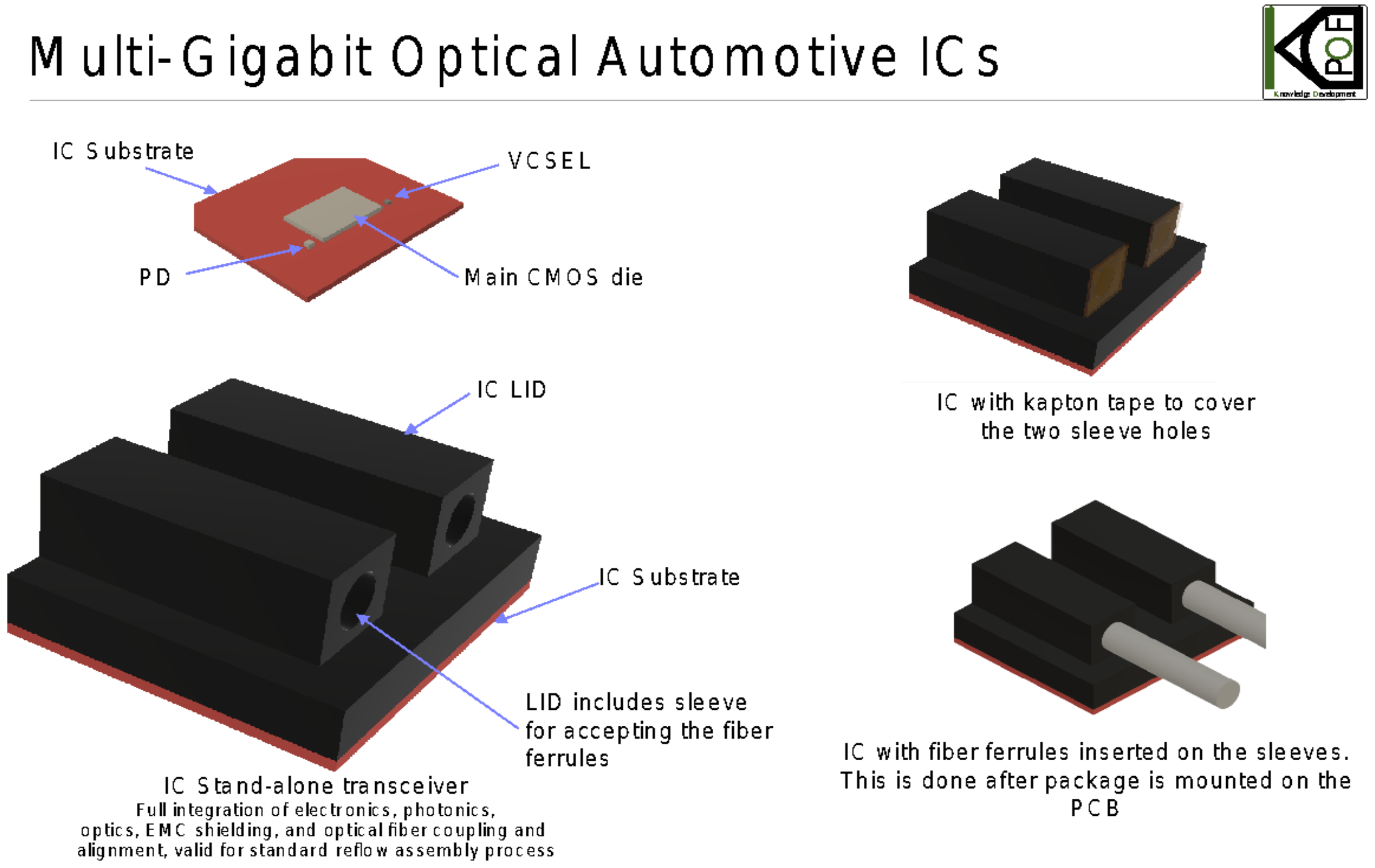
53.76 Gb/s
PAM4

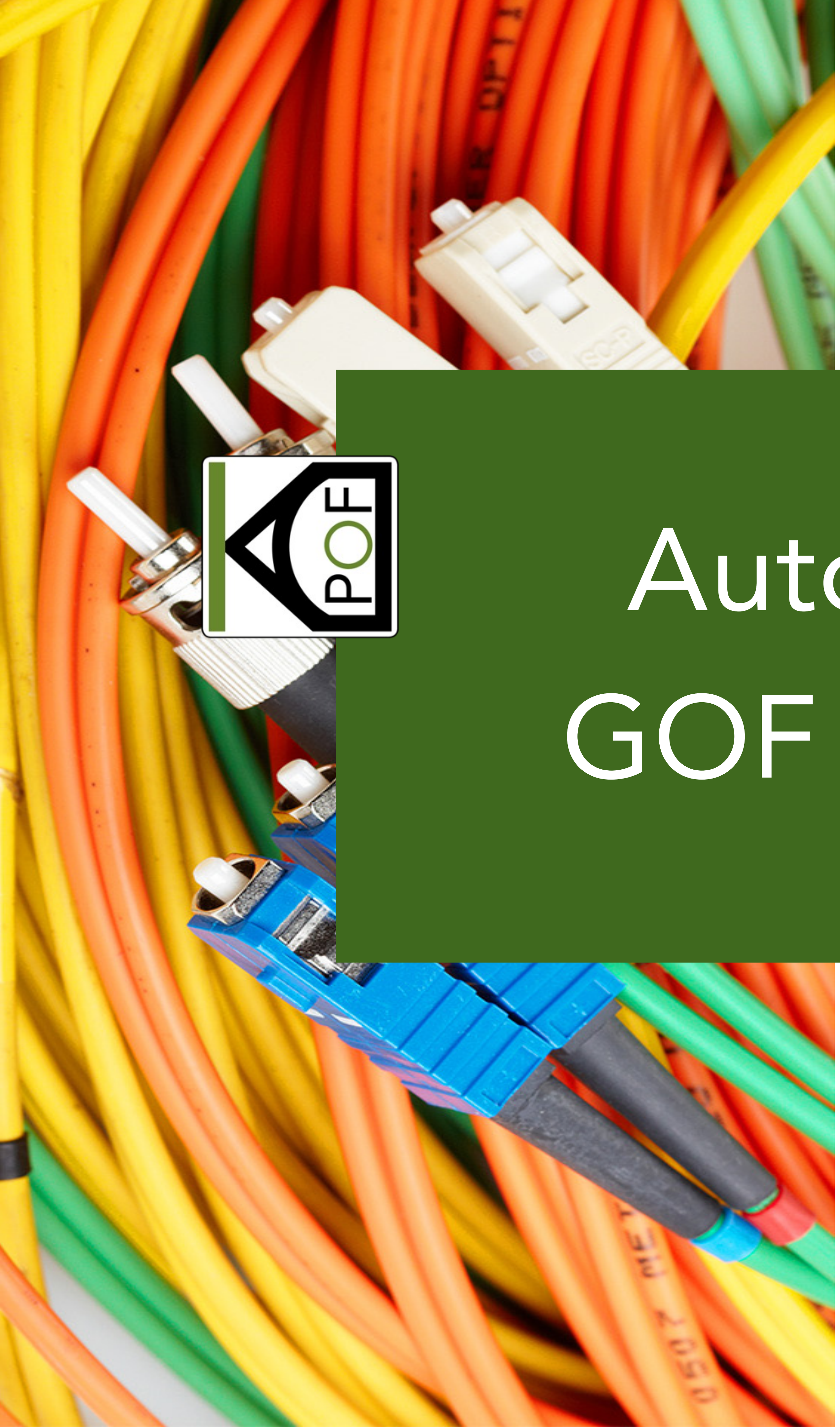


26.88 Gb/s
NRZ

Integration

- Integration of >=10 Gb/s copper PHYs in switch will be complicated
- Optical transceiver will always be in the connector
  - Middle of the board and edge connector options possible
- Integration of PCS & PMA in switch no sense
- Different electrical interfaces to support connection to switch
- Multiple port transceivers is the most probable way of integration. High density connectors
- In collaboration with switch IC suppliers to agree on interfaces

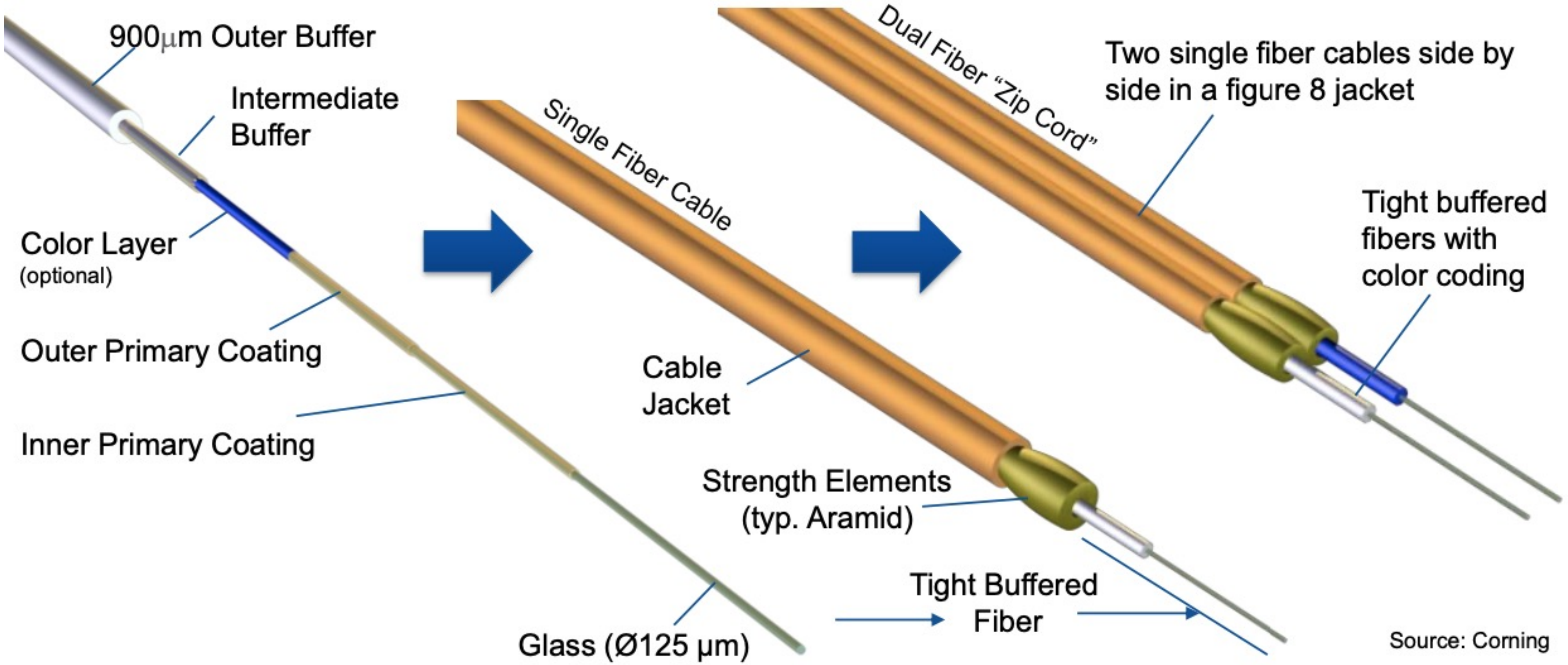




Automotive-grade GOF and connectors

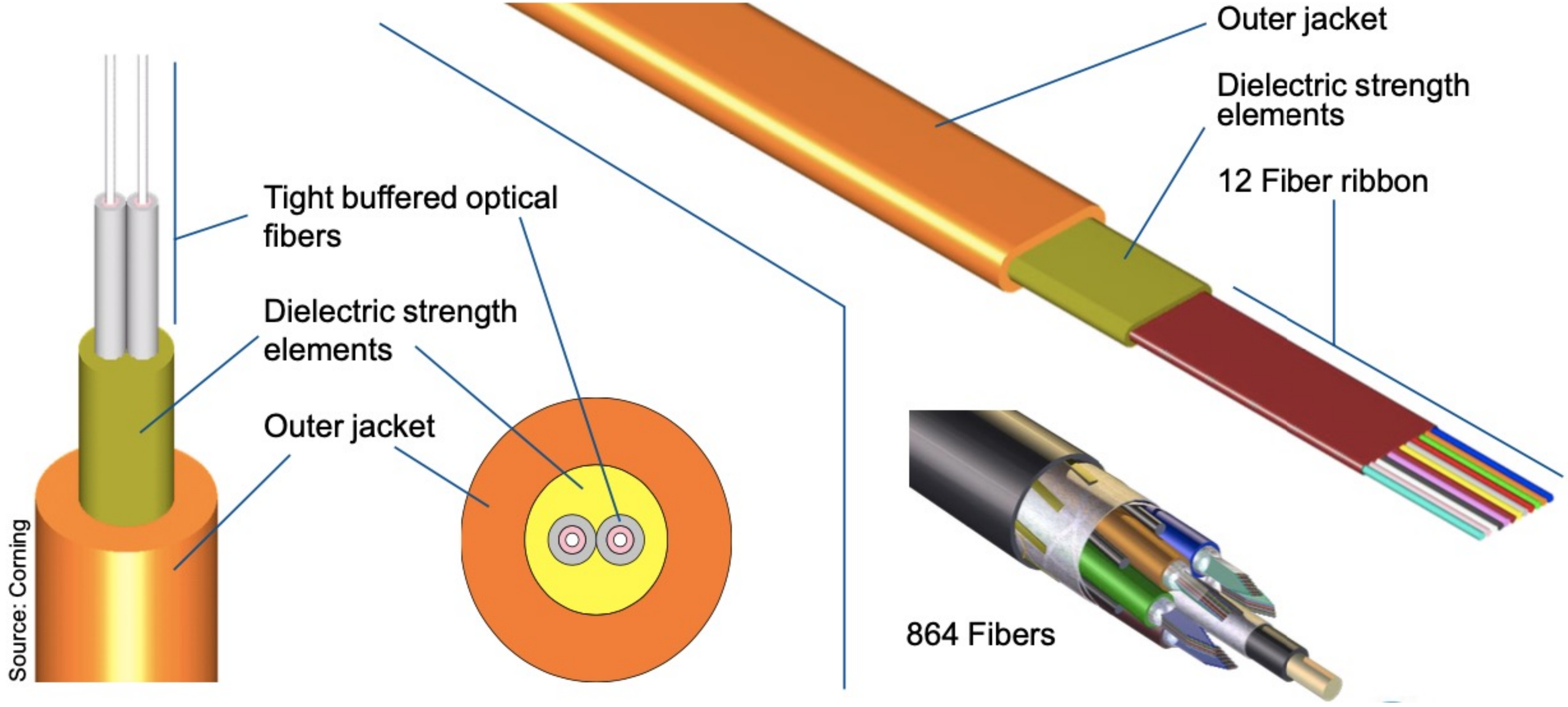
GOF CABLES FOR AUTOMOTIVE

900 um Tight Buffered Fiber → Typical Interconnect Cable



GOF CABLES FOR AUTOMOTIVE

Many Options for Multi-Fiber Cable (selection)

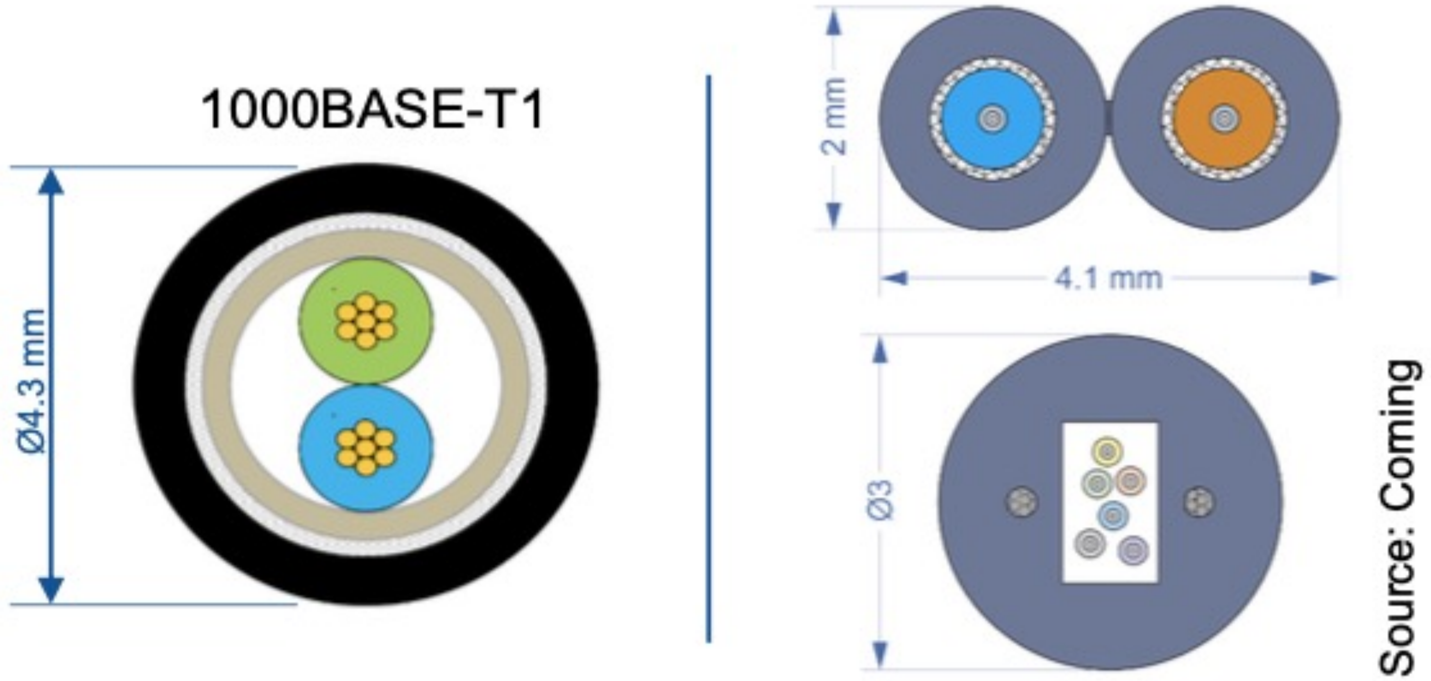


SCALABLE TECHNOLOGY

Optical cable is smaller/lighter for multi-gigabit

- Electrical communications cable (copper)
  - Insulated to avoid short circuits
  - Conductor pairs to balance signals and minimize cross-talk
  - Shielded to minimize EMC/EMI
  - Increase in data rate → shield (EMI), dielectric layer (x-tak) → more specific

- Glass Optical Fibre Cable
  - Plastic sheets to protect fiber mechanical and environmental factors (i.e.125°C)
  - Aramid standards for tensile strength (>200N)
  - No need for EMI shielding
  - Increase in data rates → cable size unchanged from 1Gbps up to 100 Gbps.



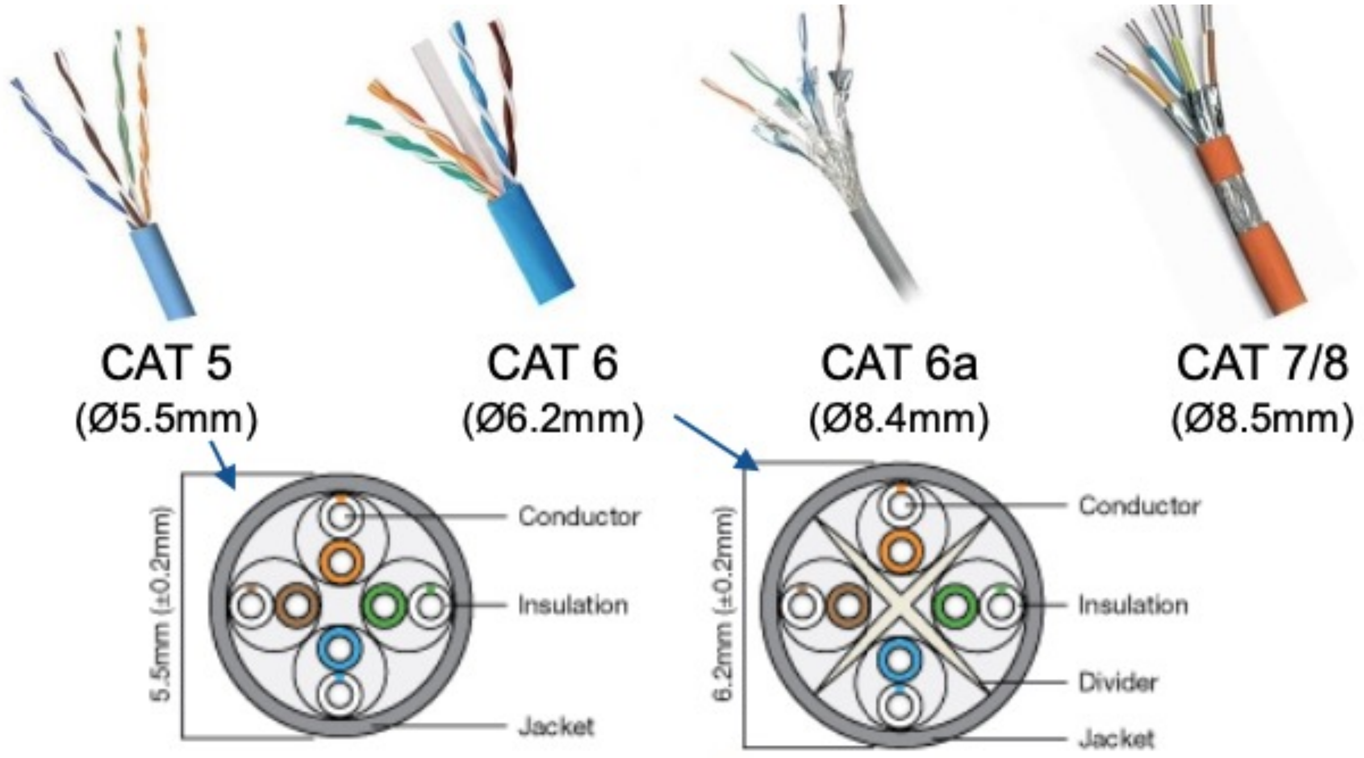
	1000BASE T1	Optical Cables
"Conductor"	2x AWG26 Cu	2x 125/50 µm Glass
Diameter	4.3 mm	4x2 mm
Weight	23.2 g/m	7.4 g/m
Min. Bend Radius	21 mm	15 mm
Data rate	≤1 Gbps	100+ Gbps

Scalable technology

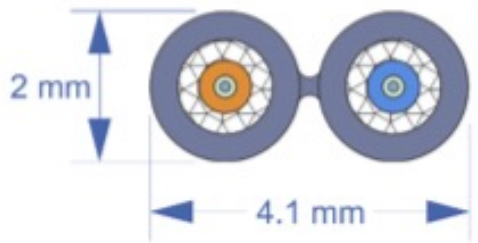
Optical fiber systems can scale to higher data rates w/ same cable design

	Max. Speed	Complexity*	Distance
CAT 3	0.01 Gbps	•	100 m
CAT 5	0.1 Gbps	••	100 m
CAT 5e	1 Gbps	••	100 m
CAT 6	1 Gbps	•••	100 m
CAT 7	10 Gbps	••••	100 m
CAT 8	**40 Gbps**	•••••	**30 m**

*… shield, twist, etc.

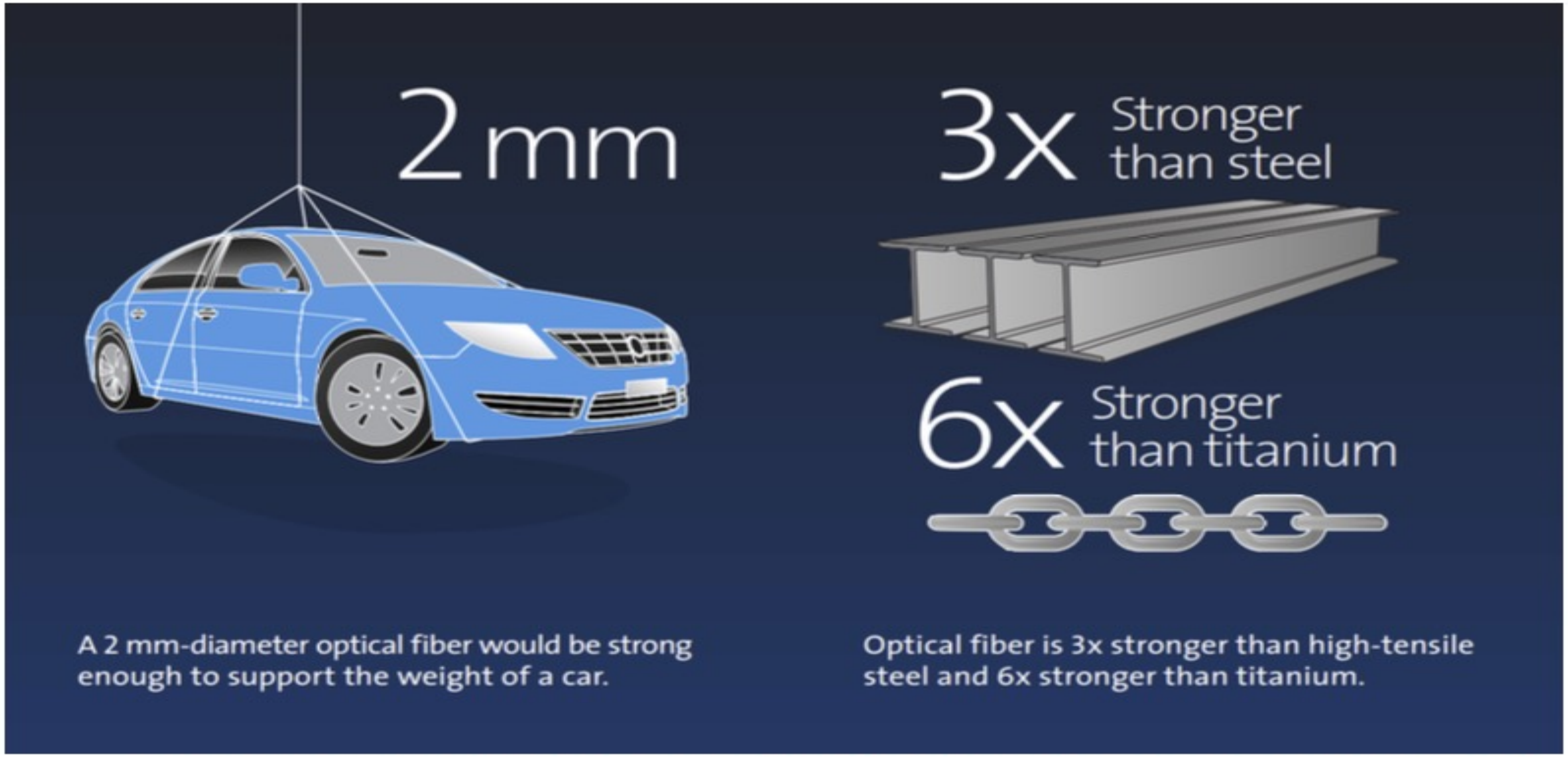


Fiber	Bandwidth	850 nm*	
MM 50μm	2000MHz.km	**$40G_{SWDM}$ 240 m**	<3.0 dB/km



- Same fiber from 0.01–100 Gbps
- Same Cable/Connector design
- No Shielding Needed

OPTICAL FIBER IS INHERENTLY STRONG

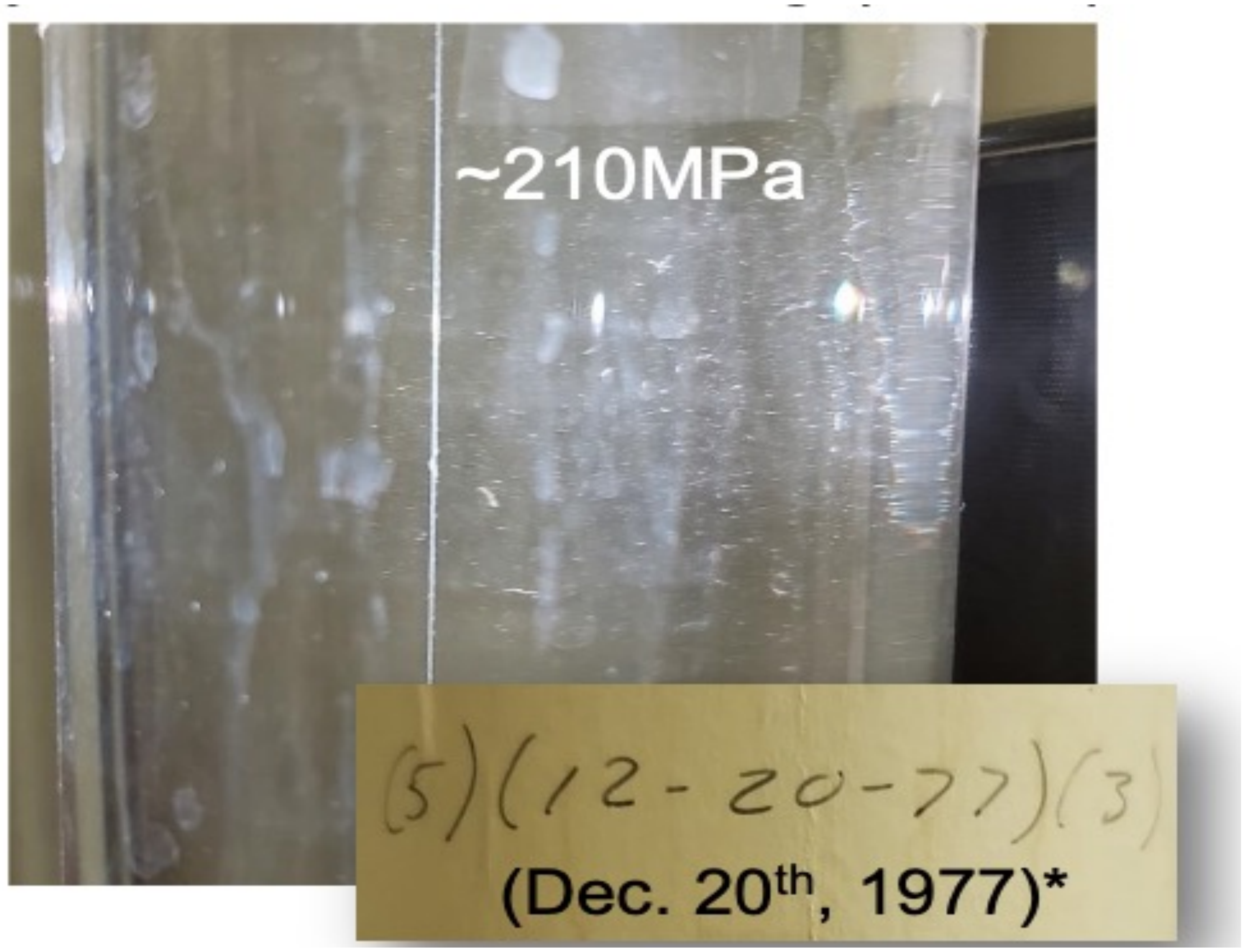


* Source: https://www.corning.com/media/worldwide/global/documents/Optical_Fiber_Infographic.pdf

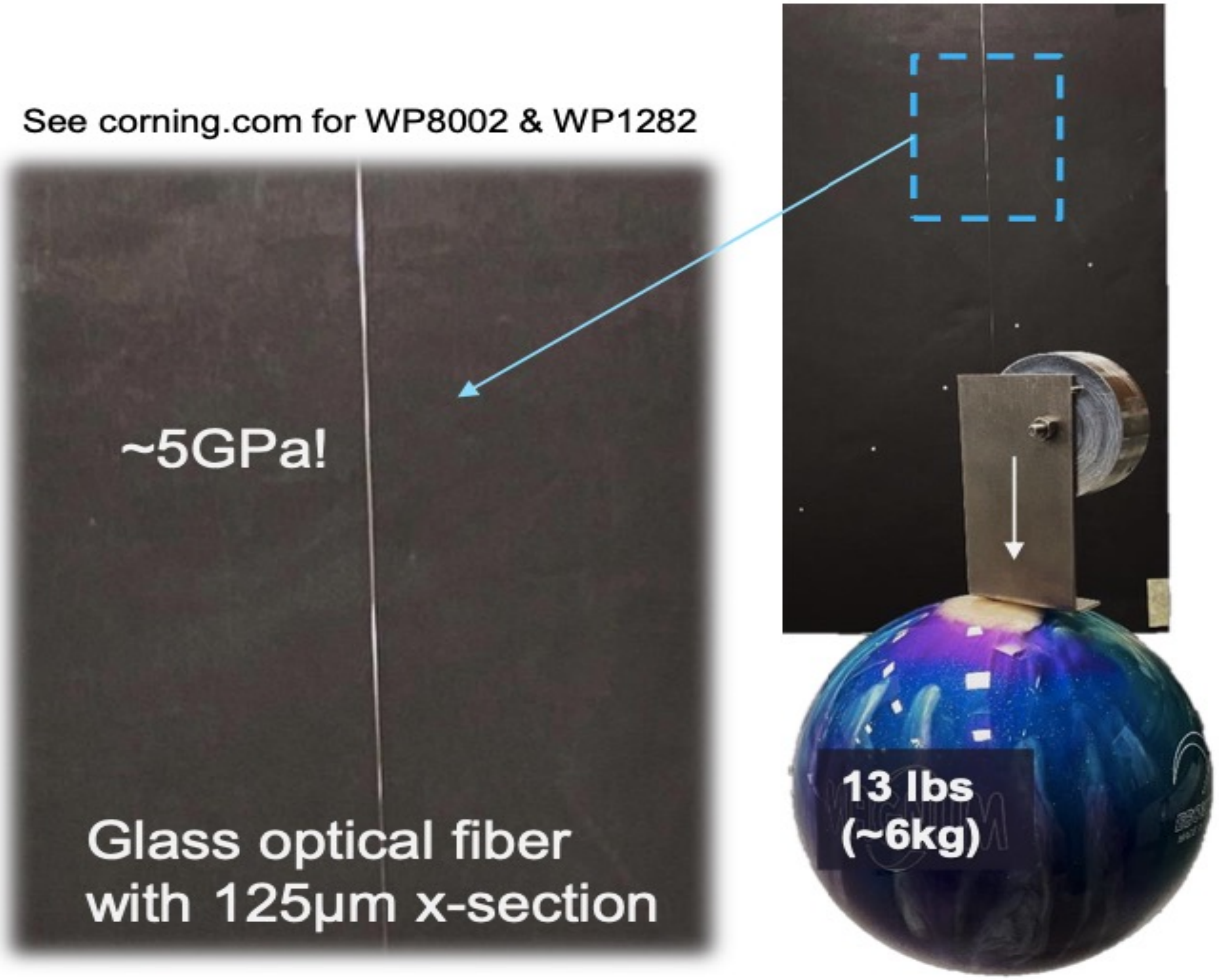
FUSED SILICA WITH VERY HIGH INTRINSIC STRENGTH

Experiments

- Glass optical fibers have been in tension (F=2.6N) for nearly 50 years without breaking (below)



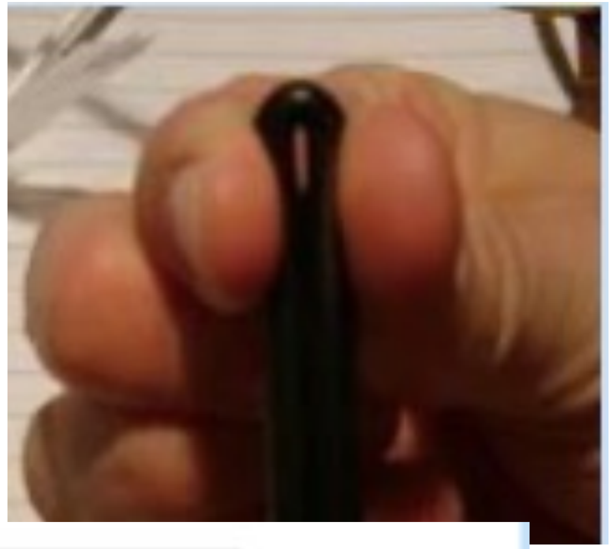
See corning.com for WP8002 & WP1282

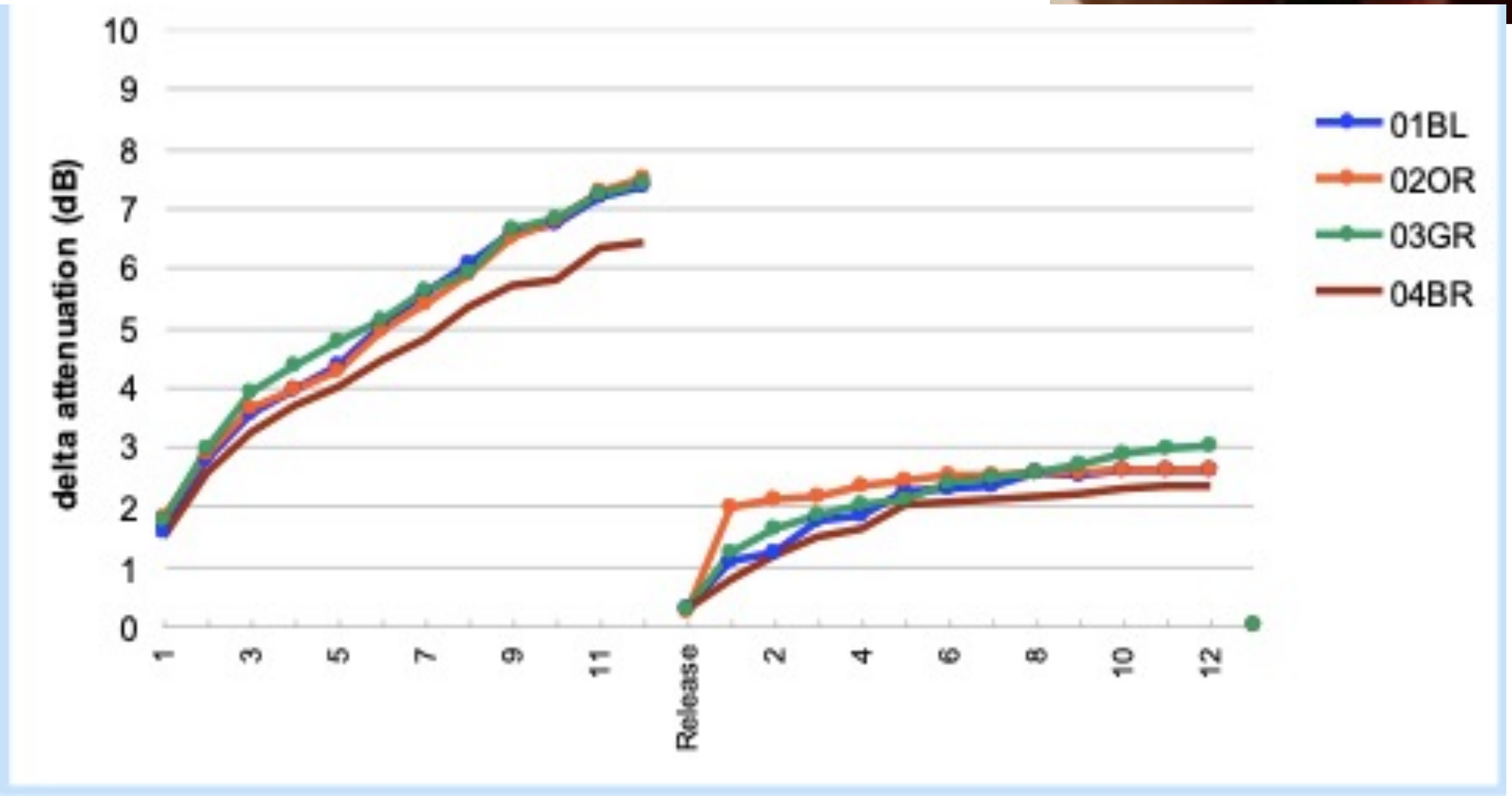


GOF for AUTOMOTIVE

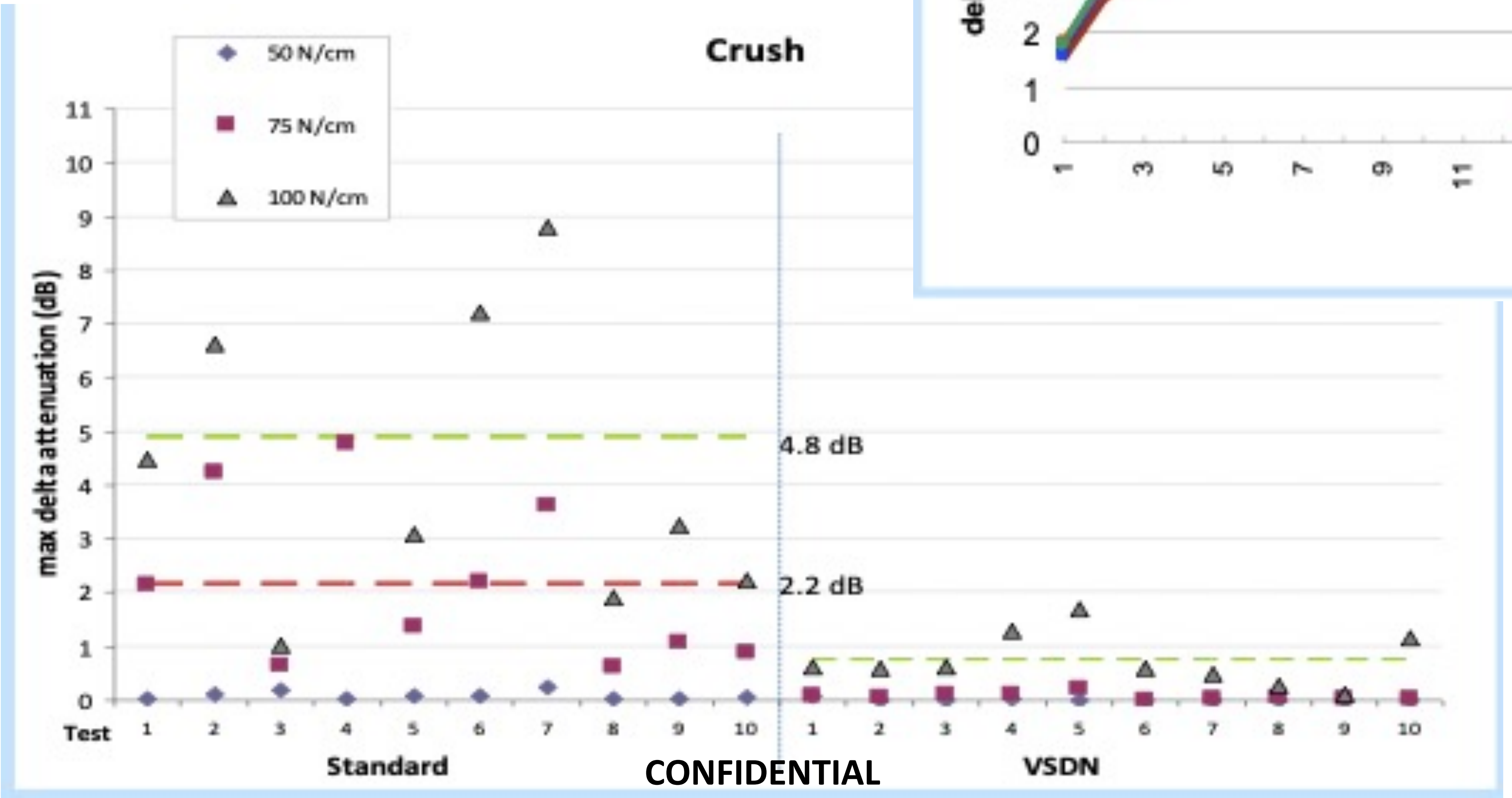
- Environmentally robust fiber cable for challenging applications has been demonstrated

Pinch test





Crush test



Source: Corning

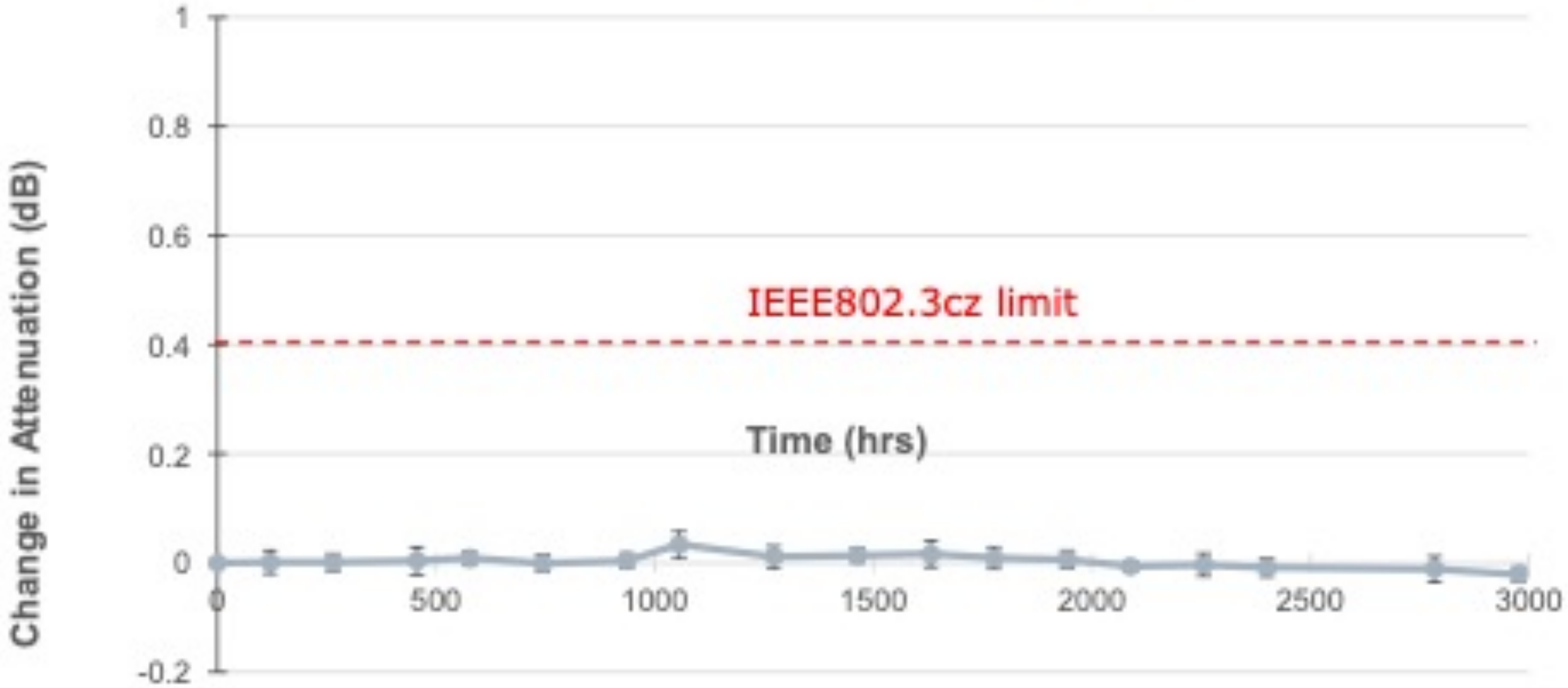
GOF for AUTOMOTIVE: Thermal stability

Nominal Target = 105°C, Stretch target = 125°C

Glass optical fibers and cables inside thermal aging chamber

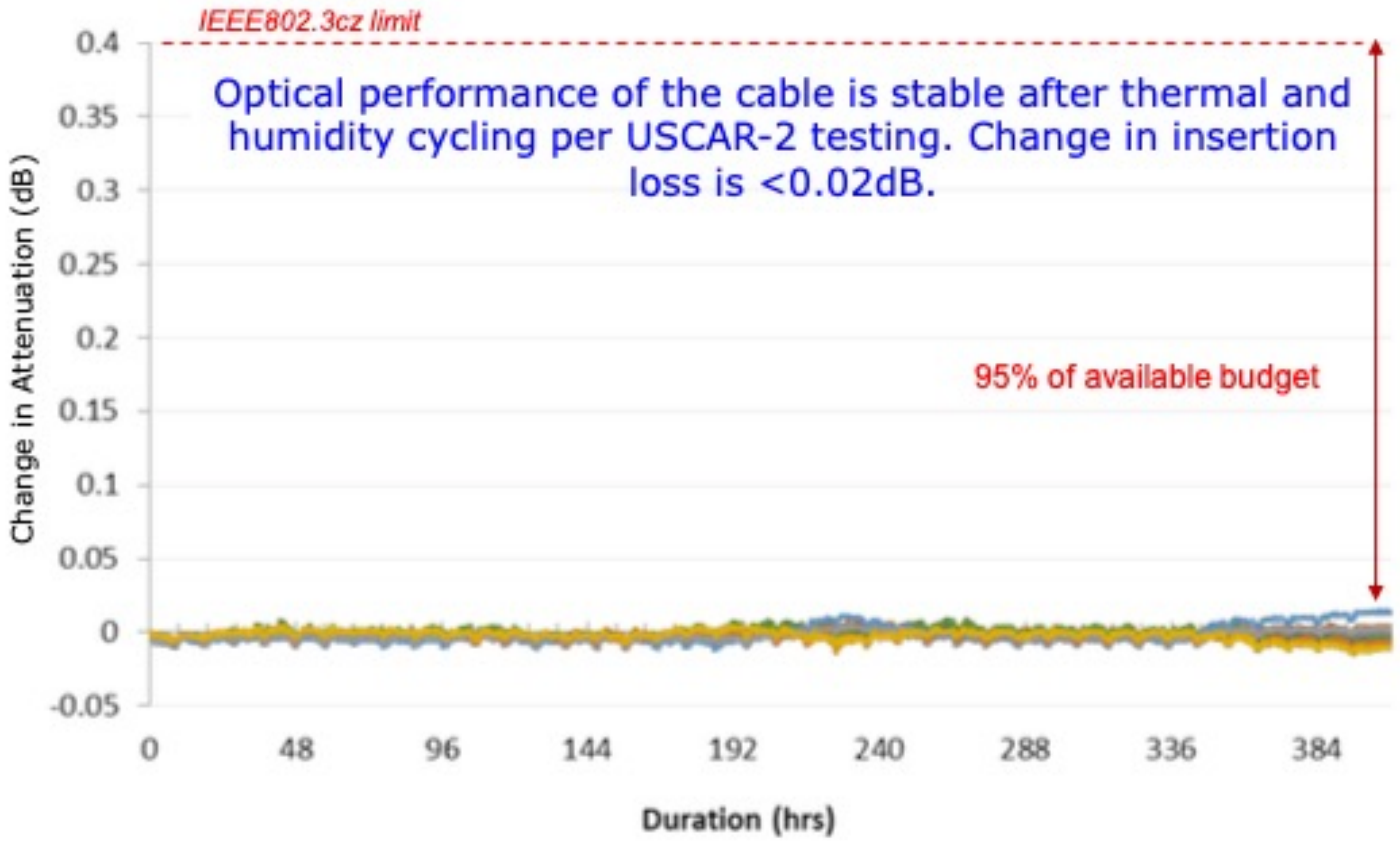
Source: Corning

Less than 0.05dB change in attenuation after 3000hrs of thermal aging at 150°C

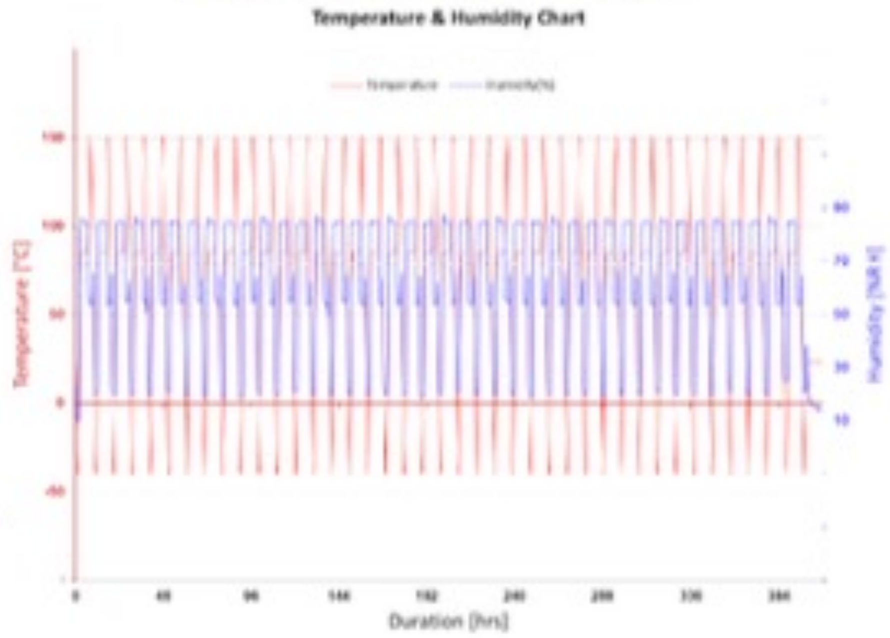


GOF for AUTOMOTIVE: Environm. cycling

Temp+RH Cycling (-40 to 150C) <0.02 dB



Duration: 400hrs; Temperature: -40°C to 150°C; 10 Samples

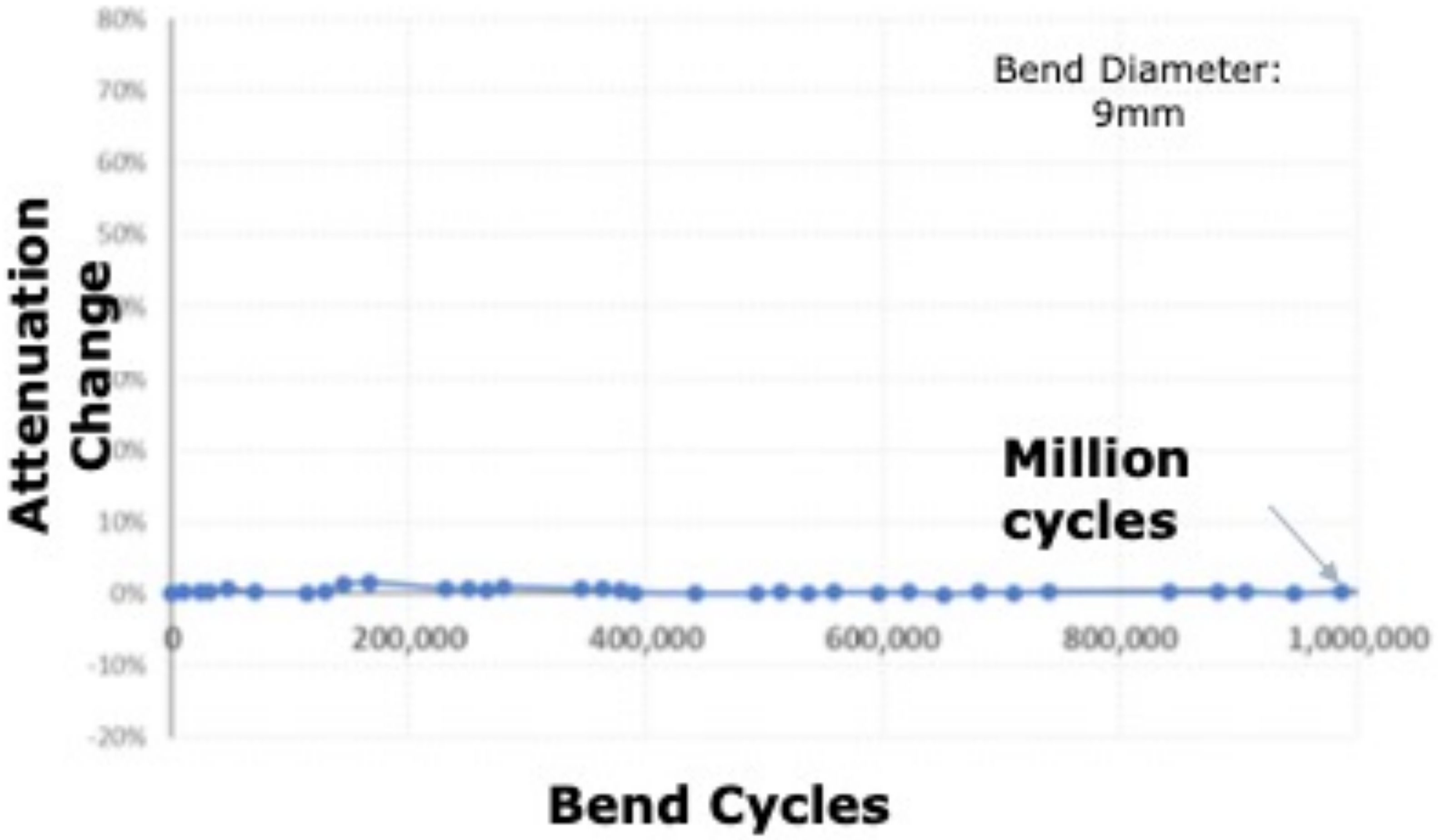


Source: Corning

GOF for AUTOMOTIVE: Cyclic bend

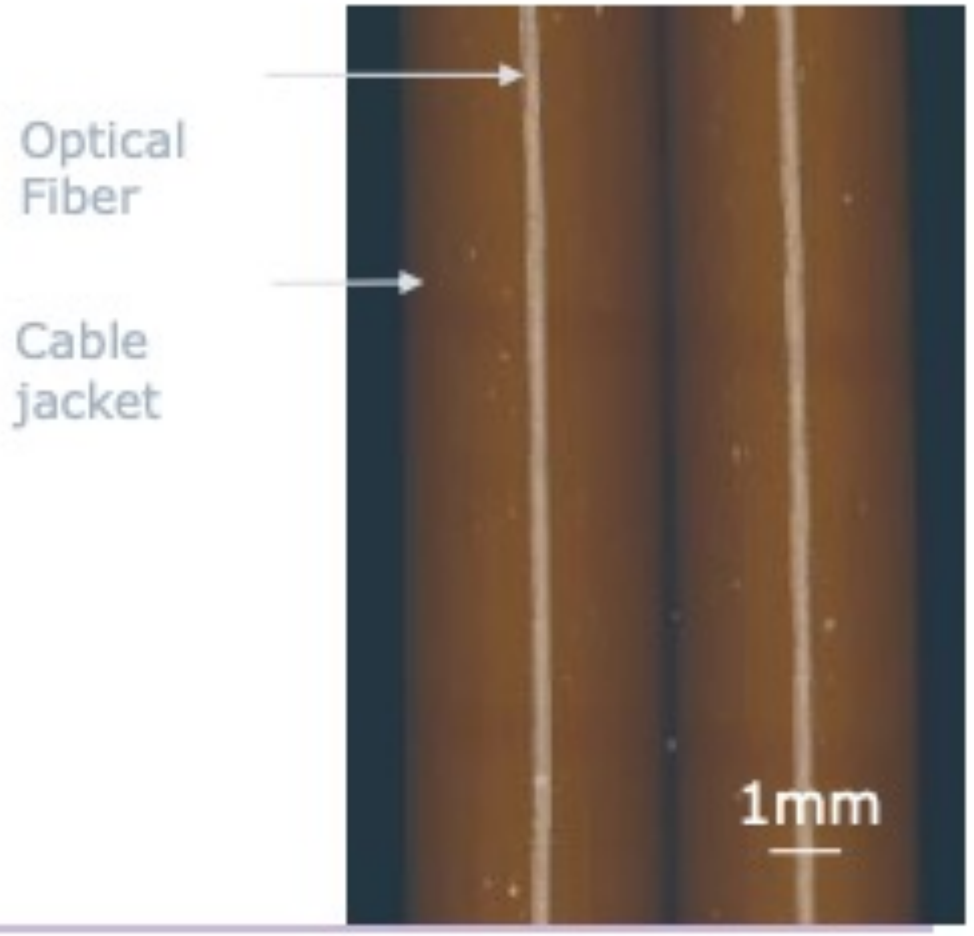
Cyclic bending of glass optical cable around 9mm diameter mandrel

No notable degradation after million bend cycles at 9mm diameter



No fiber damage after bend cycle testing

(X-Ray Microscopy Image)



Source: Corning

GOF for AUTOMOTIVE: Chemical loads

Source: Corning

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

+

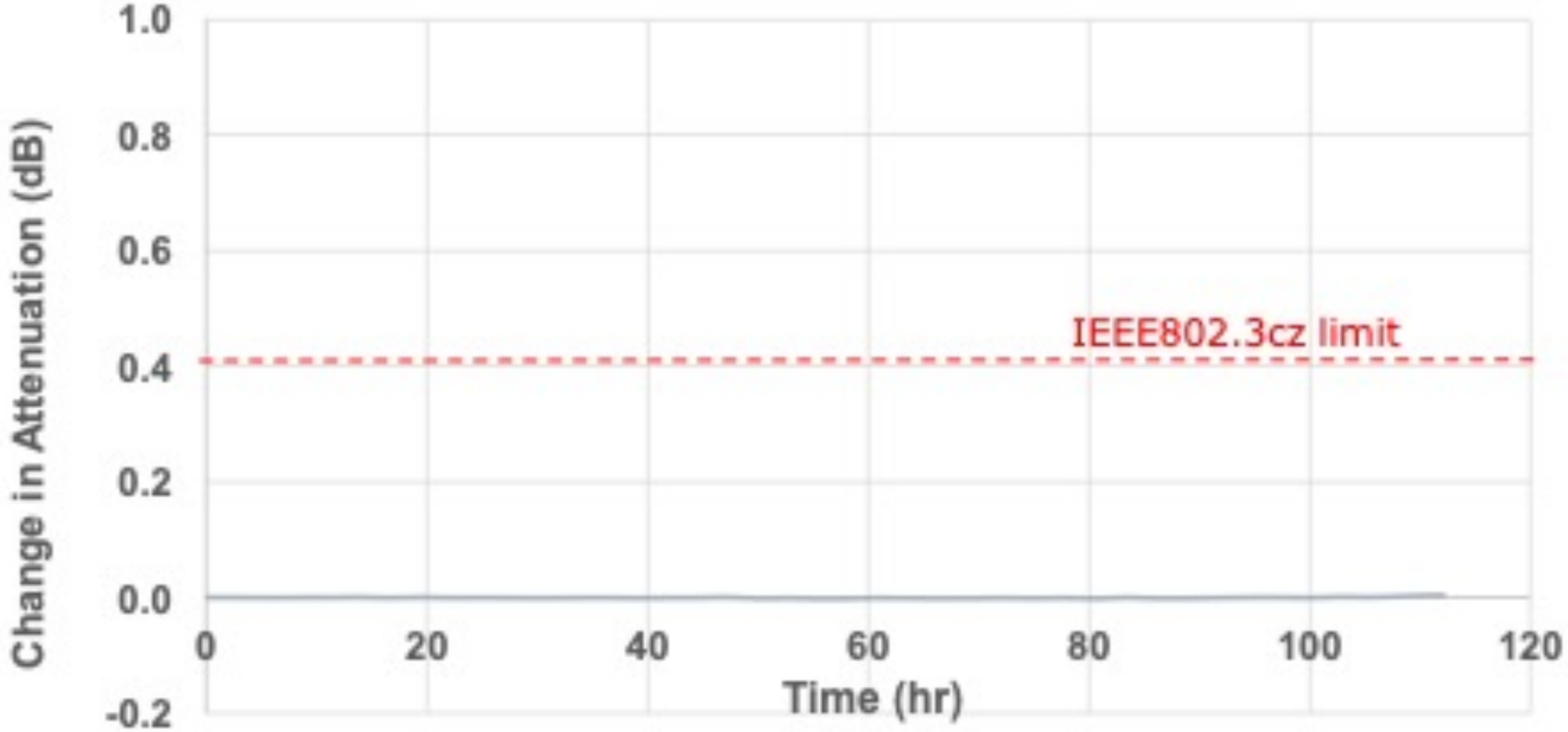
Static Mandrel Wrap, 9mm diameter, 2 Months

No cracking, swelling or discoloration

GOF for AUTOMOTIVE: Vibrations

Connector in vibration (random) testing

No notable change in attenuation after "random vibration" testing of the connector

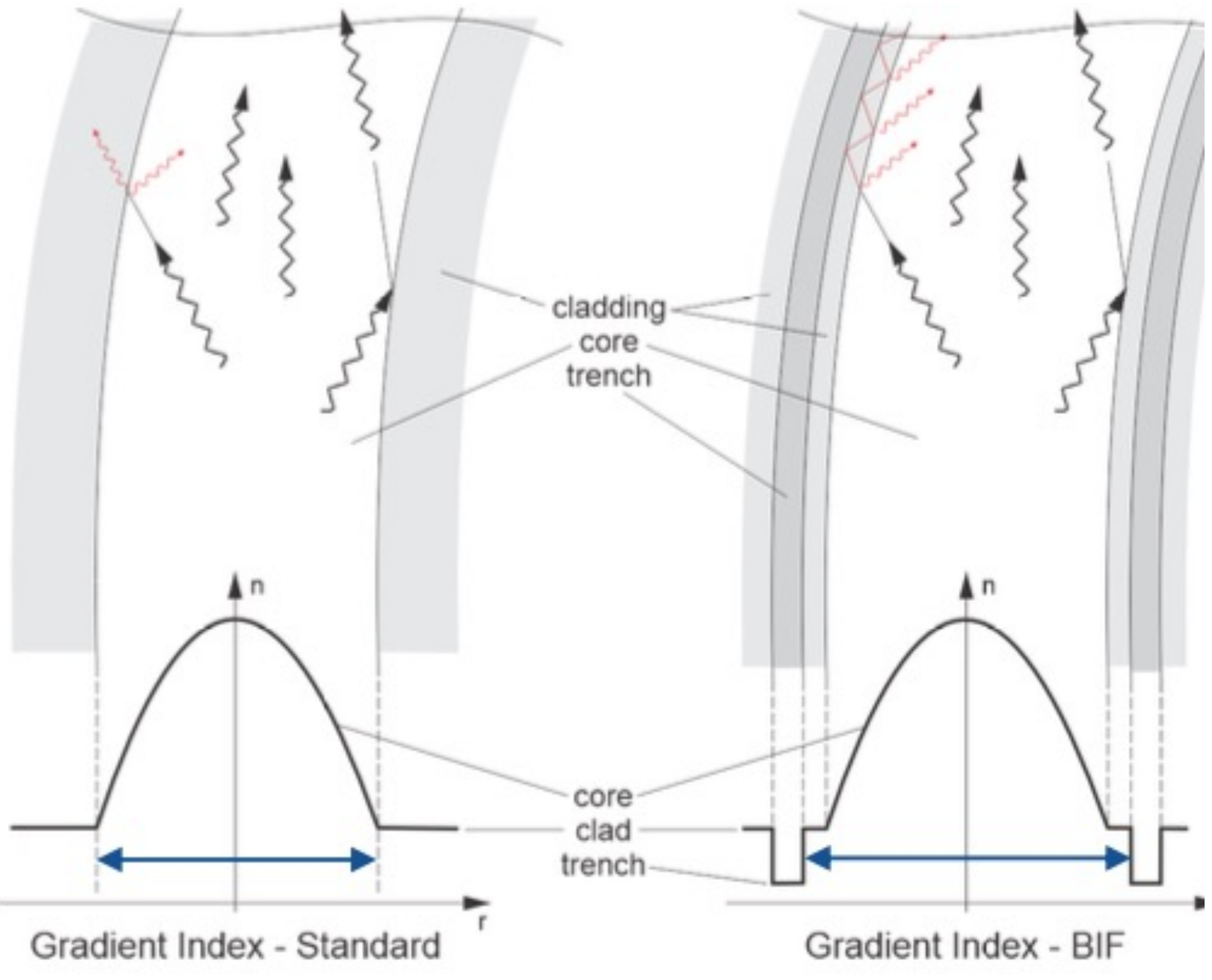


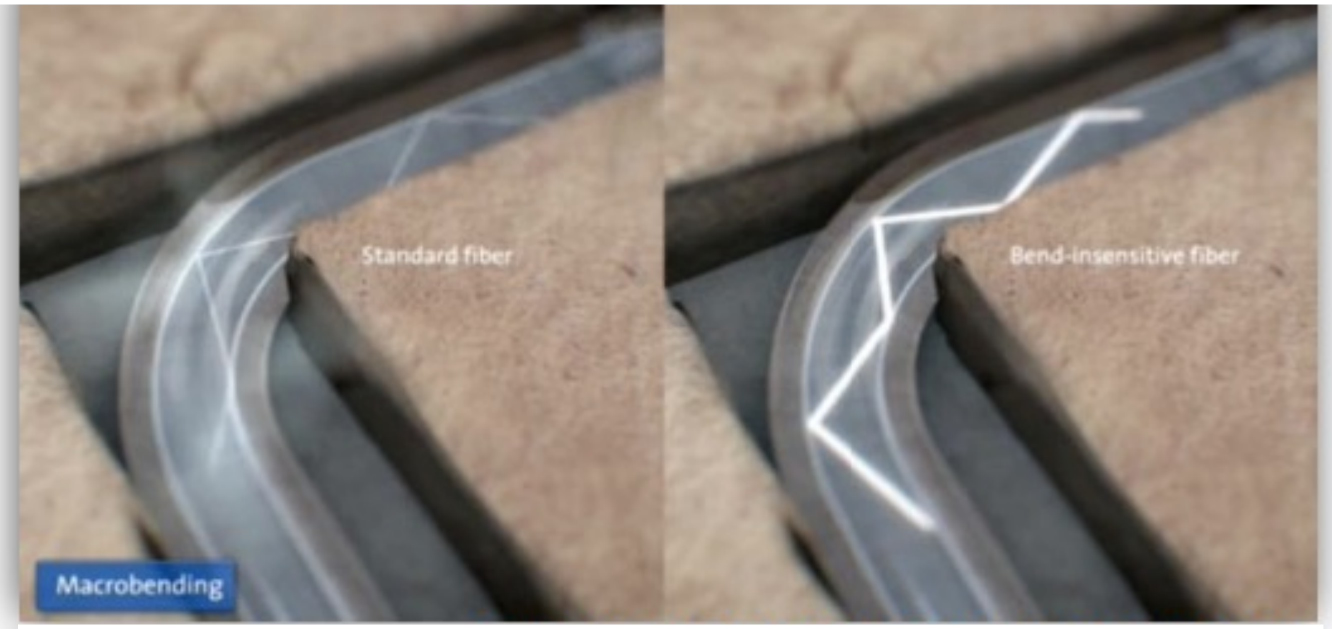
Source: Corning

GOF for AUTOMOTIVE

Bend Insensitive Fibers (FIB) for more link margin

BIF adds a layer in the cladding with a lower index of refraction (n) to provide an addition reflection. This guides the light – that would be lost in standard fiber.





* Source: https://youtu.be/N_kA8EpCUQo?t=151

REPETITIVE BENDING TOLERANCE

Optical cable can be rugged and flexible

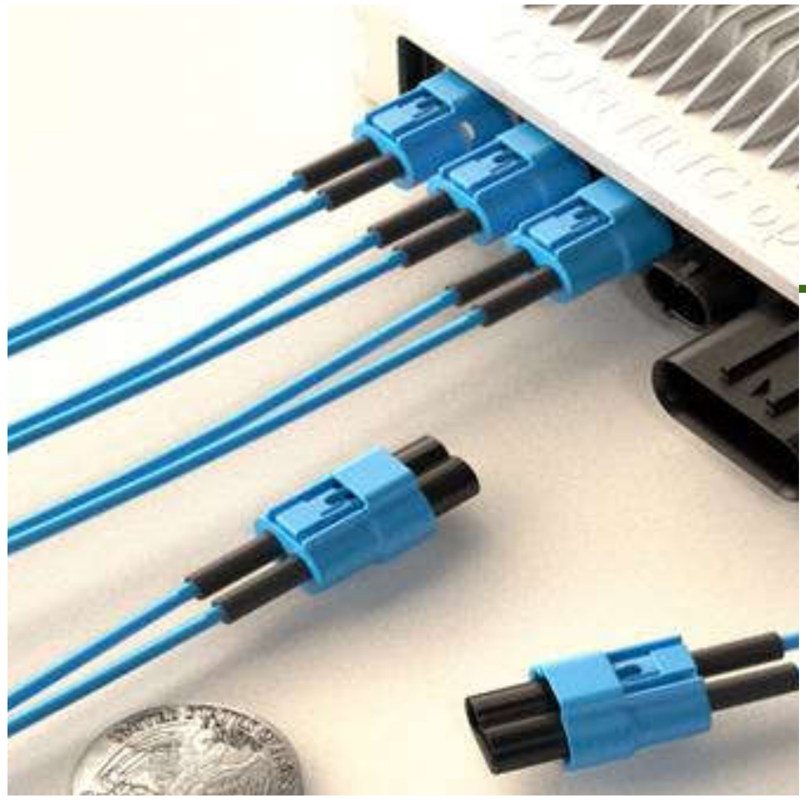
Copper is a ductile material (metal)

- Low yield stress, 69-365 Mpa
- Fatigue (work hardening) and permanent deformation are dislocation-driven once yield stress is exceeded
- High bend radius (e.g. 21mm (STP))
- Tight bends increase Loss/x-talk

Glass optical fibre is a brittle material

- High intrinsic strength, ~ 5 Gpa
- Is defected driven, not prone to fatigue
- Capable of smaller bend radius (7.5 mm)

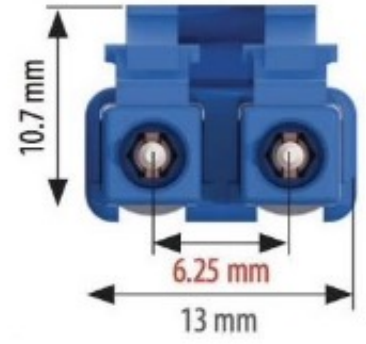
GOF CONNECTORS FOR AUTOMOTIVE
building on long history



Fiber to
the Home

Military

Data
Center

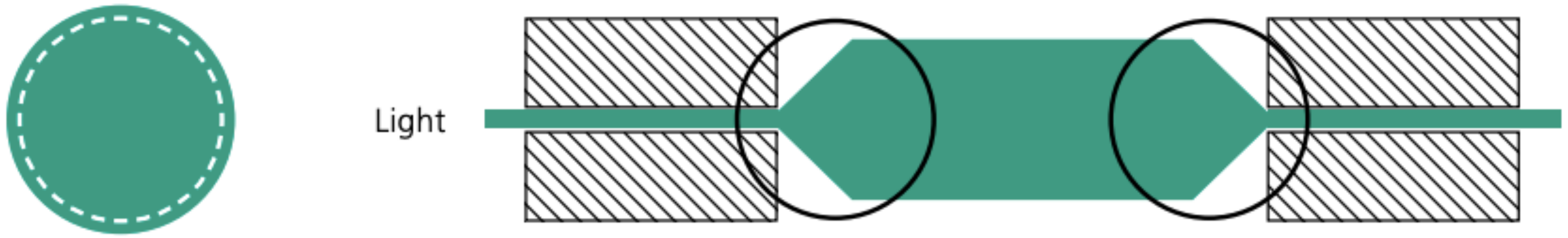


Hyperscale

Automotive

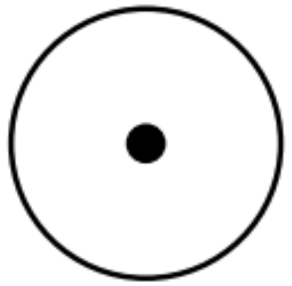
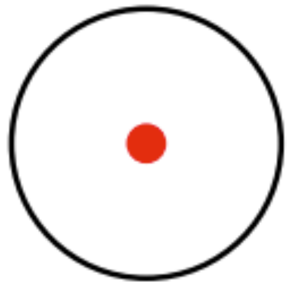
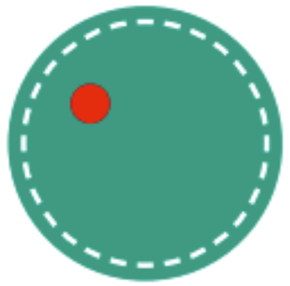
CONNECTOR ROBUSTNESS TO CONTAMINATION

Expanded beam



Ø = 3.000 µm
A = 7'068'583 µm²
Factor A = 3.600

The following diagram is a scale representation of physical contact and expanded beam diameters showing typical contaminant sizes:

Clean Surface	Contaminated	Result
		Dust Particle of Ø = 100 µm can cover the full transmission core of the fiber and cleaning is mandatory.
		Dust Particle of Ø = 100 µm covers 3.33 % of the lens surface and 90 % of the transmission power is still given.

● Dust Particle Ø = 100 µm

CONNECTOR ROBUSTNESS TO CONTAMINATION
(Other markets use MM GOF in harsh environments)

Lighting & Network

PA Market

Video

Broadcast

Defense & Government

Railway

Oil & Gas Station

Fiber Type	Multimode
Insertion Loss	Typical 0.7 dB / Connector
	Maximum 1.0 dB / Connector
Return Loss	N/A
Wavelengths	850 nm / 1300 nm
Lifetime	> 10`000 mating cycles
Tensile Strength	1`800 N
Compressive load	50`000 N
IP Rating	IP68 (mated and unmated)
Free fall Resistance	500 falls onto concrete from 1.2 M height
Bump Resistance	4000 bumps @ 40 g acceleration
Vibrational Sinusoidal	10 - 500 Hz, 0.75 amplitude @ 10 g acceleration
Compatibility	MIL-DTL-83526
Flammability	UL94 V-0
Temperature Range	-40° C to +70° C

CONNECTOR ROBUSTNESS TO CONTAMINATION
(Other markets use MM GOF in harsh environments)