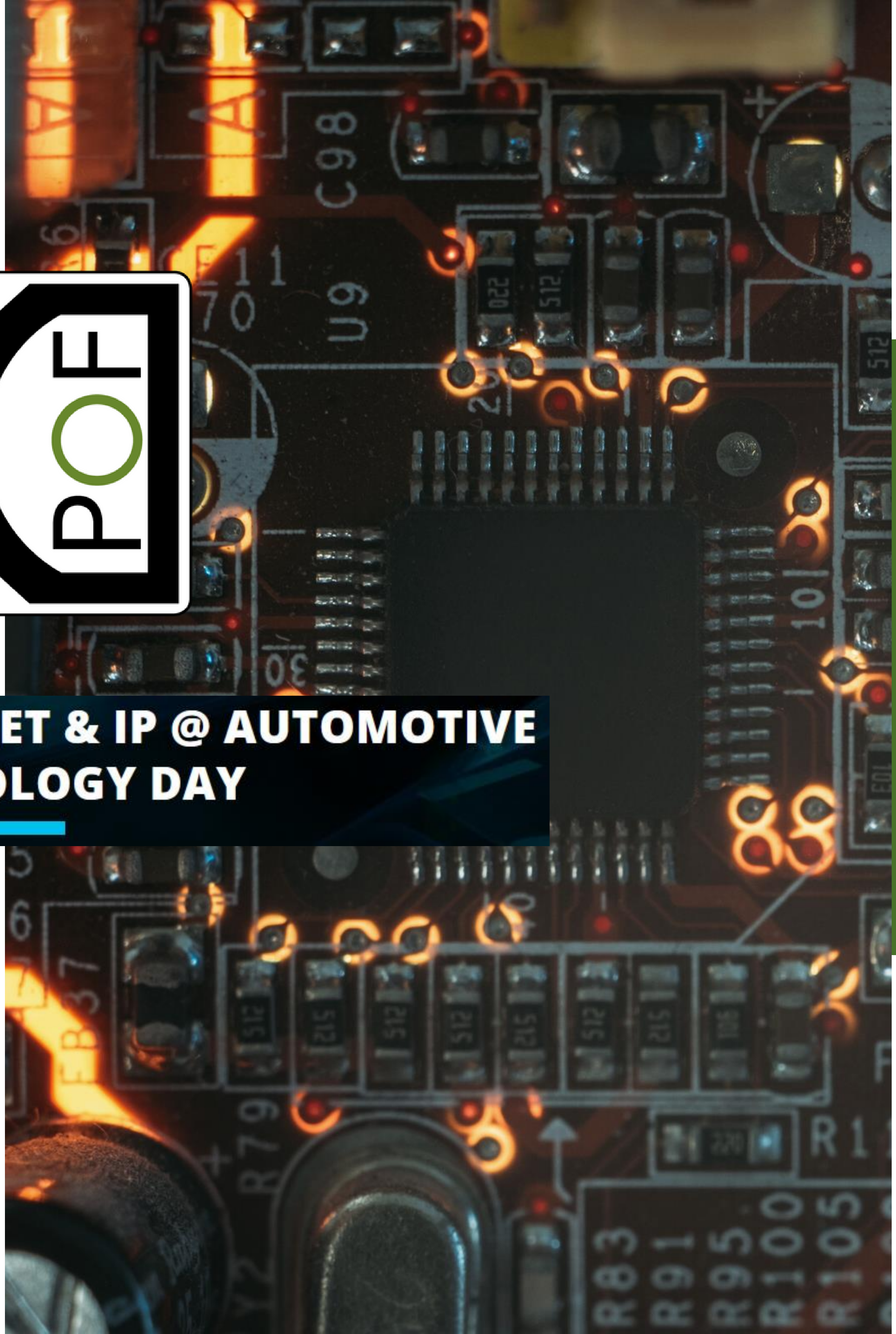


ETHERNET & IP @ AUTOMOTIVE TECHNOLOGY DAY

nGBASE-AU: A New Multi-Gigabit Glass Optical Fiber Automotive Ethernet Standard.
PoC for Camera Interconnection

September 2023

www.kdpof.com

Funded by the European Union
IPCEI ME

Index

IEEE Std 802.3cz: New optical nGBASE-AU physical layer

Camera PoC of 10GBASE-AU PHY and connectivity solution

Q&A

IEEE Std 802.3cz: New optical nGBASE-AU physical layer

IEEE SA STANDARDS ASSOCIATION

IEEE 802.3 Use cases (simplified!)

How are the use cases different?

	LAN/Data center (i.e. nGBASE-SR)	Automotive
Reach/ # Inliners	100m / No IL	40m / 4 IL
Reliability	Not so stringent	Less than 15 FIT and 15 years
Temperature range	Commercial: 0°C ~ +70 °C / Industrial -40°C ~ +75 °C	Extended : -40 °C ~ +105/125 °C
EMC	Less stringent	Stringent
Cost	Moderate	Low
Engineered/ flexible network	Flexible network	Engineered network
Asymmetry	No	Yes for sensors
Others	None	Mechanical and chemical loads (vibrations, contamination, …), dependability, diagnosis

IEEE 802.3 way for improvement

How to increase the reach and speed of data transmission?

- Increase the number of lanes
- Increase of DSP complexity
- Use of better light sources
- Improve media/cable

Thanks to Maths & Physics!

LAN IEEE 802.3 standards

100BASE-T4 (IEEE 802.3u):
4 Lanes and CAT3

1000BASE-T (IEEE 802.3z):
DSP and CAT5

10GBASE-SR (IEEE 802.3ae):
Light sources

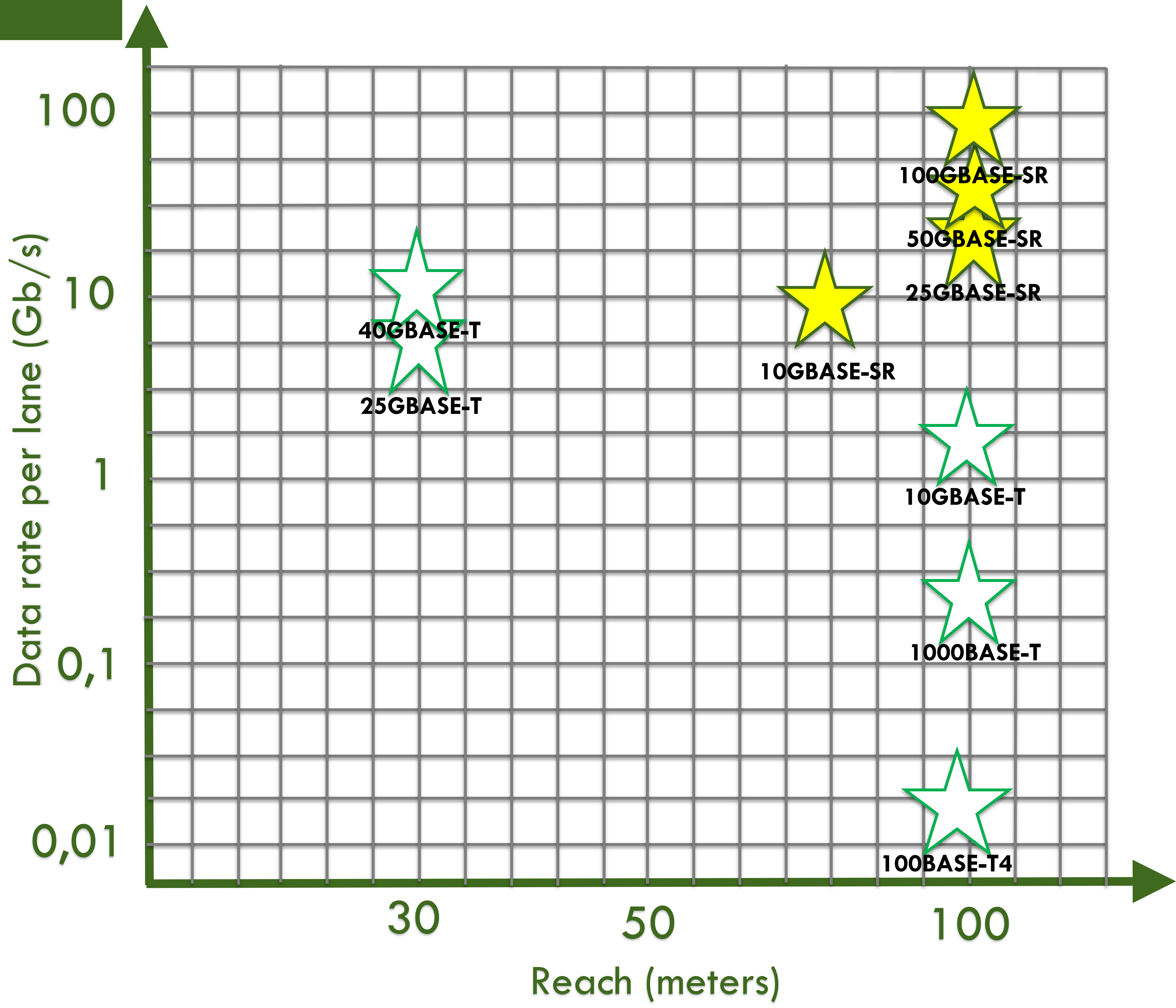
10GBASE-T (IEEE 802.3cg):
DSP and CAT6A

25, 40GBASE-T (IEEE 802.3bq):
DSP and CAT8

25GBASE-SR (IEEE 802.3by):
Light sources

50GBASE-SR (IEEE 802.3cd):
Light sources

100GBASE-SR (IEEE 802.3db):
Light sources



Automotive IEEE 802.3 standards

100BASE-T1 (IEEE 802.3bw):
DSP (lane decrease)

1000BASE-T1 (IEEE 802.3bp):
DSP and UTP/STP

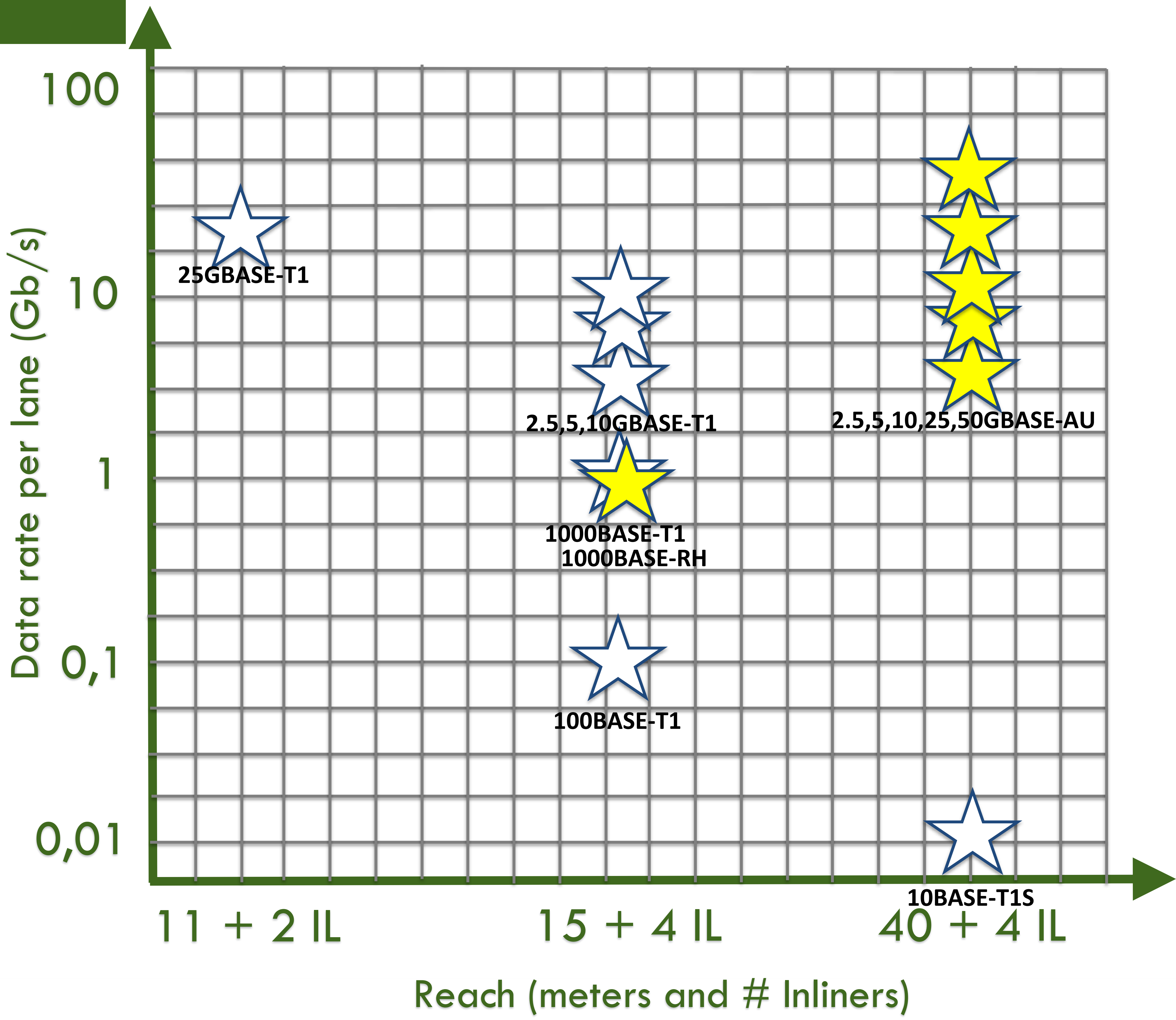
1000BASE-RH (IEEE 802.3bv):
DSP

10BASE-T1S (IEEE 802.3cg):
Cost reduction

2.5,5,10GBASE-T1(IEEE 802.3ch):
DSP and STP/SDP

2.5,5,10,25,50GBASE-AU (IEEE 802.3cz):
Light source and OM3

25GBASE-T1 (IEEE 802.3cy):
DSP and SDP/Coax



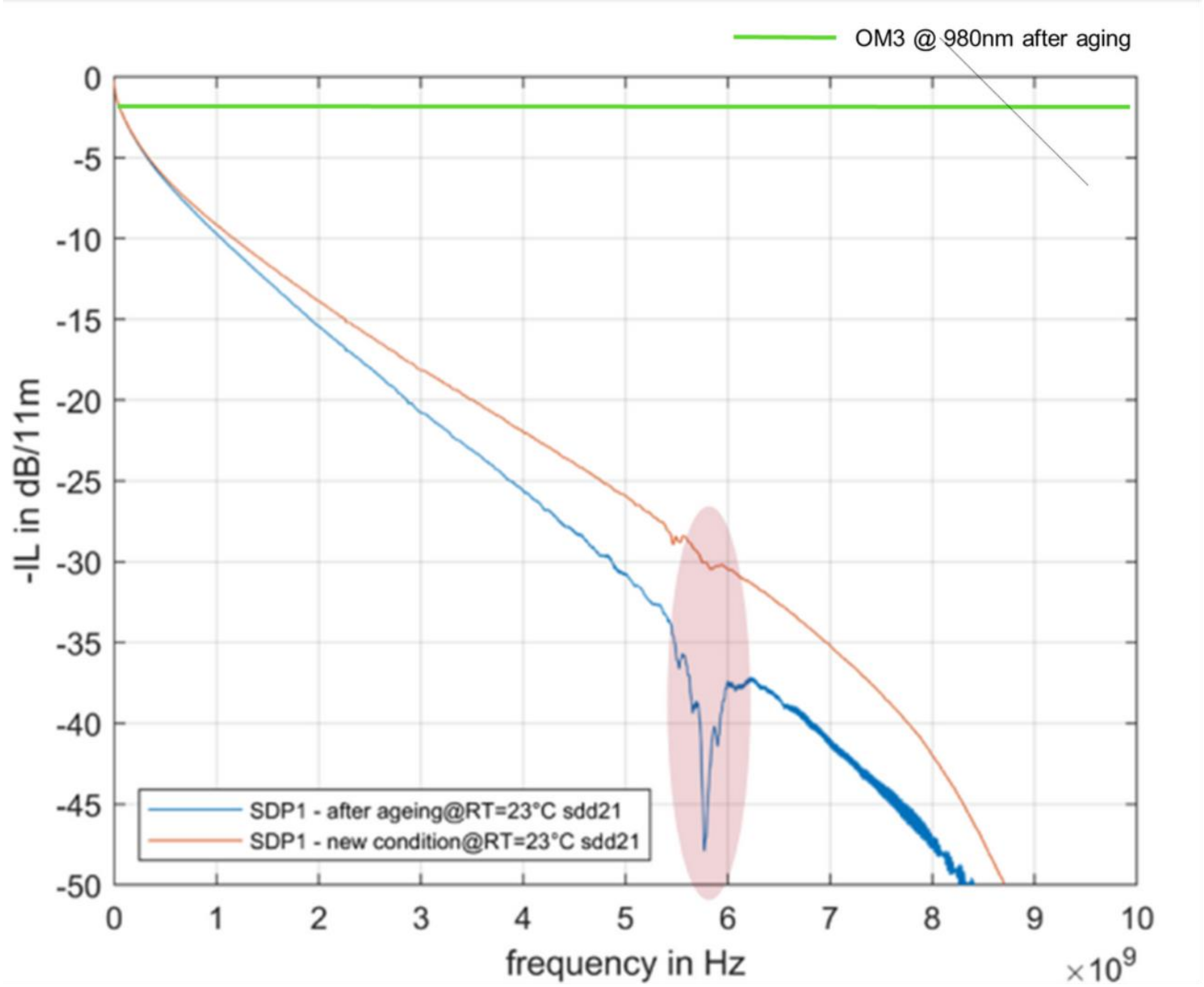
IEEE 802.3cz nGBASE-AU Standard

- CFI July-2019, TF June-2020, WG Ballot March-2022, SA Ballot Sept-2022, **Standard 2023**
- Ethernet PHYs specification targeted for Automotive application
  - Data rates of **2.5, 5, 10, 25 and 50 Gb/s** (PAM2 for all rates but 50 Gb/s which uses PAM4)
  - Max reach of **40 meter** (cars, buses, trucks) and up to **4 inline connectors**
  - 980 nm VCEL wavelength specified to allow for a highly reliable light source at designated temperature range -40 ºC ~ +125 ºC (4 FIT)
  - EMC requirements naturally covered using OM3 glass optical fiber
  - Link budget specified to allow low-cost, small-size, auto-grade optical connectors
  - **Adaptive** data-aided equalization and timing recovery for best RX sensitivity and production yield
  - Energy Efficient Ethernet (**EEE**) for power saving in low traffic conditions, **asymmetric** rate use cases
  - Advanced **diagnosis**, **dependability** function with **OAM** channel

	Automotive
Reach/ # Inliners	40m / 4 IL
Reliability	Less than 15 FIT and 15 years
Temperature range	Extended : -40 °C ~ +105/125 °C
EMC	Stringent
Cost	Low
Engineered/ flexible network	Engineered network
Asymmetry	Yes for sensors
Others	Mechanical and chemical loads (vibrations, contamination, …), dependability, diagnosis

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

Reduced DSP complexity



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

Because the Optical channel is easier!

Optical transceiver does NOT have to compensate:

- High attenuation vs frequency
- Ageing
- Echo cancelling

Optical transceiver's electronics are simple

- **Small silicon area**
- **Short latency**
- **Low power consumption**
- **Low cost**

Reduced connector complexity

Table 166–11— BASE-AU illustrative link power budget

Parameter	2.5GBASE-AU	5GBASE-AU	10GBASE-AU	25GBASE-AU	50GBASE-AU	Units
Effective modal bandwidth at 980 nm[a]	950					MHz·km
Power budget	13	12	11.1	9.1	5.4	dB
Operating distance (max)	0.2 to 40					m
Channel insertion loss[b] (max)	10.5			8.5	4.5	dB
Channel insertion loss (min)	0					dB
Allocation for penalties[c]	0.6				0.9	dB

[a] Per IEC 60793-2-10.
[b] The channel insertion loss is calculated including aging using the maximum distance specified in Table 166–8, cabled optical fiber attenuation of 2 dB/km at 980 nm plus an allocation of 0.4 dB for cable attenuation penalty and connection insertion loss given in 166.6.6.2.1.
[c] The allocation for penalties considers addition of two factors, the receiver sensitivity loss caused by modal noise and the macro-bending loss. Maximum macro-bending loss budgeted is 0.2 dB.

The maximum number of connections is calculated based on the allocation of total connection insertion loss shown in Table 166–20.

Table 166–20— BASE-AU total connection insertion loss

Parameter	2.5GBASE-AU	5GBASE-AU	10GBASE-AU	25GBASE-AU	50GBASE-AU	Units
Total connection insertion loss (max)	10			8	4	dB

For example, the allocation of total insertion loss for 25GBASE-AU supports four connections with a maximum insertion loss equal to 2 dB per connection.

Because the Link budget is higher!

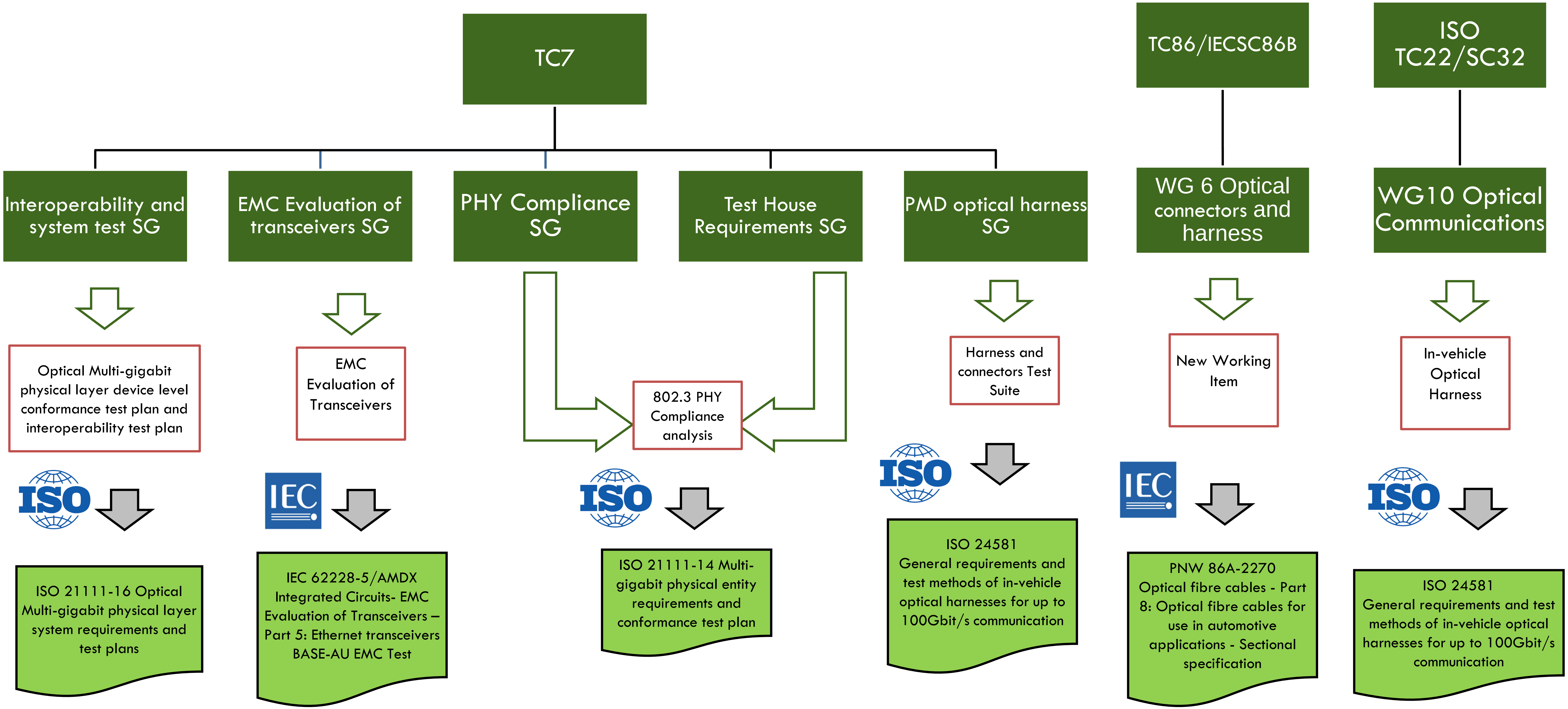
Insertion loss budget for cable and connectors is really high (4 – 10 dB) vs nGBASE-SR (1.8 – 1.9 dB), and allows margin to, for example,

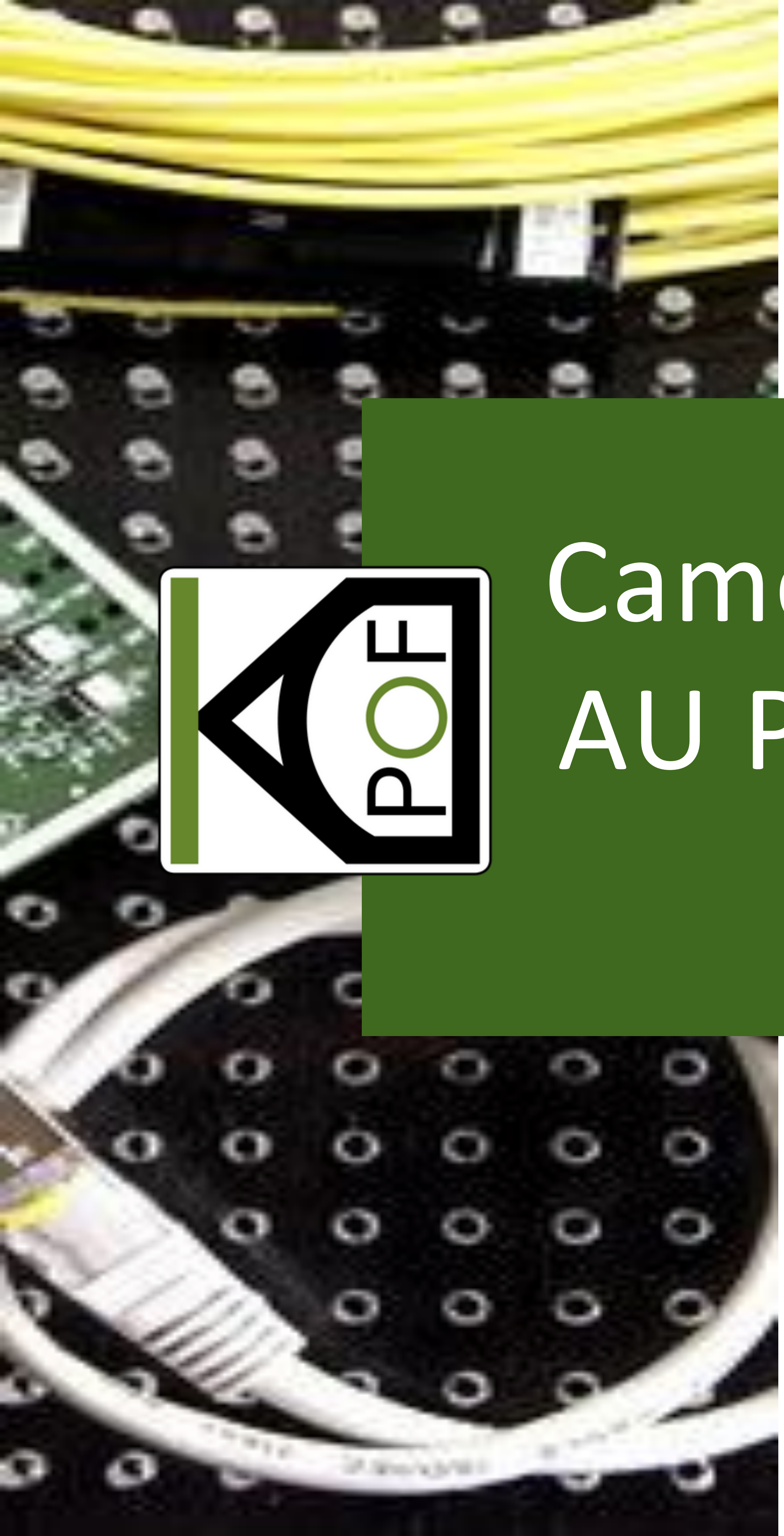
- Cope with contamination and mechanical loads
- Reduced alignment accuracy
- Trade off between number of connectors and insertion loss

Optical connectors can be simple

Low cost connectors

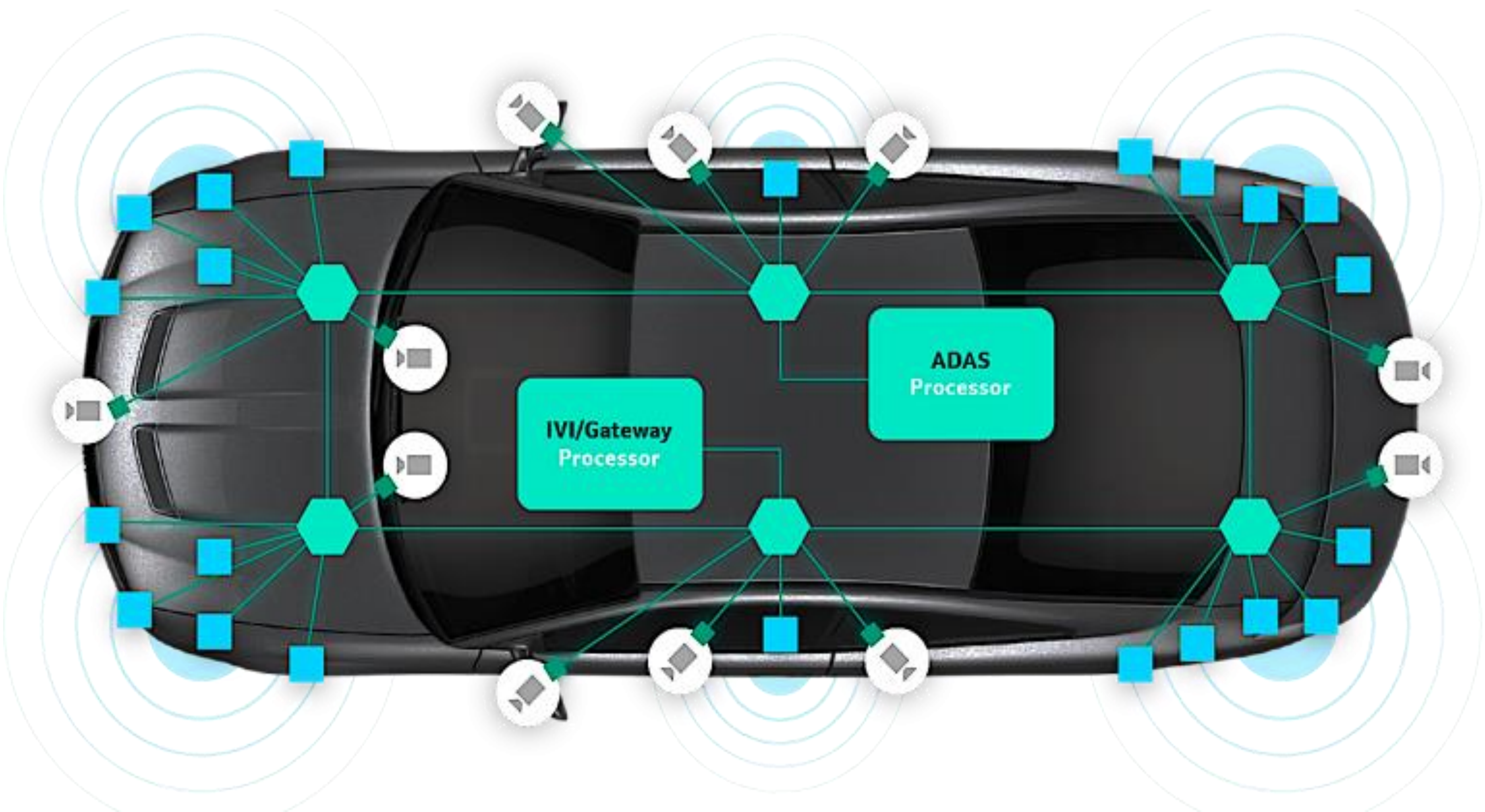
Other Optical Standardization efforts: Open Alliance, IEC and ISO





Camera PoC of 10GBASE-AU PHY and connectivity solution

Automotive market

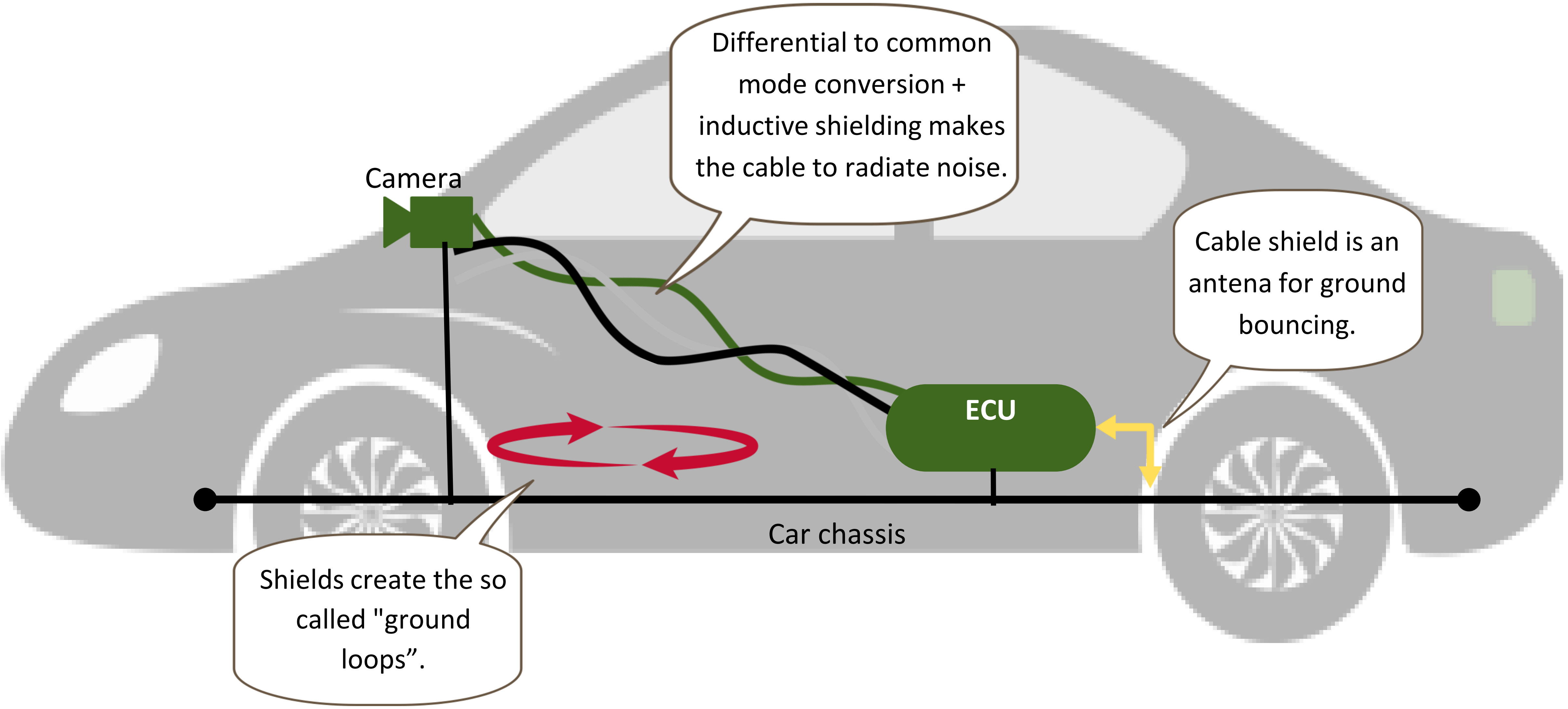


https://www.designnews.com/automotive-engineering/why-cars-are-migrating-zonal-electric-architecture

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

Speed and complexity with copper



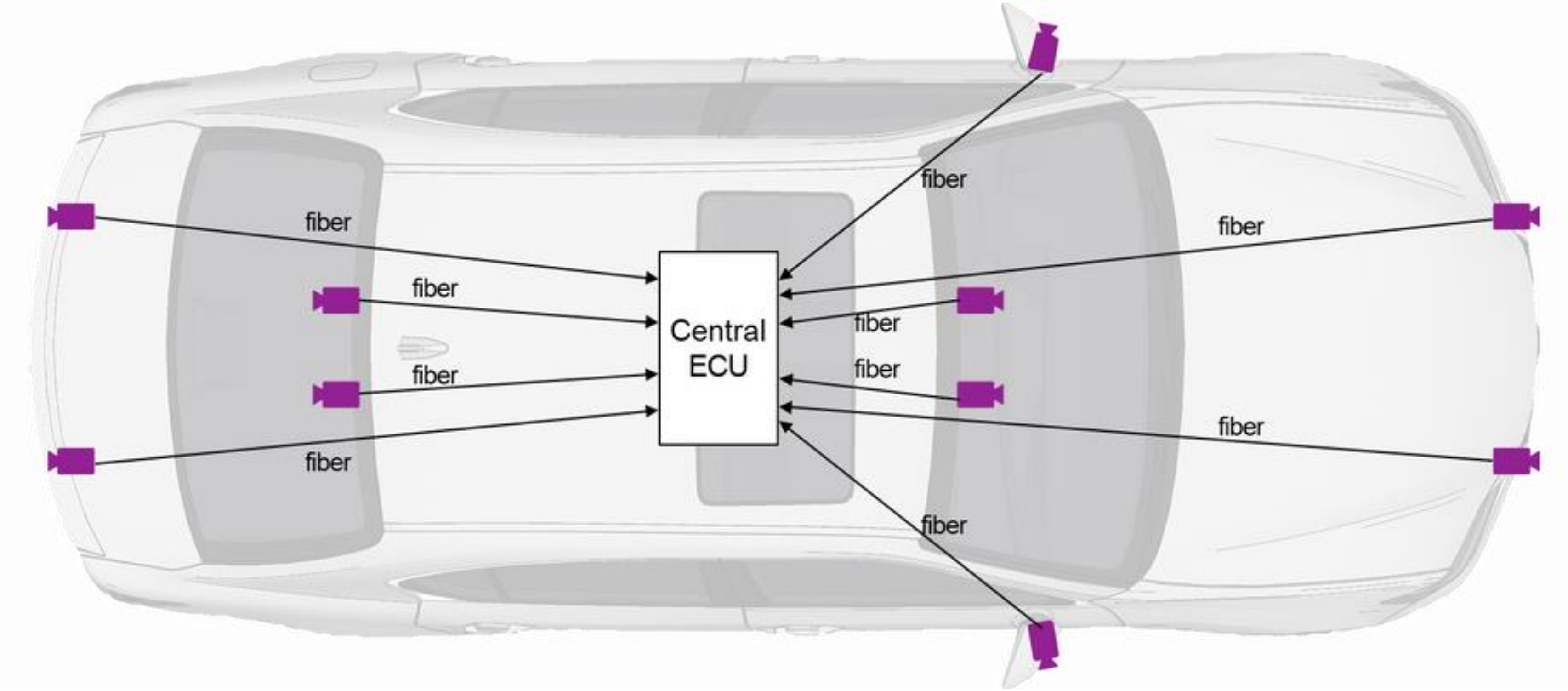
- **Attenuation/bandwidth**: Attenuation increases at high frequencies
- **EMC problems**: The higher the communication speed, the worse is the problem
- **Electrical noise**: Mainly in EVs
- **Galvanic Isolation**: Battery and engines operate at up to 800V and also connected to the 12V of the car

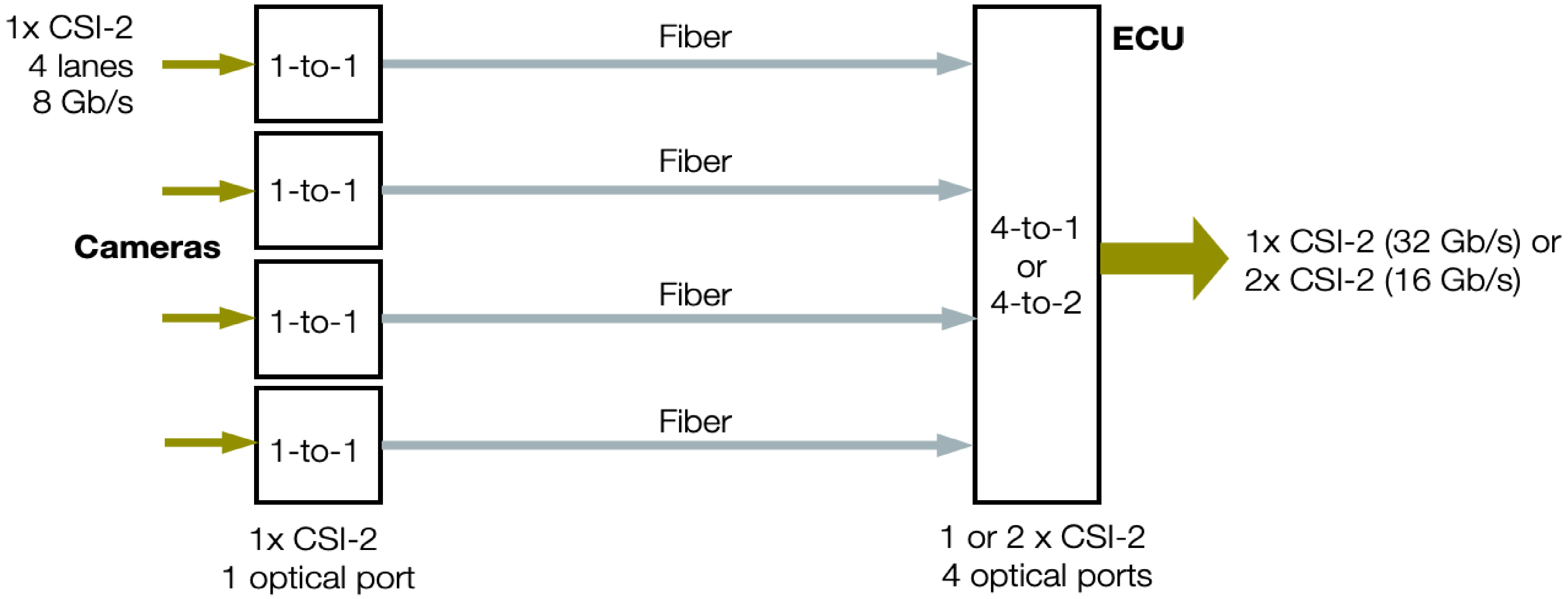
Features

- 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 10 Gb/s downstream
  - 1 Gb/s upstream
- 90° or 180° connectors (small)
- Power supply over **hybrid connectors** and cables already prototyped
- Several TIER-1 and OEM interested -> **Camera PoC** compatible with different camera suppliers

Mated Camera connector

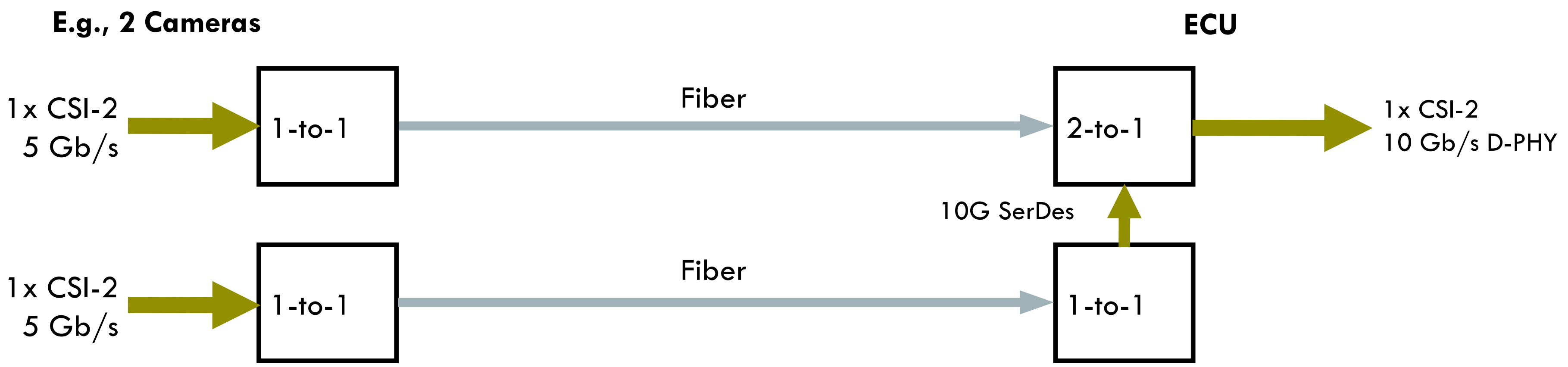
Camera PoC

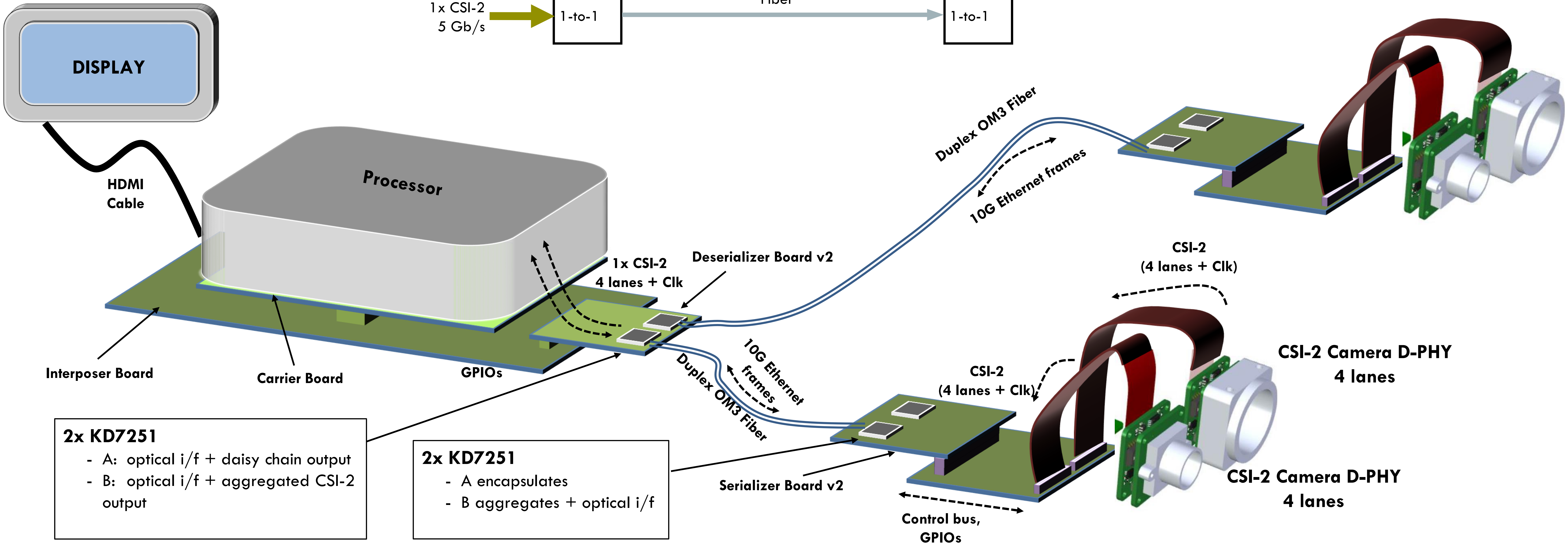




- Up to 10 cameras in high-end platforms with raw-data transmission
- Most of the cameras are ~3 Gb/s, some of them are ~8 Gb/s
- # CSI-2 ports per SOC limited, max 4 (e.g. Xavier, Renesas): virtual CSI-2 channels over single CSI-2 port are used
    - Dual and quad deserializers are currently used with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

Camera PoC: System description





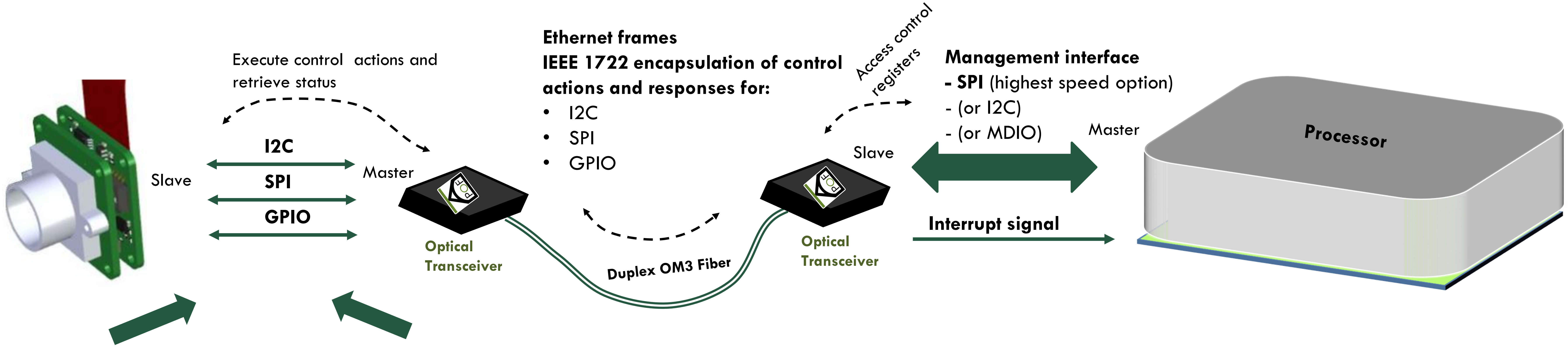
2x KD7251

- A: optical i/f + daisy chain output
- B: optical i/f + aggregated CSI-2 output

2x KD7251

- A encapsulates
- B aggregates + optical i/f

Management bus: Proxy concept



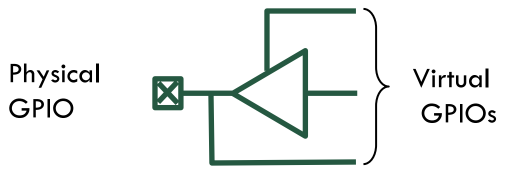
SPI / I2C:

- Perform write transfer
- Perform read transfer

GPIO:

- Normal input
- Normal output
- Pulsed output

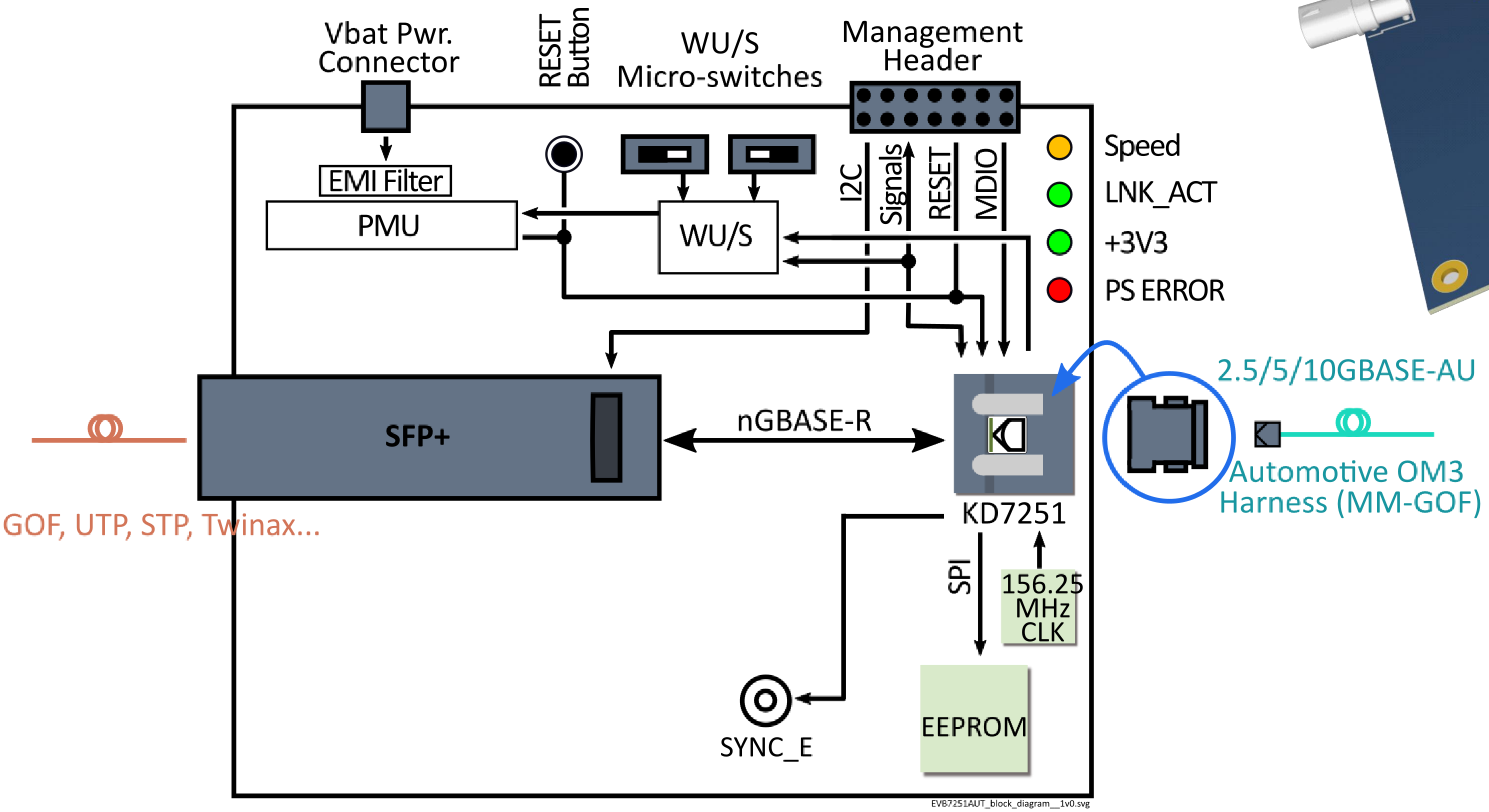
- Support of virtual GPIOs, enabling other features:
  - Tri-state control

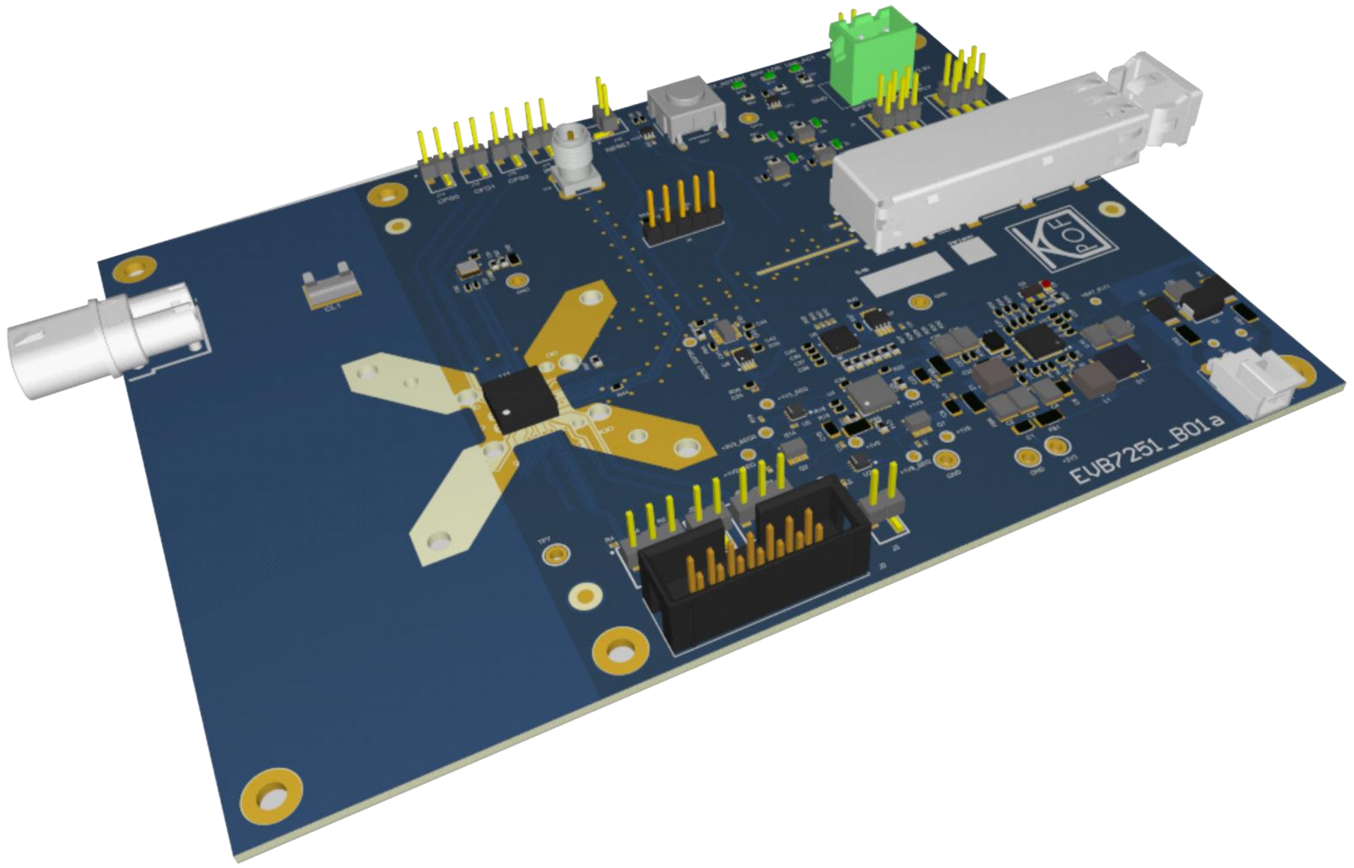


  - Latched low input
  - Latched high input

- Timed transitions
  Move pin @t= …
  PTP-synchronized actions

KD7251 eval-board





Questions?

Thank you!

www.kdpof.com

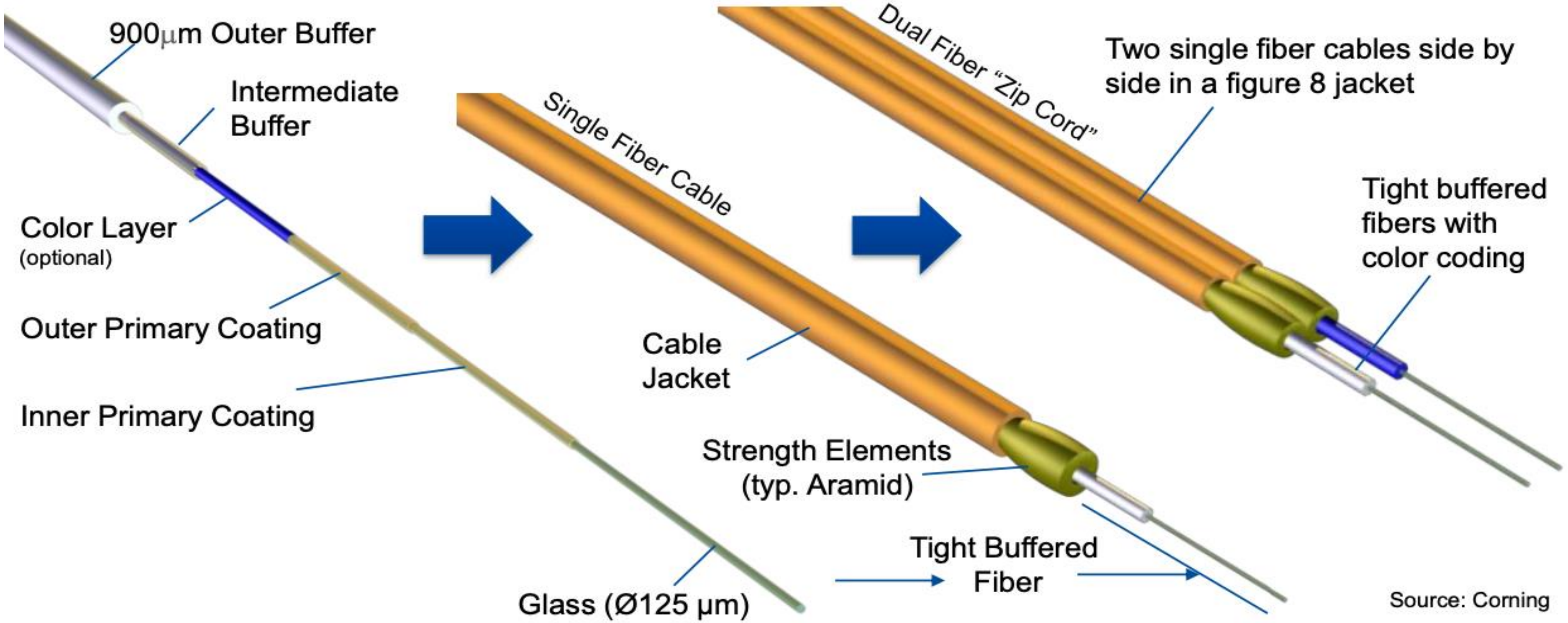
Ronda de Poniente 14, 2CD, 28760,
Tres Cantos, Madrid, Spain.
+34 918 043 387

Backup slides

Optical vs Copper PHY complexity comparision

	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
PHY configuration	**Symmetric** configuration	Master/Slave configuration
Power consumption	**Lower**, based on complexity	Higher, based on complexity
Photonics devices	**VCSEL** and **PD**	No
Packaging	**BGA** substrate w/ **lid** implementing EMC shielding and optical coupling. **Standard reflow** process. Footprint 8x8 mm^2	Standard BGA. Standard reflow process. Similar footprint
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 mm^2**	PHY IC needs to be placed close to the ECU edge, close to MDI with critical layout Port PCB area: ~50 x 20 mm^2
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
Technology	CMOS	CMOS

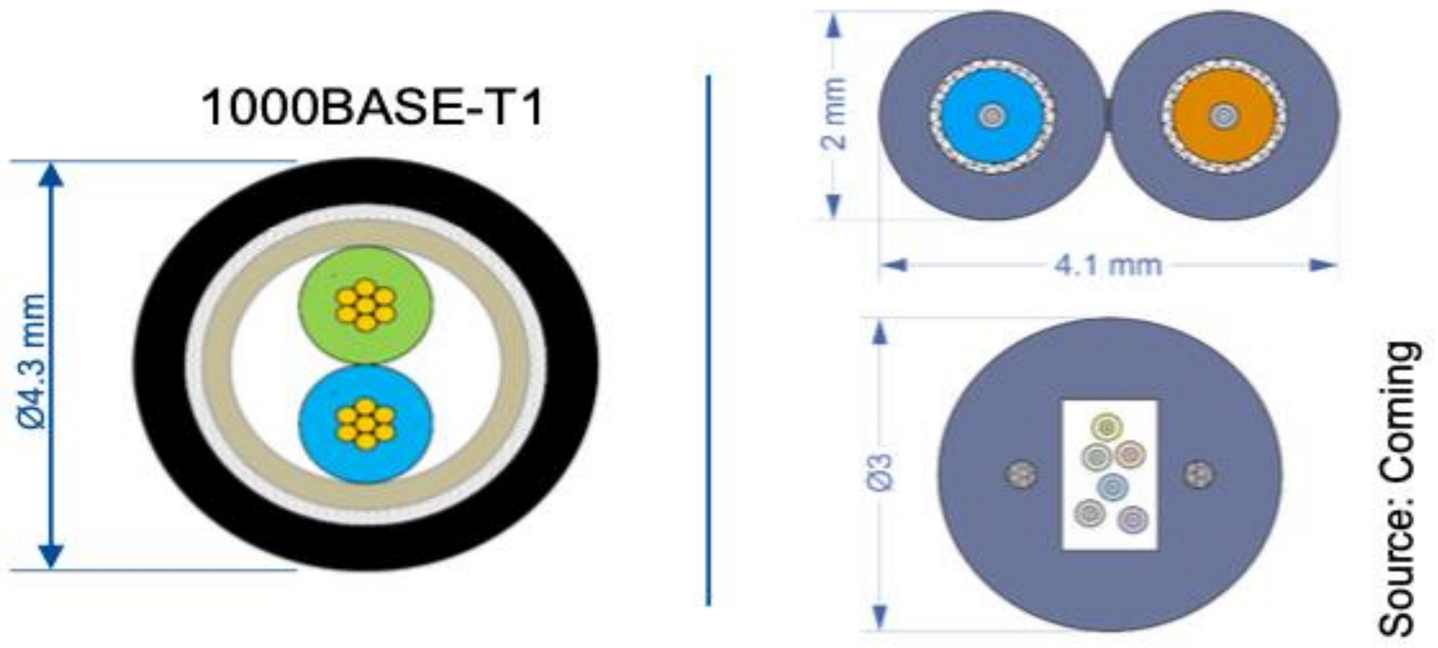
900 um Tight Buffered Fiber → Typical Interconnect Cable



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.125ºC)
  - Aramid standards for tensile strength (>200N)
  - No need for EMI shielding
  - Increase in data rates → cable size unchanged from 1Gbps up to 100 Gbps.

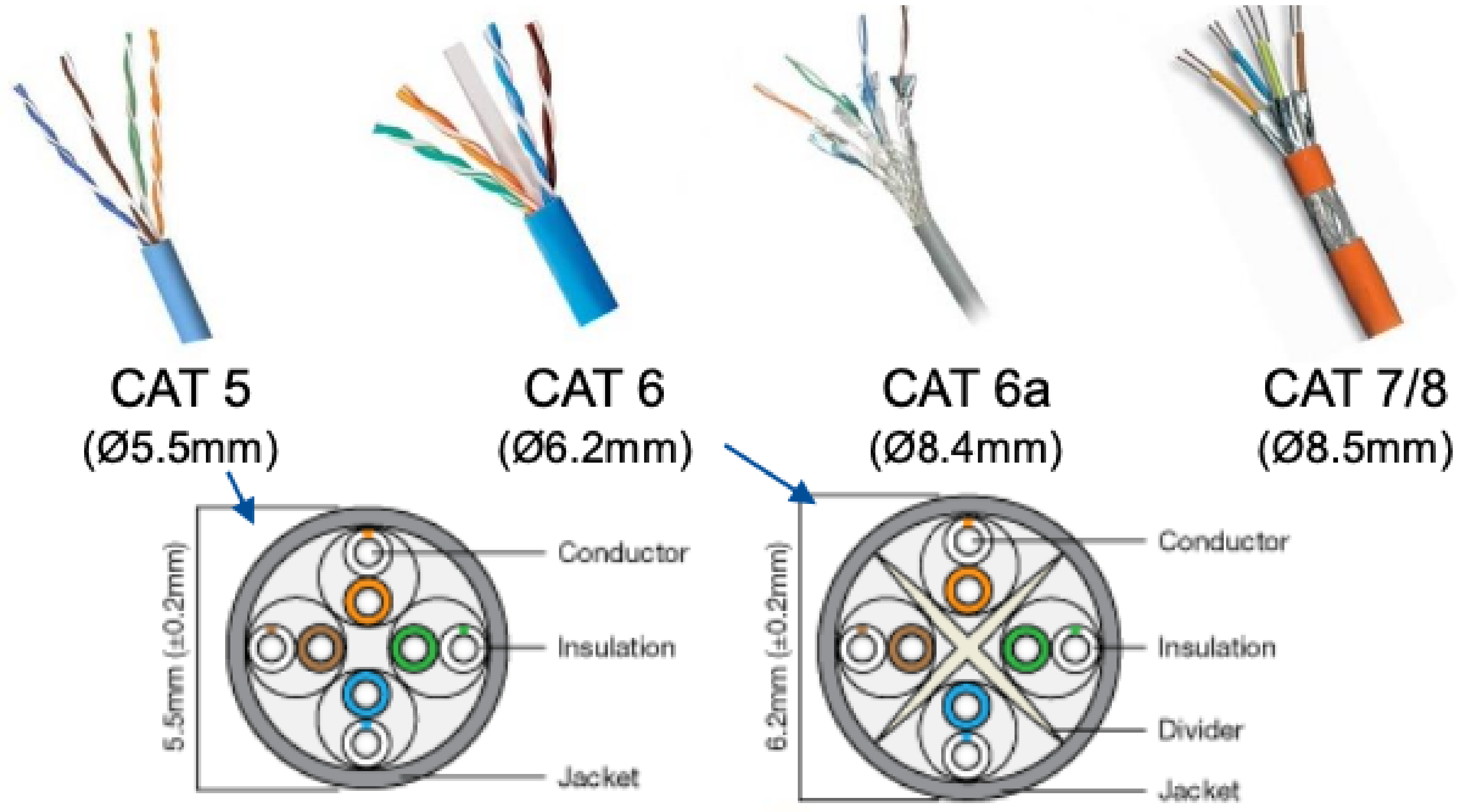


	1000BASE T1	Optical Cables
"Conductor"	2x AWG26 Cu	2x 125/50 µm Glass
Diameter	4.3 mm	4x2 mm
Weight	23.2 g/m	7.4 g/m
Min. Bend Radius	21 mm	15 mm
Data rate	≤1 Gbps	100+ Gbps

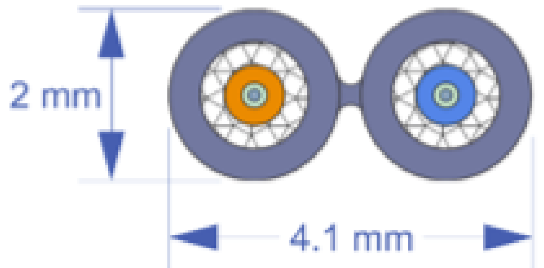
Optical fiber systems can scale to higher data rates w/ same cable design

	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