Automotive Glass Optical Fiber

WHITE PAPER

2025

Automotive Glass Optical Fiber

WHITE PAPER

Table of contents

High-speed changes for automotive

A full mutation of the E/E architecture inside the vehicle

As today's digital revolution gathers pace, cars must follow this megatrend by becoming smarter and even more connected. One aspect of this revolution is the increase in telecom network bandwidth since the 1980s, enabling more and more mobility services.

Electrification, autonomous and connectivity of the vehicles are changing Electrical / Electronic (E/E) architecture. This is crucial to meet the challenges and complexities through the life of a vehicle of roughly 15 years.

OEM are working on 2 approaches *(Figure 1)* which are different but complementary to each other at the same time. They can co-exist on the same vehicle to enhance the benefit of both:

- **Domain focus:** connect Electronic Control Units (ECU), consolidate functions and hierarchical structure within the domain (body, propulsion…)

- **Zonal focus:** connect physically close nodes to a zonal gateway, independent of what function they provide. These zonal gateways are interconnected to each other and to the central computing node via fast communication protocols (Automotive Ethernet has been well accepted).

Harnesses have reached their complexity limit: it is a product with high diversity, always customer specific. Its production is complex and is mostly handmade.
Handling in Tier 1 and OEM is not easy: flexible and long derivatives branches, high harness weight, narrow pathways for instance.
Harness handlers' interest is to reduce the vehicle production time through harness simplification, rethink the customization of wiring harness for each Customer-end definition and reduce cost by standardization.
As a result, these mutations can reduce the number of ECUs per vehicle from hundreds to less than 10 (end goal). It will increase the number of lines of code and software complexity. Vehicles would become software-defined, and less hardware centric.

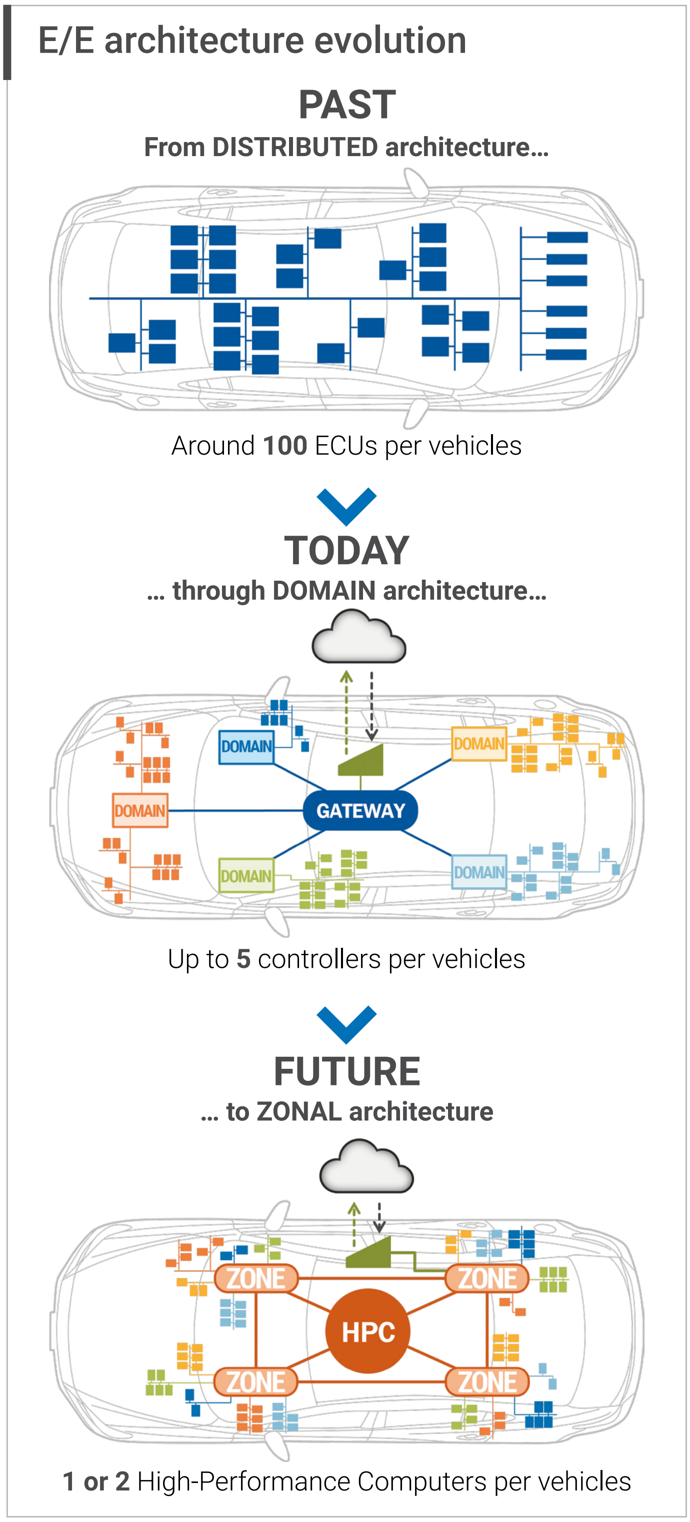


Figure 1. Evolution of the automotive E/E architecture.

The technical needs to reach the market ambition

Despite the continuous optimization of copper-based channel quality, a decrease of signal noise margin is still a requirement due to (protocol dependent) channel rise.

Communication channels from zonal controller to another zonal controller or from zonal critical device must be higher than 25 Gb/s for ADAS functionalities. It may be more than 40 Gb/s for a full Ethernet architecture with ADAS for instance.

Following Automotive Ethernet IEEE 802.3ch MultiG-BASE-T1 standard, shielded pair have found their limits due to the length of the communication. Channel are defined in this standard for 11 meters or 15 meters node to node channel. Those channels are defined with a maximum data rate of respectively 25 Gb/s and 15 Gb/s using this technology.
Optical fibers are a future proof-technology, intrinsically immune to ElectroMagnetic Interferences and capable of reaching up to 100 Gb/s over 100 m *(Figure 2)*.

Communication channel technologies

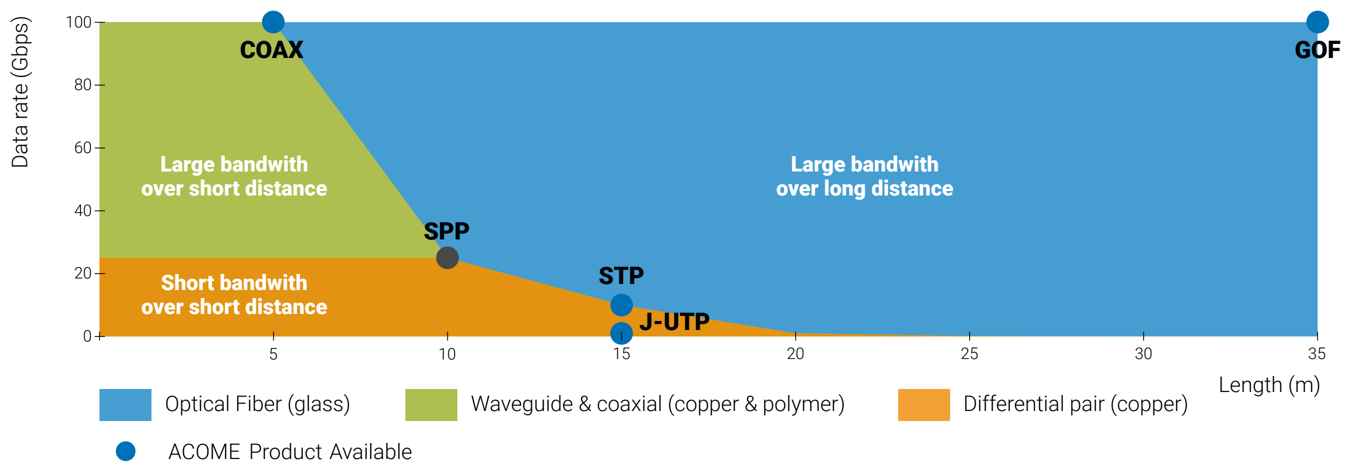
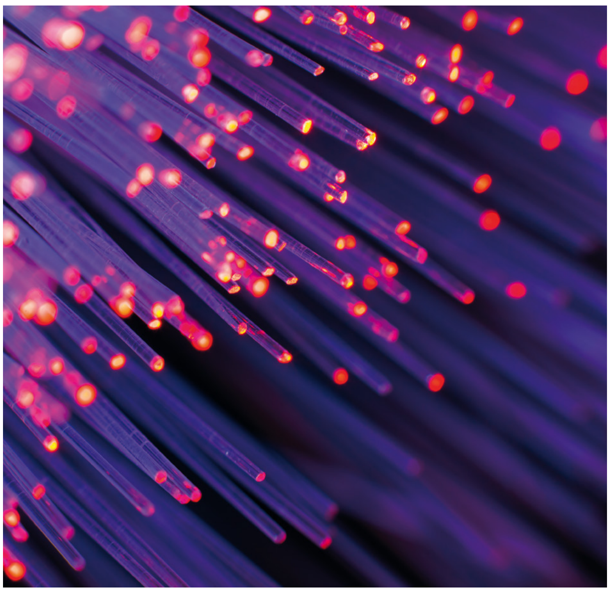
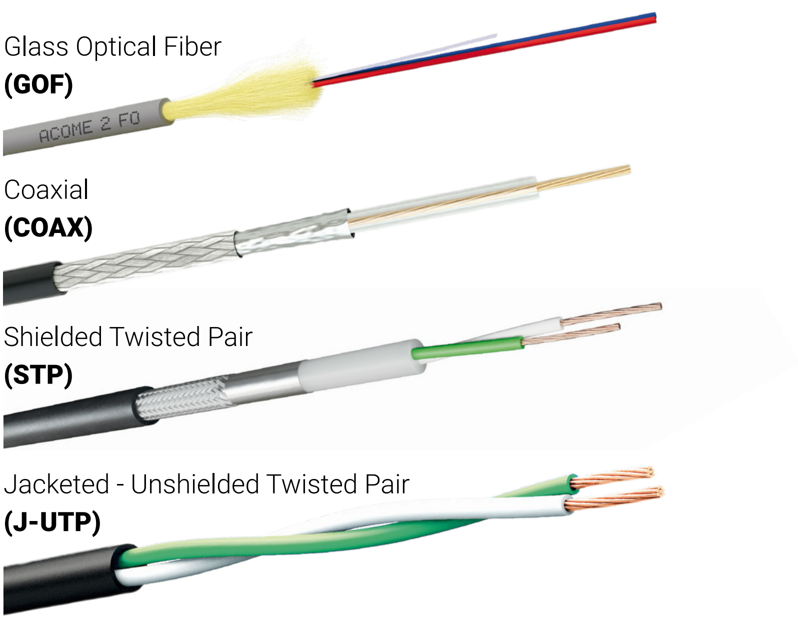


Figure 2. Different type of communication channel and ACOME products.





The position of the copper inside the data cables

Global copper needs

Copper is a strategic mineral thanks to its multiple properties: corrosion resistance, thermal and electrical conductivity. Copper has become an essential metal in our modern, ecological and economic transition. However, as many natural resources, copper sources are extremely limited.

> ***"The cumulative quantity of metals to be produced by 2050 would represent the cumulative quantity produced from Antiquity to 2018".***
> *(Vidal, 2018)*

Various sectors with innovative activities and deployment lead to a sharp increase of copper demand.
Since 1977, the global demand has been increasing and reached in 2018 the global consumption of around 32 Mt of yearly end-use demand of copper. No industrial sector is showing a decline in the demand.[1]

50 years ago, the demand was driven by production, transport and consumption of electricity *(Figure 3)*. Today, other models of electrical energy consumption are arising. It leads to an additional high copper request.

For instance, to meet the climate change challenge, the automotive field is adopting a technological breakthrough by electrical energy. These major changes trigger a huge extra copper consumption.

Read our article
Copper, from inflation to scarcity

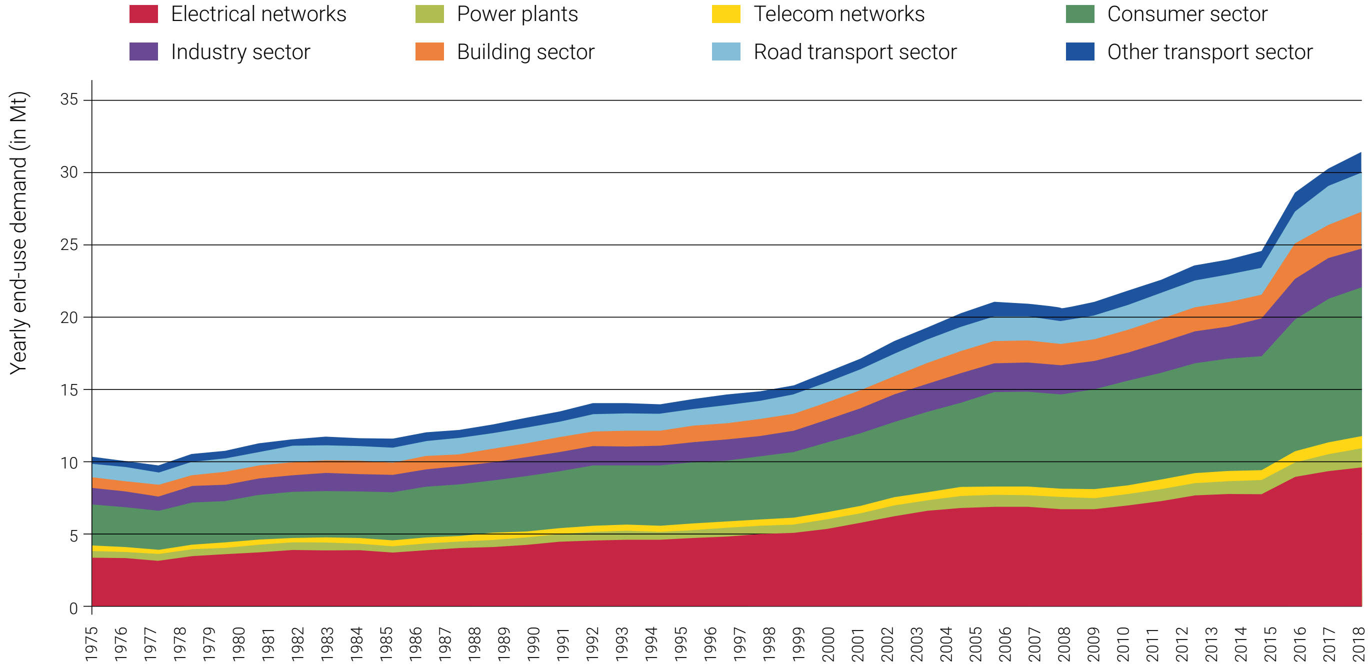


Figure 3. Global copper demand by end-uses category.

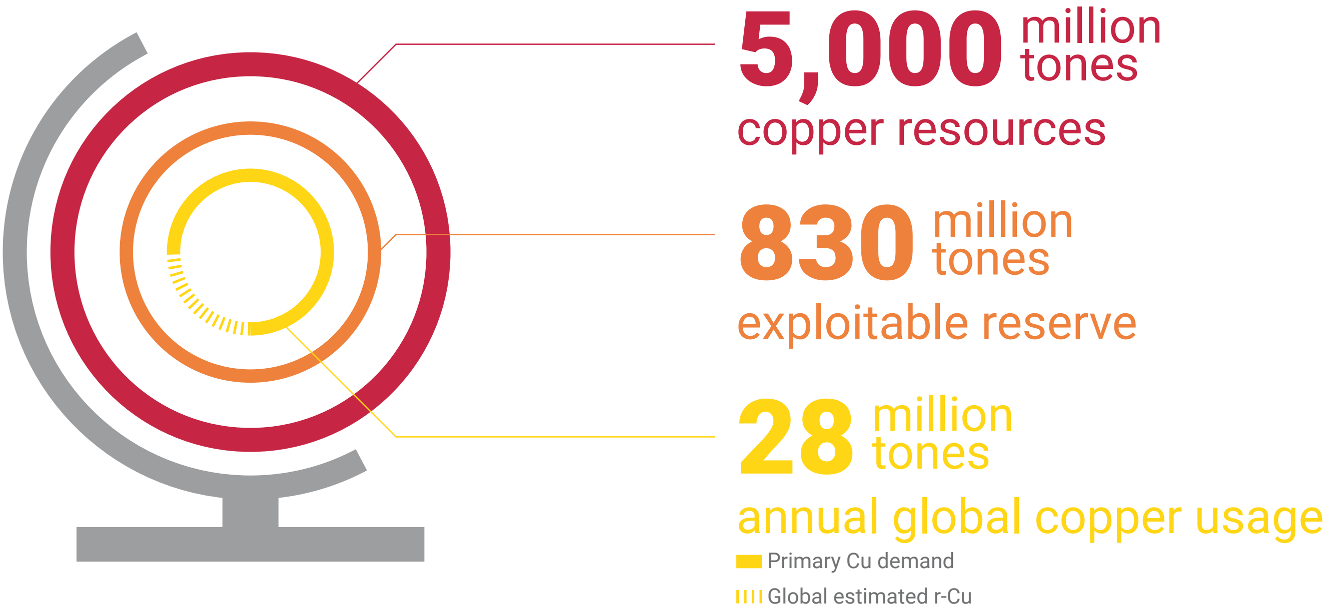


Figure 4. Global copper resources availability.

Copper availability at risks

Copper needs are rising steadily for every activity sector and particularly in the automotive industry with the cars electrification. Nevertheless, copper resource is naturally limited. *Figure 4* shows this limitation.
However, the remaining ore deposits have seen a decline of copper.[2] As a result, more ore needs to be extracted to obtain a given quantity of copper, which implies having to consume more energy, water and larger lands.

It is possible to grow the recycled copper part shown on *Figure 4* by developing an industrial recycling branch. In 2020, manufacturing of new copper-based products requires around 23 Mt of copper in a year.[3] In the same time, around 13.6 Mt of copper-based products reaches their end-of-life. Only 4.1 Mt (~30%) of copper are recycled and used as second life material.
The automotive industry is willing to use recycled copper. However, the data signal propagation happens at the surface of the conductor especially at high frequency. This skin effect is then imposing to use primary copper. Even with this solution, high data rate applications are limited with copper. Scarcity and data speed dependency lead to apply a new model of data cables.

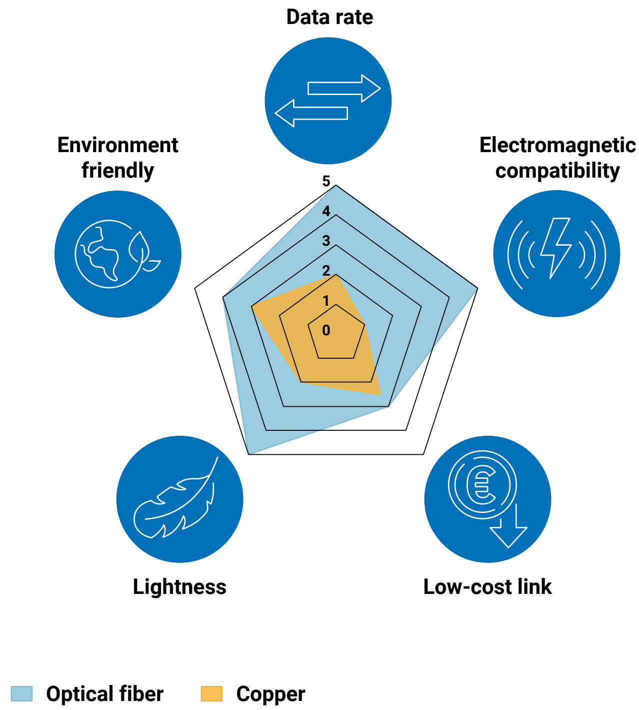


Figure 5. Comparison between an optical fiber and copper link.

Optical fiber technology in automotive is a high-speed data cable alternative to reduce the risk of copper scarcity.

The optical fiber as an alternative solution

What is optical fiber?

Communication at long distance with visible optical carrier light has been common for many years. Fire, reflecting mirrors or signaling lamps provide fast and long-range communication. The problem is that the light transmission is restricted by the atmosphere (rain, snow, fog, dust, brightness of the environment) and it is limited to a straight line of sight. Through laser investigations and developments, research effort led to light wave carrier. Parallel laboratories did assessment of a new dielectric waveguide (or optical fiber) in 1966.[4]
The first optical fibers showed high attenuation (1,000 dB.km-1) but it was resolving the main limitations of long-distance light communication.

Optical fibers are basically thin optical waveguide typically made of glass or plastic, designed to carry light over distances. They are used for transmitting signals and their operation is based on the principle of total internal reflection of light inside the fiber material.
Here are the key elements of how optical fibers work:

- **Core and Cladding:** the optical fiber consists of a core (inner part), where light propagates, surrounded by a reflective cladding (outer part). The cladding material has a lower refractive index than the core material which also have a high purity for defect-less light transmission.
- **Propagation:** light travels through the fiber, undergoing successive total internal reflections. This enables light to travel long distances with minimal signal loss.
- **Signal:** the light/electromagnetic wave is generated by a laser or light-emitting diode at a specific wavelength band. At the opposite end of the fiber, there is a receiver that captures the light and converts it into an electrical signal.

An optical fiber communication system is similar to any type of communication system *(Figure 6)*. The information has to be transported from a source to a destination. To be transmitted, the information passes the communica-

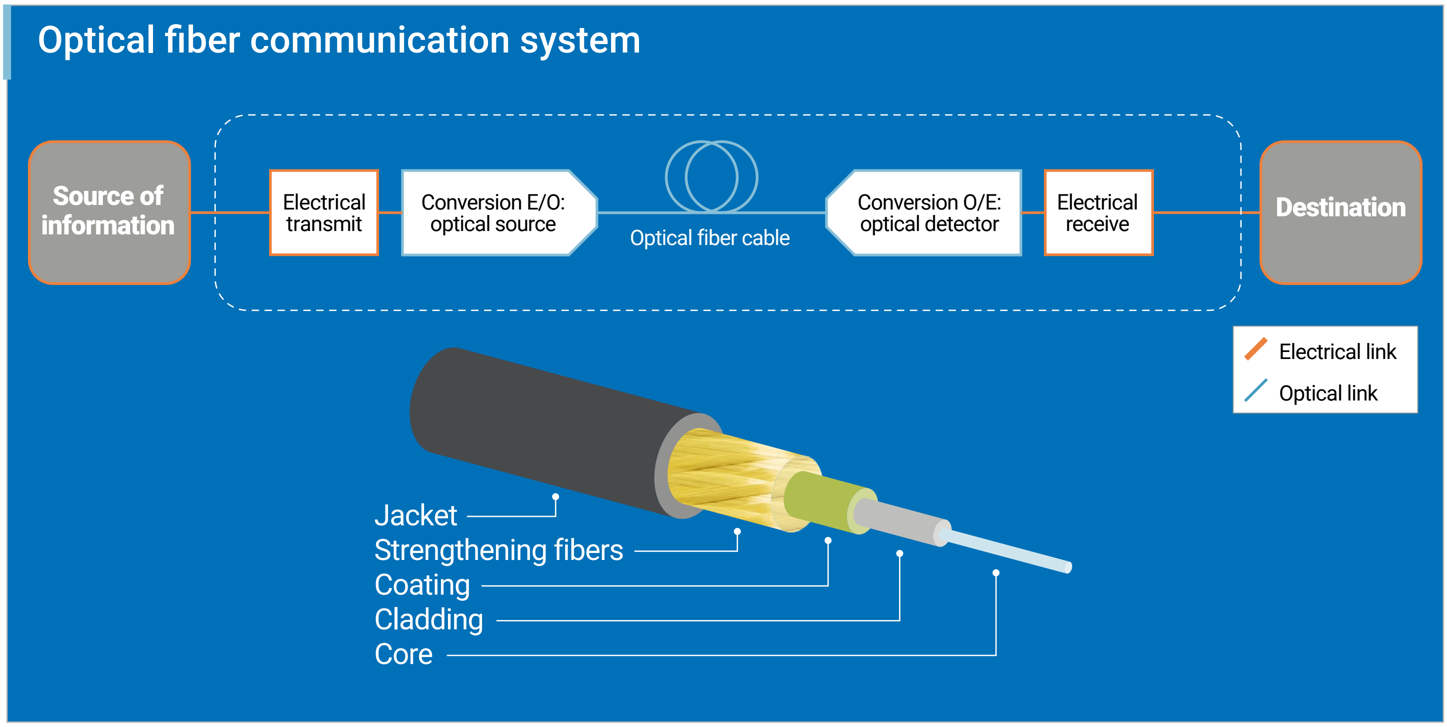


Figure 6. Optical fiber communication system.

tion system: a modulator and a demodulator linked by a transmission media. The carrier of the signal can be a pair of wires, a coaxial cable or a radio link. In Any case the signal is attenuated and suffers loss over the length. In the case of optical fiber, the signal is transmitted with light. The electrical information source is then converted in to modulated light waves by an optical source. The electrical-optical conversion may be either a semi-conductor laser or a light-emitting diode (LED). The optical fiber carries the light waves to the optical-electrical convertor. The optical detection module could be either photodiodes or phototransistor and photoconductor. Electrical interfacing is then assured to the destination device.

A huge variety of optical fiber on the market

The optical fiber performance, adaptability and immunity to interferences are making it a cornerstone technology in modern communication and technology-driven fields. It's essential to understand the range of fiber types to answer the multiple application to choose the right technology for automotive application.

Plastic Optical Fiber (POF)

PMMA core and PFA cladding

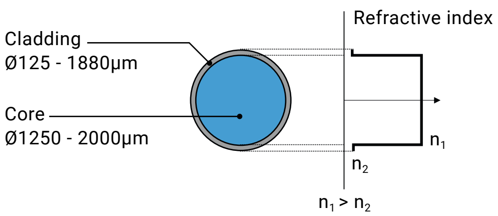


Figure 7. Plastic Optical Fiber

Advantages
- Cost effective
- Limited performances
- Operating at <70°C

Limitation
- Bending losses

Application
- Short-haul indoor applications

Plastic-Clad Fiber

Glass core and plastic cladding

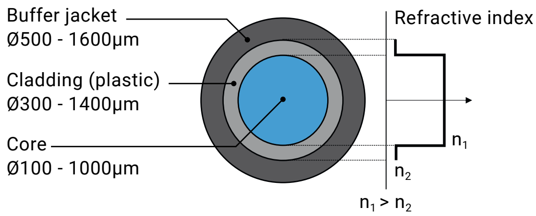


Figure 8. Plastic-Clad Fiber

Advantages
- Mechanical strength of GOF

Limitation
- Limited performances
- Operating temperature of POF

Application
- Shorter-distance applications

Silica Glass Optical Fiber (GOF)

Multimode Step Index Fiber

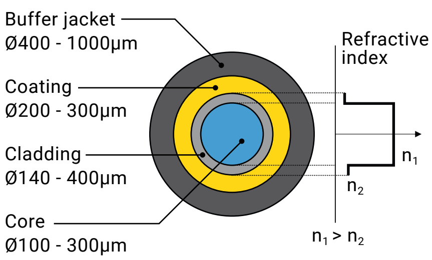


Figure 9. Multimode Step Index Fiber

Advantages
- Efficient coupling to LEDs
- Larger core diameters

Limitation
- Limited bandwidth
- Short-haul applications

Application
- Data links, LANs

Multimode Graded Index Fiber

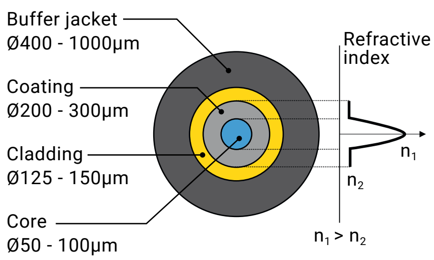


Figure 10. Multimode Graded Index Fiber

Advantages
- Improved performance
- Lower modal dispersion

Limitation
- Tolerance to bending

Application
- Telecommunication, data links, LANs.

Single-Mode Fiber (SMF)

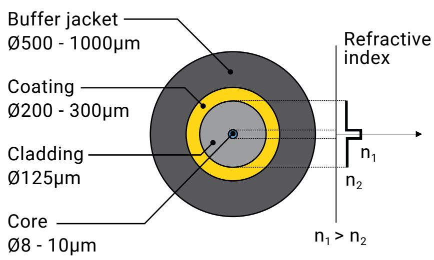


Figure 11. Single Mode Fiber

Advantages
- High efficiency,
- Zero-dispersion wavelength

Limitation
- High costs equipments

Application
- Medium- to long-haul transmission

Why is Glass Optical Fiber the best choice for automotive applications?

Advantages of Optical Fiber communication

Data transmission efficiency

Optical Fibers (OF) can carry frequency between 1013 and 1016 Hz with a yield more important than metallic cable systems (20 MHz up to 10 km distance). The several developments over the last 20 years have result OF conception with very low attenuation or transmission loss compared to copper conductors (down to 0.15 dB.km-1).

Electrical environment immunity

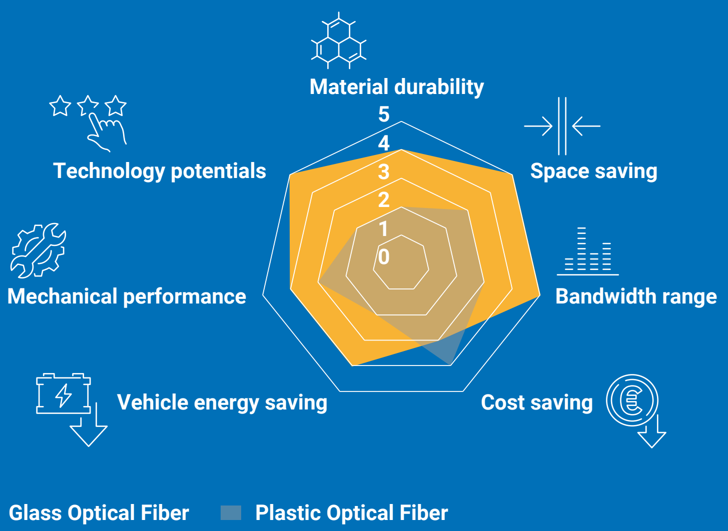
OFs offer complete immunity to ElectroMagnetic Interference (EMI), RadioFrequency Interference (RFI), or switching transients giving ElectroMagnetic Pulses (EMPs), ensuring secure data transmission without interference. OF hence require no metallic shielding. They are also made of electrically non-conductive materials; they are then suited for electrically hazardous environments. OF cannot create arcing or spark hazards in case of sheath defect. Additionally, they emit no electromagnetic signals during operation, maintaining high degree of signal security in sensitive embedded environments.

Mass and space reduction

Glass Optical fiber (GOF) cables are significantly lighter than their Ethernet twisted pair counterparts, contributing to a notable reduction in overall mass, crucial for weight-sensitive embedded systems. Replacing Ethernet twisted pair cables, with their copper conductors, by a GOF could reduce the data link weight by 68 %.[5]
SPE has a standard diameter of 4.10 mm. GOF reaches 0.250 mm diameter. At least two of them could fit in a 3 mm

Glass or Plastic Optical Fiber?

A comprehensive comparison is presented in the following figure and reveals distinct characteristics, applications, and trade-offs between these two fiber types: plastic and glass core.



While POFs seems to have short-haul, low-cost efficiency, there characteristics are not fully suitable for automotive applications. GOFs shows better space management by their size and the bending limits with better sustainability regarding the operating temperature required. Also, GOF shows better data transmission performances and IEEE P802.3cz Multi-Gigabit Optical Automotive Ethernet Task Force could not reach data transmission objectives adopted with the POF cable.

Figure 12. Glass and Plastic Optical Fiber comparison

diameter cable with the standard mechanical reinforcement in it. The cable is 27% thinner with higher data transmission performance.
Both characteristics allow substantial reduction in physical space requirements and are advantageous in the compact environments of embedded systems Ethernet twisted pair cables, being bulkier, and may pose more challenges in terms of space utilization in small space applications.

Data performances enhancement
Ethernet twisted pair cables have evolved and can reach 20 Gb/s over 20 m. But they may face limitations in achieving the high data transfer rates demanded by modern embedded applications. GOF are future-proof and can deliver superior data performance (e.g. 50 Gb/s), with significantly higher bandwidth.

Environment Impact
GOF systems generally consume less energy, leading to a better autonomy for embedded systems and thus carbon footprint reduction over the battery operational life. For the same amount and speed of data transmission, one GOF needs 25% of energy needed for single pair ethernet usage. This aligns with the growing emphasis on energy-efficient solutions.

Adopting fiber optic allows for liberation from the market price fluctuation of copper. The main material needed in optical fiber system (Glass optical fiber, semi-conductor lasers and detector…) is Silicon. It is made from silica, not a scarce resource yet and has a less fluctuating market price.

The fragility dogma on Glass Optical Fiber

The standard multimode glass optical fibers are categorized by generation from OM2 to OM5. For any generation, they are frequently described as fragile and sensitive. Several technological layers are successively added on the core to preserve the performance from external degradation and keep a strong and resilient wire for high requirements systems as vehicles applications.
The first layer of 250 µm coating is capable of improving the mechanical performances allowing a tensile strength up to 45 N and bending radius lower than a diameter of 5 mm. Then, an additional thermoplastic layer covers the wire to protect from ageing in order to prevent important signal loss from glass oxidation.
The finished glass optical fiber is finally assembled with aramid or glass yarns in an external sheath for an optimized additional mechanical protection. This last layer of protection gives the finished size of the cable and also protect from liquids.

Supporting this white paper, an optimized automotive specific cable with two GOF cables has been evaluated for some dedicated severe automotive tests. The cable conception is fully adapted to automotive environment with 3.1 mm external diameter polymer sheath.

Thermal resistance
Performed at T2 (105°C) class temperature, the coating preserves its chemical and mechanical integrity after 3,000h ageing in a cable or without additional protective layers.

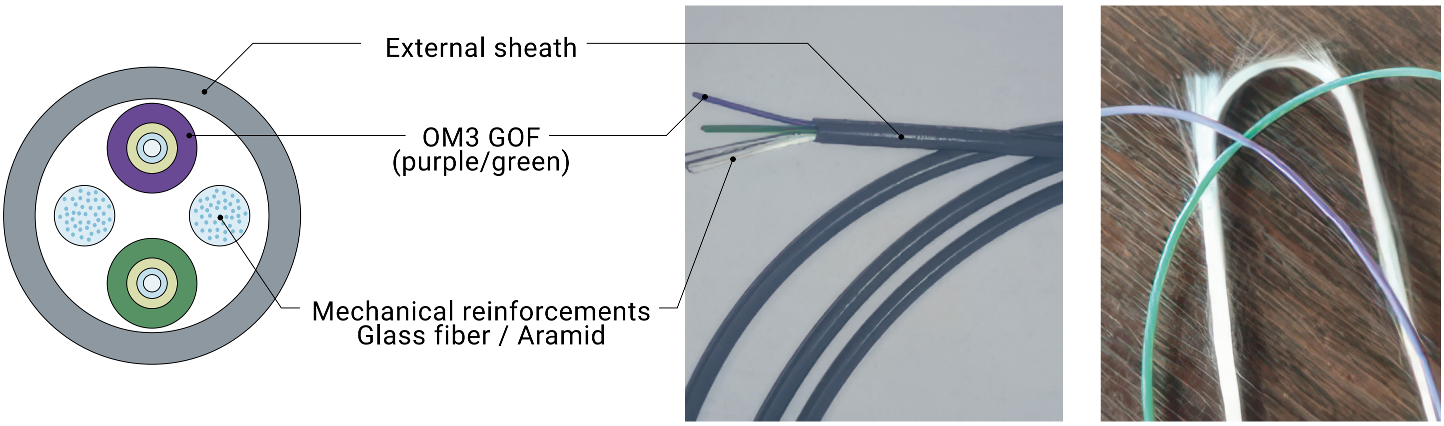


Figure 13. ACOME automotive cable with two glass optical fibers. Stripped cable after 100,000 cyclic bending.

Mechanical tests

For standard tensile tests, the cable supported tensile force of 100 N for an elongation of the cable and optical fiber of 0.6%, preserving OF life time. The crushing resistance reached 200 N/mm² without signal attenuation increase. The shock resistance reached 6 J without sheath or optical fibers break.
The whole 3.1 mm of diameter cable handled a static bending of 10 turns on a diameter of 20 mm (< 7D) without signal attenuation increase.

As Takashi Fukuoka[6] demonstrated in IEEE802.3cz workgroup, optical fibers cables showed an excellent resistance to the cyclic bending compared to copper wire and with shielding. Cables with two GOF has been tested at -90°/0°/+90° at a speed of 15 cycles per minutes with mass applying 1 kg/mm². Aramid or glass reinforcements resist up to 100,000 cycles without sheath or optical fibers break (Figure 13). Meanwhile, standard shielded automotive datalink broke quickly after 10,000 cycles.

Environment compliance

Because its light transmission-based technology, Glass Optical Fibers can be sensitive to dust or other blocking particles and fluids. To complete the evaluation, the literature like Thomas Theuerkorn[7] works showed once it's connected, even immersed in dust, water or oils, these won't interfere with signal transmission. In fact, once connected, inside the standard known connectors the two fibers are perfectly in contact to prevent dust or liquid penetration. The dust perturbation risk is possible only when disconnecting connectors. A simple drying swipe or air pulsed cleaning at the connectors ends before reconnecting could easily remove the physical interferences.

Our Glass Optical Fiber Cable is compliant with the new norm ISO24581

Optical fibers in vehicles of tomorrow

Optical Fiber takes the data transmission limits off. With that, self-driving or high-definition infotainment can be integrated in vehicles. Those applications required low latency and high data rate. For example, self-driving need at least 60 Gb/s for a safe and efficient functioning. This level of speed can be easily reached by glass optical fiber.
Zonal architecture and software-defined vehicles (SDV) will multiply the used cases of Optical Fiber technology by bringing more short links with huge volume of data to transmit in a swift time.

With all these constraints, GOF is found in a sweet spot whereas copper links would need a lot of efforts and technological investments.

In a system economical point of view, GOF is a new communication link in vehicles. The harness components have to be developed and mature for car requirements. Current connectors and transceivers are dedicated for networks and LANs with lower environmental requirements: < 70°C in usage where T3 class temperature impose 125°C in usage. Developments of more robust components will potentially generate price growth until a technology maturation leading to cost reduction. However, key components as transceiver already shows technological maturity cost reduction by 85 % from 2016 to 2023 (Figure 14). And the forecast[8] positively estimates a continuity to almost 95% of the reduction in the years of potential concrete applications of GOF in vehicles.

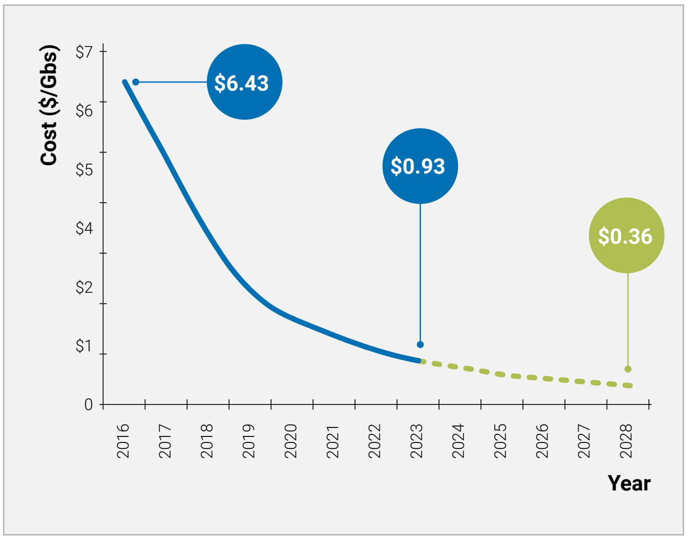


Figure 14. Evolution of the cost of a transceiver per Gbit per second over the year.[8]

A bright future of Glass Optical Fiber in Automotive industry

Automotive industry will integrate more and more data dependent systems. As a datacenter on wheels, latencies and speed will become essential for zonal architecture and software-defined vehicles… GOF offers the possibility to transmit from 1 Gb/s to 100 Gb/s without any particular cable design modification. Its natural immunity brings a full integrity of the signal whatever the environment for good application versatility. It is lightweight, smaller and more performing than single pair ethernet cable. Copper scarcity and its price fluctuation will become a major concern and Glass Optical Fiber is a solution for automotive data transmission to emancipate from copper. Telecom industry also observed 75% of energy consumption saving by replacing copper. Transpose to automotive field, it offers energy savings and less environment impact for electrical vehicles

It still remains some progress on full optical fiber systems in automotive (connectors, ONT, …).

But today, this technology already reached a high-level of maturity even for challenging embedded system such as aeronautics. It is for example commonly used for transmitting data between various system, including flight controls, navigation and communication system. The Glass Optical Fiber with connectors are already proved a lot of robustness in these strict embedded systems. GOF is perfectly adapted for automotive environment.

Glossary

ADAS	Advanced Driver-Assistance System	**MMF**	MultiMode Fiber
BEV	Battery Electric Vehicle	**OEM**	Original Equipment Manufacturer
E/E	Electrical / Electronic	**OF**	Optical Fiber
E/O	Electrical/Optical	**OM**	Optimized Multimode
ECU	Electronic Control Unit	**ONT**	Optical Network Terminal
EMI	ElectroMagnetic Interference	**PFA**	PerFluoroalkoxy Alkane
EMP	ElectroMagnetic Pulses	**PHEV**	Plug-in Hybrid Electric Vehicle
FCEL	Fuel Cell Electric Vehicle	**PMMA**	PolyMethyl MethAcrylate
GOF	Glass Optical Fiber	**POF**	Plastic Optical Fiber
HEV	Hybrid Electric Vehicle	**PVC**	PolyVinyl Chloride
ICE	Internal Combustion Engine	**RFI**	RadioFrequency Interference
IEEE	Institute of Electrical and Electronics Engineers	**SDV**	Software-Defined Vehicles
IPCC	Intergovernmental Panel on Climate Change	**SMF**	Single-Mode Fiber
J-UTP	Jacketed-Unshielded Twisted Pair	**SPE**	Single Pair Ethernet
LAN	Local Area Network	**SPP**	Shielded Parallel Pair
LED	Light-Emitting Diode	**STP**	Shielded Twisted Pair

Figures

References

1 G.S. Seck et al. Resources, Conservation and Recycling 163(1), 2020.
Retrieved from: https://doi.org/10.1016/j.resconrec.2020.105072
2 Mudd et al., Econ. Geol. 108, 2013
3 Source: https://copperalliance.org/wp-content/uploads/2022/11/Global_2020-1024x725.png
4 John M. Senior, Optical Fiber Communication 3rd Ed., 2009
5 2x OM3 8.15g/m SPE 25g/m ou 22 with foam. ACOME: https://www.acome.com/fr/produits/batiments-intelligents
6 Fukuoka T., IEEE P802.3 – OMEGA Study group, 2020.
7 Theurkorn T., Detroit AWH/EDS - Corning, 2023.
8 LightCountingOptical Components Market Forecast, April 2023.

Find out more on
www.acome.com

Contributors

Florent PICOT
Project Manager for Innovations, ACOME

Jérôme JONCQUEL
System Engineer for Automotive Data Cable, ACOME

Magali DERENNE
Project Manager for Automotive Data Cable, ACOME

Gaby GUERARD
Optical Laboratory Expert, ACOME

Vivien WOURMS
Product Marketing for Automotive Data Cable, ACOME

ACOME GROUP

52 rue du Montparnasse
75014 Paris - France
T. +33 1 42 79 14 00

www.acome.com