

On-train fiber optic connectivity

White paper

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A new generation of networks



Inter-vehicle fiber optic jumper cable system

- 4 Benefits of fiber technology
- 4 Rolling stock fiber optic cables
- 7 Rolling stock fiber optic connectors
- 8 Connectivity: from components to systems
- 9 Return on experience
- 9 Conclusion

Over the past years, the emergence of Ethernet as an industry standard for communication on-board trains has moved from concept to reality. Pushed by new applications such as on-board passenger entertainment, passenger information, video monitoring, Internet on board or modern train control systems, the demand for bandwidth of train backbone networks keeps increasing. In this context, fiber optic technology has all its place at least from a system performance point of view.

Nevertheless, the railway industry is generally still hesitant to make systematic use of this technology on board rolling stock. Industry's doubtful perception of fiber optic connectivity technology often results in the expression of concerns about its suitability for use on trains due to the specific environmental conditions. Indeed, a train is a moving object subject to strong mechanical stresses and high safety requirements.

Of course, most of the concerns are focused on the area where fiber optic connectivity components would be subject to the most severe environmental constraints: inter-vehicle jumper systems. Today's connectivity technology and experience however tend to demonstrate that fiber optic is and will remain a fully appropriate technology for the rail industry in the future.



Benefits of fiber technology

Optical fibers are recognised as the medium with the highest bandwidth transmission capabilities. Thanks to optical transport systems, a 100 Gigabit-Ethernet standard has even been developed to push the limits further. Moreover, a large part of modern rolling stock equipment is electrically powered and therefore subject to constant electromagnetic interference and electrostatic shock.

Optical fibers being intrinsically immune from any electric or electromagnetic phenomenon, appear in principle to be ideal medium for data transmission in railway rolling stock. Screening effectiveness, screen resistance or impedance control are topics that no longer need to be addressed with fibers, while weight savings are achieved by replacing copper-based data cables.

Rolling stock fiber optic cables

Railway cables must in general comply with two types of requirement:

- Fire safety requirements
- Environmental requirements

Fire safety requirements

Fire safety is a hot topic in the railway industry. Public transport operators must ensure that, in the case of a fire incident on board, passengers and staff can be safely evacuated and not suffer injury from generated smoke.

As a leading market for railway technology, Europe is intensively working on the final development of a European fire safety standard for rolling stock equipment designated EN 45545. Ultimately, such a standard should supersede current national standards applicable in individual countries (e.g. BS6853, NF F 16-101, DIN 5510, UNI CEI 11170).

Nonetheless, other standards might well remain in force in other continents (e.g. NFPA 130, etc.). Specifically, this means that in the near future, all cables installed on a train – including fiber optic cables – will have to comply with the requirements of this standard. HUBER+SÜHNER has already anticipated this trend and already offers fiber optic cables meeting the fire performance requirements of the CEN/TS 45545-2 European fire safety standard in terms of:

- Flame propagation on single cable (EN 60332-1-2)
- Flame propagation on cable bundle (EN 50266-2-4)
- Smoke density (EN 61034-2)
- Smoke toxicity (NF X70-100-1 and -2)

Image: Flame propagation test on a cable bundle



Environmental requirements

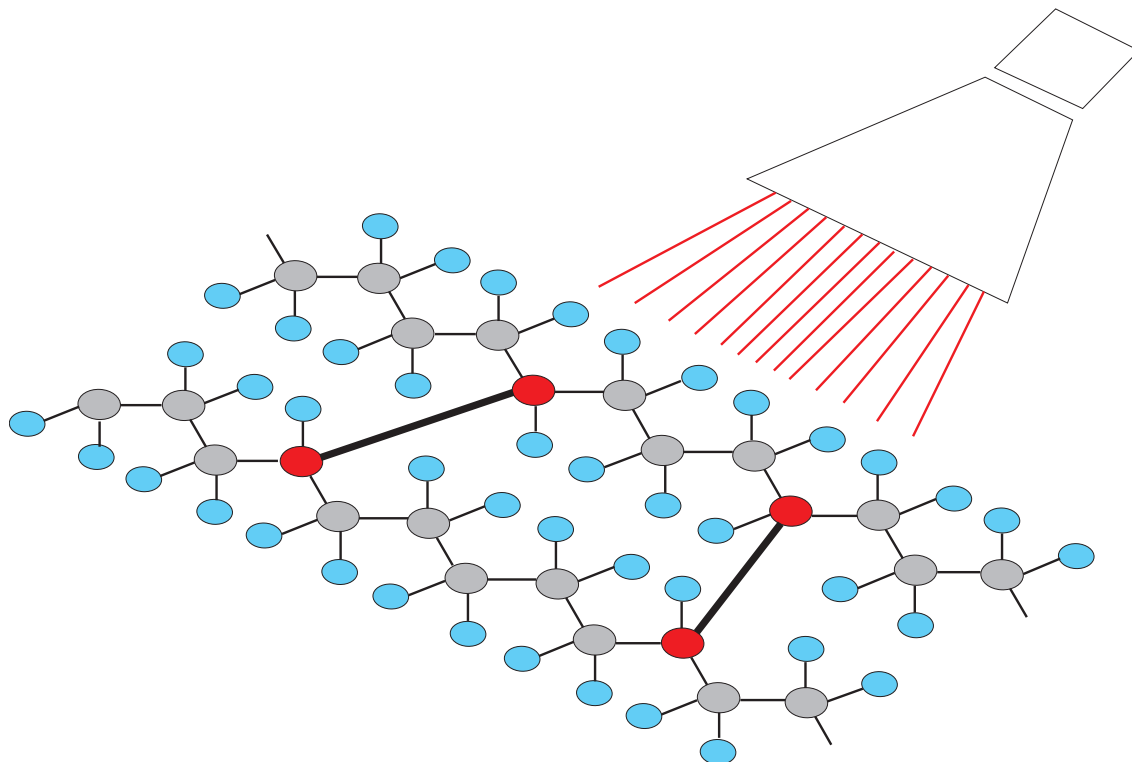
Although environmental requirements are very well defined by European standards for electrical cables (EN 50306, EN 50264, EN 50382), there is no standardised requirement defined yet for special cables such as fiber optic cables. Environmental requirements should in principle cover characteristics such as fire resistance, abrasion resistance, fluid resistance, traction resistance, water absorption etc.

The RADOX® material technology is recognised worldwide in the rolling stock market for its environmental resistance properties. Based on an electron-beam cross-linking process, this technology has been widely used for more than 25 years on electric cables.

Today, these cables are installed on every type of rolling stock equipment worldwide, such as electric or diesel locomotives, EMUs, DMUs, Metros or LRVs. Therefore, the concept of using electron-beam cross-linked jacket materials for fiber optic cables seems obvious.

However, in contrast to electrical cables made of copper, the operating principle of electron-beam cross-linking is theoretically not compatible with the physical properties of optical fibers.

What is electron-beam cross-linking?



Interconnection of adjacent molecules with networks of bonds

It is the interconnection of adjacent long molecules with networks of bonds (cross-linking) induced by electron-beam treatment. Electron-beam processing of thermoplastic material results in several enhancements, such as an increase in tensile strength and resistance to abrasions, stress cracking and solvents.

High performance optical fibers normally used for high data rate transmission are made of silica (glass) and the effects of high energy (MeV) electron-beaming on this material considerably degrades its light transmission properties. More precisely, if a fiber optic cable is considered, the thickness of the cable jacket may not be sufficient to stop the electron-beam before it reaches the glass fiber. Upon impact with the glass material, the kinetic energy of the electrons transforms into heat. Therefore, condensing an electron beam onto particles of glass may generate enough heat to even create defects in the structure of the material itself. As a consequence, this might bring the optical glass fibers to a state where it is no longer relevant to use them for high bit rate transmission.

The combined expertise of HUBER+SUHNER in the electron-beam cross-linking process and fiber optic cable technology has overcome these issues and RADOX® fiber optic cables are now fully available. Furthermore, in order to meet the requirements of European standards, these cables use the standardised RADOX EM 104 jacket material fulfilling all the environmental requirements defined in table 4 of EN 50254-1. Among a number of characteristics, the material fulfils specific requirements for elongation at high and low temperatures, water absorption, ozone resistance or fluid resistance.

Environmental resistance properties of the jacket material are a requirement for cables. However, these are not sufficient when the cables are subject to dynamic mechanical stress factors. This could be the case for the inter-vehicle connections during installation operations or even during servicing of the trains. Parameters such as crush resistance (e.g. up to 4000 N/cm), tensile strength (e.g. up to 2000 N) or repeated bending over tens of thousands of cycles should then be carefully considered to ensure that cables will not be damaged during installation or service.

Alternatively, adaptation of installation procedures can also be considered.

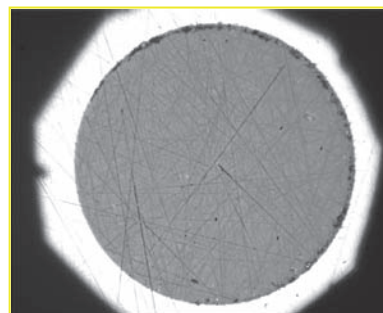
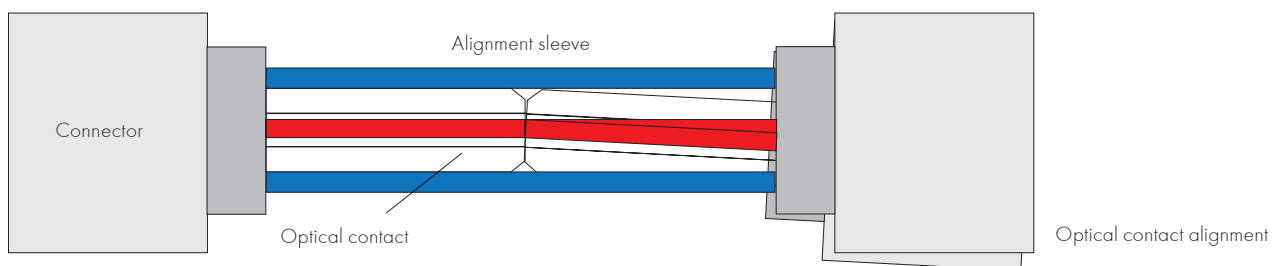
Rolling stock fiber optic connectors

The connector technology applied to rolling stock application has today reached a high level of maturity and reliability for inter-vehicle applications. Although qualification processes and related norms and standards (NF F 61030, EN 50467, IEC 61373) are very demanding in the railway industry, there are several suppliers throughout the world who are capable of delivering state-of-the-art connector solutions either with circular or rectangular footprints. However, although this situation applies to electrical connectors for power and signals, there is still a certain way to go before reaching an equivalent situation for fiber optic connectors.

Nevertheless, thanks to the specific adaptation of connector inserts, solutions are already available offering both the reliability of proven and familiar railway connector body designs and the performance of fiber optic technology.

Indeed one of the difficult aspects in the design of such connectors is to combine mechanical resistance to stringent environmental constraints (shock, vibration) with low optical attenuation performance into a unique design. The goal is to achieve a sustainable minimum signal attenuation in order to guarantee a high transmission bandwidth.

Degradation of the quality of optical contacts (scratches, dust,...) or misalignment are responsible for major signal losses. The connector design should obviously take these critical aspects into consideration.



Scratched optical contact

Additionally, the effects of mechanical stress on the optical fibers within the connector should be minimised as they are a cause of unintentional increase in signal attenuation. A proper strain relief management at the termination point between the optical cable and the back shell of the connector ensures that a pulling force on the cable does not directly induce tension on the fibers or on the contacts.

Today, reliable fiber optic railway connectors can be found either with circular or rectangular footprints, with variable fiber counts and either with butt joint or expanded beam technologies, thus responding to a wide range of application constraints and system performance requirements.

As far as fiber connection technology is concerned, the selection is given by various criteria.

As an example, in applications where train vehicles need to be regularly reconfigured, expanded beam solutions may be preferred, which are less sensitive to dust contamination and consequently require less systematic cleaning of contact surfaces. In this case, optical performances are limited (typical insertion loss < 1 dB for single mode at 1310 nm and < 0.7 dB for multimode at 850 nm), resulting in the possible requirement for additional active equipment.

On the other hand, in applications where optical link budgets are tight, butt joint technology may be preferred, which offers improved optical performance (typical insertion loss < 0.5 dB for single mode at 1310 nm and < 0.2 dB for multimode at 850 nm) but requires a more systematic cleaning of the contact surfaces.

As far as connector body technology is concerned, the choice here is also driven by different criteria. As an example, installation constraints may require rectangular bodies and consequently solutions such as HAN® connectors with fiber optic inserts and contacts are preferred. Where installation constraints require circular bodies, solutions based on MIL-DTL-5015 or MIL-DTL-38999 design standards with fiber optic inserts and contacts are also available. Such solutions offer the great advantage of using existing connector designs, which are already familiar and qualified in the rail industry, thus limiting intensive qualification process requirements.

Connectivity: from components to systems

The ability of the industry to deliver state-of-the-art fiber optic connectivity components for rolling stock applications does not necessarily imply that reliable cable system solutions are easy to achieve.

In this respect, inter-vehicle jumper systems are a perfect example. Because such assemblies are permanently exposed to dynamic mechanical and environmental constraints, their design is the key to meeting the service life expectations of the rolling stock industry. Indeed, as the connector is often a fixed part in these assemblies, the cable and its termination into the back shell of the connector are highly challenged. Under these circumstances, fiber optic cable construction, system design and termination process remain areas where know-how, competence and experience are crucial to meet demanding dynamic test conditions induced by inter-vehicle movements over millions of cycles on multiple axes.

The combined competences of HUBER+SUHNER in the areas of inter-vehicle jumper systems (see related white paper) and fiber optic cable systems are unique. With its market experts and engineers, HUBER+SUHNER designs adapted components and systems, defines test procedures, carries out tests, delivers advice, on-site technical support and technology trainings from the project development phase onwards, as part of its co-design approach.

Return on experience

Fiber optic cable systems have already been implemented in certain projects. Where some of these projects are quite recent, others have used the technology for more than 10 years without reports of failures due to the nature of the transmission medium. For these projects, topics such as handling, installation procedures, maintainability or mechanical endurance have always been addressed and solved. Such examples are living proof that fiber is reliable.

Conclusion

Technology benefits, availability of environment-specific components and designs, positive return on experience: most of the ingredients seem to be in place for a promising future for fiber optic technology in trains.

Nevertheless, because the implementation of new technologies requires confidence and trust, the dual experience of HUBER+SUHNER in rolling stock cabling systems and fiber optic connectivity solutions supports the railway industry in making the step to a new generation of train communication networks.

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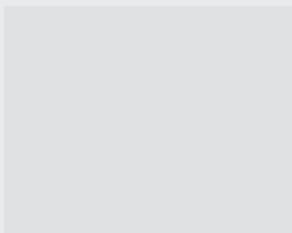


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