



International
Standard

ISO 24581

**Road vehicles — General
requirements and test methods of
in-vehicle optical harnesses for up
to 100 Gbit/s communication**

*Véhicules routiers — Exigences générales et méthodes d'essai des
faisceaux optiques embarqués pour les communications jusqu'à
100 Gbit/s*

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 32, *Electrical and electronic components and general system aspects*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document contains general requirements and test methods for in-vehicle optical harnesses used for high speed communication. Reliable and robust data communication at high data rates is becoming increasingly crucial for the safe operation of automotive systems. Optical communication using graded index all-silica multimode fibre offers superior bandwidth and immunity to electro-magnetic noise. Optical fibre cables and connectors need equal processability, reliability and robustness against environmental influences to be integrated into the vehicle's wire harness. This document provides a set of test methods and requirements to verify the suitability of optical fibre cables and connectors for in-vehicle harness integration. Optical fibre cables can be used for different data transmission standards, such as Ethernet or other proprietary protocols. This means that some performance related requirements have limits depending on the physical layer they are intended for.

ISO 21111-4 is limited to the use of the 1000BASE-RH physical layer. Thus, the transmission rate is 1 Gbit/s and the communication distance is 15 m maximum with four in-line connections.

The optical harnesses defined in this document may cover any applications at high data rates as well as long distances, regardless of the physical layer (by OSI model). Therefore, this document is applicable for articulated-bus for public transportation and/or large-trailer for logistics.

Road vehicles — General requirements and test methods of in-vehicle optical harnesses for up to 100 Gbit/s communication

1 Scope

This document specifies the performance requirements and test methods for optical harnesses for up to 100 Gbit/s per fibre channel for in-vehicle data communication between electronic devices including in-line connections. The optical harness consists of cables and connectors, including cable to cable (in-line) connectors and electronic device (header) connectors. Safety (electrical safety, protection, fire, etc.) and electromagnetic compatibility (EMC) requirements are outside the scope of this document.

Specific to the optical header connector, only mechanical reference plane (MRP), optical reference plane (ORP) and relevant mechanical dimensions are within the scope of this document.

The optical coupling system inside an optical header connector and the optoelectronic component itself are beyond the scope of this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16750-3, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment — Part 3: Mechanical loads*

ISO 16750-4, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment — Part 4: Climatic loads*

ISO 19642-1, *Road vehicles — Automotive cables — Part 1: Vocabulary and design guidelines*

ISO 19642-2, *Road vehicles — Automotive cables — Part 2: Test methods*

ISO 8092-2, *Road vehicles — Connections for on-board electrical wiring harnesses — Part 2: Terminology, test methods and general performance requirements*

ISO 21111-4, *Road vehicles — In-vehicle Ethernet — Part 4: General requirements and test methods of optical gigabit Ethernet components*

IEC 60068-2-60, *Tests — Test Ke: Flowing mixed gas corrosion test*

IEC 60793-1-46, *Optical fibres — Part 1-46: Measurement methods and test procedures — Monitoring of changes in optical transmittance*

IEC 60793-1-47, *Optical fibres — Part 1-47: Measurement methods and test procedures — Macrobending loss*

IEC 60794-1-21, *Optical fibre cables — Part 1-21: Generic specification — Basic optical cable test procedures — Mechanical tests methods*

IEC 60794-1-22, *Optical fibre cables — Part 1-22: Generic specification — Basic optical cable test procedures — Environmental test methods*

IEC 61300-1, *Fibre optic interconnecting devices and passive components — Basic test and measurement procedures — Part 1: General and guidance*

IEC 61300-2-22, *Fibre optic interconnecting devices and passive components — Basic test and measurement procedures — Part 2-22: Tests — Change of temperature*

IEC 61300-3-4, *Fibre optic interconnecting devices and passive components — Basic test and measurement procedures — Part 3-4: Examinations and measurements – Attenuation*

IEC 61300-3-6, *Fibre optic interconnecting devices and passive components — Basic test and measurement procedures — Part 3-6: Examinations and measurements — Return loss*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

buffered optical fibre

optical fibre with an additional layer that surrounds the fibre for the purpose of mechanical insulation and protection from physical damage

3.2

optical header connector

connector which may include an optical transceiver, media dependent interface and socket connector portion that is mated with the cable plug

3.3

optical in-line connector

connector prepared for relaying optical signals, obtained by mating an optical cable plug and an optical cable socket

3.4

system power budget

allocation of available optical power in order to ensure that adequate signal strength is available at the receiver

4 Abbreviated terms

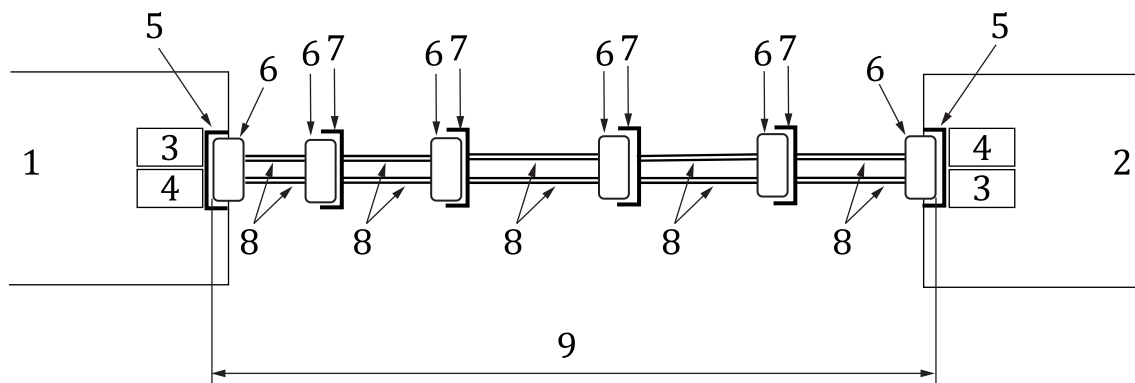
AOP	average optical power
DC	direct current
DUT	device under test
ECU	electronic control unit
FOT	fibre optic transceiver
GI-MMF	graded index – all-silica multimode fibre (excluding GI-POF)
LD	laser diode
MRP	mechanical reference plane

ORP	optical reference plane
PCB	printed circuit board
PD	photodiode
PMD	physical media dependent
TIA	trans impedance amplifier
VCSEL	vertical cavity surface emitting laser

5 Optical channel

5.1 General

The optical channel is composed of all optical elements that guide the optical signal from the light source of the optical transmitter in a first ECU to the photodetector of the optical receiver in a second ECU. The objective of the optical harness is to carry the optical signal between these ECUs with minimum loss and signal distortion. The optical harness may consist of multiple segments of optical fibre cable as defined in 6.3. Each end of a cable segment is terminated by an optical cable plug as defined in 7.3 or an optical cable socket as defined in 7.4. To connect two cable segments, one cable end shall be terminated with a cable plug. The other end that mated with the opposing cable shall be terminated with a cable socket accordingly. The mated combination of a cable plug and a cable socket is referred to as an in-line connection. See Figure 1.



Key

- 1 ECU-1 or other device-1
- 2 ECU-2 or other device-2
- 3 optical transmitter (light source)
- 4 optical receiver (photodetector)
- 5 optical header connector
- 6 optical cable plug
- 7 optical cable socket
- 8 optical fibre cable
- 9 optical channel

Figure 1 — Optical channel connecting ECUs

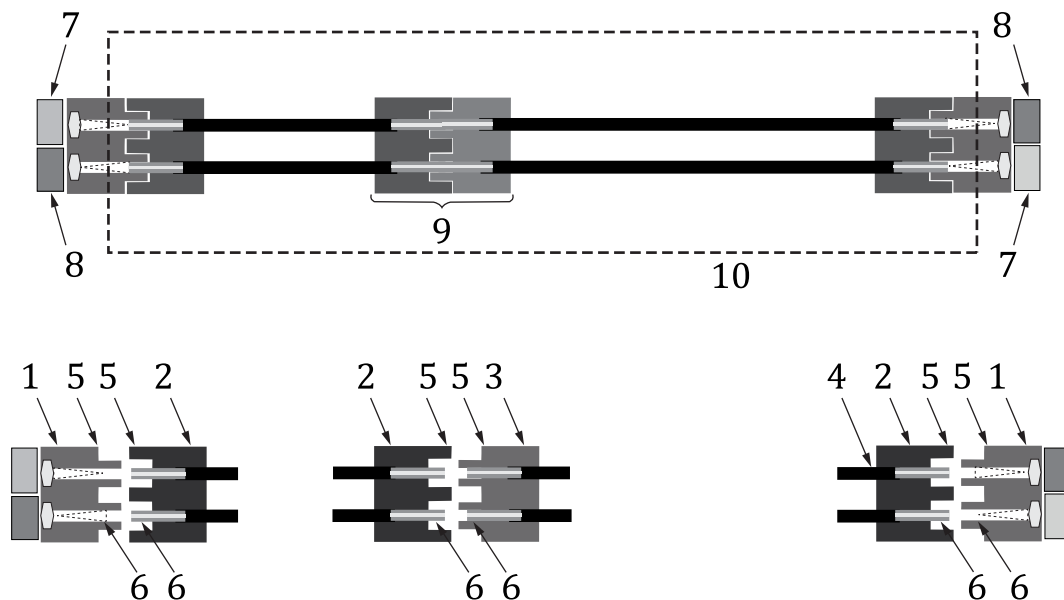
In this document, the mating socket of the ECU (header connector) is only defined with regards to its mechanical and optical mating interface to ensure its mating compatibility with the optical harness. Any optical guiding structures within the ECU or active components of the PMD are beyond the scope of this document.

The optical header connector is defined in 7.2. It shall follow the mechanical interface definitions of a socket connector to mate with an optical cable plug of a specified connector family. The optical path within the ECU and thus inside a header connector is not part of this document. The optical channel consists of optical fibre cables based on GI-MMF defined in Clause 6 and cable connectors defined in Clause 7 without any active (optoelectronic) power consuming sub-component.

5.2 Optical harness

The optical harness consists of one or more segments of optical fibre cable with optical cable plugs and/or optical cable sockets attached. The mated connection of two segments by a cable plug and a socket is referred to as an in-line connection. See Figure 2. The dashed line in Figure 2 encloses the optical harness and the housing parts of the header connector that are defined in this document. The total attenuation of the optical harness is also affected by the layout shape (bending and number of in-line connections) mounted on the vehicle. It shall not exceed the sum of the system power budget and system margin of the optical transceiver of the communication system. Optical harness design guidelines are provided in Annex B.

The length and number of segments allowed depend on each communication system specification (e.g. ISO/IEC/IEEE 8802-3). Additionally, when constructing a multi-giga optical Ethernet as specified in IEEE802.3cz:2023, the modal noise penalty listed in Annex D shall be satisfied.



Key

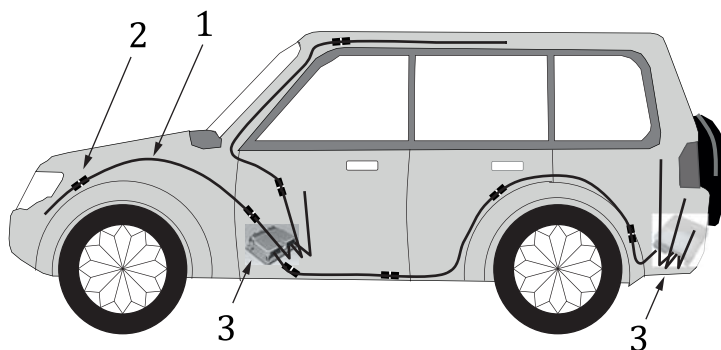
- 1 header connector housing
- 2 cable plug
- 3 cable socket
- 4 optical fibre cable
- 5 MRP
- 6 ORP
- 7 optical transmitter (light source)
- 8 optical receiver (photodetector)
- 9 optical in-line connection
- 10 optical harness

Figure 2 — Optical harness and relation between connectors

5.3 Optical harness application examples

Since the route of the long optical harness may correspond to the vicinity of the ceiling or the exposed part of the vehicle, various qualification tests shown in [Clauses 6 to 9](#) of this document shall be required.

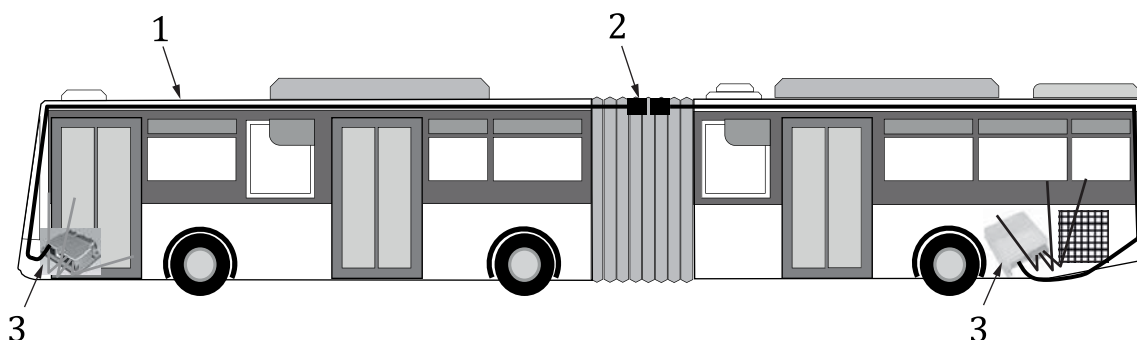
The optical harness is applicable to the engine compartment harness (see [Figure 3](#)), the roof harness (see [Figure 4](#)) and the exposure harness (see [Figure 5](#)). These harnesses should conform to individually specified temperature ranges.



Key

- 1 engine compartment harness
- 2 in-line connection
- 3 backbone ECU

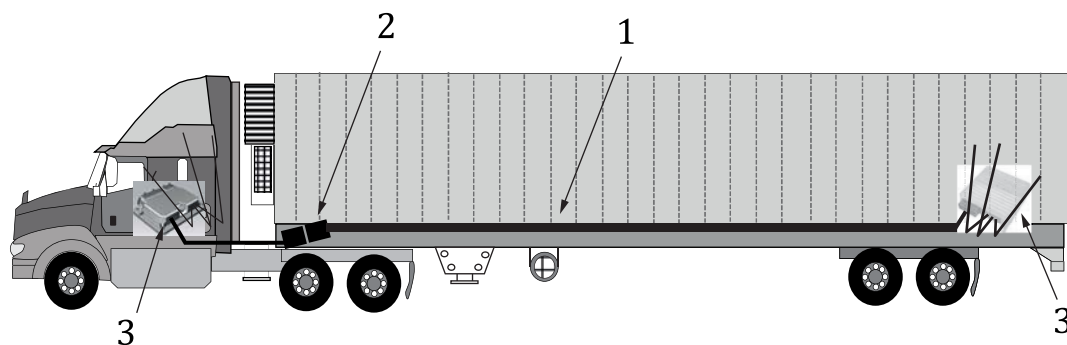
Figure 3 — Optical harness application example for the passenger car



Key

- 1 roof harness
- 2 in-line connection
- 3 backbone ECU

Figure 4 — Optical harness application example for the articulated bus

**Key**

- 1 exposure harness
- 2 in-line connection
- 3 backbone ECU

Figure 5 — Optical harness application example for the trailer

6 Optical fibre and optical fibre cable

6.1 General

Optical fibres with appropriate bandwidth characteristics at the wavelength of the selected PMD shall be implemented as the optical harnesses according to this document and used for communication with the specified data rates. IEC 60793-2-10 defines different subcategories of GI-MMF. Cables used in an automotive harness shall protect the optical fibre from environmental loads during shipment, storage, processing, installation into the vehicle and during a vehicle's operation. As a wire harness is typically deeply woven through a vehicle's body, it needs to last the entire lifetime of a vehicle. In many in-vehicle applications, the optical fibre cable shares the same installation space or even the same harness as other general wires for electrical functions. Thus, the optical fibre cable should be able to withstand the same environmental loads such as temperature, humidity, chemicals, shock, vibration, bending, abrasion and pull and shear forces as electrical cables intended for the same installation space.

6.2 Optical fibre

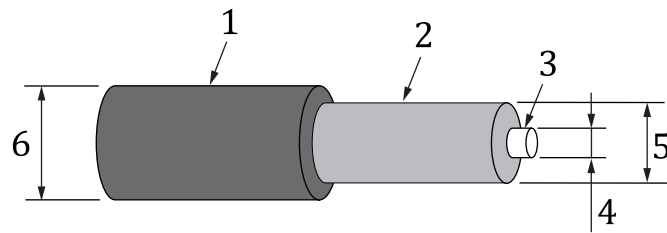
6.2.1 GI-MMF

IEC 60793-2-10 defines the dimensional requirements of optical fibre types with their core and cladding properties. See [Figure 6](#). Optical fibres of subcategory A1-OM3 and A1-OM4 are defined for link length and signal bandwidth suitable to the requirements of the applications this document is targeting.

All optical cables specified in this document shall conform to subcategories A1-OM3 or A1-OM4 as specified in IEC 60793-2-10 and have an operating temperature range of up to +125 °C.

6.2.2 Buffered optical fibre structure

GI-MMF 50 µm is commercially available to cable manufacturers as a pre-product. For processability reasons, the all-silica fibre is protected by a primary coating applied during the fibre manufacturing process. Typical primary coatings have an outer diameter of 250 µm. Other coating diameters and/or additional coating layers may be applied depending on the application and cable requirements. [Figure 6](#) shows an example of a typical GI-MMF buffered optical fibre structure.

**Key**

- 1 primary coating
- 2 cladding
- 3 core
- 4 nominal core diameter (50 µm)
- 5 nominal cladding diameter (125 µm)
- 6 nominal primary coating diameter (250 µm)

Figure 6 — Typical structure of a buffered optical fibre (GI-MMF 50 µm)**6.2.3 Requirements of optical fibre**

[Table 1](#) shows the optical fibre requirements covered in this document and the references that define their test methods. The structural requirements of the optical fibre itself as well as the propagation characteristics are specified for ultra-high-speed optical communication.

Table 1 — Requirements of optical fibre

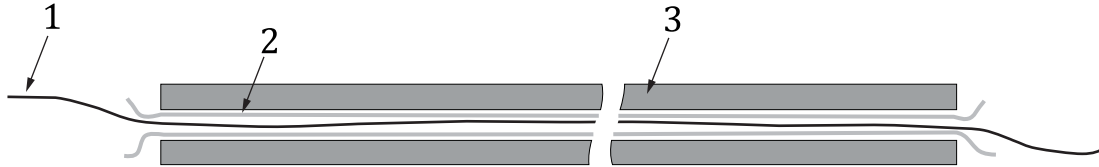
No.	Requirement	Reference
1	Cladding diameter	IEC 60793-1-20 IEC 60793-2-10
2	Core diameter	IEC 60793-1-20 IEC 60793-2-10
3	Cladding non-circularity	IEC 60793-1-20 IEC 60793-2-10
4	Core non-circularity	IEC 60793-1-20 IEC 60793-2-10
5	Primary coating diameter	IEC 60793-1-21 IEC 60793-2-10
6	Primary coating non-circularity	IEC 60793-1-21 IEC 60793-2-10
7	Attenuation coefficient	IEC 60793-1-40 IEC 60793-2-10
8	Modal bandwidth	IEC 60793-1-41 IEC 60793-2-10
9	Numerical aperture	IEC 60793-1-43 IEC 60793-2-10
10	Chromatic dispersion	IEC 60793-1-42 IEC 60793-2-10
11	Change of optical transmission	IEC 60793-1-46 IEC 60793-2-10
12	Differential mode delay	IEC 60793-1-49 IEC 60793-2-10

6.3 Optical fibre cable

6.3.1 Cable structure

The optical fibre cable shall have the optical performance specified in [6.3.2](#). It shall also be subjected to the equivalent mechanical and environmental tests on automotive electrical wires and cables specified in ISO 19642-2. Therefore, tough and flame-resistant jacketing materials shall be used.

An example of the optical fibre cable is shown in [Figure 7](#). Strength members may be built into the cable structure to ensure the specified tensile strength.



Key

- 1 optical fibre or buffered optical fibre
- 2 strength members
- 3 jacket

Figure 7 — Optical fibre cable structure

6.3.2 Requirements and test methods for optical fibre cable

[Table 2](#) shows the references that contain requirements and test methods that the optical fibre cable shall also conform to in addition to the requirements and test methods defined in each subclause in this document. When the requirements specified in the subclause in this document deviate from the specifications in the reference document, the requirements in the subclauses in this document prevail.

Table 2 — Requirements and test methods for optical fibre cable

Subclause in this document	Requirement	Reference
6.3.3	Cable attenuation	IEC 60793-1-40
6.3.4	High storage temperature exposure	ISO 19642-1
6.3.5	Low storage temperature exposure	ISO 19642-1
6.3.6	Operation temperature range	ISO 19642-1 IEC 60794-1-22
6.3.7	Minimum attenuation increase by the residual bending stress (temporarily allowable bending radius)	IEC 60793-1-47
6.3.8	Maximum bending attenuation	IEC 60793-1-47
6.3.9	Tensile strength	ISO 19642-2
6.3.10	Crush toughness	IEC 60794-1-21 IEC 60793-1-46
6.3.11	Impact resistance	IEC 60794-1-21 IEC 60793-1-46
6.3.12	Static torsion toughness	IEC 60793-1-46
6.3.13	Resistance to flame propagation	ISO 19642-2 ISO 21111-4

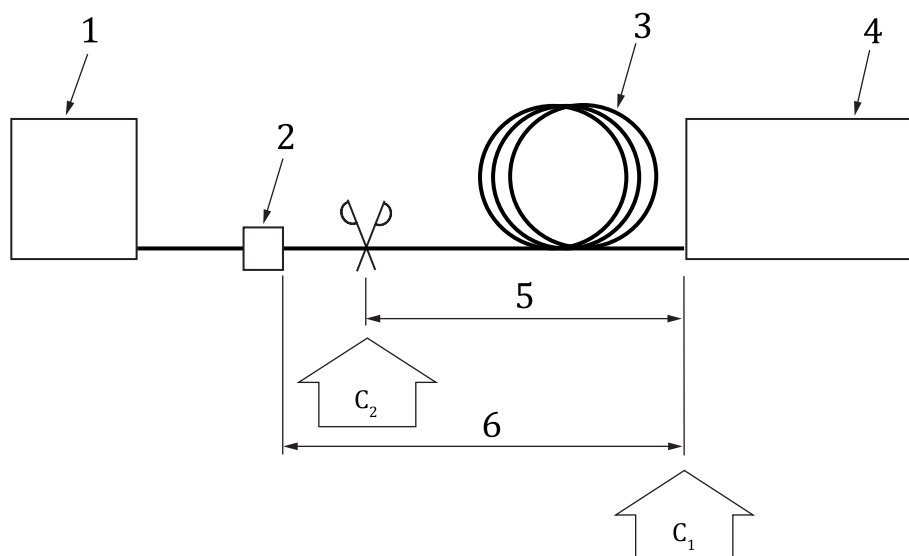
6.3.3 Cable attenuation

6.3.3.1 Purpose

The buffered optical fibre with 50 μm GI core is a key parameter for determining the maximum link length of the optical channel. Optical fibre cable attenuation is a measure of the decrease in optical power of a fibre at a particular wavelength. Cable attenuation depends on the measurement conditions and the configuration and length of the optical fibre cable. Cable attenuation should therefore be properly allocated to the link power budget of the optical communication system that is shown in [Annex A](#).

6.3.3.2 Test setup

An optical cable of 51 m is prepared as the DUT. Both fibre ends of the DUT shall be cut and polished or otherwise prepared (according to the test equipment specifications for testing, e.g. for splicing). One end of the DUT is connected to the optical power meter set at a designated wavelength. The other end is connected to the stabilized light source defined in [8.5.1](#) via the launch optics defined in [8.5.2.1](#). See [Figure 8](#) for the attenuation measurement system.



Key

- 1 stabilized light source as defined in [8.5.1](#)
- 2 launch optics as defined in [8.5.2.1](#)
- 3 DUT
- 4 optical power meter as defined in [8.5.2.1](#)
- 5 the cutting length of the DUT (50 m ± 0,5 m)
- 6 initial length of the DUT (51 m ± 0,5 m)
- C₁ measurement point of the fibre end of initial DUT
- C₂ measurement point of the fibre end of short DUT that is cut 50m from optical output end

Figure 8 — Cable attenuation measurement system

6.3.3.3 Test method

The optical power at C₁ is measured as the initial value before fibre cutting. The launching condition shall be retained while the fibre is cut at C₂ and the fibre cross-section is polished. After that, optical power at C₂ is measured.

The attenuation of the optical fibre cable between the two cross sections C_1 and C_2 on the DUT is calculated using [Formula \(1\)](#).

$$A = -10 \log_{10} \left(\frac{P_1}{P_2} \right) \quad (1)$$

where

A is the attenuation at the designated wavelength, expressed in dB;

P_1 is the AOP at cross-section C_1 , at the designated wavelength;

P_2 is the AOP at cross-section C_2 , at the designated wavelength.

Measuring the attenuation of a long optical fibre cable (e.g. on a cable drum) should be performed according to IEC 60793-1-40.

6.3.3.4 Requirement

The cable attenuation of 50 m, A , shall be maximum 0,2 dB or less. The cable attenuation coefficient is maximum 4,0 dB/km at the designated wavelength.

6.3.4 High storage temperature exposure

6.3.4.1 Purpose

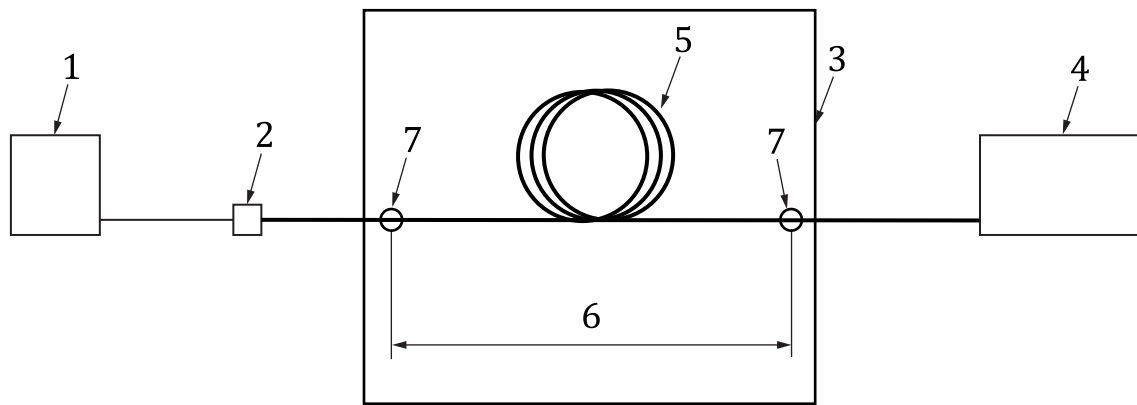
Optical harnesses are required to provide stable performance under the vehicle environment. The initial performance of the optical fibre cable should be maintained after being held at $T_{\max}$ for a long time.

6.3.4.2 Test setup

A cable sample of 60 m shall be prepared as described in IEC 60794-1-22:2017, Method F1. The length of the DUT shall be 50 m. The DUT shall be lightly bundled and placed in the programmable oven described in [8.5.2.3](#). The remaining fibre (5 m in each) of both ends of the DUT shall be routed outside the programmable oven defined in [8.5.2.3](#). See [Figure 9](#).

Both fibre ends of the DUT shall be cut and polished or otherwise prepared (according to the test equipment specifications for testing, e.g. for splicing). One end of the DUT is connected to the stabilized light source defined in [8.5.1](#) via the launch optics defined in [8.5.2.1](#). The other end of the DUT is connected to the optical power meter set at the designated wavelength.

The supplier and the vehicle manufacturer shall agree on the test temperature condition. Unless otherwise provided, the designated temperature, $T_{\max}$, shall conform to Class C as defined in ISO 19642-1:2023, Table 1.

**Key**

- 1 stabilized light source as defined in [8.5.1](#)
- 2 launch optics as defined in [8.5.2.1](#)
- 3 programmable oven as defined in [8.5.2.2](#)
- 4 optical power meter as defined in [8.5.2.1](#)
- 5 DUT
- 6 length of the DUT (50 m ± 0,5 m)
- 7 service hole of programmable oven

Figure 9 — Optical fibre cable test setup for aging**6.3.4.3 Test method**

Before the programmable oven is operated, the AOP at the end of the DUT is measured as the initial value. The programmable oven is operated with the setting temperature of $T_{\max}$ and held for 3 000 h. The DUT is taken out of the programmable oven after being held for 24 h at room temperature as defined in ISO 19642-1:2023, 3.2.2. The AOP at the end of the DUT is measured after high temperature exposure test as the after value.

The attenuation increase of the DUT after the high temperature exposure test is calculated using [Formula \(2\)](#).

$$A_{\text{Increase}} = -10 \log_{10} \left(\frac{P_{\text{After}}}{P_{\text{Initial}}} \right) \quad (2)$$

where

A_{Increase} is the attenuation increase of the DUT after high temperature stress;

P_{Initial} is the AOP at the end of the DUT before the test;

P_{After} is the AOP at the end of the DUT after the test.

6.3.4.4 Requirement

The attenuation increase of the DUT (A_{Increase}) shall be 1,0 dB or less after the high temperature exposure test.

6.3.5 Low storage temperature exposure**6.3.5.1 Purpose**

Optical harnesses are required to provide stable performance under the vehicle environment. The initial performance of the optical cable shall be maintained after being held at $T_{\min}$ for a long time. The low temperature exposure test is not an aging test, but it shows the cable behaviour when cable materials contract differently.

6.3.5.2 Test setup

The DUT and the check system are prepared in the same manner as [6.3.4.2](#). The supplier and the vehicle manufacturer shall agree on the test temperature condition. Unless otherwise provided, the designated temperature, $T_{\min}$, shall conform to Class C as defined in ISO 19642-1:2023, Table 1.

6.3.5.3 Test method

Before the programmable oven is operated, the AOP at the end of the DUT is measured as the initial value. The programmable oven is operated with the setting temperature of $T_{\min}$ and held for 96 h. The DUT is taken out of the programmable oven after being held for 24 h at room temperature as defined in ISO 19642-1:2023, 3.2.2. The AOP at the end of the DUT is measured after the low temperature exposure test as the after value.

The attenuation increase of the DUT after the low temperature exposure test is calculated using [Formula \(3\)](#).

$$A_{\text{Increase}} = -10 \log_{10} \left(\frac{P_{\text{After}}}{P_{\text{Initial}}} \right) \quad (3)$$

where

A_{Increase} is the attenuation increase of the DUT with low temperature stress;

P_{Initial} is the AOP at the end of the DUT before the test;

P_{After} is the AOP at the end of the DUT after the test.

6.3.5.4 Requirement

The attenuation increase of the DUT (A_{Increase}) shall be 1,0 dB or less after the low temperature exposure test.

6.3.6 Operation temperature exposure

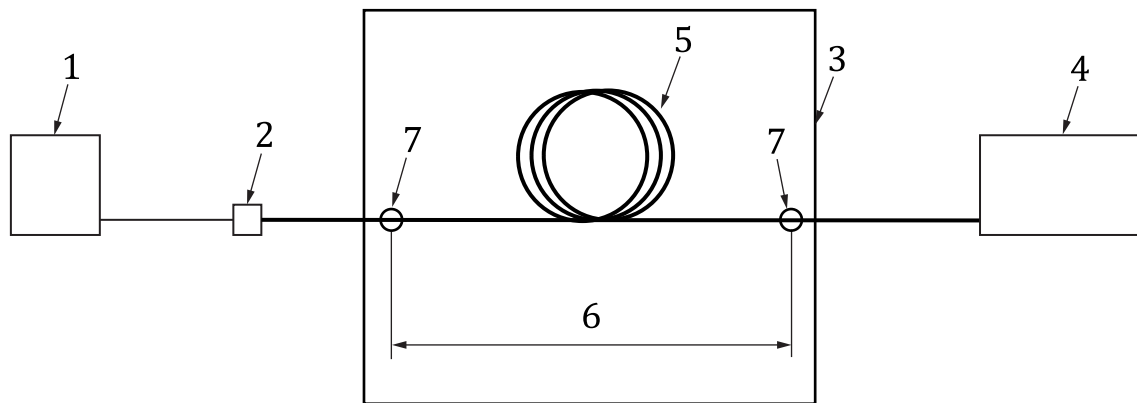
6.3.6.1 Purpose

The cable used in the optical harnesses shall perform in a stable manner during operation and within the operating temperature range. The temperature cycling test determines the optical cable performance during and after the test as the temperature range confirmation test.

6.3.6.2 Test setup

A cable sample of 60 m shall be prepared as described in IEC 60794-1-22, Method F1. The length of the DUT shall be 50 m. The DUT shall be lightly bundled and placed in the programmable oven described in [8.5.2.3](#). The remaining fibre (5 m in each) of both ends of the DUT shall be routed outside the programmable oven defined in [8.5.2.3](#). See [Figure 10](#).

Both fibre ends shall be cut and polished or otherwise prepared (according to the test equipment specifications for testing, e.g. for splicing). One end of the DUT is connected to the stabilized light source defined in [8.5.1](#) via the launch optics defined in [8.5.2.1](#). The other end of the DUT is connected to the optical power meter set at the designated wavelength.

**Key**

- 1 stabilized light source as defined in [8.5.1](#)
- 2 launch optics as defined in [8.5.2.1](#)
- 3 programmable oven as defined in [8.5.2.2](#)
- 4 optical power meter as defined in [8.5.2.1](#)
- 5 DUT
- 6 length of the DUT (50 m ± 0,5 m)
- 7 service hole of programmable oven

Figure 10 — Optical fibre cable test setup for temperature cycling

6.3.6.3 Test method

The temperature cycling test shall be performed as described in IEC 60794-1-22:2017, Method F1, with the following parameters: soak time of 1 h; temperature ramp of 60 °C/h; for 12 cycles. The supplier and the vehicle manufacturer shall agree on the test temperature condition. Unless otherwise provided, the designated temperatures ($T_{\max}/T_{\min}$) should conform to Class C as defined in ISO 19642-1:2023, Table 1. The AOP from the DUT is measured as the initial value before the temperature cycling test. During and after the test, the AOP change shall be monitored according to IEC 60793-1-46 at intervals of 10 min or less. The AOP change refers to the ± deviation from the initial value.

The value of the minimum optical power measured during the test or the optical power measured after the test is introduced in [Formula \(4\)](#). They are compared with the values defined in [6.3.6.4](#) as the attenuation amount during or after the test.

$$A_{\text{Increase}} = -10 \log_{10} \left(\frac{P_{\text{Minimum or } P_{\text{After}}}}{P_{\text{Initial}}} \right) \quad (4)$$

where

- A_{Increase} is the attenuation increase of the DUT with temperature stress;
- P_{Initial} is the AOP at the end of the DUT before the test;
- P_{Minimum} is the minimum AOP at the end of the DUT during the test;
- P_{After} is the AOP at the end of the DUT after the test.

6.3.6.4 Requirement

The attenuation change, A_{Increase} , shall be 1,0 dB or less during and after the test.

6.3.7 Minimum attenuation increase by the residual bending stress

6.3.7.1 Purpose

When an optical fibre cable is bent in a small radius, the optical performance can permanently degrade and/or the cable can kink permanently. Optical wire harnesses are often randomly bent during transportation or assembly into a vehicle body. A minimum allowable bending radius is defined to determine the residual bending attenuation and to avoid a permanent kink or other deformation due to excessive cable bending.

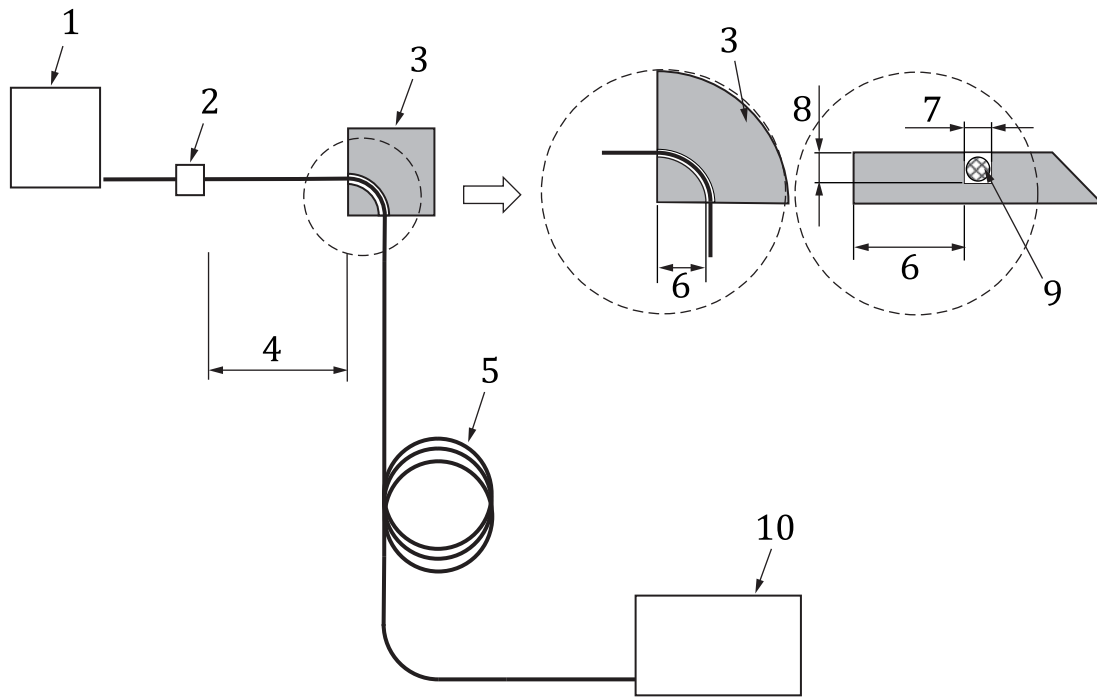
6.3.7.2 Test setup

A 5 m optical fibre cable is prepared as the DUT. Both fibre ends of the DUT shall be cut and polished or otherwise prepared (according to the test equipment specifications for testing, e.g. for splicing). One end is connected to the stabilized light source defined in [8.5.1](#) via the launch optics defined in [8.5.2.1](#). The other end is connected to the optical power meter set at the designated wavelength. The distance from the launch optics to the bent portion is defined as ≥ 1 m. Use a quarter circle guide groove in the bending test jig described in IEC 60793-1-47, which has a groove with the same width as the diameter of the DUT. This test shall be operated at room temperature as defined in ISO 19642-1:2023, 3.2.2. The test equipment and the DUT are connected on the laboratory table.

6.3.7.3 Test method

The AOP at the end of the DUT before bending is measured as the initial value. The DUT should be carefully placed into the guide of the bending jig that has a 10 mm-radius groove and held for 24 h. See [Figure 11](#).

After 24 h, the DUT should be released carefully from the bent stress. The AOP at the end of the DUT is measured after 10 min from the bending operation as the measurement value after the test.



Key

- | | | | |
|---|--|----|--|
| 1 | stabilized light source defined in 8.5.1 | 6 | bent radius: 10 mm, angle: 90° |
| 2 | launch optics defined in 8.5.2.1 | 7 | groove width: DUT outer diameter + 0,1 mm |
| 3 | bending test jig | 8 | groove depth: DUT outer diameter + 0,1 mm or larger |
| 4 | distance between launch optics and bent portion: ≥1 m | 9 | cross section of the DUT |
| 5 | DUT | 10 | optical power meter defined in 8.5.2.1 |

Figure 11 — Minimum residual bending stress measurement setup

The attenuation increase of the DUT after the bending operation is calculated using [Formula \(5\)](#).

$$A_{\text{Increase}} = -10 \log_{10} \left(\frac{P_{\text{After}}}{P_{\text{Initial}}} \right) \quad (5)$$

where

A_{Increase} is the attenuation increase of the DUT with bending stress;

P_{Initial} is the AOP at the end of the DUT before the test;

P_{After} is the AOP at the end of the DUT after the test.

6.3.7.4 Requirement

The attenuation increase of the DUT (A_{Increase}) after the bending operation shall not exceed 0,2 dB.

6.3.8 Maximum bending attenuation

6.3.8.1 Purpose

Bending the optical fibre cable can result in increased optical signal attenuation. Some modes are changed into higher order modes and may exceed the propagation condition of the graded index core due to the fibre being bent. The respective modes thus enter the leakage mode and result in additional attenuation of the optical signal. Depending on their position in the vehicle body after assembly, optical fibre cables in a

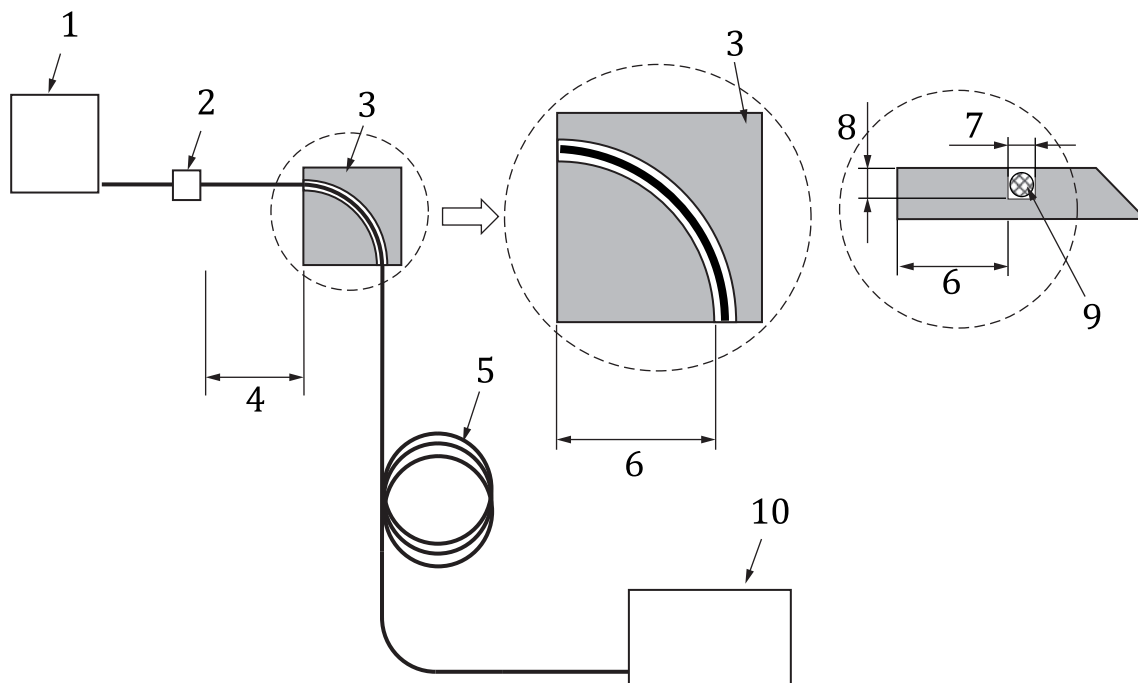
harness are bent in the same manner as any other electric wire cables. To be able to calculate the expected attenuation of an installed optical harness, the maximum bending attenuation increase is defined.

6.3.8.2 Test setup

A 5 m optical fibre cable is prepared as the DUT. Both fibre ends of the DUT shall be cut and polished or otherwise prepared (according to the test equipment specifications for testing, e.g. for splicing). One end is connected to the stabilized light source defined in 8.5.1 via the launch optics defined in 8.5.2.1. The other end is connected to the optical power meter set at the designated wavelength. The distance from the launch optics to the bent portion is defined as ≥ 1 m. Use a quarter circle guide groove in the bending test jig described in IEC 60793-1-47, which has a groove with the same width as the diameter of the DUT. This test shall be operated at room temperature as defined in ISO 19642-1:2023, 3.2.2. The test equipment and DUT are connected on the laboratory table.

6.3.8.3 Test method

The AOP at the end of the DUT before bending is measured as the initial value. The DUT should be carefully placed into the guide of the bending jig that has a 15 mm-radius groove. The AOP at the end of the DUT with bending operation is measured as the measurement value with bending stress. See Figure 12.



Key

- | | | | |
|---|---|----|---|
| 1 | stabilized light source defined in 8.5.1 | 6 | bent radius: 15 mm, angle: 90° |
| 2 | launch optics defined in 8.5.2.1 | 7 | groove width: DUT outer diameter + 0,1 mm |
| 3 | bending test jig | 8 | groove depth: DUT outer diameter + 0,1 mm or larger |
| 4 | distance between launch optics and bent portion: ≥ 1 m | 9 | cross section of the DUT |
| 5 | DUT | 10 | optical power meter defined in 8.5.2.1 |

Figure 12 — Maximum bending attenuation measurement setup

The maximum bending attenuation of the DUT with bending operation is calculated using [Formula \(6\)](#).

$$A_{\text{Bending}} = -10 \log_{10} \left(\frac{P_{\text{Bent}}}{P_{\text{Initial}}} \right) \quad (6)$$

where

A_{Bending} is the attenuation increase of the DUT with bending stress;

P_{Initial} is the AOP at the end of the DUT before the test;

P_{Bent} is the AOP at the end of the DUT while bent.

6.3.8.4 Requirement

The attenuation increase of the DUT (A_{Bending}) while bent shall not exceed 0,2 dB.

6.3.9 Tensile strength

6.3.9.1 Purpose

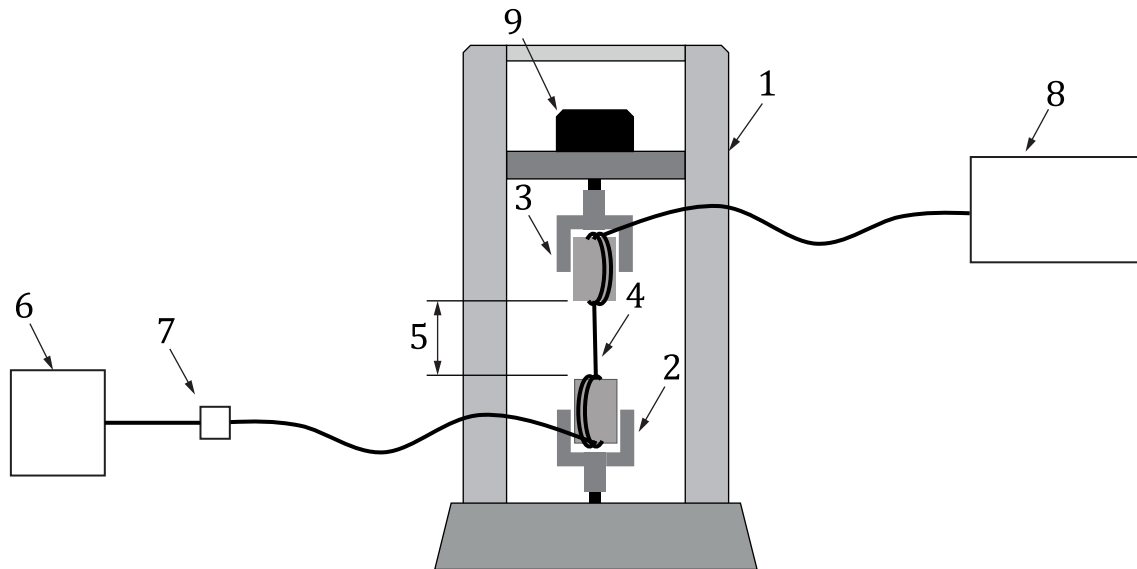
Optical fibre cables used for the vehicle are routed in the same way as the typical wire harness. Therefore, the tensile strength requirement of the optical fibre cable is the same level as the requirement for an electrical wire used for the vehicle. The tensile strength of an optical fibre cable is independent of the number of optical channels implemented in the cable due to its optical fibre cable construction.

6.3.9.2 Test setup

A 5 m optical fibre cable is prepared as the DUT. Both fibre ends of the DUT shall be cut and polished or otherwise prepared (according to the test equipment specifications for testing, e.g. for splicing). A tensile strength tester shall be strong enough to hold and measure the specified load (see [8.5.2.4](#)) and shall provide a speed of 50 mm/min for the movable stage. One side of the DUT is wound around the mandrel of the lower wire clamp. The other side of the DUT is wound around the mandrel of the upper wire clamp of the tensile strength tester defined in [8.5.2.3](#). The mandrels in the clamps shall have a minimum diameter of 25 times the cable diameter, but not less than 60 mm. An example of the test apparatus for breaking force is described in ISO 19642-2:2023, 5.4.3.

One end of the DUT is connected to the stabilized light source defined in [8.5.1](#) via the launch optics defined in [8.5.2.1](#). The other end of the DUT is connected to the optical power meter set at the designated wavelength. See [Figure 13](#).

The upper and lower wire clamps in the tensile strength tester are set so that the length of the straight part of the DUT between both clamps becomes longer than 100 mm and shorter than 200 mm. Any DUT slack between the upper and lower wire clamps is eliminated. The upper clamp moves to elongate the straight part of the DUT. See [Figure 13](#). This test shall be operated at room temperature as defined in ISO 19642-1:2023, 3.2.2.



Key

- | | | | |
|---|--|---|---|
| 1 | tensile strength tester as defined in 8.5.2.3 | 6 | stabilized light source as defined in 8.5.1 |
| 2 | lower wire clamp: mandrel diameter is 60 mm or larger | 7 | launch optics as defined in 8.5.2.1 |
| 3 | upper wire clamp: mandrel diameter is 60 mm or larger | 8 | optical power meter as defined in 8.5.2.1 |
| 4 | DUT (simplex or duplex cable) | 9 | load cell |
| 5 | distance between clamps (testing area of the DUT):
100 mm to 200 mm | | |

Figure 13 — Tensile stress measurement setup

6.3.9.3 Test method

The AOP at the end of the DUT before the loading operation is measured as the initial value. The DUT is pulled at a pulling speed of 50 mm/min. Once the load reaches 120 N, this state shall be kept for 1 min. Then, the load shall be removed from the DUT. The AOP at the end of the DUT is measured after 1 min from the loading operation as the after value. The attenuation increase of the DUT after the loading operation is calculated using [Formula \(7\)](#).

$$A_{\text{Increase}} = -10 \log_{10} \left(\frac{P_{\text{After}}}{P_{\text{Initial}}} \right) \quad (7)$$

where

A_{Increase} is the attenuation increase of the DUT after loading operation;

P_{Initial} is the AOP at the end of the DUT before the test;

P_{After} is the AOP at the end of the DUT after the test.

6.3.9.4 Requirement

The attenuation increase of the DUT (A_{Increase}) after the loading operation shall be 0,2 dB or less.

6.3.10 Crush toughness

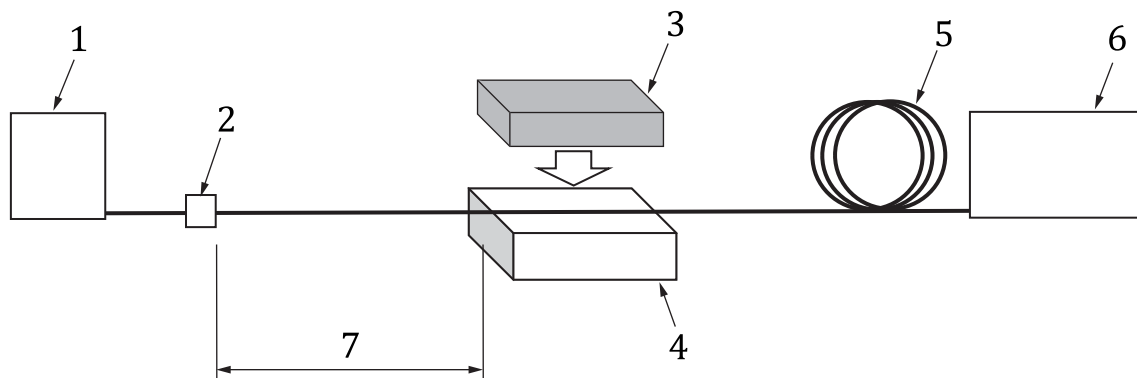
6.3.10.1 Purpose

The optical fibre cable used in the vehicle may be subjected to side pressure during cable routing and/or under assembled situation. Therefore, the cable performance after crush load shall be determined.

6.3.10.2 Test setup

A 5 m optical fibre cable is prepared as the DUT. Both fibre ends of the DUT shall be cut and polished or otherwise prepared (according to the test equipment specifications for testing, e.g. for splicing). One end is connected to the stabilized light source defined in 8.5.1 via the launch optics defined in 8.5.2.1. The other end is connected to the optical power meter set at the designated wavelength. The distance from the launch optics to the crush portion shall be at least 1 m.

Metallic pressurizer jig shall weigh $105\text{ kg} \pm 1\%$ and shall be a square of $100\text{ mm} \pm 5\%$ size with rounded edges. Key item 3 in Figure 14 is simplified as the “metallic pressurizer jig”. The surfaces of the metallic pressurizer jig and the metallic base stage in contact with the DUT shall be flat. The DUT is put on the metallic base stage. See Figure 14. The apparatus for measuring the change in optical transmittance using a stabilized source is described in IEC 60793-1-46, method A.



Key

- 1 stabilized light source as defined in 8.5.1
- 2 launch optics as defined in 8.5.2.1
- 3 metallic pressurizer jig
- 4 metallic base stage that is larger than the metallic pressurizer jig
- 5 DUT
- 6 optical power meter as defined in 8.5.2.1
- 7 distance between launch optics and crush test portion: $\geq 1\text{ m}$

Figure 14 — Crush toughness measurement setup

6.3.10.3 Test method

The AOP at the end of the DUT is measured as the initial value before the crush operation. The DUT is pressed from the upper side by the metallic pressurizer jig. See Figure 14. The DUT is crushed for 3 min by the metallic pressurizer jig. The AOP at the end of the DUT is measured 1 min after release from the crush operation as the measurement value after the test. The test method shall follow the specification defined in IEC 60794-1-21.

The attenuation increase of the DUT after the crush operation is calculated using [Formula \(8\)](#).

$$A_{\text{Increase}} = -10 \log_{10} \left(\frac{P_{\text{After}}}{P_{\text{Initial}}} \right) \quad (8)$$

where

A_{Increase} is the residual attenuation increase of the DUT due to crush stress;

P_{Initial} is the AOP at the end of the DUT before the test;

P_{After} is the AOP at the end of the DUT after the test.

6.3.10.4 Requirement

The residual attenuation increase of the DUT (A_{Increase}) after the crush operation shall be 0,2 dB or less.

6.3.11 Impact resistance

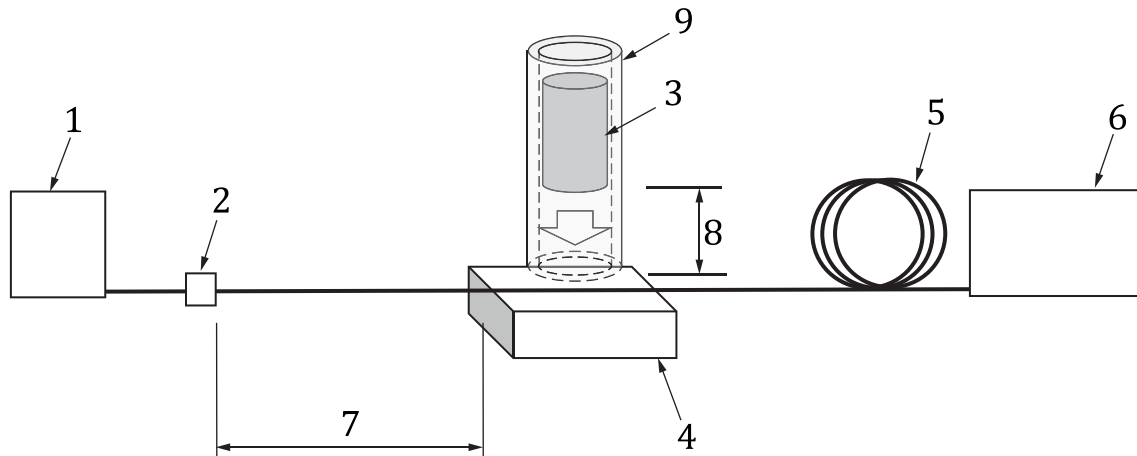
6.3.11.1 Purpose

The optical fibre cable used in the vehicle may be subjected to impact during cable routing. Therefore, the cable performance after impact shall be determined.

6.3.11.2 Test setup

A 5 m optical fibre cable is prepared as the DUT. Both fibre ends of the DUT shall be cut and polished or otherwise prepared (according to the test equipment specifications for testing, e.g. for splicing). One end is connected to the stabilized light source defined in [8.5.1](#) via the launch optics defined in [8.5.2.1](#). The other end is connected to the optical power meter set at the designated wavelength. The distance from the launch optics to the crush portion shall be at least 1 m.

The impact jig shall be a metallic cylinder with a diameter of 30 mm ± 5 % with round edge and 1 kg ± 1 % in weight. Key item 3 in [Figure 15](#) is simplified as the “impact jig”. The central part of the DUT is put on the metallic base stage. See [Figure 15](#). The apparatus for measuring the change in optical transmittance using a stabilized source is described in IEC 60793-1-46, method A.



Key

- 1 stabilized light source as defined in [8.5.1](#)
- 2 launch optics as defined in [8.5.2.1](#)
- 3 impact jig
- 4 metallic base stage; that is larger than the impact jig
- 5 DUT
- 6 optical power meter as defined in [8.5.2.1](#)
- 7 distance between launch optics and impact portion: ≥ 1 m
- 8 height of fall: 50 mm
- 9 fall guide: inner diameter is from 32 mm to 33 mm

Figure 15 — Impact resistance measurement setup

6.3.11.3 Test method

The AOP at the end of the DUT is measured as the initial value before the impact jig is dropped. The impact jig is naturally dropped from a height of 50 mm onto the DUT. After the test, the impact jig is removed. The AOP at the end of the DUT is measured after the impact jig drop as the measuring value after the test. The test method shall follow the specification defined in IEC 60794-1-21.

The attenuation increase of the DUT after the edge impact operation is calculated using [Formula \(9\)](#).

$$A_{\text{Increase}} = -10 \log_{10} \left(\frac{P_{\text{After}}}{P_{\text{Initial}}} \right) \quad (9)$$

where

A_{Increase} is the attenuation increase of the DUT after edge impact stress;

P_{Initial} is the AOP at the end of the DUT before the test;

P_{After} is the AOP at the end of the DUT after the test.

6.3.11.4 Requirement

The attenuation increase of the DUT (A_{Increase}) after the impact operation shall be 0,2 dB or less.