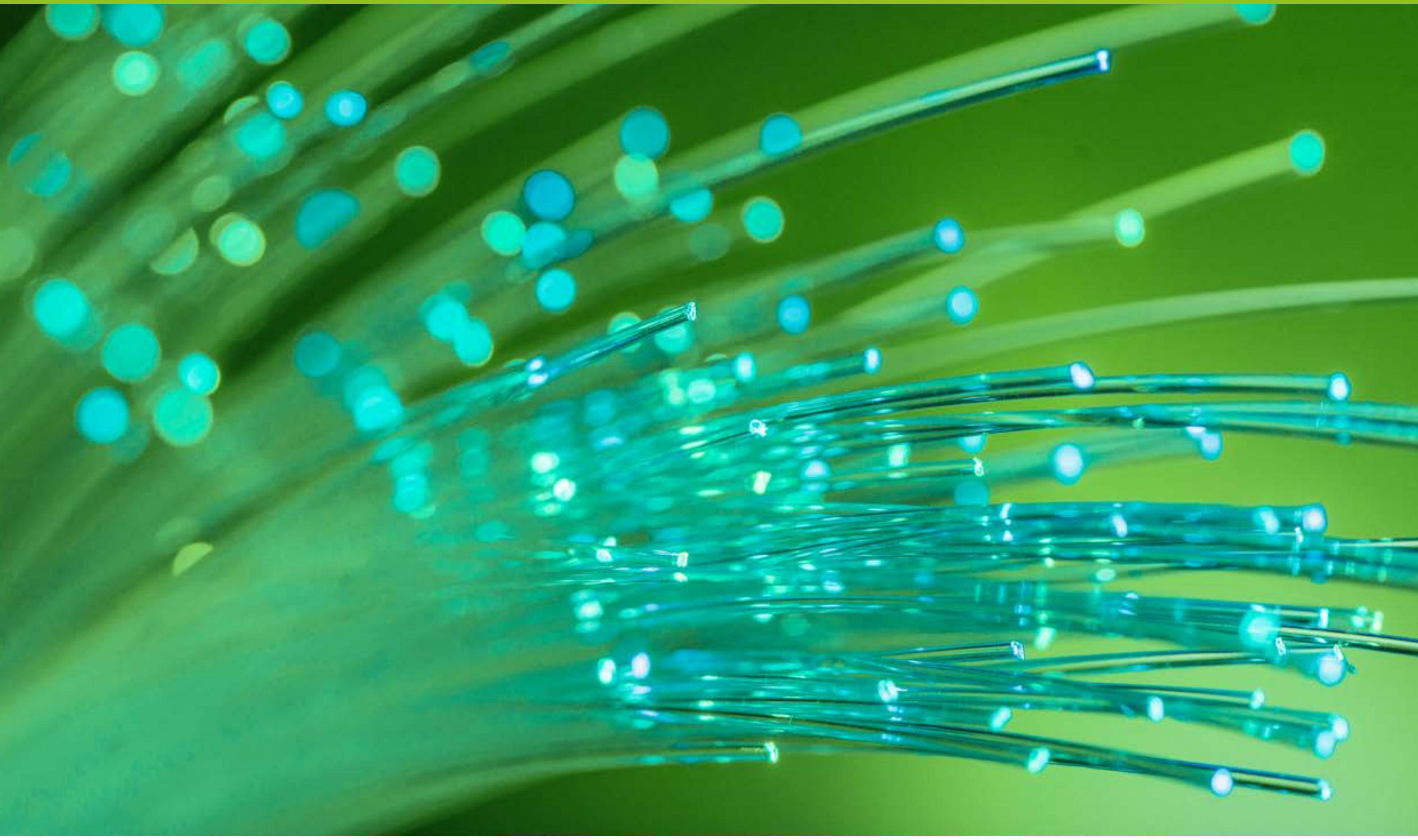
White paper



# Fiber optics

## High-speed data transmission for industrial applications

**Find out more about:**

→ Requirements on data transmission via fiber-optic cable
→ Various fiber and cable types and their areas of application
→ FO connection technologies and their characteristics

# Introduction

**284 to the power of 1021 – that's a number with 21 zeros. The American market research company IDC forecasts that the volume of data created and replicated will be to the magnitude of this 21-zero figure by 2027. It does not take much imagination to figure out that 284 zettabytes will bring the Internet of Things to its knees without a nationwide broadband expansion.**

The first transatlantic fiber-optic cable was put into operation in 1988, making it possible to send data back and forth between the continents at high speed. The extension of broadband in the mid-1990s not only added more long-distance routes. The end of the fiberglass transmission paths also moved closer to end devices such as data centers, industrial plants, and private personal computers – in other words, towards the so-called "last mile."

For the transmitted data, the transmission routes across continents, countries, and municipalities mean a long journey full of couplings, branches, and bundles. The requirements for the security and reliability of the transmission paths are correspondingly high. Speed, immunity to interference, and failsafe performance are basic requirements for industrial and semi-industrial data transmission.

## Contents

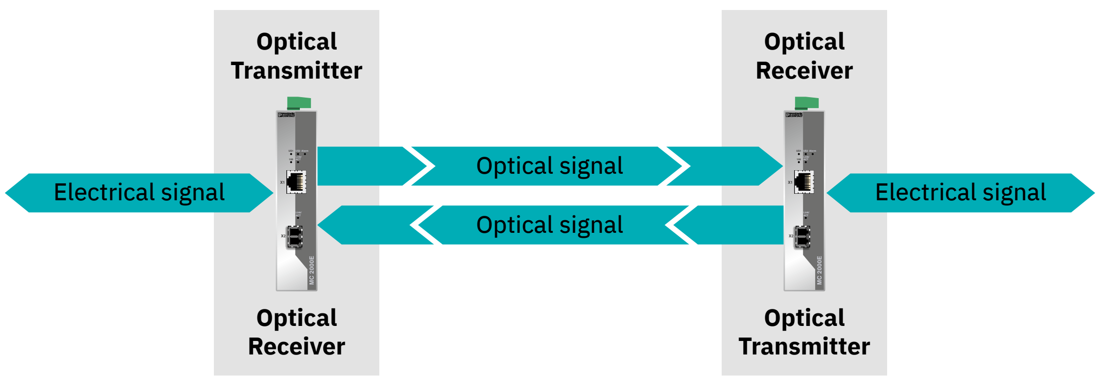
# 1 The advantages of fiber optics

**The principle of fiber-optic cables (FO) is simple. They transmit data in the form of light over long distances. To achieve this, the electrical signals in the transmitter are converted into packets of light (photons and sent to the receiver through plastic or fiberglass. There, the sent light signals are converted back into electrical signals, then evaluated and processed.**

**But what is the added value of data transmission via fiber optic cables compared to transmission via copper? Let's take a closer look at the characteristics of fiber-optic cables:**

## Speed and distances

In copper conductors, electrons transmit the electrical signals; in fiber-optic cables, photons do this job. The photons in fiber-optic cables are significantly faster than electrons in copper conductors. While electrons in copper move at less than 1% of the speed of light, photons travel at up to 70% of the speed of light. In addition, there is very little signal loss when transmitting optical signals in fiber-optic cables. As a result, fiber-optic cables enable longer transmission distances of up to 50 km and data rates of up to 40 Gbps – making them ideal for applications that require long distances and large data volumes. The actual range depends, among other things, on which fiber-optic cable is selected. You can read more about this in the "Which fiber for which application?" section.




*Principle of optical data transmission*

## Reliability and security

Data transmission via fiber-optic cables is considered to be very reliable. As the fiber core is made of glass or plastic – both non-conductive materials – no complex shielding concepts are necessary. This metal-free transmission means absolute insensitivity to EMC and ESD interference, which means that fiber-optic cables can be laid in parallel with other supply cables. Impedance problems and crosstalk phenomena are not issues with fiber-optic transmission either. In contrast to copper conductors, fiber-optic cables with coatings are also better protected against environmental influences such as temperature fluctuations, moisture, and humidity.

Fiber-optic cables also offer advantages in terms of cybersecurity. Although fiber-optic networks do not offer 100% protection against unauthorized access, they are significantly more secure against eavesdropping than copper cables. This is because fiber-optic cables do not emit any signals to the outside, so direct access to the fiber is required via bend couplers or at contact points, for example.

## Costs

The disadvantages of fiber-optic technology include the complex assembly and the precision required for laying and installation. This requires expensive equipment, more complex measurement technology, and well-trained specialists. The equipment for manufacturing a fiber-optic cable and the measurement technology needed to monitor production is cost-intensive and requires a great deal of experience and expertise in this highly specialized field.

# 2 Which fiber for which application?

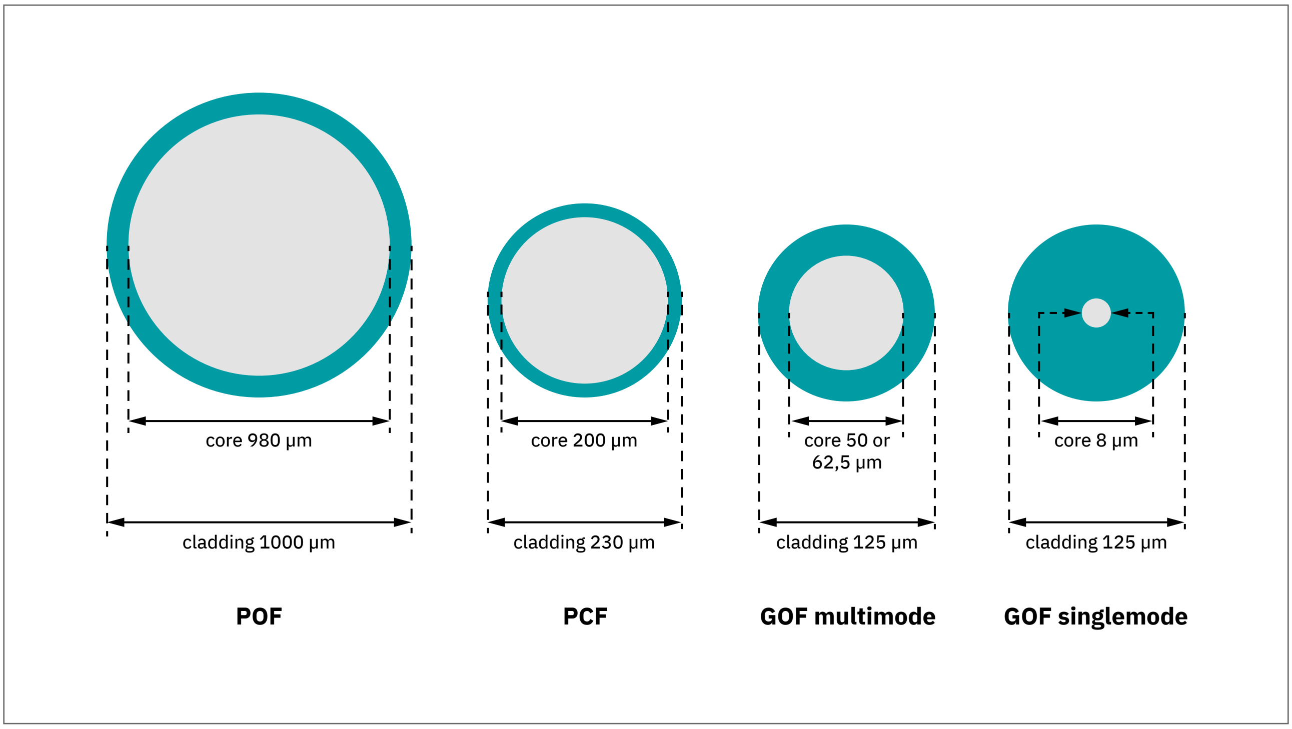
**Transmission requirements for industrial and semi-industrial automation can vary greatly: short, medium, or long distances; speeds of less than 100 Mbps or up to 40 Gbps; within bus or Ethernet structures. But no matter what your application requires, you can find the right cable for fiber-optic data transmission to meet your needs. Even when used under harsh conditions, such as those on wind farms, fiber-optic cables reliably complete their task. In addition, the cables and lines are up to 90% lighter and thinner than copper cables.**

**That is why their applications range from use in vehicle technology and industrial cabling, Local Area Networks (LAN) in data centers, to wide area networks and FTTH (Fiber To The Home). The key to cabling is selecting the right type of fiber and fiber category.**

## Fiber types

It is very important to differentiate between types of fibers. Due to the different core and cladding diameters, single mode (SM) and multimode (MM) fibers are not compatible with each other. The table provides a brief overview of the fiber types.

| Type | Max. link length | Data rate/ application |
|---|---|---|
| POF | 100 m | 50 Mbps |
| PCF | 2 km | 100 Mbps |
| GOF MM | 550 m | 10 Gbps |
| GOF SM | 10 km | 100 GBASE-LR4 |




*Each type of fiber has its own specific application.*

**POF for short transmission distances up to 100 m and up to 50 Mbps**
In POF (polymer optical fiber) cables, both the core and the cladding are made of plastic. The typical core diameter is 980 µm; for cladding, it is 1,000 µm. POF cables have short transmission distances of up to 100 m and data rates up to 50 Mbps (depending on the active components), making them suitable for automotive engineering and industrial cabling. The robustness and size of the fiber make it easy to assemble in the field. Due to high attenuation and dispersion, the typical POF fiber is not suitable for high data rates or long distances.

**PCF for medium transmission distances up to max. 2,000 m and up to 100 Mbps**
PCFs (polymer-clad fibers) are plastic-coated fiber-optic cables made of glass. Known under various designations such as PCS (polymer-clad silica), HCS (hard-clad silica), and HPCF (hard polymer-clad fiber), these cables are robust and easy to assemble. PCF fibers with a typical core diameter of 200 µm and a cladding diameter of 230 µm are often encountered in industrial cabling with medium lengths of up to 500 m and data rates of ≤100 Mbps. Other areas of application include automotive, sensors, and medical technology.

**GOF multimode for long transmission distances up to 550 m at up to 10 Gbps**
In GOF (glass optical fiber) multimode cables, the fiberglass has a core made of quartz surrounded by a cladding of reflective glass. Multimode cables have core diameters of 50 µm or 62.5 µm. The cladding diameter is 125 µm. The larger core diameter allows more light energy to be coupled at the beginning of the fiber, but attenuation is higher along the length of the fiber. That is why GOF multimode fibers are mainly used in Local Area Networks (LANs) and data centers, where they can handle transmission distances of up to 550 m at 10 Gbps.

**GOF single mode for long transmission distances up to 50 km and up to 40 Gbps**
The GOF (glass optical fiber) single-mode fibers have a much smaller core diameter of approximately 8 µm. For single-mode fiberglass, we differentiate between core diameter and mode field diameter. The mode field diameter depends on the wavelength. The larger the wavelength, the larger the field diameter. Since only one light mode can be transmitted in the fiber, a great deal of signal light can be fed into the fiber and transmitted. The fiber's coefficient of attenuation in the transmission range is very low. The low attenuation and low dispersion are the ideal conditions for using single-mode fibers for distances of up to 50 km and data rates of up to 40 Gbps.

## Cable types

Packaging the sensitive fibers in robust cables protects them from mechanical stress and environmental influences such as moisture. Depending on where they are used, the cables must meet special requirements. For example, fire plays a decisive role for indoor cables. In the event of a fire, the cable cladding should prevent the spread of fire, smoke development, and the formation of toxic and corrosive gases. A high level of robustness is particularly important for outdoor fiber-optic cables to ensure a long service life. Outdoor cables should be weatherproof, moisture-resistant, UV-resistant, and stable against mechanical strain.

Depending on the application, the cable structure determines which cable type is used.

**Loose tube cables**

In loose tube cables, a single cable can accommodate many GOF fibers. A coating protects the individual fibers, which can reach a diameter of 250 μm. To exclude environmental influences, these are bundled in a tube and usually coated with a water-repellent gel. Depending on the number of fibers, loose tube cables have one or more tubes. It is not uncommon to combine up to 24 fibers in one tube. Loose tube cables allow a high fiber density at a small diameter.

Unlike breakout cables, the connectors of loose tube cables cannot be mounted directly on the fibers. So-called fiber-optic pigtails are usually used for the connection instead.

A pigtail is a fiber-optic connector that has a preassembled plug on one end and is spliced to the fibers of the incoming cable on the other open-end side.

The loose tube cables are designed especially for harsh environments and have a high tensile strength. The fibers are physically very well decoupled from forces due to the cable structure. Loose tube cables can be used in environments with temperature fluctuations and high humidity. These cables are available both as purely outdoor cables and as universal cables for both indoor and outdoor use.

*Loose tube cable*

**Breakout cables**

Breakout cables are " splittable" fiber-optic cables. They consist of several individual single-core elements housed in a shared protective cable cladding. In contrast to loose tube cables, all wires have their own cladding and their own strain relief. Breakout cables were developed to avoid or replace splicing work on site, because FO connectors can be mounted directly onto the individual cables. Breakout cables are suitable as patch cables with connectors assembled on both sides or for laying as cables by the meter between two points in the field to subsequently assemble connectors in the field.

*Breakout cable*

**Mini breakout cables**

In the compact mini breakout cables with GOF fibers, the individual wires with a 900 µm diameter are located in a shared cable cladding. The cable cladding protects the cable structure from external influences. Mini breakout cables are an outstanding choice for future-proof cabling for distributors and junction boxes. Designed as universal cables, they are suitable for applications both inside and outside of buildings.

*Mini breakout cable*

**Duplex cables**

Fiber-optic duplex cables with GOF fibers usually consist of two 900 µm diameter wires, each of which is routed in a separate cladding. As a typical patch cable, it is preassembled at both ends, allowing direct connection to both active and passive components. The wide range of connector combinations and the various fiber categories enable use in numerous applications.

*Duplex cable*

## Fiber categories

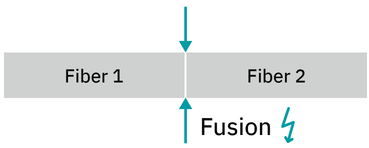
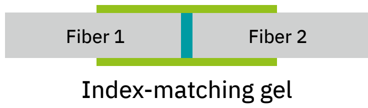
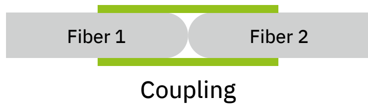
If you have been reading about fiber-optic cables, you have probably already come across designations such as “OM3” and “OS2 fiber-optic cables.” This is a reference to the fiber optic cables.” This is a reference to the fiber categories of the FO. The fiber categories specify the attenuation coefficient and the bandwidth length product for which the fiber-optic cable is designed. Single-mode fibers are available in the categories OS1 and OS2; multimode fibers are available in the categories OM1, OM2, OM3, OM4, and OM5.

The following table describes which transmission rates and ranges apply to each category.

**Transmission rates and ranges by category**

| | Duplex cable | Cladding color | Category | Typical range |
|---|---|---|---|---|
| Multimode |  | Orange | OM1 | 1000Base-SX: max. 350 m<br>1000Base-LX: max. 550 m |
| |  | Orange | OM2 | 1000Base-SX: min. 500 m<br>1000Base-LX: min. 500 m |
| |  | Aqua | OM3 | 1000Base-SX: max. 1,000 m<br>1000Base-LX: max. 500 m<br>10GBASE-SX: max. 300 m |
| |  | Violet | OM4 | 1000Base-SX: max. 1,500 m<br>1000Base-LX: max. 600 m<br>10GBASE-SX: max. 550 m |
| Singlemode |  | Yellow | OS2 | 10GBASE-LR: min. 10 km |

**Connection technologies and characteristics**

| Fusion splice | Mechanical splice | Connectors, couplings |
|---|---|---|
|  |  |  |
| Thermal connection of two optical fibers | Mechanical guide with or without index adjustment | Mechanical coupling of connectors |
| Not detachable<br>IL<0.1 dB (GOF) | Sometimes detachable<br>IL ~0.2 dB (GOF) | Detachable<br>IL ~0.2 ... 0.5 dB (GOF) |

## Connection technologies

Splices or connectors are suitable for connecting fiber-optic cables to each other and to other components. The table above provides an overview of the various connection technologies and their characteristics.

**Fusion splicing**
A fusion splice is a non-detachable connection between two optical fibers. In thermal fusion splicing, the fibers are fused together by an electric arc. Fusion splice connections are durable and have little attenuation (less than 0.1 dB). They can connect the fibers of loose tube cables to pigtails in distributor boxes and repair fiber breaks. They are also used when it is difficult or impossible to route factory-assembled patch cables.

The disadvantage is that only trained specialists can carry out fusion splicing. It requires special equipment (fusion splicer with fiber processing tools) and experience in proper handling.

**Mechanical splicing/field assembly**
In contrast to fusion splicing, mechanically spliced fibers are not permanently coupled. Instead, the ends of two fibers are brought together and fixed in a special connecting sleeve or V-groove. It is important that the fiber ends are clean and straight. To match the refractive indices, an index-matching gel is usually filled between the two fiber ends. With identical GOF optical fibers and very precise coupling, the attenuation is approximately 0.2 dB.

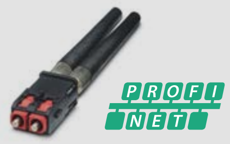
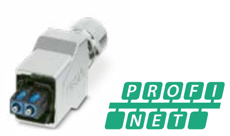
Mechanical splicing is mainly used as a connection technology in connectors for field assembly. In conjunction with the right tools, these connectors can be assembled directly to suitable fiber-optic cables in the field. This connection technology is popular on end sockets, connection housings, and for repair purposes.

**Plug-and-play connectors**
The great advantage of these connectors comes from their flexibility. They are used wherever a connection needs to be easy to disconnect again. Another advantage is the simple and secure operation. No trained specialists or special equipment are required to establish a connection.

On the other hand, disadvantages include the higher losses of ~0.2 to 0.5 dB with GOF connections and the lower durability compared to splice connections.

There is a choice of different connectors with various characteristics and areas of application. Below, you will find an overview of the most important connectors.

**Transmission rates and ranges by category**

| | Type | Standard | Application | Characteristics |
|---|---|---|---|---|
|  | BFOC (ST) | IEC 61754-2 | Industry, automation | Bayonet lock |
|  | SC/SC duplex | IEC 61754-4 | Older LAN | Push-pull |
|  | LC/LC duplex | IEC 61754-20 | LAN, WAN | Locking lever |
|  | SC-RJ | IEC 61754-24 | PROFINET | Push-pull |
|  | F-SMA | IEC 61754-22 | Industry, medical technology | Screw |
|  | Version 6 | IEC 61754-24-21 | Industry | Locking lever |
|  | Version 14 | IEC 61754-24-11 | PROFINET | Push-pull |
|  | M17 MPO | | Harsh environments | Screw |

# 3 Applications

Fiber-optic cables are mainly used for data transmission in communications engineering and IT. They have the long ranges and high transmission rates these applications require. Because fiber-optic cables have been used in the field for decades, fibers, cables, and components have been extensively tested and qualified in accordance with standards for harsh ambient conditions.

Optical transmission via fiber-optic cable has exceptional characteristics, small dimensions, and flexibility. These features also make it suitable for other industries – from building infrastructure and factory automation to data centers. Examples of applications include the transmission of control signals, machine communication, Industry 4.0 applications, and even artificial intelligence. Fiber-optic cables are often used as an alternative to copper cables, particularly in applications where electromagnetic interference occurs.


*Example application: Use of fiber-optic cables in wind farms*

In addition to data transmission, other potential areas of application include medical technology for flexible transportation of laser radiation and in measurement technology – more precisely in sensors, spectrometers, and other optical measuring devices.

Even when used under harsh conditions, such as those on wind farms, fiber-optic cables reliably complete their task. Here, they transmit the data about the wind farm's usage, performance, and capacity utilization.

In addition to FO installation cabling, splice distributors, also known as splice boxes, are also used for the FO cabling. These serve as a transfer point between the passive FO cabling and the active components with corresponding FO interfaces. These boxes are also the termination point of the FO installation cables, mainly loose tube cables. The selection of the fiber type depends on the maximum link length and the data rates.

## Conclusion

Optical technologies will continue to advance in many areas of application over the coming years. Their small dimensions and flexibility make fiber-optic cables a strong alternative not only in data transmission and measurement technologies, but also in medical, industrial, and lighting applications.

# Contact

## You can count on our support

Are you looking for an expert partner in the field of fiber- optic connectivity and cabling? We speak your language. Whether you are looking to optimize an existing application or implement a new solution, our experts in fiber-optic connectivity will provide you with comprehensive expertise and help you choose the right components for your FO cabling.

**Visit us at:**
phoenixcontact.com/lwl

***Frank Kölske***
*Product Marketing Data Connectors*
*fkoelske@phoenixcontact.com*

***Joel Boone***
*Product Marketing Manager*
*jboone@phoenixcontact.com*

***Olivia Koicuba***
*Product Marketing Specialist, Device Connectors*
*okoicuba@phoenixcontact.com*

3011706540