WHITE PAPER

Optical Fiber vs. Copper: The Key Distinctions

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Executive Summary

This white paper has been written to compare and contrast the differences of optical fiber versus copper cabling in industrial networking. Both types of cabling play important roles in industrial networking and they both have applications that make one or the other desirable depending on the circumstances.

Two examples of industrial applications are discussed when optical fiber is an ideal solution. This first is in renewable energy, specifically in wind farms and the second being intelligent transportation, specifically in tunnels. Both of these applications have similar environmental and operational factors that make optical fiber the ideal choice of networking cable in the infrastructure. To summarize the challenges that these industries face, network specialists must build reliable networking infrastructure that can communicate over extremely long distances and the cabling must be immune to electromagnetic interference (EMI).

Often times, devices, monitoring equipment, wind turbines and more can be equipped with RJ45 connectors. When this equipment is placed into applications or already coexisting in an application, there may be a need that arises to take advantage of benefits reaped from the Industrial Internet of Things (IIoT). In these instances, a conversion from copper to optical fiber can be an optimal solution. A media converter does exactly this, and can help networking specialists achieve reliable results with simple changes.

Read further to find out the main differences of optical fiber and copper Ethernet cabling. Also, see real world applications where media converters may be used to update and optimize networking communication systems and take advantage of the benefits of optical fiber. Finally, see a full portfolio of solutions available by Moxa.

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MOXA Reliable Networks Sincere Service

Device Connectivity in Remote and Harsh Environments

In the day and age we live, Ethernet holds a high importance to ensure smooth and efficient communications. Ethernet enables devices to communicate with each other, which enhances functionality and improves operational efficiencies, even without any human interaction. In the industrial arena, this linking of physical sensors, devices and machines to the Internet generates a massive amount of data. By applying deep analytics, powerful new insights are possible. This revolution is sometimes referred to as the IIoT.

In the rapidly expanding industry of renewable energy, companies are racing to utilize the IIoT to converge networks, enhance operational efficiencies and maximize profits. Specifically in wind power, there is a surge in the utilization of this energy production method and producers want to ensure that their operations run smoothly and produce maximum power. It is important that existing wind farms and new installations be interconnected as part of a robust, secure and flexible network to maximize the benefits realized through the IIoT.

Another promising industry where opportunity lies to create value with the IIoT is intelligent transportation in major urban centers. Road safety and efficiency require reliable real-time information and communications. Intelligent Transportation Systems (ITS) must reliably provide data about traffic flow, speed and density of traffic, as well as video surveillance and weather information. This is important to increase traffic flow, reduce congestion and improve incident response time. For these reasons, it is imperative to have a reliable network infrastructure that adheres to ITS best practices. Within this infrastructure, it is important for network designers and systems engineers to consider the most efficient and productive topology, given the harsh conditions to which networks are exposed.

The topic of networking infrastructure is enormous given the different types of technologies that are available and being constantly innovated. In brief, as part of a networking infrastructure, there can be many different components such as devices (routers, switches, converters, computers, etc.), cables, control centers and the software systems necessary to control the network. In industrial environments, unique topology solutions are pieced together to solve complex networking challenges and ensure reliability, durability and to be prepared for evolving circumstances. Within the infrastructure, cabling is an important consideration for a variety of reasons. The following pages detail the pros and cons for two typical cable types: **optical fiber** and **traditional copper Cat 5 twisted pair (TP) cable**.

Optical Fiber Versus Copper

When it comes to networking communication cables there are not a lot of options beyond the main categories of optical fiber and copper. Thus, the following sections will describe the differences and key characteristics of each cable type. It is true that there are also several different types of cables within each category of optical fiber and copper. For the purposes of this white paper, single-mode and multi-mode optical fiber and Cat-5, TP copper cable will be discussed.

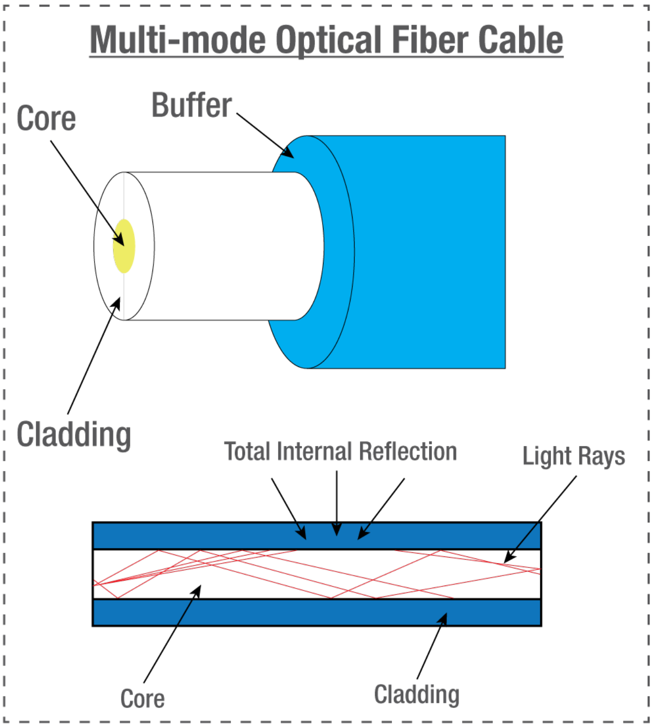
1. Distance

The most prominent differentiator between optical fiber and copper cable is the distance in which a signal can travel. In an ordinary Cat-5, TP copper cable, the maximum distance that a signal can travel is 100 m at 100/1000 bps. In optical fiber cabling, the transmission distance can go up to 40 km with speeds of 100/1000 bps.

Cable:	Distance:	Speed:
Optical Fiber	2 – 40 km	100/1000 bps
1000Base-TX Copper	100 m	100/1000 bps

The technical explanation for this vast difference in distance transmissions is related to attenuation, which is the reduction of the amplitude of a signal, electrical current or other oscillation[1]. In optical fiber cables, attenuation can be as low as 0.4 dB/km for a single-mode fiber solution, which allows for extremely long data transmissions. In a copper cable, the attenuation is much greater, at 20 dB/km with a cable thickness of 0.4mm[2]. In simplified terms, this means the loss of signal per kilometer in optical fiber is much less than copper, allowing the data signals to travel much further.

It is helpful to understand the construction of optical fiber cables vs copper cables to elaborate how this extended distance transmission is achieved. In general, with an optical fiber cable, imagine the cable to be like a "light pipe." Light is trapped in the fiber via total internal reflection, which is a result of the refractive index of the transparent core relative to the surrounding cladding.



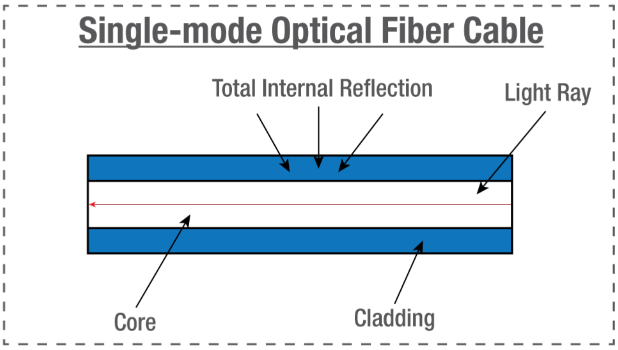
Multi-mode Optical Fiber Cable

The illustration on the right demonstrates a multi-mode optical fiber cable construction. In a multi-mode optical fiber cable, the fibers are made of flexible extruded glass that is slightly thicker than human hair. This unique construction makes multi-mode a perfect solution in many medium-distance application

[1] http://english.oxforddictionaries.com/attenuation
[2] https://www.lntwww.de/Applets:Attenuation_of_Copper_Cables

scenarios. This is because the light is dispersed over many different paths or modes. As these light waves travel through the fiber, there is slight signal distortion, however, this construction is still highly capable of transmitting high bandwidth over medium distances.

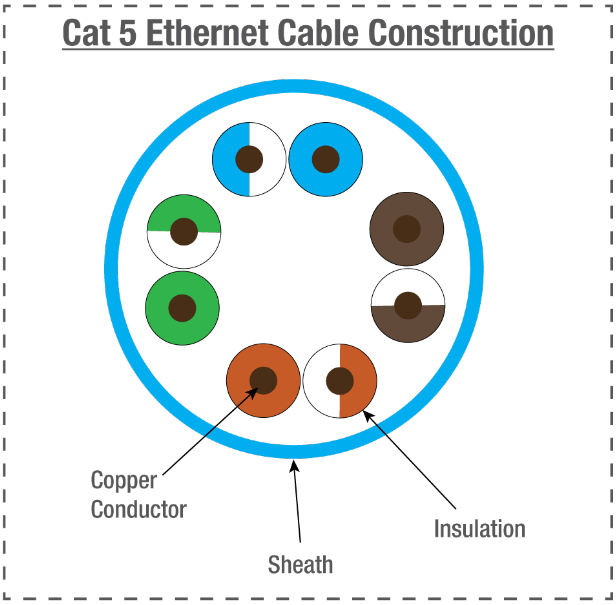
Single-mode Optical Fiber Cable[3]



The illustration to the left demonstrates a single-mode optical fiber cable. The main difference between a multi-mode and single-mode optical fiber is there is only one light wave, or mode, travelling through a single strand of fiber versus many as demonstrated in multi-mode. With a single light wave travelling through the fiber, there is significantly less distortion caused from light waves crossing paths like in multi-mode cables. Therefore, a transmission can travel extremely long distances. On a physical level, the actual thickness of a single-mode optical fiber cable is between 8.3 to 10 microns. The propagation of single-mode optical fiber cabling is between 1310 to 1550 nanometers (nm). These two measures are correlated because as light travels through the fiber, the physical diameter of the fiber is the exact distance of the light wave's oscillation. Thus allowing the wave to continue on its path for lengthy distances.

Cat-5, Twisted-Pair Copper Cable

The construction of copper cables has evolved significantly over time, but the basic construction consists of bare copper at the base that is wrapped in a primary insulation. With Cat-5, TP cables, two individual cables are twisted together at a specific twist rate and in a single cable, there is typically 4 pairs of individual cables. Each pair of cables are twisted at different twist rates to ensure the cables do not cause crosstalk interference amongst each other. With that, data signals are sent through the copper medium and received by receiving devices.



2. Isolation Protection

Diving deeper into the differences between optical fiber and copper cables, one characteristic that stands out is the isolation protection that inherently comes with fiber. Essentially, this means that optical fiber is non-conductive and therefore not affected by electrical currents. Electrical currents exist in many locations, especially in industrial applications.

Copper cables can be affected by electrical noise, including EMI (Electrical Magnetic Interference), RFI (Radio-Frequency Interference), ground potential or ground loops. These

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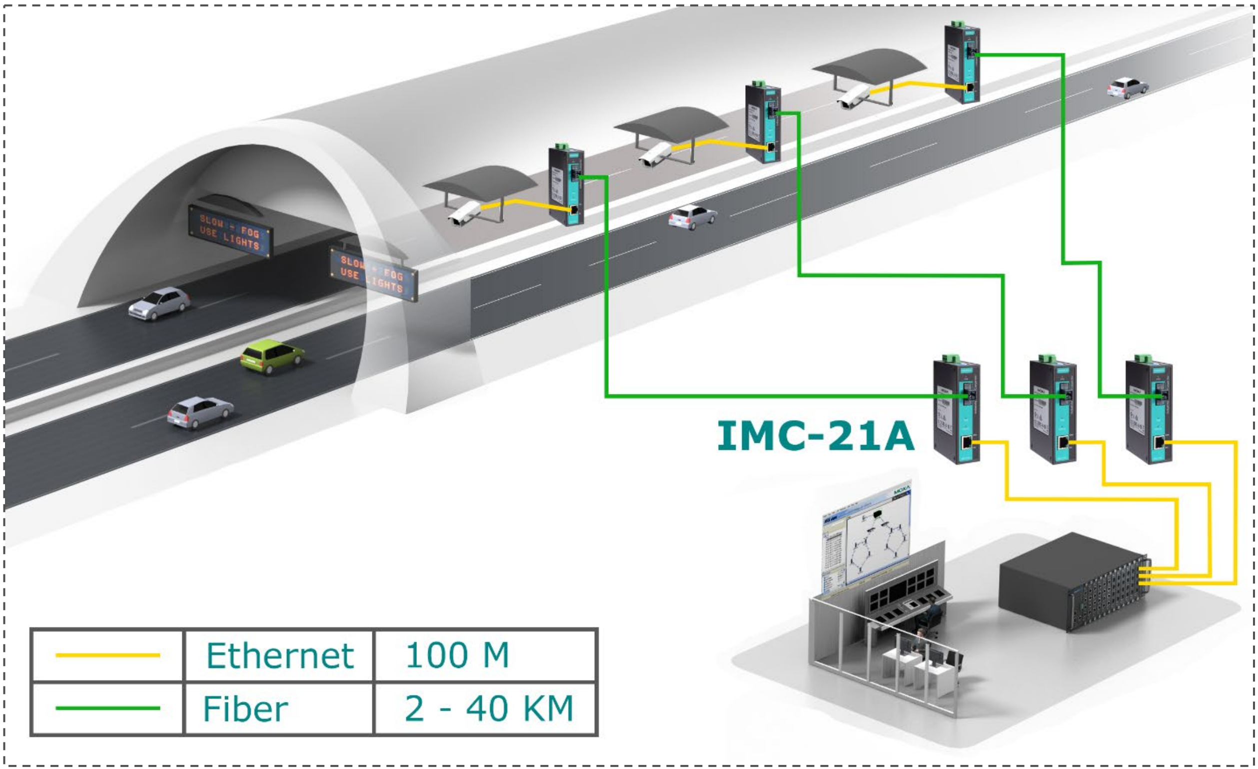
[3] http://fiberonda.com/single-mode-vs-multi-mode-fiber-optic-cable/

interferences reduce the speed of transmission and lead to significant lost and/or corrupted data packets. This will lead to excessive retransmissions and significant inefficiencies within a network.

Application Scenario #1 – ITS – When to Use Optical Fiber to Extend Transmission Distance of Ethernet Devices:

Smart cities all around the world are utilizing data and technology to make transportation safer, more efficient and sustainable, which has enhanced the need for connectivity in intelligent transportation. This is to ensure road safety and maximize efficiency. In ITS, copper Ethernet cables and devices are a popular choice for networking infrastructure, but they do have one large limitation: they have a maximum distance transmission of 100 meters. Imagine the scenario of setting up a control system to monitor tunnels with surveillance cameras. In this scenario, it may be necessary to convert copper Ethernet signals to optical fiber to transmit the signal over an extended distance. This conversion solution would be simple and cost effective allowing networking specialists to extend the distance between an Internet Protocol (IP) camera and a control center.



As well as video surveillance in tunnels, condition monitoring is of high importance. If there is an accident in a tunnel, it is important for controllers and emergency responders to be able to access the situation and response accordingly. To understand the scope of this scenario, across Europe, there are thousands of kilometers of tunnels to be monitored and in Germany alone, there are more than 300 tunnels with a cumulative total of 240 kilometers[4] in length.

[4] https://eneo-security.com/en/solutions/motorwaytunnel

Distance is one factor, but there are also many external conditional factors that need to be considered when setting up the network infrastructure for tunnels and other ITS networks. The physical elements of the network, such as cables and devices can be exposed to electromagnetic interference (EMI) caused by power lines, lightning, television and radio broadcast signals, ignitions and more. In the scenario of a tunnel, to ensure there is an uninterrupted signal, a robust type of cabling is required. Fiber optic cabling is the natural solution to ensure consistent, reliable data transmission. With optical fiber, network designers can be certain that their network will not be susceptible to EMI nor to ground faults.

	Power Lines	Lightning	Broadcast Towers	Electrical Motors	Ignitions
Copper	✗	✗	✗	✗	✗
Fiber	✓	✓	✓	✓	✓

✗ = Susceptible to EMI
✓ = Immune to EMI

Application Scenario #2 – Renewable Energy – Wind Farms

Wind farms are subject to unique conditions that require unique networking solutions to ensure safety, reliability and operational efficiency in energy generation. To understand the scale of the wind power industry in Europe, the current cumulative capacity is 204,814 MW[5]. This translates to tens of thousands of wind turbines operating throughout Europe. It also shows there is an enormous opportunity to realize IIoT benefits and to improve operational efficiencies to best produce this clean energy.

The unique environmental factors that are present in wind farms are to do with the enormous amount of energy being generated from each turbine. As the giant blades on a wind turbine spin, power is generated and flows down the tower of the turbine. The power is then converted and routed to a utility grid and transferred away. Communications data that is routed anywhere near this will be exposed to large amounts of noise, which can result in data signal loss, depending on the cabling.

Not only are wind turbines producing a significant amount of power, they are also exposed to electrical strikes from lightning. Wind farms are built in remote areas with wide-open

[5] https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2019.pdf

exposure, they stand many meter high into the sky and are built from materials susceptible to lightning strikes. Thus, the risk of a lightning strike is very high. Most wind turbines have built in lightning rods to limit the damage caused by lightning strikes, but depending on the physical networking equipment and cabling, there can still be risk of damage.

Another operational factor that exists in wind farms is the physical distance between wind turbines and the distance to the control operation. This distance often exceeds the maximum communication distance of copper cabling and thus, optical fiber is a perfect solution.

It is incredibly important that wind turbines remain connected to the network to ensure safety, monitor the various sensors built into the turbines, monitor weather conditions and to take advantage of the IIoT. The IIoT is applicable in renewable energy and especially in wind farms. These wind farms are a fundamental part of energy production, thus collecting data, planning for predictive maintenance and maximizing operational efficiencies are top of mind for wind farm operators.

A further consideration in wind farms is legacy turbines that are being retrofitted to extend communication distance and reap the benefits of the IIoT. These turbines were originally equipped with networking communication equipment that has RJ45 connectors. This presents a need to convert an Ethernet signal from copper to optical fiber. This not only makes the network more reliable, but enables controllers to remain connected and ensure safety and efficiency.

To summarize the unique nature of wind power, in terms of networking, consider these problems and needs:

Problem 1: What is the most efficient way to keep turbines connected to ensure safety?

Problem 2: What type of networking infrastructure is needed that can handle extreme environments with high levels of EMI?

Need 1: The need to be able to constantly monitor wind turbines to ensure safety and take advantage of the IIoT.

Need 2: The need for fail-safe systems to function in the unlikely event of an emergency or problem.

With these problems and needs in mind, network designers and systems engineers need to evaluate what topology makes the most sense given the environmental circumstances that exist within existing wind power farms. Upon completion of this evaluation, many wind power farms have upgraded from copper to optical fiber utilizing media converters. This is not the only networking solution, but in terms of legacy turbines, this is an effective solution. The conversion of copper to optical fiber also ensures that turbines will remain connected while dealing with high levels of EMI and in the event of lightning strikes, controllers can continue to monitor turbines.

Solutions

Moxa's media converters are applicable in many applications, including intelligent transportation and renewable energy. Not only are they solving a variety of unique challenges, but Moxa strives to provide the best quality networking equipment on the market. If you are in the need for an Ethernet to fiber media converter, do consider these advantages of using Moxa devices.

Solution 1: **Industrial-Grade Design**

Moxa designs media converters to endure harsh environments, such as operating in extremely high or low temperatures, enduring a high rate of EMI and they are backed with various industrial certifications to ensure reliable operations.

Solution 2: **Easy and Flexible Deployment**

Moxa media converters have been developed with easy plug-and-play design allowing for efficient mass deployment in many application scenarios. Moreover, the high port-density modular design enhances network flexibility in large-scale deployments.

Solution 3: **Increased Transmission Distance**

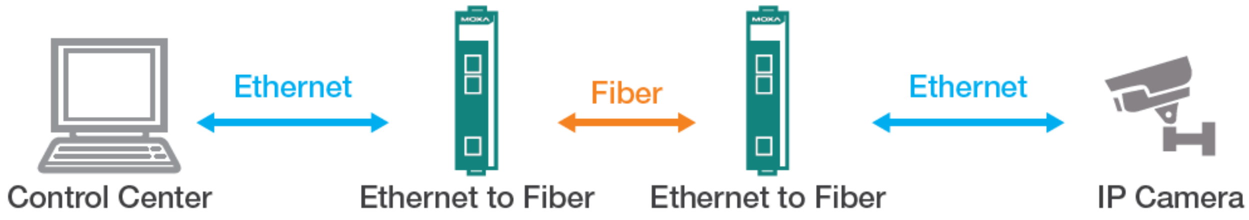
The inherent benefits of converting an Ethernet signal from copper transmissions to optical fiber allows for extremely lengthy transmission distances. Optical fiber cabling has an attenuation of 0.2~0.4 dB/KM which allows for a maximum transmission for a single-mode solution up to 120km. Convert any legacy device with a Moxa media converter and extend the reach of your network well beyond a typical copper infrastructure which can transmit only up to 100m.

Solution 4: **Isolation**

Protect your network with an upgrade to optical fiber and never worry again about ground faults, ground loops and disruptions from natural elements such as lightning. Optical fiber is immune to these types of disruptions due to being non-conductive.

Moxa's Standalone Ethernet-to-Fiber Converter Solutions

Extending the distance of your Ethernet devices' transmission distance and reaping the benefits of optical fiber?



Consider these offerings:

Model	IMC-21	IMC-21A	IMC-21GA	IMC-101	IMC-101G	IMC-P101	PTC-101	PTC-101-M12
Interface A	10/100 BaseT(X), RJ45	10/100 BaseT(X), RJ45	10/100/1000 BaseT(X), RJ45	10/100 BaseT(X), RJ45	10/100/1000 BaseT(X), RJ45	10/100 BaseT(X), RJ45	10/100 BaseT(X), RJ45	10/100 BaseT(X), M12
Interface B	100BaseFX	100BaseFX	100/1000 BaseSX/LX, 100/1000 BaseSFP slot	100BaseFX	100/1000 BaseSFP slot	100BaseFX	100BaseFX	100BaseFX
Port Alarm	-	-	-	√	√	√	√ (LV model)	√ (LV model)
Power Alarm	-	-	-	√	√	√	√ (LV model)	√ (LV model)
PoE	-	-	-	-	-	√	-	-
Industrial Certifications	-	-	-	C1D2, ATEX, IECEx	C1D2, ATEX, IECEx	-	IEC 61850-3	EN 50121-4

Conclusion

For additional information on Moxa's industrial-grade media converters, visit: https://www.moxa.com/en/products/industrial-network-infrastructure/ethernet-media-converters