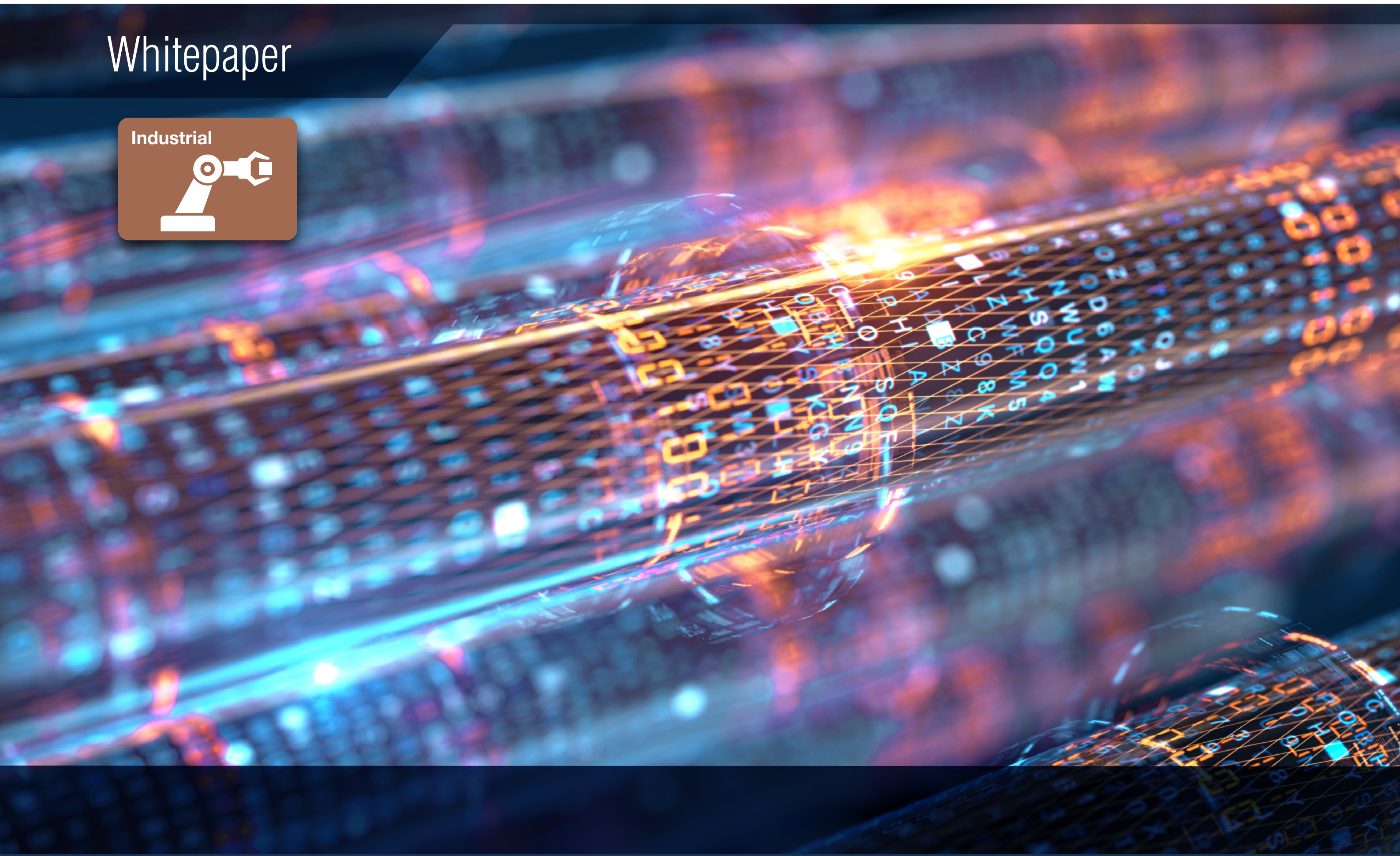
Whitepaper

Industrial

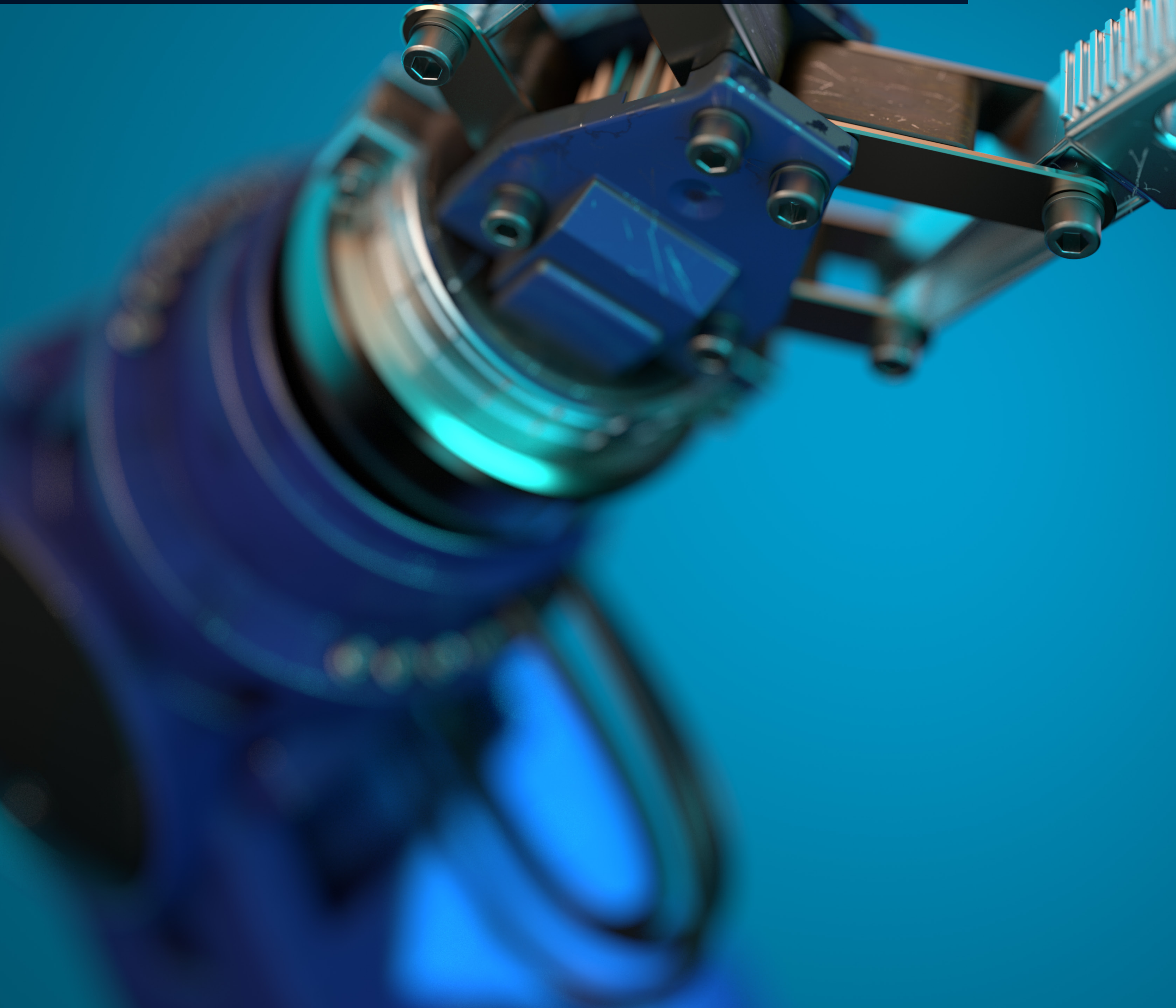


The Rise of Single Pair Ethernet in IIoT

The Specialist in Electronic Component Distribution

Executive Summary

Traditionally the networking architectures used within the industrial domain have been many and varied. With its established enterprise IT roots, Ethernet was always going to be the backbone network of choice to link the worlds of operational technology (OT) and information technology (IT) together. However, since the arrival of Industrial IoT (IIoT), connecting all the production assets, such as sensors, actuators, robots, and the myriad of other equipment, typically involved proprietary, vendor-specific networking. The availability of single-pair Ethernet (SPE) looks set to change this legacy approach. This white paper investigates the technology of SPE, its advantages and benefits, and how it enables cloud to sensor connectivity using a single protocol stack.



The challenges of connectivity in the industrial domain

From the shop floor to the top floor, the IIoT platform centralizes real-time data from sensors, actuators, cameras, and other endpoint devices to provide manufacturing facilities actionable insight into their equipment's performance. This information allows them to make informed based decisions to increase efficiency, optimize productivity and improve operations.

Traditionally, links to these edge-based devices use Fieldbus industrial automation protocols and rely on programmable logic controllers (PLCs) and protocol converters, or gateways, to connect to the Ethernet backbone. Standards such as PROFIBUS DP, DeviceNet and Modbus RTU are examples of the more popular technologies. Due to the highly fragmented Fieldbus sector, many networking methodologies are proprietary, making interoperability with other implementations a significant issue. Also, they are often highly complex, requiring specialist knowledge and skilled labour to deploy, commission and maintain.

Reaping the benefits of IIoT relies heavily on using an open protocol that adheres to an industry standard to ensure interoperability between different implementations. Here, Ethernet would seem the obvious choice, and, over the years, speeds have increased to 1Gbit/s levels. But Ethernet does lack one key performance parameter, which is determinism. Deterministic networks exchange data in a precise manner with a defined latency.

Several industrial Fieldbus protocols have evolved over the years into their Ethernet TCP/IP versions. For instance, PROFINET evolved from PROFIBUS, EtherNet/IP from DeviceNet, and Modbus TCP/IP from Modbus. These Ethernet derivatives, which include others such as EtherCAT, have advanced over the years, moving from 10BASE-T (10Mbits/s) right up to 1000BASE-T1 (1Gbits/s). They offer all the benefits of commercial Ethernet but with proprietary modifications that provide lower latency and determinism.

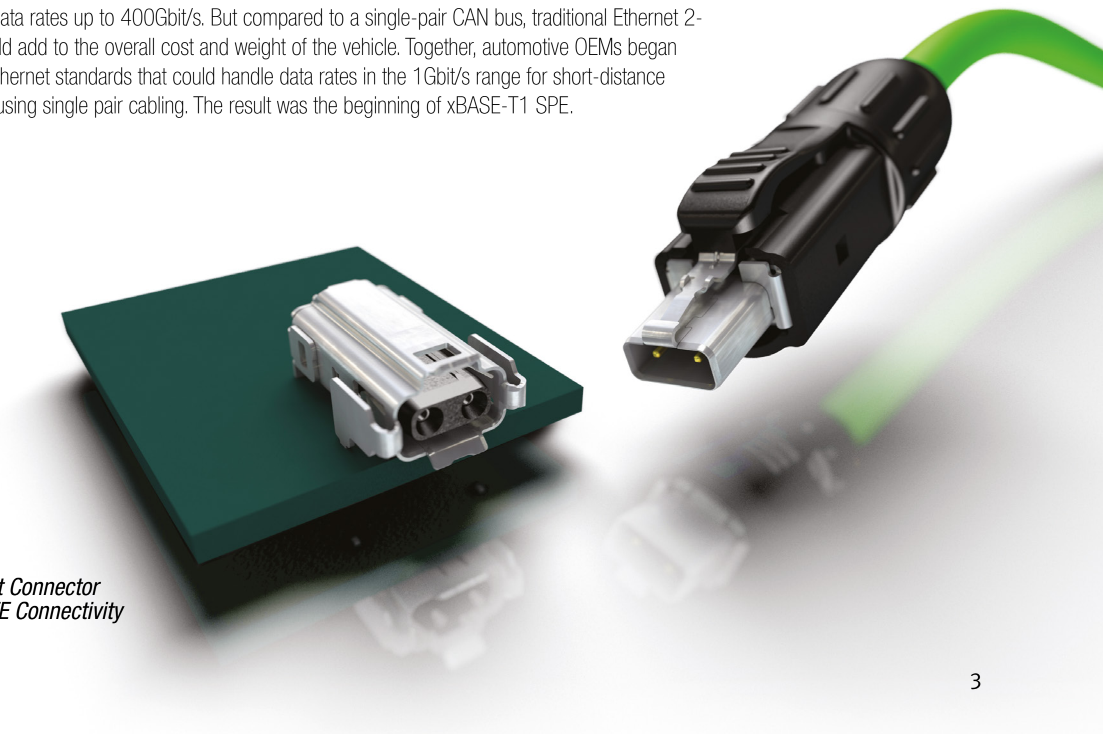
Although most of the Fieldbus systems and Real-Time Ethernet protocols are standardized by the IEC in the 61784/61158 standards, automation devices supporting different protocols are not interoperable with each other. They often cannot coexist in a common network infrastructure. In addition, different device information models make data analysis labor-intensive and time-consuming.

However, Ethernet time-sensitive networking (TSN) has changed this by making Ethernet deterministic by design. TSN refers to a set of IEEE 802 standards that guarantee determinism and throughput in Ethernet networks, thus standardizing real-time Ethernet across the industry. However, all of these Ethernet derivatives so far have ended at the last intelligent component of the machine because the cable and the connector's size were too big to implement connections to the smallest sensor or other endpoint devices.

In 2016, the IEEE 802.3 Ethernet Working Group initiated a drive to create a unified network as an alternative to the fragmented Fieldbus landscape, using single-pair cabling.

The automotive industry was one of the first sectors to recognize the advantages of using Ethernet to meet the data rates needed in modern cars. Like industrial applications, automotive applications rely on a form of Fieldbus technology, namely the CAN bus, for communications between the Electronic Control Unit (ECU) and sensors and actuators. However, the slow data rate of CAN (1Mbit/s) or even the faster CAN-FD (5Mbit/s) was running out of steam to support the multiple cameras, radars and LiDAR range sensors used in Advanced Driver-Assistance Systems (ADAS).

Ethernet can deliver data rates up to 400Gbit/s. But compared to a single-pair CAN bus, traditional Ethernet 2- or 4-pair cabling would add to the overall cost and weight of the vehicle. Together, automotive OEMs began developing a set of Ethernet standards that could handle data rates in the 1Gbit/s range for short-distance communication links using single pair cabling. The result was the beginning of xBASE-T1 SPE.



Single Pair Ethernet Connector IEC63171-6 from TE Connectivity

Convergence from the cloud to the field level

IIoT requires industrial system integration to become vendor-independent and support end-to-end interoperability from the sensor to cloud. Here, standardized communication supports the digital transformation across all industries, including factory automation and process automation. Seamless access to production data and process conditions facilitate the availability and optimization of production processes.

Communication standards, such as the Open Platform Communications Unified Architecture (OPC UA), standardize device models for the uniform configuration and diagnostics of devices from different manufacturers in the network. Ethernet technologies of particular note are the Advanced Physical Layer (APL) and Time-Sensitive Networking (TSN). APL enables seamless Ethernet connectivity down to the field level, providing power and communication over two wires with long cable lengths and intrinsic safety. TSN makes Ethernet deterministic by default, allowing IT and OT protocols to coexist in a common network infrastructure.

The original 10BASE-T implementation uses two wires for transmitting the data and the other pair for receiving. At 10Mbit/s, this standard is much faster than the original coax cable for IT protocols and uses CAT 5 or higher cable with RJ-45 connectors. However, it uses a physical star topology using a logical bus, rather than the bus topology of the coax solution. This star topology requires a centralized hub, or Ethernet switch,
to handle data movement between devices connected to its ports.

Leveraging these existing IEEE 802.3u standard rules, 100Base-T, otherwise known as Fast Ethernet, transmits data at 100Mbit/s and requires CAT 5 UTP cable. The fastest form of Ethernet is Gigabit Ethernet (1000BASE-T) is an order of magnitude high with data rates to 1Gbit/s. It requires the use of CAT 5 or higher grade cable and uses all four pairs.

SPE IEC 63171-2 Solution Phoenix Contact

Most of today's industrial automation profiles are based on the 4-pair Ethernet specification, making cable dimensions and the associated connector sizable. The size was never an issue for commercial applications, but it did limit its use in industrial applications. For instance, the thicker CAT 5e/CAT 6 Ethernet cables meant fewer could run side-by-side in a conduit. They also took longer to drawn and fix, which extends deployment and commissioning times. In addition to the cable's physical size, its weight and maximum bending radius were also limiting factors.

The success of xBASE-T1 SPE in automotive applications brings potential advantages of developing the IEEE 808.3 standard further to bring IIoT to field-level devices. The IEEE 802.3bw (100Base-T1) and IEEE 802.3bp (1000Base-T1) SPE standards for use in cars deliver end-to-end communication using unshielded twisted pair (UTP) cables for distances up to 15m.

Compared to CAT 6 Ethernet IEEE 802.3ab, which operates at 125MHz and uses all four-pairs, the IEEE 802.3bp standard needs to operate at 600MHz to achieve the same 1Gbits/s (1000Base-T1) data transfer rate, hence the requirement for shielding for transmission lengths longer than 15m up to a maximum of 40m.

For industrial network applications, the IEEE 802.3cg variant is of particular interest. This standard operates at 20MHz to enable transmission rates of up to 10Mbit/s over a maximum distance of 1,000m on shielded twisted pair (STP) cable, which can replace almost all Fieldbuses. The newer IEEE 802.3ch standard enables data rates of up to 10Gbit/s (4GHz) over a distance of 15m of STP cable, fulfilling the needs for high-resolution sensors and video transmissions.

Remote Powering

In addition to changes in the data rates, the technique known as Power over Ethernet (PoE), defined by the IEEE 802.at standard, enables power delivery on the same Ethernet cable as the data. Supporting the delivery of up to 25.5W at 48Vdc, PoE is used mainly in building automation and communications infrastructure, powering remote devices such as surveillance cameras and wireless access points. The simultaneous transmission of data and power via 'classic' industrial Ethernet requires two pairs of copper wires for fast Ethernet (100MB) and four pairs for Gigabit Ethernet.

Like PoE, the capability to deliver power to the device was developed specifically for the xBASE-T1 SPE market. The IEEE 802.3bu standard employs the Power over Data Lines (PoDL) technique. PoDL allows for both data and power to be delivered via a single wire pair.

This specification outlines ten classes (0 – 9) of power delivery capability, from 0.5W (Class 0) up to a maximum of 50W at the connected device. Each class provides a range of working voltages and maximum current to deliver the maximum power – up to 10W at 24Vdc and up to 50W at 48Vdc. The more recent IEEE 802.3cg standard adds six more classes of PoDL-powered devices (10 – 15).

For data transmission speeds of 10Mbit/s up to 100Gbit/s, a point-to-point (PtoP) connection is typically used. All these protocols can be combined with PoDL for remote powering applications.

IEEE 802.3cg also defines the 10BASE-T1S as a PHY that can be employed in two possible ways - a PtoP system with a reach of at least 15m and a point to multipoint (PtoMP) communication, also called a MultiDrop (MD) segment. This PtoMP topology is more or less a 'classical' bus system with at least a 25m reach and up to 8 edge nodes. Unfortunately, 10BASE-T1S does not yet support PoDL in PtoMP.

The next aspect to consider is how to deploy SPE into the sometimes hazardous and environmentally challenging industrial domain. Here close attention, particularly from the interconnect perspective, is required.

Deploying SPE

The operating environment of any manufacturing process can vary tremendously. Extremes in temperature and humidity are commonplace. There are also shock loads and vibration from motors, actuators, and other moving assets to consider. All impact the reliability of the overall operation and the equipment itself, placing greater importance on the connectivity between those assets and the process control equipment.

One of the most noticeable differences between xBASE-T1 SPE and the 4-pair Ethernet standards is the absence of the RJ-45 connector. This connector format was never suitable for industrial applications; even in office environments, the locking mechanism often breaks.

As longer transmission distances are more susceptible to EMC, the IEC 63171 connector standard necessitates a shielded structure that can also operate reliably in harsh industrial environments. In IIoT implementations, where ingress protection is paramount, such as in bottling facilities, two of the six connection methodologies based on this standard have IP67 ratings.

Of these two options, the IEC 63171-5 standard for industrial M8 / M12 connectors has risen in popularity for IIoT SPE implementations. The metric circular connection system is one of the most reliable, resilient, and robust interconnect methods. The M12 connector size is already standard for sensor/actuator cabling or data transmission. With the shift to SPE and demand for miniaturization, the M8 size, which is a third of the size of an M12 connector, is likely to become increasingly popular.

Accordingly, the SPE mating face integrates into the M8 designs with screw, snap-in, and push-pull locking. For the M12 size, screw and push-pull locking are standardized. An additional benefit to using the established M8 / M12 format for SPE implementations is to ensure market acceptance. It also reduces the necessary investment costs, as many providers have corresponding housing designs in stock.

The switch from a 4 or 8 pole cable into a 2-wire cable represents the next milestone in network technology and will impact all markets and industries. Compared to a four-pair CAT 6 cable, which uses AWG 23 conductors, a single-pair cable is up to 60% lighter in weight. Fewer conductors also make the cables thinner, permitting a tighter bending radius during installation and a higher cable density in the rack.

SPE Connector
by Amphnol AICC

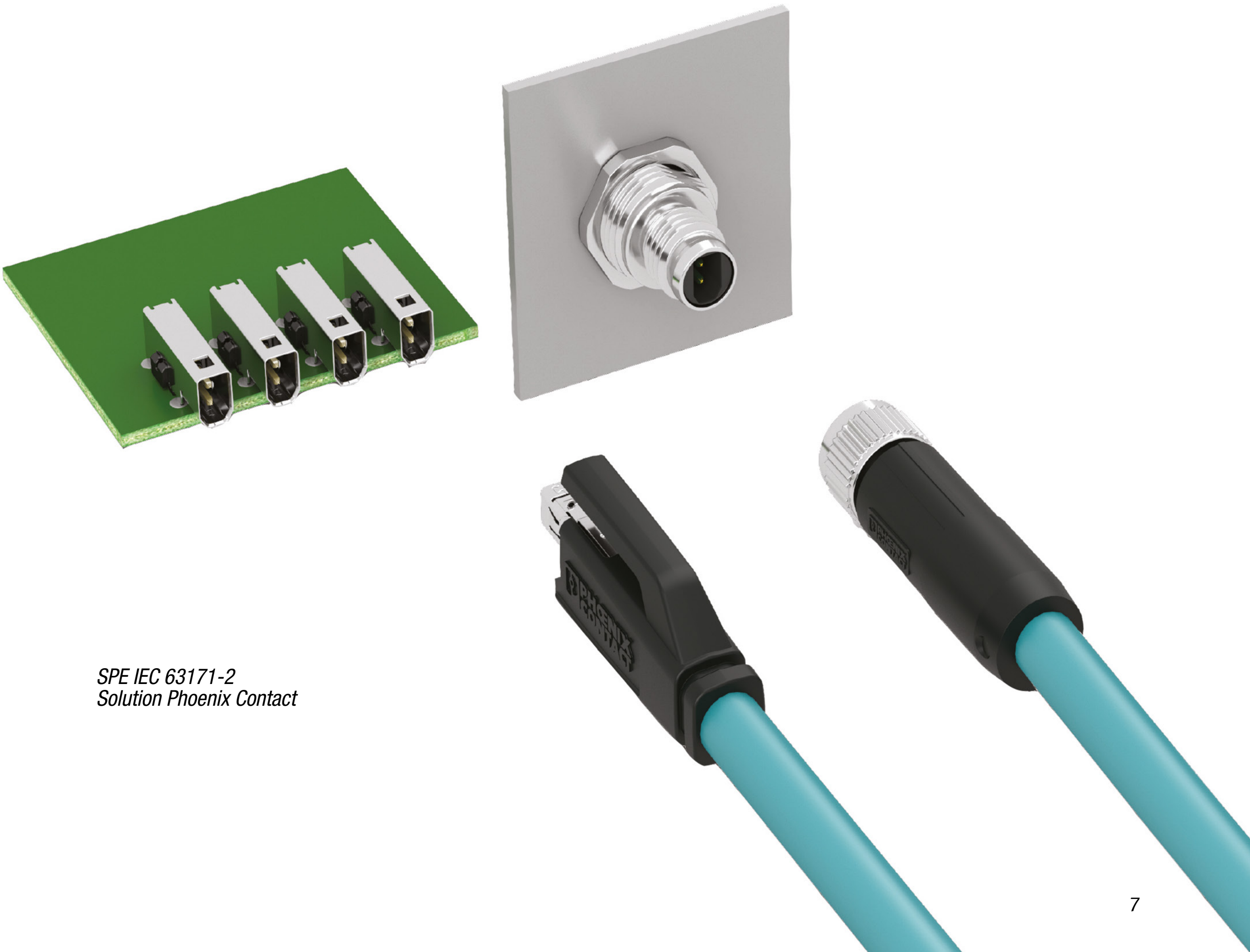
The role of industry consortia in accelerating SPE deployment

SPE delivers many quantifiable benefits to IIoT and industrial automation implementations. The significant advantage of SPE is the consistent IP-based communication with a uniform protocol standard right down to the field level, reducing parameterization, initialization and programming time compared to Fieldbus implementations. It uses a miniaturized M8 / M12 interface with thinner, lighter and more cost-effective cabling, capable of surviving the factory floor's harsh environment. Multiple IEEE 802.3 standards are available to balance bandwidth, power, and reach, with more expected to follow soon.

For new IIoT implementations, SPE with classic industrial Ethernet eliminates the need for intermediate PLCs and protocol converters, or gateways, easing complexity and reducing costs. SPE also provides a relatively low-cost upgrade path when replacing old wired sensors and actuators in existing systems to provide better performance and power, all with one single-pair cable.

With the IEEE 802.3 standards, the Single Pair Ethernet System Alliance and the Single Pair Ethernet Industrial Partner Network industrial consortia are growing the SPE ecosystem, working with members to develop IP-capable endpoint devices and IEC 63171 interconnect technologies.

SPE can replace a big part of the actual existing field bus systems saving weight and space, and reducing installation time. The future of industrial Ethernet, in many IIoT cases, will see the coexistence of single- and four-pair wiring - SPE connecting to the PoDL-powered field device and classic Ethernet linking seamlessly to the enterprise data center and production management system. Via its many sensor and connector suppliers, including AVX, Molex, TE Connectivity, Amphenol, and Phoenix Contact, TTI aims to help its customers better understand the SPE standard and implement the technology into their IIoT applications more effectively.



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About TTI, Inc.

TTI, Inc., a Berkshire Hathaway company, is an authorized, specialty distributor of electronic components. Founded in 1971, the emphasis on a broad and deep product portfolio, available-to-sell inventory and sophisticated supply chain programs have established TTI as a distributor of choice to manufacturers in the industrial, defense, aerospace, transportation, medical, and communications sectors worldwide. TTI and its wholly owned subsidiaries, the TTI Family of Companies, Mouser Electronics, Sager Electronics and Exponential Technology Group employ over 8,000 people in more than 148 locations throughout North America, South America, Europe, Asia and Africa. Globally, the company maintains about 288,000 square meters of dedicated warehouse space housing over 850,000 component part numbers.

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