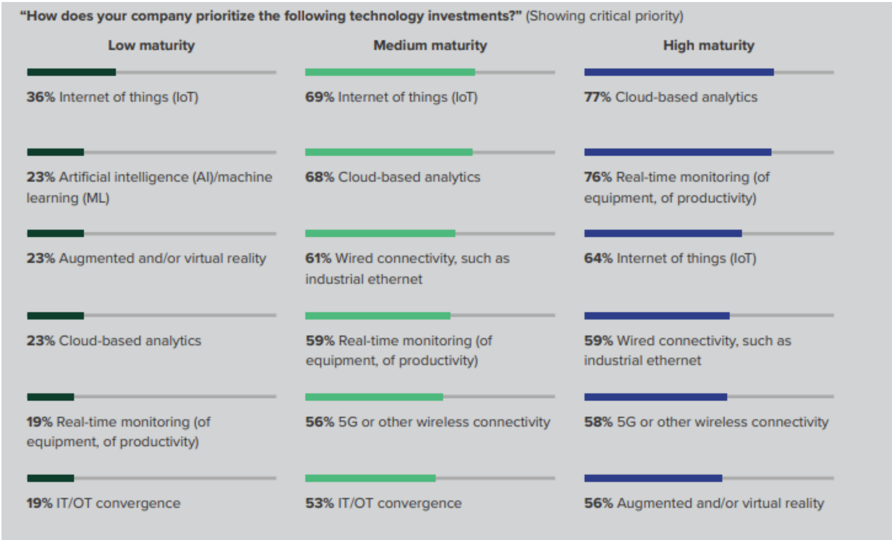
# Why single pair Ethernet is becoming increasingly critical to factory automation

In asset-intensive industries such as manufacturing, the industrial internet of things (IIoT) provides a connection between physical objects and digital systems elsewhere in the business. Today's data-driven environment allows businesses to better understand their operations, leading to innovation and ongoing prosperity. IIoT connectivity delivers remote monitoring and visibility, and, when combined with technologies such as machine learning, it can unlock more advanced capabilities, such as predictive maintenance or insights for strategy developments.

In fact, a Forrester thought leadership paper commissioned by Analog Devices[i] contained an online survey of 312 senior manufacturing leaders responsible for defining industrial connectivity strategy at their organisations. This found that connectivity is the foundation for the insights that drive innovation. It also compared the technology investments companies currently prioritise: Fig 1 shows some of the results.




**Nb. Low, Medium or High Maturity refers to the level of strategic importance a company gives to their innovation efforts**

**Fig.1: How companies prioritise their technology investments (From Forrester Consulting Thought Leadership Paper, 'Seamless Connectivity Fuels Industrial Innovation', commissioned by Analog Devices**

Among other points, it is interesting to note that, for medium and high maturity companies, wired connectivity has slightly higher importance than 5G and wireless. However, the key point is that, overall, wired connectivity is one of the critical issues for such companies – but how is this being implemented, and how will it change in the future?

Simon Seereiner, Head of Product Management SAI & IE at Weidmüller, explains: We now use IP-based communication pretty much everywhere - in smartphones and on our computers but also in industrial facilities. Over the last 20 years, we have seen more and more Ethernet-based communication architectures being implemented in industrial applications, such as Profinet, Ethernet IP and Ethercat[ii].

All of these are Ethernet-based field-bus systems. However, there is a lack of consistency right at the last hurdle, i.e., at sensor-actuator level. At this level, we are still using bus architectures such as Profibus, CAN and ASI. This issue grows with an enterprise's IoT-based, Industry 4.0 infrastructure, which involves dense data volumes being generated by each sensor on every machine or equipment item on the factory floor; this calls for multiple gateways to convert to Ethernet-based communication.

By contrast, today's approach is to establish consistent connectivity so that IP-based communication can be implemented even at the very lowest sensor-actuator level. This brings the promise of a simplified, unified network solution covering the entire factory infrastructure; a concept not previously possible with standard Ethernet-based networks which were too expensive and complicated to use in this context. However, it is now being achieved with an increasingly popular version of Ethernet networking, called Single Pair Ethernet (SPE). While driven by the automotive industry, SPE is equally useful in factory automation – replacing analogue sensors or industrial bus systems, especially if they are multi-protocol.

SPE has been around for 10 – 12 years or so, but engineers are now becoming aware of its advantages over conventional Ethernet, which requires at least two wire pairs at 100 Mb, and four wire pairs for Gigabit cables. With SPE technology, only one pair of wires is needed for the same transfer rates, meaning that only a quarter of the amount of copper is required, as well as only a quarter of the processing time. This not only saves space, but also a huge amount of installation effort and money.

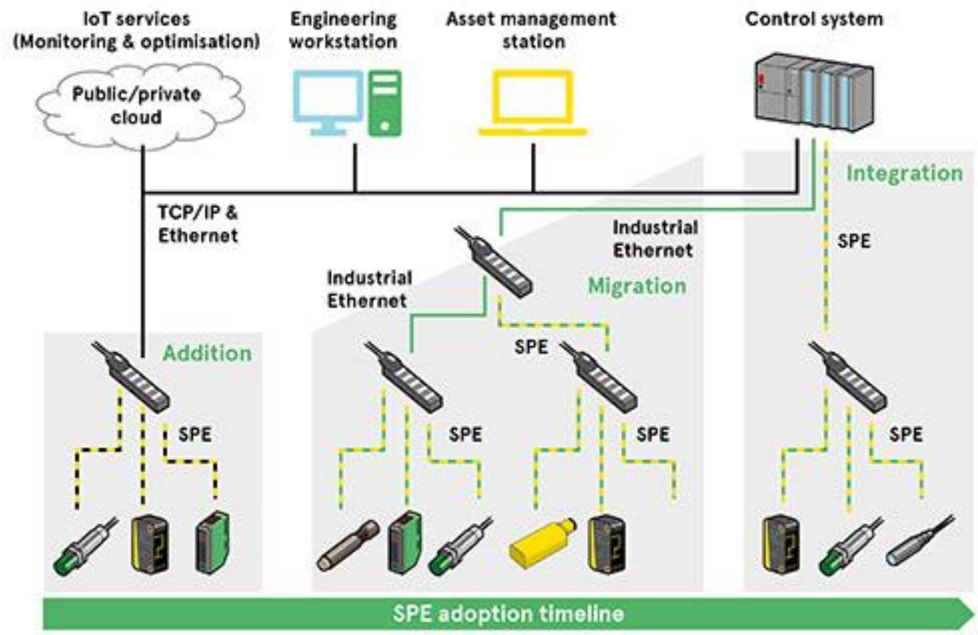



**Fig: A typical IIoT deployment scenario**

A further key benefit is that the single-pair SPE cable can transfer power as well as data. This is based on a technology called Power over Data Line (PoDL), which allows delivery of up to 60 W to an interface during simultaneous data transmission (100 Mbit), over distances of up to 1000 m. Sensor systems, for example, can therefore be supplied with just one single two-wire cable. As a result, such systems can be easily and cheaply set up in industrial applications with a high density, which in turn helps to increase levels of automation and networking while also implementing processes with an ever-increasing degree of automation.

## A closer look at SPE benefits

We have seen from the above that SPE can be a single-technology, IP-based replacement for older systems based on sensors and actuators connected to an industrial Ethernet system via fieldbus links. Here are some ways in which SPE overcomes the challenges of the more traditional approach[iii]:

The first advantage to a single twisted pair is more reliable mechanical connectors. Instead of needing eight different conductors to carry signals, only two conductors are used, and only two physical contacts are required for the system to work. This also allows the use of more robust connectors that require stronger mechanical links, such as Mx connectors which can provide environmentally sealed connections.

The second advantage is the significant decrease in cable size. This allows for an increase in cable density when routing networks, thus allowing for more devices to be connected simultaneously (as a result of laying more cable in the same cable ducts). Reduced cable size also reduces the weight of the cable, meaning easier installation when compared to thicker, heavier cables. This also makes it easier for operators to adjust the network as the cable is easier to move and manipulate.

Next there is cost; reducing the number of conductors in a cable reduces its price. Cheaper cables allow for lower-cost installations, which incentivise industrial facilities to upgrade their networks.

Since a cable cannot become simpler than a single-twisted-pair, such a cable installation will most likely be compatible with future changes to the network.

The fourth advantage is simplified mechanical connectivity. While such a cable can be fitted with strong, dedicated connectors, the use of just two wires allows for a designer to choose any connection type they want with ease. If, for example, a sensor system that requires power and a network connection were incredibly small, then an installer could connect a twisted pair using directly soldered connections. Failing that, terminal blocks can be implemented with ease. An installer could also use a cable crimping system to attach their own custom connector that fits with the hardware in question.

## SPE standardisation

Ethernet is defined by a number of IEEE 802.3 standards; a subset of these defines the SPE options. These are IEEE 802.3 1000Base-T1, IEEE 802.3 100Base-T1 and IEEE 802.3 10Base-T1.
The standards use a single twisted pair cable, Unshielded Twisted Single Pair (UTSP), Category 6A, with differential signals transmitted in full duplex[iv].

Signals between two SPE electronic control units are transmitted simultaneously in both directions. They overlap and run in opposite directions on the SPE cable. Since the respective transceivers know their transmit signals, they can filter out the receive signals.

The 1000Base-T1 interface is based on BroadR-Reach and has been standardised as Single-Pair Ethernet (SPE) by the IEEE working group 802.3bp. 1000Base-T1 corresponds in its technical values to classic Ethernet. Thus, the frame format and the minimum and maximum frame lengths are retained. The error rate is 10−1010-10 and the data rate is 1 Gbit/s. The standard can work with autonegotiation and bridge distances of up to 15 m (1000Base-T1A) or 45 m (1000Base-T1B), as found in buses and trucks. As a modulation method, 1000Base-T1 uses the multivalued pulse amplitude modulation PAM3.

The IEEE working group 802.3bu has standardised a procedure for 1000Base-T1 for the transmission of supply voltages via the STP cable under the designation Power over Data Lines( PoDL).

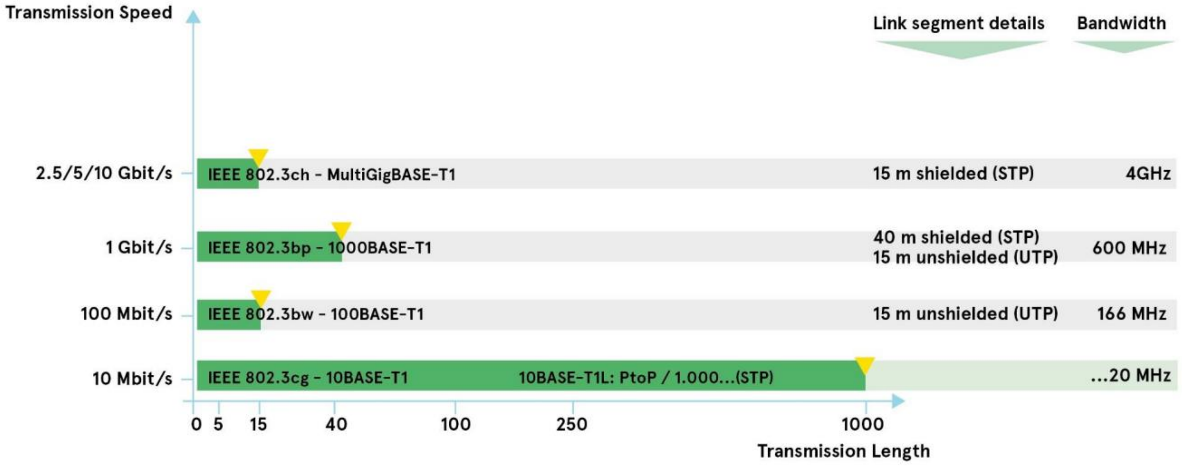



**Fig: Current IEEE 802.3 Standards for SPE**

ISO/IEC JTC1 SC25 WG3 defines the cabling required for the standard, and in turn relies on component standards for cables and connectors created in IEC standardisation groups. Several standards have already been published as part of the introduction of SPE.

IEEE 802.3bp 1000 BASE-T1 "Physical Layer Specifications and Management Parameters for 1 Gb/s Operation over a Single Twisted-Pair Copper Cable" defines single-pair transmission by way of a 15 m UTP channel (type A, unshielded) and a 40 m STP channel (type B, shielded). Both channels are specified for a bandwidth of 600 MHz, may include up to four connectors, and guarantee a transmission capacity of 1 Gbit/s.

The large-scale deployment and successful marketing of SPE depends on full compatibility between all devices, cables and connectors. Two connector faces have managed to win through in the international standardisation selection:

- The connector face as per IEC 63171-1 for wiring premises: This is based on a suggestion by CommScope and known under the synonym variant 1 (LC style) for $M_1I_1C_1E_1$ environments.
- The connector face as per IEC 61076-3-125 is recommended for industry and industry-related applications: This is based on a suggestion by Harting[v], specifically designed for use in environmental conditions up to $M_3I_3C_3E_3$, and known as variant 2 (industrial style)

MICE describes environmental conditions for installations and provides planners and users with valuable advice for the specification of technical equipment and cabling systems. This involves a description of requirements for their mechanical robustness (M), IPxx degree (I), chemical and climatic resistance (C), and electromagnetic safety (E). In the broadest sense, $M_1I_1C_1E_1$ describes the kind of environment found in an office building, for example, and $M_3I_3C_3E_3$ a rather extreme environment that can potentially occur in industry or outdoors.

Based on the connector face defined in the standard, Harting is preparing a comprehensive product portfolio for industry. Prototypes of this connector face were first introduced around two years ago at the SPS 2016 exhibition, along with the two further connectors ix Industrial and M8 d-coded. Following the standardisation of the Harting ix Industrial, this is now the second connector to become an industry standard.

**Fig: HARTING modular SPE connectors according to IEC63171-6**

## Specification of key components

**Cables**: Based on the needed transmission speed and link length, two basic types of SPE cables are available and standardised. For 10 Mb/s networks of up to 1000 metres cable length, the following standards specify the cable design:

- IEC 61156-13-SPE data cable up to 20 MHz bandwidth for fixed installation
- IEC 61156-14-SPE data cable up to 20 MHz bandwidth for flexible installation

For one Gb/s networks up to 40 metres these standards are available:

IEC 61156-11-SPE data cable up to 600 MHz bandwidth for fixed installation

IEC 61156-12-SPE data cable up to 600 MHz bandwidth for flexible installationAll these cables are shielded to provide the needed crosstalk resistance for the 40 metre 1GBASE-T1 and 1000 metre 10BASE-T1L as demonstrated in Fig 2. Depending on the use case, different cable jacket materials are possible. The copper cross section of the cable must be selected according to the needed link length and the power over data line (PoDL) requirement. 26AWG and 22AWG wires are typically taken for link lengths of up to 20 metres and 40 metres respectively. For longer link lengths up to 1000 metres 16 AWG or 18 AWG cables must be used.

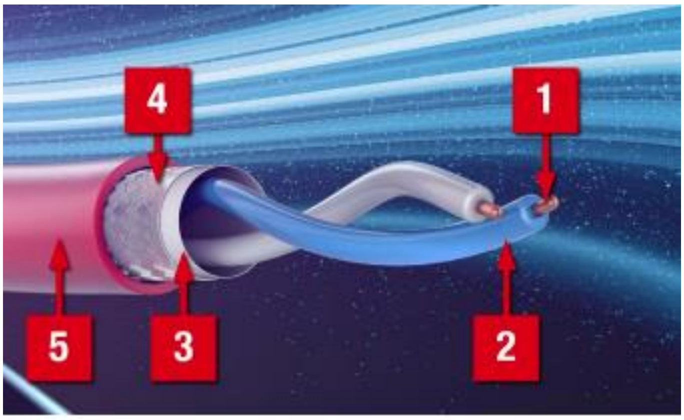



Figure 2: Design for a typical SPE cable (1-copper wire, 2-wire isolation 3-shielding foil, 4-shielding braid, 5-cable jacket)

To realise 1 Gigabit per second transmission rate over a single pair, the standards define high electrical properties for an SPE cable.

These include the s-parameters insertion loss (IL), return loss (RL), and alien crosstalk (AXT) over a frequency range up to 600 MHz.

The foil shield provides a high shielding effectiveness against high frequency electromagnetic fields. The braided shield is used for mechanical stabilisation and shielding of low frequency electromagnetic fields. The effect of a braid depends on the thickness of individual wires and on the degree of coverage. SPE cables for industrial environments should provide a coverage of a minimum 85%. The braiding of a cable also mainly defines the values for the transfer impedance of a cable shielding.

The shielding effect of a cable works in both directions, which means that the shielding attenuation reduces both the radiation of disturbances of the cable signal as well as disturbances of other devices acting on the cable from outside.

**Connectors**: SPE needs completely new types of connectors. These connectors are smaller than the typical RJ45 and offer the same robustness as the often used industrial style M12D- and X-coded connectors. This new SPE interface is defined in the IEC 63171-6 standard and includes different M8/M12 versions for very harsh industrial applications and an IP20 interface for in-cabinet applications. All these connector types are based on the same connector inserts and use a robust pin and socket contact system. This modular design concept with identical terminal inserts in all versions allow the mating of IP20 plugs to IP65/67 jacks for testing or set up.

This SPE connector series is specified for 60V DC/4 amps at 60°C and fulfils the requirements for all power over data line (PoDL) classes. For harsh industrial environments with a heavy EMC disturbance the connector has a 360° shielding shell to provide the shielding connection from the cable shielding to the PCB with four shielding pins. These through hole reflow (THR) solder pins also offer a robust connection between the jacks and the PCB. The connector mating face design is symmetrical, and the contacts are arranged in parallel with the identical contact length. The RF compliant connected technology allows signal transmissions up to 1000BASE T1.

**Fig: Different recommended SPE connectors according to IEC 63171-6**

**Filter topologies**: the MDI [Medium Dependent Interface] forms the connection between the cable and the physical medium - the PHY chip - which generates bits from data signals and passes them on for further processing.

The passive components of the MDI have various tasks such as correct forwarding of data signals, signal interference suppression, and electrical isolation or transport of electrical energy up to 60 W in the case of Power Over Data Line (PoDL).

To ensure error free data communication, limits for return loss and mode conversion loss have been defined in various IEEE 802.3 standards. Figure 4 illustrates the MDI limits for 10BASE-T1 according to IEEE 802.3cg and 100BASE-T1 according to IEEE 802.3bw.

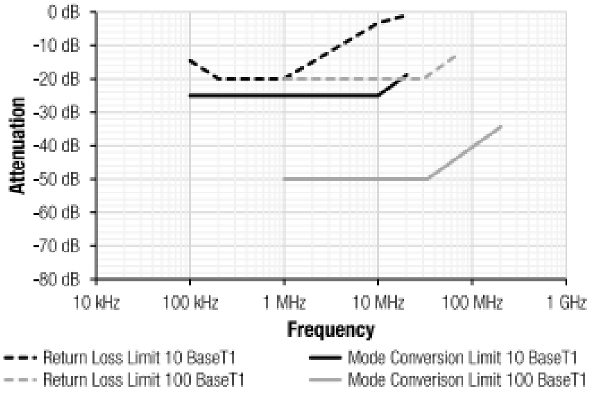



**Fig: Limits of return loss and mode conversion for MDI 10BASE-T1 (Black) and 100BASE-T1 (Grey)**

## Examples of SPE components

**Microchip LAN8670/1/2**[vi] is a high performance 10BASE-T1S single-pair Ethernet PHY transceiver for 10Mbits/sec half duplex networking over a single pair of conductors. Utilising standard Ethernet technology in sensor/actuator networks reduces application costs by eliminating gateways necessary with legacy networking technologies. The ability to connect multiple PHYs onto a common mixing segment further saves implementation costs by reducing cabling and switch ports. The LAN8670 is designed for use in high reliability, cost-sensitive industrial, backplane, and building automation sensor/actuator applications.

Note that the transceiver has full 10BASE-T1S capability. 10 Mbps IEEE 802.3cg 10BASE-T1S is a slightly different type of Single Pair Ethernet. Not only does it benefit from using a single twisted pair of wires, but it also offers bus topology connectivity, in addition to the conventional switched point to point. Connecting devices on a common bus offers further system cost reductions by reducing the number of PHYs and cabling needed in the network. Up to at least 8 devices (PHYs) can be supported over the shared 10 Mbps bus of up to at least 25 m in length.

10BASE-T1S is also deterministic by inherently avoiding collisions from devices simultaneously trying to transmit on the bus, through a method known as PLCA (Physical Layer Collision Avoidance).

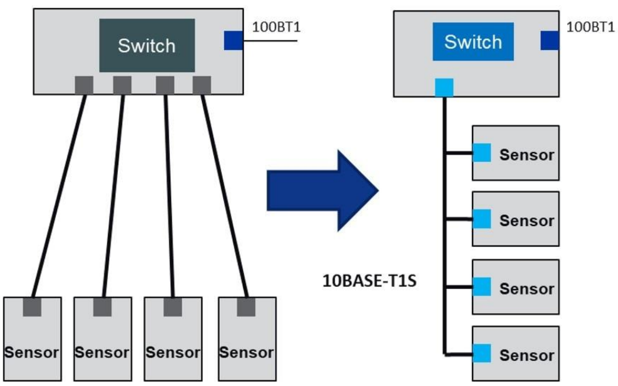



**Fig: 10BASE-T1S architecture**

**Analog Devices' ADIN1110** is an ultra-low power, single port, 10BASE-T1L transceiver design for industrial Ethernet applications and is compliant with the IEEE® 802.3cg-2019™ Ethernet standard for long reach, 10 Mbps single pair Ethernet (SPE). Featuring an integrated media access control (MAC) interface, it enables direct connectivity with a variety of host controllers via a 4-wire serial peripheral interface (SPI).

This SPI enables the use of lower power processors without an integrated MAC, which provides for the lowest overall system level power consumption. The SPI can be configured to use the Open Alliance SPI protocol or a generic SPI protocol. The programmable transmit levels, external termination resistors, and independent receive and transmit pins make the device suitable for intrinsic safety applications. It is used in applications such as field instruments, building automation and fire safety, factory automation, edge sensors and actuators, condition monitoring, and machine connectivity.

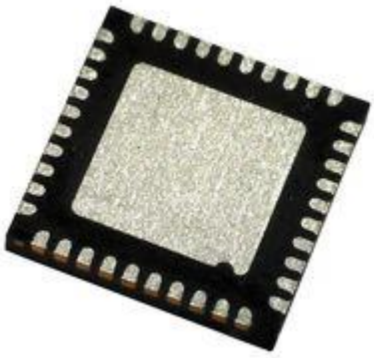


**Fig: Analog Devices ADIN1110 ultra-low power single port 10BASE-T1L transceiver**

**Würth Elektronik Single Pair Ethernet Signal Transformers** feature the super small WE-STST series with transformers that measure only 4.7mm x 3.22mm x 2.9mm (L x W x H). These devices are machine-manufactured and offer 1.5 kV isolation voltage and 350 µH open-circuit inductance (OCL) as per IEEE 802.3. They have an operating temperature range of -40°C to +105°C. Typical applications for Würth Elektronik WE-STST transformers include Ethernet 10/100/1000 Base-T, Ethernet 2.5/5G and 10G Base-T, single pair Ethernet, ultrasonic sensors, and G.fast.

The WE-STST provides a discrete solution for Ethernet designs. This can save over 50 % of PCB space compared with individual transformer solutions using ring cores, while still providing the possibility of high transmission rates. Its innovative automated production reduces electrical deviation and increases reliability as well as quality[vii].

**Fig: Würth Elektronik tiny Ethernet and LAN transformer**

**Weidmüller** IP20 and IP67 patch cables, also used for free field coupling, support Power over Data Line (PoDL). These cables can contribute to SPE installations, allowing uniform Ethernet-based communication from the sensor to the cloud. They can be used across applications thanks to ranges of up to 1,000 m and transmission properties of up to 1 Gbit/s

Fig. 8 below shows an example of one of these patch cables, offered with the description: Plug acc. to IEC 63171-2, SPE plug (IEC 63171-2) - IP20 female straight, Plug acc. to IEC 63171-2, SPE plug (IEC 63171-2) - IP20 female straight, T1-B, PVC, 1 m.

**Fig: WEIDMÜLLER 2725850010 Ethernet Cable, SPE Jack to SPE Jack, STP (Shielded Twisted Pair), Black, 1 m, 3.3 ft**

The **HARTING T1 Industrial Series of connectors** feature an Internationally standardised mating face according to IEC 63171-6. They can be used to construct future-proof and standardised Single Pair Ethernet (SPE) communication networks with standardised cabling according to ISO / IEC 11801 and TIA 42.

Designed for industrial applications up to $M_3I_3C_3E_3$ environmental conditions (See under 'SPE Standardisation' above for a definition of MICE), they meet all IEEE 802.3 requirements for SPE. They have a robust industrial design with 360° shielding, locking lever protection and high mating cycles.

**Fig: HARTING SPE Jack, 1 x 1 (Port), 2P2C, IP20, Through Hole Mount – part of the HARTING T1 Industrial Series of connectors**

## A secure and co-ordinated future for Single Pair Internet

The future of SPE is being managed by the SPE Industrial Partner Network, which provides the assurance of quality for uniform and coordinated infrastructure that meets set standards. The seven brands HARTING, TE Connectivity, HIROSE, Würth Elektronik, LEONI, Murrelektronik, and Softing IT Networks form the founding members of the SPE Industrial Partner Network[viii].

They describe themselves by saying: “Our strong partner network is unanimous in its support of the T1 Industrial interface according to IEC 63171-6 as a uniform Media Depended Interface (MDI) as defined by the ISO/IEC JTC 1/SC 25/WG 3 and TIA42 in 2018.

“To ensure the reliable establishment of the entire future SPE ecosystem, standards for transmission protocols, cabling and device components are also jointly supported. Therefore, all members of the partner program, as well as ISO/IEC JTC 1/SC 25/WG 3, are in close exchange and intensive cooperation with IEEE 802.3 and IEC SC46C for uniform transmission standards and copper data cables.”

## References


[i] Forrester Thought Leadership Paper: Seamless Connectivity Fuels Industrial Innovation (analog.com)

[ii] Why is Single Pair Ethernet (SPE) technology becoming increasingly important in communication architecture within the industrial sector? (weidmuller.co.uk)

[iii] What is Single-Pair Ethernet? (electropages.com)

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[vi] DS-LAN8670-1-2-60001573C.pdf (farnell.com)

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