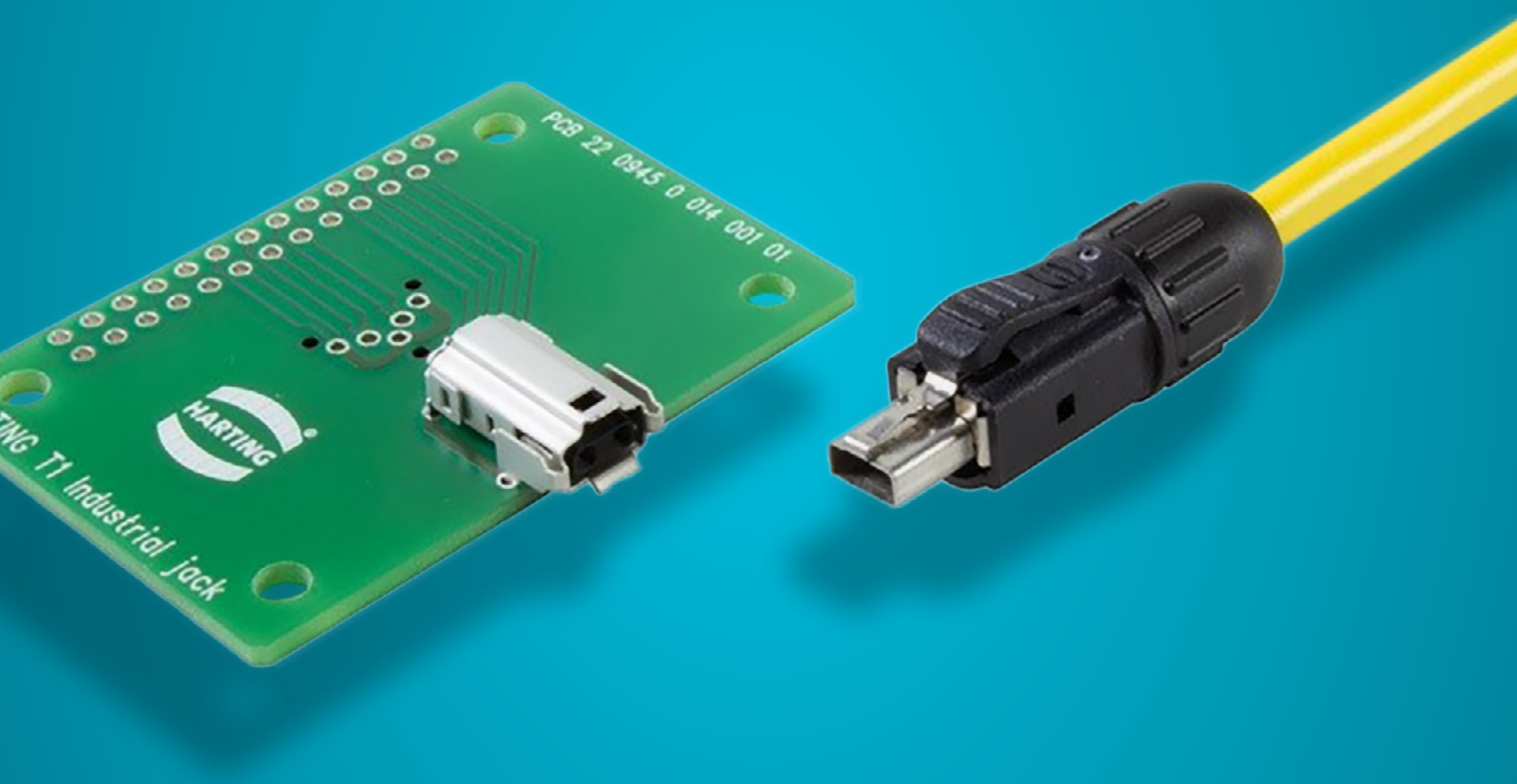
INDUSTRIAL IOT

WORLD ON A WIRE – **SINGLE PAIR ETHERNET**

WHITE PAPER



TOPICS INCLUDE: TECHNOLOGY – STANDARDS, STANDARDS, STANDARDS * THE NUTS AND BOLTS OF I/O – CABLES AND CONNECTORS * GIMMICK POWER MANAGEMENT ICS – ONE LESS WORRY * REAL TIME? – AN ABSOLUTE MUST * STANDARDISED DATA EXCHANGE DOWN TO THE FIELD * LATCHED – I/O LINK FOLLOWS * HACKER ATTACKS – GATEWAY LIMIT SWITCH?

uk.rs-online.com

Cover image: Harting

Single Pair Ethernet – World on a Wire

The increased collection, evaluation and use of data in the industrial environment – driven by AI technology, among other things, – is increasing the pressure to implement a uniform, practicable and affordable infrastructure from company headquarters down to the field level. In this area, Single Pair Ethernet (SPE) is one of the mega-trends in industrial data transmission and an "enabler" of the IIoT and Industry 4.0. This technology can make the "Industrial Internet of Things" a reality. Every sensor or actuator in the areas of application of industrial and building automation as well as in the automotive and transportation sectors can be accessed via the internet and can transfer its data barrier-free to or from the cloud.

The control and field level in automation technology is characterised by highly fragmented fieldbus infrastructures. The data islands this causes require complex gateways that complicate access to the data of the devices in the field. Eliminating these gateways could significantly reduce the costs and complexity of these installations and remove the data islands they have created (Table 1).

Fieldbus	Data rate	Cable length
Profibus DP	9.6 kb/s to 12 Mb/s	100 m to 1200 m
Profibus PA	31.25 kb/s	1900 m
CANopen	62.5 kb/s to 1 Mb/s	30 m to 1000 m
DeviceNet	125 kb/s to 500 Mb/s	100 m to 500 m
AS-Interface	167 kb/s	100 m
CC-Link	10 Mb/s	100 m
IO-Link	230 kb/s	20 m

Table 1. Common fieldbus technologies (source: Belden)

One way of eliminating this fragmentation is to extend the Ethernet from the control level to the field level. However, this approach has been made more difficult by the cable length limitation to a maximum of 100 m, the use of a minimum of two wire pairs and by connectors that are less usable.

The automobile industry faced a similar situation in the fragmentation of communication technology. This situation has been further exacerbated by advanced developments such as autonomous driving.

Data rate and cable length standards

Single Pair Ethernet now allows data to be transported at 10 Mbps, 100 Mbps and 1 Gbps over two-wire copper cables while at the same time supplying end devices with power via Power over Data Line (PoDL). Specifically, the data rates and cable lengths are:

- 10 Mbps (duplex) up to 1000 m, transmission with a bandwidth of 20 MHz (10BaseT1L)
- 10 Mbps (half-duplex) up to 40 m, transmission with a bandwidth of 20 MHz (10BaseT1S)
- 100 Mbps (duplex) up to 15 m, transmission with a bandwidth of 66 MHz (100Base-T1)
- 1000 Mbps (duplex) up to 40 m, transmission with a bandwidth of 600 MHz (1000Base-T1)

10BaseT1L (with the suffix L) is the "long-range" version of the single-pair Ethernet variant standardised in IEEE 802.3cg for a cable length of 1000 m. 10BaseT1L works full-duplex – which means that the send and receive signals are transmitted simultaneously via one pair of wires. A station can use echo compensation to remove its own transmission signal from the overall signal and isolate the receive signal. 10BaseT1L uses twisted-pair cables with a bandwidth of 20 MHz and a characteristic impedance of 100 Ω.

Ethernet APL (Advanced Physical Layer) offers additional precautions for applications in the process industry. It is based on 10BaseT1L in accordance with IEEE 802.3cg. The structure can consist of a "trunk" cable (cable bundling) with a maximum length of 1000 m between the field switches in Zone 1 hazardous areas and a maximum of 200 m between a field switch and a field device in Zone 0. Ethernet APL contains extensions that are specially tailored to the requirements of the process industry, such as intrinsic safety (IEC TS 60079-47) and port profiles for Power Management ICs for field devices.

10BaseT1S (with the suffix S) is the "short range" version of the single-pair Ethernet variant standardised in IEEE 802.3cg. 10BaseT1S works in the half-duplex process and can be operated with both point-to-point and multi-drop technologies (Fig. 1). The latter is defined with a bus length of 25 m with 10 cm-long stubs. In this topology, there is no need for a switch because the arbitration scheme PLCA (Physical Layer Collision Avoidance) is used, which ensures that no data collisions occur. The standard provides for at least eight stubs, but there can be many more.

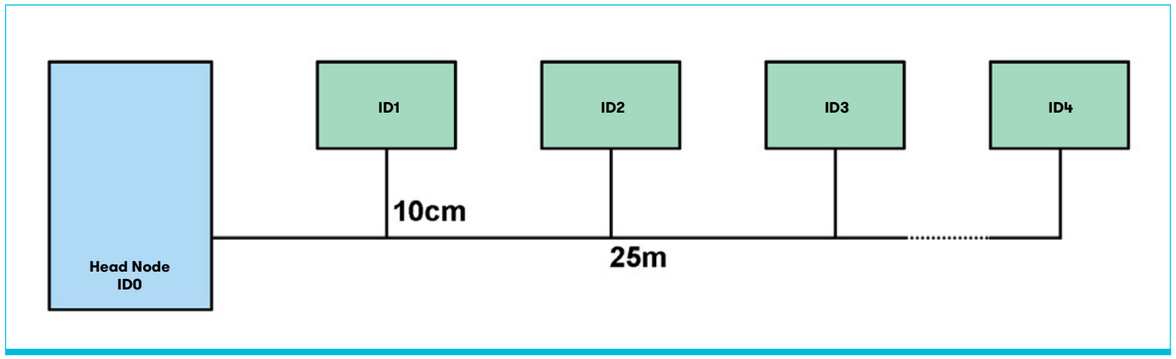


Fig. 1. 10BaseT1S works in the half-duplex process and is operated in a multi-drop technology, which defines a bus length of 25 m with 10 cm-long stubs. (Fig.: channel-e)

10BaseT1S is a topology that is useful in automotive, industrial and building automation applications to integrate a multitude of network participants in a confined space. It works without switches and only requires small microcontrollers and relatively uncomplicated PHYs for implementation.

The structure of the 10BaseT1S network is very simple: all the participants "hang" on a wire; one of the participants, who is also a communication participant on the bus, is defined as a head node with ID 0, and all others can then be numbered consecutively. The task of the head node is to prevent data collisions on the bus – in other words, to coordinate the arbitration via PLCA. To do so, it sends a so-called beacon, from which moment "the clock starts running". A time window of typically 25 µs opens (but this can be set at will) for the first participant (the head node themselves). Within this window, the node can then begin to "speak" (transmit opportunity). If they let the time pass, the next participant gets their 25 µs, and so on until the last node.

Then everything starts all over again – the head node sends a beacon and the time windows run through from node 0 to node N. If a participant exercises their right to send within the 25 µs, they can place an Ethernet frame on the bus. Since the bus participants have different "communication needs", no fixed cycle time can be specified for such a multi-drop network – especially since a cycle can change further in time due to exception rules. A bus participant with a slow MCU will thus be allowed to give an idle signal that allows it to extend the time window (in our example, 25 µs). Nodes that are particularly important can be allowed to put more than one frame on the bus.

100Base-T1 is standardised in the IEEE standard 802.3bw. It is a single-pair Ethernet variant for a cable length of 40 m and a transmission rate of 100 Mbit/s. 100Base-T1 works full-duplex and uses twisted-pair cables with 66 MHz bandwidth and a characteristic impedance of 100 Ω.

1000Base-T1 is standardised in the IEEE standard 802.3bp. It is a single-pair Ethernet variant for a cable length of 15 m to 40 m (depending on isolation) and transmits data at a rate of 1 Gbit/s. 1000Base-T1 works full-duplex and uses twisted-pair cables with 600 MHz bandwidth and a characteristic impedance of 100 Ω.

MultiGigBase-T1, which is to be specified in the 802.3ch standard, is still in the standardisation phase. It is to allow single-pair Ethernet with 2.5, 5 and 10 Gbit/s and bridgeable distances of up to 15 m.

The role of cables

Cables play a key role in the SPE environment. Because only two twisted wires and a shield are required, they are significantly thinner, more flexible, lighter and more cost-effective. In practice, SPE cables are easier to lay and have smaller bend radii. To save on weight – one of the most important advantages for the application of SPE in the automotive industry – the cable manufacturer Belden offers a weight reduction of up to 60% compared to CAT6 variants (Cat 6A S/FTP AWG 23).

The following standard projects are in progress within the IEC Working Group SC46C for the standardisation of data cables by the meter:

- IEC 61156-11 – SPE data cables up to 600 MHz bandwidth for fixed installation (final version published)
- IEC 61156-12 – SPE data cables up to 600 MHz bandwidth for flexible laying
- IEC 61156-13 – SPE data cables up to 20 MHz bandwidth for fixed installation (horizontal floor wiring)
- IEC 61156-14 – SPE data cables up to 20 MHz bandwidth for flexible installation (work area wiring)

Other standardisation projects, for example for bandwidths with data rates above 1 Gbit/s for the targeted bandwidths in the GHz range, will be processed in the future.

In addition to using single-pair copper cables, Single Pair Ethernet enables so-called cable sharing. This entails using a four-pair cabling to implement four SPE connections that are independent of each another via a single cable.

The linking element – the connector

Historically, it did not make sense to use connectors in a closed system, such as a vehicle. That is why mating faces did not exist in the original SPE standards.

In the context of application areas and performance standards of Single Pair Ethernet in the industrial sector, bipolar connectors have also been standardised, eliminating the disadvantages of RJ45 connectors – such as unreliable locking and poor protection against dirt and moisture.

The mating face for connectors is specified in the current standards. The definition of the mating face guarantees mating compatibility and thus the use of products from different manufacturers. There are corresponding versions of connectors in protection classes IP20 to IP65/67 (see Figure 2 and Figure 3).

Measured by media attention, two "players" who offer the market different mating faces have established themselves in the field of connectors and sockets. These players or mating faces can be attached to the user organisations SPE Industrial Partner Network and the Single Pair Ethernet System Alliance.

Harting, a member of the SPE Industrial Partner Network, has developed connecting components with a mating face in accordance with IEC 63171-6 (Fig. 2) for industrial application. This SPE connector can ensure both 1 Gbit/s for shorter distances and 10 Mbit/s for long distances.

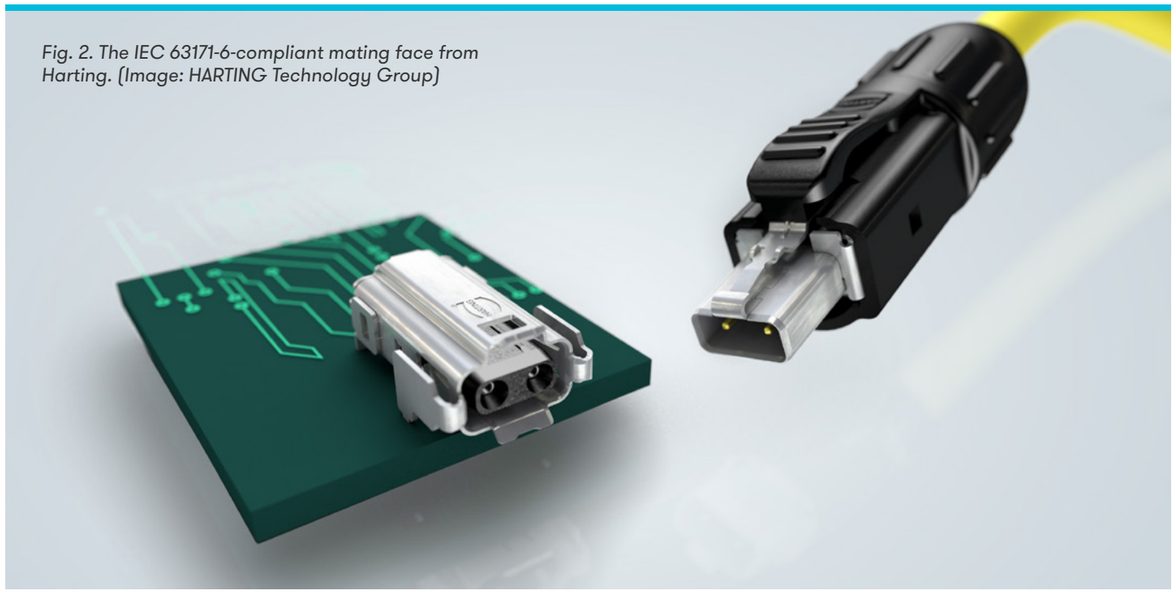


Fig. 2. The IEC 63171-6-compliant mating face from Harting. (Image: HARTING Technology Group)

Weidmüller – member of the Single Pair System Alliance – offers connectors compliant with IEC 63171-2 for the IP20 environment and variants compliant with IEC 63171-5 for the IP67 environment for wire diameters AWG 26 to AWG 22 (Fig. 3).

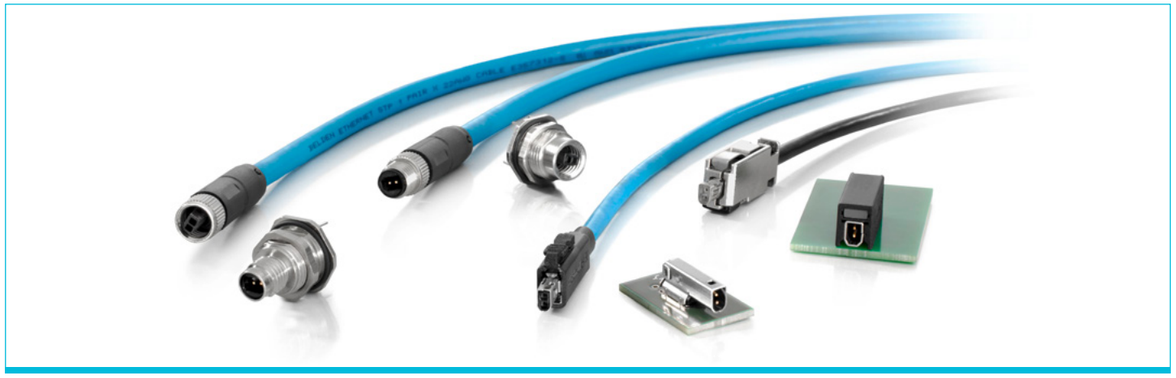


Fig. 3. IEC 63171-5-compliant SPE connectors with mating faces from the manufacturer Weidmüller. Here there are also M8/M12 versions. (Image: Weidmüller)

What both of these connectors have in common is that they are almost delicate compared to RJ-45 connection technology (Fig. 4).

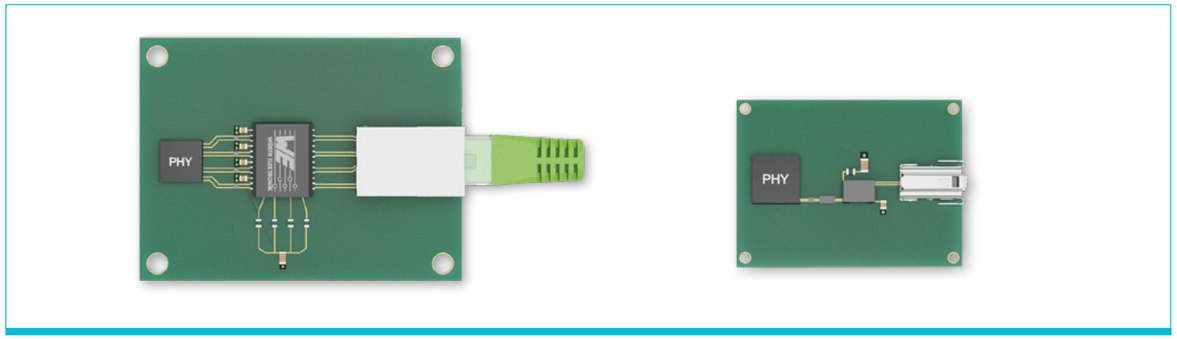


Fig. 4. Comparison of control variables between RJ-45 (left) and the Harting T1 connector. (Image: Würth Elektronik)

IEC 63171	Basic standard for specifications and test sequences
IEC 63171-1	CommScope proposal for M1I1C1E1 applications
IEC 63171-2	Reichle & DeMassari proposal for M1I1C1E1 applications
IEC 63171-3	Siemon proposal for M1I1C1E1 applications
IEC 63171-4	BKS proposal for M1I1C1E1 applications
IEC 63171-5	Phoenix Contact proposal based on the mating face of IEC 63171-2 for M2I2C2E2, M3I3C3E3 applications. (Fig. 3)
IEC 63171-6	Harting, Hirose and TE Connectivity proposal for M2I2C2E2, M3I3C3E3 applications. Published (Fig. 2)

Table 2. Overview of standards with regard to mating faces

The MICE classification …

… defines the requirements for cables and connectors in different environments.

The four environments that make up the abbreviation "MICE" are:

- **M:** Mechanical (shock, vibration, impact, pushing, pulling, bending)
- **I:** Ingress (or immersion, e.g. of water and dust)
- **C:** Climatic/chemical (temperature, UV exposure, humidity, contact with impurities such as oil or gas)
- **E:** Electromagnetic (voltage peaks, EMI/RFI interference, magnetic fields, transients)

The number after each letter of the acronym indicates the degree of exposure to environmental factors:

- **1:** Low severity (e.g. office environment)
- **2:** Medium severity (e.g. light industrial environment)
- **3:** High severity (e.g. extreme industrial environment)

DM1I1C1E1 describes an environment in an office building and M3I3C3E3 an environment that can be found in industry or outdoors.

One less worry – with PoDL, data and power supply can be transmitted at the same time

One of the key capabilities of Single Pair Ethernet is the simultaneous transmission of data and power supply via the cable pair – Power over Dataline (PoDL). In the IEEE 802.3bu standard "Physical Layer and Management Parameters for Power over Data Lines (PoDL) of Single Balanced Twisted-Pair Ethernet", the provision of remote power supply via single-pair Ethernet channels is specified in the same way as Power over Ethernet (PoE) (Fig 5).

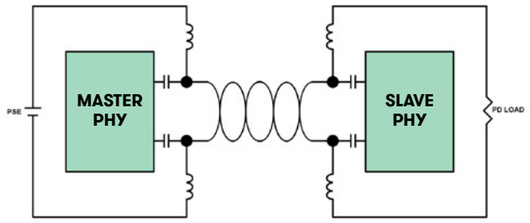


Fig. 5. Simultaneous transmission of data and power supply via the cable pair.
(Fig.: channel-e)

The objectives and specifications for PoDL operation include:

- Allowing operation of a powered device even if there is no data.
- Supporting voltage and current levels for the automotive, transportation and automation industries.
- Supporting quick-start operation with predefined voltage/current configurations and optional operation with runtime voltage/current configuration.

Electrical energy can be transmitted via PoDL in 10 voltage/current classes with power between 0.5 W and 50 W (consumer power, feed-in power = 63.3 W). The maximum current is 1.6 A (Table 3). An extension by 5 additional classes is in progress (Table 4).

This type of power supply requires two-core lines with cables compliant with IEC 61156. STP cables of Category 7 are not suitable.

Class	0	1	2	3	4	5	6	7	8	9
Voltage [V]	5.5-18	5.5-18	14-18	14-18	12-36	12-36	26-36	26-36	48-60	48-60
Electric current [A]	0.1	0.22	0.25	0.47	0.1	0.34	0.21	0.46	0.73	1.3
PD output [W]	0.5	1	3	5	1	3	5	10	30	50

Table 3. PoDL classes (PD= Powered Device)

Class	10	11	12	13	14	15
Voltage [V]	20-30	20-30	20-30	50-58	50-58	50-58
Electric current [A]	0.092	0.240	0.632	0.231	0.6	1.579
PD output [W]	1.32	3.2	8.4	7.7	20	52

Table 4. Additional PoDL classes (PD = Powered Device)

PoDL offers both reliable error protection and detection functions for the identification of devices as well as direct communication with devices to ensure a safe, error-free power supply.

An additional communication protocol is used to determine the required supply class, namely SCCP (Serial Communication Classification Protocol). PSE (Power Sourcing Equipment) and PD (Powered Device) negotiate the supply requirements of the PD using this protocol. The PSE detects the presence of a consumer by performing a signature check for the presence of a 3 V Zener diode at the input of the PD.

The maximum remote feed power for the PoE standard IEEE 802.3bt is 100 W for NEC Class 2 devices. This means that future PoDL expansions will probably also remain below 100 W and for the 24 V supply voltage used in industrial automation, the maximum peak current is rounded off to 4 A.

Take the best with you – OPC UA, TSN and I/O-Link

Single Pair Ethernet must be seen in the context of other standardisation efforts. Communication standards such as Open Platform Communications Unified Architecture (OPC UA) and Time-Sensitive Networking (TSN) are indispensable for networking the sensor via the machine and higher-level systems in the cloud.

At the control level, OPC UA is already being used in plants as a higher-level communication standard. The protocol is to be expanded in the future and ensure uniform data exchange down to the sensor level. Expandable information models should take into account the requirements of devices and applications.

The standards of time-sensitive networking enable data communication to be controlled in a synchronised, prioritised and arbitrated form. TSN can be used to ensure that an application does not disrupt the data transmission of the other applications, nor is it impaired by their communication.

IO-Link was developed as an industrial communication interface for field devices, sensors and actuators. The interface offers three different transmission rates and a maximum cable length of 20 m. On the whole, the simple integration into automation systems as well as the high degree of standardisation of shared functions and the terminal device description are the two main advantages of this communication technology.

The concept study “Extension of IO-Link for Single Pair Ethernet transmission” proposes the introduction of an EtherType for I/O-Link. There are already EtherTypes for ProfiNet and EtherCat, for example. This is a field in an Ethernet frame that is used to indicate which protocol is encapsulated in the “payload” of the frame. According to the study, this method can be implemented with very little hardware and software outlay.

One more worry – IT security right up to the limit switch

“Total” networking means the number of possible gateways for hackers increases. All the devices that are built into the network can exchange data with each other. What is desired from an automation point of view turns out to be potentially dangerous from a security point of view. If everyone and everything can “talk” to everything and everyone, unwanted “conversations” are likely to occur – for example in the form of data theft or changes to the system.

Only the intended data exchange should be permitted in the network. To make sure this happens, suppliers, device manufacturers, system integrators and operators must work together. Security measures must interlock and build upon each other.

In “Industrial Automation and Control Systems (IACS)”, the IEC 62443 series of standards defines a standard for IT security in industrial communication networks. It defines the roles and the allocation of responsibilities for product manufacturers, system integrators and operators, so that the actions of all those involved can build upon each other.

Security begins with the development of devices and the integration of functions into the components – but in the big picture, it goes far beyond this.

Status

As far as the availability of the individual networking components for SPE is concerned, the user organisations inherently have a good overview and should be the first point of contact when are looking for information. What is definitely available at this point are cables and connectors. Switches are “in the pipeline”, with Harting, EKF and Belden (Hirschmann) having exhibited initial samples at trade fairs and seminars. PHYs should be available sooner from semiconductor manufacturers who already supply the automotive industry with SPE components (TI, analogue devices, microchips).

Texas Instruments has announced a PHY for 10BASE-T1L (DP83TD510E) for industrial applications in early 2021. The module can transmit data over a distance of up to 1.7 km and thus exceeds the requirement stipulated in the 802.3cg specification. The DP83TD510E is designed for use in intrinsically safe Ethernet APL (Advanced Physical Layer) systems and can implement Ethernet networks in process automation systems that require intrinsic safety.

There is currently no information on the availability of PoDL Power Management ICs.

The user organisations

SPE INDUSTRIAL PARTNER NETWORK

Single Pair Ethernet Industrial Partner Network

The SPE Industrial Partner Network is based in Rahden, Westphalia. It functions as an association of companies with equal rights which is always open to additional members. The network began at the 2019 Hannover Messe (trade fair), when an SPE cooperation between Harting, TE Connectivity and Hirose was introduced. In October 2019, this became the Single Pair Ethernet Industrial Partner Network. There were a total of seven founding members at the time – in addition to the companies mentioned, these were Würth Elektronik, Leoni, Murrelektronik and Softing IT Networks. In February 2020, the network had 17 members. The newly added companies were igus, Dehn, Helukabel, Molex, Amphenol ICC, Lütze, Escha, Perinet, EKF and Zheijang. As of September 2020, there are currently 23 companies on board, with Hirschmann, Metz Connect, Sinbon, Lapp, Nexans, THK and Fluke Networks having just joined (Zheijang is no longer a part of it).
https://www.single-pair-ethernet.com

((Logo copyright: © Single Pair Ethernet Industrial Partner Network))

Single Pair Ethernet
System Alliance

Single Pair Ethernet System Alliance

The Single Pair Ethernet System Alliance started at the 2019 Hannover Messe, when Phoenix Contact, Weidmüller Interface, Reichle & Massari (R&M), Belden and Fluke Networks announced a technology partnership for Single Pair Ethernet (SPE). In April 2020, the association officially made an appearance as the Single Pair Ethernet System Alliance. As of September 2020, there are 15 companies on board. Over the course of time, the companies Telegärtner, Rosenberger HF-Technik, Dätwyler, Kyland, Sick, ORing Industrial Networking, Microchip, Draka/Prysmian, Zhaolong Cables & Interconnects, EFB Elektronik and Vericom have joined the Alliance (Belden/Hirschmann is no longer represented).
https://singlepairethernet.com

((Logo copyright: © Single Pair Ethernet System Alliance))

Single Pair Ethernet Consortium

The Single Pair Ethernet Consortium (SPEC) belongs to the American TIA. It is open to TIA members, but companies that are not TIA members can also participate as affiliated members. TIA is the Telecommunications Industry Association, which represents over 400 companies worldwide. It is accredited by the American National Standards Institute (ANSI). The organisation was initiated in September 2019, with founding members Belden, CommScope, Panduit, and Siemon Company. As of September 2020, a total of 11 members are listed. AEM, Anixter, Berk-Tek, Fluke Networks, Leviton, Superior Essex and R&M have joined the organisation during this period.
https://spec.tiaonline.org

((Logo copyright: © Single Pair Ethernet Consortium))

OPEN Alliance (One-Pair Ether-Net) Special Interest Group (SIG)

The Special Interest Group (SIG) of the OPEN Alliance (One-Pair Ether-Net) is an open industry alliance (non-profit) in which the automotive industry and technology providers primarily work together to promote Ethernet-based networks as the standard in automotive networking. The founding members in November 2011 were BMW, Broadcom and NXP Semiconductors. In the same month, the companies C&S, UNH-IOL, Harman, Hyundai, Freescale and Jaguar Landrover joined the industry organisation. Continental, TÜV Nord, Valeo and JAE Europe followed in December 2011. As of September 2020, more than 340 members are currently represented in the OPEN Alliance SIG.

The acronym “OPEN” originally stood for One-Pair Ether-Net. Both 100Base-T1 and 1000Base-T1 technology use just one twisted-pair cable. However, the alliance currently supports the provision of Ethernet-based communication in the automotive sector regardless of the cabling used.
https://www.opensig.org

((Logo copyright: © OPEN Alliance))

Industrial networking – the market situation

HMS Networks publishes an annual analysis of the industrial networks market with a focus on newly installed nodes within factory automation worldwide.

The 2020 study includes estimated market shares for fieldbuses, industrial Ethernet and wireless. Due to the unique general market conditions as a result of the coronavirus situation, estimated growth rates are not included this year.

More market shares for industrial Ethernet, while fieldbuses continue to yield

In the study, HMS comes to the conclusion that Industrial Ethernet continues to take market share from fieldbuses. Industrial Ethernet now accounts for 64% of the global market for newly installed nodes in factory automation (compared to 59% in the previous year).

With a 17% market share each, EtherNet/IP and PROFINET share first place in the entire market. EtherCAT continues to do well worldwide with 7%, and Modbus-TCP overtakes Ethernet POWERLINK (4%) with 5%.

The market shares of fieldbuses continue to decline

HMS estimates that fieldbuses have decreased to 30% of the newly installed nodes (compared to 35% in the previous year). At 8%, PROFIBUS is still number one in this segment and for the first time accounts for less than 10% of the entire market for industrial networks. Modbus-RTU is in second place with 5%, followed by CC-Link with 4%.

Wireless remains stable and looks good for the future

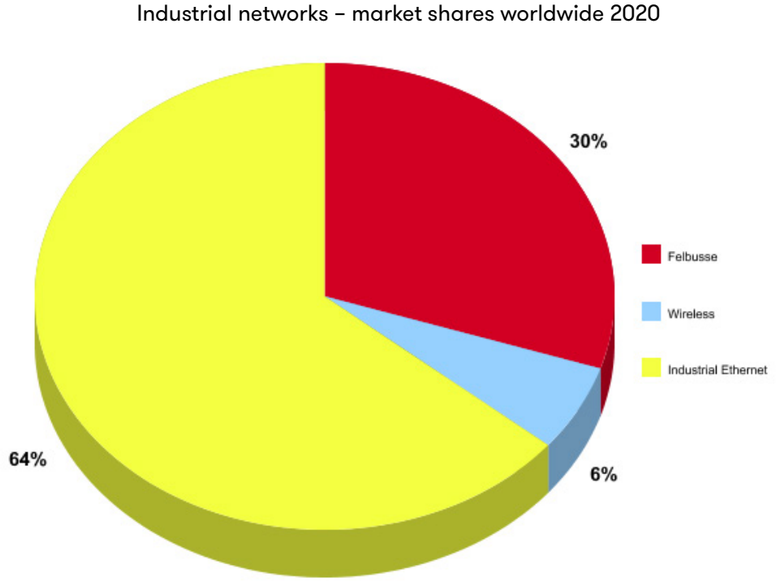
Wireless technologies hold a 6% market share, with WLAN remaining the most popular technology, followed by Bluetooth. Wireless is keeping its market share in a growing market, which is not bad, but HMS Networks expects the wireless share to grow over time.

With all ongoing activities around the world in wireless cellular technologies (e.g. LTE/5G campus networks), HMS is of the opinion that the market demand for wirelessly connected devices and machines will increase.

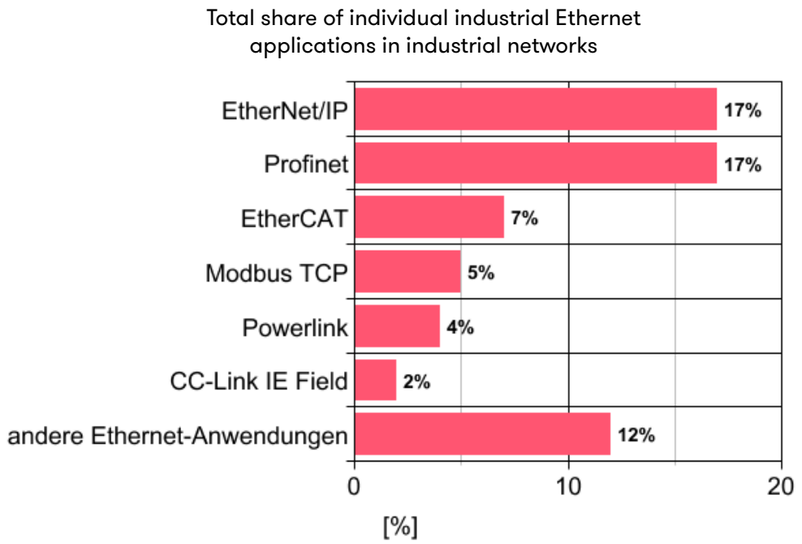
Regional variations

EtherNet/IP and PROFINET are leaders in Europe and the Middle East, with PROFIBUS and EtherCAT in second place. Other popular networks are Modbus (RTU/TCP) and Ethernet POWERLINK. The US market is dominated by EtherNet/IP, with EtherCAT gaining some market share. PROFINET and EtherNet/IP lead a fragmented Asian market, followed by PROFIBUS, EtherCAT, Modbus (RTU/TCP) and CC-Link/CC-Link IE Field.

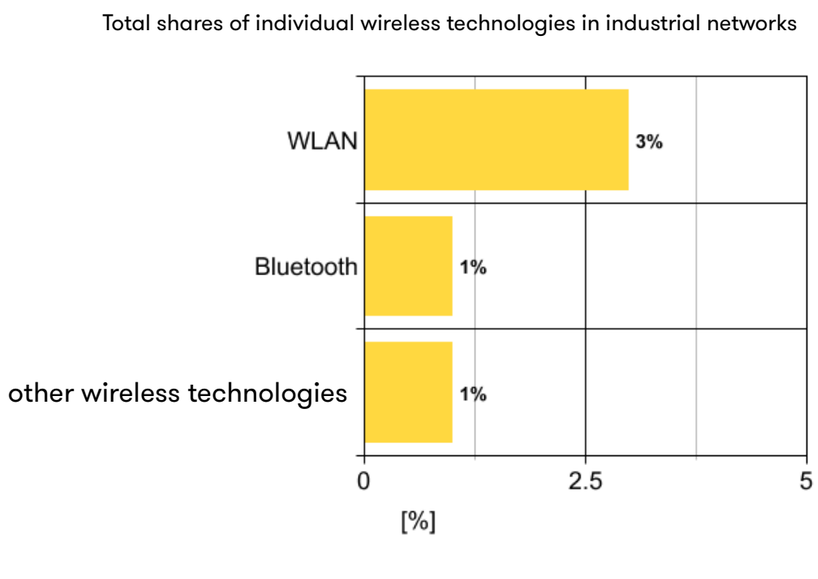
According to documents from HMS Networks



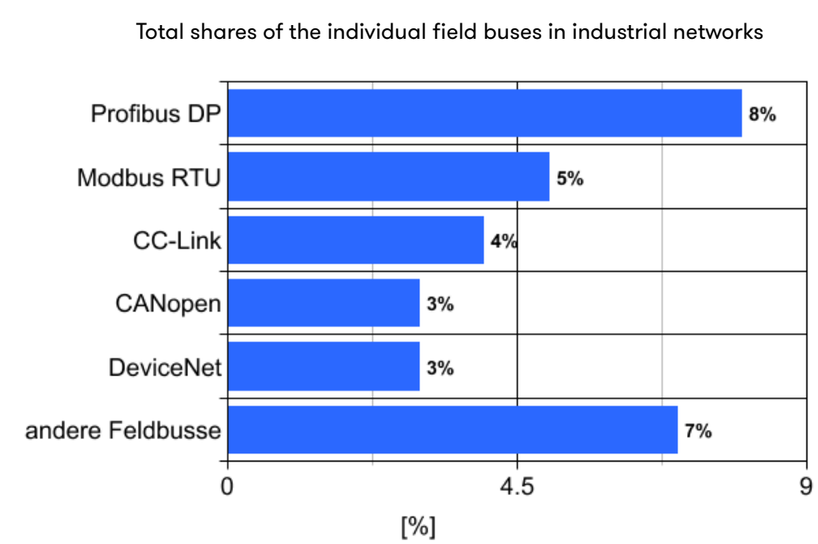
((Fig. A)) Graphic: channel-e



((Fig. B)) Graphic: channel-e



((Fig. C)) Graphic: channel-e



((Fig. D)) Graphic: channel-e

Benefits of Single Pair Ethernet at a glance

- Monolingualism: “Ethernet is spoken” from the sensor to the cloud.
- Simplified cabling: Compact, lighter cables with up to 60% less weight and less space required than conventional Ethernet cables.
- Less space required in the end devices and switches: much smaller plug sockets (standardisation specified) compared to RJ-45 sockets.
- Potentially 10 times the transmission capacity: 1000Base-T1 and MultiGig. Base-T1.
- Potentially 10 times the range: 1000 m at 10 MBit/s.
- Multi-drop networking: Integration of up to 50 end devices into the network without a switch.
- Cable synergies: Cable sharing allows four-pair cabling to be used for four independent SPE connections via one cable.
- Power supply of the end devices: Data and power supply are transmitted via Power over Data Line (PoDL) on the same wire pair.
- 10 MBit/s SPE variant S can also be used in the environment of explosion-proof systems.