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Single Pair Ethernet

The network infrastructure for Industry 4.0

Let’s connect.

Whitepaper

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1. The network infrastructure for Industry 4.0

The potential of Single Pair Ethernet is huge and experts consider it to be the next generation of communication architecture in automation. Originally developed for automotive applications, it promises nothing less than a continuous connection from the sensor to the cloud. And this is the case in practically every application, whether in industry, logistics, buildings or wherever data is generated. The concept behind it is essentially an extension of the Ethernet to the sensor, that is wherever "tracks" (in the literal sense) rather than data highways are needed in every inch of space within the plant – it is compact, flexible and offers extensive reach. This explains why there is such a high level of interest in standards across all industries and why the standardisation process is well underway. Naturally, at this stage of the process, some manufacturers tend to communicate proposals as regulations without further ado in order to issue their product as a new standard. This whitepaper highlights all aspects of the new Single Pair Ethernet technology and focuses on application, standardisation and connectors.

Efforts to use Ethernet as a fieldbus alternative first immerged in the late 1990s. Seamless Ethernet networking from the control unit to the IT world offers huge advantages. For instance, the fill level of a tank can be reported directly to both the system control unit and to the purchasing department, without the need for gateways or a duplicate infrastructure for the control unit and IT. The introduction of the Industrial Ethernet and its defined response time conquered the IT standard as well as time-critical applications such as fast-running machines. However, Ethernet remained a data highway that became increasingly faster and broader. For simple sensors, the technology is too costly and overdimensioned. The current RJ45 connectors and cables are not ideal for industrial use at field level for connecting the sensors. Complex encapsulation up to the sensor is too expensive and is often unfeasible due to lack of space. A further obstacle is the maximum cable length of 100 m, as well as the need for two-pair or four-pair cabling. This is insufficient for a widely-networked warehouse or for materials handling. Support comes in the form of an Ethernet standard that does not need to offer the high data transfer rates of the IT world, yet combines long cable lengths with a compact design as well as simple and robust cabling: Single Pair Ethernet, or SPE. At first glance, it is a "downwards" extension of the existing Ethernet standards. With lower data transfer rates, it conflicts with the constant "faster and shorter" requirements in the IT world. However, many applications are not making full use of the capacities that are now available, in particular sensor technology. Sensors are currently connected via fieldbus gateways, and some are even connected over two levels to an additional sub-bus. In such cases, a continuous Ethernet connection delivers considerable technical and economical benefits. SPE also offers further advantages that are covered in the following sections.

2. Motivation and benefits of SPE technology

Instead of two or four pairs of wires, SPE requires just one pair of wires. The impetus for this development came from wiring systems in the automotive industry, where cabling currently accounts for a great deal of the vehicle's weight – and this trend is rising rapidly. This requires an infrastructure that can deliver high performance with as few cables as possible. There are similar expectations within industry as the number of intelligent end devices in the plant is increasing, however the amount of available space is not – in fact it is quite the opposite. As more and more sensors need to be integrated into machines and systems, the cabling must therefore be designed for industrial use, and be both compact and simple. Moreover, they are installed in extreme places such as robotic arms, where mechanical flexibility and weight play an important role, i.e. lightweight cables with a small outer diameter and low bending radii are essential. This kind of structure will also reduce the costs, as less material needs to be installed. It also makes it easier to extend an existing system than with eight-wire cables. With the thinner and lighter cables, more Ethernet channels can be housed than before in existing cable runs.

The physical properties and transfer rates are defined internationally by different standardisation bodies. These new Ethernet versions are also being met with a great deal of interest in automation technology, as SPE meets the requirements for industrial communication in the digitalisation era. The transfer rates of 10 Mbit/s with a transfer length of 1,000 m up to 1 Gbit/s with a transfer length of 40 m to 100 m are completely adequate, even for sophisticated sensors. Scanners and cameras for monitoring or for detecting a component's type and location can also be continuously integrated into the network via Ethernet. The achievable response times even allow TSN (Time-Sensitive Networking) applications. Another major advantage of SPE is the possibility of supplying power to the connected peripherals via PoDL (Power over Data Line).

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PoDL makes up to 60 W of power available to the PSE (Power Source Equipment). This allows the sensors to be supplied both with energy and with a data interface, even under extremely cramped conditions. An additional, separate supply line is not required.

The IEEE has defined a classification into different power classes for this purpose. Since classes 1–9 are already assigned to POE, the power classes for PoDL start at 10.

The following table describes the resulting outputs for different supply voltages at the end device depending on the length and the cross-section of the cable line.

Class	**10**	**11**	**12**	**13**	**14**	**15**
$V_{PSE\ Min/Max}$ (V)	20/30	20/30	20/30	50/58	50/58	50/58
$V_{PSE\ Min/Max}$ (V)	14	14	14	35	35	35
$V_{PSE\ Min/Max}$ (V)	1.23	3.2	8.4	7.7	20	52
dc loop resistance ()	<65	<25	<9.5	<65	<25	9.5
max. length AWG18 (m)	1000	515	182	1000	515	182
max. length AWG22 (m)	542	203	72	542	203	72
max. length AWG24 (m)	341	127	45	341	127	45
max. length AWG26 (m)	214	80	28	214	80	28

Table 1: Power classes for PoDL in accordance with IEEE 802.3

Additionally, PoDL opens up further applications for SPE. In addition to building infrastructure, this includes particularly demanding applications in potentially explosive environments. This means that SPE is also attractive for process technology. There are therefore virtually no applications for which this standard does not provide new impetus: whether in IT, production or under extreme conditions, the infrastructure is easy to install thanks to the miniaturised connectors and the single pair cables.

SPE thus meets the fundamental requirements of IoT and Industry 4.0 applications – continuous, intelligent networking of an application across all levels, scalable, deterministic and fully compatible. In a nutshell: Each one can communicate with each other.

3. Standardisation, the key to success

On the basis of these benefits, renowned experts from the connector industry, automation technology and the cable industry and have joined forces to develop international standards for this technology. This clearly demonstrates the importance of standardisation, as interoperability, and thus the long-term success of SPE, can only be ensured through international standards.

It goes without saying that many bodies are involved in the international standardisation of such an important technology. At this point, only the key bodies involved are mentioned: The application and the definition of the transfer channel is being processed by the IEEE 802.3 (Institute of Electrical and Electronics Engineers; Ethernet Working Group). ISO/IEC JTC 1 SC25 WG3 (International Electrotechnical Commission, Interconnection of information technology equipment, working group 3 Customer Premises Cabling) describes the transfer requirement and its parameters for passive cabling structures in industry, in buildings, smart homes and computing centres. The requirements of mechanical and electrical properties are ultimately defined by IEC SC 48B Electrical connectors and IEC SC 46C Wires and symmetric cables. There are fixed agreements between IEEE 802.3 and ISO/IEC that define the respective tasks.

For the IEEE 802.3cg (SPE 10 Mbit/s) project, connectors and their electrical properties were defined for the first time in the IEEE environment. They are explained under the point on MDI (Medium Dependent Interface). The MDI is the interface to the active components. The passive cabling structure is not described here. The technical properties that a connector or contact point must comply with for this application are described there. In a sub-item, the current version of the IEEE document describes possible connectors that can be, but do not have to be, used on the MDI. This is occasionally misrepresented in publications. Though it is crucial for the manufacturer and the user to recognise that this is an option ("may be used") and not a regulation. Other connectors can also be used, if they meet the electrical properties of IEEE 802.3cg.

The connectors for Single Pair Ethernet are defined in the IEC 63171-X series of standards. The general electrical requirements of the interfaces can be found in the basic standard IEC 63171. The design of the mating faces and thus the mechanical requirements of the connectors are described in the subordinate series of standards. The basic standard could perhaps be likened to the engine and the standard series as the different car bodies.

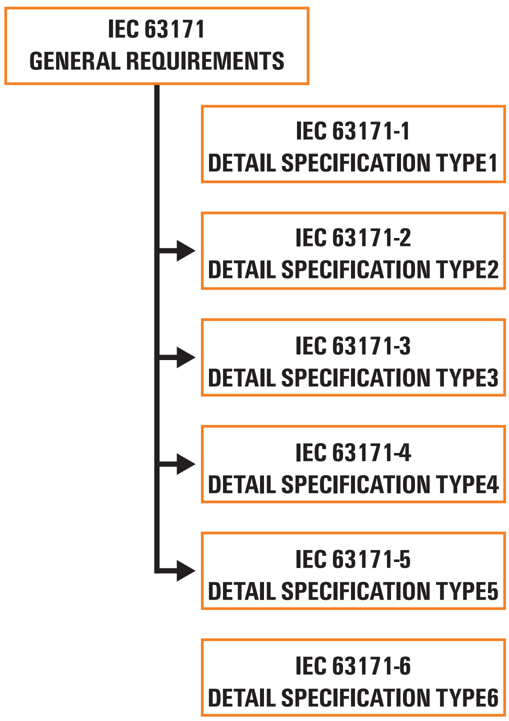

Image 1 outlines the structure of the IEC 63171 series of standards

The connectors defined in the series of standards -1 to -6 have different mating faces, dimensions and mechanical properties. Currently, neither IEC 63171-1 nor IEC 63171-6 refers to the basic standard of IEC 63171. As a result there are different mechanical requirements and different electrical requirements.

For information, the key differences of the standardised connectors are listed in the table below.

Merkmale / Norm	IEC 63171-1	IEC 63171-2	IEC 63171-5	IEC 63171-6
Style	LC-Style	rectangular	M8 / M12	rectangular / D8 / D12
Bandwidth	600 MHz	2.500 MHz	2.500 MHz	600 MHz
Transmission pairs	1	1/4	1/4	1
IP rating	IP20/IP67	IP20	IP67	IP20/IP67
Mating compatibility	No	Yes IEC 63171-5	Yes IEC 63171-2	No
Impedence	108	108	108	147
Isolation voltage	1.5 kV	2.25 kV	2.25 kV	1.5 kV
Dimension (plug)		7.6 x 10.5 mm		11.4 x 12.7 mm (IP20)
Inverted mating face possible	No	Yes	Yes	No

Table 2: Overview of the different connectors in accordance with IEC 63171

The connectors in accordance with IEC 63171-2 and IEC 63171-5 even observe stricter values. For example, they have a dielectric strength up to 2.25 kV DC. Finally it should be mentioned that the use of connectors described as "may be used" in the IEEE 802.3 environment only relate to the 10 Mbit/s application. Applications in the range 100 MBit/s, 1,000 MBit/s and MultiGig are not affected by this. Therefore, the user is obliged to select the right connector for the application.

The ISO/IEC 11801-x series of standards describes the generic cabling structure for different environments. This is also being expanded due to the new SPE applications. It defines the same connectors as in IEEE 802.3cg. A "may be used" connector is defined in the ISO/IEC as a "shall be used" connector at the TO (telecommunication outlet). There is thus a fixed definition of the mating face for the TO.

The following documents are affected by this:
Information technology – General cabling for customer premises:

- ISO/IEC 11801-1 AM1 (General requirements)
- ISO/IEC 11801-3 AM1 (Industrial premises)
- ISO/IEC 11801-6 AM1 (Distributed building services)

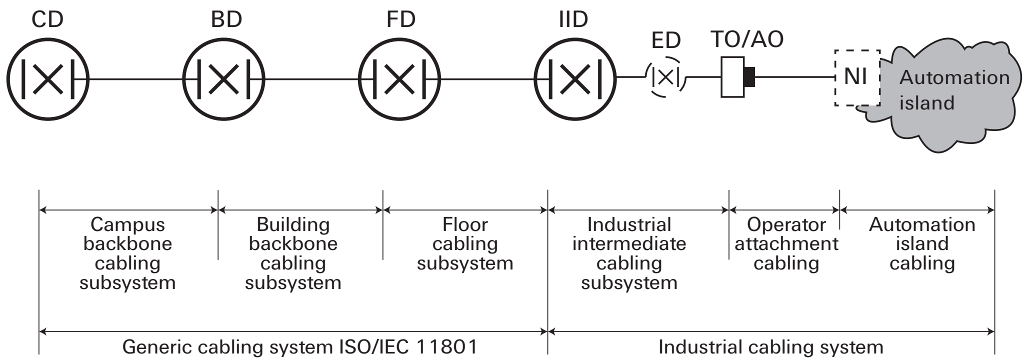

Image 2 shows the ISO/IEC 11801-3 AM1 cabling model (source: ISO IEC 11801-3)

In Figure 2, it is apparent that the TO represents the connection between automation and the factory hall. The specification for the mating face thus refers to applications outside of automation and therefore also to the connection of the automation island with generic cabling. The TO is therefore only described in the generic cabling in accordance with ISO/IEC 11801. Except for generic cabling, a TO is not used in PROFINET environments.

PROFINET and other industrial communication protocols define pure point-to-point cabling in their guidelines. Even the definition of the channel was not taken from generic cabling, instead a channel definition that has been adapted to the industrial environment was derived with the End-to-End link.

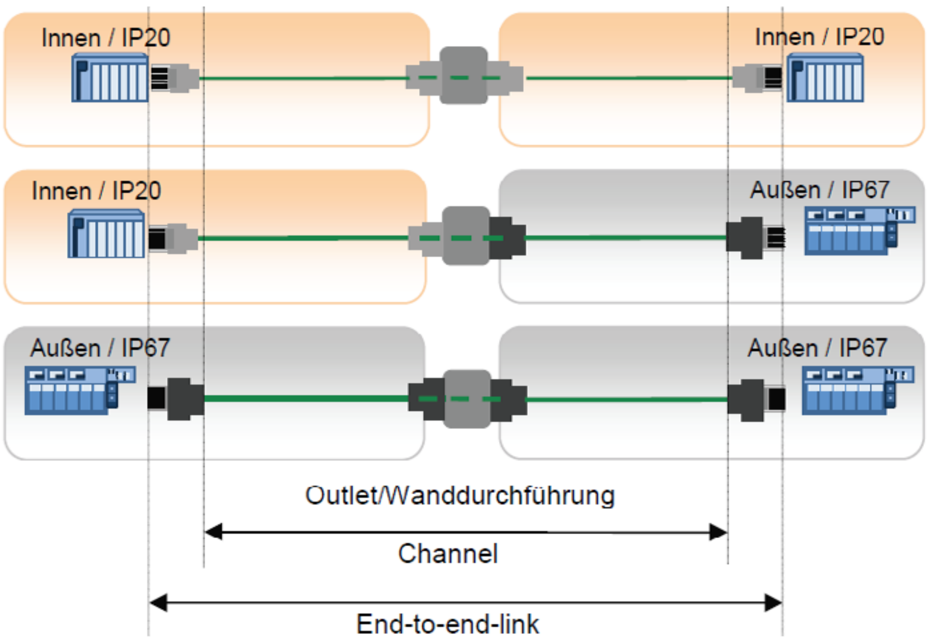

Image 3: Example variants for the End-to-End link in accordance with the PROFINET guidelines.

The normative process is currently underway but has not yet been completed. The claim that the market had already agreed upon a mating face, as was made by some manufacturers and is often mentioned in the trade press, is categorically incorrect. Important and powerful user organisations, such as PROFINET, are currently forming their own opinion and will deal with this subject area in the future.

4. SPE developments at Weidmüller: the connector is the first step

Weidmüller supports connector development for the IEC 63171-2 variant for IP20 environments and the IEC 63171-5 variant for IP67 environments. With a focus on cross-sections in the range AWG 26 – AWG 22, an extremely user-friendly portfolio can be established – with M8 connectors for plugs AND sockets. This applies both to free connectors on the cable as well as the fixed variant on the housing. This means there is no need for extension cables that only have plugs or sockets at both ends. This is essential for PoDL especially, as the live side must always be designed as a socket. A third advantage of the Weidmüller solution is the significantly improved HF performance compared with competitor products, which means that the cabling will also meet even higher performance demands in the future.

A further advantage of the solution developed by Weidmüller is that the connection systems in accordance with IEC 63171-2 (IP20 environment) and IEC 63171-5 (IP-67 environment) have the same mating face. Both can therefore be freely combined. This compatibility is most beneficial in field measurement technology. Furthermore, the mating face can also be used independently of any application, from the workstation through computing centres and industrial cabling and to the cloud.

On this basis, the developers have established the key properties for SPE connectors used at machine level in order to satisfy all forms of industrial application. Initially the product range is wide, although this does not mean a plethora of different components, but rather components that are as versatile as possible to use. This includes the above mating face that is the same for IP20 and IP67 environments. This limits the number of components without reducing the application possibilities, which is advantageous in warehousing. The mating face naturally needs to be available as a free connector and also on the device side as both male and female. PoDL and daisy chaining are therefore supported, as was already typical for devices with M12/M8 connectors. This also includes straight and angled variants with and without LED for IP20 printer circuit board connectors; as well as continuous IP67 cabling on the basis of M8/M12 connectors.

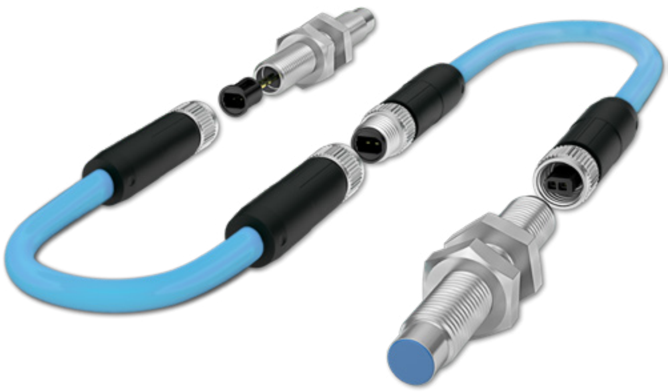

Image 4: The Single Pair Ethernet connector range is freely combinable and supports end-to-end, application-independent transmission, from the workstation through the industrial cabling to the cloud..

A further point is unrestricted **industry suitability**, which includes a robust locking mechanism as is the case with RJ45 connectors. The pull-out force is at least 50 N. Also, all components should also be easy to assemble in the field. Typical key technical data defined were cabling in the AWG 26 – AWG 22 range, an industrial dielectric strength of 2.25 kV DC and a permissible pollution degree of 2 on the printed circuit board. The electrical and mechanical connection must also be guaranteed in extreme applications at machine level. A Flexion Test in accordance with IEC 60998-2-X provides evidence for this. As part of this test, not only is the cable tested for axial strain, it is also loaded vertically. This simulates the loads that the cable is subjected to on a robotic arm, for example.

Image 5: Double port density thanks to halved size compared to RJ45 connectors.

As there is virtually no space for cabling in many Industry 4.0 applications, the **design** must remain **compact**. With a pitch of 7.62 mm, the version developed by Weidmüller is just half the size of an RJ45 connector. This means that two Single Pair Ethernet ports can be installed in the space occupied by an RJ45 PCB connector, doubling the port density.

A subsequent group of properties can be summarised under **Performance / Future Sustainability**. These points go together as they ensure flexibility in terms of faster transfer rates in further development and also enable existing installations to be expanded. The connector therefore offers investment security in all respects. This is guaranteed through aspects including high TCL (Transverse Conversion Loss) as well as good RL (Return Loss). The return loss describes the impedance behaviour between the connector and the socket. A high return loss ensures optimal data transfer to the interface. The TCL describes the connector symmetry. Optimal symmetry minimises external interference and is therefore an important characteristic for robust industrial environments. The connector is also suitable for use in Multi-Gig applications (2.5, 5, 10 Gigabit), as it is designed for data transfer rates of up to 4.0 GHz. This mating face therefore provides a solution for transfer rates of 10 Mbit to 10 Gigabit, from the sensor to the cloud.

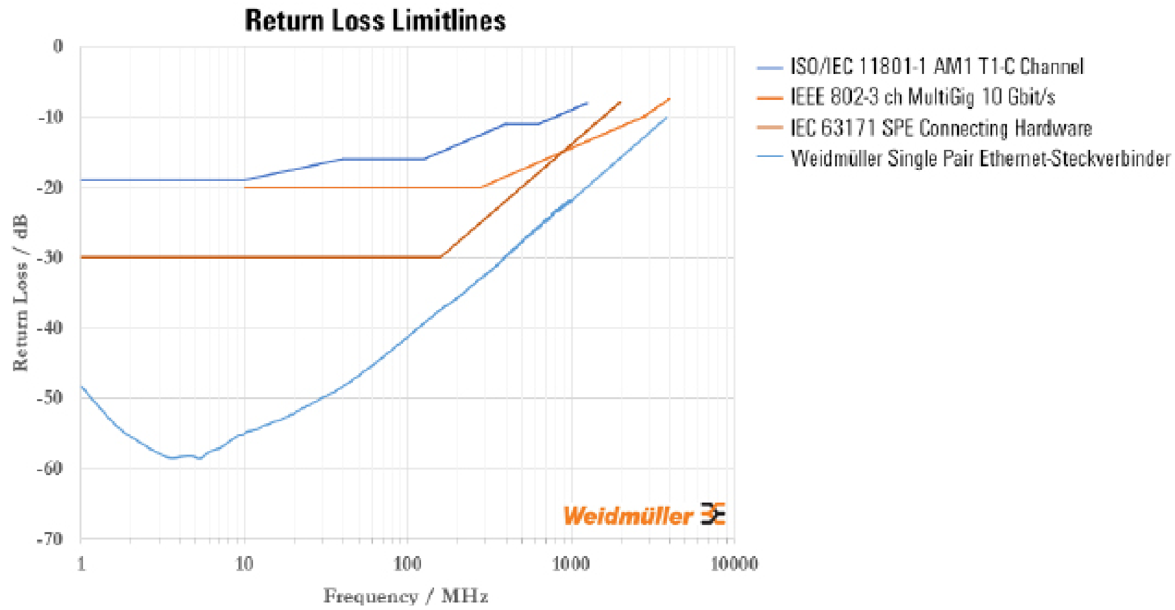

Image 6 illustrates the behaviour of the connector's return loss compared with current standards.

5. Even greater flexibility with a four-chamber solution

Besides the connector for a single cable as described above, Weidmüller is also planning to bring a four-chamber version onto the market that can be used to achieve four SPE cablings via one interface (cable sharing). The arrangement of contacts allows for ideal electrical properties. The contact pairs are arranged perpendicular to each other and minimise interference between the individual cables. The additional shielded cross reduces the remaining interference.

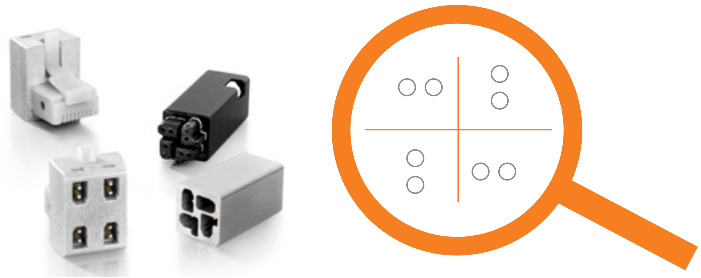

Image 7 illustrates the arrangement of contacts in the four-chamber system.

Thanks to this extremely compact design, four Single Pair Ethernet ports are possible in the installation space of an RJ45 connector.

A typical application would be a welding robot with closely spaced sensors at the far end of the arm. These can be connected without the need for an additional switch or via trunk cable. This kind of bundled structure is difficult to implement using other connection technologies.

Due to the increased demand for these connectors in category 8.2 in accordance with ISO/IEC 11801-1:2017-12, the four-paired connection technologies can be used in accordance with IEC 63171-2 and IEC 63171-5, independently of any application. Computing centres, offices, homes and industry are equally conceivable areas of use. With these features, the SPE solution from Weidmüller offers perspectives that go beyond those generally required in industry. The offering will be completed with active components in the future, meaning that the user will have a complete SPE infrastructure from a single source.

The right cable

Standardisation also deals with cabling of course. Manufacturers are currently developing lighter, thinner and more cost-effective cables that allow more Ethernet channels in existing cable runs, while supporting PoDL and enabling data and power to be transferred over distances of up to 1,000 m. They are also distinguished by broader bandwidth and robustness to electromagnetic interference. In the future, this will enable a cabling and network standard that can communicate with each sensor or actuator while supplying it with power. Just like the connectors, the cables also need to be robust enough for industrial use. Typical examples include a smaller bending radius for installations where there is a shortage of space as well as the Flexion Test previously mentioned.

The aim of the following four cable projects was to meet the channel requirements of IEEE 802.3. This is where both the mechanical and the electrical requirements are described in the series IEC 61156-11 to -14.

IEC 61156-11 MULTICORE AND SYMMETRICAL PAIR/QUAD CABLES FOR DIGITAL COMMUNICATIONS - Part 11: Symmetrical single pair cables with transmission characteristics up to 600 MHz - Horizontal floor wiring - Sectional specification

IEC 61156-12 MULTICORE AND SYMMETRICAL PAIR/QUAD CABLES FOR DIGITAL COMMUNICATIONS - Part 12: Symmetrical single pair cables with transmission characteristics up to 600 MHz - work area wiring

IEC 61156-13 MULTICORE AND SYMMETRICAL PAIR/QUAD CABLES FOR DIGITAL COMMUNICATIONS - Part 13: Symmetrical single pair cables with transmission characteristics up to 20 MHz - Horizontal floor wiring - Sectional specification

IEC 61156-14 MULTICORE AND SYMMETRICAL PAIR/QUAD CABLES FOR DIGITAL COMMUNICATIONS - Part 14: Symmetrical single pair cables with transmission characteristics up to 20 MHz - work area wiring (Currently in preparation)

Impulses from the automotive industry

To conclude, let us take a look at the latest developments from the automotive industry, the original initiator of SPE. This sector is also driving forward standardisation. Ethernet systems are being increasingly installed in the current vehicle generations. Further innovations in the areas of driver assistance systems, such as Lidar (light detection and ranging, used for detecting objects), high-resolution displays, autonomous driving, 4K cameras and infotainment can only be achieved by networking control units and sensors. The development of the automotive Ethernet has resulted in two official IEEE standards: 100BASE-T1 (100 Mbit/s based on BroadR-Reach technology) and 1000BASE-T1 (1 Gbit/s). Fundamentally, this was centred around defining limit values for the connector and cable components as well as associated measurement methods based upon the requirements of the entire channel that was defined in the IEEE standard.

Hardware for the Ethernet of the future

SPE will play a major role in many areas of communication architecture. It offers continuous, scalable and deterministic networking from the sensor to the cloud. Thanks to PoDL, besides a data interface it also delivers power wherever it is needed, even where there is a severe shortage of space – provided that the cabling is suitably compact. Weidmüller has therefore developed a connector that is only half the size of an RJ45 connector and offers the same mating face for both the IP20 and the IP67 versions. It can be used from the workstation through to computer centres and machine-oriented sensors. This makes the Weidmüller solution the ideal tool for IoT and Industry 4.0 applications.

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