A technical paper of the Single Pair Ethernet System Alliance

Authors:

Simon Seereiner	Weidmüller Interface GmbH & Co. KG
Frank Gudat	Kyland Technology EMEA GmbH
Matthias Gerber	Reichle & De-Massari AG
Bruno Escher	Draka Comteq Germany GmbH
Stephan Schreiner	Rosenberger Hochfrequenztechnik GmbH & Co. KG
Sascha Lambauer	Weidmüller Interface GmbH & Co. KG
Martin Miller	Microchip
Ralf Tillmanns	Weidmüller Interface GmbH & Co. KG

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Introduction

IP-based multidrop networks offer a number of industries exciting possibilities for integrating IP-based devices into an Ethernet network. For example, the IEEE adopted the 10BASE-T1S standard in November 2019. The suffix "S" stands for "short range". This standard works in half-duplex mode and can be operated in both point-to-point and multidrop applications. It defines a minimum length of 25 m with 10 cm stubs.

An advantage of this network topology is that the network nodes do not require an active Ethernet-switch. The PLCA (Physical Layer Collision Avoidance) arbitration scheme ensures that no data collisions occur in the bus line. The standard provides for at least eight stubs, but there can be many more.

In addition, the IEC NP 61158-1 project (Type 28 AUTBUS) is currently being developed in international standardisation. The multidrop bus described there will make it possible to operate up to 256 nodes in a length segment of up to 500 m with a bandwidth of 100 Mbit.

Objective of the Whitepaper

This Whitepaper is aimed at product managers and developers of Single Pair Ethernet infrastructure components who want to learn more about multidrop Single Pair Ethernet. It provides a comprehensive explanation of the concept of multidrop SPE technology and its use cases. It gives an overview of the current technology, the use cases addressed and the current status of connectors and standardisation.

Overview of multidrop technologies today

Motivation for multidrop

Multidrop networks integrate many network nodes in a small space. These networks offer advantages in automotive applications as well as in industrial and building automation.

The technology does not require Ethernet-switches, as all participants are connected to a single bus. One of these communication participants on the bus is also defined as the server The server has the task of preventing data collisions on the bus. This is achieved by means of Physical Layer Collision Avoidance (PLCA for short).

To this end, the server opens a time window typically of 25 µs for the first node. The node may transmit data within this window (transmit opportunity). If it allows the time period to elapse, the next node in the network is given the opportunity to transmit within 25 µs. This procedure is repeated until the final node gets an opportunity to transmit, after which the cycle is completed and everything starts again from the beginning.

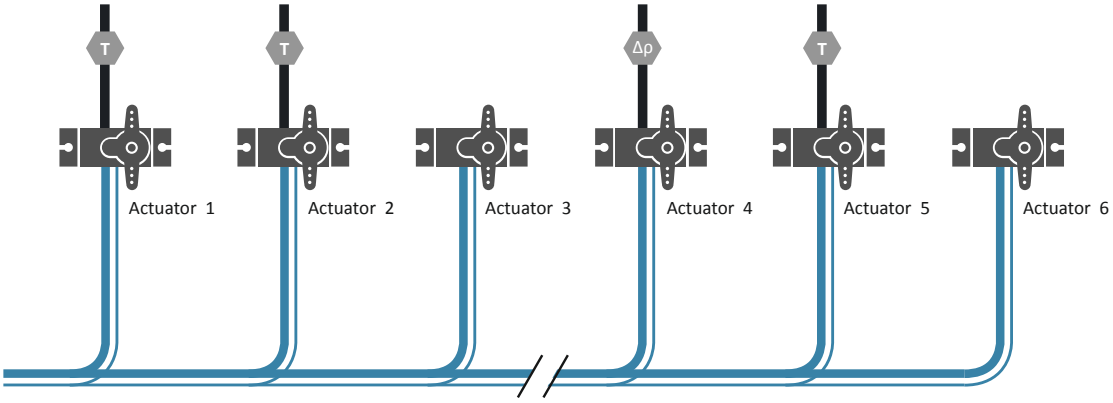
The advantage of this method is that several participants can communicate within a network without switches. This allows for very compact structures when setting up networks, while simultaneously keeping the costs for the infrastructure low. The technology is already used today in vehicles to integrate many different devices into a transparent network in a way that saves space and weight.

Which multidrop buses are used today

MP-Bus

The MP-Bus (Multi Point Bus) was developed by Belimo for controlling ventilation dampers. It is a 3-wire server-client bus system with power, ground and data and can control up to 16 devices in a bus structure. The application is mainly designed for the control of actuators. The return channel for sensor data is very limited. The transmittable data rate is low compared to Single Pair Ethernet, but there is sufficient power supply for the mechanical movements. The power can be supplied as a DC or AC current.

The MP-Bus



The transmission distances depend on the required current transmission power and the wire diameter used. Typical operating distances range from a few metres to a few dozen metres.

The bus server frequently serves as a gateway to higher-level protocols such as BACnet or IP. SPE would be suitable for connecting the actuators and sensors with IP. However, implementing the free choice of topology is a challenge without the use of active SPE bridges.

ASi bus

AS-Interface, or ASi for short, stands for Actuator Sensor Interface. It has been an international standard according to IEC 62026-2 since 1999. As the name suggests, sensors and actuators are connected to it and operated.

The latest version is ASi-5, but the previous version ASi-3 is still widely used among ASi users. The system is operated on 2-wire technology with parallel, unshielded wire pairs. It also enables safety and IO-Link connections, for example, and offers the possibility of setting up all common topologies. The maximum cable length without repeaters is 200 m with ASi-5. Up to 384 digital inputs and 384 digital outputs can be connected to ASi-5. It can be connected to all common fieldbus systems by means of an ASi gateway and is currently the most widely used in the intralogistics sector.

Compared to ASi, SPE offers the advantage that communication does not require a gateway, which has to be parametrised. This means that customers do not have to use another software tool. However, ASi is not routable and therefore offers its own security features.

Multidrop in vending machines

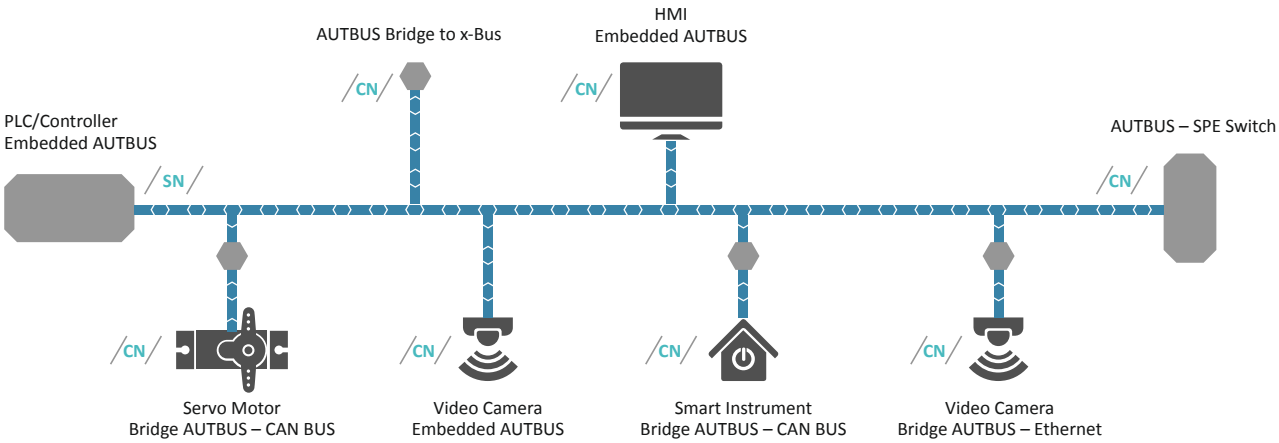
The multidrop bus (MDB) is a multidrop bus computer network protocol used by the vending industry, published by the American National Automatic Merchandising Association and supported by the European Vending Association and the European Vending Machine Manufacturers Association.

The physical connection is implemented as a serial bus with a fixed data rate of 9600 baud. The multidrop bus is used, for example, in coin changers, banknote readers, cashless payment systems and beverage and cigarette vending machines.

AUTBUS Multidrop (IEC 61784-1-22 Industrial networks – Profiles 22)

AUTBUS Multidrop is an industrial broadband fieldbus newly created by Kyland Technology, which is a multi-drop, single-pair solution based on static/dynamic time-driven and Orthogonal Frequency Division Multiplexing (OFDM) technology. The OFDM method has so far been popularly used in wireless communication. With the features of broadband, low latency and deterministic, AUTBUS is now to be established in the field of industrial communication. The mission-critical deterministic challenges can be solved in a wide variety of industrial applications. Leveraging the tunnelling technology, AUTBUS can carry IPV4/IPV6 data over single pair, it simultaneously enables the transmission of both time-sensitive and non-time-sensitive data as a virtual bus. With the qualified two-wire cable, up to 254 multi-drop connections can be achieved over a distance of up to 500 metres at a transmission speed of 100Mbit/s. At the time this Whitepaper was realized the AUTBUS is still in standardization phase (planned to be released at the end of 2022) and is listed under the number IEC 61158 Type 28 and IEC 61784 CPF22. Possible areas of application are factory automation, buses and trains, building automation, but also traffic control systems and video transmission.

AUTBUS Multidrop Gateways external and embedded



This standardisation project (together with the planned companion projects IEC 61158-3-28, IEC 61158-4-28, IEC 61158-5-28 and IEC 61158-6-28) defines a new wideband fieldbus type entitled "Autbus".

Areas of application for multidrop with Single Pair Ethernet

Automotive industry

By now, almost all automotive OEMs have introduced Single Pair Ethernet technology with 100 Mb/s or more in their production vehicles. However, it turns out that only about 7 percent of the nodes require a data rate in the range of 100 Mb/s and beyond, while 93 percent of in-vehicle network (IVN) nodes are supplied with data rates below 10 Mb/s. This is where the new multidrop competes with Single Pair Ethernet technology. In this range, the new 10BASE-T1S SPE standard competes with established, cost-optimised systems such as CAN, FlexRayTM and LIN.

However, the introduction of multidrop in 10BASE-T1S can considerably reduce the network complexity and thus also the costs compared to star-shaped wiring. The optional integration of the MAC into the phy chip offers further potential for cost reduction, which in turn further reduces system costs.

Thus, the 10BASE-T1S is another building block for automotive Ethernet in the lower data rate range, offering data rate scalability from 10 Mb/s into the future multi-gigabit range. The system enables Ethernet-based end-to-end communication without additional gateways for subscribers with lower data rates. It can be optimally integrated into a vehicle's zonal architecture and can access technologies such as MACSec, IPSec and D/TLS for data security. Multidrop also offers a simple and easily expandable option for including control units, sensors and actuators – which may only be available as optional equipment for the vehicle – in the wiring harness.

Owing to the different data rates, possible applications for multidrop in vehicles include ultra-short-range radars, ultrasonic sensors, audio services, lighting applications and direct control tasks in the powertrain. Wiring – for example, within and to a door with window lifters, settings for mirrors and central locking – is also one of the many conceivable use cases.

Industrial EtherNet/IP in-cabinet bus

The EtherNet/IP in-cabinet bus system connects component devices – pushbuttons, indicators, overload protection devices, etc. – in the panel. It replaces the fixed wiring between the devices with composite network wiring. The advantages include quick installation, programmable function changes and "intelligent" devices that provide more information for maintenance and process optimisation.

The system uses a Single Pair Ethernet bus, which reduces complexity and the average quantity of device interfaces. Mains power and switching current are bundled in a multi-core cable, and installation is via insulation displacement connectors. This simplifies cabling and installation.

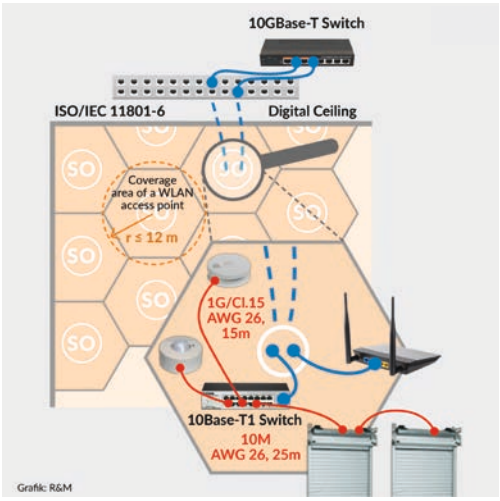
The relative positions of the devices on the bus cable can be localised, eliminating the need for manual selector switches or configuration tools attached directly to the devices and thus reducing device and installation complexity.

This bus solution reduces interface components by using the 10BASE-T1S standard. Thus, multidrop cabling can be set up with one interface per device and one switch port supporting many devices.

The network and control power supply via a single cable avoids parallel routing and ensures further cost savings. In addition, more devices can provide diagnostic, prognostic and asset identity information, which can prevent unplanned downtime and improve equipment efficiency.

Elevators (Lifts)

Multidrop technology also offers many advantages in the area of elevator and escalator systems. In elevator systems, for example, more and more sensor technology is being installed in the shaft. At the same time, passenger cars are getting larger, reducing the space available in the shaft. In the future, all devices responsible for safety and comfort in an elevator system should be able to be integrated into a single network. Multidrop systems can significantly reduce the amount of wiring required within elevator shafts. Another advantage is that functionalities such as additional cameras, LED lights or safety control panels can be added very easily. All devices can then be integrated into one transparent, IP-based network.



Varianten der PHY-Implementierung.

Building infrastructures

In intelligent buildings, there are many areas of application for the SPE multidrop protocol. In existing digital ceiling solutions, for example, a suitable SPE switch can be placed directly at the service outlet, where it can convert Ethernet signals to SPE.

SPE multidrop with a speed of 10 Mbit is particularly suitable where applications are installed in a row with regular intervals. For example, blind controls on a window front are predestined for the use of SPE multidrop.

Charging stations for electric vehicles

As electric mobility continues to gain ground, the number of charging stations for electric vehicles in public spaces is growing. This requires not only power lines, but also wireless or wired communication – for access control for charging, billing or remote maintenance, for example. A multidrop solution is particularly suitable in this case for the simple networking of charging stations, for future extensions and, if required, also for the connection of additional devices to the charging station.

Parking management

Paid parking areas usually have entry and exit stations with barriers, automatic pay stations and video cameras. More state-of-the-art parking areas also have sensors for determining parking space occupancy and signalling systems for traffic management. In the future, services such as app-based parking reservations and cashless payment of parking fees will be offered, among others.

Existing parking areas can be modernised with a multidrop solution, making it easy to connect devices such as video cameras, parking sensors and parking reservation systems.

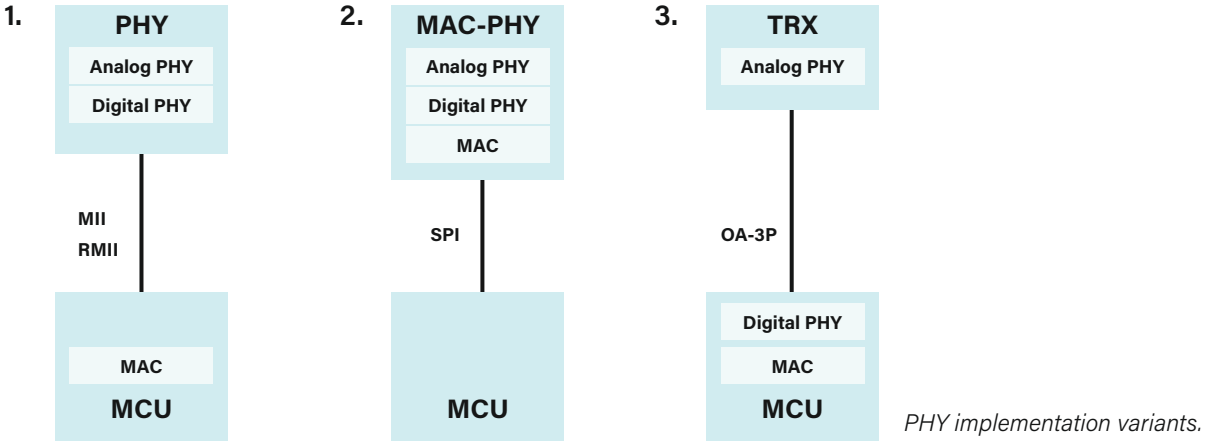
Technology for 10BASE-T1S multidrop

10BASE-T1S PHYs supporting full-duplex point-to-point operation can operate at an effective data rate of 10 Mb/s in each direction simultaneously. They support up to four inline connections and a range of up to at least 15 m.

In addition, the 10BASE-T1S-PHY can operate with half-duplex communications on a mixed segment using a single balanced wire pair connecting up to a minimum of 8 PHYs to form a trunk with a range of up to 25 metres. The PHYs can be placed in-line with the trunk or at the end of stubs up to 10 cm long. The total effective data rate is 10 Mb/s and is shared between the nodes. A larger PHY quantity and range can be achieved if the specifications in the IEEE802.3cg standard for mixed segments are met in IEEE 802.3cg clause 147.8.

PHY implementation of multidrop

Each technology can be implemented in different ways. In the case of SPE, currently these three variants are available:



PHY implementation variants.

1. PHY: The MCU (microcontroller unit) or switch is connected to the PHY via a MII (Media-Independent Interface) using a purely digital connection. The PHY encloses everything specific for the physical layer (coding, arbitration, analogue cable driver, etc.). The MAC (Media Access Controller) in the MCU filters the incoming Ethernet packets. This is the classic implementation of Ethernet-based systems.
2. MAC-PHY: The MCU is connected via SPI (Serial Peripheral Interface). The MAC-PHY filters the incoming Ethernet packets and transfers only those relevant for the MCU to the application interface. As a rule, a MAC-PHY is selected if a small MCU without a MAC is to be used.
3. Transceiver: The transceiver contains only the cable driver. All digital parts of the PHY are housed in the MCU. Since the transceiver has a straightforward function, it can be accommodated in a small housing with only a few pins (8 for example). This type of CAN-equivalent implementation is usually the most cost-effective.

Connectors for Single Pair Ethernet

It has been found that different connectors must be used for different applications. This is because different application areas have different requirements for data rates (10 Mbit/s to 1 Gbit/s), cabling diameters (AWG 18 – AWG 27) and cabling lengths (up to 1,000 m).

In the automotive sector, short distances and high speeds are in demand. A standardised interface per automotive series is not absolutely necessary in this area. Since the volume in this segment is very high, connectors can be developed and used specifically for the requirements of a given automotive series.

Another area of application is building automation. Many market participants are convinced that SPE is ideal for connecting a variety of building automation applications to the data network. SPE components are much more compact than standard RJ45 connectors, which makes it possible to increase the connection density on network devices in the building sector. This is the basis for connecting light, temperature, smoke or air sensors to the network or for controlling windows and shutters. The application example of digital ceilings is often mentioned in this context. In this case, SPE channels are bundled within the structured digital ceiling cabling across several zones up to the floor distributor. This makes it very easy to integrate things like smoke detectors or lighting sensors into a building network.

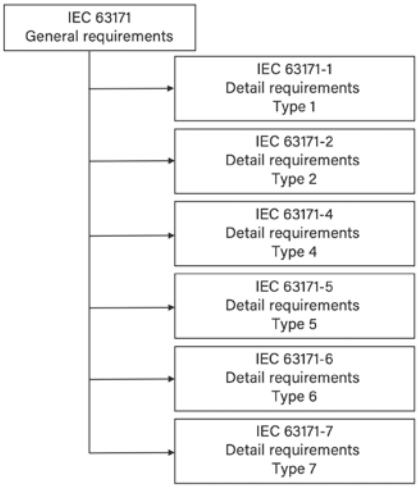
In the application area of factory automation, complete digitalisation is currently underway. Nowadays, an average factory already produces a terabyte of data per day. Yet less than one percent of the data collected is actually used and evaluated. To make the data accessible, continuous communication suitable for industrial use is required. This is exactly what SPE stands for: continuous, scalable and deterministic networking from the sensor to the cloud. Another challenge is that the number of intelligent end devices is constantly increasing, but the amount of available space is not – in fact it is quite the opposite. In addition, more and more sensors are being integrated into machines and systems. Thanks to its compact and simple design, SPE provides cabling for this that is suitable for industrial use – even at extreme usage sites where lightweight cables with a small outside diameter and small bending radius are essential, such as in robotic arms.

	Automotive	Building automation	Process automation	Factory automation
				
Application focus	Wiring harness in the automobile	Switch cabinet wiring Field cabling (e.g. KNX)	Field cabling sensors	Ind. switch cabinet wiring Field cabling Field cabling sensors
Transmission rate Transmission distance	10 MBit/s - 1 GBit/s 15-40 m	10 MBit/s - 1 GBit/s < 1000 m	10 MBit/s < 1000 m	10 MBit/s - 1 GBit/s ≤ 100 m
Conductor cross-section	AWG 26-22	AWG 26-22	AWG 22-18	AWG 26-22
Mech. / electr. robustness	medium – high	low – medium	high (+Ex)	medium – high
Current connectors	Automotive-specific connectors	Individual wiring, terminal, EIB, RJ45	Terminal, plug connector, M12	RJ45, single wiring, terminal, M8/12

Different industry requirements for Single Pair Ethernet

IEC-standardised connector variants

The IEC 63171-x series of standards not only standardises the individual mating face variants, but also the electrical and transmission properties. The properties are described in IEC 63171 "Connectors for electrical and electronic equipment – Shielded or unshielded free and fixed connectors for balanced single-pair data transmission with current-carrying capacity – General requirements and tests". The entire series of standards has the following structure:



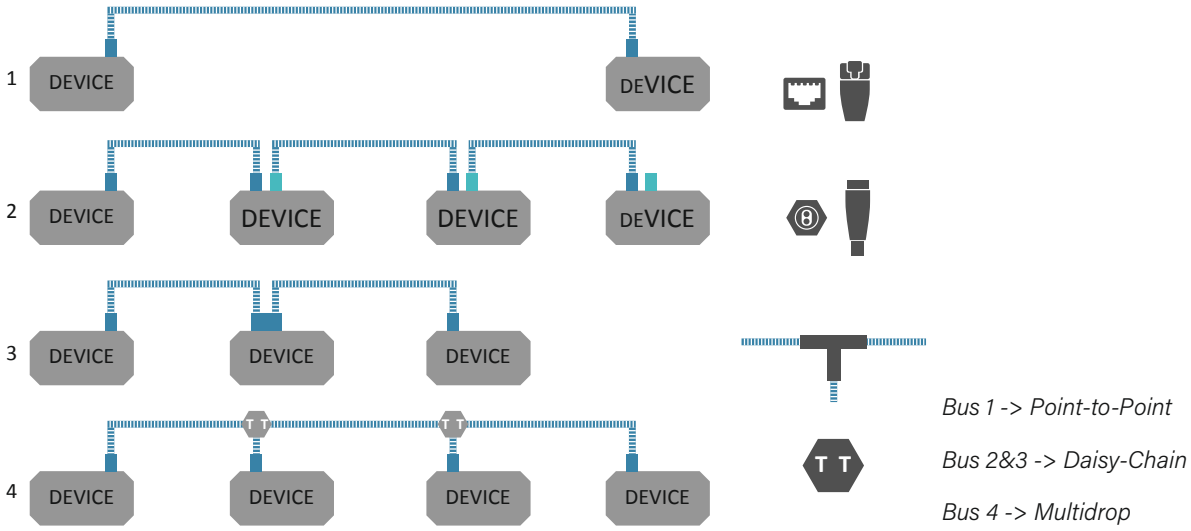
The current IEC 63171-x lists the different connectivity variants.

Multidrop bus topologies

The bus topologies for multidrop can take different forms, as shown in the image below. Normally, a point-to-point connection is established with Ethernet (see 1). If a switch functionality is built into the device, daisy-chain topologies can be established (see 2). Like multidrop, these allow the devices to be arranged in a line or even in a ring.

Multidrop topologies start as soon as a cable gets a branch without an active component that allows a device to communicate with several other devices simultaneously. This is called a T- or Y-branch. They are often implemented in IP67 with circular connectors (see 4). True multidrop refers to a continuous cable that is branched off as needed using insulation displacement technology (IDC). This means that the branch can be placed at any point. Likewise, the cable can be cut at any point and a branch can be realised there with the help of a connector.

Multidrop-Bus-Topologien



Bus 1 -> Point-to-Point

Bus 2&3 -> Daisy-Chain

Bus 4 -> Multidrop

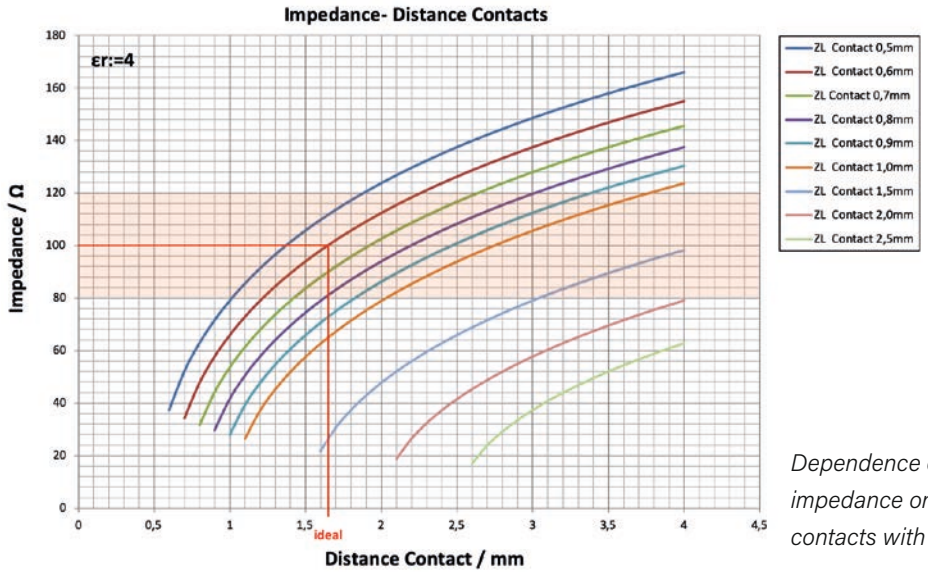
It is important that the devices are always equipped with a connector socket. This is the only way to build devices that support the different topologies. However, there are important boundary conditions for the infrastructure in multidrop applications. Different distances between the devices, different cable pitch diameters in connection with the PHYs used require a consistent physical adaptation of the cables and the connectors.

The following boundary conditions are important here.

Requirements for multidrop connectors

Impedance

In the cabling infrastructure for application-neutral design, the normative impedance (characteristic impedance) has been set at the value of 100 ohms. All individual components – for example electrical connectors, cables, etc. – must be oriented towards this characteristic impedance. The defined characteristic impedance also affects the dimension of the mating face in the area of the mating zone between socket and plug. Decisive for the design of the mating system is the contact thickness, the distance between the two contacts and the material of the contact carrier (permittivity of the plastic).



Dependence of the characteristic impedance on the distance between contacts with different contact diameters

Dielectric strength

Dielectric strength refers to the property of preventing arcing between two points up to a certain voltage. The dielectric strength of a connector is tested with DC or AC current.

Although there may be a high insulation resistance between two points of the connector, the dielectric strength is often limited. It mostly depends on the geometrical properties within the connector. A distance between the shield housing and the contact of an electrical connector can, despite a high insulation resistance, have a relatively low dielectric strength if the distance or the insulation material are not chosen appropriately.

The standards of IEC 63171 as well as IEEE 802.3cr limit the dielectric strength as follows:

- between the contacts with at least 1000 V DC
- between contact and shield with at least 1500 V AC or 2250 V DC

Transmission properties

The transmission properties are divided into three categories:

- Category A from 0.1 to 20 MHz
- Category B from 0.1 to 600 MHz
- Category C from 0.1 to 1250 MHz

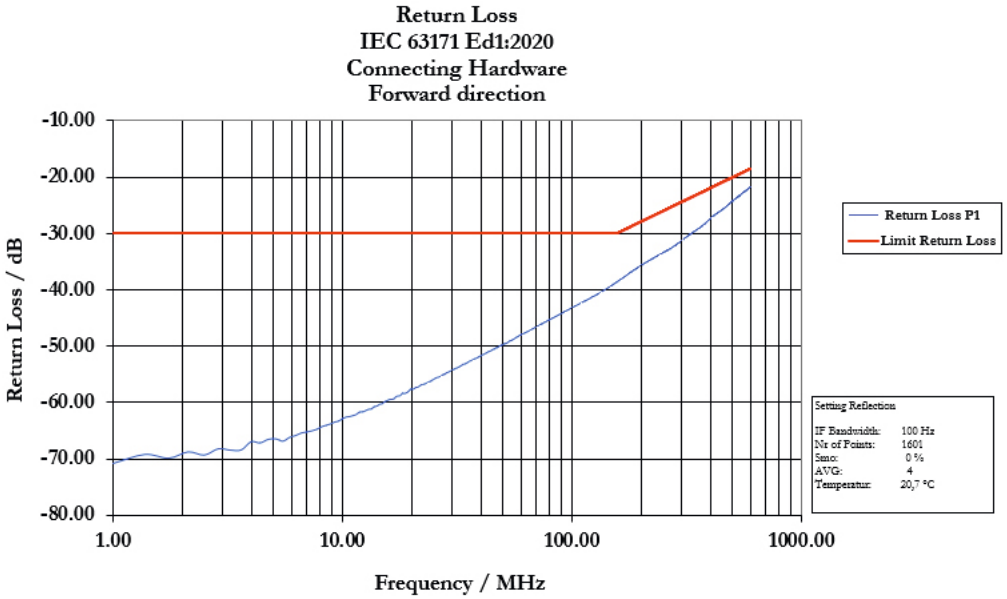
Category A supports the 10 Base-T1 application from IEEE 802.3cg, Category B the 100/1000 BASE-T1 application from IEEE 802.3bw/bp and Category C the MultiGig 2.5G BASE-T1 application according to IEEE 802.3ch.

Category according to IEC 63171	Application	IEEE standard
A (20 MHz)	10BASE-T1S 10BASE-T1L	802.3cg
B (600 MHz)	100BASE-T1 1000BASE-T1	802.3bw/ 802.3bp
C (1250 MHz)	2.5GBASE-T1	802.3ch

Return loss (attenuation)

In a reflection, an incoming signal is partially reflected by an impedance difference. Since the impedance depends on the frequency, the reflection also depends on the frequency. The return loss is specified in dB and is the logarithmic ratio between the reflected signal and the input signal. The greater the return loss, the better the impedance adaptation. Return loss is particularly important for applications with simultaneous transmission in two directions.

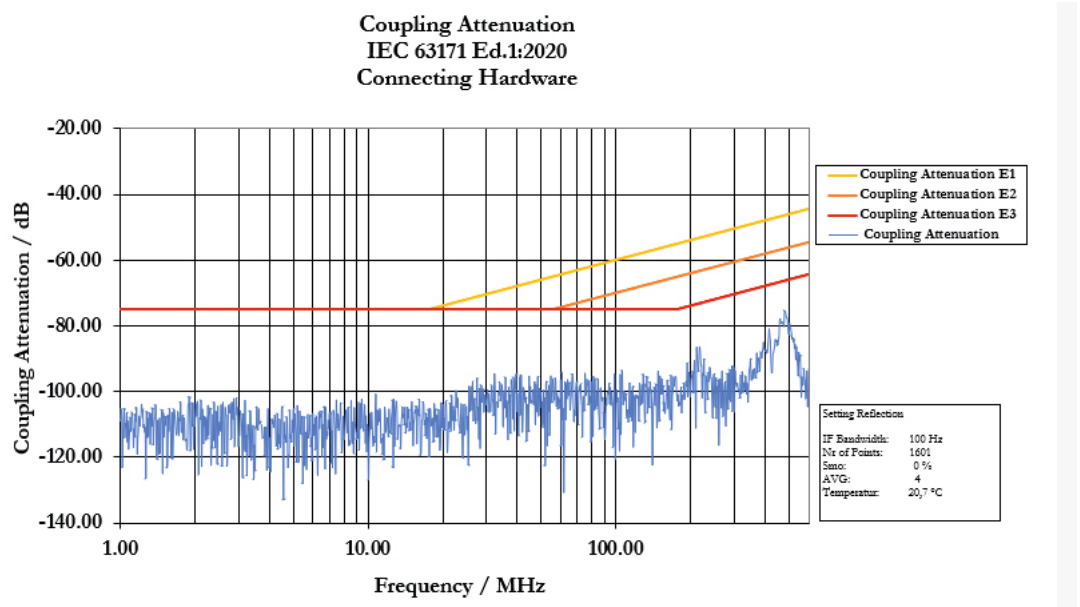
In the SPE environment, the requirement for return loss in electrical connectivity is more strictly defined than the requirement for Category 8.1 /8.2 from ISO/IEC 11801-1. For this reason, the geometric design of an SPE connector must be selected more homogeneously than for an RJ45 connector.



Typical measurement result of electrical connectivity according to IEC 63171-2

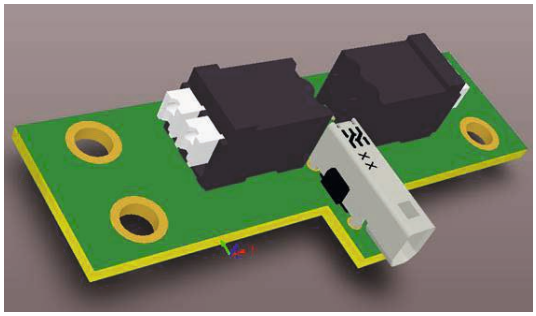
Coupling attenuation

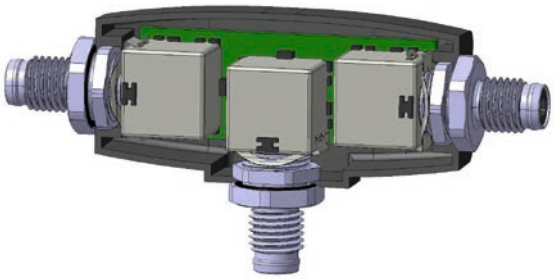
Another parameter describing transmission properties is coupling attenuation. On account of the inhomogeneity of the connector, interference from the shielding can induce interference on the data contact pair. Not only the shielding effectiveness of the connector has an influence on the coupling attenuation, but the symmetrical design of the connector can also influence coupling attenuation.



Typical course of the coupling attenuation of electrical connectivity according to IEC 63171-2

A possible connector for multidrop applications is currently under discussion at the IEEE 802.3da. Since there are still no clear specifications for the channel definition (length segments, number of nodes, stubs/drop lines) for multidrop, no connector has been defined as of yet. However, the basic principles of connector technology mentioned above must be adhered to. Therefore, the IEEE will probably adopt one of the IEC 63171-SPE connector variants.





Picture of a possible connector with a drop line

Powering of SPE systems

Within the framework of SPE, the "Power over Data Line" (PoDL) offers the possibility of supplying sensors and other Ethernet nodes with low power consumption by means of remote power supply via the SPE two wire cable. With this differential remote power supply, a DC supply voltage is superimposed on the AC-coupled data signal by means of inductors in the PSE (Power Sourcing Equipment) and at the PD (Powered Device). PSE and PD are standard terms used in Power over Ethernet discussions.

There are 16 different performance classes for the devices, ranging from 0.5 W to 52 W, which can also differ in the supplied voltage. Classes 0 to 9 were originally designed for 100BASE-T1 and 1000BASE-T1 data links in the automotive sector, while classes 10 to 15 were introduced into the Ethernet standard in the course of the 10BASE-T1 extensions.

Class	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
V max (V)	18	18	18	18	36	36	36	36	60	60	30	30	30	58	58	58
V min (V)	4.94	4.41	12	10.06	10.3	8.86	23.3	21.7	40.8	36.7	14	14	14	35	35	35
I max (mA)	101	227	249	471	97	339	215	461	735	1360	92	240	632	231	600	1579
P max (W)	0.5	1	3	5	1	3	5	10	30	50	1.23	3.2	8.4	7.7	20	52
R_Loop (Ω)	6	6	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	65	25	9.5	65	25	9.5

Table based on information from IEEE Std. 802.3bu and IEEE Std. 802.3cg

This development can also be seen in the permissible loop resistances (R_Loop) of the channel, which are low at 6 Ω or 6.5 Ω for classes 0 to 9 due to the short cable lengths in the vehicle. This contrasts with classes 10 to 15, for which a relatively high resistance of up to 65 Ω was selected in the course of the introduction of 10BASE-T1L, also against the background of the possible 10BASE-T1L cable length of over 1,000 m.

For point-to-point data links, such as those provided for 10BASE-T1L, 100BASE-T1 and 1000BASE-T1, the PSE and PD first negotiate at start-up whether the device must be supplied and, if so, which performance class – and thus also supply voltage – must be provided by the switch.

However, such an approach is unfortunately not possible within the multidrop architecture specified in 10BASE-T1S. In this case, only one supply voltage can be specified on the cable, which is then available to all participants – required or not.

Since a fundamentally different procedure is required for PoDL in multidrop systems than in the other SPE variants, PoDL was initially explicitly excluded for multidrop applications within the IEEE standardisation. In order to expand the usability of multidrop technology, however, the IEEE "Multidrop Enhancements Task Force" was founded as early as June 2020. In addition to the topics of "greater range" and "more subscribers", it also deals with PoDL in multidrop systems.

For the future, it can therefore be assumed that PoDL will also be available for SPE multidrop and that several low-power consumers can be easily connected in line as well as daisy-chain topology by means of a twisted pair cable for power supply and data traffic. In a connection, the stubs for each node are connected to a continuous, uninterrupted twisted pair cable. In a daisy chain connection, the twisted pair cables and the stubs are connected to a T- or Y-connection (see multidrop bus topologies), which can also be, for example, a connection between the connections on a conductor path.

Standardisation

The standardization of SPE and Multidrop is discussed and promoted in the following committees, among others.

1. IEEE: Specification of the transmission channel and PHY from the Media Dependent Interface (MDI) downwards. The IEEE only works on the technical aspects of the Ethernet standards.
2. Ethernet Alliance: Non-profit organisation for organising Ethernet events such as plug fests. It serves to promote the work of the IEEE.
3. OPEN Alliance: Further defines specifications to enable applications of the technology in vehicles and other applications (interoperability test, energy saving modes, cable diagnostics, SPI protocol for the MAC PHY, etc.). The OPEN Alliance was started by automotive interests, but now includes industrial companies too.

A multidrop cabling structure has already been processed and adopted in the standardisation project "IEEE P802.3cg™ Standard for Ethernet Amendment 5: Physical Layer Specifications and Management Parameters for 10 Mb/s Operation and Associated Power Delivery over a Single Balanced Pair of Conductors". Currently, various committees are working on further standardisation projects on the subject of multidrop.

10BASE-T1S Multidrop (IEEE 802.3cg)

IEEE 802.3cg defines half-duplex communication on a multidrop mixed segment using a single balanced wire pair, allowing 8 PHYs or more to be connected to a trunk of up to at least 25 m. No power has been defined for multidrop.

10 Mbit/s Single Pair Multidrop Segments Enhancement (IEEE P802.3da)

The "10BASE-T1M" project describes an IEEE 802.3 physical layer specification for a 10 Mb/s Ethernet LAN (Local Area Network) with a single pair of conductors as a common transmission medium with a range of up to 50m minimum.

Outlook

Single Pair Ethernet and multidrop offer many advantages for new applications, combining compact dimensions with an industrial-grade contact system, easy installation and future-proof transmission rates. Multidrop takes Ethernet to the next communication level and is predestined for future compact digital communication interfaces. It marks the future of a uniform Ethernet communication infrastructure.

With multidrop, switches are no longer used within a segment, but instead it enables line or daisy-chain topologies. Integrating one or more switches allows a tree structure to be built. Each device in the line can provide a connection to an IP network, if required. Since protocols no longer need to be converted, installation is simple and cost-effective.