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MEETING SINGLE-PAIR ETHERNET AND POWER DELIVERY CHALLENGES

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MEETING SINGLE-PAIR ETHERNET AND POWER DELIVERY CHALLENGES

Ethernet networks are by far the most dominant technology for networking today, connecting business and enterprise networks, data centers, industrial automation systems and more. Hundreds of millions of Ethernet network interface cards (NICs), repeater ports, and switching hub ports have been sold to date and the market continues to grow. Networks migrating to Ethernet platforms include security networks, intelligent industrial networks, and intelligent building platforms.

While Ethernet started out as a protocol for copper coaxial cable, it has migrated to balanced twisted-pair and optical fiber. The latest iteration is Single-pair Ethernet (SPE). As its name suggests, SPE cabling uses only one pair of wires to transmit data rather than the 2-pair solution that has long been standard in the majority of Ethernet cabling.

Using SPE as a technology platform for applications that currently use Fieldbus or similar network protocols would create a common network and a common link between information technology (IT) systems and operational technology (OT) devices that may be operating in different environments.

COVER ARTICLE BY
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and Harshang Pandya

In 2018, Industrial Ethernet surpassed traditional fieldbuses for the first time (Figure 1). By 2019, Industrial Ethernet made up 59 percent of the global market compared to 52 percent in 2018.[1]

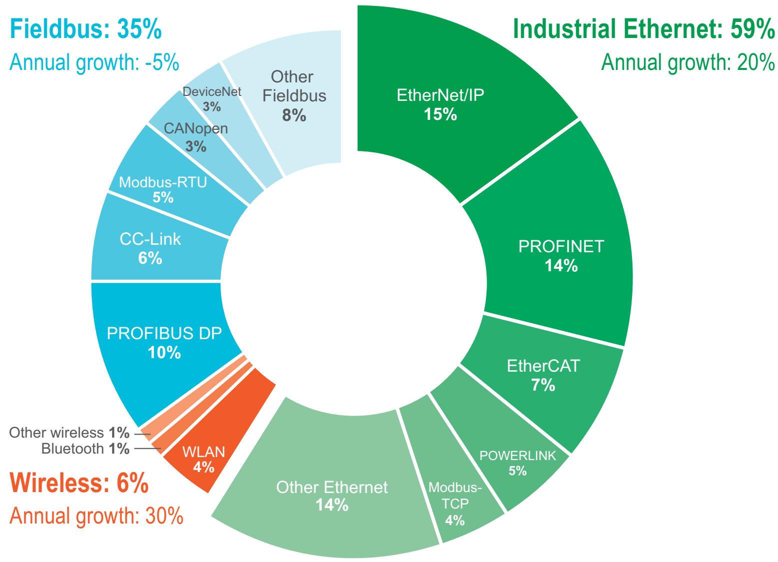


FIGURE 1: Growth of Industrial Ethernet.

APPLICATIONS SUITABLE FOR SINGLE-PAIR ETHERNET TECHNOLOGY

Driving interest in SPE technology is the desire to use a common network for IT and OT devices rather than Fieldbus technologies, such as Profibus, Modbus, CAN bus, and Foundation Fieldbus.

The initial applications for SPE were and continue to be in automotive and transportation environments, which were addressed by the IEEE 802.3bw standards in 2015. They supported 100 Mb/s over a 15 m (≈49 ft) reach in automotive environments, such as infotainment systems and other device connections. Over the next year, the 802.3bp-2016 standard increased the speed to 1 Gigabit over 15 m for automotive applications and 100 Mb/s over 40 m (≈131 ft) to support aircraft, railways, buses, heavy trucks, and industrial controls. These standards also include power to devices with Single-pair Power over Ethernet (SPoE) that delivers up to 52 W.

A single-pair connection is ideal for applications that require limited power and low bandwidth but need a longer distance, such as industrial automation. For industrial applications, SPE is much faster than many legacy systems used to support sensors for temperature, light motion, slow pressure, and controls (e.g., valves, relays, and contacts).

Four-pair Ethernet has been used for some time in industrial applications, so the introduction of SPE continues the trend of reducing the size of cable. It also provides the opportunity to drive SPE to the edge of the network where industrial controls and gateways exist that require translation.

Additionally, SPE technology is also well suited for intelligent building applications where it could replace legacy Fieldbus technology, such as RS485-based systems that traditionally support access and Heating, Ventilation, and Air-Conditioning (HVAC) controls. Devices, such as sensors for air quality occupancy, ambient light levels, temperature, and even lighting control are well suited for a single-pair infrastructure because they require limited power and low bandwidth.

With SPE, power delivery and signal delivery take place over the same pair.

SINGLE-PAIR ETHERNET STANDARDS

Among the main organizations setting standards for SPE are IEEE via its 802.3 Working Group and The Telecommunications Industry Association (TIA) with its TR-42 Engineering Committee.

There are several IEEE standards that are of specific interest today for expanding SPE in industrial and intelligent building applications:

- IEEE 802.3bu addresses power over data lines (PoDL). This standard was developed to support automotive applications, but it is also relevant when expanding SPE to support factory automation and the needs of commercial buildings.

- To support these two applications, IEEE developed the 802.3cg standard that is different from most new data communications standards because rather than expanding the speed supported, it supports a very low data rate of 10 Mb/s while expanding the reach to 1000 m (≈3281 ft), which is significantly longer than previous copper cabling standards.

The IEEE 802.3cg standard offers three implementations:

1. 10BASE-T1S describes a link segment or a point-to-point type of system with four connections up to a 15 m reach (≈49 ft) and with PoDL delivery. This type of implementation would be used in a control panel on a factory floor.

2. 10BASE-T1L supports a 1000 m reach (≈3281 ft). It is also a point-to-point implementation that supports up to 10 connections providing data and power.

3. 10BASE-T1S (Multi-Drop) supports up to eight nodes or eight devices on the same channel (called a mixing segment) for a total of 25 m (≈82 ft). The Single-pair Multi Drop (SPMD) implementation does not support power delivery.

In addition, IEEE 802.3da will include enhancements to the SPMD implementation. Although it likely will be another year or two until it is fully developed from a cabling standpoint, it will increase the reach up to 50 m (≈164 ft) and the node counts up to 16 devices on the same channel. It will also support power delivery via PoDL.

The TIA is also developing several standards supporting SPE:

- ANSI/TIA 568.5 is an SPE cabling and components standard. It is the single-pair equivalent of the 568.2 standard for 4-pair cabling, supporting SPE in general use environments.
- TIA-568.6 supports SPMD cabling and components. It will likely be finalized when the IEEE 802.3da standard is completed.
- TIA-568.7 addresses SPE cabling and components for harsher, industrial environments with higher levels of Mechanical, Ingress, Climatic/Chemical, Electro Magnetic (MICE) ratings or internet protocol (IP) ratings, such as industrial process control and factory automation environments.
- ANSI/TIA-5071 covers SPE cabling field testing, including the reporting and accuracy requirements of SPE field test equipment.
- An addendum to TSB-184-A will be developed to provide guidance for power delivery SPE cables.

TOPOLOGIES

Cabling topologies for SPE will have some differences compared to traditional 4-pair copper cabling. Instead of the 100 m (≈328 ft) four connection channel, two options are available:

- SP1-400 supports a maximum reach of 400 m (≈1312 ft) with up to five connections. This topology assumes 23 AWG conductors.
- To reach 1000 m (≈3281 ft) and support up to 10 connections requires SP1-1000, which specifies 18 AWG conductors. One of the reasons so many connections are supported is that it can be difficult to pull 1000 m of cable. This allows installers to pull smaller lengths of cable and connect them either in line or within a junction box (Figure 2).

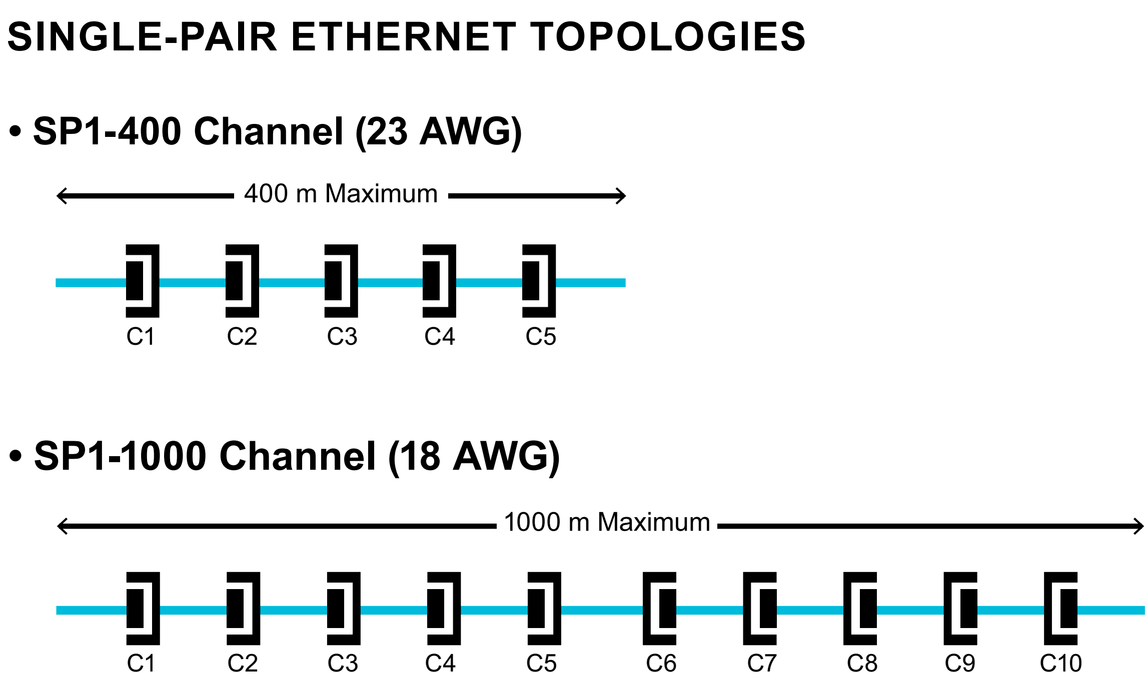


FIGURE 2: Single-pair Ethernet Topologies.

POWER OVER ETHERNET

Power over Ethernet (PoE) has been around since 2003. The first IEEE standard, 802.3af-2003, delivered 15 W over two of the four pairs. IEEE 802.3at-2009 increased the amount of power to 30 W but still used only two of the four pairs to deliver that power.

It is important to note that IEEE 802.2bt-2018 provides 60W and 90W but uses all four pairs to deliver the power to equipment. In 802.3af and 802.3at users have two options for power delivery. Mode A delivers power using the same two transmit and receive (TX/RX) pairs that support 10BASE-T using common mode voltage. Method B employs the unused pairs. All four pairs are used for signal delivery (Figure 3).

Both 2-pair and 4-pair power delivery requires a conductive path made possible using multiple conductors, or multiple pairs of conductors, because of the use of small conductor gauges and the voltage drop inherent with the 100 m (≈328 ft) reach.

With SPE, power delivery and signal delivery take place over the same pair.

TIA 568.5 will specify the design of the cable, the conductor, sizing, and the DC resistance, which will make the power delivery possible using only those two conductors.

Moreover, with SPE technology the power level goals are roughly half those of 4-pair. This is an advantage for SPE because with 4-pair cabling one of the concerns is the heat generated by PoE with large cable bundles. Overheating typically only happens at the 90W PoE level where the temperature in the cable exceeds the temperature rating of the cable; at 15W and 30W, and even 60W, power levels do not significantly increase the temperature of cables inside of a bundle.

For 4-pair deployment, TIA standards recommend limiting the bundle size based on the conductor. Larger conductors have higher ampacity ratings and dissipate heat better, or do not heat as much, because they have less resistance. TIA standards assume a cable rating of 60° C (140° F), but there are some 4-pair cables that have ratings of 90° C (194° F) or even 105° C (221° F).

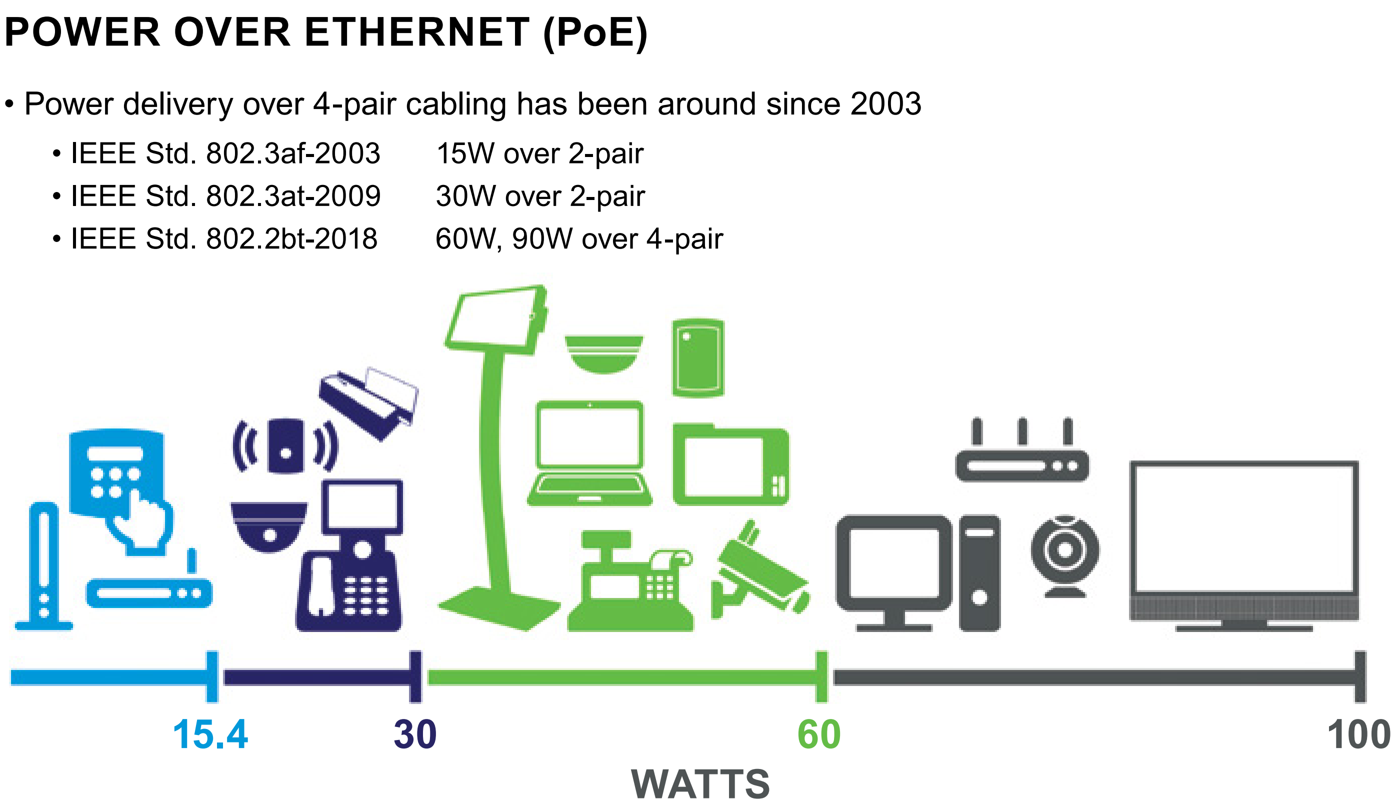


FIGURE 3: Power over Ethernet (PoE).

For single-pair, the TIA TR-42.7 task group is evaluating the capabilities of the different cable designs outlined in 568.5 to determine if there are similar heating issues and whether there needs to be specific recommendations for SPE cabling, similar to what was done with 4-pair cabling in terms of power levels and bundle size.

Figure 4 shows different cable bundle sizes and the current levels applied to them. The dotted line represents the likely response of a 1.6 amps threshold, which is the top power level applied to these single-pair cables. The temperature rise is meaningful. The 61-cable bundle size heats up to more than 25° C (77° F). If the ambient temperature is 25° and the cable heats up an additional 25° C, this gets close to the temperature rating of 60° C (140° F), which would become a problem.

WHERE DOES SPE FIT IN THE CURRENT ETHERNET ENVIRONMENT?

Single-pair Ethernet technology was not designed to replace 4-pair cabling but rather to support devices that are not operating on Ethernet today; they may be running on legacy systems, such as Fieldbus or other OT networks. There are several today that are either proprietary to a single manufacturer or are legacy systems that have been operating for a number of years; they would benefit from the security and flexibility to connect without a gateway to an Ethernet network.

It is likely that a 10BASE-T1 SPE switch will have either a 100/1000BASE-T RJ45 4-pair Ethernet uplink port or possibly a 1000BASE-SX optical fiber uplink port. The ability of a 4-pair cable to support four SPE links simultaneously is still under evaluation.

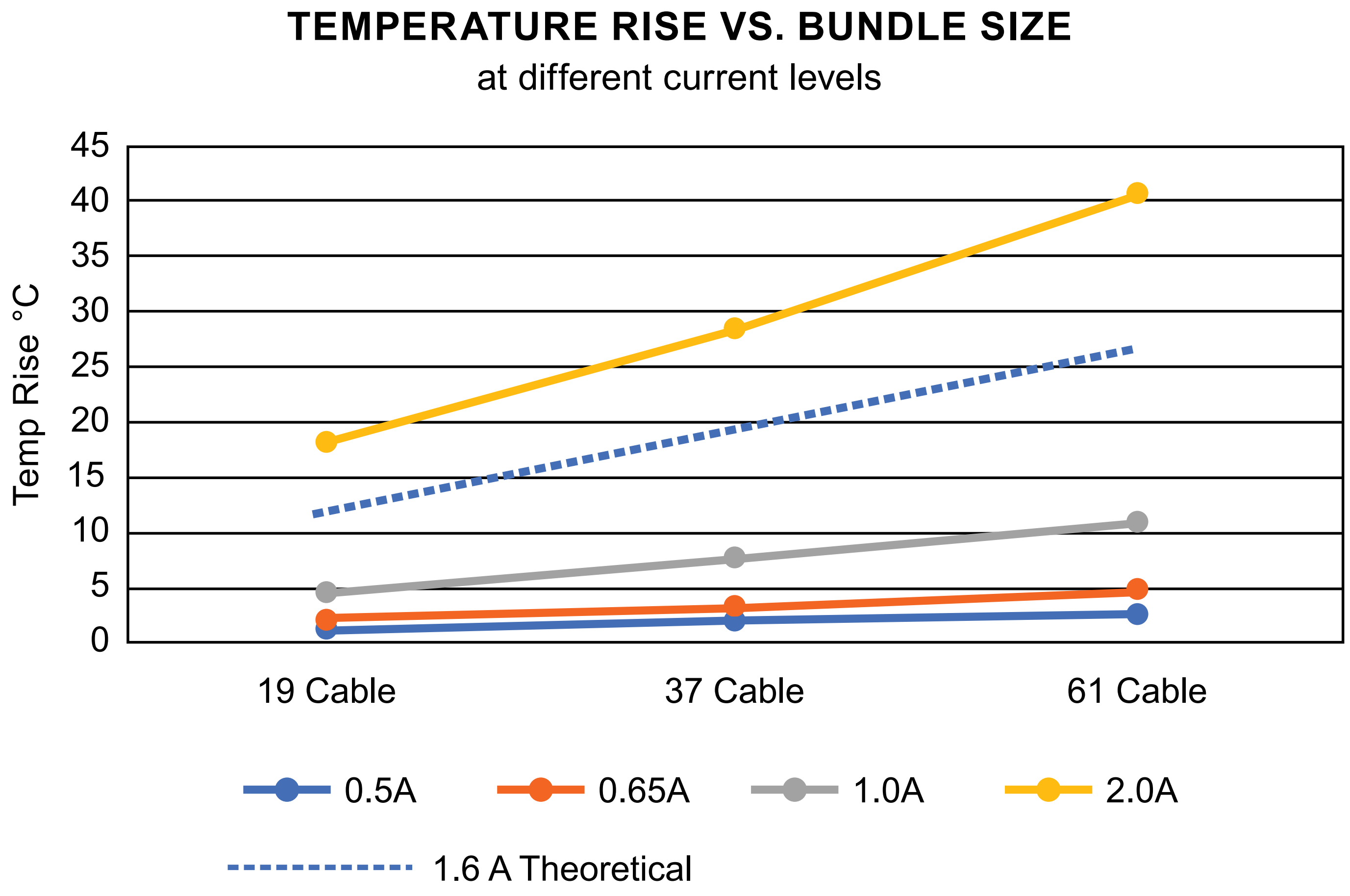


FIGURE 4: Temperature rise versus bundled cable size.

ELECTRICAL AND POWER DELIVERY

Understanding reach for traditional 4-pair copper cabling is easy. The magic number is 100 m (≈328 ft) whether working with Cat 5, Cat 6, or Cat 6A cable. Whether power levels are 15W, 30W, 60W or 90W, the cables would support 100 m with PoE over the entire length.

This is not necessarily the case with SPE. There are two parameters that determine the distance supported: insertion loss and direct current (DC) resistance.

Insertion loss is what causes the signal strength to diminish over the length of the cable.

Figure 5 shows the signal (the amplitude of the sine wave) diminishing over time. Electrical transmission requirements are developed to ensure signal strength remains above a minimum value for a specified cable length. Once the signal strength drops below that value, the active equipment on the end of the link may not be able to identify that piece of data.

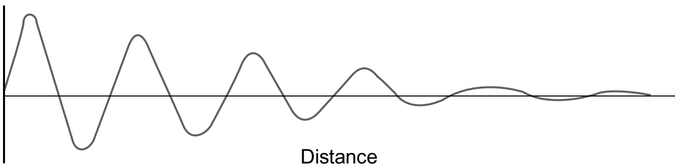


FIGURE 5: Signal strength over distance.

For an SP1-400 link, the electrical signal will support 400 m (≈1312 ft) when using a 23-gauge cable. For an SP1-1000 link, that distance extends to 1000 m (≈3281 ft) and requires 18-gauge cable.

The DC resistance is an even more important parameter when it comes to power delivery because the DC resistance of a cable causes the voltage to diminish over the cable length (Figure 6).

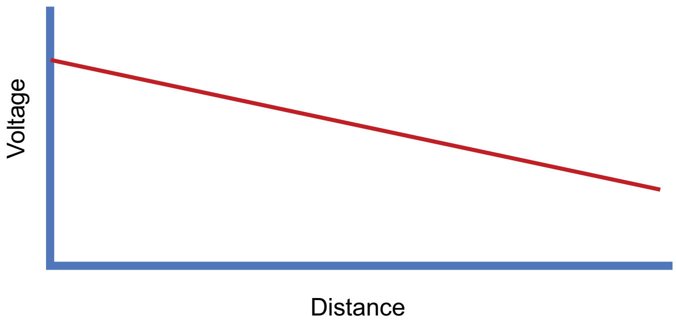


FIGURE 6: Voltage reduction over distance.

As the distance increases, the voltage goes down until it is so low that the device at the end can no longer function properly. The factors that affect the power delivery distance include PoDL classification, conductor size, and the number of connections within the channel.

There are several PoDL classifications. IEEE 802.3cg introduced six new power classifications to support 10 Mb/s applications. Each classification defines the following:

- Voltage (V)
- Current (mA)
- Power (W)
- Max DCR (Ω)

The DCR value is used to calculate maximum theoretical power delivery distance. There may be situations where it is possible to exceed some of the numbers calculated because not every cable is exactly the same in terms of the size of the conductor or the resistance value; however, it is a good guideline.

The DCR loop is the combined value of the resistance of the cable, the cords, and the connections. There are essentially three differences between the power classes.

Note that in Table 1 the DCR values of 10 and 13 are the same (65), 11 and 14 are the same (25), and 12 and 15 are also the same (9.5). The difference between those classes is the starting voltage: 10 through 12 start with 30 volts, while 13 through 15 start with 58 volts.

$$DCR_{loop} = DCR_{cable} + DCR_{cords} + DCR_{connections}$$

Class	10	11	12	13	14	15
VPSE(max) (V)	30	30	30	58	58	58
IPI(max) (mA)	92	240	632	231	600	1579
PPD(max) (W)	1.23	3.2	8.4	7.7	20	52
DCR (Ω)	65	25	9.5	65	25	9.5

TABLE 1: Shows the variety of different power levels that can be achieved, going up to 52 W for power class 15.

POWER CLASS 10 & 13 (1.23 W / 7.7 W)

AWG	No. of Connections 2	5	10
18	1000	1000	1000
20	793	793	793
22	544	534	517
23	431	423	410
24	342	336	325
26	215	211	204

POWER CLASS 11 & 14 (3.2 W / 20 W)

AWG	No. of Connections 2	5	10
18	519	494	451
20	326	310	283
22	205	195	178
23	163	155	141
24	129	123	112
26	81	77	70

POWER CLASS 12 & 15 (8.4 W / 52 W)

AWG	No. of Connections 2	5	10
18	187	161	118
20	117	101	74
22	74	64	47
23	58	50	37
24	46	40	29
26	29	25	18

Maximum channel length determined by insertion loss limit.

Channels that exceed 400 m or have more than 5 connections do not comply with the SP1-400 channel topology requirements.

TABLE 2: Maximum channel length determined by insertion loss limit.

Considering the first column in Table 2, using 18 or 20-gauge cable enables power delivery to exceed the electrical transmission distances; these are cases where the distance is limited by the standards-defined insertion loss rather than DCR resistance. Another area to watch for when using the highest power class (15) is that to get to 52 W using 18-gauge cable, the maximum theoretical distance with 10 connections supported is only 118 m (≈387 ft), which is almost one-tenth of the maximum distance based on the insertion loss at 1000 m (≈3281 ft). Even when using a point-to-point topology with only two connections, the cable will support only 187 m (≈614 ft). Therefore, there is a very significant difference between the maximum channel allowance based on electrical transmission versus power delivery.

In some cases, it may make more sense to consider 4-pair PoE instead of SPE because of the distance limitations, such as when the end device needs more than 20 W and the transmission distance is 100 m (≈328 ft). Much of this decision will be controlled by device manufacturers and whether they support 4-pair PoE with an RJ45 connection or SPE with a different type of connection.

WHAT ABOUT WIRELESS?

Many people view wireless solutions as the primary alternative to SPE. There are many options and one of the simplest ways to include an IoT device is to connect it wirelessly and put a battery in it. However, in a commercial environment, that is not necessarily the best option or practice.

The main advantages that SPE provides over a wireless battery system is the reliability of the connection, the security of the connection, and the ability to remotely reset the device. If the system loses communication with the device and there is centralized power delivery, resetting the port essentially turns the device on and off. This is not possible with a wireless connection.

Batteries are another issue to consider when installing IoT devices in a commercial building or in an industrial setting. Over the next five years, it is predicted that there will be 75 billion connected devices globally.[2] Most of these are going to be sensors that could potentially use batteries with wireless connectivity. While the batteries may last for years, at some point those batteries will need to be replaced and thousands of these devices could be located behind walls or in other hard to reach locations. In addition, there is an environmental impact involved with disposing single-use batteries. On balance, SPE will be easier to maintain, more reliable, and more sustainable than using wireless devices with batteries.

SPE TESTING

Although SPE technology is still in development, much progress has been made in standards development to define single-pair cabling, but wide-scale adoption will only be complete when testing requirements are specified and field testers are available to ensure that the cabling can be certified to meet networking standards.

The good news is that the standards committees are equally active in defining field testing requirements for SPE. TIA-5071, which is in the draft stages, defines two levels of field testers:

- Level SP1 defines tester requirements for cabling specified in TIA-568.5D. It is intended for long-reach single-pair cabling and defines the 400 m (≈1312 ft), four-connector channels and 1000 m (≈3281 ft) 10-connector channel requirements. The requirements are similar to those in 4-pair cabling and include both DC and radio frequency (RF) parameters. The RF frequency range of 0.1-20 MHz is specified for channel and permanent link (PL) configurations.

- Level SP2 is for shorter reach but higher performance SPE cabling systems. The DC and RF parameters (RF frequency range to 600 MHz) are specified for channel and PL configurations. The best equipment to support this will be defined over a larger frequency range compared to SP1's different limits and different accuracy requirements for tester performance.

The International Electrotechnical Commission (IEC) is also refining field test standards for SPE. IEC 61935-4 will specify two similar levels and will also define a new level, SP3, for cabling RF parameters specified to 1.2 GHz.

Testing Differences between 4-Pair Ethernet and SPE

It may seem like SPE cabling is a subset of 4-pair in test requirements, but that is not exactly the case. There are several technical challenges associated with testing SPE links. The first one involves long reach and how attenuation or insertion loss causes the signal to decay as the length of the cable increases.

Field testers comprise a main and a remote unit for certification testing (Figure 7). Over long single-pair device under test (DUT), it is challenging to communicate data between the two units to coordinate the testing, set the parameters, align the test sequencing, and finally to exchange the results.

In addition, the test parameters are different for SPE compared to 4-pair cabling performance testing. The RF parameters for SPE cabling are defined from 0.1 MHz upwards, unlike the 4-pair cabling systems where these parameters are defined only from 1.0 MHz. The insertion loss increases rapidly with frequency for long length channels. As a result, the SPE networking standards will utilize lower frequency components of the spectrum, so the test equipment must ensure that lower frequencies are properly communicating over the cabling.

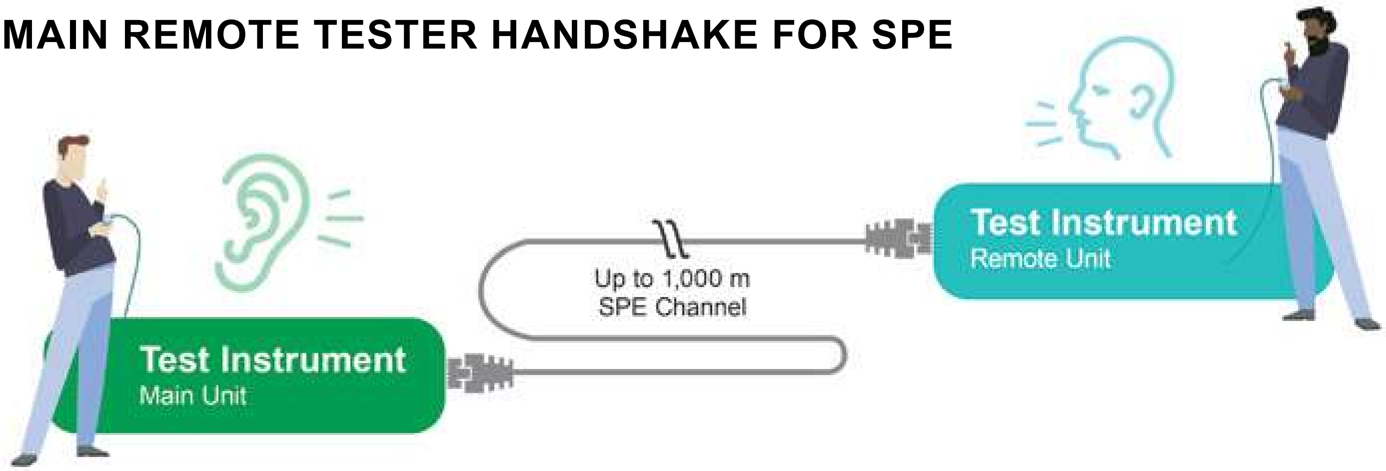


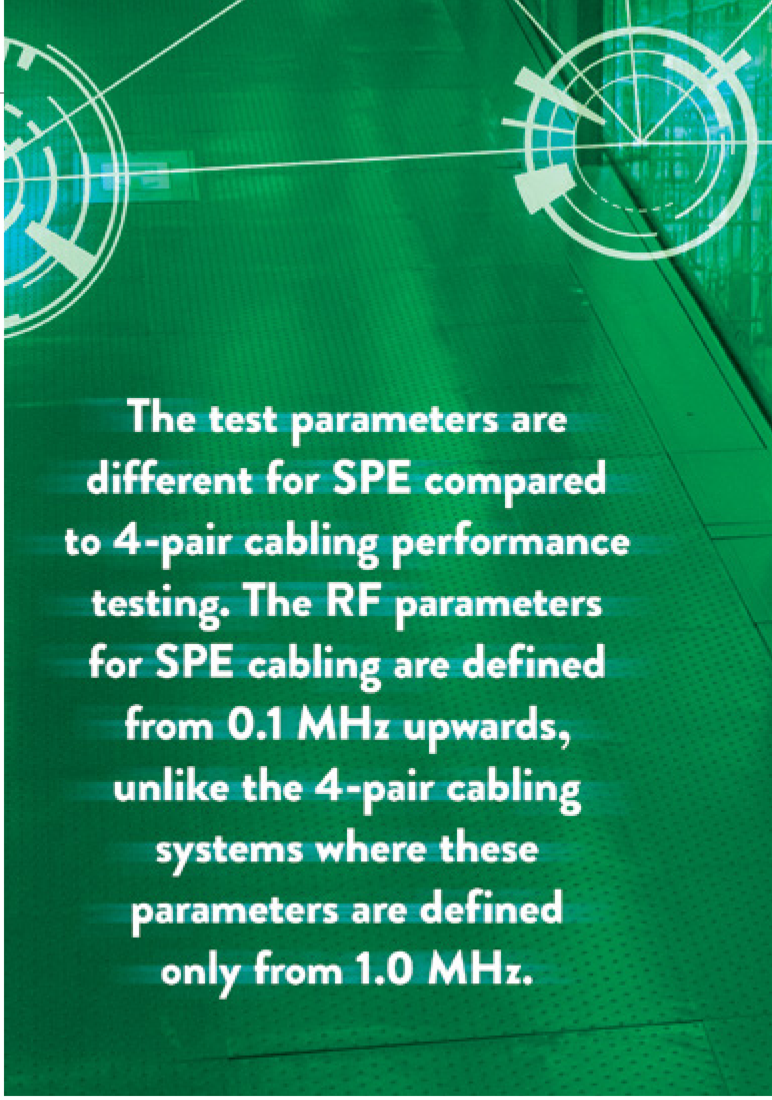
FIGURE 7: One of the challenges in testing SPE cables is the long reach and how the attenuation or insertion loss causes the signal to decay as the length of the cable increases.[3]

In addition to extending in the low frequency range, SPE testers will need to support much finer frequency-step resolution compared to 4-pair cabling systems. This is because longer cable length causes sharper variations across frequency.

Unless the frequency steps for measurements are finer than those defined in 4-pair testing, there is a risk of missing frequency points corresponding to worst case situations (Figure 8).

In current discussions, standards groups are looking at up to 20 kHz of minimum spec size as compared to 150 kHz for a 4-pair cable tester.

The SPE field tester requirements will also include connectivity and DC measurements. A shield continuity measurement for which the SPE cable is a shielded cable will be important for the SPE field tester to ensure the shield is connected end to end. As mentioned earlier, DC loop resistance is an extremely important barometer for supporting SPE performance.



CABLE TESTER FREQUENCIES

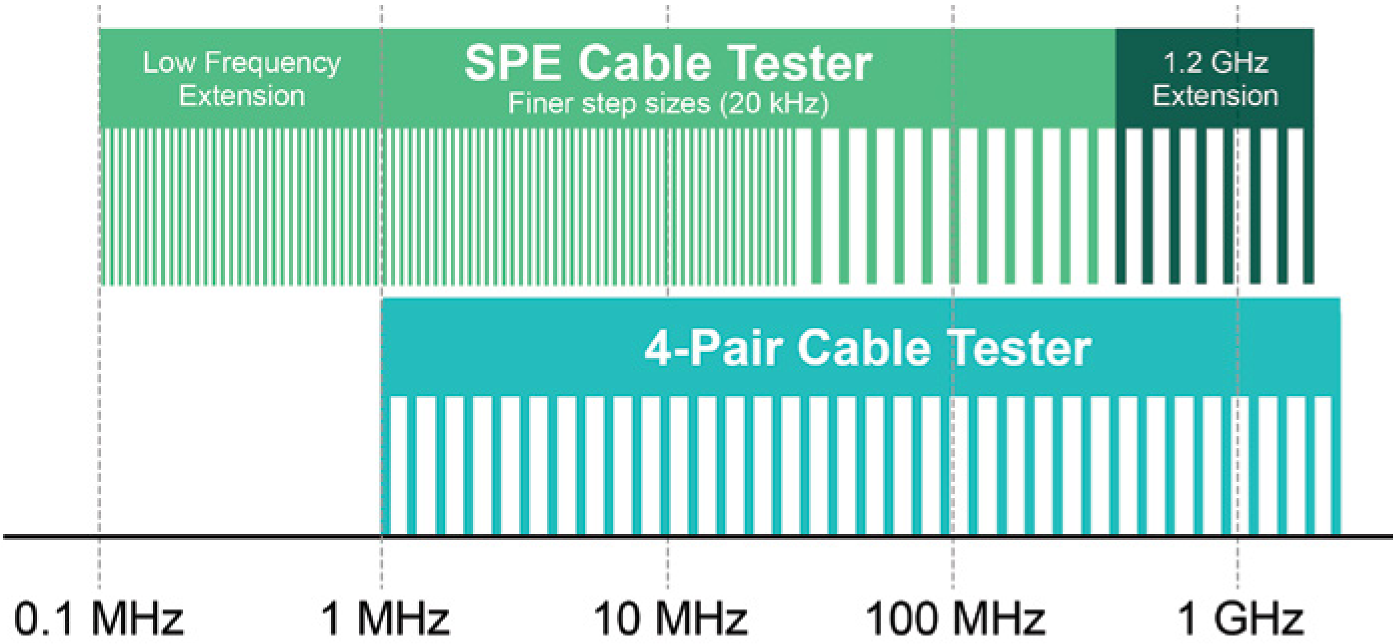


FIGURE 8: Testers for SPE will need to support finer frequency step resolution compared to 4-pair systems.

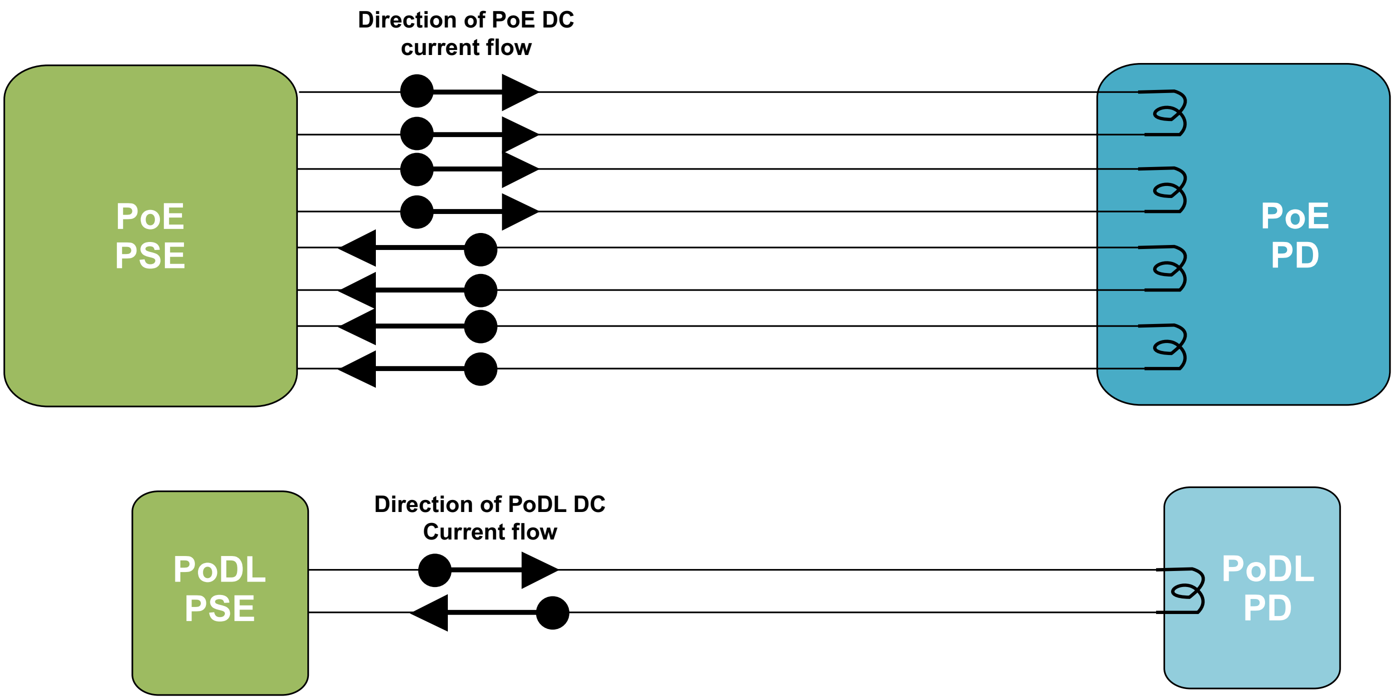


FIGURE 9: Direction of current flow for 4-pair cabling versus SPE. Top: 4-pair solution. Bottom illustration: SPE. PSE is defined as power source equipment.

In 4-pair cabling using PoE, both wires of the pair carry current in the same direction. A resistance unbalance between the two wires may cause a magnetic saturation in the network interface device at the far end that may impact communication performance through packet loss (Figure 9).

Resistance unbalance is not as big of a concern for SPE because the PoDL current flows in opposite directions in transformer magnetics, unlike PoE. Note that only shielded SPE cables can be tested for resistance unbalance between two signal wires.

There are two broad implementation possibilities for field test equipment. The first uses existing 4-pair cable certifiers with new types of adapters. The other possibility is to develop new testers for SPE.

There are several advantages to using the same field tester for both SPE and four-pair cable certification, as well as DC resistance unbalance and PoE load testing. Having a single multifunction test solution purpose built for smart building technologies results in an overall lower cost of ownership, simplicity in documentation and reporting, and fewer tools for tracking and training.

Field testers for SPE that use IEC 63171-6 connectors, designed for industrial applications, are already available. Over the next year, industry experts expect that connectors with LC connectivity also will become available. New SPE testers for smart building technologies are available from some manufacturers with more expected.

CONCLUSION

Looking forward, what is most important to remember is that SPE enables the convergence of traditional IT and OT networks operating over optical fiber or 4-pair Ethernet cabling into a common intelligent building or industrial network. This extends the Ethernet network to new systems and devices and offers the potential to quickly deploy and power buildings and industrial internet of things (IIot) devices.

Single-pair Ethernet cabling will be tested in familiar ways, using either an existing tester with a new adapter or new equipment that is specific for SPE testing. New standards and best practices will ensure that SPE cables will safely deliver power to all new devices, furthering the advancement and deployment of SPE technology.

This article was written on behalf of the Fiber Optics Technology Consortium (FOTC).

Resistance unbalance is not as big of a concern for SPE because the PoDL current flows in opposite directions in transformer magnetics, unlike PoE.

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3. Figures 7 and 8 courtesy of AEM.