# Power over Ethernet – The Story So Far

## Introduction

Power over Ethernet (PoE) does exactly what its name suggests; it delivers usable power over Ethernet (twisted-pair) cabling. Providing both the power and data required by an attached device provides significant benefits such as ease of installation and relocation of the powered device without the need to consider the location of the power source. Remote control and monitoring are also easier to achieve with a remote power solution. Even though there are some obvious benefits to PoE, there are some things to know and others to be considered.

## The Standards

PoE has been in use in various forms for many years and the IEEE has standardized four versions. The first PoE standard IEEE 802.3af-2003 allowed for the powering of devices up to 15.4 W. The second standard IEEE 802.3at-2009, so called PoE plus or PoE+, was specified a maximum powering provision of 30 W. The new standard IEEE 802.3bt-2018 specifies PoE type 3 and type 4 (sometimes referred to as PoE++) to deliver a maximum 60 W and 100 W respectively.

While these values are the reported maximum powers that can be provided by the power source equipment (PSE), it is not the actual power that is ultimately delivered to the powered device (PD). The resistance of the copper cabling coverts some of the sourced power into heat and as such only 12.95 W to 15.4 W of power is actually delivered to the PD for type 1, 25.5 W to 30 W for type 2, 51 W to 60 W for type 3, and 71 W to 100 W for type 4.

## Power Delivery Method

In addition to the four present power levels that are deliverable using PoE, there are numerous power delivery methods. However, only two power delivery methods have been standardized by the IEEE; they are referred to as Alternative A and Alternative B and describe the methods employed to deliver the power from the PSE to the PD.

The references to Alternative A and B only apply to the PSE since the PDs are normally designed to support both power delivery techniques as shown in Figure 1 to Figure 6.

It is generally understood that the two alternatives simply define whether the power is transmitted via used or unused pairs. This is the case for 10BASE-T and 100BASE-T Ethernet where only the orange and green pairs are used. However, this is not so for 1000BASE-T and 10GBASE-T where all four pairs are used for data transmission. Figure 1 shows the endpoint PSE location of Alternative A for 10BASE-T/100BASE-TX using the data pairs and Figure 2 shows the endpoint PSE location of Alternative B for 10BASE-T/100BASE-TX using the unused (blue and brown) pairs.

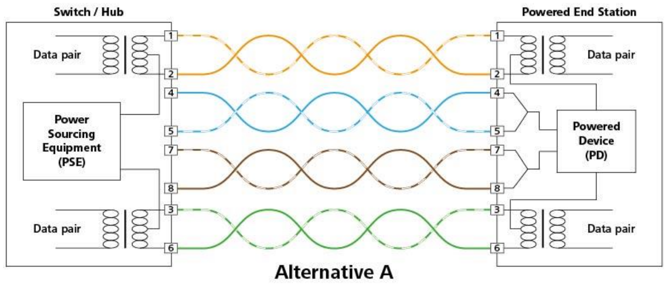


Figure 1

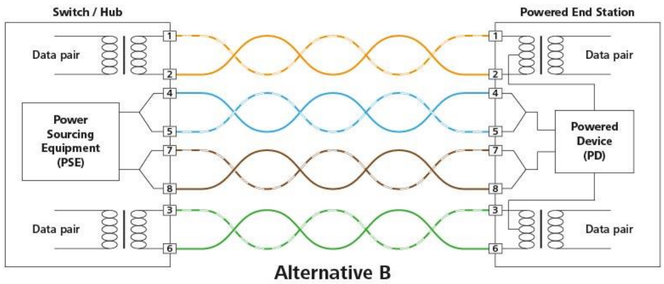


Figure 2

For the four-pair signaling of 1000/2.5G/5G/10GBASE-T, the two alternatives simply determine which two pairs deliver the power. Figure 3 and Figure 4 show the endpoint PSE location of Alternative A and Alternative B respectively, with Figure 3 using the orange and green pairs, and Figure 4 using blue and brown.

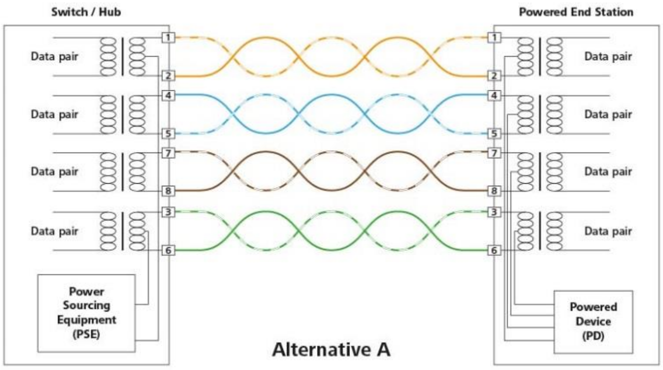


Figure 3

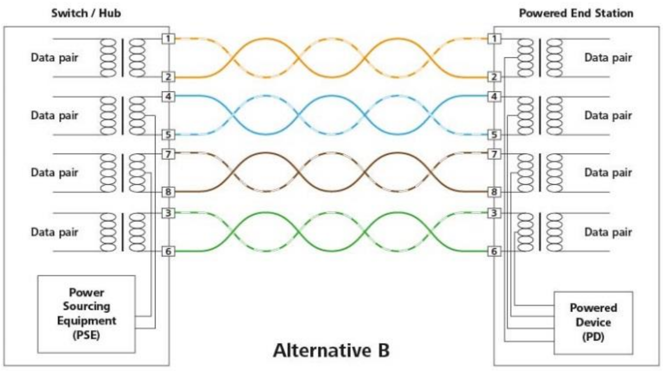


Figure 4

PoE type 3 and type 4 allow all four pairs to carry a certain amount of current. Figure 5 and Figure 6 show the endpoint PSE locations for 4-pair PoE for 10BASE-T/ 100BASE-TX and 1G/2.5G/5G/10GBASE-T respectively.

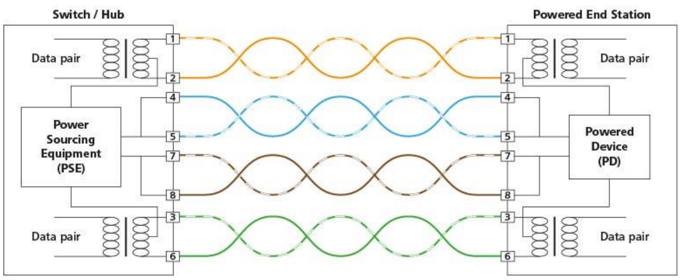


Figure 5

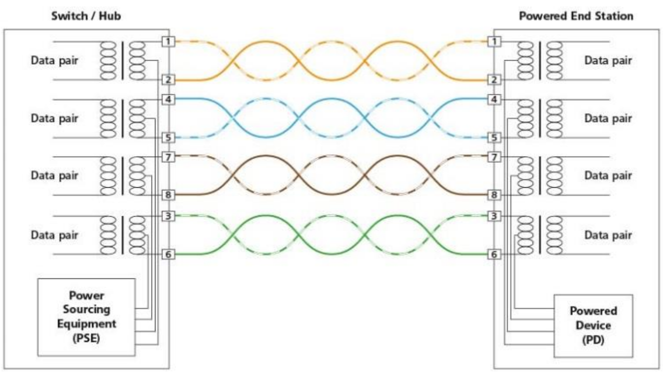


Figure 6

Figure 1 through Figure 6 depict the use of power source equipment within the endpoint (switch or hub). The same configurations are also available in a mid-span solution.

## Endpoint PSE or mid-span PSE

Figure 7 shows the 2-pair PoE mid-span configuration for Alternative A for a four-pair Ethernet system. Figure 8 shows the 4-pair PoE mid-span configuration for a four-pair Ethernet system.

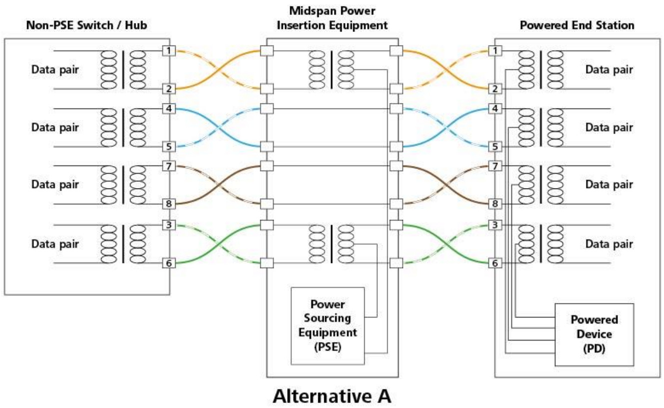


Figure 7

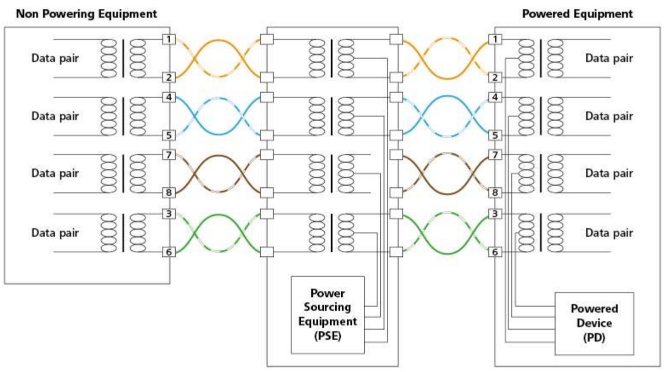


Figure 8

In this type of powering solution, the switch or hub can be of a standard design without integral power source equipment. While the switch cost will of course be lower, the combined cost of a separate switch and mid-span PSE will likely be greater, and occupy more rack space. The benefits of keeping them separate enable them to be upgraded independently and also to only provide power on those ports where it is needed.

Figure 9

**Figure 10**

Figure 9 shows a typical combined switch and PSE with 24 powered ports. Figure 10 shows a mid-span PSE device that supports 16 incoming Ethernet ports and 16 outgoing Ethernet + PoE ports.

Although referred to as mid-span, these devices are usually situated adjacent to the Ethernet switches.

## Types of Powered Devices

Thousands of devices now support remote powering from the PSE. These PDs have the benefit of not requiring the installation of both dedicated power and network cables to the same location. Many domestic and commercial IT devices operate on low voltages and include power transformers to reduce mains voltages down to something more usable. These generally take the form of small power supply units. Delivering power over the cabling reduces the need for this type of power provision and the significant inefficiencies they have in converting from mains voltages to much lower DC voltages. There are numerous applications for PoE, the most popular of which are wireless access points, IP cameras and IP telephones. Typical examples of which are shown in Figure 11 to Figure 13.

**Figure 11**


**Figure 12**

**Figure 13**

Devices such as IP telephones used in voice over IP (VoIP) networks often incorporate two RJ45 sockets, one used for the incoming powered Ethernet connection, back to the switch, and the other a regular unpowered socket to allow a desktop or laptop computer to be connected, thus eliminating the need for a second RJ45 connection in the wall.

## Connector Impact

So, how does PoE work? Is the power always on? How does the PSE know how much power to supply? How do you turn the PSE off? This section will answer all of these questions and more.

The low voltage PoE is not always on. If no device is detected then the power is off. Only when a PD is attached to a PoE enabled source is the power made available to the PD. This addresses any concerns over people receiving electric shocks from Ethernet sockets or patch cords if they are left accessible. There is a *handshake* that occurs between the PSE and the PD prior to the power being enabled. This only takes a fraction of a second and during the handshake the PD communicates its powering requirements back to the PSE so that the correct mode can be set in the PSE.

A PSE device can provide power using only one (at a time) four-wire connection, regardless of whether the Ethernet protocol is two- or four-pair. In either type the two conductors of each utilized pair carry the same current. Table 33-2 is extracted from IEEE Std 802.3-2015.

 

Table 33–2—PSE Pinout alternatives

| Conductor | Alternative A (MDI-X) | Alternative A (MDI) | Alternative B (All) |
|---|---|---|---|
| 1 | Negative $V_{PSE}$ | Positive $V_{PSE}$ | |
| 2 | Negative $V_{PSE}$ | Positive $V_{PSE}$ | |
| 3 | Positive $V_{PSE}$ | Negative $V_{PSE}$ | |
| 4 | | | Positive $V_{PSE}$ |
| 5 | | | Positive $V_{PSE}$ |
| 6 | Positive $V_{PSE}$ | Negative $V_{PSE}$ | |
| 7 | | | Negative $V_{PSE}$ |
| 8 | | | Negative $V_{PSE}$ |

Although the power is off when there is no PD connected to the link and the handshake between the two activates the power, the removal of the PD doesn't benefit from the same degree of control. In other words, the PSE cannot anticipate the removal of the PD through the unplugging of a patch cord and as such the voltage and current are still present when this action occurs. The net result of unplugging the cord is a small arc discharge between the removed plug and socket on one or more of the contacts. The discharge may cause a crater damage on the surface of the contacts which in turn increases the corrosion and over time will cause a connector failure.

Literature shows that when a plug is un-mating from a jack, if contacts are not opened simultaneously, the total power would be instantaneously carried by the last connected pair. Assuming a connector is delivering PoE type 4 applications at maximum 100 W remote power. During un-mating operation, the last connected pair may carry 100 W power at 55 V open circuit voltage, which is equivalent to 2 A current on each conductor of that pair. For this reason, IEC 60512-99-002 specifies a test schedule to validate the ability of a connector to withstand the un-intended un-mating operations when remote powering PoE type 4 applications.

The critical aspect of connector design to successfully withstand this situation is to ensure the two electrical contacts from plug and jack have enough length of wiping zone so that the mating point is not the discharge point. Figure 14 and Figure 15 demonstrate this mating operation using CAD model of HellermannTyton GST keystone jack.

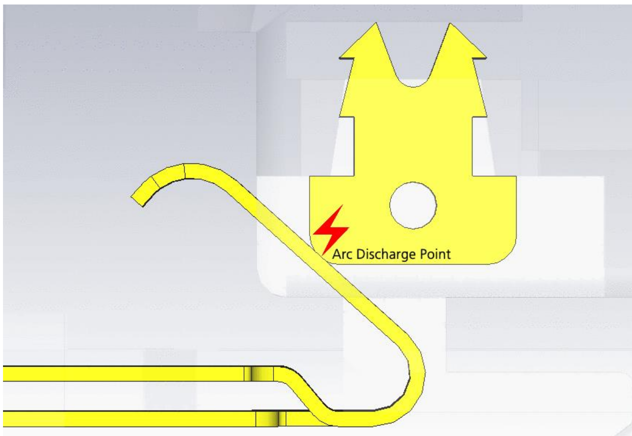


Figure 14

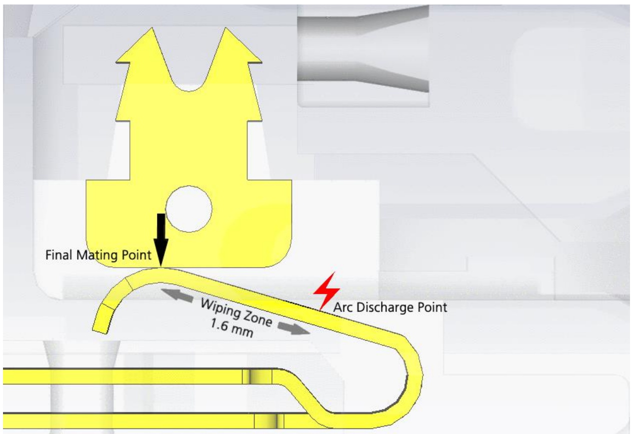


Figure 15

Figure 16 and Figure 17 show the arc discharge experiment results on a HellermannTyton GST Category 6A jack and a Category 6A plug after 50 mating cycles under 2 A per conduct condition. It can be seen that the discharge caused crater damage on the copper plating. Also, the wiping trails indicate that the mating points are not the discharge points for this connector design.

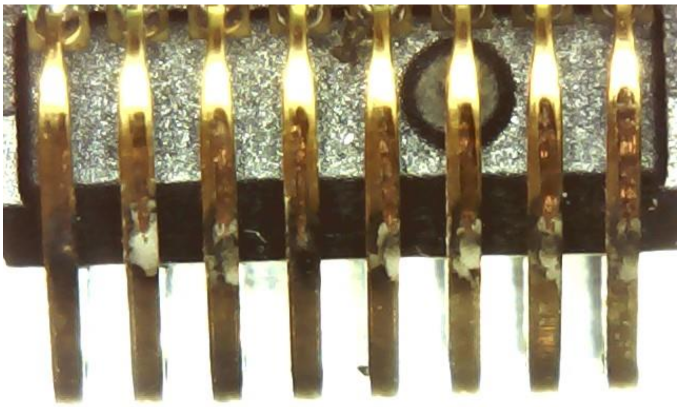

Figure 16

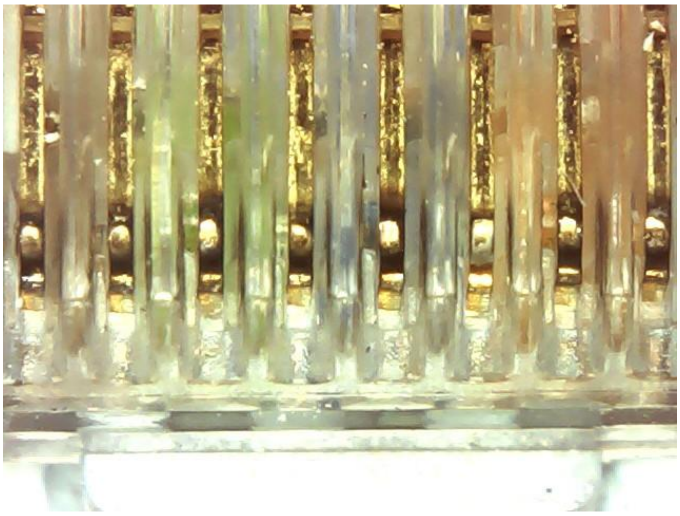

Figure 17

The arcing only occurs for the initial disconnection within a single link and not any subsequent disconnection on the same link. While it is inconvenient if this pitting and deterioration occurs at the telecommunications outlet (TO), it is easier to replace it than an RJ45 soldered to the motherboard of a $1300+ laptop. The decision about which connection to break first requires careful consideration.

This deterioration can be avoided but not easily. While the PSE will only provide power to an appropriate PD, the power can be remotely switched off using, for example, a web-style interface, usually provided in the PSE. Using this approach however means that a call to the IT department would be required any time a user wanted to unplug a PD; this is clearly impractical especially in an open environment such as a university.

The second solution to this problem involves the inclusion of a sacrificial connection between the TO and the PD. This through-coupler should be where the initial disconnection takes place since it is the easiest and most cost-effective component to replace. The only requirement is that the user remembers to disconnect at this point before any other, as once the link is broken the power is removed and the risk of sparks and pin damage is eliminated altogether.

Moreover, when a connector continuously carries DC power, the connector starts to generate heat. This temperature rise inside of the connector plus the ambient temperature negatively impacts the current-carrying capacity. The temperature rise inside of the connector is characterized by the thermal properties of the materials that are used for the contacts, terminals as well as the insulating materials of housing. IEC 60603-7 specifies a current-carrying derating curve to determine a connector's ability to carry DC current at different ambient temperatures. For example, a connector shall be able to carry 1 A current at 60°C ambient temperature, which is the worst-case scenario for PoE type 4. Figure 18 shows a measured current-carrying derating curve of a HellermannTyton GST Category 6A connector. It is clear that the GST connector's capacity of current-carrying exceeds the standard specification.

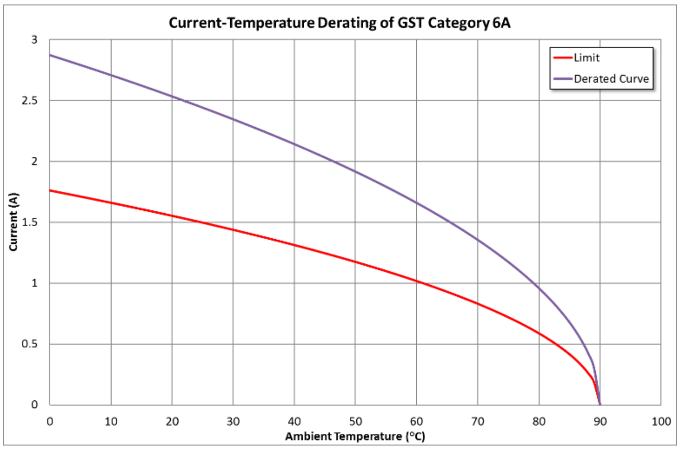


Figure 18

## Temperature Rise of Cabling

The effect of passing a current along a copper conductor causes it to heat up; the greater the current the greater the rise in temperature. This is a well-known physical characteristic of copper cables. Maximum temperature rise typically occurs in or around the cable located closest to the general geometric center of the grouping or bundle of cables. Cables surrounding this "worst case" cable typically experience lower temperature rises with temperature rise decreasing towards the surface of the bundle. If the cable is insulated then the heat will not dissipate freely, which would worsen the temperature rise compared with the cable in a ventilated environment. Figure 19 and Figure 20 show the heat distribution of different cable bundles in different installation environments.

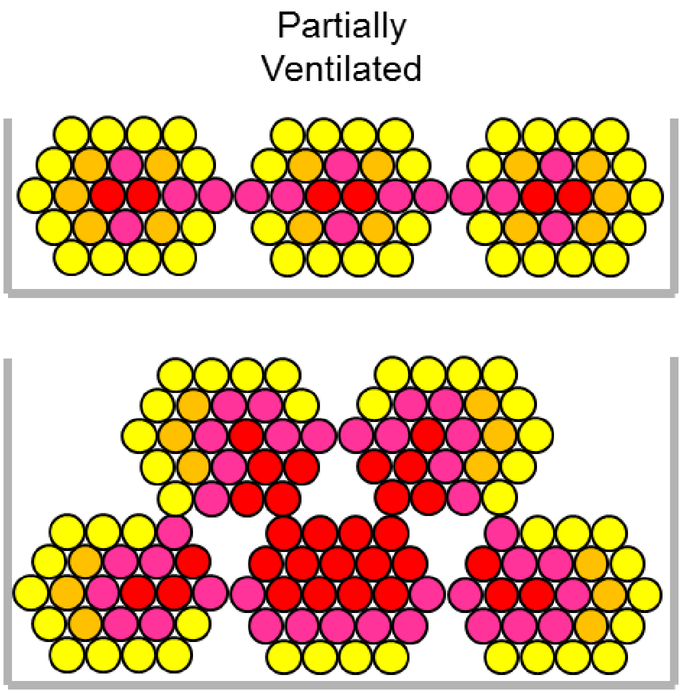


Figure 19

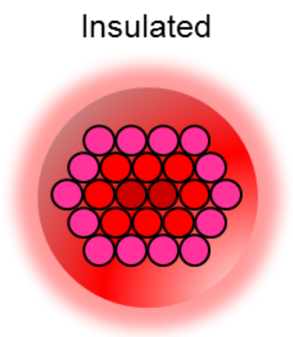


Figure 20

The increased amount of heat within the network adversely affects the resistance of the cabling, which in turn causes more power to be lost as heat. While this *chain reaction* does reach equilibrium and stabilizes, it has been proven that the temperature inside a bundle of cables, all delivering PoE, can rise by 40°C in some circumstances. Therefore, standardization organizations recommend maximum 15°C temperature rise in cable bundles when twisted-pair cables are energized by DC power. This recommendation guarantees that cable bundles can operate at maximum 45°C ambient temperature while the highest local temperature inside of bundles shall not exceed 60°C, which is the typical rated highest operation temperature of horizontal cable.

To give installation recommendations using HellermannTyton branded cabling products for PoE applications, several horizontal cable bundles were built in the HellermannTyton laboratory and the temperature rise was monitored under different conditions. Figure 21 shows a cable bundle with 168 Category 6 U/UTP cable elements for temperature rise test in ventilated condition. Figure 22 shows a cable bundle was tested in conduit condition.

Figure 21

Figure 22

Figure 23 is the maximum temperature rise of the cable shown in Figure 21 energized by 600 mA (PoE type 3), 800 mA and 1 A (PoE type 4) current per pair.

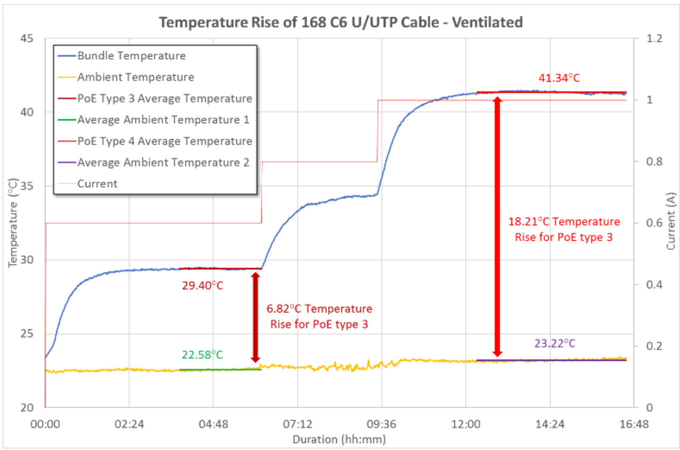


Figure 23

After a good deal of experiments and data analysis, theoretically maximum bundle sizes were determined for the mainstream HellermannTyton cabling products. Table 1 lists the maximum cable bundle size for 15°C temperature rise in difference installation environments and PoE applications at 20°C ambient temperature. In this assumption, the cable element at the geometrical center shall operate at 35°C local temperature. Therefore, the maximum channel length is recommended as well.

**Table 1**

| | Ventilated | | Conduit | | Maximum Channel Length (m) |
|---|---|---|---|---|---|
| | Type 4 | Type 3 | Type 4 | Type 3 | |
| C6A U/UTP | 168 | 574 | 98 | 350 | 96 |
| C6A U/FTP | 161 | 525 | 105 | 378 | 97 |
| C6 U/UTP | 133 | 469 | 77 | 301 | 94 |

Table 2 lists the similar information for 45°C ambient temperature. In this assumption, the cable element at the geometrical center shall operate at 60°C local temperature. It can be noticed that the recommended maximum channel lengths are shorter than 20°C ambient temperature.

**Table 2**

| | Ventilated | | Conduit | | Maximum Channel Length (m) |
|---|---|---|---|---|---|
| | Type 4 | Type 3 | Type 4 | Type 3 | |
| C6A U/UTP | 147 | 511 | 84 | 315 | 89 |
| C6A U/FTP | 140 | 476 | 91 | 343 | 93 |
| C6 U/UTP | 112 | 420 | 70 | 266 | 83 |

In field installation, it is rare that the cabling system is installed in a single giant bundle with several hundreds of cable elements. In ISO/IEC 14763-2, the size of cable bundles is restricted to a maximum of 24 4-pair balanced cables in order to support remote powering. Figure 24 illustrates this recommendation. If the maximum temperature rise still exceeds 15°C, the cable bundles should be separated by vertical "chimneys" width of 0.3 of bundle diameter allowing each bundle to cool by convection.

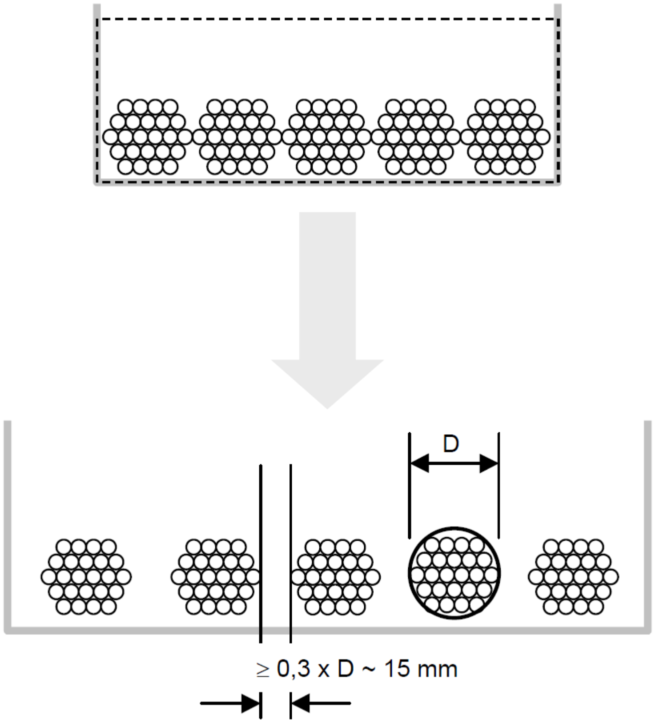


**Figure 24**

Figure 25 shows Category 6 U/UTP cable bundles were tested with this recommendation without separation. Figure 26 plots the monitored temperature rise at different positions. The maximum temperature rise is about 7°C.

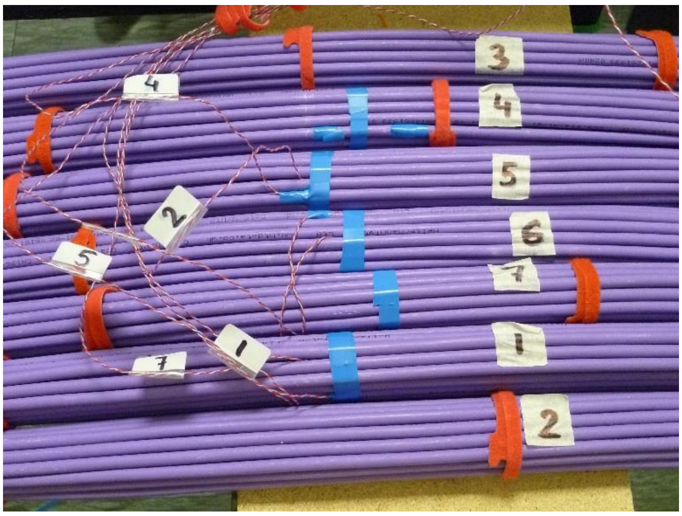

**Figure 25**

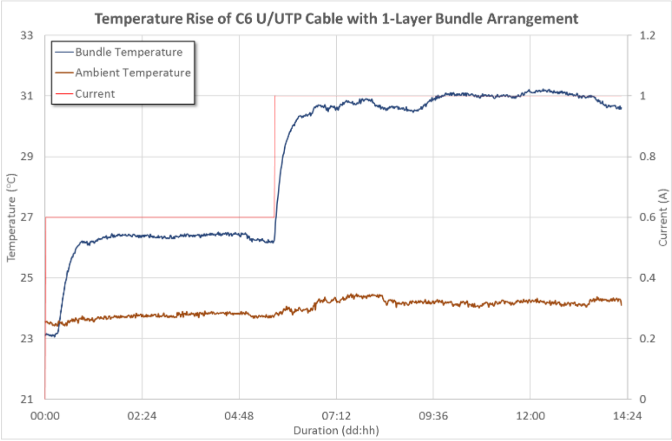


Figure 26

For cable installation in a ventilated condition, HellermannTyton recommends maximum two-layer stack up of 24-element cable bundle to deliver PoE type 3 and maximum one-layer without separation for PoE type 4[1]. Table 3 lists this recommendation.

Table 3

| | Category 6 | Category 6A |
|---|---|---|
| **PoE Type 3** | Two layers | Two layers |
| **PoE Type 4** | One layer | One layer |

## The Future of PoE

IEEE 802.3bt-2018 was published by IEEE which is to source between 71 W and 100 W, delivering a minimum power of 71 W with up to 0.96 A per conductor. This suggests however, that up to 29 W of power could be lost as heat in every PoE circuit. Today's PDs don't require this degree of power to operate and at present, with the exception of VoIP telephones, wireless access points and the like, they are not deployed in large numbers. However, the significant increase in available power from the next generation of PSE will mean that more applications can take advantage of remote powering. Applications from 10GBASE-T wireless access points supporting larger numbers of connected users, to building management and control systems to LED lighting are all valid reasons for increasing the amount of power that can be delivered using data cabling.

The use of PoE for commercial LED lighting solutions is still in its infancy. Figure 27 shows a typical configuration for such a system where the power and control for the lighting is supplied over standard data cabling. Environmental sensors taking readings of ambient light levels or human activity are also connected to the network such that lights can be intelligently controlled and power consumption minimized.

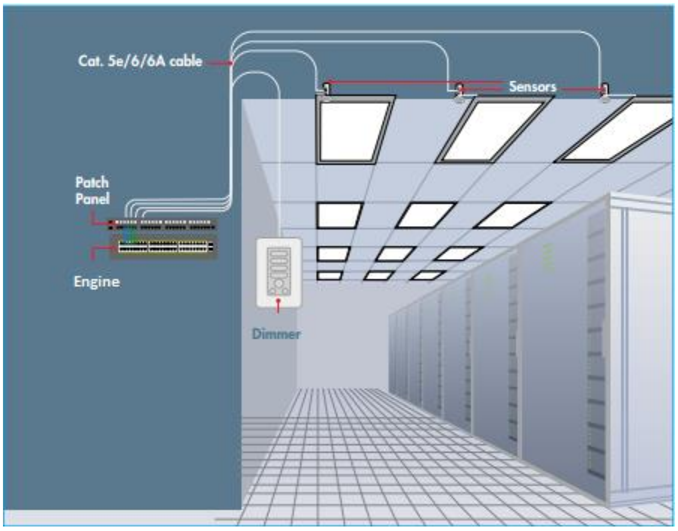


Figure 27

This increased usage of data infrastructure is not without its implications however. With up to 29 W of power being lost as heat for every active link, and the utilization of large number of links for non-traditional services such as LED lighting, it is now more important than ever to ensure that the type and performance of the chosen infrastructure products are given careful consideration.

As previously explained, these elevated powers will give rise to elevated temperatures which in turn will reduce the end-to-end performance of the data infrastructure and ultimately reduce either its length or data throughput. Knowing where these circuits are within your building infrastructure and the circuits that they will likely affect as their temperature increases, will become ever more important, especially as the lines blur between facilities and IT with respect to physical network design, installation and management.

Managing the cabling used to deliver remote power on a day-to-day basis will be the key to successfully utilizing higher-powered Ethernet networks. Careful consideration should be given to those devices that

[1] Temperature rise performance in conduit/insulation condition is currently under studying.

 

utilize Ethernet cabling to deploy power but do not meet the requirements of the 802.3 range of standards. These non-standardized devices may source even higher power levels and be accompanied by greater temperature rises and reductions in effective channel length which in turn will accelerate the performance decline of the infrastructure.

Further evaluation of the impact of 802.3bt and beyond is needed to determine the long-term effects on twisted-pair cabling systems.

## HellermannTyton Connectivity

HellermannTyton's C5e copper-based networking products have been proven to support both PoE type 1 and type 2, as described in IEEE 802.3at, up to a maximum distance of 90 m in permanent link and 100 m in channel configurations. HellermannTyton's C6 and C6A products have been proven to support both PoE type 3 and type 4, as described in IEEE 802.3bt, considering the installation environment, size of cable bundle and the amount of ventilation available to minimize undesirable temperature rises. Installing in accordance with HellermannTyton's installation guidelines will maintain unwanted temperatures rises within acceptable levels.

Careful consideration should also be made when selecting a method to allow the safe and reliable *unplugging* process for connected devices, especially those that will be plugged and unplugged on a regular basis, such as hot-desk workers or student laptops, etc. However, the inclusion of a sacrificial connection point, to eliminate connector damage, has the potential to negatively impact the performance of the infrastructure and would not be included in the system warranty due to its limited life expectancy if plugged and unplugged regularly.

## Conclusion

The use of twisted-pair cables to deliver both power and data to remote devices will likely see an upturn in the future as the amount of available power increases to a useful level and more sophisticated and power-hungry devices utilize it. This increase comes with a greater responsibility to know how much power is being delivered over the cabling system and what routes it takes. Keeping up to date and accurate records of power consumption and understanding how the cabling system is ventilated will ensure a healthy network infrastructure for all users. Ensuring that those departments responsible for the distribution of both power and IT services, over what has largely been considered an IT resource, should be clearly defined to avoid one powered service from disrupting another.

Adhering to industry standards and HellermannTyton's installation guidelines is an essential first step in ensuring a successful and high-performing remotely-powered building infrastructure.

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