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Veracity White Paper 002:

PoE Explained

Introduction

Since its standardisation in 2003, Power over Ethernet (PoE) has found widespread application in markets such as VoIP telephony, wireless LANs, IP video security and access control. As discussed in Veracity's earlier article, *Power Without the Struggle*, its benefits as a power delivery method include drastically lower installation and maintenance costs, and its technology offers a supply that is reliable, safe, efficient and robust, while being as simple as possible to install.

PoE gives network installers control over the power distribution to their equipment, however for many this is not their forté: while the concepts behind PoE are straightforward in absolute terms compared to the complexities of other IT technology, the fundamentals of electrical power and its delivery are new territory to a significant proportion of users.

This white paper, therefore, intends not only to serve as a reference to those technical features of PoE that are relevant to users of network equipment, but also to provide further explanation of the basic principles behind the technology, so that these features may be understood well enough to enable the effective design, installation and troubleshooting of PoE-enabled networks.

Contents

Concepts and Terminology

Power over Ethernet is defined across a single network link, and so the three basic components of a PoE connection are:

- The equipment that delivers power to the cable (often referred to as a *PSE*, which stands for *power sourcing equipment*)
- The device which receives its power from the cable (also known as a *powered device*, or *PD*)
- The cable itself

Typical PDs include IP cameras, wireless access points (APs), etc., and the PSE would normally be a PoE-enabled network switch or a *midspan* power injector, patched in to add PoE capability to a non-PoE network switch channel or similar. These two configurations are shown in figure 1 below.

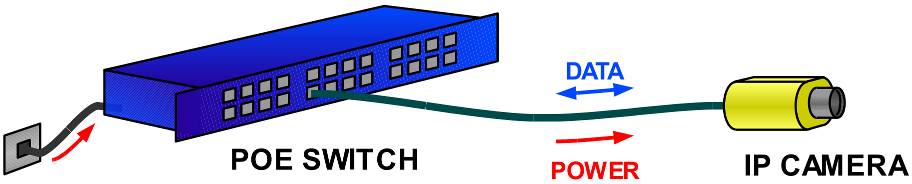


Figure 1a. *A PoE network switch can deliver power to a PD, such as an IP camera, over its data cable*

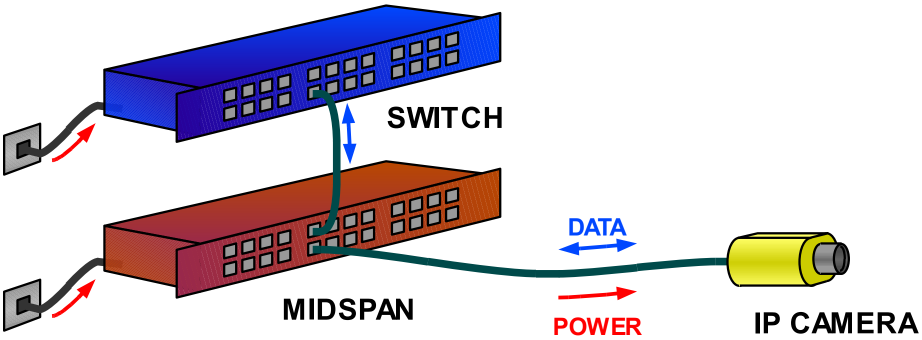


Figure 1b. *A midspan PSE can be used to add PoE capability to standard network switch channels*

The terms PSE, PD and midspan are defined in the current IEEE specification for PoE, *802.3af*, which is part of the 802.3 set of standards that define Ethernet[1]. Nearly all devices described as incorporating PoE comply with this standard (although the manufacturers' literature should always be consulted).

So that 802.3af PoE can coexist with existing Ethernet technology, PDs must display a *signature* to advertise that they can accept PoE, and optionally a *power class*, to indicate how much power they require. The PSE detects these before it connects power to the cable, in order to protect incompatible devices. Signature detection and power classification will be described in more detail in later sections.

PoE is also designed to operate over standard network cable: Cat 3, Cat 5, Cat 5e or Cat 6 (often collectively referred to as Cat 5), using conventional RJ45[2] connectors.

1 Technically PSE, PD and Midspan refer only to the power circuits of the equipment used, but they are commonly used to refer to the equipment itself

2 Often (and more correctly) referred to as *8P8C* connectors

Electrical Power

Before delving further into the details of PoE itself however, it is worth covering some of the fundamental concepts behind electrical power transmission, in general terms, as for many people an introduction or refresher in this area will lift one of the barriers to understanding PoE.

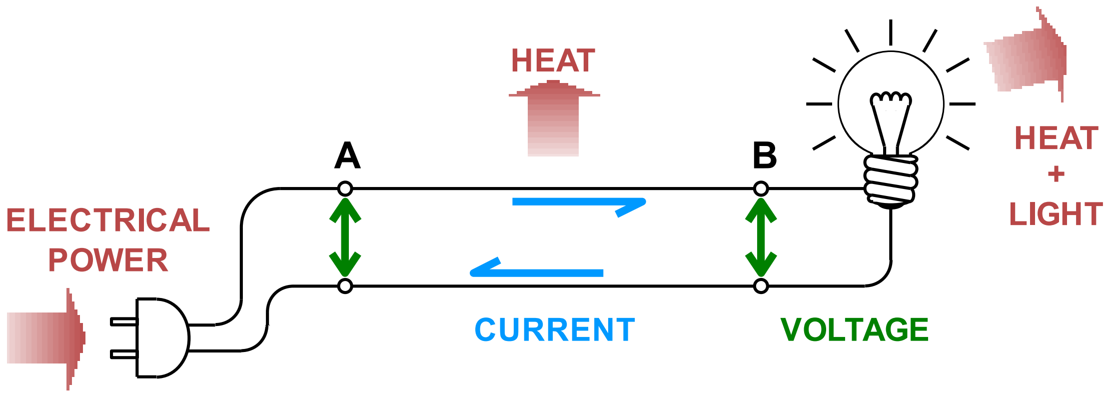


Figure 2. *Power being transferred over an electrical cable to a light bulb*

Figure 2 shows a common, simple example of electrical power being transferred over a long cable. The configuration forms an electrical *circuit* with properties that can be defined as follows:

- *Voltage* is measured between any two points in a circuit: it can be thought of as the "force" available to cause electricity to flow.
- *Current*, measured in *amps*, describes the "rate of flow" of electricity around the circuit. Its value is the same at every point in the loop shown.
- *Power* is the rate at which *energy* is transferred, and is measured in *watts*. Electrical devices may convert this energy into different forms – light, motion, etc. - but in most cases it ends up as *heat*.

The electrical power being delivered to a device or part of a circuit can be calculated by multiplying the voltage measured across it by the current flowing. For example, if the voltage across the lamp in the illustration, measured at point B, is 115 volts, and the current flowing around the circuit is 0.8 amps, then the amount of electrical power being converted into heat and light by the lamp is equal to 115 x 0.8 = 92 watts.

It can also be seen that some of the power delivered to the circuit is lost as heat in the cable. This means that:

- The total power that must be drawn from the mains supply is more than that required by the lamp. In fact this can as much as double the power requirement of the circuit.
- There is a *voltage drop* across the cable. In other words, the voltage across the lamp at point B is lower than the voltage delivered at the mains socket, point A.

This power loss and voltage drop is caused by the cable's *resistance*. Resistance is proportional to length and reduces with wire thickness, so the longer a cable is, or the lighter its gauge, the greater the power loss and voltage drop across it. In the example, the voltage at point A may be 120 volts (enough for the lamp to draw its rated 100 watts) but the resistance of the long cable causes 5 volts to be dropped along the way to point B.

These losses also increase as the current flowing through the conductor increases, which means it is more efficient to transfer electrical power at a higher voltage, as the current necessary to deliver the same power will be lower, so less power is lost in the cable. This is the reason that power grid transmission lines operate at such high voltages.

Cat 5 Cable and Power Transmission

The principles of carrying electrical power over Cat 5 are no different to those of other power distribution systems, such as the AC mains wiring in the previous example, but as the power is being transferred over light-duty cable for long distances, the effects of the power loss and voltage drop become significant. (The amount of power that is lost as heat in the cable is detailed in the next section).

The arrangement and connection to the cabling used for PoE also differ slightly from conventional power wiring, in order to work around the existing standard for Ethernet data. Cat 5 network cables contain a bundle of eight wires, arranged as four *twisted pairs*[3] as shown in figure 3. In the most common type of Ethernet, *100BASE-T* or *Fast Ethernet*[4], only two of the four pairs are used to carry data; each pair carrying a signal in one direction. These are known as the *data pairs*, and the remaining two are unused and are referred to as the *spare pairs*.

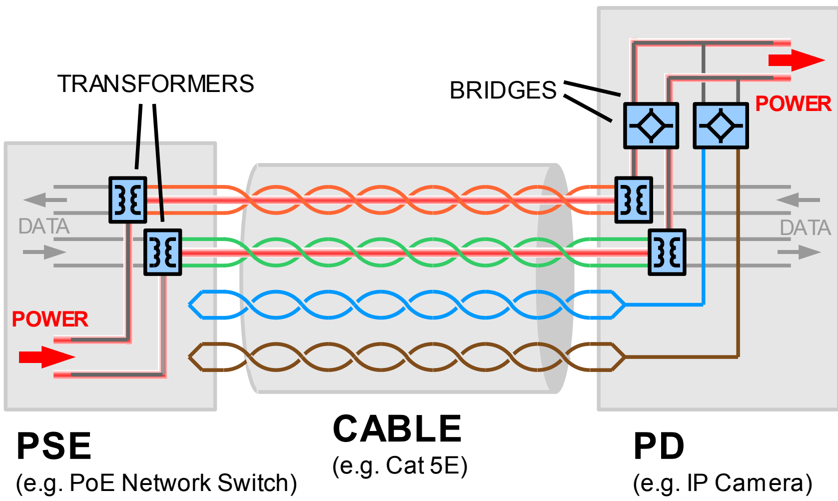


Figure 3. *PoE power transmission using the data pairs of Cat5 cable*

3 Twisting together the two wires used for a signal greatly reduces the amount of interference the wires pick up or emit

4 Specifically 100BASE-TX, in full-duplex mode

Although each data signal can be carried within a single pair, PoE treats each pair of wires as a single conductor (a reason for this is that using both wires halves the overall resistance). As electrical current must flow in a loop, two pairs are required to allow power to be carried by the cable, and either the data or spare pairs can be used for this. The PD must be able to accept power from whichever pairs the PSE delivers it to.

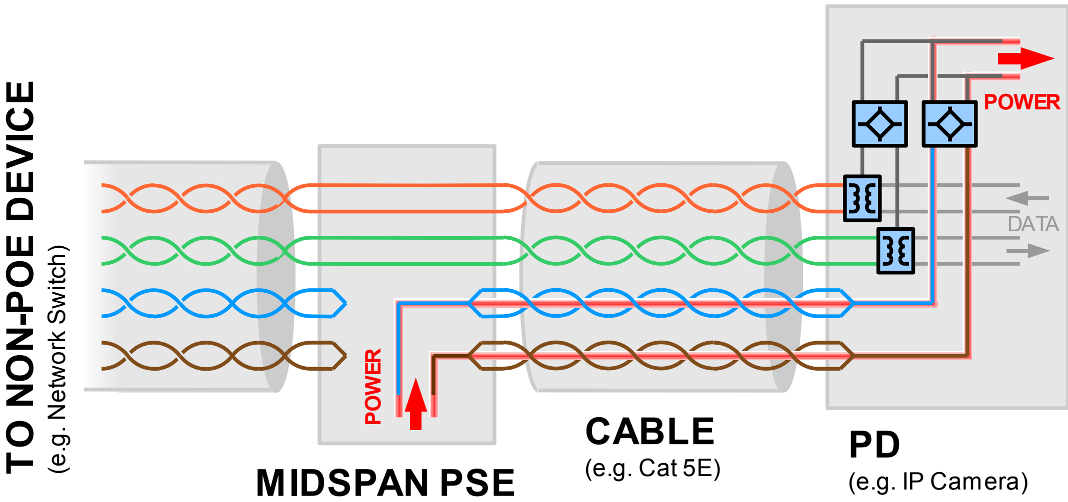


Figure 4. *Upgrading a Cat5 connection to PoE, using a midspan to inject power on the spare pairs*

Normally, the data pairs are used to carry the PoE power, and the spare pairs remain unused. The example shown in figure 3 above illustrates how electrical power can be connected to the data pairs in the cable, and the path it follows. As the PoE current, carried in common by the wires, is DC[5], while the data signal carried within the pair is very high frequency, both can exist on the same cable without degrading performance, and electrical *transformers* can be used to separate them at either end. *Bridge* circuits in the PD correct the electrical *polarity*, and allow power to be received from either the data or spare pairs, while preventing current from being able to flow back down the unused wires.

The current flow when using a midspan PSE to deliver PoE over the spare pairs of the cat 5 cable is shown in figure 4. No transformers are required to inject the DC current as the pairs are not shared with data, and the original Ethernet signal on the data pairs can pass straight through from one cable to the other (typically the midspan will be patched in straight after a non-PoE network switch).

Although this method of power injection is defined in the standard, many midspans connect their power to the data pairs using transformers[6] – the method employed will usually vary from brand to brand. Furthermore, it is possible to support gigabit Ethernet (which typically uses all four pairs for data), by always injecting power via a transformer or equivalent arrangement.

5 *Direct current*, which typically does not change over time, as opposed to constantly-changing *alternating current* (AC)

6 This is because IEEE 802.3af, like so many standards, rather conveniently incorporates matter that has already been patented by contributing manufacturers

Power Classification

As well as enabling the basic function of delivering power over network cables, the PoE specification incorporates some more advanced features in order to enhance efficiency, reliability and safety. *Classification* is one such feature: as part of the start-up process when a PoE connection is made, the PD can advertise its *power class*, which is an indication of how much electrical power it requires to operate.

There are five power classes in total, although only three different bands of power level that devices can fall into. These are listed in figure 5 below.

Class	Min. PSE power	Max. PD power	Example PD
1	4 watts	3.84 watts	VoIP telephone
2	7 watts	6.49 watts	IP video camera
3, 4, or 0	15.4 watts	12.95 watts	Wireless access point

Figure 5. *PSE and PD power limits by class*

As can be seen, each class specifies two different values for power: one for the PSE, and one for the PD; and this is to account for the power that is lost in the cable. Hence it is important to remember that only devices of up to 12.95 watts can be powered using PoE, even though the PSE specifies a 15.4 watt output – and this is complicated further as these numbers may frequently be rounded to 13 watts and 15 watts respectively.

Note also that these figures are *upper limits* to power. Power cannot be "forced" down the cable – a surprisingly common misconception. The PD simply presents a load to the cable and draws as much current as it needs. Most PoE-powered devices will draw a fixed level of power, so for example a 5 watt IP camera will advertise itself as Class 2, as it will never need more than 6.49 watts, and then draw enough current at its local voltage to provide the 5 watts it requires to operate.

Classification is an *optional* stage of the power-up procedure: to save cost, some PDs will leave out the classification circuitry, and will be detected as *unclassified*, which is Class 0. Such devices may draw any power level up to the limit, in contrast to Class 3 devices which are known to require more than 6.49 watts. In either case it is perfectly possible that the device may normally draw a level of power far lower than indicated – for example an IP dome camera may only require 4 watts when stationary, but take 10 watts when moving. Class 4 is a reserved class and will be used for future standards; see the later section on PoE Plus.

The figures in the table are also based on the *worst-case* operating conditions for PoE. PSE voltage is nominally 48 volts, but its allowable range is between 44 and 57 volts: because efficiency increases with voltage, the losses are based on a PSE supplying the 44 volt minimum. A worst-case value for cable resistance is also assumed, and this is based on a maximum length[7] of light-gauge cable, with an allowance for connectors, patch panels, or bad wiring.

7 100 metres, which is the maximum distance for a twisted-pair Ethernet connection

Power Management

Classification is just one feature of PoE which enables enhanced *power management* of network devices. For example, most PoE network switches and midspans have a *power budget* that is not sufficient to deliver full PoE power to all of their ports. A small network switch with four PoE ports will often have a power budget of 30.8 watts; a limit set by the capabilities or restrictions of its own power supply. It can allocate its power to any combination of devices whose requirements, indicated by their power classes, do not exceed this limit, so for example it could enable power to four Class 2 devices with no risk of overload, as the total power needed by them will never exceed 28 watts. However only two Class 3 devices could be powered safely, so any further PoE devices connected would be denied power. Such operation is essential for correctly-designed PSEs to be able to guarantee continuous power delivery to devices whose requirements may change over time.

At the other end of the scale, remote power management of complex installations is possible, using SNMP or other technologies to control and monitor switch and midspan ports, in a similar manner to and often in parallel with the control of network data traffic in managed installations. This allows devices' power draw and budget allocation to be monitored, and devices can be switched on or off, reset and prioritised as desired. The PSEs can also be connected to an *uninterruptible power supply* (or *UPS*), to provide a power backup for all or selected network devices.

This intelligence and control means that PoE-enabled network installations can be designed to be far more power-efficient than the mains-powered alternative. However it is important to remember that as all the power is routed through the PSE equipment, the requirements in the wiring closet can be much higher, and AC power installations should be designed for the worst-case load.

With the greater power requirement in the wiring closet comes an increased amount of heat, along with associated concerns over cooling and ventilation, although it must be noted that most of the electrical power drawn from a PSE will be directed to remote devices rather than converted to heat in the PSE itself. For example, a midspan that can deliver 24 channels of maximum-class PoE has a budget of 370 watts (15.4 watts × 24 ports). If its power input is rated 4 amps at 120 volts AC, then it requires a maximum of 480 watts (4 amps × 120 volts[8]). This means that, at maximum load, 480 watts is required from the AC supply, of which 370 watts is routed to external equipment, and the remaining 110 watts goes towards heating up the midspan.

8 AC (RMS) and DC voltage levels can be treated the same way in power calculations (although *peak* AC voltage is higher)

Safety Measures

The PoE standard incorporates a number of measures to ensure its safe operation, both to protect legacy equipment from damage and to protect users from the hazards of electrical power. The main safety features of PoE are as follows:

- *Signature detection*, as mentioned previously, prevents damage to legacy devices by ensuring that PoE voltages can only be applied to the cable once a compatible PD has been detected. All 802.3af PDs must display a *signature* when unpowered, whose electrical characteristics can be detected by the PSE using a safe, low-voltage technique.

- *Current limiting* is employed to protect the PSE from overload and to quickly disable malfunctioning PDs. The current drawn on each enabled port is continuously monitored, and power is disconnected if it increases beyond the allowed limit. This limit can be set to correspond to the connected device's power class for added protection.

- *Polarity protection* provided by the bridges in the PDs power input circuitry means it can safely receive power regardless of the configuration and polarity of the voltage on the cable. This makes it immune to reverse connections on crossover cables or different types of equipment. Badly-wired or incompatible equipment will either work safely or will not connect at all.

- *Automatic disconnection* of devices is performed when the monitored current falls below a minimum level, returning the cable to its original unpowered state, ready for the safe connection of another PoE or non-PoE device.

- *Low voltages* are used to protect installers from electric shock hazards. The voltage used by PoE (up to 57 volts) is high enough to be efficient but low enough to be safe. This has the further advantage that cabling does not have to be installed by a qualified electrician.

- *Isolation* of the cable from other devices protects further against electrical hazards. Both PD and PSE should provide a 1500 volt isolation barrier between the cable and ground or any accessible parts (although some PSE manufacturers flout this rule).

In addition to these designed-in features, the fact that PoE is *standardised* mitigates the risk of using different and incompatible local power supplies, with exposed power connectors that cannot be securely fitted.

PoE Plus and Custom PoE

802.3af is by far the dominant incarnation of PoE on the market today, but is not the only one. Other implementations exist: either those that pre-date the standard, misinterpret it, or increase the available power for specific applications.

All classes of product which employ PoE include some devices which require more power than the 802.3af standard can deliver, either due to developments in technology, such as the 802.11n wi-fi standard, or to meet the needs of extra features, such as PTZ control of IP cameras. In response to this demand, the IEEE has been working on an enhanced standard, called *802.3at* or *PoE Plus*. PoE Plus is due to be finalised in mid 2009, and at the time of writing increases the power available at the PD to over 25 watts, by increasing the minimum PSE voltage, and by increasing the maximum current while reducing cable losses by specifying a minimum of Cat 5 cable. Plans to make up to 60 watts available, by using all four pairs and a higher current, will not be incorporated at this point.

PoE Plus PDs advertise themselves as Class 4 devices, and are only allowed to draw power levels beyond the limit of standard PoE once they have established that their PSE is PoE Plus compliant, either by recognising the way the PSE performs the classification procedure, or by negotiating a particular power allowance once the data connection to the PSE has been established. The latter would enable finer control of power budget allocation than the existing classification scheme - in theory, PDs should support both options.

PoE Plus is now close enough to completion that the most recent “pre-standard” equipment should remain compatible with future devices, however there are other high-power supplies available which allow anything up to 80 watts to be injected to the cable. These either use the 802.3af standard but with an increased current limit, or connect their supply directly to the spare pairs with no requirement for signature detection. This “always-on” type of PSE in particular requires extra care when installing; only PSEs that have been approved by PD manufacturers should be used and they should be labelled accordingly to prevent them from being used with other devices later on.

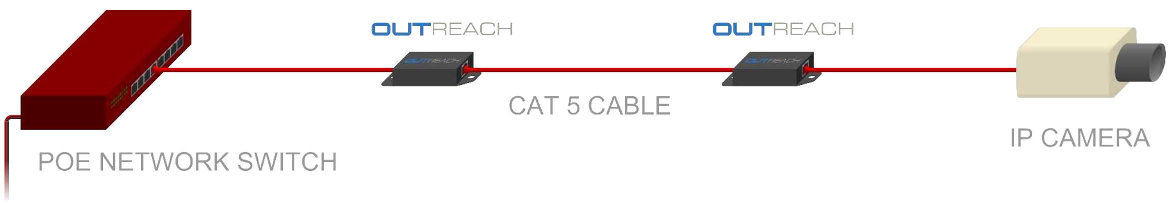
Conclusion

PoE, like all technologies, can be used most effectively if its workings are known and understood. When the terminology, principles, basic and advanced features are explained, its ease of use and subtle technological benefits can be appreciated, and it can be deployed with confidence and in the optimal manner by installers of network equipment.

Appendix: How Veracity's products enable PoE applications

Extend the range of PoE using OUTREACH

OUTREACH allows network installers to overcome the 100 metre (328 foot) distance limitation of conventional Ethernet. OUTREACH is simply connected in-line with the cable to restore the network data and intelligently forward power to PoE devices.

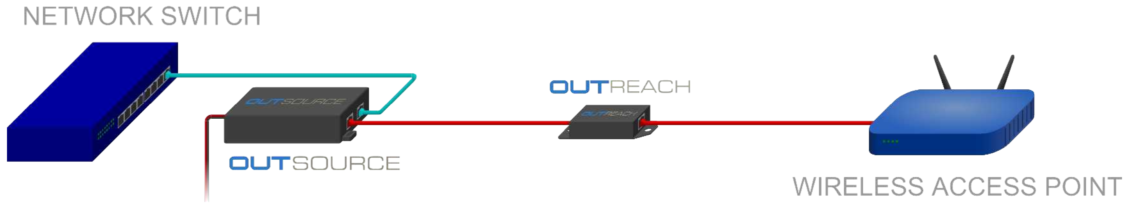


OUTREACH is compact, wall-mountable and self-configuring, and multiple OUTREACHes can be connected in a chain to extend Ethernet connections with or without PoE to up to 1000 metres (3280 feet).

In the example shown, two OUTREACHes allow an IP camera to be located up to 300 metres (1000 feet) away from a standard PoE network switch. As power for all devices is sourced from the switch, no other electrical installation is required.

Add or boost PoE power with OUTSOURCE

OUTSOURCE is a single-channel 802.3af PoE injector, used to upgrade individual network ports to PoE.



It can also deliver boosted power to OUTREACH for long-distance or high-power applications. In the example above, OUTSOURCE injects PoE power into a standard network switch channel, and provides the extra power required to enable an OUTREACH and a wireless access point of any power class, across 200 metres (660 feet) of cat 5 cable.

OUTSOURCE midspans are also available in multi-port, rack-mounted, and PoE Plus variants.

Extend PoE Plus and custom PoE with OUTREACH PLUS

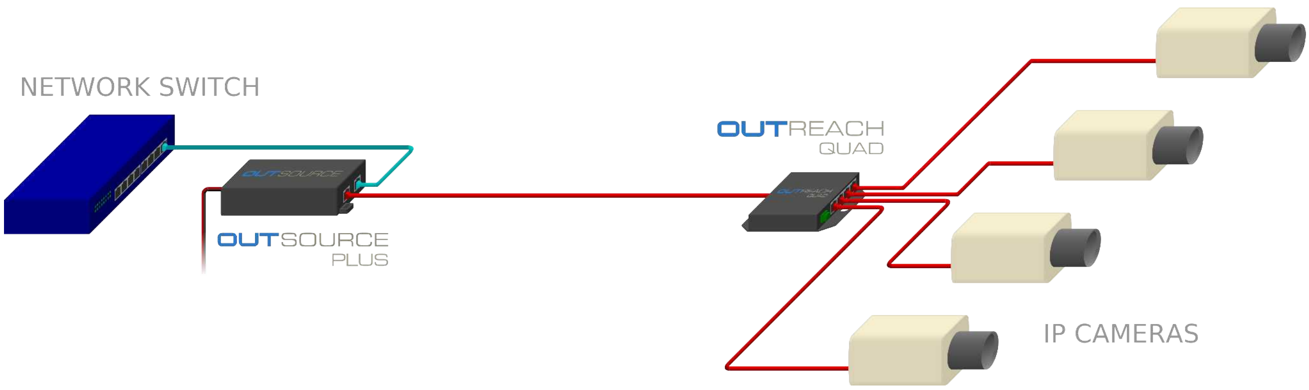
OUTREACH PLUS adds high-current capability to OUTREACH's Ethernet extension technology. It can be used to extend network connections to devices such as PTZ cameras, access control interlocks, videoconferencing phones and high-power wireless devices (e.g. 802.11n WAPs), without further electrical power installation.

OUTREACH PLUS is compatible with high-power PoE standards such as PoE Plus (802.3at) and many manufacturer-specific PoE implementations.

Extend, expand and distribute PoE using OUTREACH QUAD

OUTREACH QUAD uses Veracity's patented power management technology to allow PoE to be safely forwarded to multiple network devices beyond the 100 metre (328 foot) cat 5 cable limit.

OUTREACH QUAD can be powered by PoE or PoE Plus, either conventional or OUTSOURCE-enhanced, and incorporates an unmanaged 10/100 network switch with four intelligent PoE-forwarding ports. It can be designed-in to installations to reduce cabling costs, or used to quickly add new devices to existing networks.

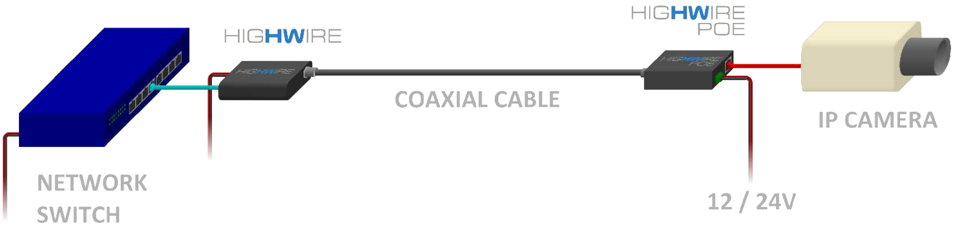


In the typical application shown, OUTREACH QUAD enables up to four IP cameras to draw their power from a single OUTSOURCE PLUS midspan, located up to 200 metres (660 feet) away.

OUTREACH QUAD is also available with an adaptive 12 volt DC output, which can be used to power auxiliary equipment including camera heaters, fans, or non-PoE network devices.

Upgrade to IP video without re-cabling using HIGHWIRE and HIGHWIRE POE

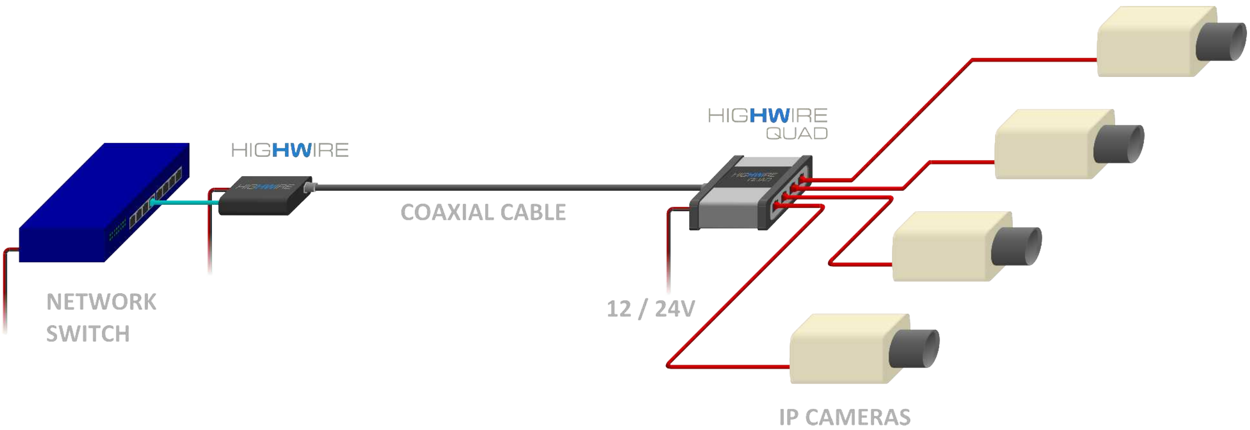
HIGHWIRE POE allows an analogue IP camera to be replaced with a PoE-powered IP camera, without the expense and inconvenience of replacing the existing coax cable or camera power supply.



Veracity's HIGHWIRE technology creates an instant 100BASE-T Ethernet connection across up to 270 metres (900 feet) of standard RG-59 cable, so no installation of Cat 5 is necessary. HIGHWIRE POE also converts the existing 12 volt DC or 24 volt AC supply into a universal PoE power source for the new camera.

Upgrade to IP video and add extra cameras with HIGHWIRE and HIGHWIRE QUAD

HIGHWIRE QUAD allows an analogue IP camera to be replaced with up to four PoE-powered IP cameras, again with no need to replace the existing coaxial cable.

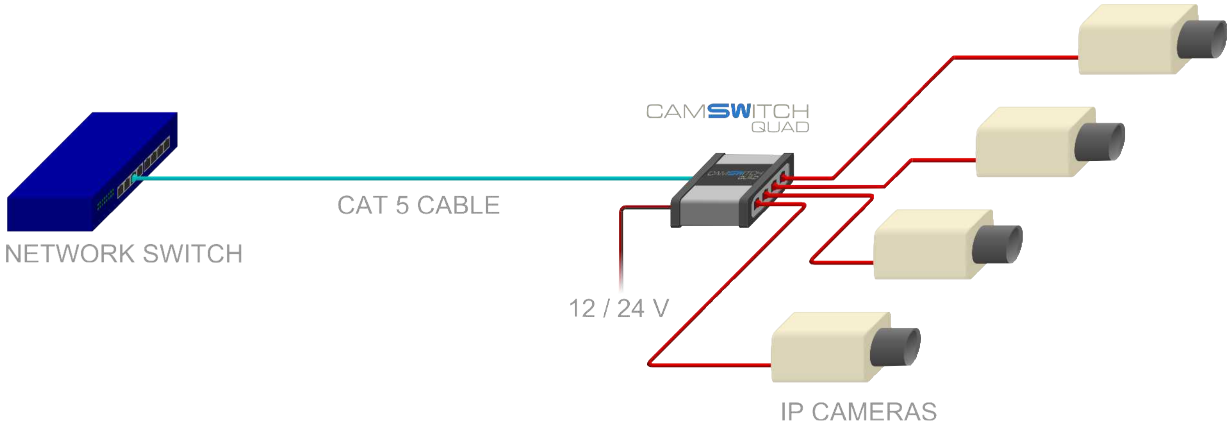


HIGHWIRE QUAD integrates a HIGHWIRE Ethernet-over-coax interface with a four-port 10/100 PoE switch, all powered from a legacy 12 volt DC or 24 volt AC supply. A standard HIGHWIRE at the other end of the coaxial cable is used to convert the signal back to Ethernet.

All Veracity's HIGHWIRE products are compact, rugged and wall-mountable. Straightforward installation is assured, as all connections – power input, coaxial, Ethernet and PoE – are set up automatically, and the Ethernet-over-coax conversion is entirely transparent to the network.

Deliver PoE from a low-voltage supply using CAMSWITCH

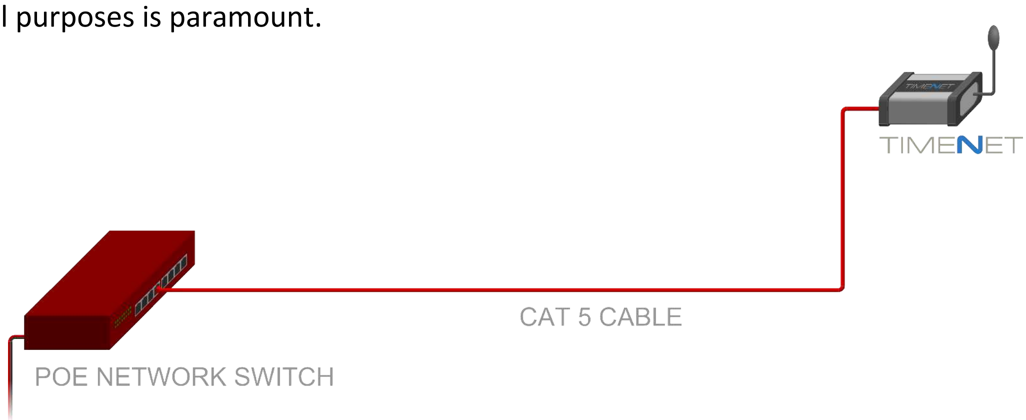
CAMSWITCH QUAD is a compact and rugged network switch which can deliver up to 30 watts of PoE power over four of its five 10/100 Ethernet ports. It features a unique 12 volt DC or 24 volt AC power input (auto-configuring) and is wall-mountable.



In the example installation shown, CAMSWITCH QUAD allows four IP video cameras to receive their PoE power from a single legacy low-voltage supply.

Synchronise networks to atomic time with TIMENET

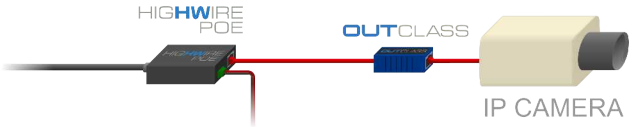
TIMENET allows all devices on a network to synchronise to the same, precise reference clock. This is an essential requirement for installations of Digital Video Recorders, where correct time-stamping for evidential purposes is paramount.



TIMENET is a self-contained NTP master clock and GPS receiver, receiving its accurate atomic time signal via satellite. Its compact dimensions and optional PoE power supply mean it is not confined to an equipment rack, and can be located at the edge of the network, at the optimal site for receiving the satellite signal.

Correct power classes and connect to non-compliant devices with OUTCLASS

OUTCLASS is an in-line adaptor which converts the power class of a PoE device's signature, preventing power budget and compatibility problems with unclassified or incorrectly-classed devices.



It displays a Class 2 signature as standard, so fitting an OUTCLASS to an unclassified 5 watt IP camera would reduce the power it requested from its PoE source from 15 watts to 7 watts. This allows the power budget of a PoE switch to be allocated effectively. In the above example, OUTCLASS enables operation with HIGHWIRE POE, as HIGHWIRE POE will not deliver PoE to devices that request more than 7 watts.

OUTCLASS can also be retrofitted to many devices that are not compliant with the 802.3af specification, including those which use different PoE configurations, or are not fully compliant by design, so that they can be used with standard 802.3af equipment.