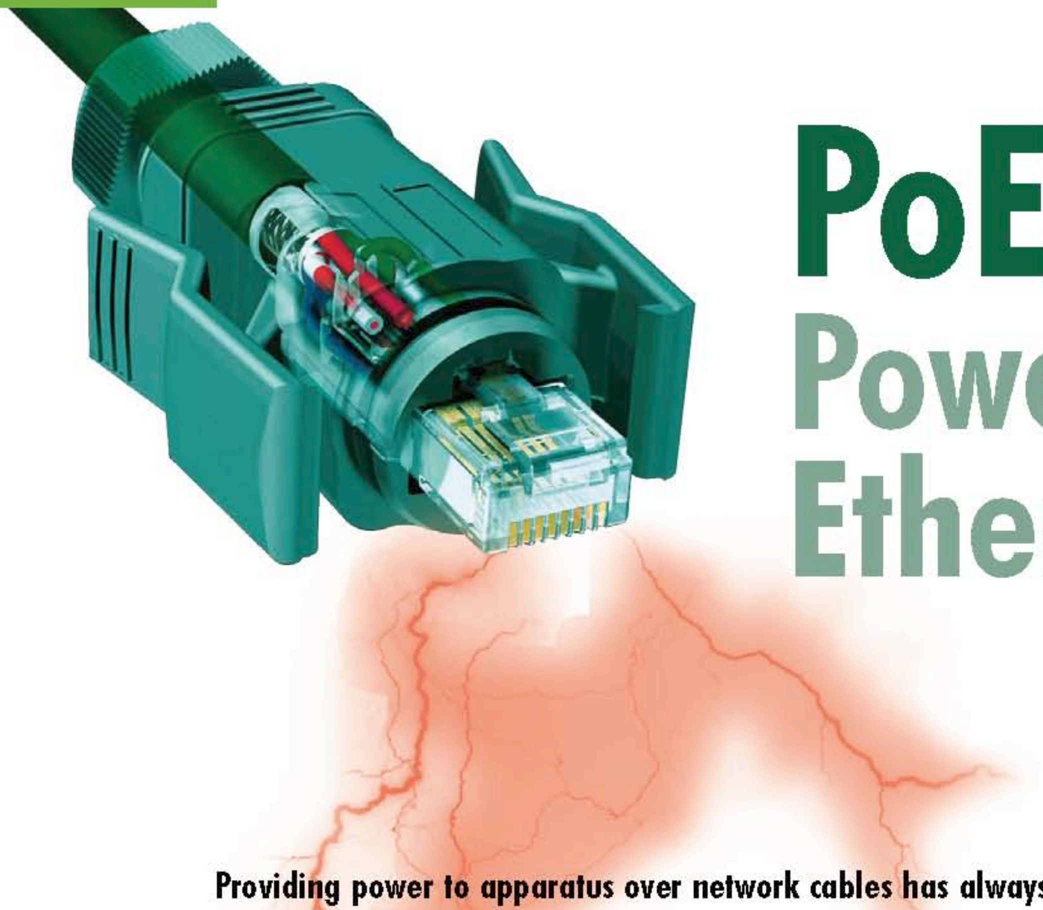

PoE: Power over Ethernet

Stefan Tauschek (Scantec)

Providing power to apparatus over network cables has always been usual practice for fixed-line telephones, and now the same capabilities are becoming available on wired Ethernet. The IEEE 802.3af PoE (Power over Ethernet) standard allows up to 13 watts to be supplied and its successor, PoEPlus (802.3at), allows up to 30 watts. In this article we look at how it works in theory and in practice.

Power over Ethernet (PoE) allows power to be supplied to all kinds of devices, from access points to IP cameras. Although users will be happy to be relieved of the problem of finding a spare mains socket when connecting up their latest gadget, things are not so easy for the manufacturer of networking equipment. A 24-port switch fully fitted out with PoE needs a power supply with a rating of nearly 1 kW. High-efficiency switching supplies and careful power management are thus needed.

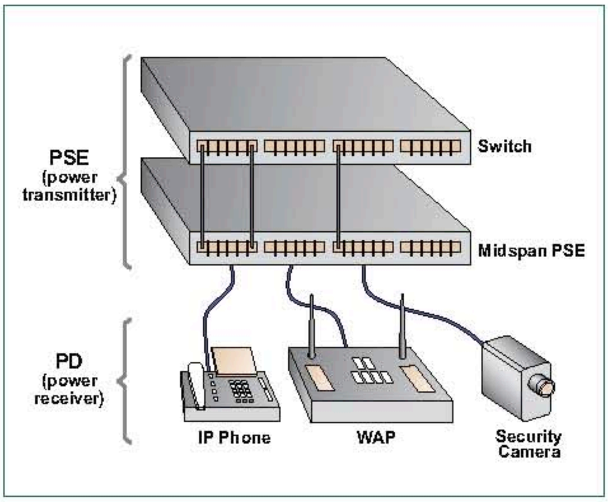

Figure 1.
Power can be supplied via endspan PSEs (PoE-capable switches or hubs) or via midspan PSEs with normal switches or hubs. The connected device which receives power is known as a PD.

IEEE standard PoE

IEEE standard 802.3af defines PoE. The standard specifies how both data and power are delivered over a network cable (generally Cat 5 or Cat 5e). An extension to the standard, 802.3at, is already being worked on. It will allow for higher power levels, sufficient to supply laptops, video phones and high-power WLAN access points without the need for separate mains adaptors.

In delivering power over a network cable PoE is reminiscent of analogue fixed-line telephone systems (POTS, or Plain Old Telephone System) which provide phantom power to apparatus over the a- and b-wires. PoE allows a modern VoIP telephone to be powered in a similar way, without needing a separate mains supply.

The problem of thin wires

Delivering electrical power over a Cat 5 Ethernet cable presents some technical difficulties. The conductors used are typically AWG 24 (approximately 0.5 mm diameter) and have a resistance of around 94 Ω per kilometre. The figure is slightly higher than might be expected because the individual twisted conductors in 1 km of cable are slightly more than 1 km long. If we consider the maximum cable run for a single segment of an Ethernet network (100 m) and use four conductors to carry power, we can expect a total loop resistance in the region of 10 Ω. If the connected device needs say 10 W of power at 5 V the current drawn will be 2 A and the cable

will drop 20 V and dissipate an astonishing 40 watts!
The conclusion is clear. To reduce losses in the cables we need to use higher voltages at lower currents to send power to the attached client devices, each of which will contain a DC-to-DC converter to reduce the voltage to the required level at a higher current. In the PoE standard the nominal voltage supplied is 48 V (with an acceptable range being 36 V to 57 V) at a maximum of 350 mA. This means the system is covered by the SELV (safety extra-low voltage) regulations [1].

Even at this voltage there is a noticeable voltage drop: 0.35 A times 10 Ω is 3.5 V. The network cable dissipates up to 1.2 W. DC-to-DC converters at both the supply and client end ensure stability of the final supply voltage.

PoE topology

As Figure 1 shows, a PoE system consists of a source (the PSE, or Power Sourcing Equipment) and a number of sinks (PDs, or Powered Devices). There are two types of PSE: so-called endspan devices and midspan devices. The former are sources of data packets and current, while the latter pass data packets through and add PoE.
Figure 2 shows how the unused pins 4 and 5 (positive) and 7 and 8 (negative) of an RJ45 connector can be used in 10BASE-T and 100BASE-T systems. An alternative is shown in Figure 3, where phantom power is supplied on data pins 1, 2, 3 and 6.

Phantom power exploits the fact that Ethernet connections provide galvanic isolation between pairs of connected devices using a transformer at each end. It is therefore possible to add a DC voltage to the signals using the centre taps of the transformers, without adverse effect on signal quality. This form of PoE is generally preferred as with existing installations it is not always certain that the so-called 'spare pairs' are actually connected in the cables or connectors. In Gigabit Ethernet systems there are no spare pairs, as all eight conductors are used (in four differential pairs) for data transfer.

PoE operation

At power-up a PSE device must first determine whether any PDs are connected and what their power requirements are, and check that there are no short-circuits in the network. To this end the PoE standard specifies a signalling protocol whereby the necessary information is exchanged at boot time to ensure effective power management.
After reset or power-up the so-called 'signature detection' sequence starts (yellow area in Figure 4). The PSE provides a 0.1 V/μs voltage ramp in the range from 2.7 V to 10 V. By carrying out two impedance measurements it can determine whether a PD is connected. If the detected impedance lies in the range 15 kΩ to 33 kΩ the classification phase begins. If an impedance outside this range is detected, power is disabled on the connection.

The next step is to determine the power classification of the PD. During this phase the PSE raises the voltage into the range 14.5 V to 20.5 V. The PD should draw a 'signature current' which signals its power class to the PSE. The PSE can then determine the PD's power requirement. The 802.3af standard specifies five power classes (see **Table 1**).

When classification is complete the PSE raises the phantom supply voltage to its nominal value of 48 V. The maximum

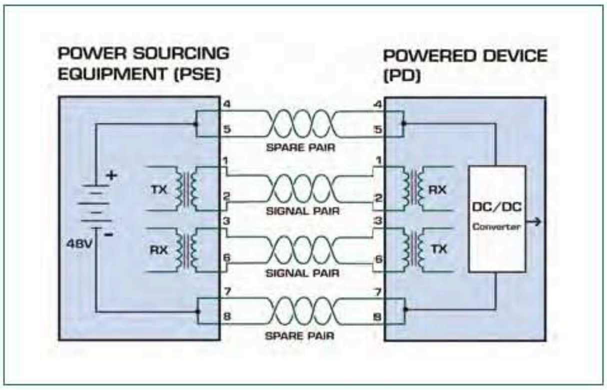

Figure 2.
In a Fast Ethernet system power can be supplied over the two spare conductor pairs.

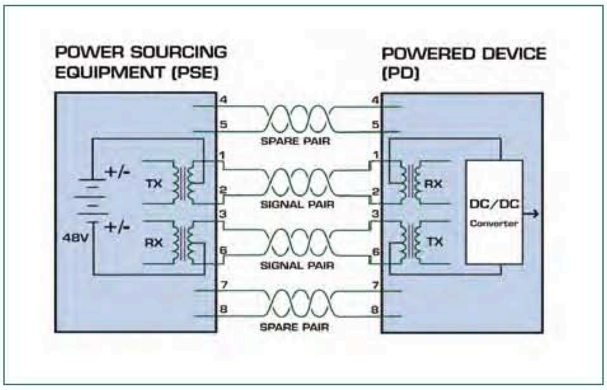

Figure 3.
Phantom power uses the data conductors and hence is also compatible with gigabit Ethernet.

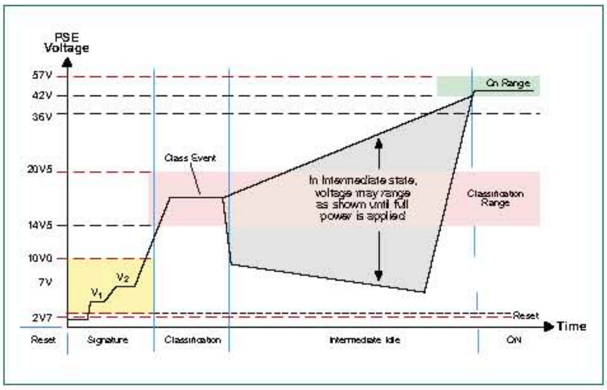

Figure 4.
Signalling protocol for 802.3af PoE.

Table 1
The 802.3af standard defines four power classes plus a reserved class, which is used for PoEPlus.

Class	Use	Signature	PSE power	PD power
0	standard	< 5.0 mA	≤ 15.4	0.44 W to 12.95 W
1	optional	10.5 mA	≤ 4.0	0.44 W to 3.84 W
2	optional	18.5 mA	≤ 7.0	3.84 W to 6.49 W
3	optional	28.0 mA	≤ 15.4	6.49 W to 12.95 W
4	reserved	40.0 mA	reserved	reserved

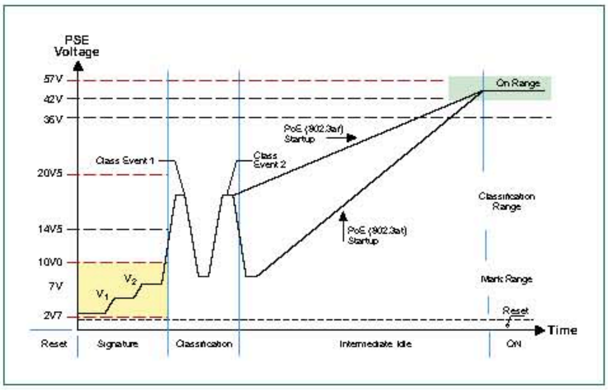

Figure 5. The classification phase in 802.at consists of two pulses.

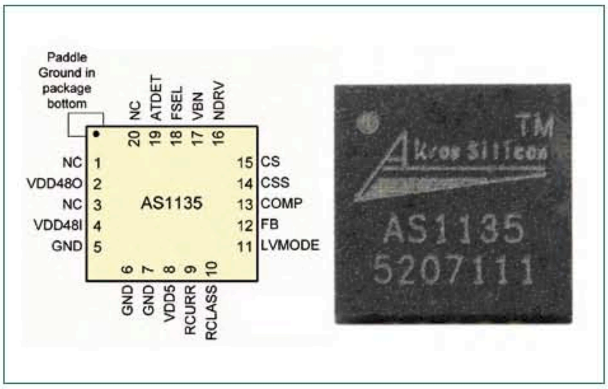

Figure 6. The AS1135 controller is available in a 5 mm square QFN package.

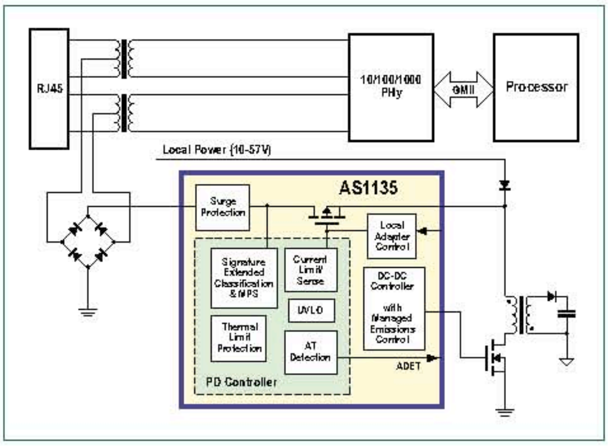

Figure 7. Block diagram of a PoE DC-to-DC converter using an AS1135.

losses in the cable are such that at least 37 V appears at the PD at a current of 350 mA, for a total power of 12.95 W.

There is thus a total of three phases: detection, classification, and application of power (operation). There are various timing requirements that must be observed. For example, under PoEPlus, signature pulses can last a maximum of 30 ms and the gap between them can be at most 12 ms.

More power

The successor to PoE, IEEE 802.3at or PoEPlus or PoEPlus, is under development. It is backwards compatible with 802.3af and will allow up to 30 W to be delivered to a PD. The standard mandates the use of Cat 5e cabling and the PSE voltage range is raised from between 44 V and 57 V to between 50 V and 57 V. The maximum current is raised to 720 mA from 350 mA and the maximum permissible cable temperature is set at 45 °C.

PSEs designed according to the new standard can be used with 'old' PDs. On the other hand, new PDs can of course not draw the full 30 watts from an old-style PSE. The new parts of the system are accommodated by extending the classification procedure. As **Figure 5** shows, there are now two classification pulses. PDs conforming to PoEPlus must initially identify themselves as class 4 devices. During the extra classification pulse they must then draw a signature current of 40 mA. A PoE standard device will ignore the second pulse, allowing a clear distinction to be made between PoE and PoEPlus devices.

Practical implementation

Many companies, including Linear Technology, Texas Instruments and National Semiconductor, are already producing chips to support PoE technology. Because of their high level of integration we will look below in greater detail at products from Akros Silicon, a relatively young company.

The AS1113, AS1124, AS1130 and AS1135 are PoE controllers fabricated using a standard high-voltage CMOS process. They are physically small and have a high level of integration. The AS1113 implements the 802.3af standard, delivering up to 13 W of power. The most recent member of the family, the AS1135 (**Figure 6**), is designed for PoEPlus applications and can deliver output powers from 13 W to 30 W. Since the various PoE devices from Akros Silicon are pin-compatible with one another, system manufacturers can lay out a single printed circuit board for both high- and low-power devices, avoiding the need for complete re-designs.

The PoE ICs include a current-mode DC-to-DC converter with soft-start and current limiting functions.

Using suitable external components, flyback, forward or buck configurations can be realised, and both isolated and non-isolated devices are supported.

The AS1135 example circuit has particularly high efficiency thanks to an active rectifier, where the conventional secondary switching diode is replaced by a synchronously-controlled FET. This technique avoids the otherwise inevitable forward voltage drop of 0.5 V or more associated with Schottky diodes, substituting the voltage drop across the very low channel on resistance of a modern MOSFET. This saves up to 0.5 W or even more at higher currents.

PoEPlus using the AS1135

The design we describe here is based on the Akros Silicon reference design. The AS1135 [2] is the first controller device to support the provisional 802.3at (*Draft 3.0*) standard, which uses a double pulse during the classification phase. It is therefore backwards compatible and can be used as a PD adaptor in power-drawing devices and in PoE-standard PSEs.

The highly-integrated DC-to-DC converter drives an external power switch and monitors the current through the primary winding of a transformer. It provides a soft-start function. The switching frequency can be set using a resistor in the range 100 kHz to 500 kHz: in the example circuit we have selected 350 kHz. The transformers do not need to be made specially: suitable types are available from distributors such as Coilcraft, Halo Electronics and Würth Elektronik.

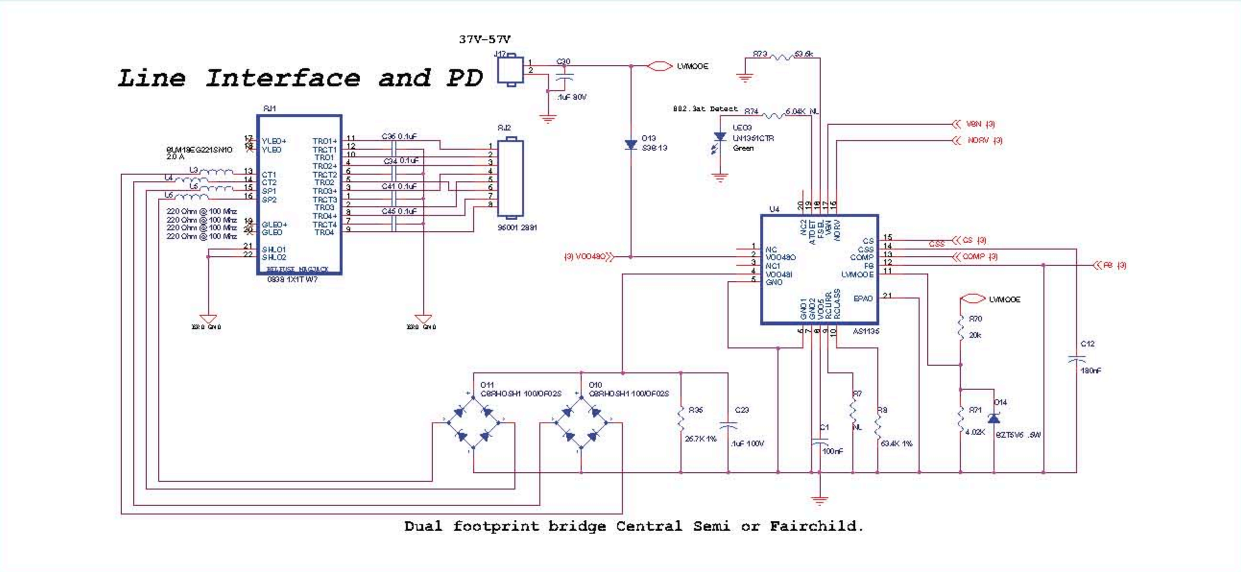

Figure 8.
Connecting an AS1135 to the Ethernet cable.

PD circuit

The Ethernet cable from a switch or midspan is terminated using a Belfuse RJ45 socket/transformer, which supports data rates up to 1 Gbit/s and which is designed for use in PoE applications. As can be seen in **Figure 7**, the centre taps are taken via a bridge rectifier to the voltage input V_{DD}48I of the IC. In the practical circuit shown in **Figure 8**, all pairs are used and so two bridge rectifiers are provided. The signature current of 40 mA is set by resistor at R_{class}, corresponding to power class 4 and thus also to PoEPlus. The resistor at R_{curr} sets the current limit: the pin being left open circuit corresponds to the maximum value of 900 mA. The feedback pin FB is not used in the isolated buck/boost converter configuration, and so is taken to ground. The capacitor on pin CSS sets the time constant for the soft-start function: 100 nF gives a value of around 2 ms.

Since in practice it is not known in advance whether a device capable of being powered using PoE will actually be used in a network that supports it, devices also need to be able to accept power from an external mains adaptor. This is very straightforward to set up using the Akros controllers. An external voltage between 10 V and 57 V is applied via a diode to pin V_{DD}48O and simultaneously via an RC network to LVMODE. This tells the controller that an external supply is available and V_{DD}48I is isolated. The DC-to-DC converter, however, remains active.

The voltage regulator circuit proper, shown in **Figure 9**, is rather more complicated. The polarity-protected, rectified voltage from the Ethernet cable is taken from pin V_{DD}48O via a pi-filter which protects the LAN signal wires from interference. From there it goes to the primary side of a transformer and thence to the primary switching transistor, which

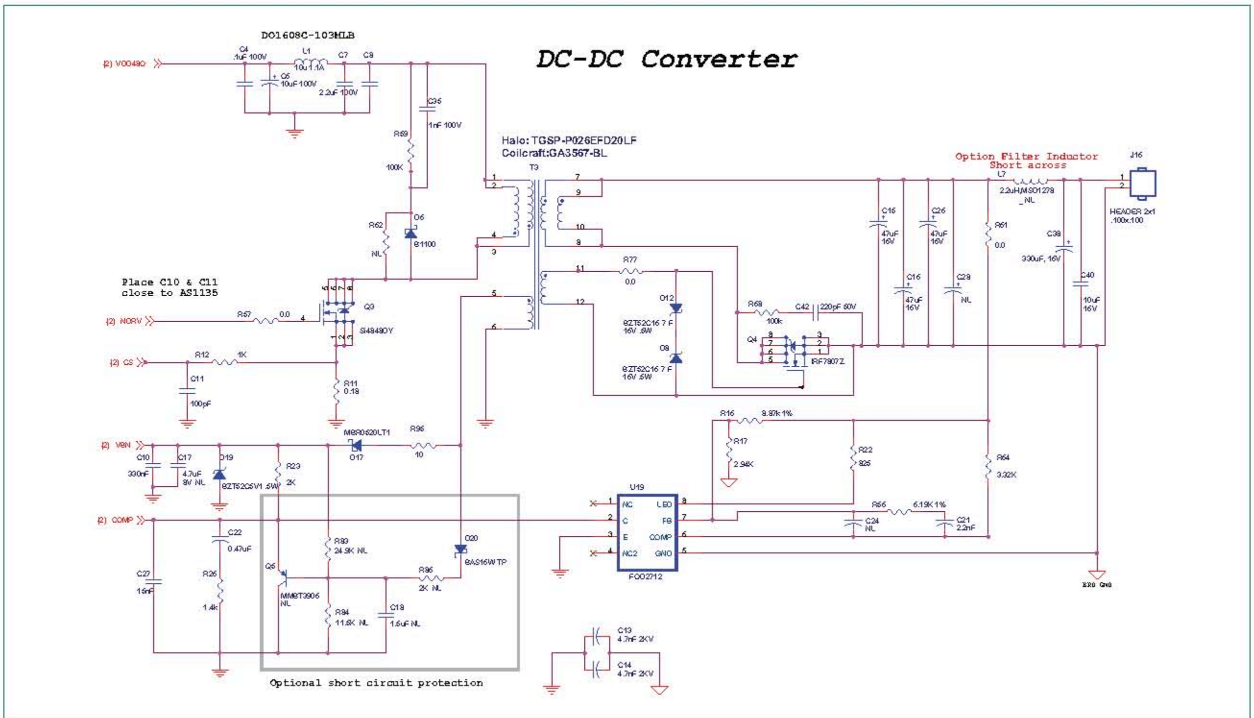

Figure 9.
DC-to-DC flyback converter with an output power of 30 W and active rectification.

About the author

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switches to ground. The device used here is a Si4848DY from Vishay, an N-channel MOSFET with an on resistance of around 100 mΩ at a current of 3.5 A. Components R59, R62, C35 and D6 form a snubber network to suppress spikes. Short-circuit protection on the secondary (device) side is provided by a limiting circuit consisting of R83, C18 and Q5. In operation the voltage difference between pins 5 and 6 of the transformer is about 6.5 V. This is sufficient to ensure that transistor Q5 remains firmly off. If there is a short circuit at the output, the AS1135 sets the mark-space ratio of the switching pulses in flyback converter configuration to a minimum and the voltage between pins 5 and 6 falls. Then Q5 starts to conduct and pulls the COMP pin of the AS1135 to ground. This in turn limits the current to about 100 mA for as long as the short-circuit persists.

The Fairchild FOD2712 optocoupler allows the AS1135 to monitor the output voltage. The frequency response of the negative feedback loop can be set using an extra RC network to achieve stable operation with a quick control response and low overshoot.

The future: 60 W

As standard PoE has become more widespread for local area networks, more and more client devices have become able to make use of it. The power limit of 13 W offered by 802.3af was, at the end of the 1990s when the standard was developed, entirely adequate as there were few devices capable of using phantom power and the Cat 3 cable that was generally installed was not electrically suitable for providing more.

Since then things have changed: now Cat 5 and Cat 5e cable are ubiquitous in network installations, offering higher bandwidth and lower resistance. Also, there has been a sharp growth in demand for devices such as VoIP telephones, IP cameras and wireless access points, which can all benefit from PoE.

PoEPlus supports these developments by doubling the available power to 30 W. But, adding to the performance also provokes the desire: and so the IEEE 802.3at working group is now looking at how power levels of up to 60 W can be delivered using Cat 5e cable.

More power using four conductor pairs

Since the PoEPlus specification stretches the physical capacity of Cat 5e cabling and connectors to the limit, a further doubling in power can only be achieved by using greater parallelisation. The IEEE working group looking at this problem is therefore intending to consider delivering electrical power over all four Ethernet cable pairs rather than just two. That would give a direct doubling of power capacity to 60 W. However, the working group appears to have suffered a case of cold feet, as in *Draft 3*, dated March 2008, a power limit of 24 W for two pairs was proposed. There is considerable concern over cable overheating, particularly in large networks with thick bundles of cables, which could lead to damage to the cable or even to fires. Whatever variation wins through, it is certain that PoEPlus in its final form will be specified for power levels in excess of 30 W, divided over four pairs of conductors.

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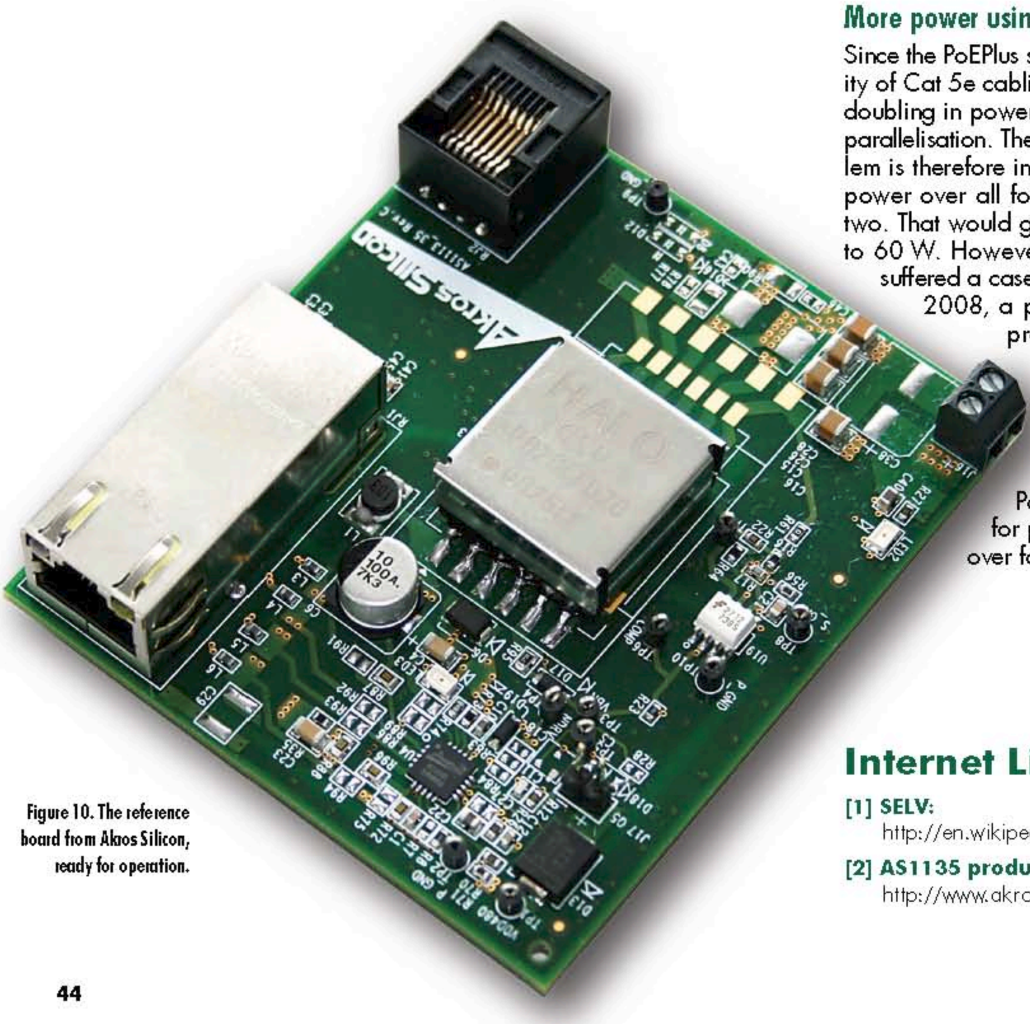

Figure 10. The reference board from Akros Silicon, ready for operation.

Internet Links

[1] **SELV:** http://en.wikipedia.org/wiki/Extra-low_voltage

[2] **AS1135 product page:** http://www.akrossilicon.com/products/as1135.html