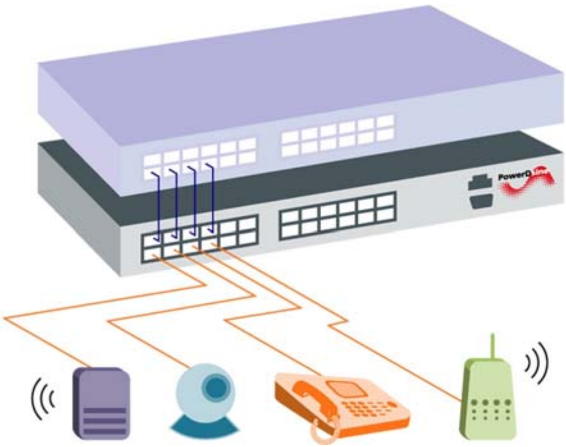
Application Note 125

# Designing
# a Low-cost IEEE 802.3af
# PD (Powered Device) Front-end



PowerDsine Proprietary Information

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# Revision History

| Revision | Release Date | Details |
|---|---|---|
| AN-125 v1.0 | February 12, 2004 | First release |
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# 1 Introduction

Have your customers ever attempted to install one of your networked devices on their corporate network, only to find out that it would either be too cumbersome, or too costly to add a power outlet at what seemed like the perfect location? Have users of your wireless access points needed to install one where electric power infrastructure just couldn't reach? If you answered any of the above answers with a yes, then you too have encountered the need for Power over Ethernet (PoE).

Power over Ethernet is a revolutionary technology that integrates data and power on standard Ethernet wiring. It supplies reliable, uninterrupted power to IP telephones, Wireless LAN and other Ethernet devices via commonly used CAT-5 cable infrastructure.

PoE saves time and money by avoiding the complexity and expense involved in the installation of separate Ethernet infrastructure, power cabling and AC outlets. It even doubles as an Uninterrupted Power Supply (UPS) for individual devices, and along with added installation simplicity, significantly enhances network reliability. Better yet, modular PoE solutions that may easily be added to standard network device layouts, enable the implementation of highly appealing applications, with a relatively low per-port cost.

What does it take to construct or modify a networked device so that it becomes PoE-ready? That's what this application note will explain, while exemplifying the design of a PD (Powered Device) power front-end, which complies with the IEEE 802.3af Power over Ethernet (PoE) standard.

The target audience for this application note includes engineers who wish to equip new generations of IP phones, WLAN or Bluetooth access points, LAN controlled security cameras and other Ethernet controlled terminals with PoE capabilities.

## PowerDsine's Certification Program

PowerDsine, who has played a significant role in the creation of the IEEE 802.3af PoE standard, has also pioneered a service for vendors of PoE-enabled terminals (PDs) who wish to verify their equipment's interoperability with PowerDsine's own PSE products (for information regarding this service, please feel free to contact PowerDsine's Customer Care department at techsupport@powerdsine.com).

To date, over a hundred PDs have been tested and certified by PowerDsine, including most leading IP phones, Wireless LAN access points and security cameras. This service is provided free of charge.

# 2 Power over Ethernet (PoE) Basics

While adding PoE support to networked devices is relatively painless, it should be realized that power cannot simply be transferred over existing CAT-5 cables. Without proper preparation, doing so may result in damage to devices that are not designed to support provision of power over their network interfaces.

Figure 1 below illustrates the basic necessary elements required during the PoE power provisioning cycle.

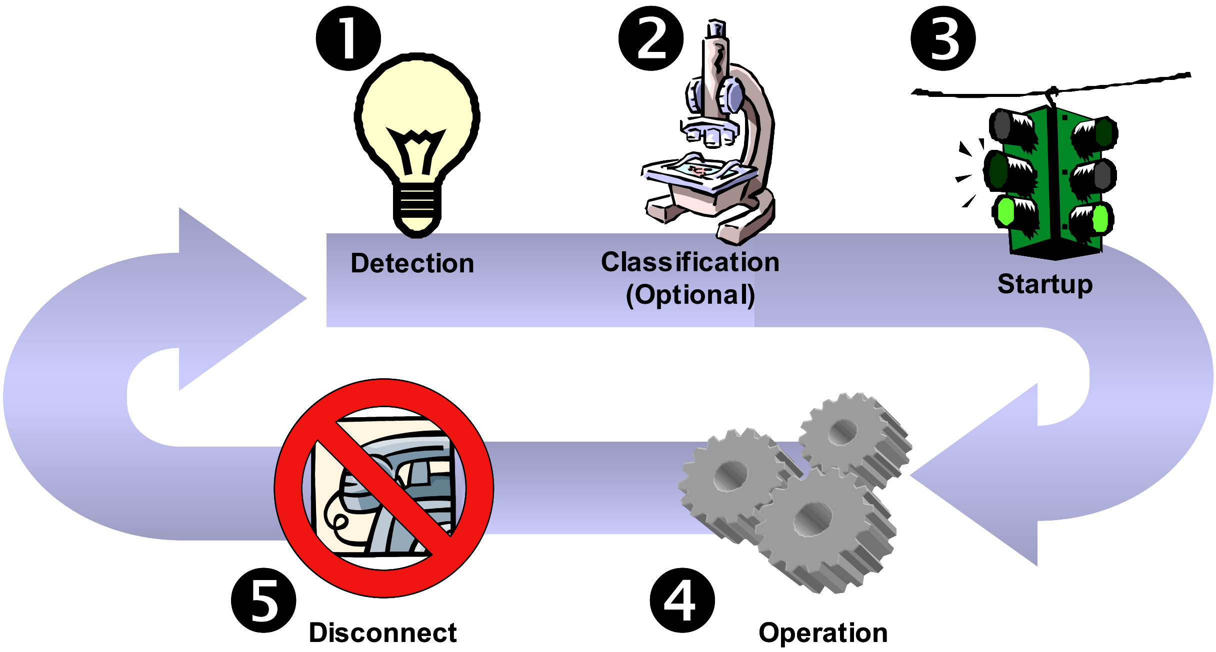


*Figure 1: PoE Basics*

## Line Detection

Before power is applied, safety dictates that it must first be established that a PD (DTE, or Data Terminal Equipment capable of being powered over Ethernet, as opposed to a non-PoE-capable legacy NIC) is connected. This process is referred to as line detection, and involves the PSE (Power Sourcing Equipment – a PoE-capable Ethernet switch or a midspan power source next to a switch) seeking a specific, 25 kohm resistor signature. Detection of this signature indicates that a valid PD is connected, and that provision of power to the device over Ethernet may commence.

## Pre-standard Line Detection

Before the IEEE 802.3af standard required that 25 kohm resistor signature detection be carried out, line detection was most commonly capacitor-based, as traditionally implemented by PowerDsine. For the most comprehensive coverage of the PD market, PowerDsine continues to support two distinct detection schemes. These include resistor detection (as required by the standard) and input stage capacitor detection (an input stage capacitor is unique to Powered Device design and will therefore never be found in legacy network equipment).

## Classification

Once a PD has been detected, the PSE may optionally perform classification, to determine the maximum power, which should be allocated to that PD. PowerDsine's PSE induces 18 Volts during the classification phase, to which a PD will respond by consuming a certain current level. Depending on this current consumption level, the PD will be assigned to one of 5 classes: 0 (undefined class) indicates that full 15.4 Watt power should be provided, 1-3 indicate various required power levels and 4 is reserved for future use. As most current PDs do not support classification, they are assigned to class 0. Special care must be employed in the definition of class thresholds, as classification may be affected by cable losses.

While classification could theoretically be achieved using different resistors to represent each PD class, a sophisticated electrical circuit is actually employed for this purpose. Please see the Classification section for more details on the implementation of this circuit.

## Startup

Once line detection and optional classification stages have been completed, the PSE must switch from low voltage to its full voltage capacity (48 Volts) over a fairly long amount of time (a minimum of 15 microseconds). A gradual startup is required, as a sudden rise in voltage (reaching high frequencies) would introduce noise on the data lines.

## Operation

During normal operation, the PSE provides 48 Volts and 15.4 Watts of power. While the IEEE standard focuses on single-port functionality, multiple port solutions are not uncommon (24 or 48 ports are typically provided), requiring that total switch power levels be taken into consideration.

### Power Management

While a 24-port system designed for full 15.4 Watt power provision requires 370 Watts (!) and introduces numerous cooling and cost-related challenges, common PoE scenarios are typically less demanding. For example, the total power consumption of an application involving 20 IP phones (typically 4-5 Watts), 2 Wireless LAN access points (8-10 Watts) and 2 network cameras (10-13 Watts) per switch will be 146 Watts. A 150 or 200 Watt power supply should enable a power sourcing switch to easily face this challenge.

Under some conditions, the total output power required by PDs may exceed the maximum available power provided by the PSU (Power Sourcing Unit). In order to keep the majority of ports active, within available power limits, PowerDsine has devised a power management system based on dynamic logic, which controls the output power delivered to each port. For the greatest possible flexibility, this system supports multiple power supplies, which may be configured to switch or share current consumption.

The PSU's input power consumption is monitored by measuring port voltage and current. Ports exceeding power consumption thresholds are deactivated (and tagged) according to predefined priorities, until aggregate power consumption has been sufficiently reduced.

Power budget is managed according customer-configured or factory preset parameters, including maximum available power, port priority and maximum allowable power per port. Parameter configuration may be performed through an easy-to-use software interface, via RS-232 serial communications or via remote SNMP.

Power management is handled entirely within the PSE, and power allocation is based directly on the results of the classification process.

## Power Disconnect Scenarios

The IEEE 802.3af standard requires that devices powered over Ethernet be disconnected safely, as per a number of scenarios.

The first scenario is an overload (a PD drawing a higher power level than the allowed 12.95 Watts), or an outright short circuit, caused by a failure in cabling or in the PD. In both cases, the PSE must disconnect power between 50 to 75 milliseconds from the event, while limiting the current drain during this period to protect the cabling infrastructure. Immediate disconnection is detrimental to the cabling infrastructure, which has to allow for an inrush of currents and filter out various transients.

The second scenario involves a PD that has been disconnected. The danger here is that the disconnected PD will be replaced by a non-PoE-ready device while power is still on. Imagine disconnecting a powered IP phone utilizing 48 Volts, then inadvertently plugging the powered Ethernet cable into a non-PoE notebook computer. What's sure to follow is not a pretty picture. The PSE must therefore disconnect power within no more than 400 milliseconds.

The standard supports two means of disconnection, DC disconnect and AC disconnect, both of which provide the same functionality.

DC disconnect detection involves polling of current draw. A disconnected PD will open up the circuit and current will no longer flow. To avoid faulty identification of power fluctuations as disconnections, the standard defines a certain amount of time for disconnect validation, as well as a current level, below which a PD is considered to be disconnected.

The more complex AC disconnect detection involves the induction of low (5 Volt) AC voltage to the PD, in addition to the 48 Volt DC operating voltage. During normal operation, resistance will lower the AC signal to less than 5 Volts. A sudden surge to the full 5 Volt AC signal will indicate that the PD has been disconnected.

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Disconnect identification and handling is performed solely by the PSE, and requires no special handling within the PD.

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# 3 Architecture Building Blocks and Guidelines

## PoE System Architecture

A classical PoE system comprises a PSE (Power Sourcing Equipment) and a PD (Powered Device). The PSE may either be an End-span (i.e. a Layer 2 Ethernet Switch) or a Mid-span (or a power-feeding Hub), while the PD is essentially a PoE-enabled terminal (such as an IP phone, Wireless LAN access point, etc.).

A PoE system is laid out in a "star" topology, so that each PD is connected to a separate channel of the central PSE.

Power may be delivered over either data pairs (1/2 as "-" and 3/6 as "+") or spare pairs (4/5 as "+" and 7/8 as "-") of standard CAT-5 UTP cabling.

Delivering power through the RJ45 connector's central tap ("Phantom Feeding") guarantees that bi-directional data flow is maintained, regardless of the module's power status.

## The PD Signature Concept

The PD Signature concept is based on the fact that by utilizing non-hazardous, low energy probing, the PSE can distinguish between a PD, an open link and a non-PoE-enabled terminal. This low energy is completely harmless to pre-standard equipment, allowing the PSE to verify the existence of a unique PD signature. Should the PSE identify anything other than a valid PD, it will not inject power to the relevant line.

It is assumed that the hosting LAN infrastructure complies with the TIA/EIA-568 Category 5 cabling system. The detection circuit should tolerate some DC voltage bias, as presented by a Diode Bridge for example.

This application note describes circuits that will work with the proposed standard signature (of a fixed resistance nature).

## Electrical Specifications

### Isolation Requirements

One of the major goals of this document is to provide system designers with cost effective methods of supporting IEEE 802.3 standard isolation requirements. The IEEE 802.3 standard calls for 1500 VAC galvanic isolation between the link, the chassis ground and DTE circuits. As, in many systems, the power supply's return is tied to the chassis ground for enhanced EMI reduction, a conflict may occur.

The required Isolation may be achieved using the following two methods:

- Power that is fed over Ethernet is isolated from DTE circuits by an isolated DC-DC converter that can withstand 1500 VRMS.
- The terminal is housed in non-conductive casing, with no external connections other than the RJ-45 data and power connector, resulting in the internal power supply input-output no longer needing to be electrically isolated. An IP phone is a good example of such a DTE. Note that while this approach fulfills the safety standard isolation requirement, it does not meet the exact wording of the IEEE 802.3 standard. Various market leaders regard this requirement as ambiguous and open to interpretation, and have in fact adopted this approach in the design of their products.

Another issue may arise from the fact that Power over Ethernet hub ports are not required to be isolated from one another (in environment A installations). In case of power injection, the most economic solutions will use a common power supply, which feeds all channels. Therefore, when using FTP (Foiled Twisted Pair) or STP cables, care must be taken to ensure that PD units are isolated from each other in order to eliminate potential ground loops. This issue is most pronounced with grounding and equipment housed in metal casing.

## PoE Terminal Building Blocks

Figure 2 below specifies all function blocks normally required to build an IEEE 802.3af compliant PD terminal. A detailed schematic of this implementation is presented in Figure 5.

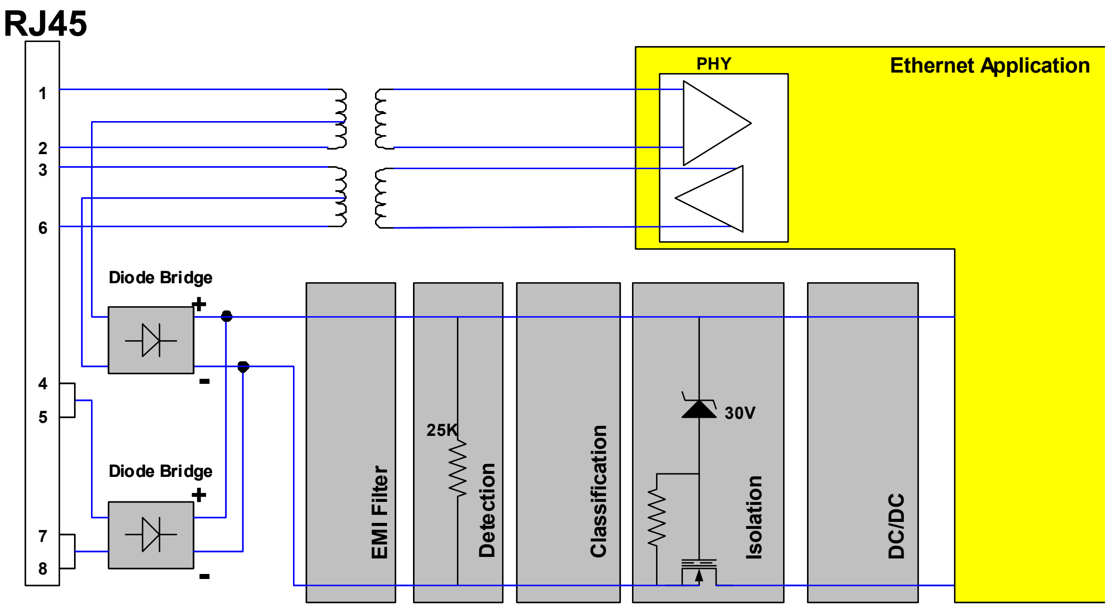



*Figure 2: PoE Terminal Functional Block Diagram*

## Input (RJ-45) Connector

RJ-45 is the standard connection interface utilized Ethernet devices. If a shielded RJ-45 socket is being used, it must be verified that this shielding will not have a galvanic connection to the power lines, as this may cause ground loops. If connection to the power supply rail is desired (possibly for electromagnetic interference handling purposes), this may be achieved via a capacitor, which will ensure that galvanic isolation is maintained.

## Rx/Tx Transformers

The selected transformers must feature a center-tap and must be capable of handling the peak and average rated current of the PD. The peak and average ratings required by the IEEE 802.3af standard are 450 mA and 350 mA, respectively.

The circuit configuration for the transformer connection is referred to a "phantom connection". In this connection, each winding carries half the current with opposite polarity, so that the total DC current transferred through the transformer equals zero. However, due to unmatched resistance of the link, the current may be split unevenly. This will translate to a DC current in the transformer windings that may degrade high frequency performance and consequently corrupt data signals. According to the IEEE specification, these transformers should be able to operate with up to 6.13 mA DC current without degradation. As the PD needs to be able to accept power from any cable pair (4/5 and 7/8 or 1/2 and 3/6), a diode bridge must be part of the input circuit. This enables full rectification and polarity insensitivity. The use of diode bridges is even more significant where Auto-MDI or MDI-X circuits are employed. In these cases, if a cross cable is used, both power and data will be enabled.

## EMI Filtering

EMI filters may be implemented to protect the circuitry from external surges and spikes originated by ESD (electrostatic discharges, either simulated or real) or other sources. They may also serve as an element for filtering emissions from the PD circuit. Additional EMI filtering may be implemented after the isolating element, or the switch, which separates the link side from the DC-DC side while in detection mode. This will allow the required circuit element values to be maintained without disturbing detection.

IEEE 803.2af requirements do not allow for massive filters, as maximum values are set for capacitance and inductance during detection. Common parts in an EMI block will include a 0.1 uF capacitor and, if necessary, an HF common mode filter.

The specific implementation of an EMI block is at the discretion of the developer.

## Detection Signature Block

As required by the IEEE 802.3a standard, this signature is a 25KΩ resistor. The tolerance values provided in the specification are for the total circuit, taking into account parasitic elements, such as current leakage from other circuit elements. It is advised that the closest possible value be selected, so that the tolerance budget provided in the specification is not "wasted" on easily satisfied elements, such as the resistor. In other words, it is much more cost effective to use an accurate resistor, rather than use an inaccurate one while compensating with very low leakage transistors or diodes.

The detection block may be preceded by diodes in various connection types. Please refer to IEEE 802.3af Annex 33A for more details.

## Classification Block

A PSE may optionally be equipped with a classification block, which allows it to classify a PD for power management purposes, prior to applying full operating power. For more details on the optional classification process, see the Classification section further on in this document.

## Isolation Block

This element is required to isolate the circuit from the media side during the detection and classification phases. Detection and classification are implemented using low voltage, so that switching to operational mode may be performed based on the voltage measured on the detection signature.

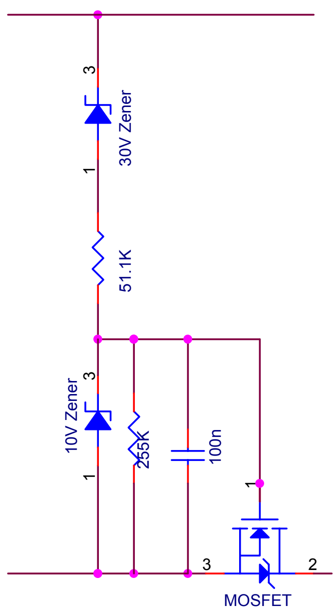



*Figure 3: Isolation Block*

Figure 3 describes a sample implementation of the Isolation Block circuit. Other solutions are possible, some of which may include dedicated IC (hot swap ICs). The basic functionality required of this block includes "switching on" when voltage sensed on the detection signature is greater than 30 volts and less than 36 volts. This block's total allowed consumption depends on the voltage level detected (see Table 4 for more details) This limitation is part of the specification and is based on the fact that the current consumed by this element is actually drawn in parallel to the detection signature, and therefore changes its actual value. The additional diode following the MOSFET is required to eliminate the possibility of PD capacitor discharge into a non-compliant device. An additional 10 Volt Zener diode ensures that the MOSFET Vgs level does not exceed 10 Volts.

### DC-DC Block

This block represents the PD's power supply. As numerous different devices may use PoE technology, there is no one solution that will fit all. The DC-DC design may be optimized to reflect the power requirements and offer the most cost effective solution for a specific circuit.

The following important issues must be considered:

- To comply with IEEE 802.3af load specifications, the total power consumption should be less than 12.95 Watts. Power supply efficiency with respect to total power consumption should be considered.
- The power supply should start consuming current and input current should be greater than 10 mA within a certain number of milliseconds (TBD) from applying voltage to its input. If off-the-shelf power supplies are used and this information is absent, please contact the manufacturer for guaranteed maximum startup times.
- If the secondary side of this DC-DC may be connected to chassis ground, the isolation required from the DC-DC is 1500 Vrms, input to output. This will enable IEEE 802.af requirements to be maintained.

## Classification

According to the IEEE 802.3af-2003 standard, a PSE may optionally classify a PD for power management purposes, prior to applying full operating power. Table 1 lists the different classes according to the power detected at the PSE output and the PD input.

| Class | Usage | PSE Output Maximal Power (W) | PD Input Power (W) |
|---|---|---|---|
| 0 | Default | 15.4 | 0.44 -12.95 |
| 1 | Optional | 4.0 | 0.44 -3.84 |
| 2 | Optional | 7.0 | 3.84 -6.49 |
| 3 | Optional | 15.4 | 6.49 -12.95 |
| 4 | Future use | As Class 0 | Future use |

*Table 1: PD Operating Power Classes*

Classifying a PD according to its power consumption may assist a PoE system in optimizing its power distribution. Such a system typically suffers from lack of power resources, so that efficient power management based on classification results may reduce total system costs.

## Classification Process

Successful classification of a PD requires the following:

- PD detection
- Assignment of the PD to a class type (from 0 to 4)

To perform classification, the PSE induces a steady voltage on the port terminals and measures the current consumed by the PD.

The PSE may remove power to a PD that attempts to draw more current than is permitted by its class.

Following detection, the PSE will provide a steady voltage level between 15.5 and 20.5 V, limited to 100 mA, for a period of 10 to 75 milliseconds, while the PD will draw current according to its class, as specified in Table 2.

| Class | Current (mA) |
|---|---|
| 0 | 0 - 4 |
| 1 | 9 - 12 |
| 2 | 17 - 20 |
| 3 | 26 - 30 |
| 4 | 36 - 44 |

*Table 2: Required Current Consumption per PD Class*

The PSE will accurately measure the current and classify the PD based on this measurement. Typical values and their classes are listed in Table 3.

| Measured Current (mA) | Classification |
|---|---|
| I <= 5 | Class 0 |
| 5 < I < 8 | Class 0 or 1 |
| 8 <= I <= 13 | Class 1 |
| 13 < I < 16 | Class 0, 1 or 2 |
| 16 <= I <= 21 | Class 2 |
| 21 < I < 25 | Class 0, 2 or 3 |
| 25 <= I <= 31 | Class 3 |
| 31 < I < 35 | Class 0, 3 or 4 |
| 35 <= I <= 45 | Class 4 |
| 45 < I < 51 | Class 0 or 4 |
| 51 <= I | Class 0 |

*Table 3: Classification According to PD Current Consumption*

## Waveform

A theoretical waveform of the PSE output during detection, classification and operation is shown in Figure 4. The voltage applied during detection is relatively low. Once the unit is recognized as a valid PoE PD, classification voltage is applied, followed by full operating power.

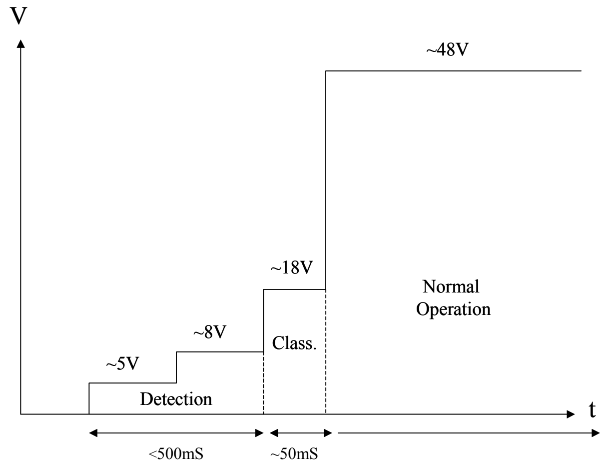



*Figure 4: Theoretical PSE Output Waveform (Open Loop)*

Upon valid detection of a PD, port power will start up immediately following the classification procedure, regardless of classification results.

# 4 Standard Requirements

## The IEEE 802.3af Standard

The IEEE 802.3 Ethernet standards committee initiated a task force called the 802.3af in 1999, to specify the method for delivery of operating power over Ethernet infrastructure. The standard was approved by the task force. It was published on July 11, 2003 as "802.3af-2003" on the basis of the standard's final draft (Draft 4.3).

802.3af-compatible Ethernet switches, mid-spans and terminals are currently offered by leading network equipment vendors, including 3Com, Avaya, Nortel, Cisco, Alcatel, HP, NEC, Fujitsu, Proxim and many others. The majority of IP telephone sets and Wireless LAN access points are already able to receive operating power through Ethernet interfaces.

## IEEE 802.3af Standard Requirements

In order to comply with the standard requirements, a device of a resistive nature must be positioned across the supply line, as detection is performed on the same path on which power is provided. The standard requires the use of a rectifier bridge, and IEEE-compliant power sources should be able to detect a resistor even when a diode bridge exists in the path. Table 4 summarizes circuit parameters as per IEEE 802.3af-2003 requirements and lists all of the electrical parameters a PD designer needs to be aware of.

| **Parameter** | **Conditions** | **Min** | **Max** | **Unit** |
|---|---|---|---|---|
| **Detection Signature** | | | | |
| V-I Slope | 2.7Vdc to 10.1Vdc | 23.75 | 26.25 | KW |
| Port Input Capacitance | During detection, 2.7Vdc – 10.1Vdc | 0.05 | 0.1 | mF |
| Port input Inductance | During detection, 2.7Vdc – 10.1Vdc | | 100 | mHY |
| Offset Current | During detection, 2.7Vdc – 10.1Vdc | | 10 | mA |
| Offset Voltage | | | 1.9 | V |
| **Startup** | | | | |
| Startup Time | Time from voltage applied till current exceeds 10mA | | 300 | mSec |
| **Normal Operation** | | | | |
| Power Consumption | | | 12.95 | W |
| Operating Input Voltage Range | | 36 | 57 | V |
| Must Turn on Voltage | | | 44 | V |
| Must Turn off Voltage | | 30 | | V |
| Input Current | Maximum current at 36V | 10 | 350 | mA |
| Input Current, Peak | Maximum duration of 50mSec, with maximum 5% duty-cycle | | 400 | mA |
| Inrush Current, CPORT>180µF | For a maximum of 50mSec | | 400 | mA |
| Inrush Current, CPORT<180µF | Limited by the PSE | | | |
| Port Capacitance | Without any current limit on the PD | 5 | 180 | µF |

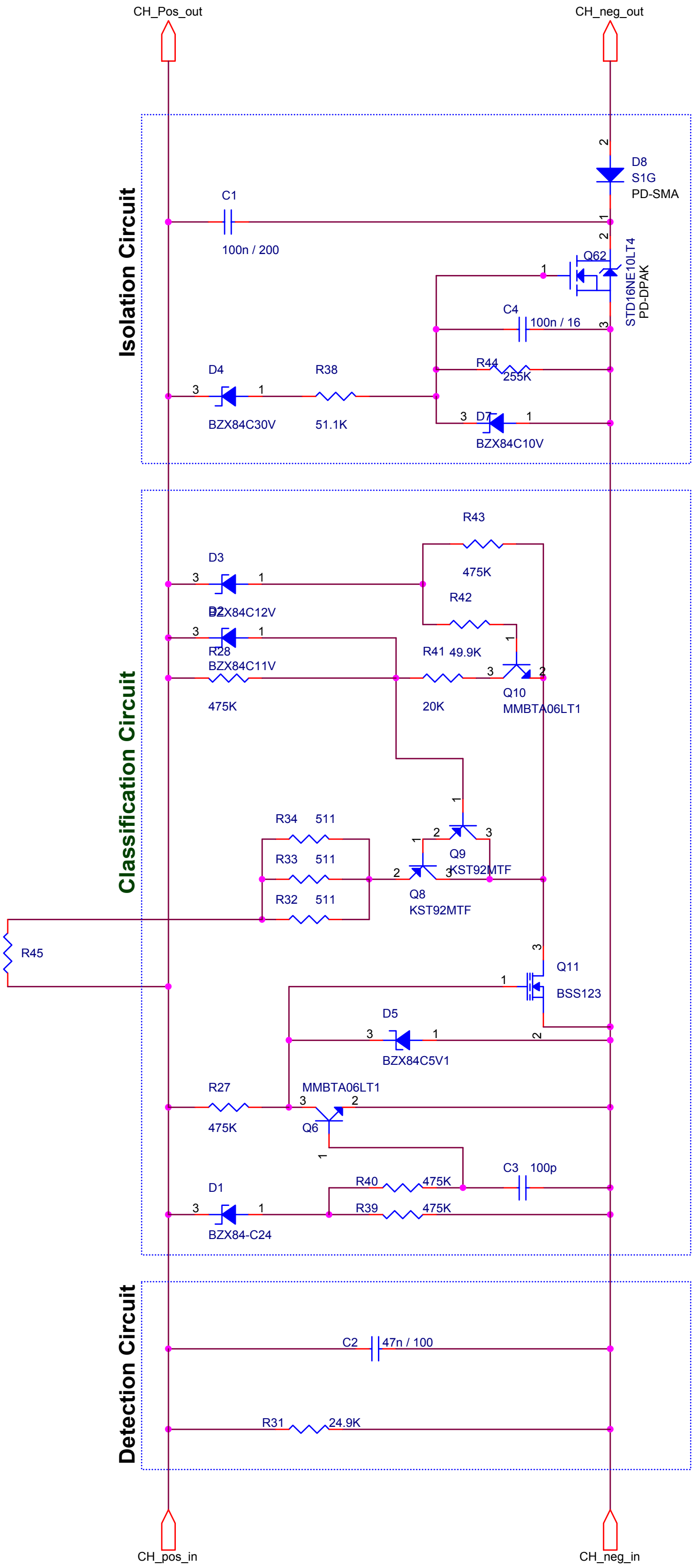
*Table 4: IEEE802.3af PD Requirements*

Table 5 presents pin out details for the PSE's RJ-45 output socket, with each channel's data and power connected to the DTE.

| Pin # | Label | Description |
|---|---|---|
| 1 | RX+ | Data Receive (-) |
| 2 | RX- | Data Receive (-) |
| 3 | TX+ | Data Transmit (+) |
| 4 | -Vdc_return (+) | Feeding power (+) |
| 5 | -Vdc_return (+) | Feeding power (+) |
| 6 | TX- | Data Transmit (+) |
| 7 | -Vdc (-) | Feeding power (-) |
| 8 | -Vdc (-) | Feeding power (-) |
| 9 | Shield | Connector shielding |

*Table 5: Channel Connectors & Pin Out*

# 5 Detailed Schematics and Bill of Materials




| | |
|---|---|
| Class4 | 35 Ohm |
| Class3 | 165 Ohm |
| Class2 | 325 Ohm |
| Class1 | 600 Ohm |
| Class0 | 1K4 Ohm |
| | R45 1% 250mW |

*Figure 5: Detailed PoE Electrical Schematics*

| Item | Qty. | Ref. | PCB Footprint | Description |
|---|---|---|---|---|
| 1 | 1 | Q62 | DPAK | TRN FET NCH 100V 16A 0.07R D-PAK LL |
| 2 | 1 | C1 | 1812 | CAP CRM 0.1uF 200v 10% X7R 1812 SMT |
| 3 | 2 | Q8, Q9 | SOT23 | TRN PNP 300V 500mA SOT23SMT225mW50MHZ |
| 4 | 2 | Q10, Q6 | SOT23 | TRN NPN 80V 0.5A hte=100 SOT23 |
| 5 | 1 | D8 | SMA | DIO RECOV. REC 400V 1A SMA SILICON SMT |
| 6 | 1 | D5 | SOT23 | DIO ZNR 5.1V 225mW 5% Ir=2uA SOT23 SMT |
| 7 | 1 | D7 | SOT23 | DIO 10V 225mW 5% Ir=200nA SOT23 SMT |
| 8 | 1 | D2 | SOT23 | DIO 11V 225mW 5% Ir=100nA SOT23 SMT |
| 9 | 1 | D3 | SOT23 | DIO 12V 225mW 5% Ir=100nA SOT23 SMT |
| 10 | 1 | D1 | SOT23 | DIO 24V 225mW 5% SOT23 SMT |
| 11 | 1 | D4 | SOT23 | DIO 30V 225mW 5% Ir=50nA SOT23 SMT |
| 12 | 1 | Q11 | SOT23 | FET NCH 100V 0.17A 6R Logic Level SOT23 |
| 13 | 1 | C2 | 0805 | CAP CRM 47nF 100V 10% X7R 0805 SMT |
| 14 | 1 | C3 | 0805 | * CAP CRM 100pF 200V 10% X7R 0805 SMT |
| 15 | 5 | R27, R28, R39, R40, R43 | 0805 | RES TCK FLM 475K 125mW 1% 0805 SMT |
| 16 | 3 | R32, R33, R34 | 1206 | *RES 511R 250mW 1% 1206 SMT MTL FLM |
| 17 | 1 | C4 | 0603 | CAP CRM 100nF 16V 10% X7R 0603 |
| 18 | 1 | R45 | 1206 | *RES 1K 250mW 1% 1206 SMT MTL FLM |
| 19 | 1 | R31 | 1206 | RES TK FLM 24.9K 250mW 1% 1206 SMT |
| 20 | 1 | R41 | 0805 | *RES 20K 100mW 1% 0805 SMT MTL FLM |
| 21 | 1 | R42 | 0805 | RES TK FLM 49.9K 125mW 1% 0805 |
| 22 | 1 | R38 | 0805 | RES TK FLM 51.1K 125mW 1% 0805 |
| 23 | 1 | R44 | 0805 | RES 255K 125mW 1% 0805 SMT |

*Table 6: Bill of Materials*

Implementation costs should not exceed $0.60 per port.

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