2. PoE and the PowerSync Analyzer

2.1. IEEE 802.3af / 802.3at Overview

The 802.3af specification was originally designed to create an environment whereby Powered Devices (PD's) from numerous different manufacturers could be interconnected to Power Sourcing inter-networking equipment (PSE) including switches, routers, and hubs produced by many different networking equipment manufacturers. It is envisioned that such interoperability will lead to lower cost and higher proliferation among both the sourcing equipment and the networked PD's. The ongoing emergence of VoIP telephony combined with ramp-up in TCP-IP networked devices show that this is a fast growing market. There are numerous new PD functions such as security, inventory management, environmental management, and other applications.

The basic features of 802.3af PoE were:

- 48V DC Supply to PD's
- Guaranteed 15.4 Watts of Power Consumption per network connection (PD and cabling)
- Power Sourcing from both "End-Point" switches/routers as well as "Mid-Span" power "adder" devices.
- Safety "interlocks" to prevent powering when no PD's are connected and to assure prompt power removal when PD's are disconnected as well as to limit DC current flow at all voltage levels.
- Physical layer mechanism for PSE's to characterize power demands of individual PD's and thus manage power delivered per port.

2.1.1. IEEE 802.3at Enhancements

The 802.3at specification both replaces and expands upon 802.3af is several key areas:

- Enable higher power PD's such as wireless access points, panning security cameras, video phones, and audio appliances requiring continuous power to 25.5 watts up to 100M from the PSE. High Power PSE's must furnish at least 30.0 Watts at the PSE port.
- Provide full backward compatibility and interoperability to existing 802.3af compliant PSE's and PD's.
- Enable Midspan PSE's to support 1000BaseT connections.
- Restrict cost increases for PSE ports and PD equipment in areas such as PSE controller devices and PoE capable magnetics such that PoE+ (high power) could become ubiquitous.
- Improve potential power management granularity and power budgeting capability over time.
- Resolve well known issues of specification clarity inherent in the 802.3af specification.

802.3at defines all PSE's as either **Type-1** or **Type-2**. Any PSE developed strictly to the original IEEE 802.3af specification will be a **Type-1** PSE. PSE's that deliver at least 30 Watts per port must be **Type-2** PSE's. Many of the 802.3at specifications are divided according to Type-1 versus Type-2 PSE's. However, 802.3at allows Type-1 PSE's to evolve in ways that gain many of the IEEE 802.3at feature enhancements described above even if they continue to limit minimum output power to the 15.4 watt range.

Changes and enhancements introduced by 802.3at are the subject of Sections 2.1.7 – 2.1.11 below.

2.1.2. The Power Connection

Under the 802.3at specification, DC power must be carried on 2 of the 4 pairs of a LAN (e.g. category 5) cable. DC voltage is carried on one cabling pair (common mode) and reference (zero volts) is carried on a second cabling pair. **ALT A** (alternative A) refers to the case where power is sourced on Pairs 2 and 3 (referring to EIA/TIA 568B), the data transmission pairs for 10/100BaseT. **ALT B** refers to the case where power is carried on Pairs 1 and 4 that are otherwise unused in 10/100BaseT.

Under 802.3af, Mid-Span PSE's MUST apply power on the **ALT B** pairs while End-Span PSE's may use either, though typically will use **ALT A**. This allows both End-Span and Mid-Span PSE's to coexist on the same cable.

Under 802.3at, Mid-Span PSE's were redefined to enable 1000BaseT LAN links, and therefore were forced to add magnetics in order to insert DC Power. With this change, Mid-Span PSE's may apply power on either the **ALT A** or **ALT B** pairs.

Power may be applied by and End-Span PSE in either an **MDI** or **MDI-X** (crossover) port configuration. This means that from the PD's point of view, the incoming voltage may look either like **Positive** or **Negative** polarity since in the latter configuration, pairs 2 and 3 (as well as 1 and 4) are crossed. PD's are required to be completely insensitive to whether power is furnished on the ALT A or ALT B pairs and whether power is positive polarity or negative polarity. In all cases, Mid-Span PSE's must apply power in the positive (or **MDI**) polarity.

Each PSE port is responsible for managing 4 basic aspects (or phases) of PoE:

1. PD Detection
2. PD Classification
3. Power-Up
4. Power-Removal

2.1.3. PD Detection

A PoE enabled PSE port provides a low power signaling mechanism that constantly monitors for an 802.3 (clause 33.3) Powered Device (PD) to appear at the end of the LAN cable. If a non-powered network device is connected, the PSE port can function just as would a non-PoE port and link to the networked device. However, if an 802.3 PD is connected, the PSE port will quickly recognize this and begin the process of powering up the PD.

The primary means of detection is a measurement of PD port electrical resistance performed by the PSE port. 802.3at specifies that compliant PDs will present a load resistance at the PSE between 19 KΩ and 26.5 KΩ given an input voltage under 10 VDC. It further specifies that the method of resistance measurement shall allow for an unknown voltage drop up to 2.8 volts associated with one or more diode junctions in series with this load resistance. This implies that "AC" resistance must be determined from a [ΔV / ΔI] measurement performed at 2 (or more) voltage levels and that the minimum detection voltage must be at least 2.8 VDC.

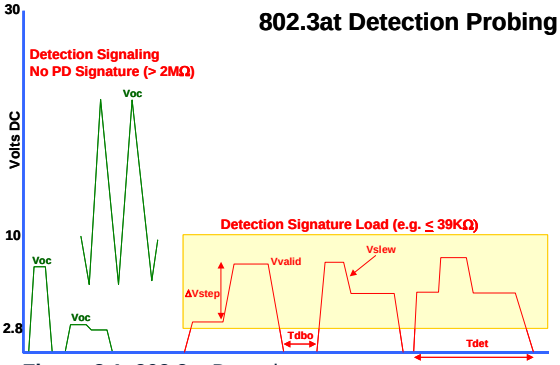

Figure 2.1 802.3at Detection

Some of the relevant specifications affecting the detection process are:

Characteristic	Minimum	Maximum	Units
Unterminated (Open Circuit) Detection Voltage		30	VDC
Terminated Detection Voltages	2.8	10	VDC
Detection Current Limit (compliance)		5	mA
[ΔV / ΔI] Voltage Step	1	7.2	VDC
Maximum Acceptable Load Resistance	26.5	33	KΩ
Minimum Acceptable Load Resistance	15	19	KΩ
Maximum Acceptable Load Capacitance	0.15	10	μF
Slew Rate of Voltage Step		0.1	V / μsec
Detection Duration		500	mSec
Detection Backoff (following unsuccessful detection) (does not apply to End-Span PSE's)	2		Sec

It should be noted that despite the various requirements described for PD Detection signaling in the 802.3 specification, that there is considerable room for design variation and that in practice, detection pulses and detection measurement schemes do vary significantly across PSE interface technologies. The 802.3at standard does *not* prohibit the use of complementary schemes that might improve detection accuracy and speed while also reducing risk of possible damage to non-PoE capable end station equipment.

2.1.4. PD Classification

IEEE 802.3at allows for PD's to communicate their power demands to a PSE port via a "Classification" process. From the perspective of a PSE port, PD's can be classified as follows:

PSE Type	Classification	Guaranteed Power at PSE Output	Minimum Power at PSE Output	Units
Type-1	Class 0	15.4	~ 0.5	Watts
	Class 1	4.0	~ 0.5	
	Class 2	7.0	~ 4.0	
	Class 3	15.4	~ 7.0	
Type-2	Class 4	30.0	~ 15.4	

A **Type-1** PSE has the option not to classify the PD in which case the PD must be assumed to require **Class 0** power.

Classification is performed by applying a voltage in the band from 15.5V to 20.5V and measuring the fixed DC current load presented by the PD. The magnitude of measured current is then translated into a classification as follows:

Minimum Current	Maximum Current	Units	Classification	PD Type
0	5	mA	Class 0	Type-1
8	13	mA	Class 1	Type-1
16	21	mA	Class 2	Type-1
25	31	mA	Class 3	Type-1
35	45	mA	Class 4	Type-2

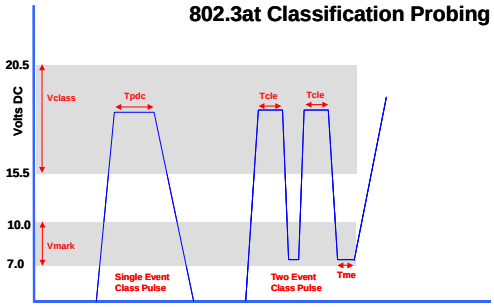

Figure 2.2 802.3af & 802.3at Classification

The PSE is free to make decisions regarding current measurements that fall between the above bands. Classification must be completed in 75 mSec, so typically classification involves a short duration pulse with amplitude between 15.5 and 20.5 Volts. A "single-event" class pulse (see Figure 2.2) may return to zero or may hold its value (or anything in between) following completion of classification.

The 802.3at specification requires that all compliant PSE's perform classification and it adds an expanded classification measurement option that allows PSE's to "signal" their 802.3at Type-2 power capability to a powered device while reading the power demand of the powered device. The "2-event" classification (see Figure 2.2) involves 2 successive classification current measurements separated by a "mark" region. The 802.3at Type-2 PD must be capable of discharging the class voltage in order to "see" this mark region and thereby detect the presence of an 802.3at capable PSE. The 2-event classification cannot ever drop below 2.8V, or the PD will reset and forget that the PSE is Type-2 power capable.

Type-2 PSE's may use either single-event or 2-event PD classification. Those that use single event method are required to us MAC layer LLDP protocol to negotiate power with a Type-2 PD following initial PD power-up. See Section 2.1.11 below for more information concerning LLDP PD power classification.

2.1.5. Power-Up

Following classification, assuming the PSE performs this step, the PSE will apply power (voltage and current) to the PD. A PSE is required to furnish between 44 V (50 V for Type-2 PSE's) and 57 V to at the PSE interface. There are two timing criteria of interest: Time from end-of-detection until power-up is complete and the rise time of the PoE voltage. The first parameter includes classification time and must be under 400 mSec. The power-on rise time is required to be longer than 15 µsec.

Other parameters of interest during the power-on event are the initial (in-rush) current and the peak-to-peak ripple and noise amplitude. PSE's are required to clamp in-rush current to 450 mA regardless of the transient load provided by a PD. AC ripple (including AC MPS signals) under 500 Hz in frequency should not exceed 500 mVpp. AC noise in the region below 150 KHz should not exceed 200 mVpp. Noise and ripple must be achieved across the full range of DC loads permitted.

While the PSE is furnishing power to the PD, the PSE is responsible for regulating total power delivered to the PD. 802.3af compliant PSE ports must have capability of furnishing a minimum of 15.4 watts given connection to a "Class 0" PD. Type-2 PSE ports must have capability to furnish at least 30 watts given connection to a "Class 4" PD. The maximum power capacity of a PSE port is often limited by a current ceiling defined as **Icut** in the 802.3 specification. Given the ceilings specified, a Type-1 PSE could theoretically furnish a peak of 22.7 watts while a Type-2 PSE could theoretically supply up to 38.9 watts continuous power. Practically speaking, typical port power capacity will be relatively close to the minimum required values of 15.4 Watts for Type-1 and 30 Watts for Type-2 PSE's.

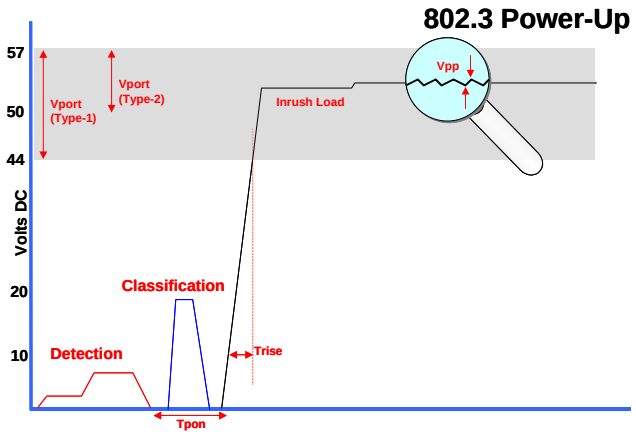

Figure 2.3 802.3at Power-Up

2.1.6. Power Removal

802.3at compliant PSE's offer one of two means to determine that a Powered Device has been disconnected, and therefore DC power should be removed. By implication, the two different mechanisms are mutually exclusive, though the specification allows for what effectively would be an impractical combination of both methods.

The AC MPS method involves the superposition of a low level, relatively low frequency AC resistance probing signal on the DC power rail. The probing signal is sourced from a high output impedance such that when exposed to a nominal load resistance of 25 KΩ, the amplitude of the signal is attenuated to well below 500 mVp-p. Typically it will be far below 200 mVp-p. When the 25 KΩ signature load is removed, the AC signal amplitude increases and can be detected on the PSE output. The PSE must then wait for an interval of at least 300 mSec, but not longer than 400 mSec to remove power. The main advantage of the AC MPS method over the DC MPS method is the ability to tolerate well below 10mA of DC load current indefinitely so long as the AC MPS load impedance of 25 KΩ is detected.

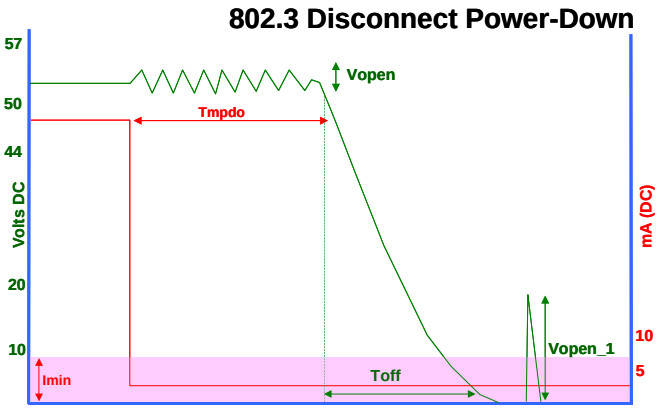

Figure 2.4 802.3at Disconnect Power-Down

The DC MPS method relies on a continuous measurement of DC load current. When the DC load current drops below 10 mA (Imin), the PSE has the "right" to remove DC power. When the DC load current drops below 5 mA, the PSE must remove DC power. As with AC MPS, the timing of the low-load current is such that the PSE must tolerate 300 mSec of low load, but not longer than 400 mSec of this condition. Additionally, the specification makes allowance for the DC MPS signature to be intermittent so long as it is present for a continous 60 msec out of every 360 msec interval. The main advantage of DC MPS is that it does not add any noise or other artifacts onto the DC power rail.

2.1.7. 802.3at Type-2 (High) Power Capacity

Under 802.3af, PSE's were required to deliver at least 15.4 Watts continuously from each port to PD's that would draw up to 12.95 Watts continuously. Additionally, since PD's were entitled to draw peak loads of up to 14.4 Watts for up to 50 msec meaning PSE's had to tolerate at least 17.6 Watts for between 50 and 75 msec.

IEEE 802.3at defines a new "Type-2" PSE that must furnish a minimum of 30 Watts continuously to PD's that draw up to 25.5 Watts continuously. Transient loading at the PD can run to 28.3 Watts for up to 50 msec meaning the PSE must tolerate overloads up to 34.2 Watts depending upon PSE port voltage. Type-2 PSE's are required to maintain minimum port voltage of 50VDC across steady state and transient loads.

One important stipulation in 802.3at is that plant cabling between PSE and PD should be Cat5e (or better) in terms of DC resistance characteristics for "Type-2" systems. This reduces line power loss and resultant cable heating.

2.1.8. 802.3at Backward Compatibility with 802.3af

Backward compatibility simply means that 802.3af PD's must fully interoperate with both 802.3at "Type-1" and "Type-2" PSE's while 802.3af PSE's must properly interoperate with Class 0, Class 1, Class 2, and Class 3 802.3at PD's.

802.3at achieves this by leaving existing mechanisms and specifications in place for PD Detection, PD Classification (at the physical layer), and PD Disconnect Detection. Many of the power overload requirements from 802.3af remain intact for "Type-1" PSE's and PD's in 802.3at. "Type-2" PSE's may use a new, 2-pulse classification probing signal that will be "transparent" to an 802.3af compatible PD but is significant to 802.3at "Type-2" PD's as it serves as a grant to draw high power levels after power-up.

2.1.9. 802.3at Gigabit-Capable PoE MidSpan PSE's

The 802.3af specification limited MidSpan PSE's to applying power on LAN pairs 1 and 4, the unused pairs for 10BaseT and 100BaseT packet transmissions. This was acceptable until 1000BaseT became prevalent, requiring all 4 Cat5e data pairs for transmission. 802.3at enables Midspan PSE's that layer power on active data pairs using magnetics (transformers). Midspan PSE's may insert magnetics and apply DC power to either LAN pairs 1 and 4 (ALT B) or LAN pairs 2 and 3 (ALT A). PSE's are therefore accountable for minimizing impairment to LAN transmission channel given the added magnetics. 802.3at adds RF channel specifications that MidSpan PSE's must meet.

2.1.10. Limiting Cost Increase for 802.3at High Power (Type-2) Links

Increasing PSE power capacity from a level of 15.4 watts to 30 watts will intuitively increase per-port manufactured costs. However, some subtle, yet critical changes in the IEEE 802.3at specification limit these added costs considerably. In the area of Ethernet magnetics, for example, the 802.3at, combined with a change in the IEEE 100BaseT specification, no longer enforces a minimum requirement of 350µH at 8mA bias current. This change is significant because achieving this minimum inductance requirement at perhaps even higher than 8mA bias (or DC unbalance) and with higher DC currents flowing would add copper cost to transformers. In place of the minimum inductance requirement is a new droop time-domain mask in the 100BaseT specification.

Another area of cost containment is the allowance of PSE foldback and early shutdown in the event of a severe overload from outside the PSE port. PSE foldback typically occurs when a load current produces a significant voltage drop across a FET switch (active element) that switches PoE power. That voltage drop, combined with load current, will heat the FET and potentially damage it. 802.3af required PSE's to sustain at least 400mA of load current for at least 50msec regardless of voltage drop. This provided a reasonable clearance between the maximum load transient a PD could produce and the maximum load transient a PSE could service. If extended to 30 watt power, this type of requirement would certainly increase PSE controller cost considerably. By allowing PSE's to remove or limit power when voltage drops below the minimum PSE source voltage, less burden is placed on the PSE active element. However, the headroom between maximum PD load transient and maximum PSE power transient is reduced or eliminated.

2.1.11. 802.3at Improved Power Management Granularity

End-Span PSE's that support LLDP will have the opportunity to assess PD power demand to 0.1 watt granularity given a PD that supports LLDP. All "Type-2" (*i.e. high power*) PD's must support LLDP. Lower power PD's under the 802.3at specification may optionally support LLDP.

Without LLDP, power granularity is very low with discrete power band maximums of 4 watts, 7 watts, 15.4 watts, and 30 watts. If a PD says it needs "class 4" power, the PSE must budget 30 watts, even if the PD only requires 16 watts. This makes it harder for the PSE to budget a finite total power capacity across multiple PD links.

2.2. Power Sourcing Equipment – Specification Latitude

The 802.3at specification leaves considerable room for implementation dependent behaviors. Additionally, many vendors of Power Sourcing Equipment (PSE) will choose to go outside the 802.3 specification in ways that will not affect the ability to power and maintain pure 802.3at Powered Devices (PD). This high degree of variation will add a number of challenges to the generation and performance of PSE specification conformance tests.

2.2.1. Signaling Variations

One area of implementation variation relates to the signaling utilized prior and during power-up. The following table describes some of the possible **variations** in the area of signaling.

Signal Type	Variants
Open Circuit Detection	• Amplitude: 2 – 30 VDC • Coarse Detection Range: Any Detection Signature > 33 KΩ • Coarse Detection Method: Not strictly specified – may use 802.3af ΔV/ΔI Steps • Measurement Timing: No firm requirements, just recommendations

Signal Type	Variants	
Connected Detection Signature	• Amplitude: 2.8 – 10 VDC (given valid PD signature from 19 to 26.5 KΩ) • Pulse Duration: 20 – 500 mSec • ΔV/ΔI Steps: 1 or more • Step Edge: Rising, Falling, Both	• Step Magnitude: 1 – 7.2 V • Pulse End: RZ or NRZ • Pulse Separation: >0 (>2 Midspan) sec
Classification	• Amplitude: 15.5 – 20.5 VDC • Classification Pulse Count: ≥ 1	• Duration: 15 to 70 mSec • Pulse End: RZ or NRZ
AC MPS Signal	• Waveform: CW or Pulsed • Frequency: 20 to 500 Hz	• Removal: Before, During, After Power-Down (or Never ?)
Power-Down	• AC MPS Threshold: 27KΩ-1.98MΩ • DC MPS Threshold: 5 – 10 mA	• Dissipation: PD Load, PSE Shunt, or Active PSE Discharge

2.2.2. Connection Alternatives

PSE's will generally be configured to source power on EITHER the (10/100BaseT) data pairs OR the unused pairs. For any given PSE port implementation, this should be a design constant. Within the 802.3af specification, Mid-Span PSE's MUST utilize the unused 10/100BaseT pairs. The 802.3at specification allows for Mid-Span PSE's that power either pair and support 1000BaseT where all 4 pairs are used for data transmission.

End-Span PSEs can provide EITHER voltage polarity, positive or negative, to which PDs must be insensitive.

2.2.3. MPS Behaviors

Generally, a PSE will be designed to utilize either the AC or DC MPS method for determining a PD disconnect. Hence, this is one fundamental characterization of each PSE port that affects both the types of tests and the method of controlling a PSE port through PD emulation. Those ports supporting DC MPS need to see a low current condition (below 10 mA) in order to remove power. Those ports supporting AC MPS need to see an effective load impedance in excess of 1.98 MΩ in order to remove power, with a PSE-dependent load threshold ranging from 27 KΩ to 1.98 MΩ! These PSE's will tolerate a PD operating at less than 0.1 watt indefinitely since a DC load current of 2 mA (assuming port voltage of 48 VDC) translates to effective 24KΩ resistive load.

2.2.4. Legacy Modes and Proprietary Detection Schemes

Prior to 802.3af, a considerable amount of "legacy" PoE equipment including first-generation VoIP phones utilized proprietary technology to generate and manage power over LAN. Typical legacy powered devices include a low frequency coupling circuit between data transmission pairs and/or the existence of a large capacitance seen by common mode measurements across either data or spare pairs. These features could be sensed by the power sourcing equipment using proprietary techniques. Protocols for determining power requirements of the PD were also proprietary and conducted at the MAC layer.

With the volume of legacy PD's in the marketplace, many new generation PSE's seek to utilize BOTH 802.3 signaling and legacy detection methods simultaneously so that either type of PD can be recognized and powered. This "hybrid" detection behavior may violate 802.3 specifications when detection signaling is not compliant with relevant 802.3af criteria including signal levels, source impedance, and slew rates. However, assuming this hybrid behavior does not damage 802.3 compliant PD's, it is desirable to customers who want maximum flexibility in their PSE.

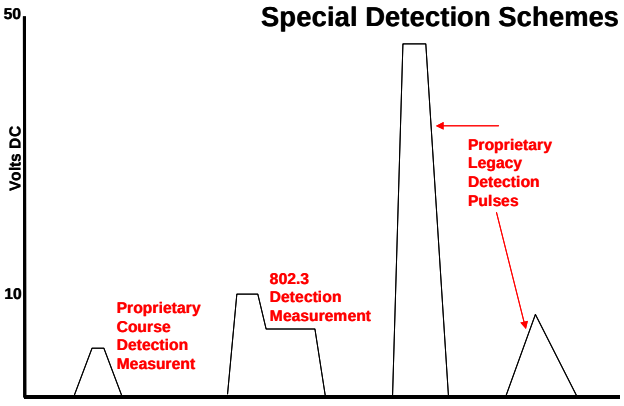

Figure 2.5 Hybrid Proprietary Detection Methods

Hybrid detection schemes may also include coarse measurements to assess possible PD connections prior to performing more refined 802.3 detection. These proprietary techniques may help to prevent damage to ordinary Ethernet interfaces (non-PD) or they may be beneficial in determining possible legacy PD connections. On the other hand, the added complexity complicates testing by adding ambiguity as to exactly how a PSE is detecting either an 802.3 or other type of PD.