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APPLICATION NOTE:

RUGGED POWER SYSTEM FOR OUTDOOR POE/POE++ SYSTEMS

EXECUTIVE SUMMARY

Systems operating in outdoor environments are subject to environmental extremes, calling for special provisions to ensure reliable operation over time. In addition to being ruggedized, power supplies in networked systems powered over ethernet cables need special considerations.

This application note discusses salient features of a power supply suitable for PoE, PoE++, and potential future versions.

INTRODUCTION

Electronic equipment and accessories are all around us. Networks of devices and networks of networks are omnipresent and continue to proliferate; and so does the need for reliable power and communication systems.

Beyond powering communication networks over existing AC and DC power grids, modern systems are often being powered over data and communication cables. Expanding power supply infrastructure to keep up with network developments has not been easy. So, the quest to find creative ways to route DC power to devices over data and communication cables is always ongoing. Examples of achieving power and communications over a common pair of conductors include AC power lines used to carry voice and RF as in PLCC, RF cables used to carry DC power, DC power traveling on data cables of high definition security cameras, etc.

The ethernet was first invented with the emergence of personal computers. In a span of a mere 3 years in the 1980s, their wide usage of network computers and dumb terminals saw explosive growth prompting providers to evolve and adopt a standard with a broad scope, the IEEE802.3. Although data rates since then have quadrupled every few years, the ethernet cable and interconnect system withstood explosive growth. With better definition and control influenced by IEE 802. x standard, data transmission rates skyrocketed from 10Mbits/sec to 100Mbits/sec

The very limited power which can be realistically sent over thin data wires has always presented challenges as to the types of devices powered from these data lines. Ethernet cables, popularly called CAT5 or RJ45 come with AWG #24 wires with a current limit of about 0.8A, which equates to about 35 Watts. The advent of higher efficiency, more intelligent computing, and audio/video devices have increased the need for optimizing the usage of this limited available power.

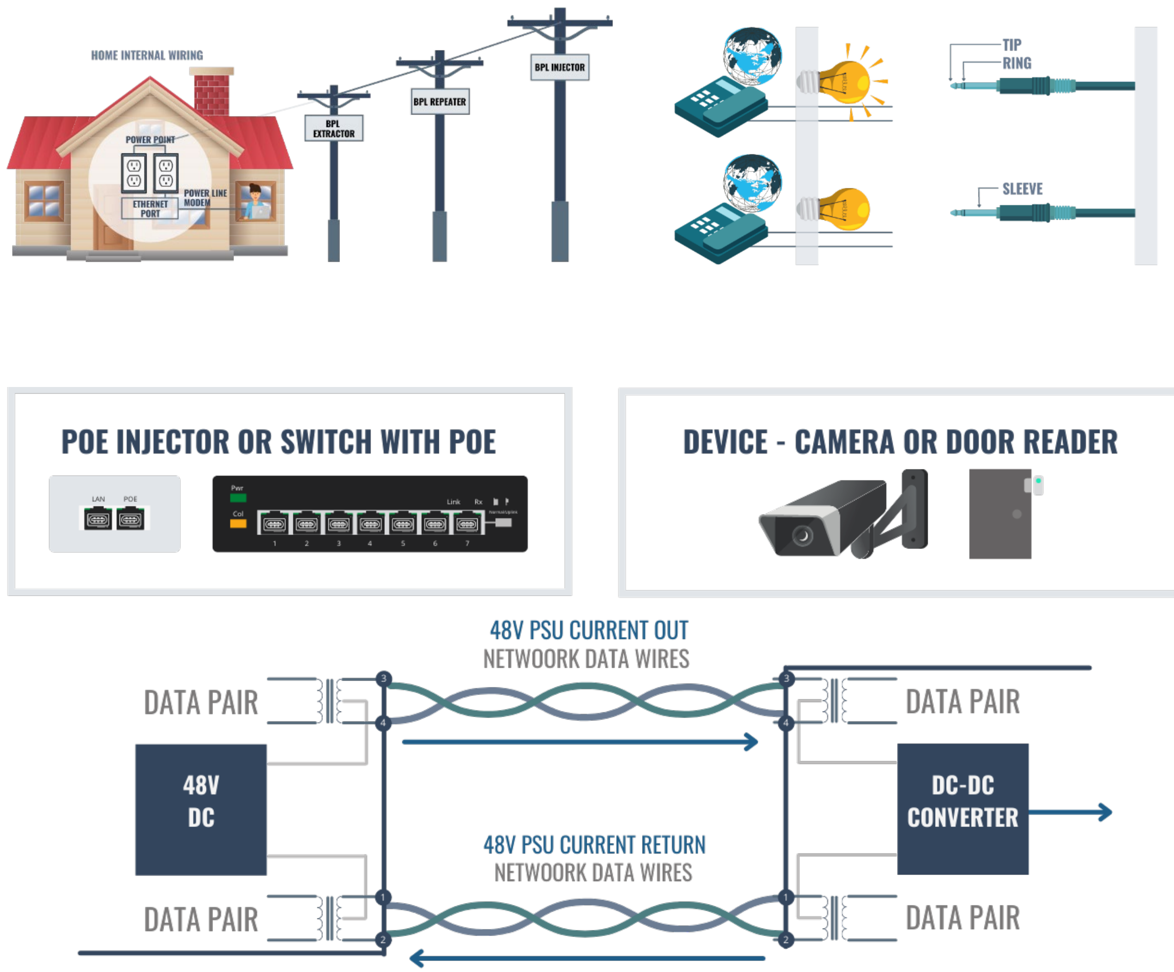


Figure 1 - Power line carrier communication (Data travels over AC mains feeds), Plain Old Telephone System (POTS) where 48V Ring voltage travels over Audio wires, Power over Ethernet where a DC power travels on data wire pairs.

WHAT IS A PoE INJECTOR!

A PoE injector simply stated is a combination of a power source, usually an AC/DC power supply with a built-in means to inject DC power into the data cable which is then delivered to a device at the other end of the data cable. The coupling mechanism for DC injection is a straightforward connection, although to isolate and transmit/receive the data, a magnetic isolation transformer called a balun is needed.

A simplified diagram, which is close to what exists in practice, is shown below. Both the data wire pairs are in the same RJ45 port. A PoE injector includes two or more RJ45 ports, One IN port, and one or more OUT ports, also labeled PoE and LAN ports, respectively, as shown in the image below. The IN and OUT ports allow for daisy-chaining multiple devices without the need for a hub.

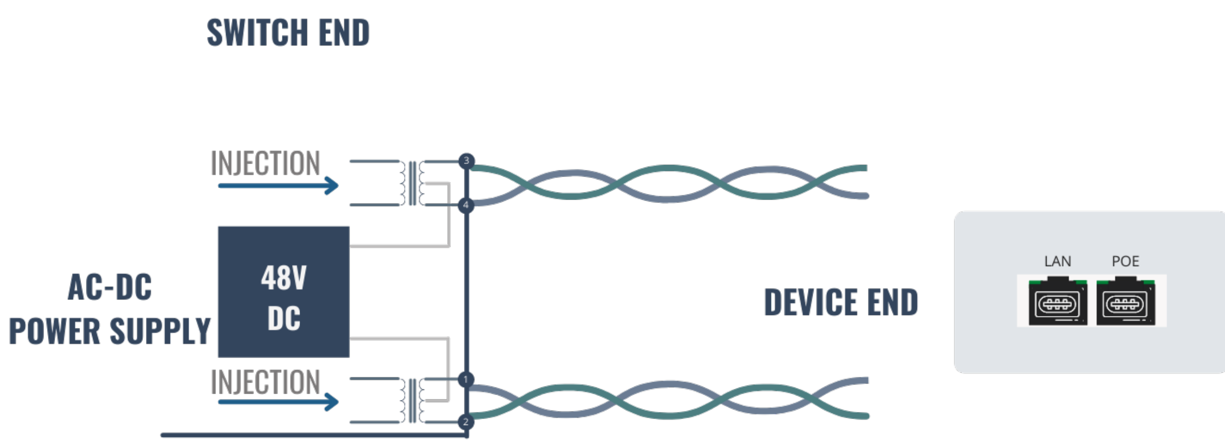


Figure 2 - PoE injector simplified implementation and view of an off the shelf product

TYPICAL PoE NETWORK

While it may not be obvious when looking at one of these devices, a typical network in a building security system may be as complex as depicted in Figure 3. Notice none of the devices at the far end are receiving AC power, which is injected into the data port thru the midspan PoE injector. More elaborate networks need more power injected along the way, hence more PoE injectors are needed. The good news is that the two PoE injectors do not come into contact in a properly done network. If they do, the injector with the higher voltage power source will shut down the other power source and it will be quickly remedied. To prevent a malfunction and/or to ensure proper levels of reliability, manufacturers of high-end PoE devices tend to supply the injector along with the device, especially with the high-end PTZ (Pan Tilt Zoom) HD cameras.

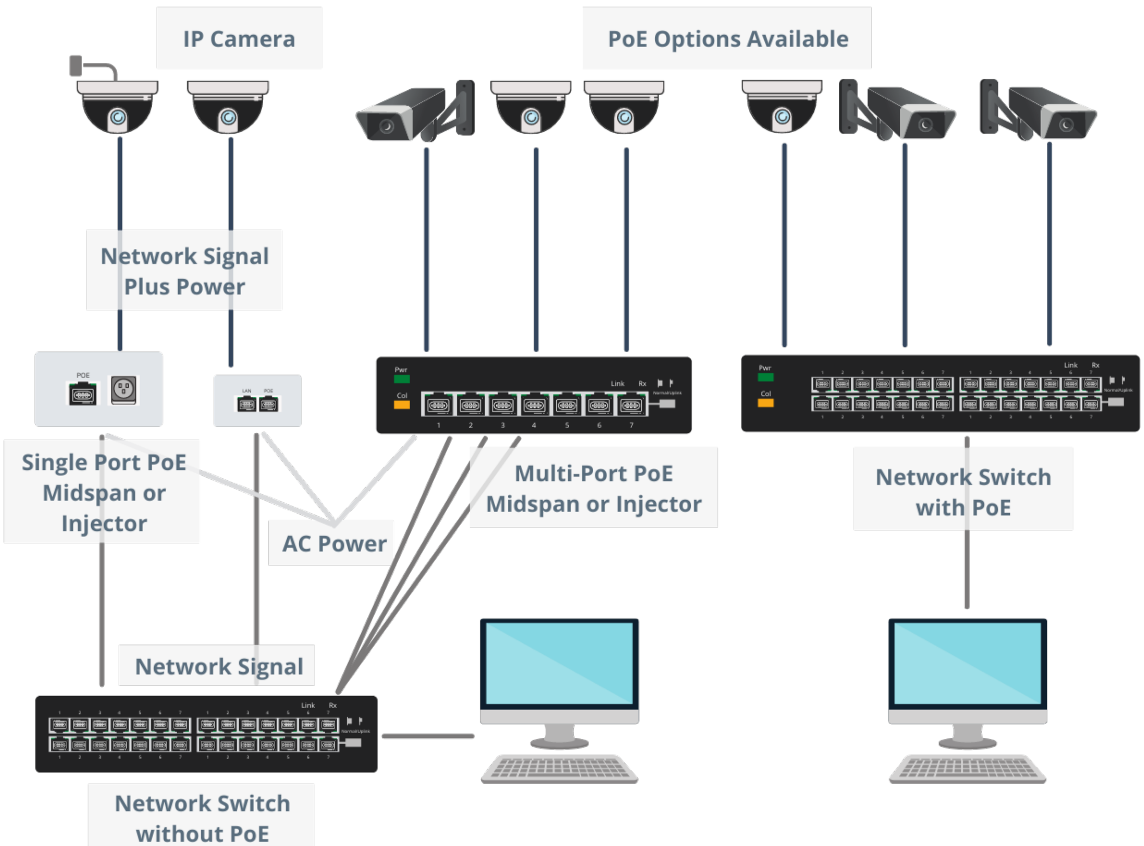


Figure 3 - PoE network

PoE AND PoE++ LOADS

There is a wide range of devices and systems that can be installed and managed over a network. With the evolution of networks and devices, the standard has, more or less, kept pace and captured the constantly evolving requirements with periodic up revisions. The table below summarizes the typical and maximum load for the various revisions in IEEE802. Notice the gradual increase in injected voltage at the Power Supply End (PSE) and consequent increase in available voltage at the Powered Device (PD) end, although the usable cable and its physical parameters remain the same. This is understandable as installers would likely stock only one type of cable (CAT5 or CAT6). Due to the length and its resistance, ultimately about one ampere is all that can be delivered.

Comparison of PoE parameters				
	Standard 802.3af (802.3a Type 1) PoE	Standard 802.3at Type 2 PoE+	Standard 802.3bt Type 3 4PPoE	Standard 802.3bt Type 4 PoE++
Rated power	12.95W	25.50W	51W	71W
Maximum power	15.40W	30W	60W	100W
Voltage Range (in PSE)	44 to 57V	50 to 57V	50 to 57V	52 to 57V
Voltage Range (in PD)	37 to 57V	42.5 to 57V	42.5 to 57V	41.1 to 57V
Maximum Current	350 mA	600 mA	600 mA per pair	960 mA per pair
Maximum resistance	20 Ω	12.5 Ω	12.5 Ω	12.5 Ω
Cable supported	CAT3 and CAT5	CAT5	CAT5	CAT5

Figure 4 - Summary of various PoE load power ratings and acceptable operating voltage

With these limitations, some very sophisticated computing and analytical devices have evolved. A modern surgical suite consisting of surgical tools, real-time diagnostic instruments, monitors, lamps, and even embedded computers is all practically usable on a PoE network. Except for the motorized bed, all of the required operating power injected from the end without a single AC power cord drop along with the network. PoE networks of much higher complexity are common in traffic management, warehousing, airport, and stadium parking, etc.

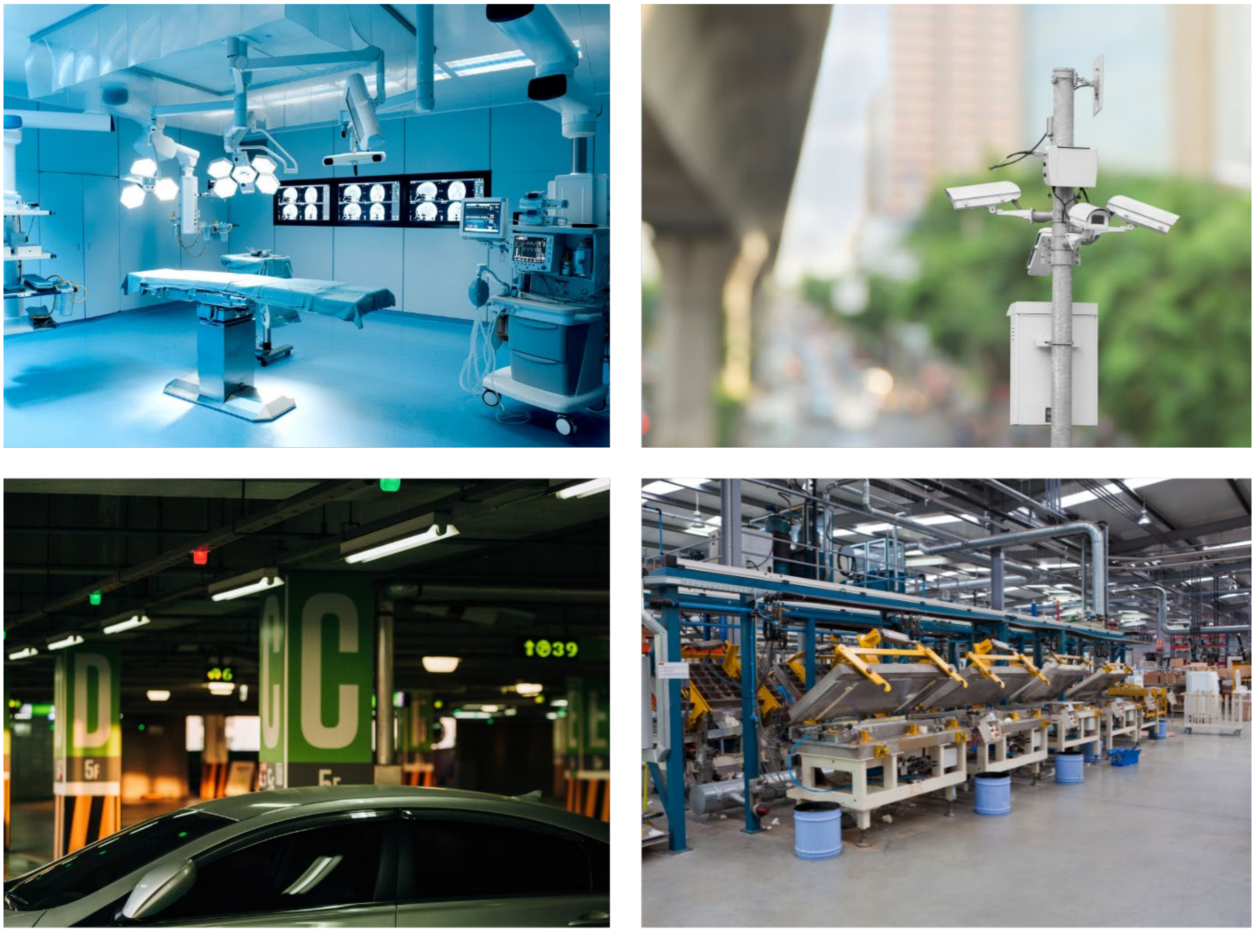


Figure 5: Large PoE/PoE++ installations

OUTDOOR PoE NETWORK CHARACTERISTICS

When it comes to an outdoor installation, the first thing that comes up in one's mind is the weather. To most people, it is a temperature range to handle. Temperature diversity in North America is generally a good representation of anywhere else on the planet (barring a few extremes in cold). Geographical considerations aside, customer expectations often outweigh actual environmental considerations due to contractual obligations. Outdoor infrastructural requirements are hard to define with a base standard, but certainly, several industrial and select MILSTD-801C standard requirements can be combined to cover weather, shock, and vibration, along with electromagnetic interferences, both natural and manmade.

In addition to listing all the applicable sections of a standard, selecting appropriate levels of threats is critical. A safe approach would be to pick 1 level of threat higher. For example, selecting lightning surge immunity per EN61000-4-5, while level 2 (1kV/500A) would suffice, Level 3 (2kV/1000A) would be an obvious choice for outdoor PoE use. An additional level of tolerance can be added externally to the system to Level 4 (4kV/2000A) at the power line entry point.

PoE injectors do not always come in one integrated unit. A more sophisticated injector is created by a PoE switch, which takes in a drive power supply (48V type) and injects it to one or more PoE ports.

The focus of this application note is the definition and analysis of critical features of the power supply that meets the criteria of an entire PoE system in a hardened outdoor network. As most of the ruggedization happens in the power supply, the several criteria that are part of it are briefly discussed further.

INJECTED /DRIVE_ VOLTAGE

The challenge of delivering meaningful power begins with voltage drop due to the resistance of the wire. The typical RJ45 cable is constructed with #24 wire, which has approximately a 2.1A maximum rating. But other criteria reduce this current substantially. The problem is with the resistance of the wire. The round-trip resistance of a 100 ft cable is roughly 5 Ohm. For an acceptable voltage drop at 48V, picking a target of 10% translates to a maximum voltage drop of about 5V, which limits the usable current to 1A. So, theoretically, a maximum of 48W is available from an off-the-shelf PoE injector. This can be a problem for some systems that have more loads or installing equipment that will be good enough for the next PoE++ and 5G enabled systems.

The IEE802.3 standard stipulates a maximum usable length of 100 meters (330 feet) of RJ45 cable that can be plugged into a power source. They do not however consider extreme operational conditions, which is a critical feature of this application note.

End users who like to claim compliance to IEE802.x would like to operate with the 330 feet of cable, 660 feet round trip, which results in a round trip cable resistance of 16.5 ohm. This very large resistance results in a current limit of a mere 0.3A to limit voltage drop to 5%. Hence, the maximum power that can be delivered via that cable at 48V is 14.5W. To enable a higher power draw, the standard and equipment providers arbitrarily decided to accept a higher voltage drop, choosing to work with a 10% or higher. Further, to overcome the voltage drop, they chose to start with as high a voltage as possible. The Safety Extra Low Voltage, SELV for short, is a voltage of about 60V beyond which is considered unsafe to touch.

PoE adopters took advantage of this limit and established 57V at the endpoint, or the power source. At the same time, they adopted a much lower minimum voltage, which in most cases is 44V. These limits allowed a 13V difference to work with, allowing a maximum current of 0.8A. This arbitrary new voltage range permitted delivery of a total of 46W at the source of the cable. With about 11W lost due to cable, the net power delivered is limited to 35W.

There is a secondary problem with going lower in voltage at the end of cable arising from increasing current due to the constant power characteristic of most switching power converters used inside the smart devices, but that’s a topic outside the scope of this application note. Suffice it is to say that about 35W of input power is available for a PoE load device. With some allowance made for its efficiency, it is safe to say that a device with a maximum power draw of 30W can be used at the end of a 330 feet ethernet cable. Fortunately, a lot can be accomplished in today’s world of computing and communications with this limited power.

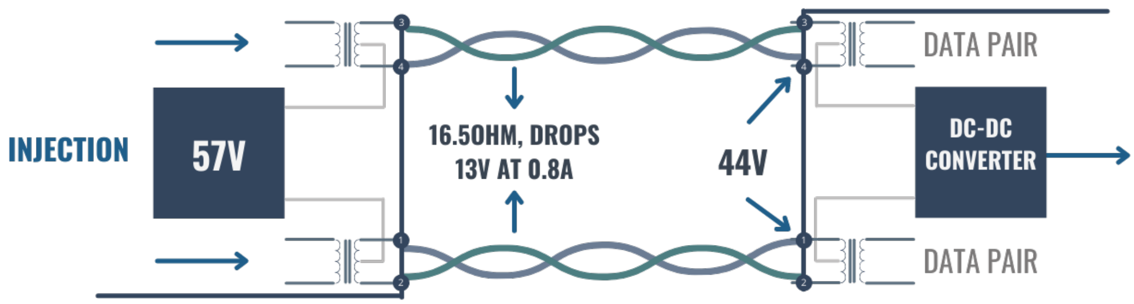


Figure 6 - Losses in a Rj45 cable of 100m length

Multiple powered devices may be operating off a single injected voltage, but they may not always be drawing the full rated power or may not all be on at the same time or longer than a few seconds. A practical example is that of PTZ cameras, where a camera draws most power when its PTZ motors are moving (these generally do not move indefinitely). Multiple cameras may not all move at the same time. So, the power system may not be rated for the worst-case maximum power of all loads combined. Knowing worst-case loading and the probability of that occurring helps in sizing the power supply accordingly.

ROUTER OPERATING POWER

In addition to PoE injected power, there may be a need for running the router. Most outdoor routers can operate over a wide input range, typically from 18-30VDC. They also have a wide range of power draw, depending on data traffic, but usually, top off at about 30W. This feed does NOT have to travel over the data cable. Since the router is usually co-located with the PoE switch, the cable harness from the power supply unit to the router is usually less than a foot, hence no significant voltage drop is expected. It can also be derived from a DC/DC converter operating off the injected voltage, but that takes away a critical part of the PoE power system, which is isolation. With a non-isolated DC/DC converter implementation, the injected voltage and router voltage share the same ground, which makes the router vulnerable to lightning strikes that tend to travel along the data cable. A few more considerations are discussed in the isolation section.

AUXILIARY VOLTAGE RAIL

PoE systems usually employ diagnostic units that may be autonomous and need to be always on, while the main injected voltage and router power may be toggled on and off for maintenance and troubleshooting. An auxiliary 12V isolated to the same level as the other two rails is quite helpful. Since it needs to be always on, it's best to derive it using an isolated AC/DC converter. Its power requirements are quite low, usually about 5W.

OPERATING ENVIRONMENT

Being outdoor, temperature extremes are to be naturally expected. However, other factors (such as additional temperature rise within an enclosure) can raise the operating temperature to near military systems' benchmark.

PoE systems typically are housed in IP67 grade shelters which provide adequate protection against water splash but do not block moisture. HEPA grade air filters can be built into vents of the cabinet, but over time build up to pollution degree 2 can be expected. Since there is no real cleaning possible, conformal coating is mandated. Likewise, blocked filters will reduce the effectiveness of system cooling.

Network OEMs typically specify operating temperatures up to 74°C for peak summer days while directly exposed to the sun for a few hours daily. It is necessary to carefully consider all load factors and ensure the power system does not hit over temperature thresholds. It may make sense to incorporate a fan that only operates at or close to this extreme condition to ensure the fan does not become a life limiter. As an example, for Arizona sites, about 800 hours of such high heat can be expected annually, where a 40,000 hours life fan can still provide about 50 years' service.

SHOCK AND VIBRATION

Outdoor systems are installed wherever possible. Traffic management systems are mounted on poles at the intersections. The constant movement of vehicles and any trains in the vicinity can cause sufficient shock and vibration to levels consistent with military systems, such that MIL 810C requirements are usually specified. Where not specified, they serve as a good marketing tool.

ELECTROMAGNETIC COMPLIANCE

Electromagnetic compliance has a very broad scope both from an emission and susceptibility viewpoints. At a minimum, lightning surge, EFT, ESD, Line voltage flicker should be specified to a level higher than a regular industrial product. Where practical, the PoE system OEM provides additional protections beyond what the power supply has, making the overall system more rugged, consistent with their claims of hardened systems.

ISOLATION

PoE systems certainly need a level of isolation higher than regular industrial systems. The long network cable acts as a sufficient antenna that can be hit by lightning. Hardening the whole PoE system starts with a power supply that is inherently designed for high isolation across all barriers as shown in the block diagram below. These isolations should be maintained by the PoE switch OEM as well.

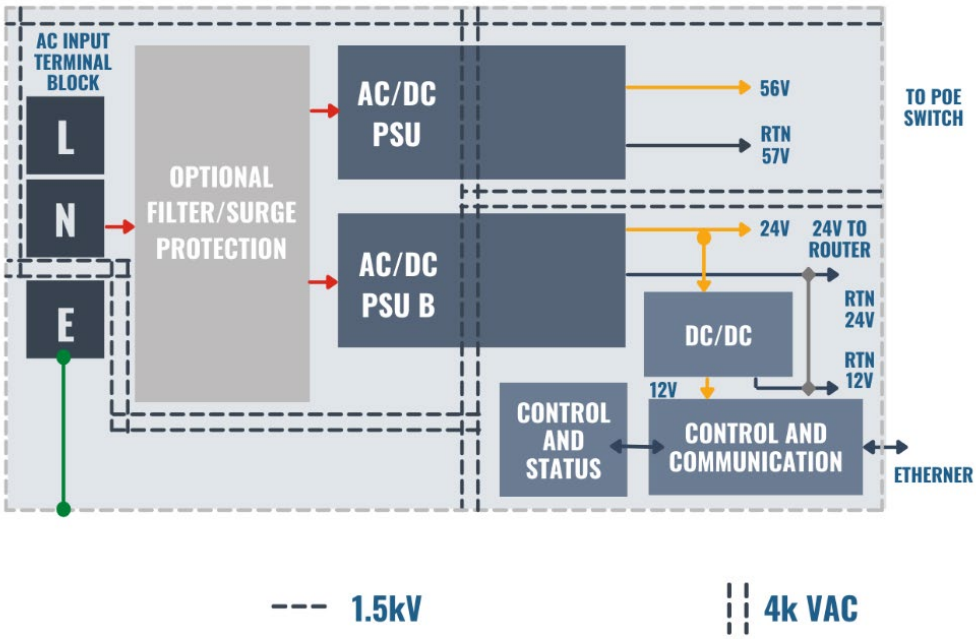


Figure 7 - Isolation across all boundaries

MAINTAINABILITY

Crews that manage large networks very often must travel to remote sites, with costs and time associated. A typical truck roll to a site within a large city has a price tag of $500 or more. Features that enable full remote diagnosis will help to reduce truck rolls resulting in lower operating costs and total cost of ownership.

REMOTE CONTROL

On a typical day, the crews on both ends are needed to diagnose a problem needing to turn on/off PoE voltage while keeping the router operational. If the router is to be diagnosed, they need to hook up a separate LAN connection, where the always-on 12V comes in handy.

PROTECTIVE BARRIERS

Crews working with live circuits must be protected from accidental contact with live input and output terminals. Hence, access barriers on any exposed live circuits are required.

SECURE SINGLE AC CORD

To prevent a loose AC cord from causing system malfunction, OEMs generally need a secure screw terminal block interface for both AC and DC outputs. Due to costs, they also require the whole unit to only receive one AC cord. All operating DC voltages should be derived by distributing AC inside the power supply.

AC INPUT VOLTAGE MONITORING"REPORTING

Due to potential voltage sags in the grid far away from substations, there is a need to monitor incoming AC voltage to report on the general health of the network and downtimes if any. To accomplish this, AC input voltage monitoring and reporting via Ethernet is often required. A real-time log and event history if made available is a huge plus.

COMMUNICATION PORT

To enable a full diagnosis, the power supply needs to have its RJ45 port with a built-in ethernet communications unit where a quick check can be done by a service technician or the port can be permanently hooked up to the network and health of the power system as a whole, including AC input, can be monitored and logged. Critical parameters like AC input voltage, DC voltage outputs presence, and any temperature alarm are quite useful in routine maintenance.

SERVICE LIFE

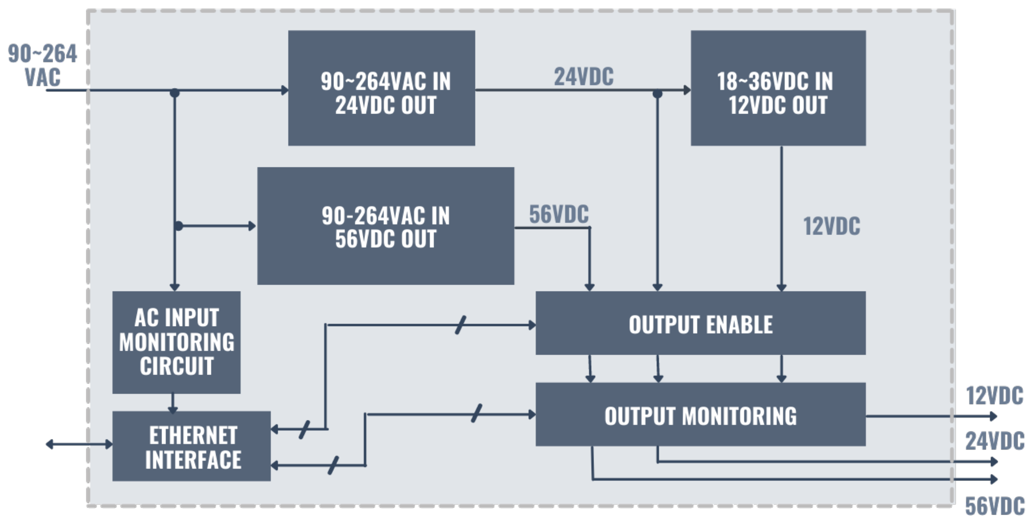
Large infrastructure programs such as traffic management, border protection, DEA, coast guard, agriculture, and water resource management, to name a few, with large capital expenses, normally require 20 years or more of assured performance.

The original warranty may be standard 1-3 years, but a reliable usage model should be drawn up to support the idea that subject to maintenance, the power system, and the network is designed to last that long. To that effect, extra-long-life electrolytic capacitors may be needed.

All the above criteria are valuable features for large complex installations but it is unusual for a regular industrial power system to have these unusual features. Which is the reason why Astrodyne TDI is launching a brand new PoE/PoE++ grade power supply. Networking OEMs can incorporate this power supply unit into their PoE switch and offer a truly hardened ultra-long life PoE system.

The Astrodyne TDI PoE power supply implementation with all the above features is shown below. The main PoE injected voltage and 24V DC router power units are both adapted from proven industrial or medical grade power supplies. The user can order the exact voltages required. Adjustability is not needed in a PoE application. Astrodyne TDI can offer different SKUs to suit multiple programs.

Astrodyne TDI PoE power supply implementation



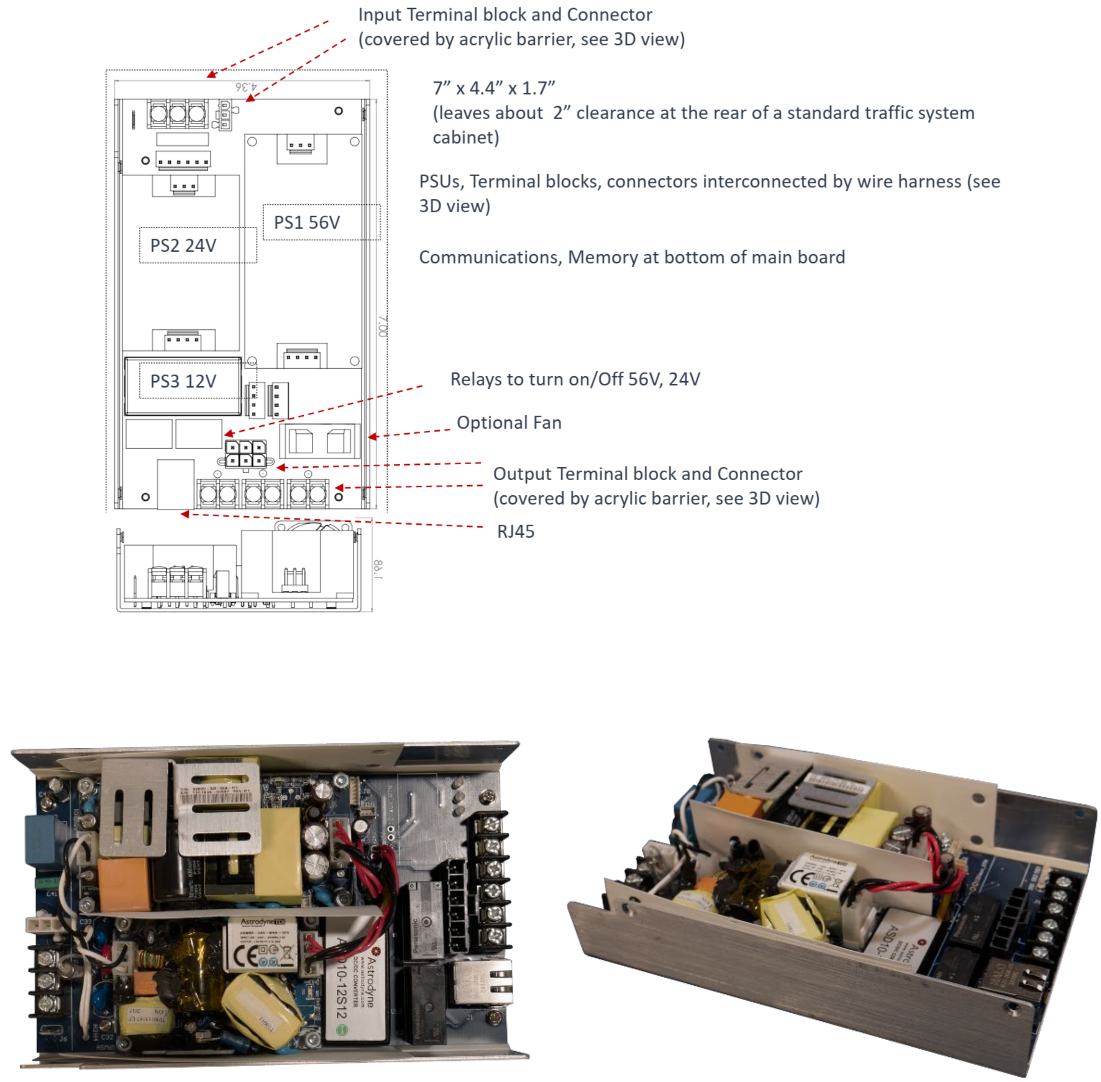


Figure 8 - Astrodyne TDI PoE power supply block diagram, features, and views

Summary·

PoE and PoE++ systems need extraordinary reliability far beyond regular commercial-grade systems. Consequently, their power systems should be of comparable hardened class. The power system provider should have a strong background in delivering such power systems. Network OEMs would greatly benefit from Astrodyne TDI's vast experience in delivering rugged power systems to demanding, medical and military applications

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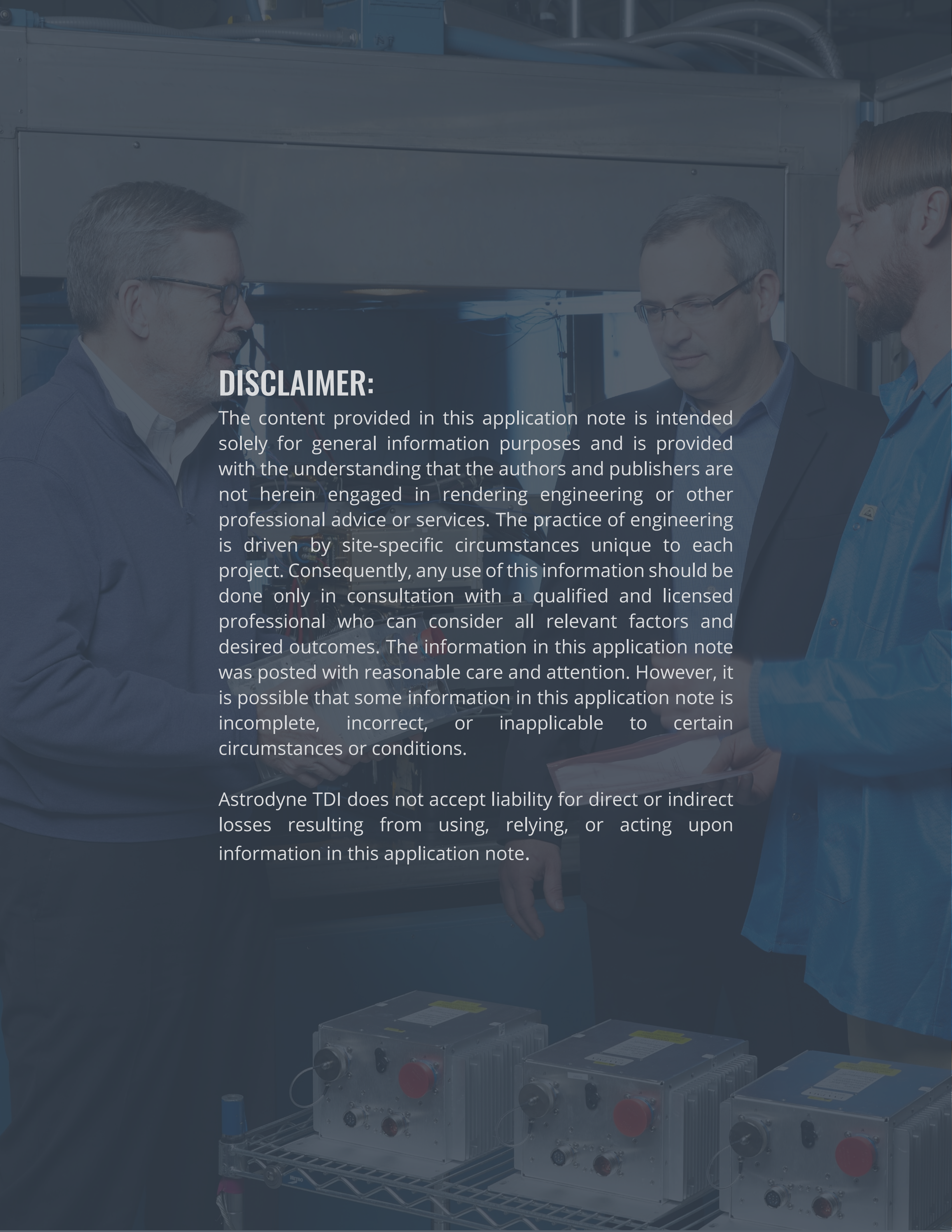
Anil re-joined Astrodyne TDI in March of 2020 as the Field Application Engineer covering the Central, Rockies and Pacific North-West regions. He previously worked for Astrodyne TDI from 2013 to 2016. Anil has his B.S. in Electronics and Communication Engineering from the University of Mysore, India. He started his career as a Radar Transmitter Engineer followed by an FAE role in RF, Microwave and EMC test instrumentation. From there, Anil lead Principal Engineering roles in high volume custom power suppliers for office equipment, gigabit routers and Dell laptops. Anil has held several sales & business development roles within large format of lithium ion battery packs. His most recent assignment was selling modular configurable power systems and high voltage DC/DC converters for a wide variety of uses in industrial, medical, BioTech and military markets. Anil has 15 plus years of experience working in 4 different countries before moving to the U.S. 25 years ago.



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