PoE and LED: Together at Last

By Chris Richardson, Applications Engineer, National Semiconductor

Low Power, Bright Lights, Long Cables

Compared to a light bulb or fluorescent tube LEDs are physically small, emit light in a directed beam and run from low voltage DC. Power over Ethernet (PoE) is an IEEE-sanctioned standard for delivering power over the standard ethernet cables that already are in place for networking. PoE power sourcing equipment (PSE) sends up to 15 W at 48 V DC over cables up to 100 meters in length. A distributed 48 V DC bus is perfect for putting low power, bright lights at the end of long cables. DC-DC converters make much better LED drivers than AC-DC converters, which use more parts, take up more space and are less efficient. LED and PoE truly seem to have been made for one another. With PoE in one hand and high power LEDs in the other, a solution was born.

A Solution in Search of a Problem

The 15 W maximum power specified by IEEE 802.11af is at the source. At a typical voltage of 48 V this translates to an output current of 350 mA. CAT5 ethernet cables were not designed with power transmission in mind and typically use thin, 24-gauge copper wires. Power loss in a long run (PoE will go as far as 100 m) can reach 2 W, leaving approximately 13 W for the load. For this 'solution without a problem' 10 1W LEDs form the light source and 12-foot long CAT5 wires connect the lamps to the power source. LEDs already boast very high luminous efficacy, with standard 1 W devices delivering 50 lm/W, and the best devices reaching 100 lm/W and continuing to improve.

Cree, Inc., a North American LED manufacturer, makes 1 W power LEDs that combine LED dice with surface mount packages that include a lens to provide a lambertian viewing angle and copper slug that the die sits on that provides a low thermal resistance interface to heatsinking. These 1 W devices, the XLamp series LEDs, are available in seven colors: red, red-orange, amber, green, cyan, blue and royal blue, as well as three color temperatures of white: cool white (5,000 K to 10,000 K), soft white (3,500 K to 5,000 K) and warm white (2,600 K to 3,500 K). PoE 'injectors' are PSEs that take in data on ethernet cable and add power to the spare pairs. Injectors with eight output ports are available from several telecom equipment manufacturers, hence the 'solution' is a lighting system with one PoE LED lamp for each color, capable of powering eight lamps at any given time.

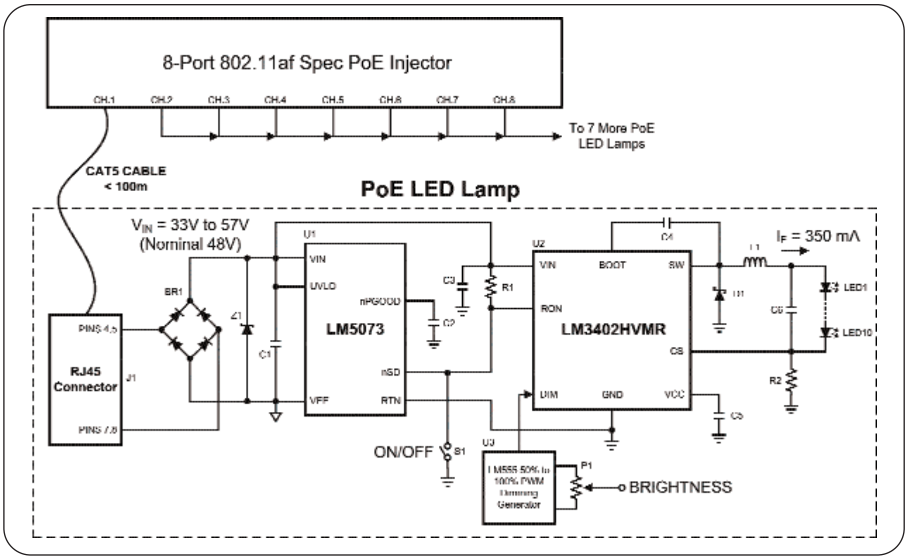
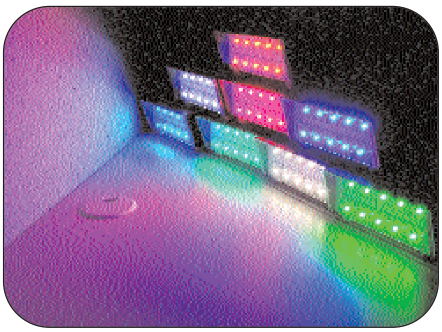


Figure 1. PoE LED Lamp Circuit Schematic



The Power Solution

Several analog semiconductor manufacturers provide the two basic pieces needed to make a 10 W PoE LED lamp, which are an 802.11af certified powered device (PD) interface and an efficient LED driver. The PD interface detects the availability of PoE from a PSE and provides soft-start for inrush current limit during startup, current limit during steady state and logic signals such as a powergood flag that signal to the load that power is ready for delivery. The LM5073, shown in the circuit schematic of Figure 1, provides a PD interface but does not include any type of switching regulator controller. The design is free to use any topology of DC-DC converter.

Ten LEDs placed in a single series chain require a total string voltage ranging from 22.5 V (the typical forward voltage for the AlInGaP-based red and amber LEDs) to 40 V (the maximum voltage needed to forward-bias the InGaN-based green, blue and white LEDs). This means that even under worst-case conditions the LED driver output voltage will be lower than the input voltage, permitting the use of a step-down, or buck regulator to drive the LEDs.

$$V_O = n \times V_F$$

'n' is the number of LEDs in series

'V_F' is the forward voltage of the LED

Even though output current is the controlled parameter, it is the relationship between input voltage and output voltage that determines the topology of DC-DC converter that can be used. Buck regulators make the best LED drivers of any switching regulator type for several reasons, in particular their high power efficiency and low parts count.

The LED driver is a DC-DC power supply that takes in the input voltage and provides a controlled output current over a range of output voltage. This stands in contrast to traditional power DC-DC converters, which provide a controlled output voltage over a range of output currents. At first glance, however, the switching regulator used for these PoE LED lamps looks very much like other buck regulator. It contains all the classic components needed: a power switch (an N-

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MOSFET internal to the IC), a Schottky diode for recirculating current, an inductor and input and output capacitors. Upon closer inspection the differences that make this buck regulator a current controlling LED driver become evident. The LED chain replaces the top feedback divider resistor and the bottom feedback divider resistor is in fact the current sensing resistor. In this configuration output voltage rises until enough current flows through the current sensing resistor to equal the feedback voltage. Put the LEDs in-between VO and CS and the current flows through them as well. The output capacitor connects in parallel to the LEDs and acts as a filter to reduce the ripple current through the LEDs. A buck LED driver can run without any output capacitor at all, in which case the inductance is solely responsible for controlling the LED ripple current. For applications that need tightly controlled ripple this can make the inductance large, and as a result can make the inductor itself too large.

The LM3402HV is a dedicated buck regulator for powering LEDs with constant current and with an input voltage range that extends to 75 V, it provides a wide input margin beyond the 48 V of PoE. Two special features distinguish the LM3402HV from its voltage regulating cousins. First, the feedback voltage (renamed CS, for Current Sense) is internally reduced to 0.2 V, minimizing the power dissipated in R2. Second, the enable pin (renamed DIM) is a fast logic input that disables only the power FET. This minimizes propagation delays and gives the best contrast ratio when dimming with PWM.

The Thermal Solution

Being a solution without a problem, the maximum case temperature was defined as 50°C, which happens to be the threshold above which the engineer building the lamps could no longer hold a finger on the boxes indefinitely. Cree also makes the XR LEDs available on 1-inch by 5-inch strips of metal-core PCB (MCPCB) with one LED occupying each square inch. All five devices are connected in series, ensuring equal drive current and balanced light output from each one. Two such strips put 10 LEDs in an area measuring 2 inches by 5 inches and provide a total light output varying from 500 lumens in cool white to 150 lumens in blue. (The royal blue LEDs are specified by radiometric power.) The two LED strips were mounted on the front of an aluminum 'project box' measuring 6 inches wide by 2.5 inches tall and 4 inches deep. Passive cooling was provided by a pair of off-the-shelf extruded aluminum heatsinks measuring 1.75 inches by 2.25 inches by 0.5 inches mounted directly behind the MCPCBs on the front face of the box. Thermal grease was applied to the MCPCBs and the heatsinks, putting the box itself to work as further heatsinking.

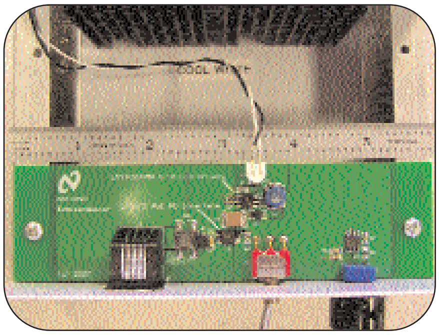

Figure 2. Overhead Shot of PoE Lamp Interior

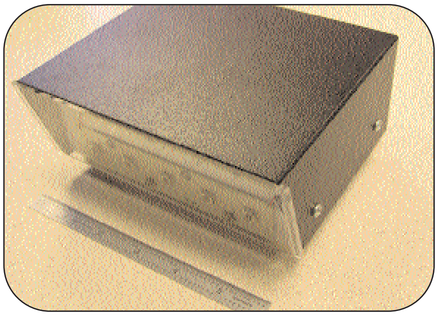

Figure 3. ¾ View of Lamp

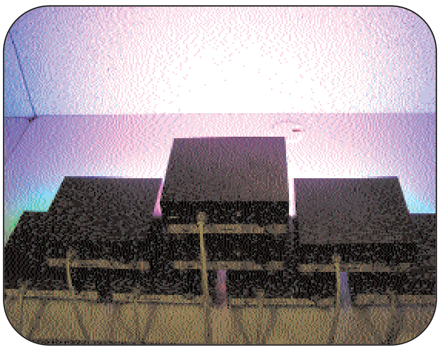

Figure 4. Eight Lamps Illuminating a Cubicle Wall

Both the LM5073 and LM3402HV are available in surface mount packages with exposed thermal pads. Power supply ICs often endure high ambient temperatures and LED applications are no exception. The thermally enhanced packages (eTSSOP-14 for LM5073, PSOP-8 for LM3402HV) make effective use of the PCB as a heatsink. The drive electronics were mounted on standard FR-4 and connected to the LEDs through a wiring harness as shown in Figure 2. Thermal resistance for packages like eTSSOP-14 and PSOP-8 on FR-4 with 2 oz copper are around 50°C/W. For these lamps the mechanical design made it impractical to put the LED driver on the MCPCB with the LEDs, but it is important to note that exposed pad packages enjoy thermal resistances below 10°C/W when mounted on MCPCB. Lighting designers can take advantage of this to get every last mW from their drive electronics.

Dimming with PWM

PWM dimming is a must if the color or color temperature of the LEDs is to be maintained over the range of light output. The trouble is finding a dimming frequency that doesn't cause audible noise.

The frequency of the power switches in LED drivers is usually between 100 kHz and 1 MHz, far beyond the range of human hearing. Dimming frequency is typically much lower because turning the output of a switching converter on and off takes much longer than turning a power MOSFET on and off. The propagation delays and output current slew rates incurred as the LED driver cycles on and off consume a fixed amount of time. As dimming frequency increases dimming period decreases and the fixed delays consume an ever greater portion of the dimming cycle.

A simple square-wave generator using an LM555 timer provides dimming from 50 percent to 100 percent and runs from spare power at 7 V from the VCC regulator of the LM3402HV. The non-ideal operation of such a low-cost, purely analog solution serves to highlight the noise concern for LED lighting designers. LM555 timers used as asynchronous multivibrators change their frequency as they change duty cycle, so the initial design used the lowest frequencies possible, 200 Hz to 300 Hz, as 200 Hz is generally regarded as the minimum frequency at which flicker or individual pulses are not visible to the human eye. The design produced a clearly audible, irritating hum at any dimming duty cycle other than 100 percent, hence the final dimming frequency was increased to 20 kHz. Audible noise persists in the final design because at the minimum duty cycle of the 50 percent the LM555 is slightly non-linear, causing a steep drop in dimming frequency right around 50 percent. Further increases in dimming frequency push the boundaries of response time for the DIM pin of the LM3402HV. A simple microcontroller capable of duty cycle from 0 percent to 100 percent at a fixed frequency would have made a superior solution for dimming, especially if it could run from the spare power of the VCC regulator like the LM555.

Results

The XR LEDs are specified by their

Table 1: Thermal Results and Efficiency	Case Temp in Thermal Steady State (°C)	Interior Ambient Temp in Thermal Steady State (°C)	LED VF at 25°C (V)	LED VF in Thermal Steady State (V)	Estimated LED Die Temp °C	Electrical Efficiency (%)	LED Current (mA)
Red	34.3	39	20.9	20.4	41.1	81.3	355
Red-Orange	34	36.5	20.9	20.4	41.1	81.6	359
Amber	35	40.2	21.4	20.9	41.1	82.8	361
Green	38.8	42.1	33.2	32.4	52.6	85.6	348
Cyan	40.1	44.7	35.6	34.6	59.5	85.8	339
Blue	38.1	44.2	34.2	33.4	52.6	84.9	344
Royal Blue	36.7	40.2	33.8	33.3	42.2	85.9	339
Warm White	37.9	46.7	34	32.6	73.3	84.1	345
Soft White	38.4	43.3	32.5	31.6	56.0	84.3	356

approximate power dissipation of 1 W, but for efficiency calculations their true typical power must be calculated as their forward current, 350 mA, multiplied by their forward voltage. Table 1 shows the typical VF for each color of LED at 25°C and in thermal steady state, measured after the lamps had been powered for one hour in a lab environment of 25°C. True die temperature is difficult to measure, but the negative coefficient of forward voltage for InGaN and AlInGaP was used to estimate final die temperature, which remained well within the 125°C limit set by Cree.

Problems to Fit the Solution

While not ready for mass production, the PoE LED lamps demonstrate the ease with which the two technologies combine to put light in locations where AC power is not available. PoE power sourcing equipment provides isolation and power factor correction, reducing the burden that lighting places on the electrical grid. The on/off and dimming controls built in to the back of the lamps could be converted to remote control via the ethernet data lines, which were not used at all. Applications for this solution could be stage or theater lighting, temporary decorative lighting, lighting for security cameras, or generating excitement on trade show exhibit floors.

Chris Richardson is an Applications Engineer in the Power Management Products group, Medium and High Voltage Division, at National Semiconductor. His responsibilities are divided between lab work, bench evaluation of new ICs, written work such as datasheets and applications notes, and training for field engineers and seminars. Since joining National Semiconductor in 2001, Chris has worked mainly on synchronous buck controllers and regulators. In the last three years he has focused on products for the emerging high brightness LED market in the automotive and industrial areas. Chris holds a BSEE from the Virginia Polytechnic Institute and State University. He can be reached at Chris.Richardson@nsc.com.