LM5070, LM5071, LM5072, LM5073

Power Supply Design for Power-over-Ethernet Applications

Literature Number: SNVA588
The Internet is becoming as essential and ubiquitous a tool for communication and entertainment as are television and the telephone. An ever-growing variety of powered devices (PDs) such as wireless routers, web cameras, VoIP phones, and others are finding more and more applications in facilitating and extending the usefulness of the Internet. All of these devices require a power source to run them and, although the obvious source of this power is the mains, this choice is unattractive because of the additional cables that need to be introduced. A far better solution is to use the Ethernet cable that transfers data to also carry power from the Ethernet hub to the PD, thus eliminating extra cables.

**Power-over-Ethernet (PoE)**

![Figure 1. Transmitting power over CAT-5 cable](image)

**No. 104**

**NEXT ISSUE:**

**Powering Applications Processors**
Power-over-Ethernet PD interface solution

LM5070 PoE PD interface/PWM controller serves isolated/non-isolated applications

- Combines a fully compliant IEEE 802.3af PD interface with a high-performance current-mode controller
- Integrates all PD system management including power up/down sequencing and fault protection
- Provides user programmability of signature impedance, UVLO thresholds, in-rush current, classification current, and DC-DC converter operating parameters
- Protection for in-rush/fault current limiting, cycle-by-cycle limiting with auto retry, & thermal shutdown
- Voltage reference and error amplifier for non-isolated applications
- Available in TSSOP-16 and tiny (5 mm x 5 mm), thermally enhanced LLP-16 packages

Product Highlight:
Highly integrated, most reliable PoE PD solution with versatile programmability

Inrush current limit programmed to 150 mA
VCC released when PowerOK* = 1
Softstart released when VCC achieves regulation

*PowerOK is an internal signal.
Power Supply Design for Power-over-Ethernet Applications

However, there are limits to the power that the Ethernet hub can provide and to the current that the Ethernet cables can handle. To ensure that neither is overloaded and to standardize and streamline the interfacing of PDs to the Ethernet power sourcing equipment (PSE), the IEEE has written the 802.3af Power-over-Ethernet specification to govern the electrical behavior of Ethernet power loads.

**IEEE 802.3af specification**

The 802.3af specification allows for power at 44V to 57V at the PSE to be delivered to the PD over a CAT-5 or CAT-6 cable by using either spare conductors in the cable or by sharing the data conductors. In the latter case, transformers can be used on both ends of the Ethernet cable to combine and separate the power and data signals. Figure 1 illustrates how both methods of transmitting power can be implemented. Classes of operation at the PSE of 4W, 7W and a maximum of 15.4W (based on the power handling capacity of the cable conductors) have been defined. The use of these classes allows the PSE to provide each power supply with only the power it requires so that more users can be serviced. Both isolated and non-isolated PDs can be powered.

The PSE identifies the validity of the power supply as follows: when the supply is connected to the Ethernet cable, the PSE initiates a *signature detection* phase during which it checks for an initial power supply impedance of 25 kΩ in parallel with 0.1 μF; this impedance must be designed into the power supply. Once this impedance is validated, the PSE classifies the power level required by the PSE by applying a voltage to the supply and checking for several specific currents, each of which identifies a class of operation. Once the right current is detected, the PSE makes the operating voltage available to the power supply, matching the maximum available current to the class of operation. Additionally, the inrush and short circuit currents drawn by the supply are both limited to an absolute maximum of 450 mA. Allowing for voltage drops in the cable, the power supply must work down to 36V.

**Design considerations for PoE power supplies**

Clearly then, every PoE power supply must have an 802.3af-compliant powered device interface (PDI) or front end. In the earliest days of PoE power supplies, their compliance to the specification was effected by discrete circuitry added at the front-end. The obvious shortcoming of this approach is that of complexity and component count coupled with greater demands on the design skills of the power supply designer.

A refinement of this approach which some IC vendors have followed, is to build just the PDI to ensure compliance with the specification and follow this with a power supply designed around a separate PWM controller. This is an improvement to the previous approach, but still requires the use of two complex ICs for a complete solution.

<table>
<thead>
<tr>
<th>Class</th>
<th>Usage</th>
<th>Maximum PSE Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Default</td>
<td>15.4W</td>
</tr>
<tr>
<td>1</td>
<td>Optional</td>
<td>4.0W</td>
</tr>
<tr>
<td>2</td>
<td>Optional</td>
<td>7.0W</td>
</tr>
<tr>
<td>3</td>
<td>Optional</td>
<td>15.4W</td>
</tr>
</tbody>
</table>

Figure 2. PoE power classes
Flexible post-regulation solutions

LM5642 Dual synchronous buck converter with oscillator synchronization

- Wide 4.5V to 36V input voltage range
- High efficiency (up to 95%)
- Synchronizable switching frequency
- 0.04% (typical) line and load regulation
- Independent enable/soft-start pins allow simple sequential startup
- Over-current, short-circuit, over-voltage and thermal protection
- Flexible dual- or bi-phase configuration
- Available in TSSOP-28 packaging

Product Highlight:
Highly efficient POL controller for distributed power architectures

LP3884x Dual-rail low 0.56V output, ultra-low drop-out (LDO) regulator family

- Dual-rail architecture allows fast transient response from input voltage as low as 1V
- ±3% \( V_{OUT} \) accuracy over full temp range
- 0.8V, 1.2V, 1.5V fixed \( V_{OUT} \) & Adj (0.56V to 1.5V)
- Stable with ceramic capacitors
- Shutdown pin allows easy sequencing
- TO263-5, TO220-5 and PSOP-8 packaging

Product Highlight:
Optimized for digital load requirements with extremely fast transient response

<table>
<thead>
<tr>
<th>Product ID</th>
<th>( I_{OUT} )</th>
<th>( V_{DROPOUT} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP38841</td>
<td>0.8A</td>
<td>75 mV</td>
</tr>
<tr>
<td>LP38842</td>
<td>1.5A</td>
<td>115 mV</td>
</tr>
<tr>
<td>LP38843</td>
<td>3A</td>
<td>210 mV</td>
</tr>
</tbody>
</table>
Power Supply Design for Power-over-Ethernet Applications

The third, most compact, and best approach is to integrate the PDI and the PWM controller into a single IC and build the entire power supply solution around it.

These three different approaches are illustrated in Figure 3.

Topological considerations for PoE power supplies

The two most important desiderata for a PoE topology are low cost and high efficiency. Low cost, which is a must for any product that will see mass usage, implies simplicity of the topology. For the power levels under consideration, the flyback converter is the natural choice. Not only is it the simplest and cheapest of all isolated topologies in its most basic form, but it is also best suited to generating multiple outputs. This topology can be configured to generate voltages of either or both polarities of any magnitude.

Though flyback converters at low power levels are usually operated in discontinuous conduction mode (DCM), the best efficiency is obtained in the continuous conduction mode (CCM) where, for a given output power, the RMS current in the primary side FET is smaller. The two arguments generally used to justify DCM operation are a smaller transformer and the migration of the troublesome right half plane zero of the control transfer function to a high enough frequency as to render it irrelevant. But at PoE power levels, the transformer cores for CCM operation are small enough to be acceptable in most applications. Furthermore, for the PoE power levels and input voltage range, a quick calculation shows that the right half-plane zero is located at such a high-frequency that it is not a problem. The right half-plane zero for a flyback converter in CCM is at

\[ f_z = \frac{V_{in} D}{2 \pi I_{in} L} \]

where \( V_{in} \), \( D \), \( I_{in} \), and \( L \) are respectively the input voltage, the duty ratio of the primary side FET, the average input current, and the magnetizing inductance of the power transformer. A reasonable value for \( L \) in CCM operation in this application is 100 \( \mu \)H. Together with minimum \( V_{in} = 36V \), maximum \( I_{in} = 360 \) mA, and corresponding \( D = 0.4 \), this locates the right half-plane zero at a lower frequency limit of \( f_z = 64 \) kHz under all operating conditions.
High-frequency, high-efficiency buck regulators

**LM2652 Dual step-down synchronous buck regulator delivers 1.5A per channel**

- 2.8V to 5.5V input range
- Best-in-class 80 mΩ switches
- 0.8V to 3.3V output voltages in 50 mV steps
- 650 kHz and 1300 kHz switching frequencies
- Synchronizable to an external 300 kHz to 1600 kHz clock
- Current-limit and thermal shutdown protection
- Available in TSSOP-28 ePad packaging

**Product Highlight:**
Four low $R_{DS(ON)}$ integrated power MOSFETs ensure high-efficiency, small external components and flexible sequencing options

**LM2734/36 step-down DC-DC regulators reach 3 MHz**

- 3.0V to 20V input range
- State-of-the-art 13 ns minimum ON-time allows for high conversion ratios without the need to reduce switching frequency
- Current-mode control improves phase margin, line regulation and transient response
- PWM provides easily filtered switching frequency for reduced output noise
- Internal softstart, cycle-by-cycle current limit, thermal, and OV protection
- Available in tiny, thin SOT-23 packaging

**Product Highlight:**
Complete, easy-to-use switcher has smallest footprint and highest power density

<table>
<thead>
<tr>
<th>Feature</th>
<th>LM2734</th>
<th>LM2736</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input range</td>
<td>3.0V to 20V</td>
<td>3.0V to 18V</td>
</tr>
<tr>
<td>Output load</td>
<td>1A</td>
<td>750 mA</td>
</tr>
<tr>
<td>Output range</td>
<td>0.8V to 18V</td>
<td>1.25V to 16V</td>
</tr>
<tr>
<td>Internal references</td>
<td>0.8V, 2%</td>
<td>1.25V, 2%</td>
</tr>
<tr>
<td>Operating frequency</td>
<td>550 kHz / 1.6 MHz / 3 MHz</td>
<td></td>
</tr>
</tbody>
</table>
conditions, which is so high that the zero is of negligible impact on the design of the feedback compensator in most PoE applications.

The flyback converter typically suffers from large voltage spikes across its power components due to the energy stored in the power transformers’ leakage inductance. But because the maximum PoE input voltage is only 57V, the transformer requires no safety isolation, and its leakage inductance can be made extremely low. This improves the efficiency and reduces the voltage spikes so greatly that all voltage snubbers and clamps can usually be eliminated from the PoE converter.

**Preferred PoE Power Supply Architecture**

The foregoing suggests that the CCM flyback topology is a preferred PoE power supply architecture. One IC is utilized that combines the PDI with a PWM regulator to implement a CCM flyback with a minimum of topological complexity and of support circuitry. In cases where the output voltage ripple needs to be low, an LC filter can be added to the output of the supply. The use of this topology has been greatly facilitated by the fact that some of the major magnetics vendors are now offering families of PoE flyback transformers that are designed and optimized for the different PoE power classes.

When using a CCM flyback supply designed for an output power of 13W with a diode rectifier, the power supply will typically be about 84% efficient at input voltage of 48V and an output voltage of 3.3V. The efficiency will increase or decrease as the output voltage respectively increases or decreases. For a given output voltage the efficiency can be increased with a cost penalty (to around 90% at an output voltage of 3.3V) by replacing the diode rectifier with a synchronous rectifier.

**Summary**

PoE power supplies need to satisfy the IEEE 802.3af specification, but they must also be affordable and efficient. The best way to meet these requirements with minimum cost and maximum efficiency is with the use of a highly integrated supply based around an IC that combines 802.3af specification compliance and PWM control to implement a continuous conduction mode flyback converter. ■
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