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<td>1.2 to 5 $V_{DC}$</td>
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<td>600</td>
<td>TPS63000</td>
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<td>Boost Driver with Integrated Power Switch</td>
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<td>TPS61500</td>
<td>32</td>
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<tr>
<td>Nonsynchronous Boost LED Driver</td>
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<td>700 or 350</td>
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<tr>
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<td>—</td>
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<td>350</td>
<td>TPS40211</td>
<td>36</td>
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<td>3 series</td>
<td>Analog or PWM</td>
<td>4.5 to 7.4 $V_{DC}$</td>
<td>10.5 typical</td>
<td>350</td>
<td>TPS61165</td>
<td>38</td>
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LED Reference Design Cookbook
Helping You Solve Your Lighting Design Challenges

The LED Reference Design Cookbook is designed to provide you with a valuable tool to help you solve your lighting design needs. Customers seeking the latest in innovative and affordable LED lighting solutions can benefit from TI's broad product portfolio of AC/DC, DC/DC, LED drivers, power management devices, wireless and wired interface control and embedded processors.

Designers have the option of not only controlling the power stage, but regulating LED currents as well, eliminating the need for multiple components and reducing system cost. Systems can be designed to accurately control voltage and current regulation for precise light intensity and color mixing, temperature monitoring to prevent thermal runaway, intelligent/adaptive dimming, and fault detection (over voltage/current, blown string). Communication with external systems is also possible via power-line communication (PLC), wireless technology or interfaces.

LED lighting designers are challenged with meeting their efficiency and reliability goals faster in advanced lighting designs. TI's lighting portfolio is helping designers achieve their goals at a faster rate.

To see the TI solutions for general lighting, signage, backlighting and automotive, all complimented by a comprehensive customer support network, visit www.ti.com/lighting.

TI has Solutions for Your Lighting Challenges:
• Precision channel-to-channel and chip-to-chip accuracy to create the best hue and luminance in your RGB message boards and video displays
• Small footprint, highest efficiency, programmable LED or OLED backlight controllers
• Blinking low-power LEDs to act as indicators in an automotive display or in a casino game
• Controllers to power and dim high brightness white or RGB LEDs for architectural luminaries and portable lighting
• Powering arrays of HB LEDs off an AC source for use in street lighting and replacing high-intensity discharge (HID) lamps
• Highly integrated ZigBee® transceivers and SoC solutions for wireless lighting control and home automation
**TPS61160/1**

**Description**
With a 40-V integrated switch FET, the TPS61160/1 is a boost converter that drives up to 10 LEDs in series. The boost converter, which allows for the use of high-brightness LEDs in general lighting, runs at a fixed frequency of 1.2 MHz with a 0.7-A switch-current limit.

As shown in the schematic below of a typical application, the default white-LED (WLED) current is set with the external sense resistor, RSET, and the feedback voltage is regulated to 200 mV. The LED current can be controlled via the one-wire digital interface (EasyScale™ protocol) through the CTRL pin. Alternatively, a PWM signal can be applied to the CTRL pin such that the duty cycle determines the feedback reference voltage. In either digital or PWM mode, the TPS61160/1 does not provide LED current in burst; therefore, it does not generate audible noise on the output capacitor. For protection during open-LED conditions, the TPS61160/1 has integrated circuitry to prevent the output from exceeding the absolute maximum ratings.

**Web Links**
Datasets, user’s guides, samples: [www.ti.com/sc/device/TPS61160](http://www.ti.com/sc/device/TPS61160)

**Ordering Information**

<table>
<thead>
<tr>
<th>TA</th>
<th>Open LED Protection (typical)</th>
<th>Package²</th>
<th>Package Marking</th>
</tr>
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<tbody>
<tr>
<td>-40°C to 85°C</td>
<td>26 V</td>
<td>TPS61160DRV</td>
<td>B2Q</td>
</tr>
<tr>
<td></td>
<td>38 V</td>
<td>TPS61161DRV</td>
<td>B2R</td>
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</tbody>
</table>

¹For most current package and ordering information: [www.ti.com/sc/device/TPS61160](http://www.ti.com/sc/device/TPS61160).
²The DRV package is available in tape and reel. Add R suffix (TPR61160DRVR) to order quantities of 3,000 parts per reel or add T suffix (TPS61160DRVT) to order 250 parts per reel.

**Typical Application Schematic**

![Typical Application Schematic](image-url)

For more reference designs, see: [www.ti.com/powerreferencedesigns](http://www.ti.com/powerreferencedesigns)
Small LCD Backlight with Digital and PWM Dimming

Efficiency vs. Output Current

PWM Dimming Linearity: FB Voltage vs. PWM Duty Cycle

PWM Dimming Output Ripple
Small LCD Backlight from LDO

TPS7510x

Description
The TPS7510x linear low-dropout (LDO) LED current source is optimized for low-power LED backlighting applications such as keypads and navigation pads. The device provides a constant current for up to four unmatched LEDs organized in two banks of two LEDs each in a common-cathode topology. Without an external resistor, the current source defaults to the factory-programmable, preset current level with ±0.5% accuracy (typical). An optional external resistor can be used to set initial brightness to user-programmable values with higher accuracy. Brightness can be varied from off to full brightness by inputting a PWM signal on each enable pin. Each bank has independent enable and brightness control, but the currents of all four channels are matched concurrently. The input-supply range is ideally suited for single-cell Li-Ion battery supplies, and the TPS7510x can provide up to 25 mA per LED. No internal switching signals are used, eliminating troublesome electromagnetic interference (EMI). The TPS7510x is offered in an ultra-small, 9-ball, 0.4-mm ball-pitch wafer chip-scale package (WCSP) and a 2.5 x 2.5-mm, 10-pin SON package, yielding a very compact total solution size ideal for mobile handsets and portable backlighting applications.

At first glance, using a linear LDO circuit to drive LEDs may seem impractical, given the linear regulator’s reputation for low efficiency. However, the efficiency of LDOs is often misunderstood. LDO efficiency is entirely based on the input/output-voltage ratio; therefore, the efficiency of driving white LEDs (WLEDs) can be quite high. For example, driving a 3-V WLED from a 3.6-V Li-Ion-battery input translates into an LED efficiency of 83%.

Device Specifications

<table>
<thead>
<tr>
<th>Device</th>
<th>VIN (V)</th>
<th>LED Configuration</th>
<th>ID(max) (mA)</th>
<th>V0 (mV)</th>
<th>IDX (%)</th>
<th>Packages</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPS7510x</td>
<td>2.5 V to 5.5 V</td>
<td>2 mm x 2 mm</td>
<td>25 mA</td>
<td>28 mV</td>
<td>±2%</td>
<td>WCSP, DSK</td>
</tr>
</tbody>
</table>

TPS7510x Package Options

Figure 1 shows a typical application for the TPS75105. Note that this device requires no external components to drive the WLEDs. The total solution is extremely small and very cost effective.

Figure 2 shows the TPS75105 efficiency data for several different WLED forward voltages over the Li-Ion battery’s range. The LED efficiency for the TPS75105 is comparable to or better than that of other WLED-driver solutions.

Figure 3 demonstrates the LED efficiency of the TPS7510x over the Li-Ion battery’s discharge curve. The average efficiency for the entire discharge range is over 80% for all three curves, and up to 90% when VLED = 3.3 V.

Web Links
Datasheets, user’s guides, samples: www.ti.com/sc/device/TPS75105

For more reference designs, see: www.ti.com/powerreferencedesigns
Figure 1 - Typical Application

![Typical Application Diagram]

Figure 2 - Efficiency Data

![Efficiency Data Graph]

Figure 3 - LED Efficiency

![LED Efficiency Graph]
Medium-Size LCD Backlight

**TPS61165**

**Description**

With a 40-V integrated switch FET, the TPS61165 is a boost converter that drives up to ten LEDs in series. The boost converter, which allows for the use of high-brightness LEDs in general lighting, runs at a fixed frequency of 1.2 MHz with a 0.7-A switch-current limit.

As shown in the schematic below of a typical application, the default white-LED (WLED) current is set with the external sense resistor, \( R_{\text{SET}} \), and the feedback voltage is regulated to 200 mV. The LED current can be controlled via the one-wire digital interface (EasyScale™ protocol) through the CTRL pin. Alternatively, a PWM signal can be applied to the CTRL pin such that the duty cycle determines the feedback reference voltage. In either digital or PWM mode, the TPS61160/1 does not provide LED current in burst; therefore, it does not generate audible noise on the output capacitor. For protection during open-LED conditions, the TPS61165 has integrated circuitry to prevent the output from exceeding the absolute maximum ratings.

**LED Current vs. Input Supply and LED Number**

<table>
<thead>
<tr>
<th>LED Number</th>
<th>Input Supply 3 V</th>
<th>Input Supply 5 V</th>
<th>Input Supply 12 V</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED number 3</td>
<td>200 mA</td>
<td>350 mA</td>
<td>820 mA</td>
</tr>
<tr>
<td>LED number 6</td>
<td>100 mA</td>
<td>175 mA</td>
<td>410 mA</td>
</tr>
<tr>
<td>LED number 8</td>
<td>70 mA</td>
<td>120 mA</td>
<td>300 mA</td>
</tr>
</tbody>
</table>

*Note: Assumption that LED forward voltage is 3.5 V, and TPS61165’s conversion efficiency is 80%.*

**Web Links**

Datasheets, user’s guides, samples: www.ti.com/sc/device/TPS61165

For more reference designs, see: www.ti.com/powerreferencedesigns

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**Typical Application Schematic**

![Typical Application Schematic](image)

**Component Details**

- L1: TOKO #A915_Y -100M
- C1: Murata GRM188R61A475K
- C2: Murata GRM188R61E105K
- D1: OSRAM LW-W SSM
Efficiency vs. Output Current

Startup

PWM Dimming Linearity: FB Voltage vs. PWM Duty Cycle

PWM Dimming Output Ripple
TPS61195

Description
The TPS61195 provides highly integrated solutions for large-LCD backlights. This device has a built-in, high-efficiency boost regulator with an integrated 3-A, 50-V power MOSFET. The eight current-sink regulators provide high-precision current regulation and matching. In total, the device can support up to 96 white LEDs (WLEDs). In addition, the boost output automatically adjusts its voltage to the WLED forward voltage to improve efficiency.

The TPS61195 supports multiple brightness-dimming methods. During direct PWM dimming, the WLED current is turned on/off at the duty cycle, and the frequency is determined by an integrated PWM signal. In PWM-dimming mode, the frequency of this signal is resistor-programmable, while the duty cycle is controlled from an external PWM signal input from a PWM pin. In analog mixed dimming modes, the input PWM duty-cycle information is translated into an analog signal to control the WLED current signal linearly over a brightness area of 12.5 to 100%. The device also allows PWM dimming to be added when the analog signal keeps the WLED current down to 12.5%. Below 12.5%, the analog signal will be translated into PWM duty-cycle information to control the on/off of the WLED current and to average the WLED current down to 1%.

The TPS61195 integrates overcurrent protection, short-circuit protection, soft start and overtemperature shutdown. The device also provides programmable output overvoltage protection, and the threshold is adjusted by an external resistor/divider combination.

The TPS61195 has a built-in linear regulator for the IC supply and is available in a 4 x 4-mm QFN package.

Web Links
Reference designs: www.ti.com/powerreferencedesigns
Datasets, user's guides, samples: www.ti.com/sc/device/TPS61195

LED Current vs. Input Supply and LED Number

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Unit</th>
</tr>
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<tbody>
<tr>
<td>Input voltage</td>
<td>4.0</td>
<td>24</td>
<td>Volts</td>
</tr>
<tr>
<td>Output voltage</td>
<td>16</td>
<td>48</td>
<td>Volts</td>
</tr>
<tr>
<td>Number of channel</td>
<td>—</td>
<td>8</td>
<td>—</td>
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<tr>
<td>Output current</td>
<td>0</td>
<td>0.32</td>
<td>Amp</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>600 KHz</td>
<td>1 MHz</td>
<td>—</td>
</tr>
</tbody>
</table>

TPS61195 Schematic
Dimming Efficiency $V_{IN} = 10.8$ V; 9s8p

Mixed Mode Dimming Waveform: 20% Brightness—Pure Analog

PWM Dimming Current Linearity $V_{IN} = 10.8$ V

Mixed Mode Dimming Waveform: 8% Brightness Mode

Mix Mode Dimming Current Linearity $V_{IN} = 10.8$ V
**Constant Current Driver with PFC**

**UCC28810 PMP4501**

**Description**

The PMP4501 is an isolated, off-line, AC-to-DC LED-current driver with PFC for applications such as commercial fixture lighting and general isolated LED drivers. The PMP4501 is a single-stage flyback PFC converter that delivers up to 34 W with a 180- to 265-VAC input voltage while providing a 10- to 48-V output voltage at a constant output current of 700 mA ±2%.

The PMP4501 implements secondary-side current control for the LED string. Overvoltage protection prevents dangerous output voltages from occurring during open-string conditions. A current-sense amplifier reduces the sensing resistor’s power dissipation, thus increasing overall efficiency. The internal reference voltage of the operational amplifier achieves excellent LED-current regulation versus output power and input voltage. The PMP4501 achieves high efficiency (90% peak), high power density and a high power factor. The reference design protects against scenarios with open and short LED strings, and the control stage is a simple and robust design.

**Design Specifications**

<table>
<thead>
<tr>
<th>Description</th>
<th>Parts</th>
<th>(V_{IN}^{(AC)}) Range</th>
<th>(V_{OUT}^{(DC)}) Range</th>
<th>Number of LEDs</th>
<th>(I_{OUT}) (max)</th>
<th>(P_{OUT}) (max)</th>
<th>Eff.</th>
<th>PFC</th>
<th>ISO</th>
<th>Dimming In</th>
<th>Dimming Out</th>
<th>EVM</th>
</tr>
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<tr>
<td>UCC28810</td>
<td>UCC28810</td>
<td>180</td>
<td>10 V</td>
<td>3-13</td>
<td>700 mA</td>
<td>34 W</td>
<td>89%</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Reference Design</td>
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<tr>
<td>PMP4501 34-W Secondary side current loop</td>
<td>TL103W</td>
<td>265</td>
<td>48.5 V</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</table>

**PMP4501 Reference Design Schematic**

For more reference designs, see: [www.ti.com/powerreferencedesigns](http://www.ti.com/powerreferencedesigns)
PMP4501 Board

Efficiency vs. Rectified-Equivalent Line Voltage and Output Power

Output Current Ripple. Input Voltage = 230 VAC, Output Voltage = 48 V @ 700 mA

Power Factor vs. Line Voltage and Output Power

AC Input Current and Voltage at Full Load and Nominal Input Voltage
**Description**

The PMP3976 circuit shown below was designed for a commercial LED lighting fixture. The SEPIC topology has the advantage over a flyback converter in that it clamps the switching waveforms on the power semiconductor, allowing the use of lower voltage and hence more efficient parts. This provides an estimated 2% improvement in efficiency in this application. Additionally, there is less ringing in the SEPIC, making EMI filtering easier.

The LED-lighting circuit uses the UCC28810 transition-mode boost controller to shape the input-current waveform. The circuit starts by charging C6 off the line. Once the controller is running, its power is provided by an auxiliary winding on the SEPIC inductor. A relatively large output capacitor limits LED ripple current to 20% of the DC current. As a side note, the AC flux and currents in the transition-mode SEPIC are quite high, so Litz wire and low-loss core material are required to reduce inductor losses.

The following material presents lab results from a prototype that was built to match the schematic. Efficiency is quite high over the European line range, peaking at 92%. This good efficiency was achieved by limiting the ringing on the power semiconductors. Also, as can be seen from the current waveform, the power factor is quite good at over 96%. Interestingly, the waveform is not purely sinusoidal but shows some steepness on the rising and falling edges. This is because the circuit measures switch current but not input current. However, the waveform is good enough to pass the European requirements for harmonic currents.

**Web Links**

Datasheets, user’s guides, samples: www.ti.com/sc/device/UCC28810

Reference designs: www.ti.com/powerreferencedesigns

---

**PMP3976 Schematic**

150VAC to 240VAC Input

![Schematic Diagram]
The circuit is built on a PMP3976 Rev A PWB.
LED Cookbook

Boost Controller with PFC

**UCC28810 PMP3976**

Load Current: Current in the LED String with a 230 VAC input

Harmonic Content

The image above shows a thermal image of the board. The ambient temperature was 26ºC with no forced air flow. The input was 230 VAC.

Efficiency

The harmonic content and the EN61000-3-2 Class C (lighting equipments) Limits are shown above; input voltage was set to 230 VAC.

Efficiency and Power Factor

<table>
<thead>
<tr>
<th>I(_{\text{OUT}})</th>
<th>V(_{\text{OUT}})</th>
<th>V(_{\text{IN}})</th>
<th>I(_{\text{IN}})</th>
<th>PF</th>
<th>P(_{\text{OUT}})</th>
<th>Losses</th>
<th>Efficiency %</th>
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</thead>
<tbody>
<tr>
<td>0.349</td>
<td>245.5</td>
<td>150.4</td>
<td>0.646</td>
<td>0.983</td>
<td>85.65</td>
<td>9.827</td>
<td>89.7</td>
</tr>
<tr>
<td>0.349</td>
<td>245.4</td>
<td>176.4</td>
<td>0.544</td>
<td>0.980</td>
<td>85.64</td>
<td>8.398</td>
<td>91.1</td>
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<td>0.349</td>
<td>245.3</td>
<td>202.6</td>
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<td>85.61</td>
<td>8.208</td>
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<td>10.184</td>
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<table>
<thead>
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<th>V(_{\text{IN}})</th>
<th>I(_{\text{IN}})</th>
<th>PF</th>
<th>P(_{\text{OUT}})</th>
<th>Losses</th>
<th>Efficiency %</th>
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<td>175.2</td>
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<td>0.983</td>
<td>105.85</td>
<td>10.742</td>
<td>90.8</td>
</tr>
<tr>
<td>0.349</td>
<td>303.8</td>
<td>199.9</td>
<td>0.588</td>
<td>0.984</td>
<td>106.03</td>
<td>9.634</td>
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<td>0.349</td>
<td>303.3</td>
<td>224.8</td>
<td>0.527</td>
<td>0.983</td>
<td>105.85</td>
<td>10.604</td>
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<td>0.349</td>
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<td>264.2</td>
<td>0.461</td>
<td>0.975</td>
<td>105.75</td>
<td>13.004</td>
<td>89.0</td>
</tr>
</tbody>
</table>

For more reference designs, see: [www.ti.com/powerreferencedesigns](http://www.ti.com/powerreferencedesigns)
The frequency response of the feedback loop is shown in the plot above. The input was set to 220 VAC. The lower gain plot was taken with a 300 V output. The upper gain plot was taken with a 250 V output.

The image above shows the drain-to-source voltage on Q3. The input was set to 250.

The image above shows the input voltage and current. The input voltage was 230 VAC.

The image above shows the voltage on the anode of D1. The input was set to 250 VDC.

The two images above show the currents in the individual windings of the inductor.
Replacement for Standard Lightbulb

**UCL64001 PMP4981**

**Description**
The PMP4981 is a reference design for an LED driver in a lightbulb-replacement circuit. The design is optimized to function with AC input sources that may be fed through an industry-standard TRIAC-based phase-cut dimmer. The PMP4981's dimming function allows the string of LEDs to be dimmed to very low levels without flickering or stroboscopic effects. Current is drawn from the TRIAC only when needed, providing high efficiency with a non-isolated driver for a very-low-cost solution. This single stage provides high reliability, long life and high performance.

**Design Specifications**

<table>
<thead>
<tr>
<th>Description</th>
<th>Parts</th>
<th>$V_{IN}$ (AC) Range</th>
<th>$V_{OUT}$ (DC) Range</th>
<th>Number of LEDs</th>
<th>$I_{OUT}$ (max)</th>
<th>$P_{OUT}$ (max)</th>
<th>Eff.</th>
<th>PFC</th>
<th>ISO</th>
<th>Dimming In</th>
<th>Dimming Out</th>
<th>EVM</th>
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<tbody>
<tr>
<td>PMP4885 low-cost offline LED lighting driver</td>
<td>UCL64001</td>
<td>90</td>
<td>24</td>
<td>7 to 9</td>
<td>450 mA</td>
<td>12 W</td>
<td>79%</td>
<td>No</td>
<td>No</td>
<td>TRIAC</td>
<td>PWM</td>
<td>Paper</td>
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</tbody>
</table>

**PMP4981 Schematic**

For more reference designs, see: [www.ti.com/powerreferencedesigns](http://www.ti.com/powerreferencedesigns)
Replacement for Standard Lightbulb

LED Current and Voltage – Dimmer at Full Power Position

Line Current and Voltage – Dimmer at Full Power Position

Rectified AC (Top) and LED Current (Bottom) – Low Conduction Angle

LED Current and Voltage – Dimmer at ~ Half Power Position

Rectified AC (Top) and LED Current (Bottom) – High Conduction Angle

Texas Instruments 4Q 2009

LED Reference Design Cookbook
UCC28810/UCC28810EVM-001

Description
The UCC28810EVM-001 evaluation module (EVM) is a 25-W TRIAC dimmable and single-stage flyback converter with PFC. The UCC28810EVM-001 provides approximately 36 V at a constant 700-mA (undimmed nominal) load current to power a string of high-brightness LEDs. This EVM allows the evaluation of the UCC28810 LED lighting controller in an application where LEDs can be used for general illumination applications that require dimming.

Using the UCC28810 transition-mode boost IC with PFC in a flyback converter yields a valley-switching design that can achieve 90% efficiency and a high power factor over a universal wide input-voltage range. The UCC28810EVM-001 also operates over a universal wide input-voltage range. High-performance TRIAC dimming detection and regulation adjustment are achieved with minimal impact on efficiency.

An input-filter damping network ensures operations with most TRIAC-based wall dimmers. No extra resistance is used across the line or in series that would reduce efficiency. Valley switching is implemented in the UCC28810EVM-001 to improve efficiency. A fast start-up circuit is also implemented, so there is no perceived delay from switching to illumination.

Web Links
Reference designs:
www.ti.com/powerreferencedesigns

Datasheets, user’s guides, samples:
www.ti.com/sc/device/UCC28810

EVM:
www.ti.com/ucc28810evm-001

Design Specifications

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<th>Parts</th>
<th>V&lt;sub&gt;IN&lt;/sub&gt; (AC) Range</th>
<th>V&lt;sub&gt;OUT&lt;/sub&gt; (DC) Range</th>
<th>Number of LEDs</th>
<th>I&lt;sub&gt;OUT&lt;/sub&gt; (max)</th>
<th>P&lt;sub&gt;OUT&lt;/sub&gt; (max)</th>
<th>Eff.</th>
<th>PFC</th>
<th>ISO</th>
<th>Dimming In</th>
<th>Dimming Out</th>
<th>EVM</th>
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<tbody>
<tr>
<td>UCC28810 EVM001 25-W PFC dimmable LED driver</td>
<td>UCC28810</td>
<td>85</td>
<td>33</td>
<td>10</td>
<td>700 mA</td>
<td>25 W</td>
<td>89%</td>
<td>Yes</td>
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<td>TRIAC</td>
<td>Linear</td>
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<td>TPS3808</td>
<td>305</td>
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UCC28810EVM-001 Block Diagram

![UCC28810EVM-001 Block Diagram](image)
Efficiency vs. Line Voltage

Efficiency as a function of line voltage. 10 Cree XLamp® 7090 XR-E, white, 700 mA LEDs connected in series was used for the load.

Power Factor vs. Line Voltage

Power factor as a function of line voltage. 10 Cree XLamp® 7090 XR-E, white, 700 mA LEDs connected in series was used for the load.

Total Harmonic Distortion vs. Line Voltage

Total harmonic distortion as a function of line voltage. 10 Cree XLamp® 7090 XR-E, white, 700 mA LEDs connected in series was used for the load.

Output Current vs. Line Voltage

Load current as a function of line voltage. 10 Cree XLamp® 7090 XR-E, white, 700 mA LEDs connected in series was used for the load.

Triac Dimming Detection Circuit Waveforms – Deep Dimming

Triac Dimming Detection Circuit Waveforms – Light Dimming
**Description**

The UCC28810EVM-002 evaluation module (EVM) is a constant-current non-isolated power supply for LED lighting applications that require high brightness, such as street, parking or area lighting. The reference design converts the universal mains (90 to 265 V\textsubscript{RMS}) to a 0.9-A constant-current source to drive a 100-W LED load. The UCC28810EVM-002 is a two-stage design.

The first stage is a transition-mode circuit with PFC. It ensures that the design meets the harmonic-current or power-factor requirements set by various standards such as the EN61000-3-2. The PFC circuit converts the AC input to a regulated DC voltage. This DC voltage can be configured as a boost-follower PFC or a fixed output voltage. The boost-follower PFC tracks the AC input's peak voltage for increased efficiency at low-line operation. The configuration with fixed output voltage removes the tracking element of the PFC circuit. The PFC's DC output voltage is then regulated to a fixed value in the region of 396 V\textsubscript{DC}.

The second stage of the design also uses transition mode but is configured as a buck converter. It converts the PFC output voltage to a fixed 0.9-A current to drive an LED load. The second stage accepts PWM dimming inputs (either externally or from an onboard circuit) and appropriately toggles itself on or off to achieve PWM dimming of the LED current.

**Web Links**

Datasets, user’s guides, samples: www.ti.com/sc/device/UCC28810

Reference designs: www.ti.com/powerreferencedesigns

EVM: www.ti.com/ucc28810evm-002

---

### Design Specifications

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<th>Parts</th>
<th>$V_{IN}$ (AC) Range</th>
<th>$V_{OUT}$ (DC) Range</th>
<th>Number of LEDs</th>
<th>$I_{OUT}$ (max)</th>
<th>$P_{OUT}$ (max)</th>
<th>Eff.</th>
<th>PFC</th>
<th>ISO</th>
<th>Dimming In</th>
<th>Dimming Out</th>
<th>EVM</th>
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</thead>
<tbody>
<tr>
<td>UCC28810 EVM002 100-W LED lighting driver</td>
<td>UCC28810, UCC28811</td>
<td>90, 265</td>
<td>55, 100</td>
<td>15-30</td>
<td>900 mA</td>
<td>100 W</td>
<td>93%</td>
<td>Yes</td>
<td>No</td>
<td>PWM</td>
<td>PWM</td>
<td>Yes</td>
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---

**UCC28810EVM-002 Block Diagram**
**Efficiency vs. Line Voltage**

UCC28810EVM-002 efficiency and power factor vs. line voltage 30 Cree XRE LED’s at 900 mA.

**Output Current vs. Line Voltage**

UCC28810EVM-002 transition mode buck PWM response (expanded). Ch1: LED VDS, Ch2: PWM, Ch3: buck inductor current 500 mA/Div, Ch4 VDD Ch1 and Ch4 Share GND reference.

**Power Factor vs. Line Voltage**

UCC28810EVM-002 efficiency and power factor vs. line voltage 30 Cree XRE LED’s at 900 mA.

**Line Regulation 30 LEDs at 900 mA, (98 W)**

LED current regulation as a function of line voltage.

**Total Harmonic Distortion vs. Line Voltage**

UCC28810EVM-002 THD vs. line voltage 30 Cree XRE LED’s at 900 mA.
Description
The UCC28810EVM-003 evaluation module (EVM) is an off-line AC-to-DC LED current driver with PFC for applications such as street, high-bay, and medium- or large-infrastructure lighting. The UCC28810EVM-003 is a three-stage converter design that delivers up to 110 W. The first stage is a universal input boost-PFC circuit providing a 305- to 400-V_{DC} output. The second stage is a low-side buck circuit providing the controlled current source, and the third stage is a series of two half-bridge DC/DC transformers that provides isolation of multiple LED strings. This patent-pending solution provides an easily scalable and cost-effective method of driving multiple LED strings.

The UCC28810EVM-003 implements single-reference current control and universal dimming (via AM or PWM) for all LEDs. The reference design effectively drives a large number of LEDs connected in series, but the voltage on the LED strings is safe (low) and isolated from the AC line. The multistring architecture implemented by the UCC28810EVM-003 is more cost-effective than an architecture with a constant voltage plus a buck stage for each LED string. The LED-driver architecture implemented in the UCC28810EVM-003 reference design is readily scalable to very high power levels. Excellent LED current matching between strings is achieved with this architecture. The UCC28810EVM-003 achieves high efficiency (91%), high power density and a high power factor. The control stage is a simple and robust design, and the EVM protects against scenarios with open and short LED strings.

Web Links
Reference designs: www.ti.com/powerreferencedesigns
Datasheets, user’s guides, samples: www.ti.com/sc/device/UCC28810
EVM: www.ti.com/ucc28810evm-003

Design Specifications

<table>
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<th>Description</th>
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<th>V_{IN} (AC) Range</th>
<th>V_{OUT} (DC) Range</th>
<th>Number of LEDs</th>
<th>I_{OUT} (max)</th>
<th>P_{OUT} (max)</th>
<th>Eff.</th>
<th>PFC</th>
<th>ISO</th>
<th>Dimming In</th>
<th>Dimming Out</th>
<th>EVM</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCC28810 EVM003 100-W isolated multi-string LED lighting driver w/multiple transformers</td>
<td>UCC28810</td>
<td>90, 265</td>
<td>22 V, 60 V</td>
<td>4X (7 - 15)</td>
<td>500 mA</td>
<td>110 W</td>
<td>91%</td>
<td>Yes</td>
<td>Yes</td>
<td>PWM</td>
<td>PWM</td>
<td>Jul-09</td>
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<tr>
<td>UCC28811</td>
<td>UCC25600</td>
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</table>

UCC28810EVM-003 Block Diagram
Efficiency vs. Line Voltage

UCC28810EVM-003 efficiency vs. line voltage and load 4 x 15 Cree XRE LED’s at 500 mA.

Power Factor vs. Line Voltage

UCC28810EVM-003 power factor vs. line voltage 4 x 15 Cree XRE LED’s at 500 mA.

I_{OUT} Matching vs. Line Voltage

UCC28810EVM-003 I_{OUT} matching vs. line voltage 4 x 15 Cree XRE LED’s at 500 mA.

UCC28810EVM-003 AC Input Current During PWM Dimming

Ch1: V_{BUCK+}, Ch2: Buck V_{DS}, Ch3: AC line current 1A/Div, Ch4: V_{BUCK -}, Ch1 and Ch 4 share GND reference.
### Description

The PMP3522 is a reference design that utilizes the UCL64010 high efficiency LED lighting driver controller. Residential downlighting has seen a great deal of transition to more efficient sources of light. Compact CFLs have become a mainstay in residential lighting, but as the lifetime cost of LED lamps falls, all the more low-power, small-form-factor designs will be needed. This reference design is an under-10-W, non-isolated SEPIC LED driver specifically laid out for residential downlighting.

### Web Links

Datasheets, user’s guides, samples: www.ti.com/sc/device/UCL64010

### Design Specifications

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<td>Input voltage</td>
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<td>290</td>
<td>V_{AC}</td>
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<tr>
<td>Output voltage</td>
<td>—</td>
<td>—</td>
<td>24</td>
<td>Volts</td>
</tr>
<tr>
<td>Output current</td>
<td>—</td>
<td>0.350</td>
<td>—</td>
<td>Amp</td>
</tr>
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</table>

### PMP3522 Schematic

For more reference designs, see: www.ti.com/powerreferencedesigns
10-Watt, Green-Mode PWM LED Driver

Laid Out for Bulb Replacement

Control Loop Frequency

Regulation

Efficiency
**Description**
Residential and commercial lighting can take advantage of the additive color mixing of red, green and blue LEDs. This reference design demonstrates how to remotely manage the color output of an LED lamp with a low-power wireless controller. The color is generated by three LEDs (red, green and blue). An MSP430™ ultralow-power microcontroller controls the brightness of each LED with constant current generated by three TPS62260 buck converters, one for each LED.

The color look-up table takes the form of an array stored in the MSP430. Whenever the rotary encoder is turned, new red, green and blue values are read from the array and used to generate the three PWM output signals. Currently 252 values are stored, which can be changed if desired. A decimal value of 100 switches the LED off, and a value of 65535 produces a mark-space ratio of 100%. When the 5-V supply is applied, the design goes into a demonstration mode where the values stored in the array are read and output in sequence in an infinite loop. As soon as the rotary encoder is turned, the sequence stops and a particular fixed color value can be selected.

There is a pin header that can be used to plug in the RF board from the MSP430 Wireless Development Tool (the eZ430-RF2500), which is separately available. With this additional module, the lamp’s colors can be controlled remotely via the wireless RF interface.

**Design Specifications**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum</th>
<th>Typical</th>
<th>Maximum</th>
<th>Unit</th>
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<tbody>
<tr>
<td>Input voltage</td>
<td>4.5</td>
<td>5</td>
<td>5.5</td>
<td>V DC</td>
</tr>
<tr>
<td>Output current</td>
<td>—</td>
<td>0.300</td>
<td>—</td>
<td>Amp</td>
</tr>
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</table>

TPS62260LED-338 Schematic

For more reference designs, see: [www.ti.com/powerreferencedesigns](http://www.ti.com/powerreferencedesigns)
Wireless-Controlled Triple LED Driver

TPS62260 TPS62260LED

### Design Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum</th>
<th>Typical</th>
<th>Maximum</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage</td>
<td>4.5 VDC</td>
<td>5 VDC</td>
<td>5.5 VDC</td>
<td></td>
</tr>
<tr>
<td>Output current</td>
<td>—</td>
<td>0.300 A</td>
<td>—</td>
<td>Amp</td>
</tr>
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</table>

### Circuit Diagrams

**Red LED**

- **U11**: TPS62260DRV
- **C12**: 22µF
- **C13**: 4.7µF
- **R11**: 10K
- **D14**: ??µmV

**Blue LED**

- **U31**: TPS62260DRV
- **C32**: 22µF
- **C33**: 4.7µF
- **R32**: 10K
- **D34**: ??µmV

**Green LED**

- **U21**: TPS62260DRV
- **C22**: 22µF
- **C23**: 4.7µF
- **R21**: 10K
- **D24**: ??µmV

V_in(max) < 6V

- **J1**: 5V
- **R2**: 330
- **C4**: 22µF
- **D1**: BZX84-C3V3
- **C1**: 4.7µF

Texas Instruments  4Q 2009  LED Reference Design Cookbook
**TPS63000 PMP3038**

**Description**
The TPS63000 provides a power-supply solution for products that use a two- or three-cell alkaline, NiCd or NiMH battery, or a one-cell Li-Ion or Li-Polymer battery. The buck-boost converter is based on a fixed-frequency PWM controller that uses synchronous rectification to obtain maximum efficiency. The maximum average current in the switches is limited to a typical value of 1800 mA, and the converter can be disabled to minimize battery drain. During shutdown, the load is disconnected from the battery. The device is packaged in a 10-pin QFN PowerPAD™ (DRC) package measuring 3 x 3-mm.

The PMP3038 circuit was designed for a torch or rugged flashlight. Most torch applications still use alkaline batteries with a common configuration of two or three cells in series that have a maximum voltage of 5 V. During operation, the $V_{BAT}$ drops below the $V_I$ of the LED, and the TPS63000 automatically switches from buck mode to boost mode to create the constant current needed for the LED. The TPS63000 can boost from voltages as low as 1.2 V. A switch that brings R4 into or out of the feedback loop provides a dimming mechanism for the flashlight to toggle between 300 and 600 mA.

**Design Specifications**

<table>
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<th>Parameter</th>
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<td>5</td>
<td>VDC</td>
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<tr>
<td>Output voltage</td>
<td>—</td>
<td>5</td>
<td>Volts</td>
</tr>
<tr>
<td>Output current</td>
<td>300</td>
<td>600</td>
<td>mAmp</td>
</tr>
<tr>
<td>Switch frequency</td>
<td>—</td>
<td>1.5</td>
<td>MHz</td>
</tr>
</tbody>
</table>

**Web Links**
Datasets, user's guides, samples: [www.ti.com/sc/device/TPS63000](http://www.ti.com/sc/device/TPS63000)

For more reference designs, see: [www.ti.com/powerreferencedesigns](http://www.ti.com/powerreferencedesigns)
Output Current Graphs with DC Coupling

Control Loop Response Graphs

Output current with \( V_{IN} = 3 \, V \).

Control loop response with 0.63 A.

Output current with \( V_{IN} = 4 \, V \).

Control loop response with 0.32 A.

Efficiency Curve for \( I_O = 0.32 \, A \) and \( I_O = 0.62 \, A \)

Turn On with 0.63 A

Efficiency
**TPS61500**

**Description**
The TPS61500 is a monolithic switching regulator with an integrated 3-A, 40-V power switch. It is an ideal driver for high-brightness 1- or 3-W LEDs. The device has a wide input-voltage range to support applications with input voltage from multicell batteries or regulated 5-V to 12-V power rails.

The LED current is set with an external sense resistor, R3, and with feedback voltage that is regulated to 200 mV by a current-mode PWM control loop, as shown in the schematic below. The device supports analog and pure PWM dimming methods for LED brightness control. Connecting a capacitor to the DIMC pin configures the device to be used for analog dimming, and the LED current varies in proportion to the duty cycle of an external PWM signal. Floating the DIMC pin configures the IC for pure PWM dimming, with the average LED current being the PWM signal's duty cycle times a set LED current.

The device features a programmable soft-start function to limit inrush current during start-up and has other protection features built in, such as pulse-by-pulse overcurrent limiting, overvoltage protection and thermal shutdown. The TPS61500 is available in a 14-pin HTSSOP package with PowerPAD™.

**Web Links**
Datasheets, user’s guides, samples: www.ti.com/sc/device/TPS61500

**LED Current vs. Input Supply and LED Number**

<table>
<thead>
<tr>
<th>LED Number</th>
<th>5 V</th>
<th>12 V</th>
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<tbody>
<tr>
<td>4</td>
<td>1000 mA</td>
<td>2000 mA</td>
</tr>
<tr>
<td>6</td>
<td>600 mA</td>
<td>1200 mA</td>
</tr>
<tr>
<td>8</td>
<td>450 mA</td>
<td>1000 mA</td>
</tr>
</tbody>
</table>

Note: Assumption that LED forward voltage is 3.5V, and TPS61500's conversion efficiency is 85%.

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For more reference designs, see: www.ti.com/powerreferencedesigns
Efficiency vs. Output Current

PWM Dimming Application Circuit: Circuit for the TPS61500 to Perform Analog Dimming Using an Injected Analog Signal

Analog Dimming by External DAC: Pure PWM Dimming Method
**Description**

The TPS40211 is a wide-input-voltage (4.5- to 52-V), nonsynchronous boost controller. It is suitable for topologies that require a grounded source n-channel FET such as boost, flyback, SEPIC and various LED-driver applications. The TPS40211 features a programmable soft start, overcurrent protection with automatic retry, and a programmable oscillator frequency. Current-mode control provides improved transient response and simplified loop compensation. The feedback pin has a reference voltage of 260 mV to help reduce the power usage and cost of the sense resistor.

The PMP4026 circuit shown below was designed with an automotive input-voltage range. The driver was built to operate under low-power to nominal battery conditions and to survive load-dump incidents. The TPS40211 was chosen for this application due to its low feedback voltage and wide input-voltage range. The application, powered directly from \( V_{BAT} \), can have a string of up to ten 700-mA LEDs in series or two parallel strings with up to ten 350-mA LEDs in each string.

An additional reference design is available. This design is a 700-mA, nonsynchronous boost current regulator for an LED driver. It has an 8- to 18-V input and a 20- to 35-V output. It can be found along with a demonstration board at: [http://focus.ti.com/docs/toolsw/folders/print/tps40211evm-352.html](http://focus.ti.com/docs/toolsw/folders/print/tps40211evm-352.html)

**Web Links**

Datasheets, user’s guides, samples: www.ti.com/sc/device/TPS40211

**Design Specifications**

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<td>40</td>
<td>Volts</td>
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<tr>
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</table>

**PMP4026 Schematic**

For more reference designs, see: [www.ti.com/powerreferencedesigns](http://www.ti.com/powerreferencedesigns)
**Nonsynchronous Boost LED Driver**

**TPS40211 PMP4026**

### Startup

The input voltage was set at 12 V, with 0.15 (LED) + 1 (resistor) A load on the outputs.

### Output Ripple Current

The image was taken with a 1.15 A/20 V load. Top waveform is FET drain, bottom is LED current.

### Efficiency

Total output current was 1.15 A, output voltage was 20 volts.

### Control Loop Frequency Response: 12 V input; 1.15 A Load

Output response to driving TP%. The input voltage was set to 12 V.

### Load Regulation of Outputs

### Load Transients
TPS40211 PMP3943

Description
The TPS40211 is a wide-input-voltage (4.5- to 52-V) nonsynchronous boost controller. It is suitable for topologies that require a grounded source n-channel FET such as boost, flyback, SEPIC and various LED-driver applications. The TPS40211 features a programmable soft start; overcurrent protection with automatic retry; and a programmable oscillator frequency. Current-mode control provides improved transient response and simplified loop compensation. The feedback pin has a reference voltage of 260 mV to help reduce the power usage and cost of the sense resistor.

The PMP3943 circuit shown below was designed with an automotive input-voltage range. The driver was built to operate under low-power battery conditions and to survive load-dump incidents. The TPS40211 was chosen for this application due to its low feedback voltage and wide input-voltage range.

An additional reference design is available. This design is a 700-mA, nonsynchronous boost current regulator for an LED driver. It has an 8- to 18-V input and a 20- to 35-V output. It can be found along with a demonstration board at: http://focus.ti.com/docs/toolsw/folders/print/tps40211evm-352.html

Web Links
Datasheets, user’s guides, samples: www.ti.com/sc/device/TPS40211

Design Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum</th>
<th>Typical</th>
<th>Maximum</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage</td>
<td>8</td>
<td>—</td>
<td>40</td>
<td>Volts</td>
</tr>
<tr>
<td>Output voltage</td>
<td>—</td>
<td>13</td>
<td>—</td>
<td>Volts</td>
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<tr>
<td>Output current</td>
<td>—</td>
<td>0.350</td>
<td>—</td>
<td>Amp</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>—</td>
<td>300</td>
<td>—</td>
<td>kHz</td>
</tr>
</tbody>
</table>

PMP3943 Schematic

For more reference designs, see: www.ti.com/powerreferencedesigns
Current Loop Frequency Response

![Current Loop Frequency Response](image)

3 Green and 1 Red OSRAM LEDs Used as Load for Vf About 12 V

<table>
<thead>
<tr>
<th>$V_{IN}$ Volts</th>
<th>$I_{IN}$ mA</th>
<th>$V_{OUT1}$ Volts</th>
<th>$I_{OUT1}$ mA</th>
<th>Efficiency %</th>
</tr>
</thead>
<tbody>
<tr>
<td>40.22</td>
<td>123.6</td>
<td>12.27</td>
<td>341.8</td>
<td>84.4</td>
</tr>
<tr>
<td>20.11</td>
<td>238.5</td>
<td>12.27</td>
<td>341.3</td>
<td>87.3</td>
</tr>
<tr>
<td>7.93</td>
<td>619.4</td>
<td>12.27</td>
<td>341.3</td>
<td>85.3</td>
</tr>
</tbody>
</table>

Regulation and efficiency: 25 degrees Celsius ambient. Target $I_{OUT}$ was 350 mA, hence actual current is 2.5% low.

When Diode Load is Opened, $V_{OUT}$ Goes to About 18 V

<table>
<thead>
<tr>
<th>$V_{IN}$ Volts</th>
<th>$I_{IN}$ mA</th>
<th>$V_{OUT1}$ Volts</th>
<th>$I_{OUT1}$ mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>40.42</td>
<td>8.79</td>
<td>18.44</td>
<td>0</td>
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<tr>
<td>20.08</td>
<td>10.75</td>
<td>18.41</td>
<td>0</td>
</tr>
<tr>
<td>8.00</td>
<td>19.12</td>
<td>18.40</td>
<td>0</td>
</tr>
</tbody>
</table>

Short Circuit: Output Current Holds Steady

<table>
<thead>
<tr>
<th>$V_{IN}$ Volts</th>
<th>$I_{IN}$ mA</th>
<th>$V_{OUT1}$ Volts</th>
<th>$I_{OUT1}$ mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>40.14</td>
<td>21.24</td>
<td>0.694</td>
<td>341.6</td>
</tr>
<tr>
<td>20.06</td>
<td>34.20</td>
<td>0.694</td>
<td>341.5</td>
</tr>
<tr>
<td>8.00</td>
<td>77.70</td>
<td>0.694</td>
<td>341.4</td>
</tr>
</tbody>
</table>
TPS61165 PMP3598

Description
The TPS61165 operates over a 3- to 18-V input supply and delivers an output voltage up to 38 V. With its 40-V rated integrated switch FET, the device drives up to 10 LEDs in series. It operates at a 1.2-MHz fixed switching frequency to reduce output ripple, improve conversion efficiency, and allow for the use of small external components. The default white-LED (WLED) current is set with the external sensor resistor $R_{\text{SET}}$, and the feedback voltage is regulated to 200 mV. In either digital or PWM dimming, the output ripple of TPS61165 at the output capacitor is small and does not generate audible noises associated with common on/off control dimming. For protection during open-LED conditions, the TPS61165 disables switching to prevent the output from exceeding the absolute maximum ratings.

The PMP3598 uses the TPS61165 in a nonsynchronous boost configuration. An additional circuit built around the op amp provides the battery under-voltage/charging indications and also provides ORing between the solar panel and battery inputs. The circuit also incorporates the necessary thermal and overcurrent protections and has load-disconnect feature.

Key considerations for this design are high efficiency and good LED-current regulation. The TPS61165 operates in a constant-current mode to regulate the LED current. The CTRL pin is used for the control input for both digital and PWM dimming. The dimming mode for the TPS61165 is selected each time the device is enabled. Analog dimming has been implemented by varying the feedback reference. A 20-kΩ variable resistor can be used to vary the LED current to achieve dimming. The converter boosts 6 to 10.5 V at 350 mA and has minimum conversion efficiency of 85%. This circuit is used for driving three 1-W LEDs or multiple 50-mA LEDs whose total power input does not exceed 3 W.

Web Links
Reference designs: www.ti.com/powerreferencedesigns
Datasheets, user’s guides, samples: www.ti.com/sc/device/TPS61165

Design Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum</th>
<th>Typical</th>
<th>Maximum</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage</td>
<td>4.5</td>
<td>6</td>
<td>7.4</td>
<td>Volts</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>10.45</td>
<td>10.5</td>
<td>10.65</td>
<td>Volts</td>
</tr>
<tr>
<td>Output Ripple</td>
<td>—</td>
<td>—</td>
<td>50</td>
<td>mV pp</td>
</tr>
<tr>
<td>Output Current</td>
<td>0</td>
<td>—</td>
<td>350</td>
<td>mA</td>
</tr>
<tr>
<td>Switching Frequency</td>
<td>—</td>
<td>1200</td>
<td>—</td>
<td>kHz</td>
</tr>
</tbody>
</table>

PMP3598 Schematic
### Switching Waveform

![Switching Waveform](image)

### Output Ripple

![Output Ripple](image)

### Open LED Protection

![Open LED Protection](image)

### Efficiency

![Efficiency](image)
Internet Technical Support

Support.ti.com

Product Information Centers

America Phone +1(972) 644-5580
Brazil Phone 0800-891-2616
Mexico Phone 0800-670-7544

Fax +1(972) 927-6377
Internet/Email support.ti.com/sc/pic/americas.htm

Europe, Middle East, and Africa

Phone

Europe Free Call 00800-ASK-TEXAS
(00800 275 83927)
International +49 (0) 8161 80 2121
Russian Support +7 (49) 95 98 10 701

Fax +49 (0) 8161 80 2045
Internet support.ti.com/sc/pic/euro.htm

Japan Phone International +81-3-3344-5317
Domestic 0120-81-0036
Fax International support.ti.com/sc/pic/japan.htm
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Asia Phone

International +91-80-41381665
Domestic Toll-Free Number
Australia 1-800-999-084
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