LED Reference Design Cookbook

Texas Instruments

www.ti.com/led

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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.

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- 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, R_{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 TPS61160/1 has integrated circuitry to prevent the output from exceeding the absolute maximum ratings.

Web Links

Datasheets, user's guides, samples:
www.ti.com/sc/device/**TPS61160**

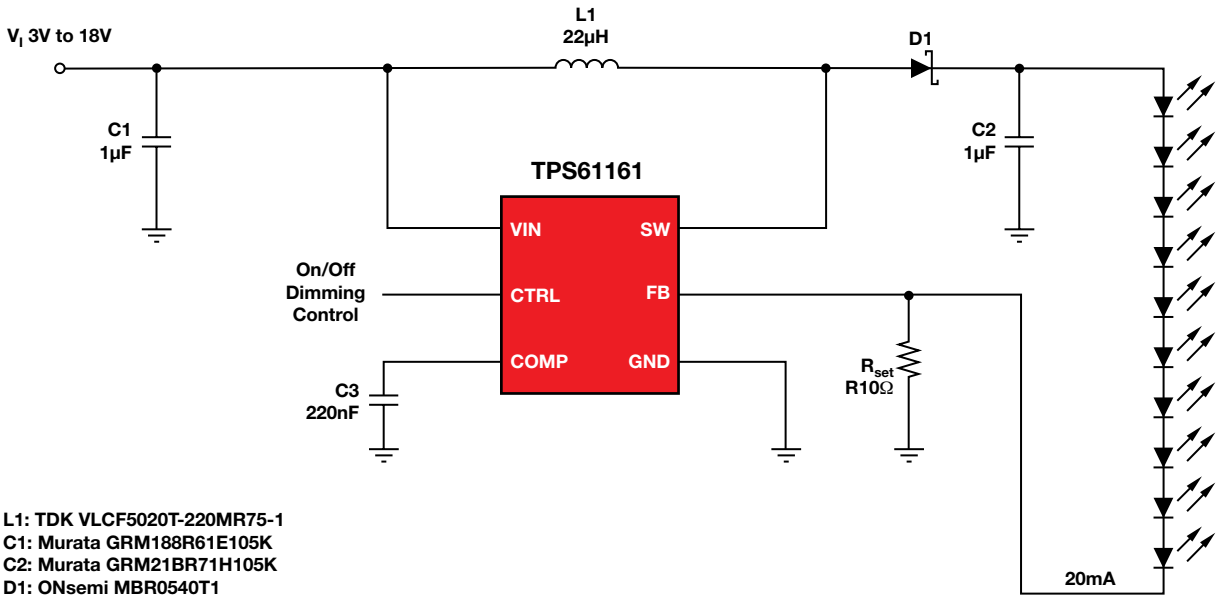
Ordering Information[1]

T_A	Open LED Protection (typical)	Package[2]	Package Marking
–40°C to 85°C	26 V	TPS61160DRV	BZQ
	38 V	TPS61161DRV	BZR

[1] *For most current package and ordering information: www.ti.com/sc/device/**TPS61160**.*

[2] *The 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.*

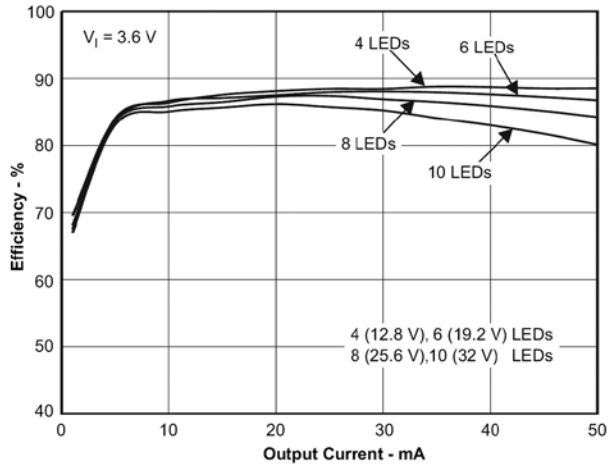
Typical Application Schematic



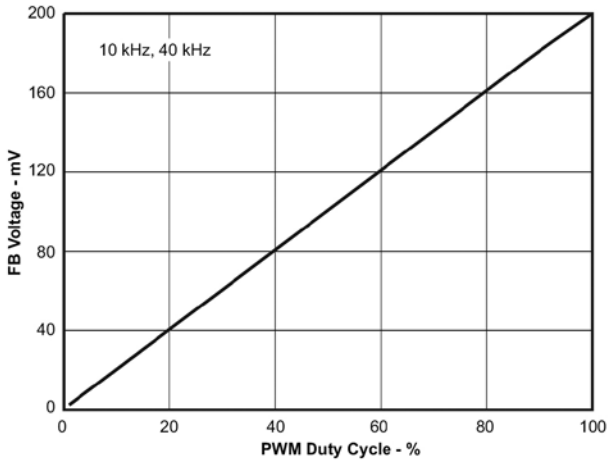
L1: TDK VLCF5020T-220MR75-1
C1: Murata GRM188R61E105K
C2: Murata GRM21BR71H105K
D1: ONsemi MBR0540T1

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

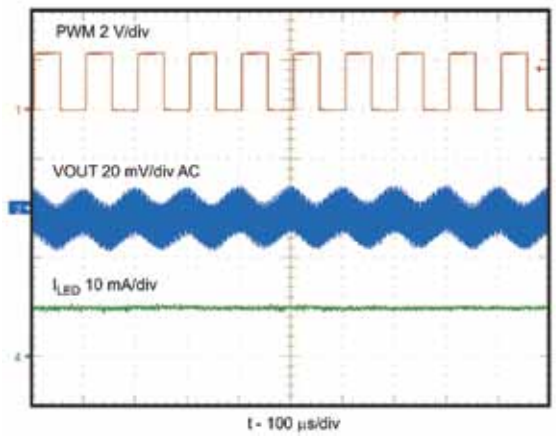
Efficiency vs. Output Current



PWM Dimming Linearity: FB Voltage vs. PWM Duty Cycle



PWM Dimming Output Ripple



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%.

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 V_{LED} = 3.3 V.

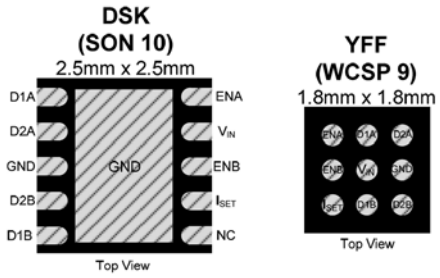
Web Links

Datasheets, user's guides, samples:
www.ti.com/sc/device/**TPS75105**

Device Specifications

Device	V_{IN}	LEDs	ΔI_{DX} MAX	VDO	ΔI_{DX}	Packages
TPS7510x	2.5 V to 5.5 V	2 mm x 2 mm	25 mA	28 mV	±2%	WCSP, DSK

TPS7510x Package Options



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

Figure 1 - Typical Application

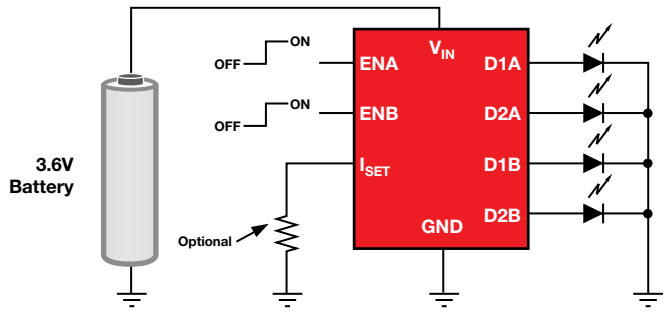


Figure 2 - Efficiency Data

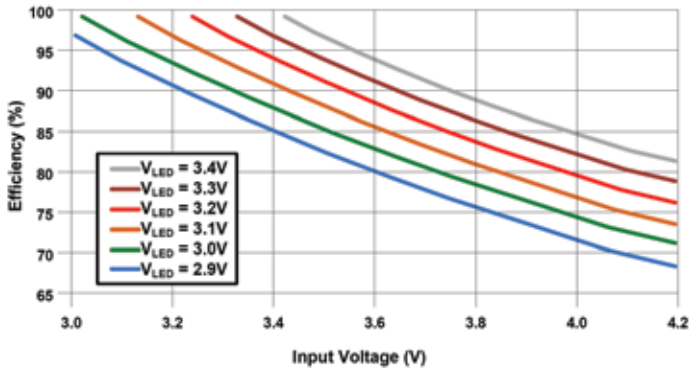
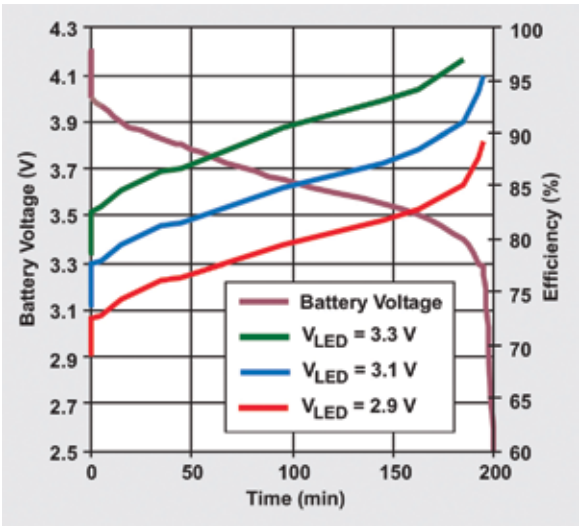


Figure 3 - LED Efficiency



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_{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.

The TPS61165 is available in a space-saving, 2 x 2-mm QFN package with a thermal pad.

Web Links

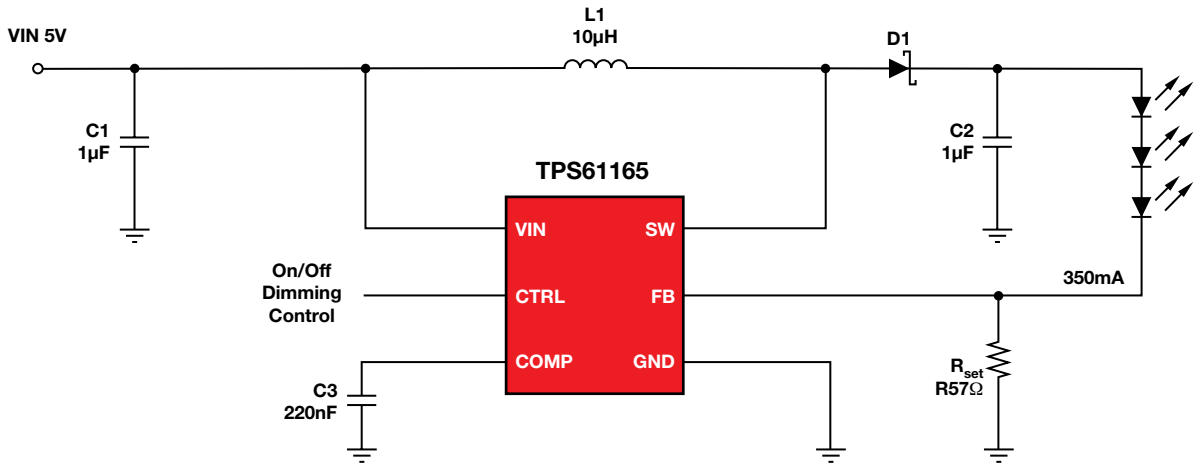
Datasheets, user's guides, samples:
www.ti.com/sc/device/**TPS61165**

LED Current vs. Input Supply and LED Number

Input Supply	3 V	5 V	12 V
LED number 3	200 mA	350 mA	820 mA
LED number 6	100 mA	175 mA	410 mA
LED number 8	70 mA	120 mA	300 mA

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

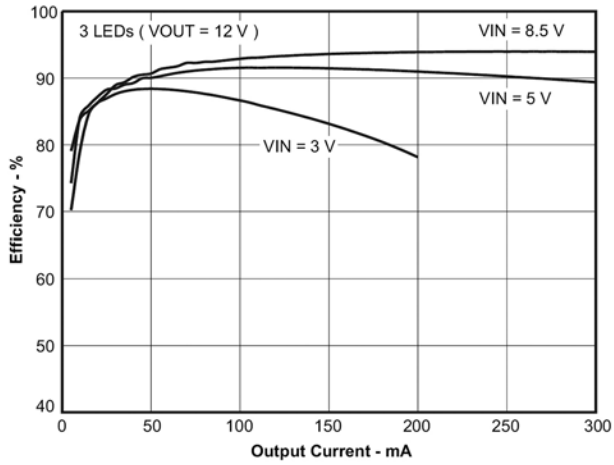
Typical Application Schematic



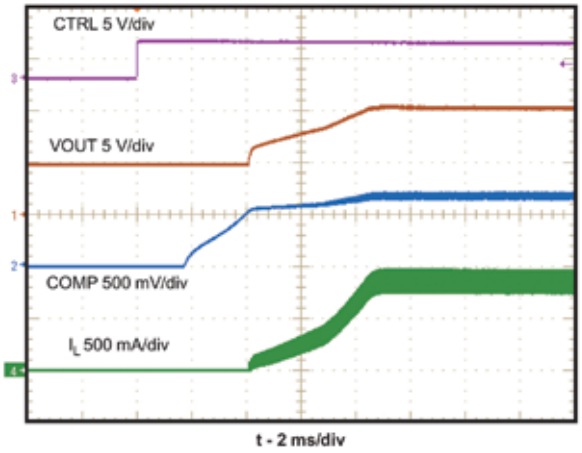
L1: TOKO #A915_Y-100M
C1: Murata GRM188R61A475K
C2: Murata GRM188R61E105K
D1: OSRAM LW-W 5SM

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

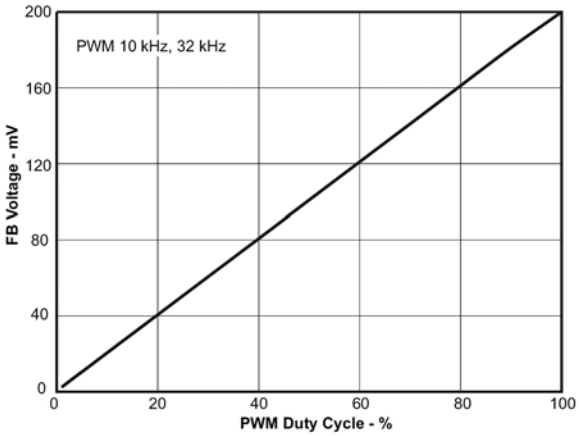
Efficiency vs. Output Current



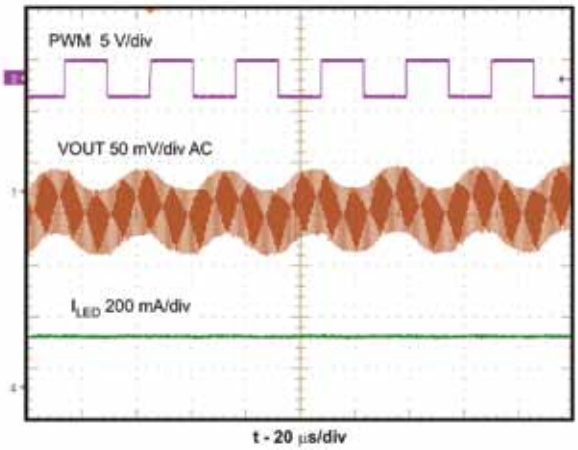
Startup



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

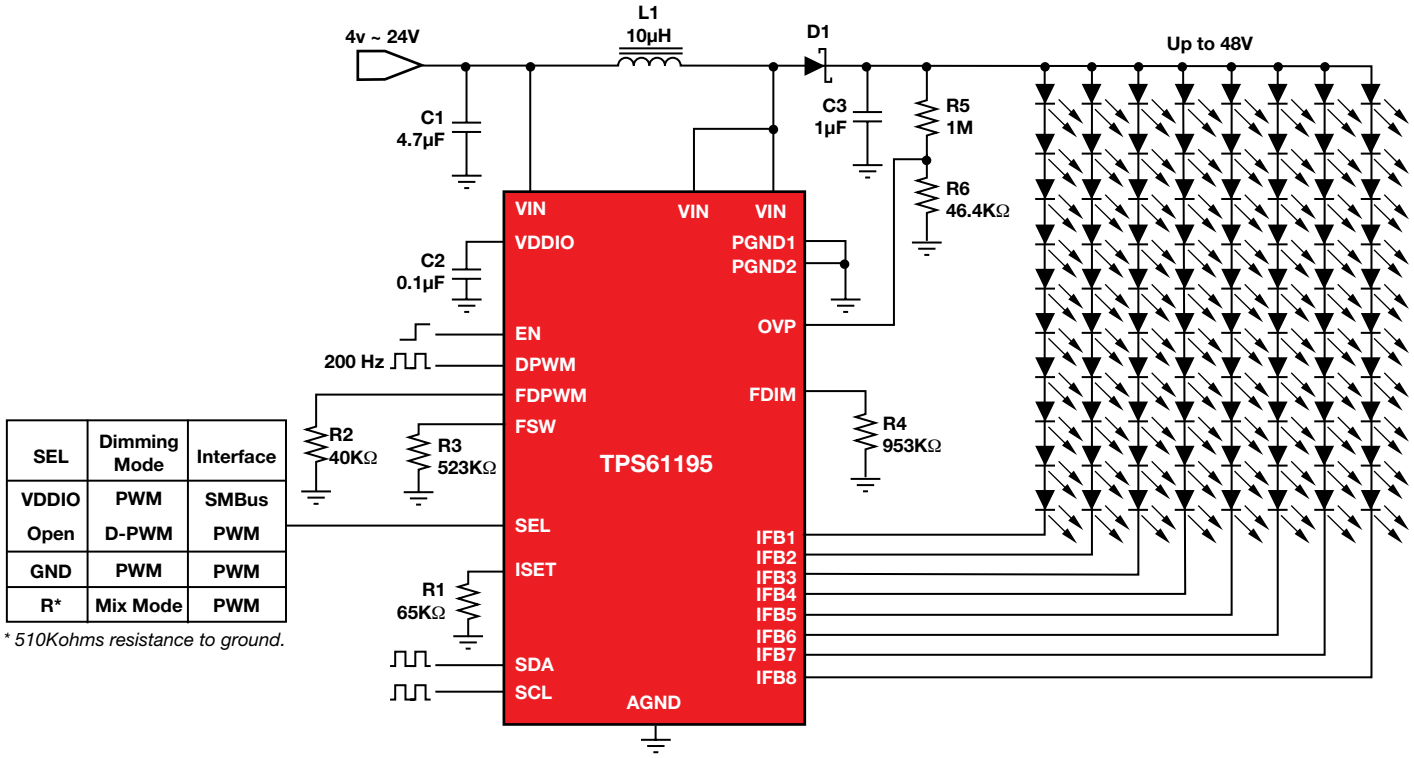
Reference designs:
www.ti.com/**powerreferencedesigns**

Datasheets, user's guides, samples:
www.ti.com/sc/device/**TPS61195**

LED Current vs. Input Supply and LED Number

Parameter	Minimum	Maximum	Unit
Input voltage	4.0	24	Volts
Output voltage	16	48	Volts
Number of channel	—	8	—
Output current	0	0.32	Amp
Switching frequency	600 KHz	1 MHz	—

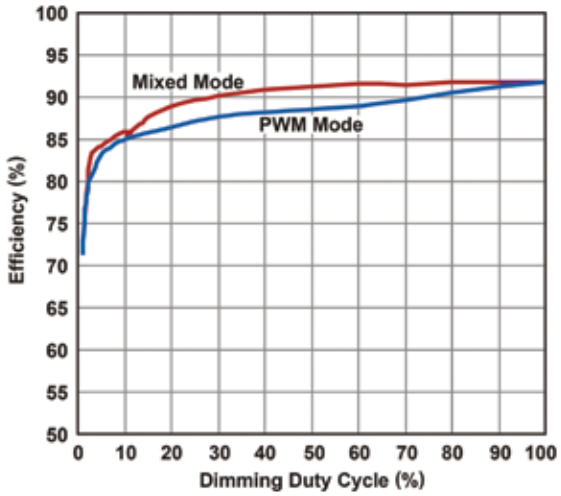
TPS61195 Schematic



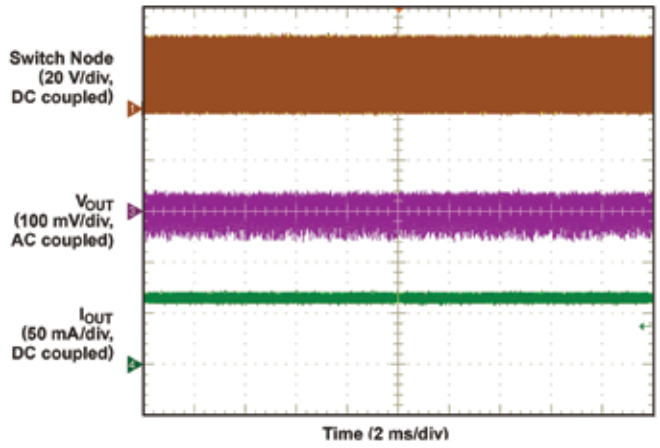
SEL	Dimming Mode	Interface
VDDIO	PWM	SMBus
Open	D-PWM	PWM
GND	PWM	PWM
R*	Mix Mode	PWM

** 510Kohms resistance to ground.*

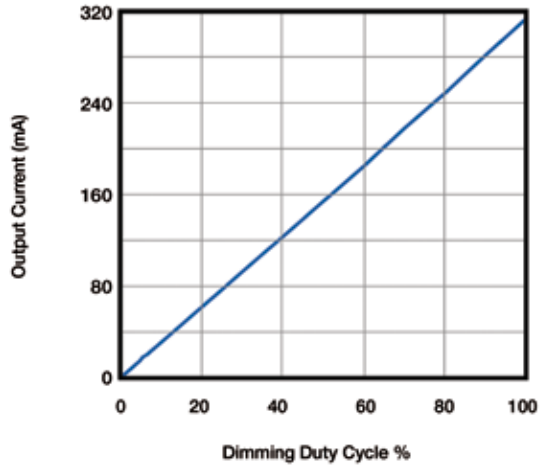
Dimming Efficiency V_{IN} = 10.8 V; 9s8p



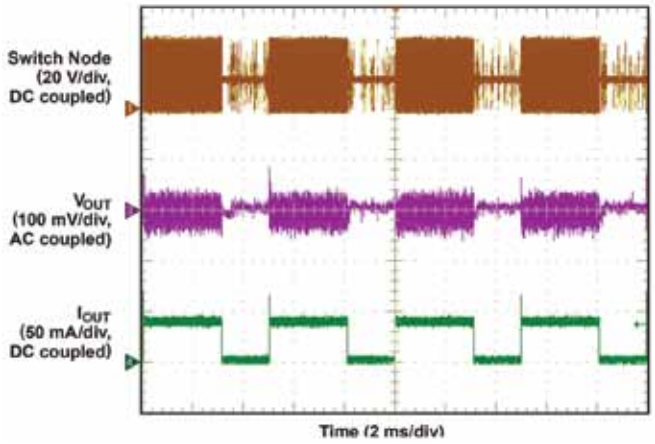
Mixed Mode Dimming Waveform: 20% Brightness—Pure Analog



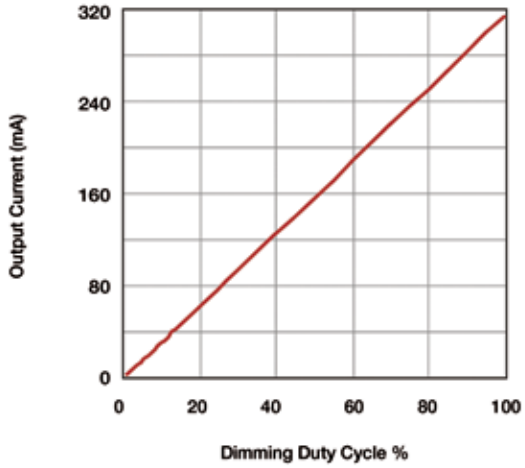
PWM Dimming Current Linearity V_{IN} = 10.8 V



Mixed Mode Dimming Waveform: 8% Brightness Mode



Mix Mode Dimming Current Linearity V_{IN} = 10.8 V



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-V_{AC} 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.

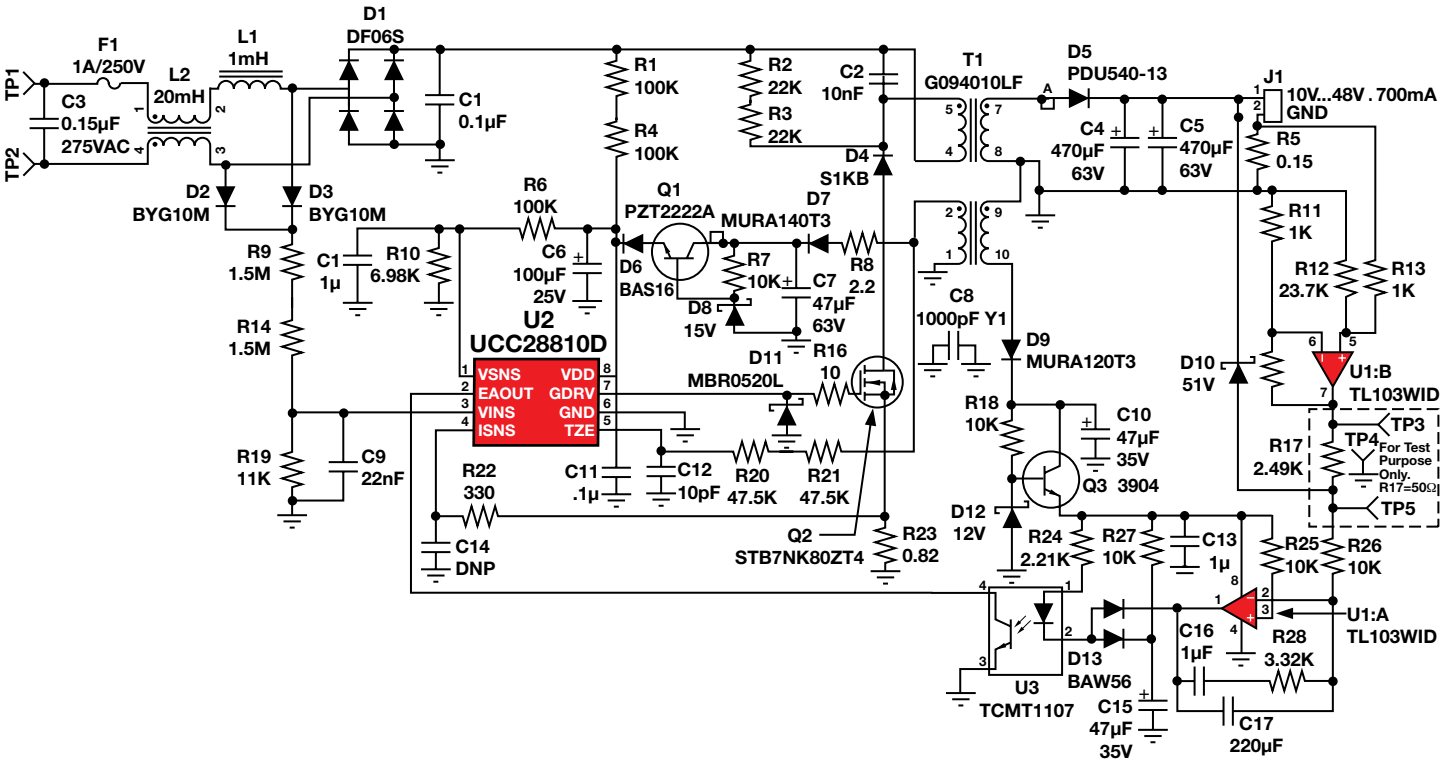
Web Links

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

Design Specifications

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

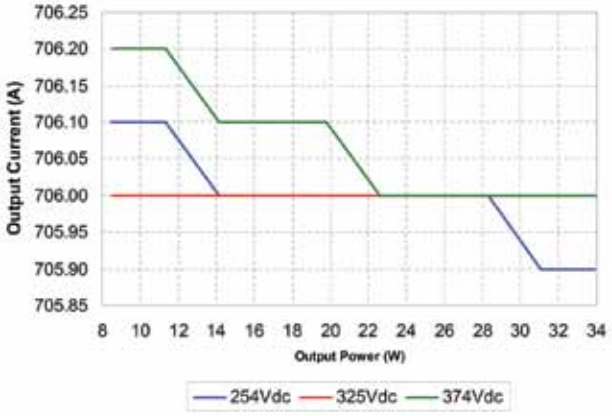
PMP4501 Reference Design Schematic



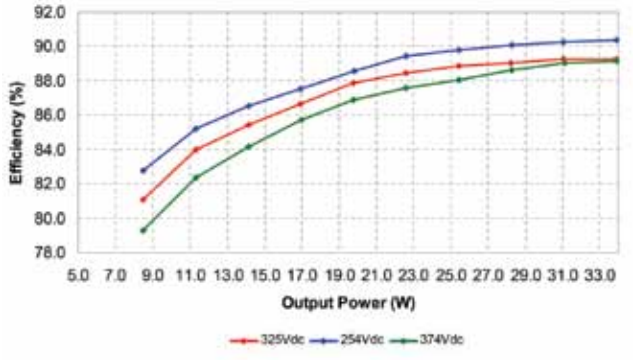
For more reference designs, see: www.ti.com/powerreferencedesigns

PMP4501 Board

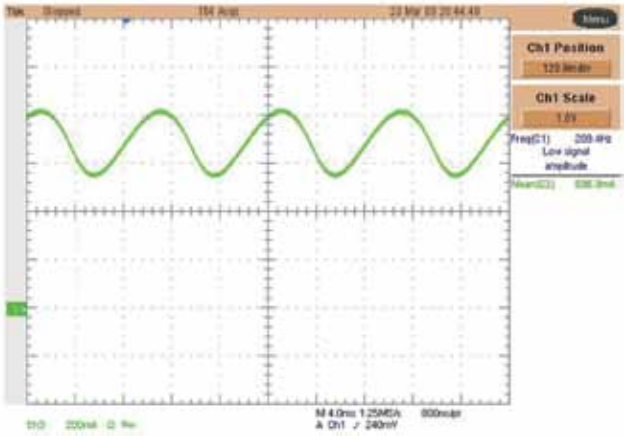
I_{OUT} Regulation vs. Rectified-Equivalent Line Voltage and Output Power



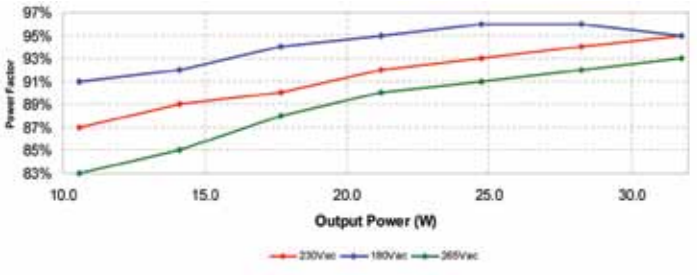
Efficiency vs. Rectified-Equivalent Line Voltage and Output Power



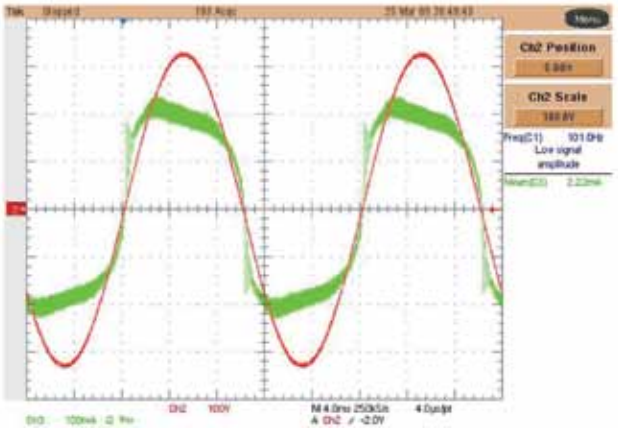
Output Current Ripple. Input Voltage = 230 V_{AC}, Output Voltage = 48 V @ 700 mA



Power Factor vs. Line Voltage and Output Power



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



UCC28810 PMP3976

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

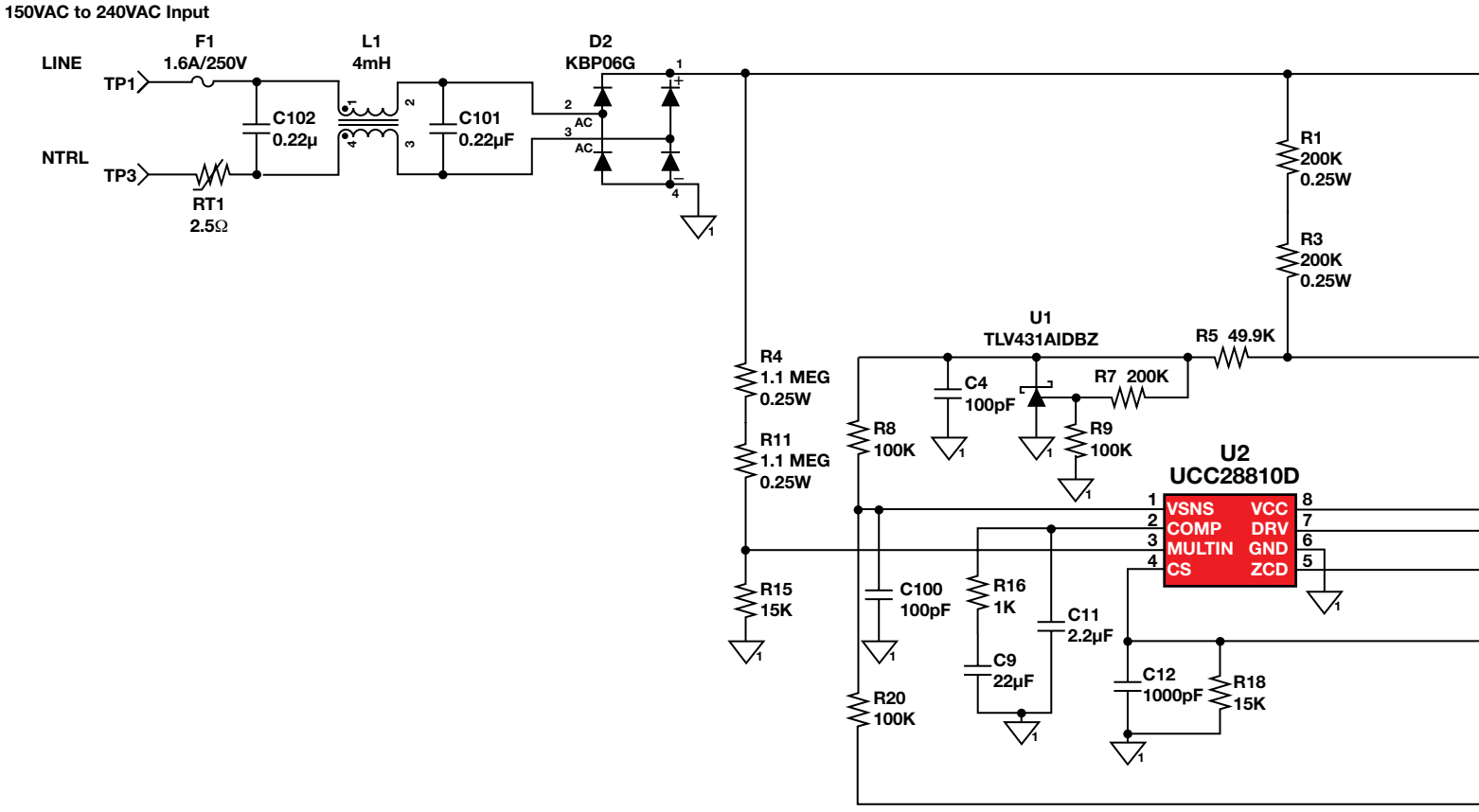
Datasheets, user's guides, samples:
www.ti.com/sc/device/UCC28810

Reference designs:
www.ti.com/powerreferencedesigns

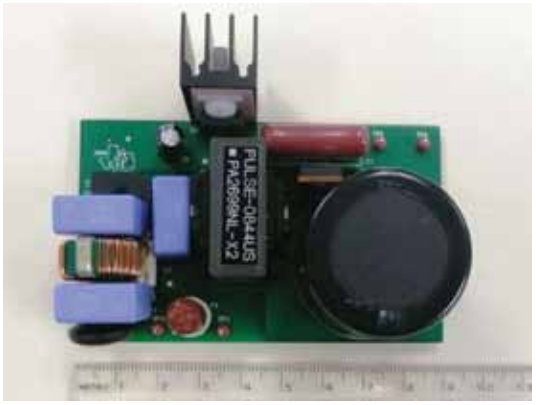
Design Specifications

Parameter	Minimum	Typical	Maximum	Unit
Input voltage	150	—	264	V_{AC}
Output voltage	—	—	300	Volts
Output current	—	0.350	—	Amp

PMP3976 Schematic

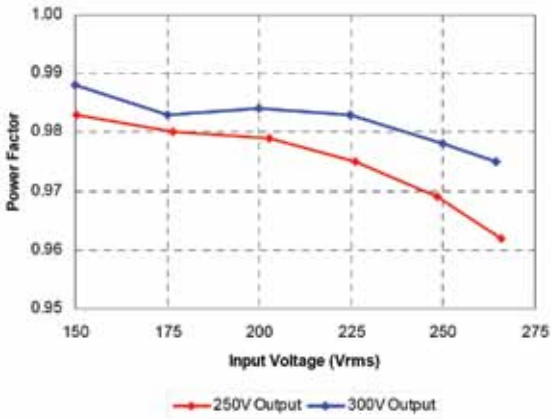


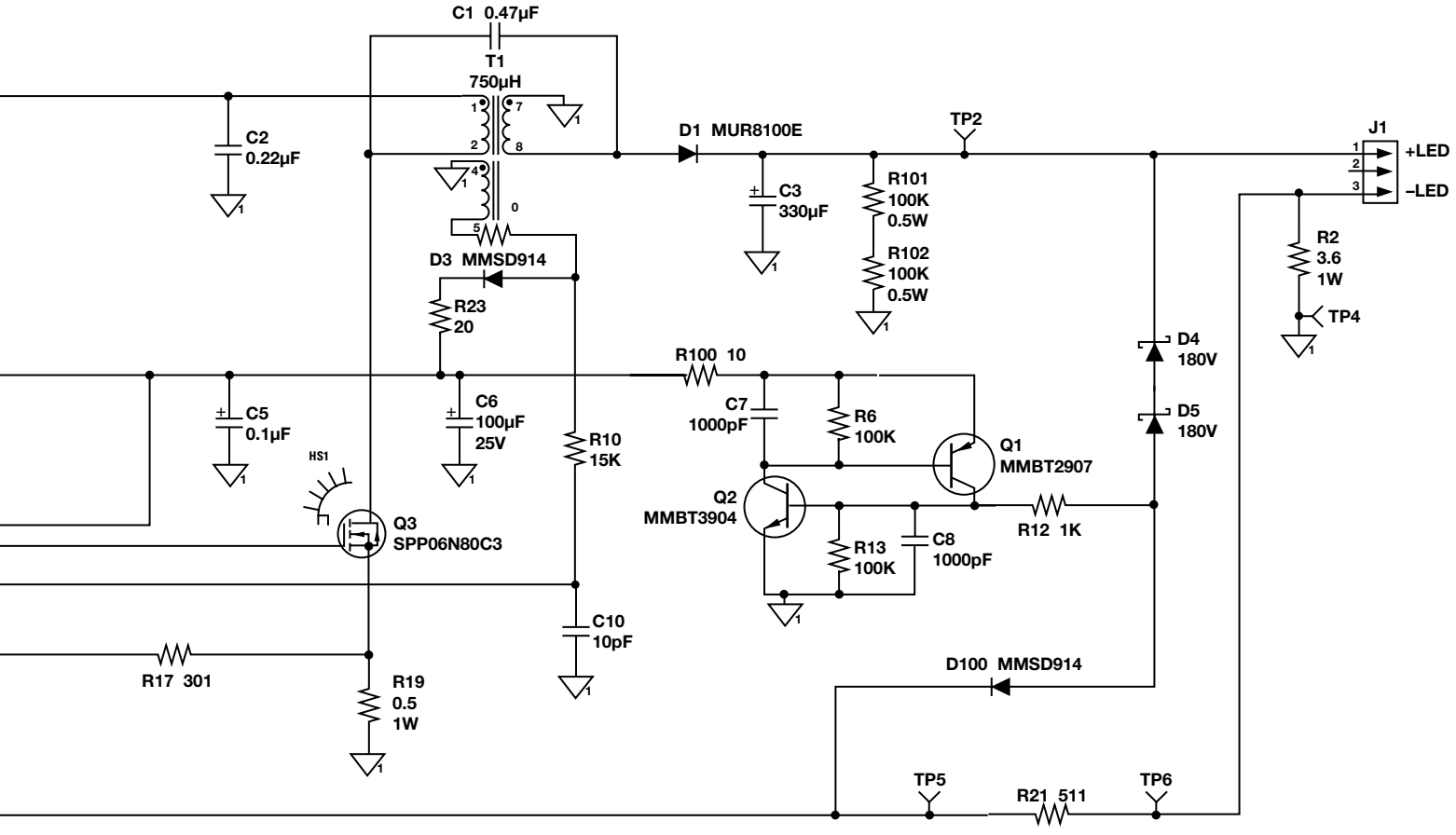
PMP3976 Rev B Demo Board



The circuit is built on a PMP3976 Rev A PWB.

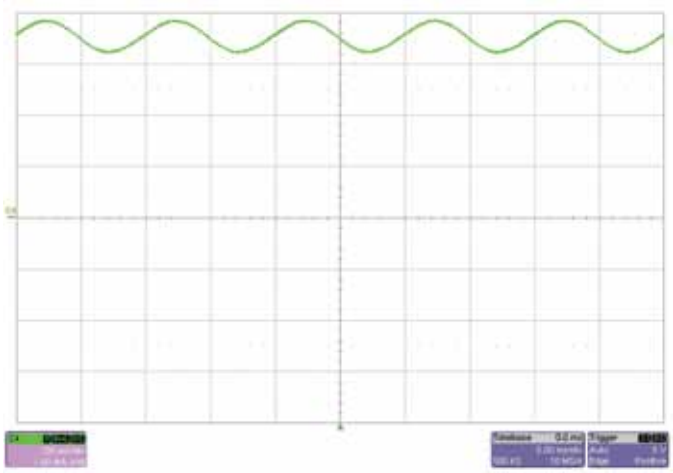
Power Factor



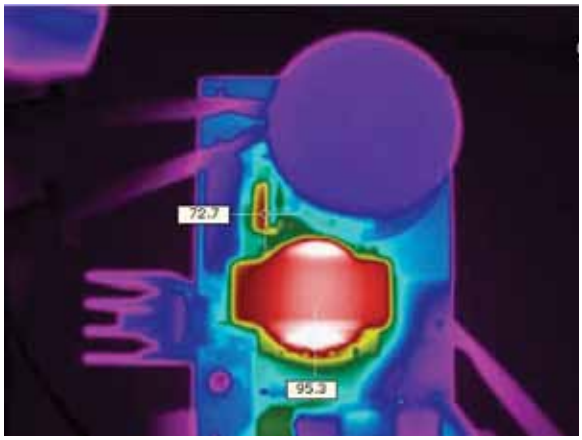


UCC28810 PMP3976

Load Current: Current in the LED String with a 230 V_{AC} input

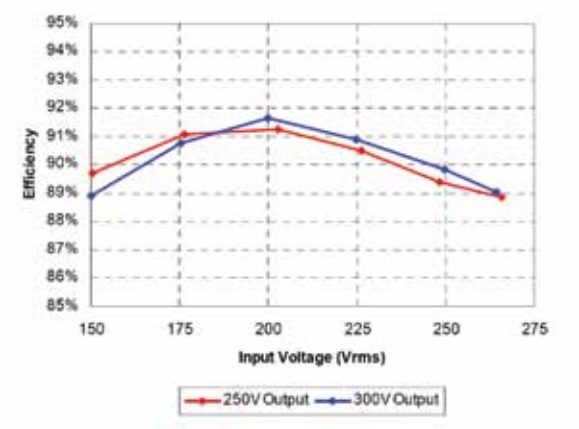


Harmonic Content

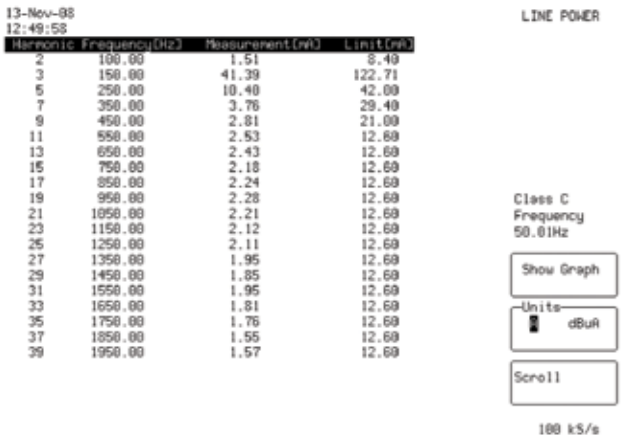


The image above shows a thermal image of the board. The ambient temperature was 26ºC with no forced air flow. The input was 230 V_{AC}.

Efficiency



Harmonic Content



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

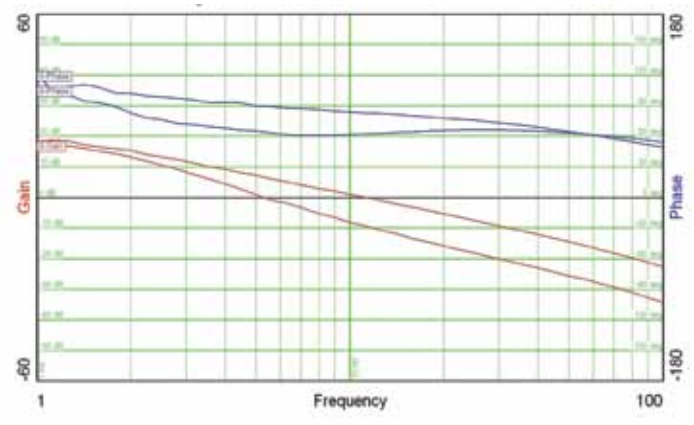
Efficiency and Power Factor

I_{OUT}	V_{OUT}	V_{IN}	L_{IN}	PF	P_{OUT}	Losses	Efficiency %
0.349	245.5	150.4	0.646	0.983	85.65	9.827	89.7
0.349	245.4	176.4	0.544	0.980	85.64	8.398	91.1
0.349	245.3	202.6	0.473	0.979	85.61	8.208	91.3
0.350	245.3	226.3	0.430	0.975	85.86	9.201	90.5
0.350	245.3	248.4	0.399	0.969	85.86	10.184	89.4
0.350	245.3	265.7	0.378	0.962	85.86	10.763	88.9

I_{OUT}	V_{OUT}	V_{IN}	L_{IN}	PF	P_{OUT}	Losses	Efficiency %
0.348	303.9	149.9	0.803	0.988	105.75	13.168	88.9
0.349	303.3	175.2	0.677	0.983	105.85	10.742	90.8
0.349	303.8	199.9	0.588	0.984	106.03	9.634	91.7
0.349	303.3	224.8	0.527	0.983	105.85	10.604	90.9
0.349	303.2	249.8	0.482	0.978	105.82	11.938	89.9
0.349	303.0	264.2	0.461	0.975	105.75	13.004	89.0

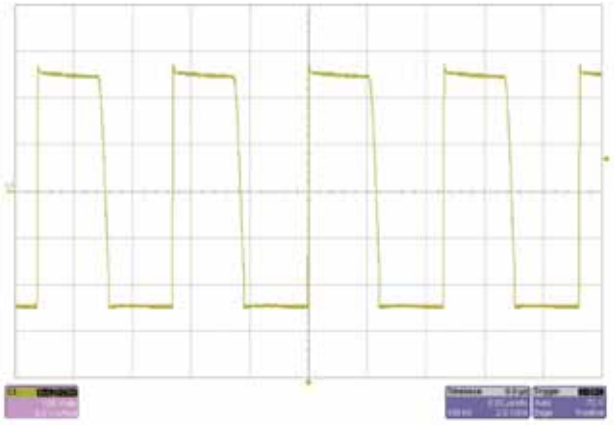
For more reference designs, see: www.ti.com/powerreferencedesigns

Frequency Response



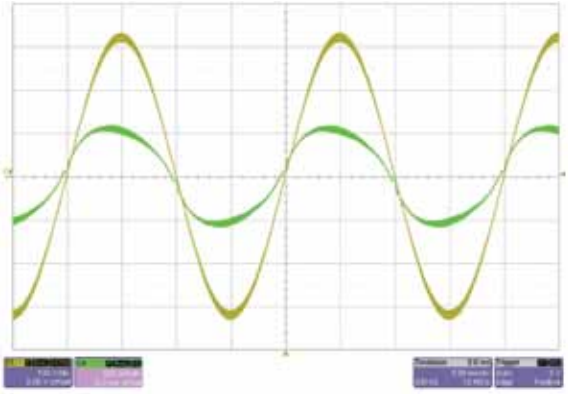
The frequency response of the feedback loop is shown in the plot above. The input was set to 220 V_{AC}. The lower gain plot was taken with a 300 V output. The upper gain plot was taken with a 250 V output.

Diode Voltage Waveform



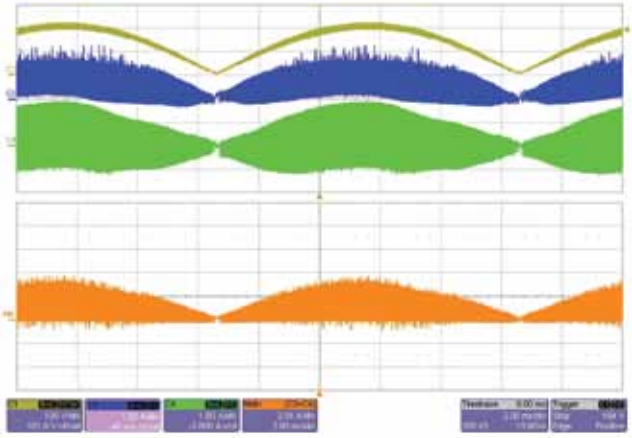
The image above shows the voltage on the anode of D1. The input was set to 250 V_{DC}.

Line Voltage and Current Waveform

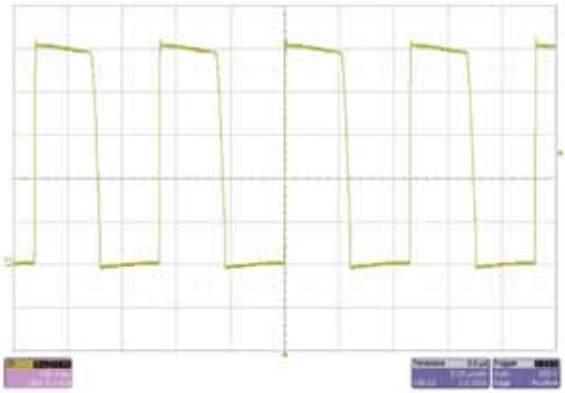


The image above shows the input voltage and current. The input voltage was 230 V_{AC}.

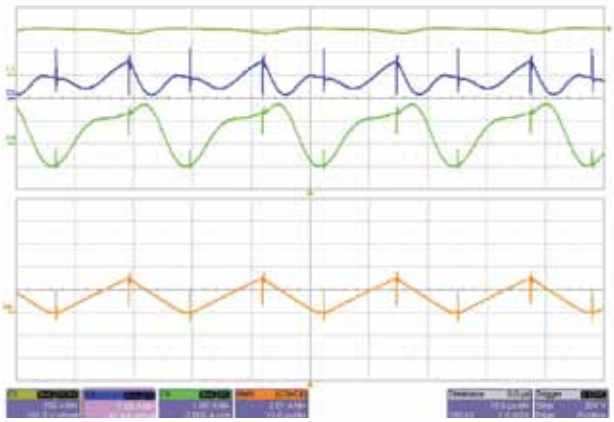
Inductor Winding Currents



MOSFET Voltage Waveform



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



The two images above show the currents in the individual windings of the inductor.

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.

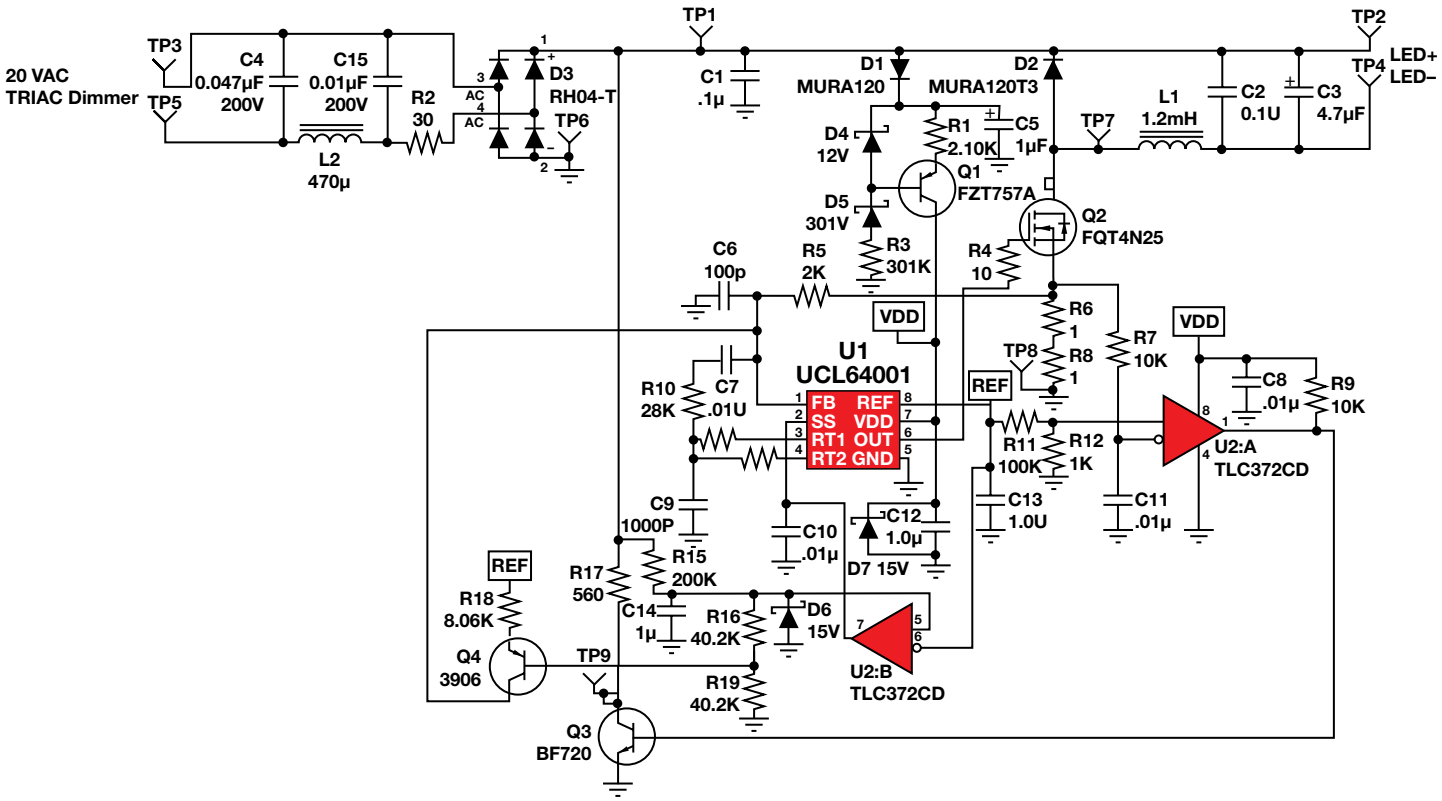
Web Links

Datasheets, user's guides, samples:
www.ti.com/sc/device/UCL64001

Design Specifications

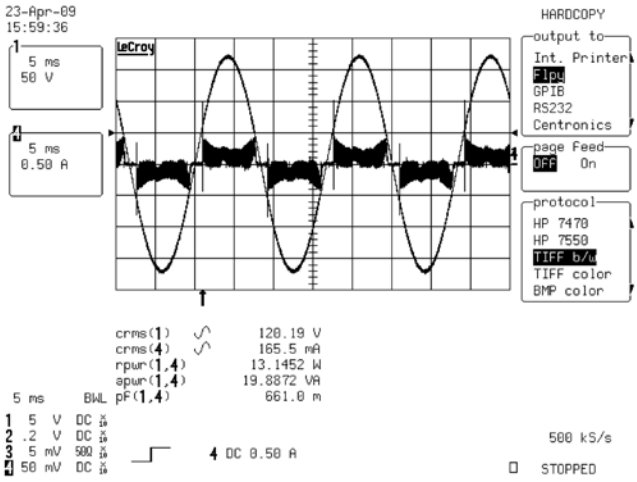
Description	Parts	V_{IN} (AC) Range	V_{OUT} (DC) Range	Number of LEDs	I_{OUT} (max)	P_{OUT} (max)	Eff.	PFC	ISO	Dimming In	Dimming Out	EVM
PMP4885 low-cost offline	UCL64001	90	24	7 to 9	450 mA	12 W	79%	No	No	TRIAC	PWM	Paper
LED lighting driver	TLC372	130	32									

PMP4981 Schematic

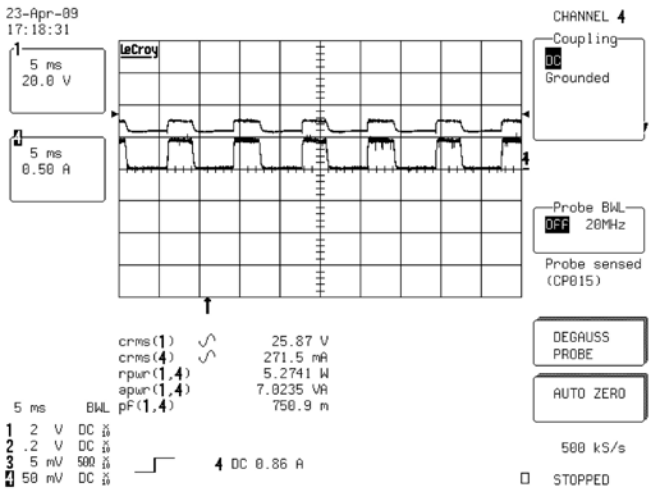


For more reference designs, see: www.ti.com/powerreferencedesigns

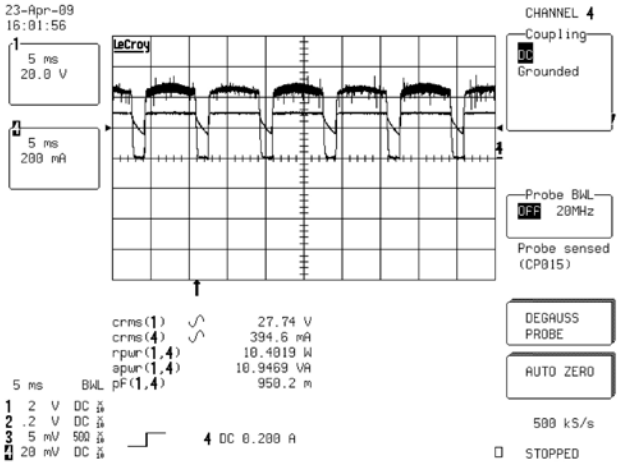
Line Current and Voltage – Dimmer at Full Power Position



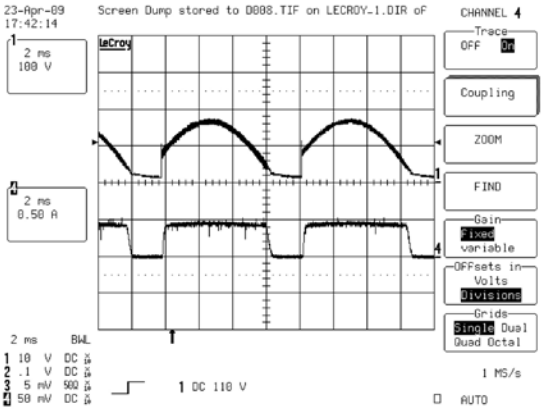
LED Current and Voltage – Dimmer at Half Power Position



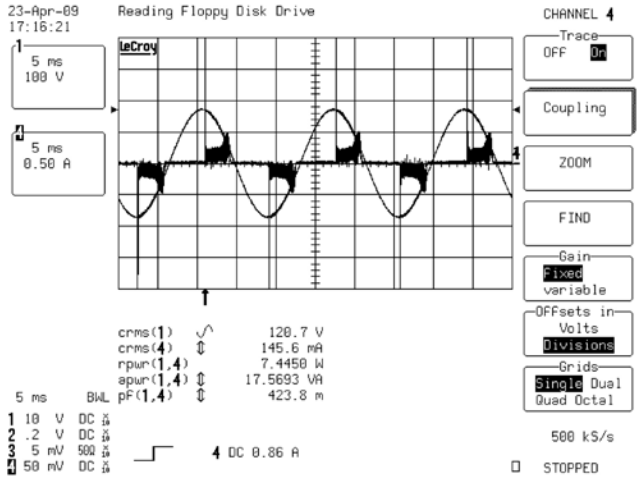
LED Current and Voltage – Dimmer at Full Power Position



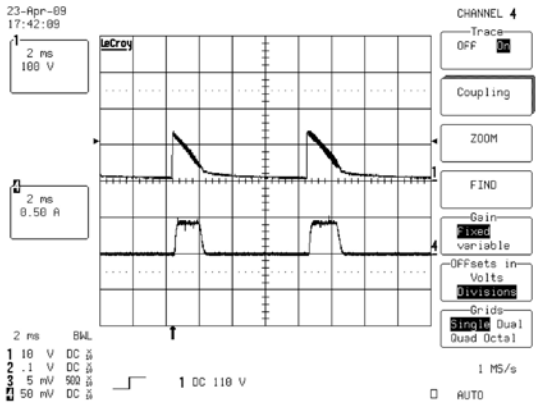
Rectified AC (Top) and LED Current (Bottom) — High Conduction Angle



Line Current and Voltage – Dimmer at ~ Half Power Position



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



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**

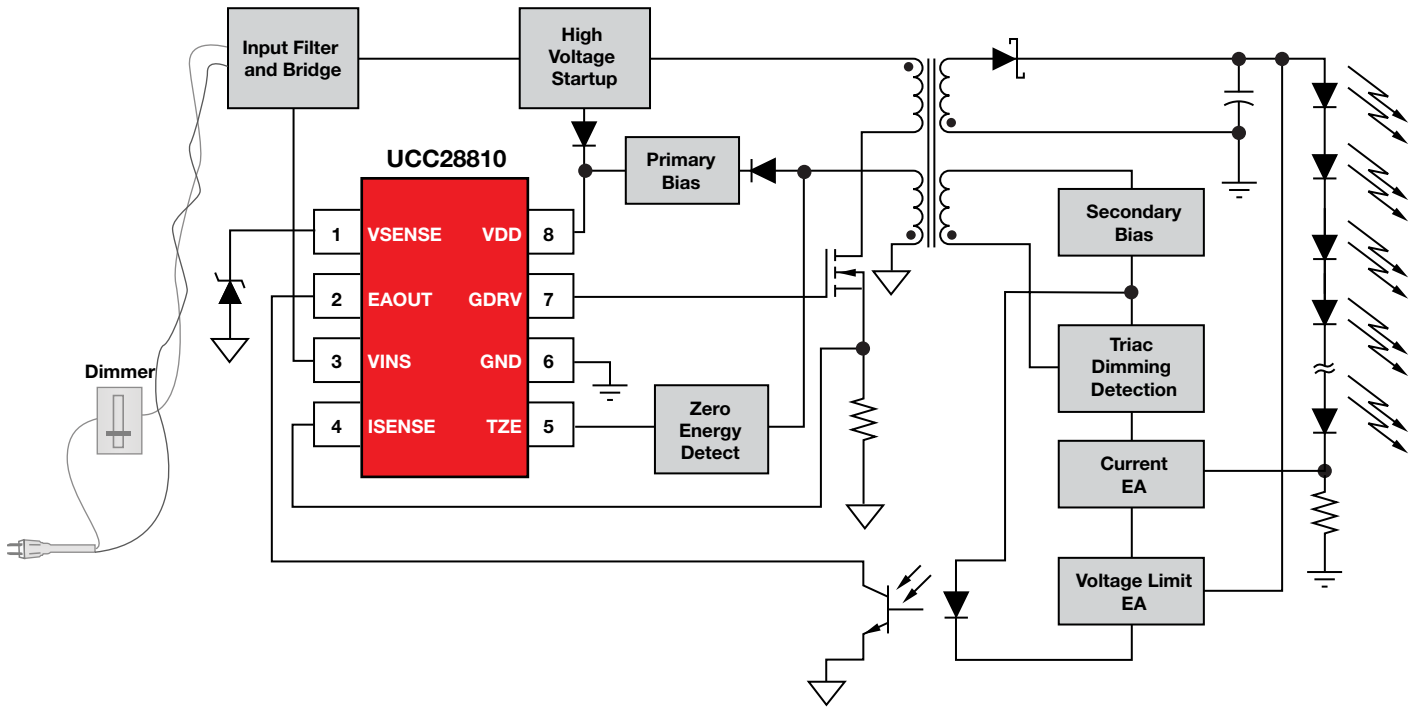
Datasheets, user's guides, samples:
www.ti.com/sc/device/**UCC28810**

EVM:
www.ti.com/**ucc28810evm-001**

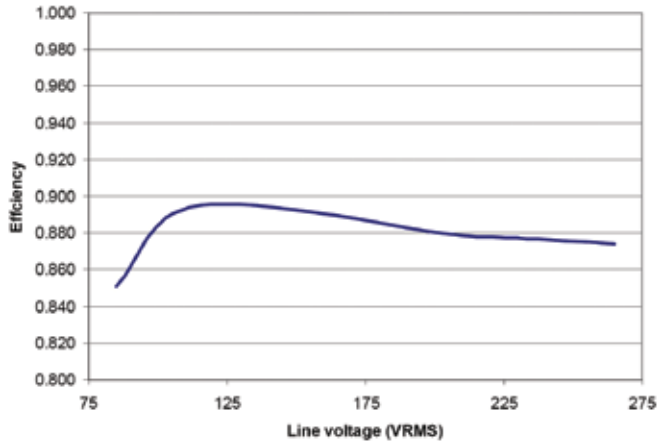
Design Specifications

Description	Parts	V_{IN} (AC) Range	V_{OUT} (DC) Range	Number of LEDs	I_{OUT} (max)	P_{OUT} (max)	Eff.	PFC	ISO	Dimming In	Dimming Out	EVM
UCC28810 EVM001 25-W PFC dimmable LED driver	UCC28810 TPS3808	85 305	33	10	700 mA	25 W	89%	Yes	Yes	TRIAC	Linear	Yes

UCC28810EVM-001 Block Diagram

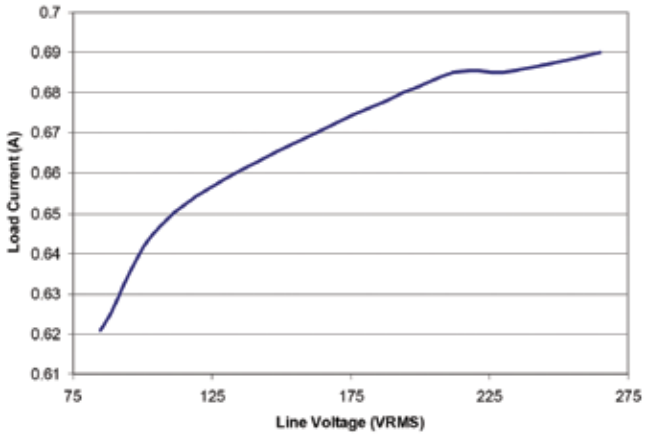


Efficiency vs. Line Voltage



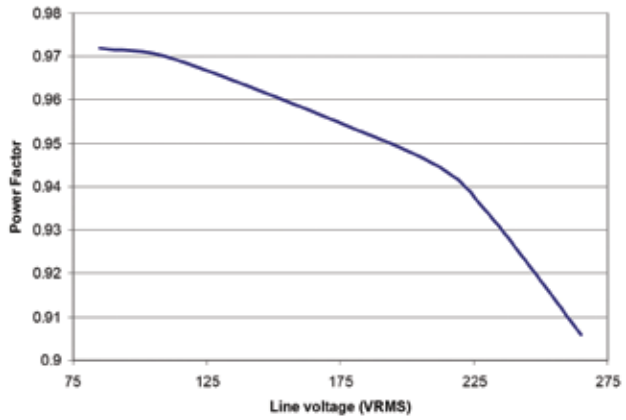
Efficiency as a function of line voltage. 10 Cree XLamp® 7090 XR-E, white, 700 mA LEDs connected in series was used for the load.

Output Current vs. Line Voltage



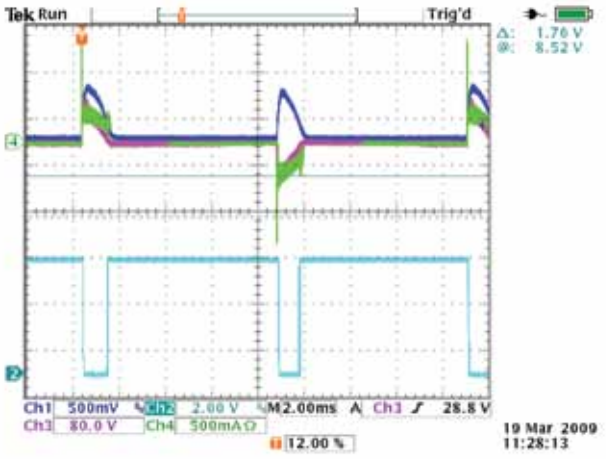
Load current as a function of line voltage. 10 Cree XLamp® 7090 XR-E, white, 700 mA LEDs connected in series was used for the load.

Power Factor vs. Line Voltage

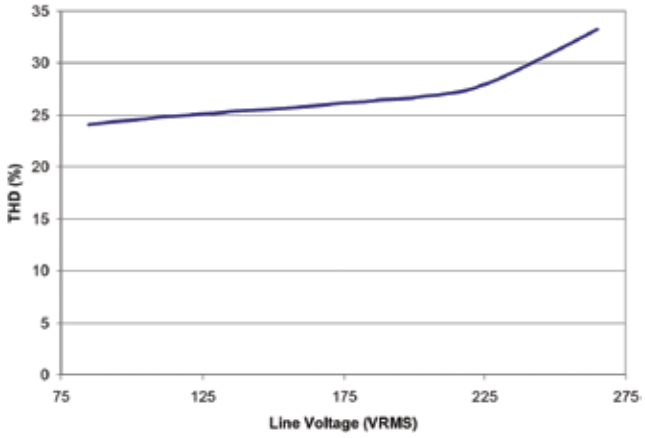


Power factor as a function of line voltage.10 Cree XLamp® 7090 XR-E, white, 700 mA LEDs connected in series was used for the load.

Triac Dimming Detection Circuit Waveforms – Deep Dimming

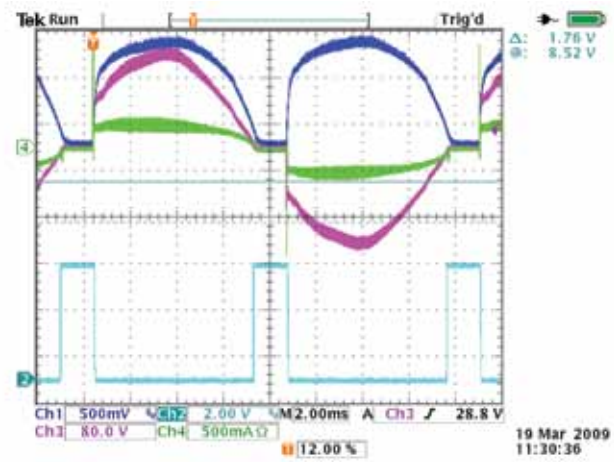


Total Harmonic Distortion vs. Line Voltage



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.

Triac Dimming Detection Circuit Waveforms – Light Dimming



UCC28810/UCC28810EVM-002

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_{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_{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

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

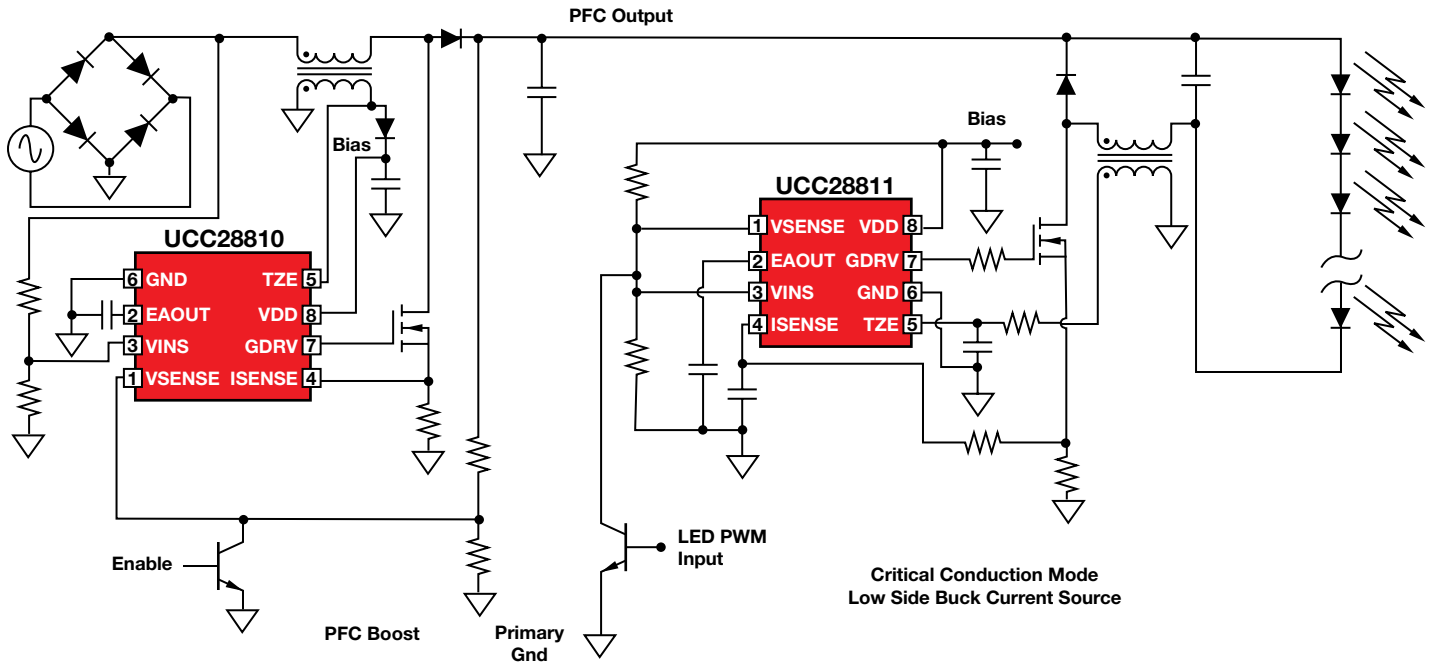
Reference designs:
www.ti.com/**powerreferencedesigns**

EVM:
www.ti.com/**ucc28810evm-002**

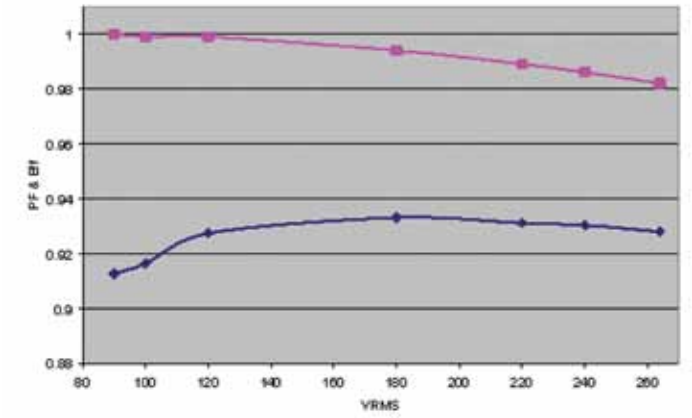
Design Specifications

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

UCC28810EVM-002 Block Diagram

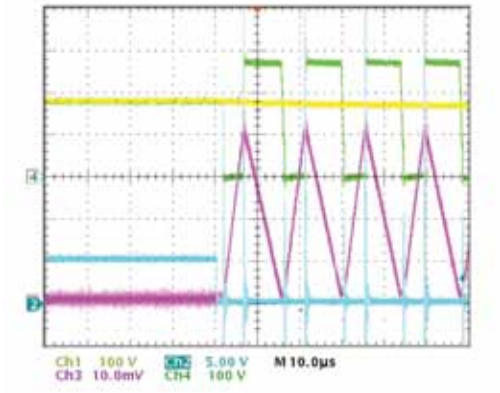


Efficiency vs. Line Voltage



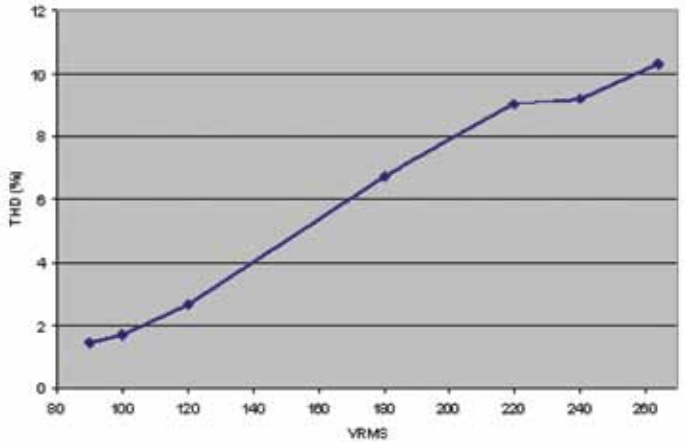
UCC28810EVM-002 efficiency and power factor vs. line voltage 30 Cree XRE LED's at 900 mA.

Output Current vs. Line Voltage



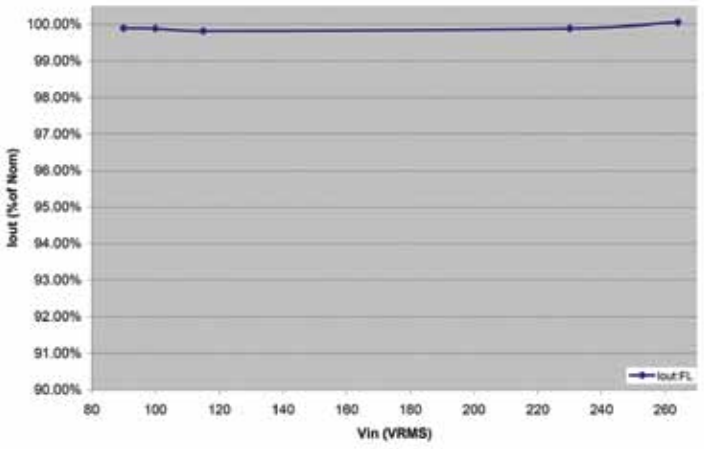
UCC28810EVM-002 transition mode buck PWM response (expanded). Ch1: LED V_{OUT}, Ch2 PWM, Ch3 buck inductor current 500 mA/Div, Ch4 V_{DS} Ch1 and Ch4 Share GND reference.

Power Factor vs. Line Voltage



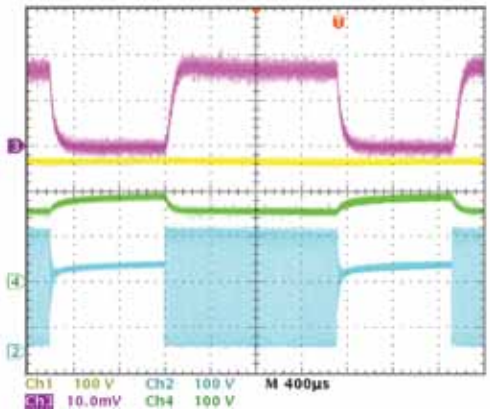
UCC28810EVM-002 THD vs. line voltage 30 Cree XRE LED's at 900 mA.

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 transition mode buck PWM response. Ch1: Buck V_{IN}, Ch2: Buck V_{DS}, Ch3: LED current (0.5 A/Div), Ch4: LED voltage. Ch1 and Ch4 share GND reference.

UCC28810/UCC28810EVM-003

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**

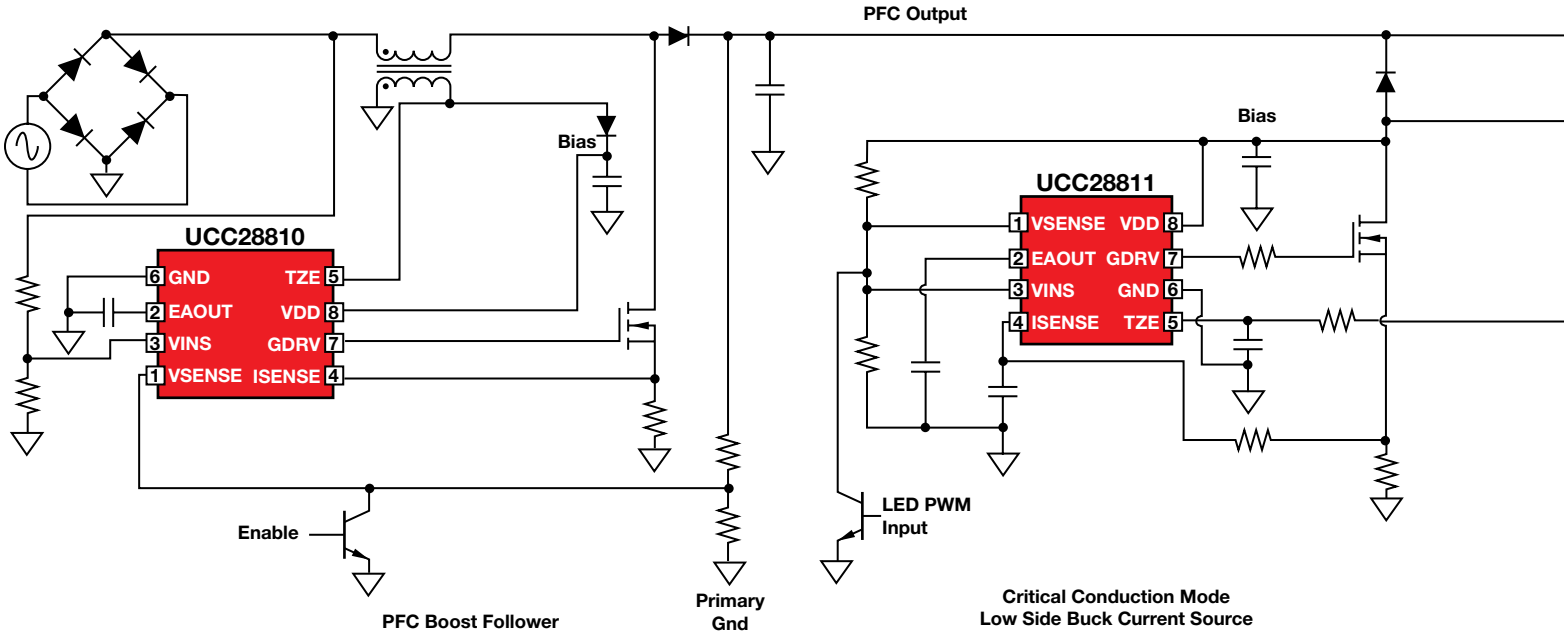
Datasheets, user's guides, samples:
www.ti.com/sc/device/**UCC28810**

EVM:
www.ti.com/**ucc28810evm-003**

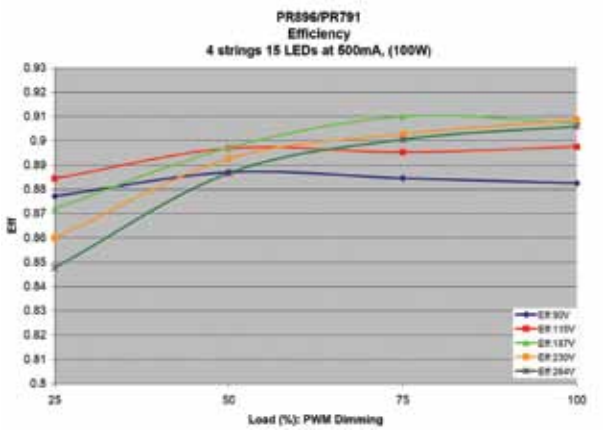
Design Specifications

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

UCC28810EVM-003 Block Diagram

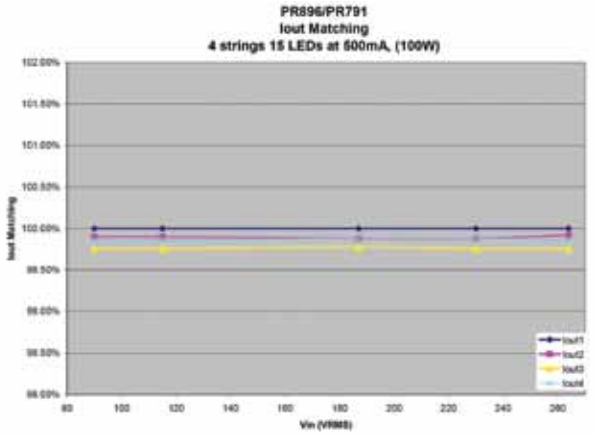


Efficiency vs. Line Voltage



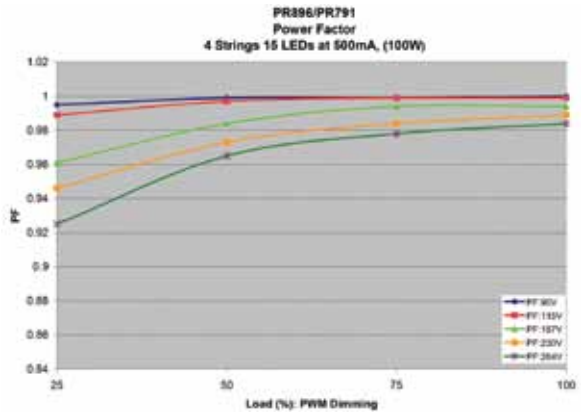
UCC28810EVM-003 efficiency vs. line voltage and load 4 x 15 Cree XRE LED's at 500 mA.

I_{OUT} Matching vs. Line Voltage



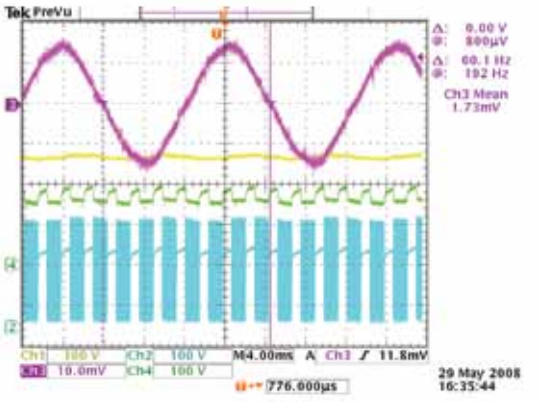
UCC28810EVM-003 I_{OUT} matching vs. line voltage 4 x 15 Cree XRE LED's at 500 mA.

Power Factor vs. Line Voltage

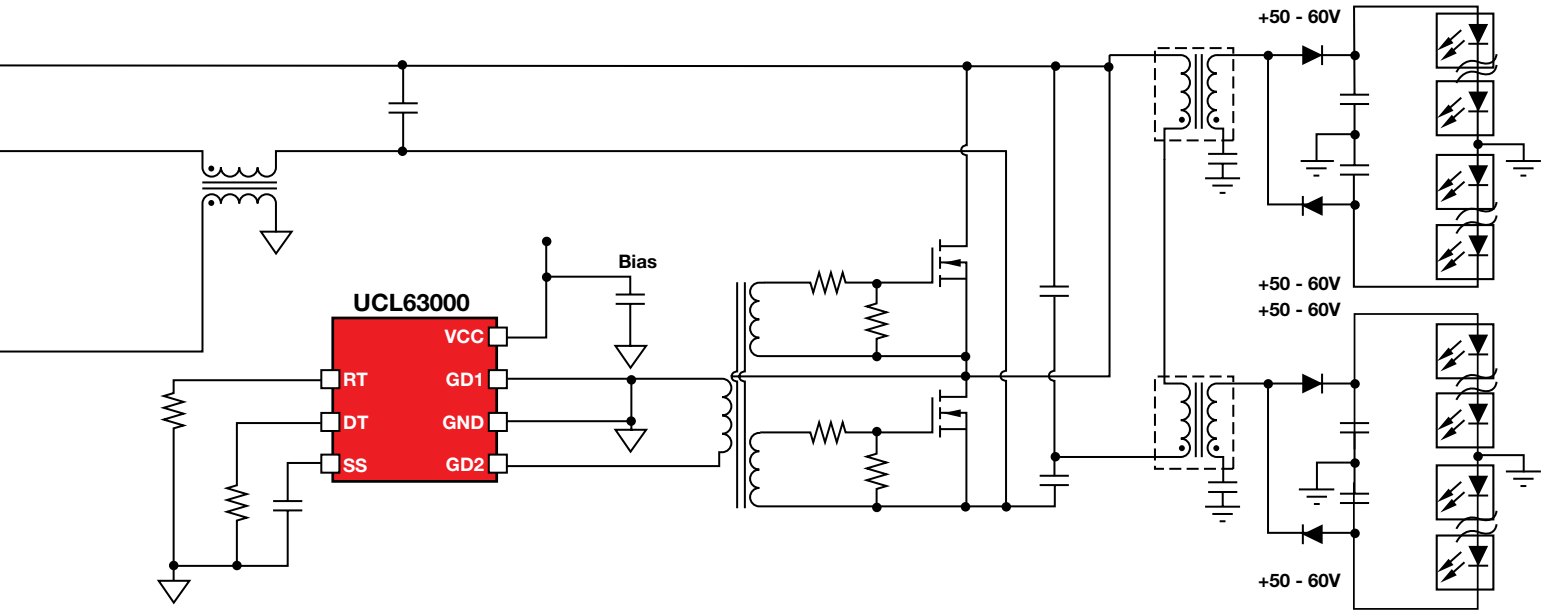


UCC28810EVM-003 power factor vs. line voltage 4 x 15 Cree XRE LED's at 500 mA.

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.



UCL64010 PMP3522

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.

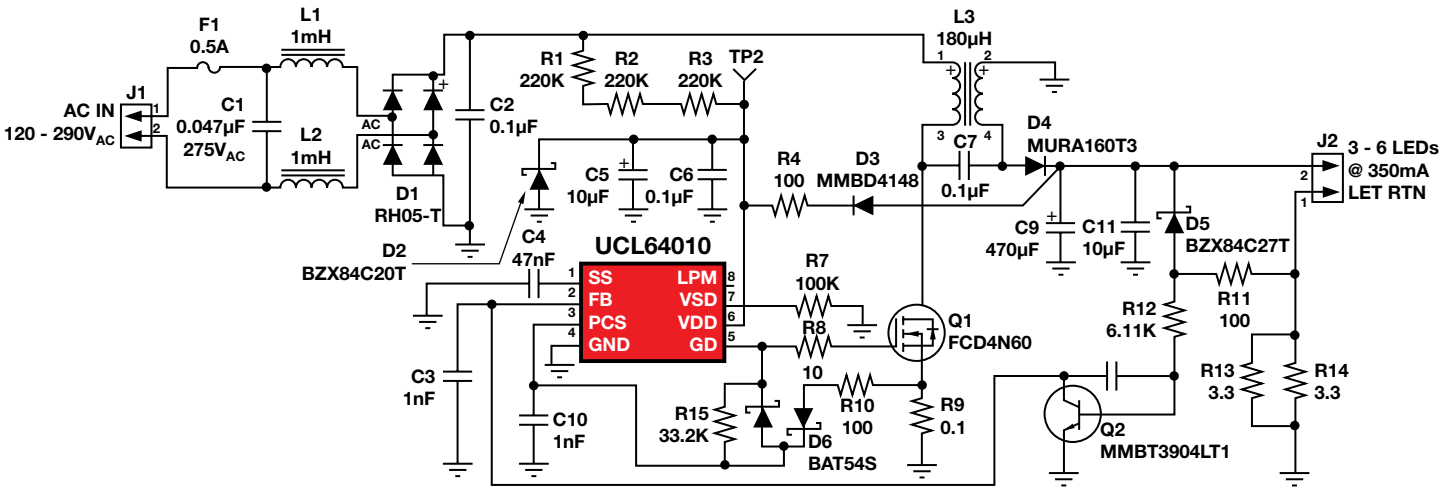
Web Links

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

Design Specifications

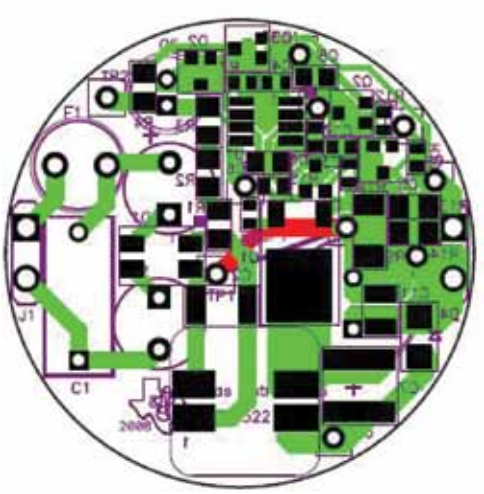
Parameter	Minimum	Typical	Maximum	Unit
Input voltage	120	—	290	V_{AC}
Output voltage	—	—	24	Volts
Output current	—	0.350	—	Amp

PMP3522 Schematic

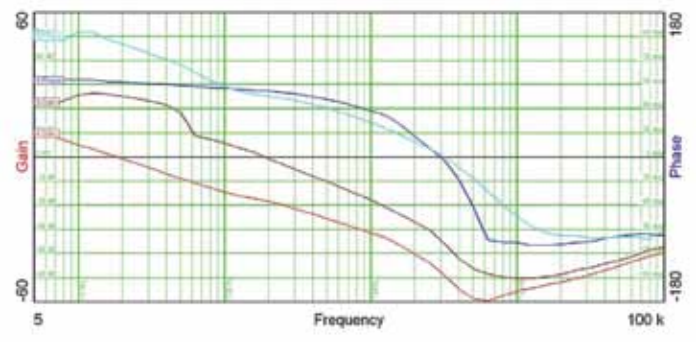


For more reference designs, see: www.ti.com/powerreferencedesigns

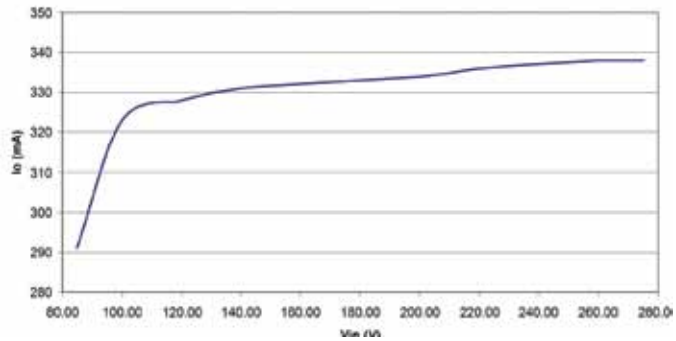
Laid Out for Bulb Replacement



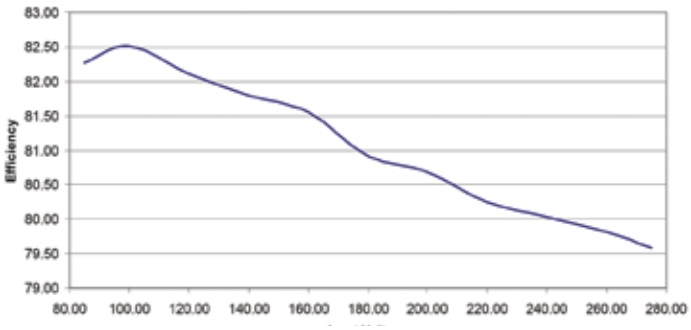
Control Loop Frequency



Regulation



Efficiency



TPS62260 TPS62260LED

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.

If a designer prefers to reprogram the MSP430, a separate MSP430 flash emulation tool can be ordered, such as the MSP-FET430UIF. More information on the eZ430-RF2500 and MSP-FET430UIF tools can be found respectively at:
http://focus.ti.com/docs/toolsw/folders/print/ez430-rf2500.html
and
http://focus.ti.com/docs/toolsw/folders/print/msp-fet430uif.html

Web Links

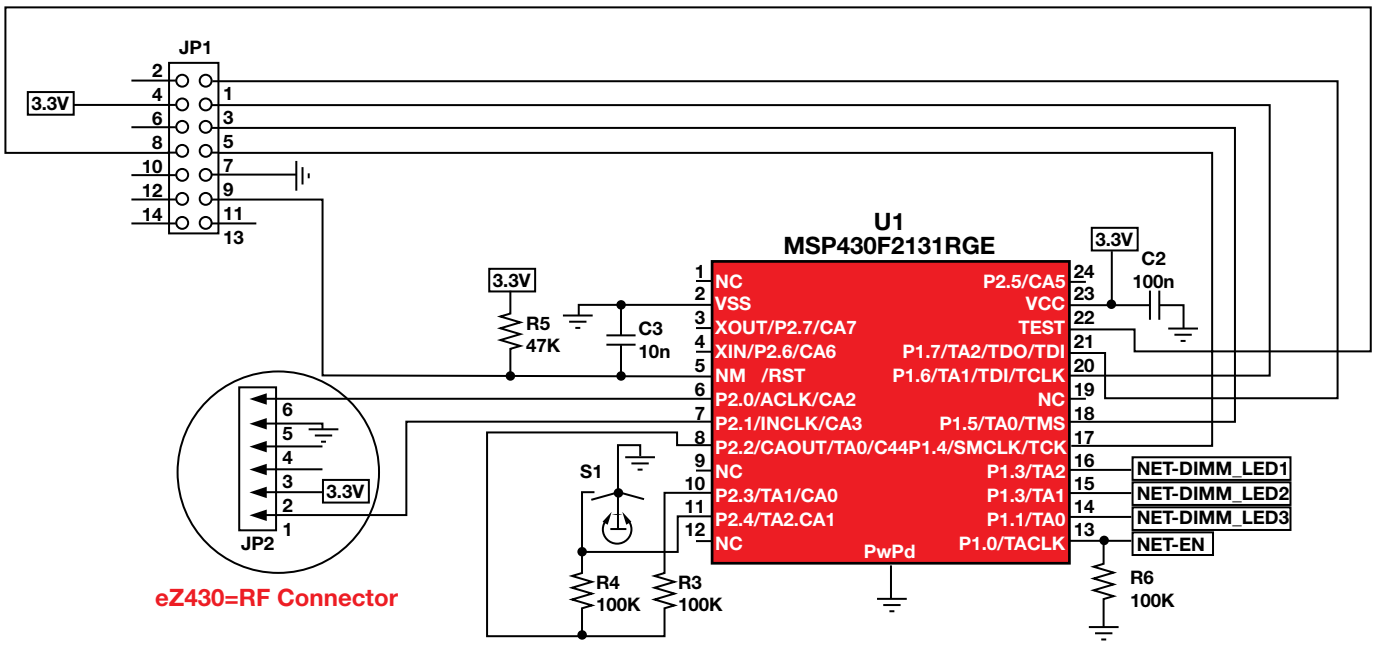
Datasheets, user's guides, samples:
www.ti.com/sc/device/TPS62260

EVM:
www.ti.com/tps62260led-338

Design Specifications

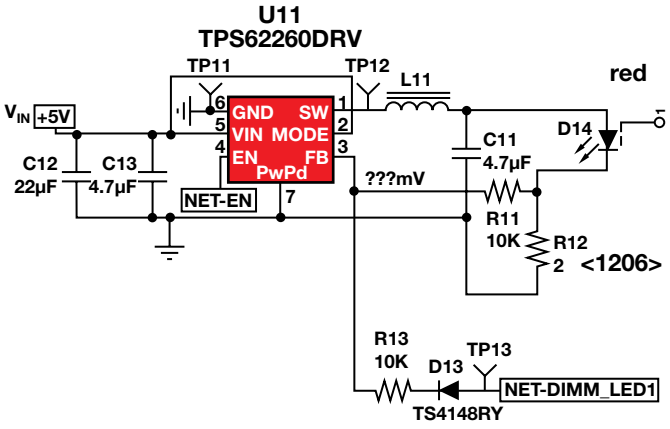
Parameter	Minimum	Typical	Maximum	Unit
Input voltage	4.5	5	5.5	V_{DC}
Output current	—	0.300	—	Amp

TPS62260LED-338 Schematic

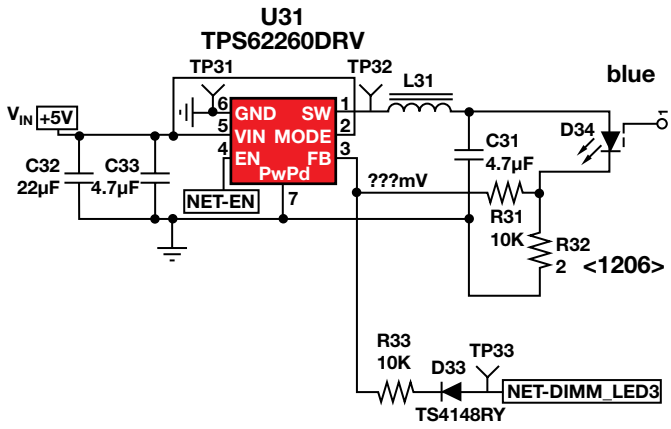


For more reference designs, see: www.ti.com/powerreferencedesigns

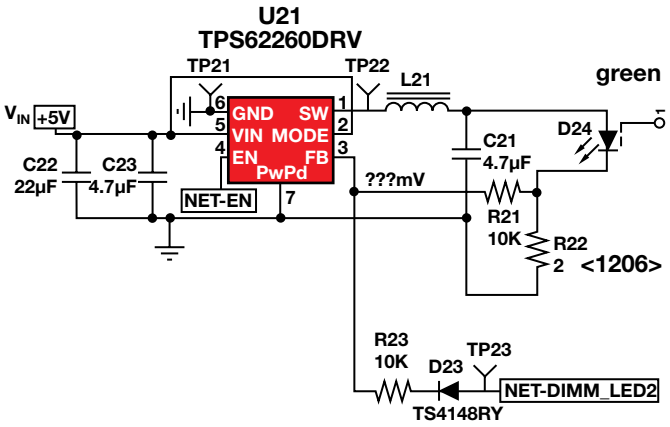
Red LED

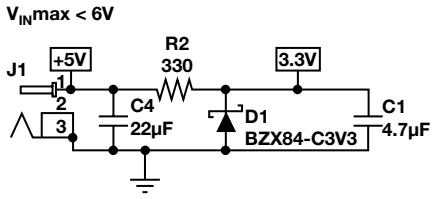


Blue LED



Green LED





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_f 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.

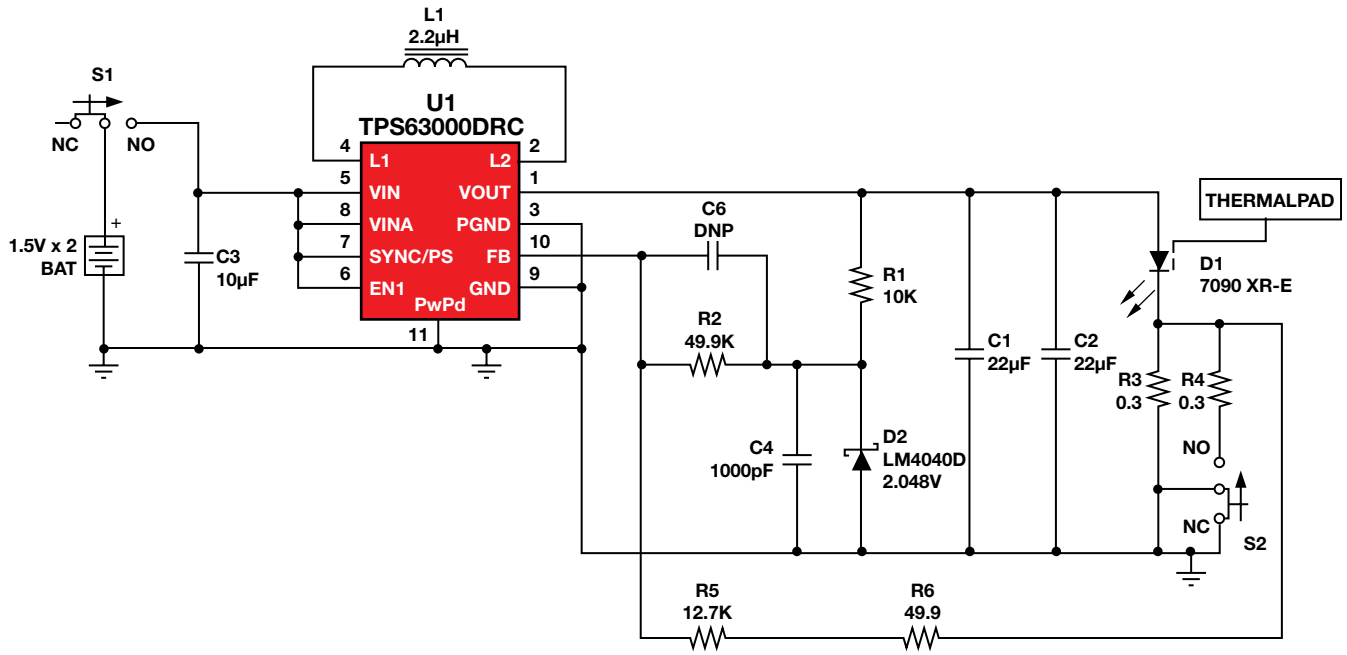
Web Links

Datasheets, user's guides, samples:
www.ti.com/sc/device/**TPS63000**

Design Specifications

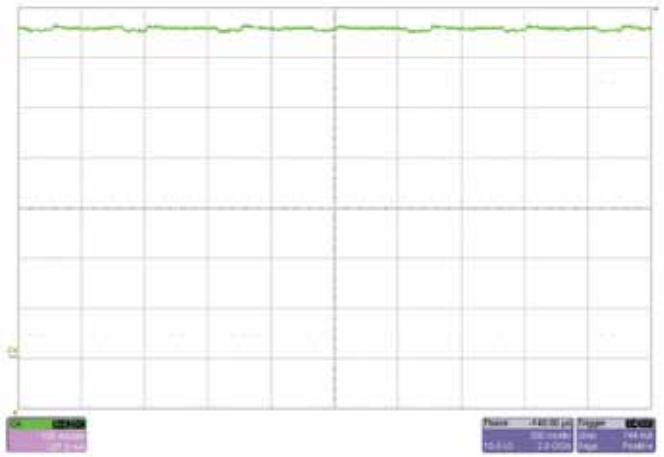
Parameter	Minimum	Maximum	Unit
Input voltage	1.2	5	V_{DC}
Output voltage	—	5	Volts
Output current	300	600	mAmp
Switch frequency	—	1.5	MHz

PMP3038 Schematic

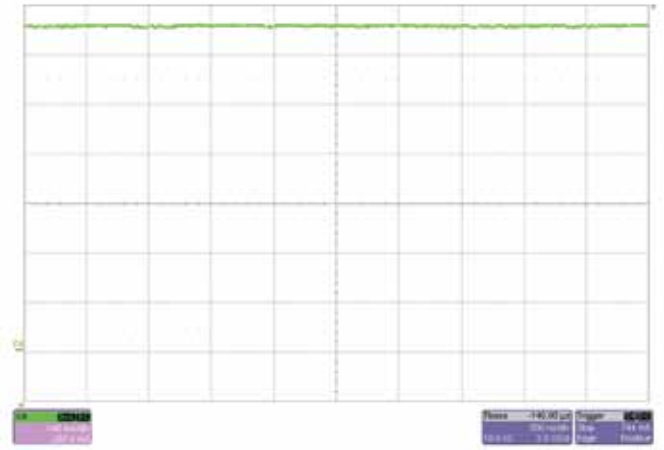


For more reference designs, see: www.ti.com/powerreferencedesigns

Output Current Graphs with DC Coupling

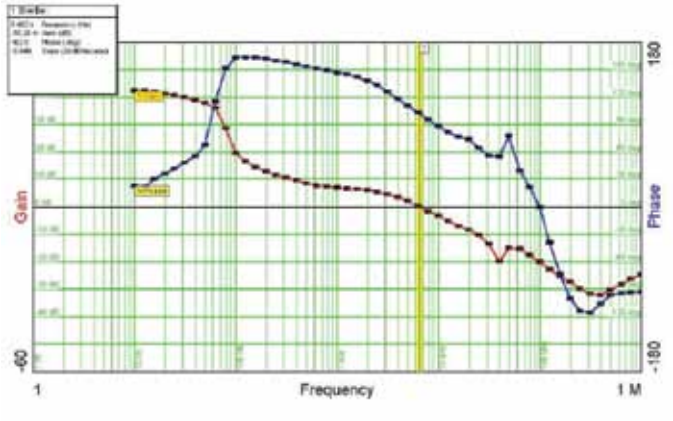


Output current with V_{IN} = 3 V.

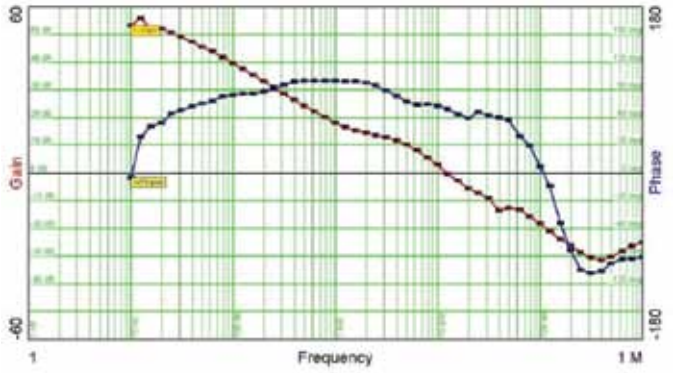


Output current with V_{IN} = 4 V.

Control Loop Response Graphs

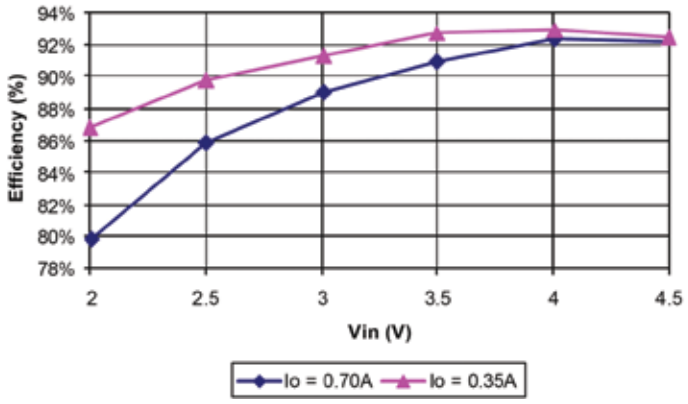


Control loop response with 0.63 A.



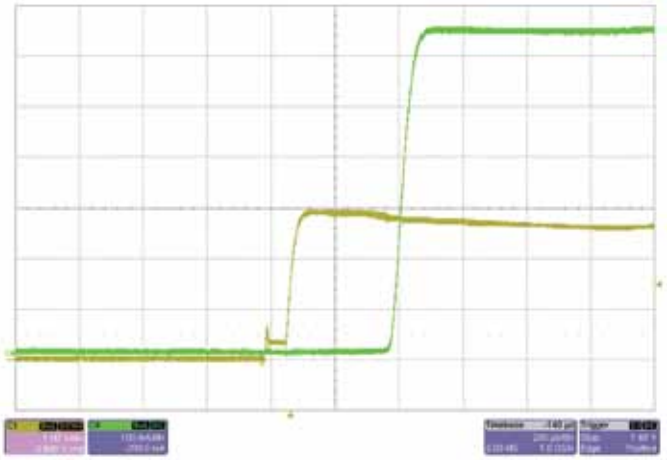
Control loop response with 0.32 A.

Efficiency Curve for I_O = 0.32 A and I_O = 0.62 A



Efficiency.

Turn On with 0.63 A



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 to12-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

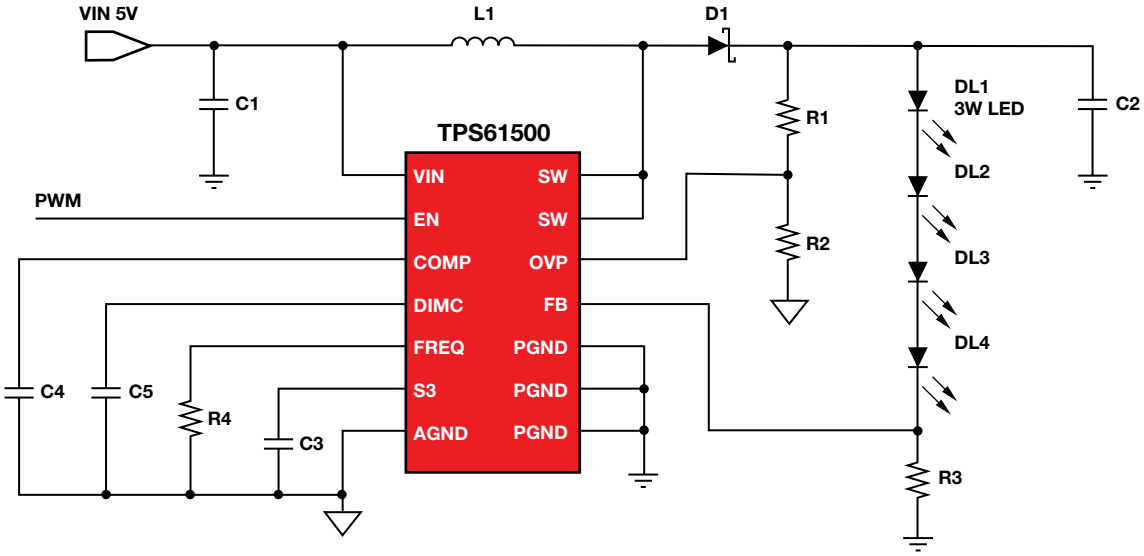
Datasheets, user's guides, samples:
www.ti.com/sc/device/TPS61500

LED Current vs. Input Supply and LED Number

Input Supply	5 V	12 V
LED number 4	1000 mA	2000 mA
LED number 6	600 mA	1200 mA
LED number 8	450 mA	1000 mA

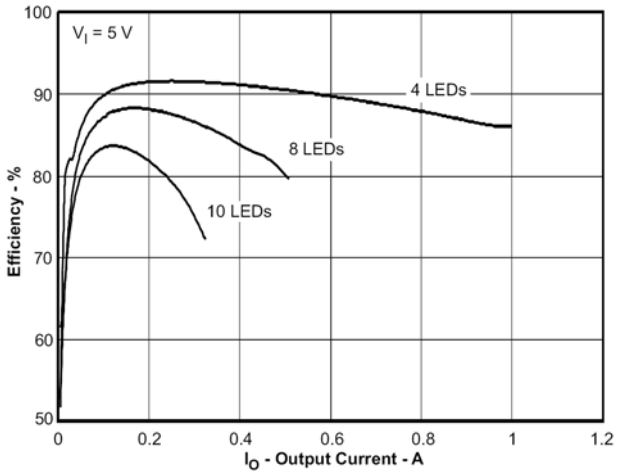
Note: Assumption that LED forward voltage is 3.5V, and TPS61500's conversion efficiency is 85%.

Typical Application Schematic

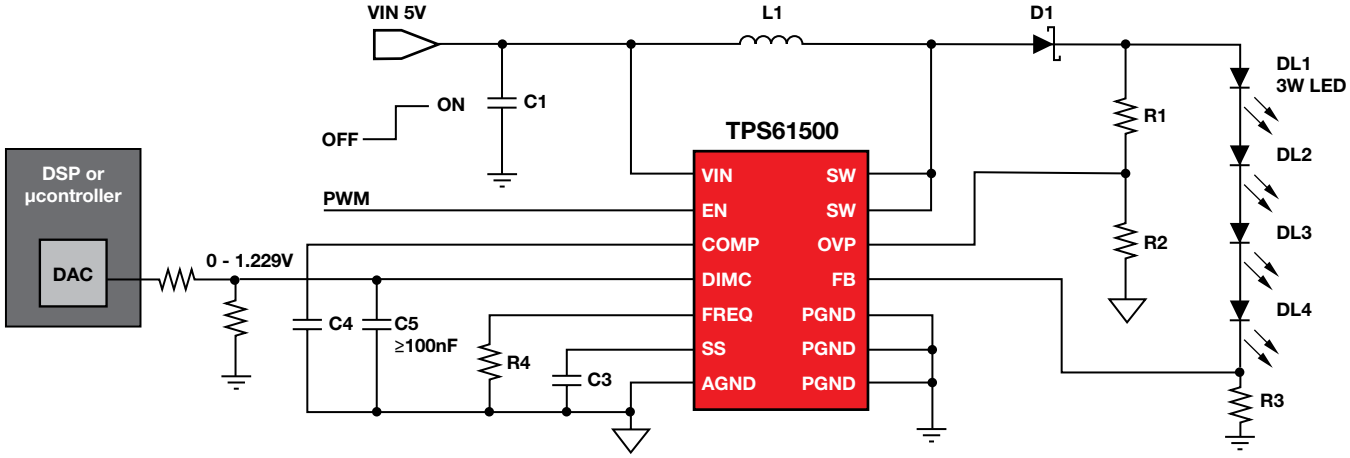


For more reference designs, see: www.ti.com/powerreferencedesigns

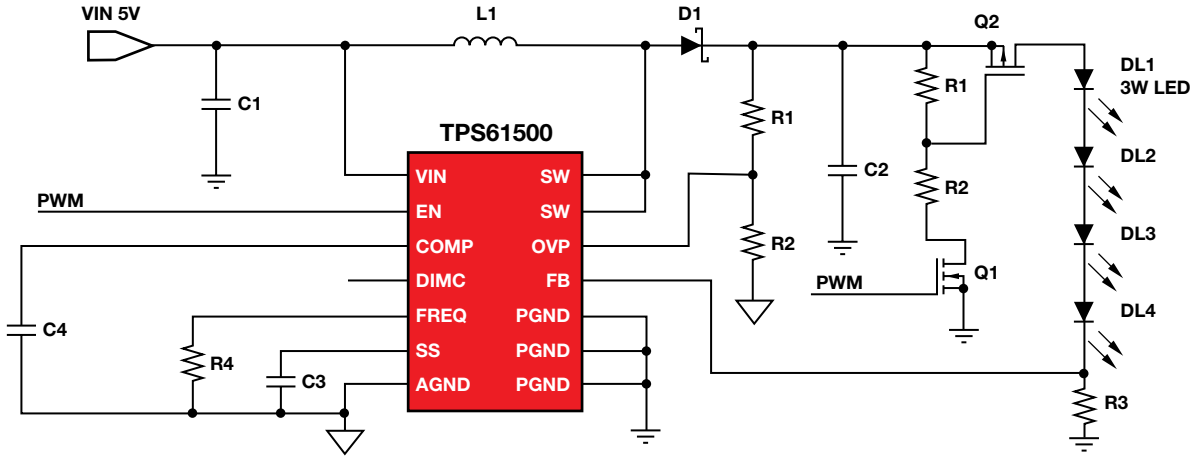
Efficiency vs. Output Current



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



TPS40211 PMP4026

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**

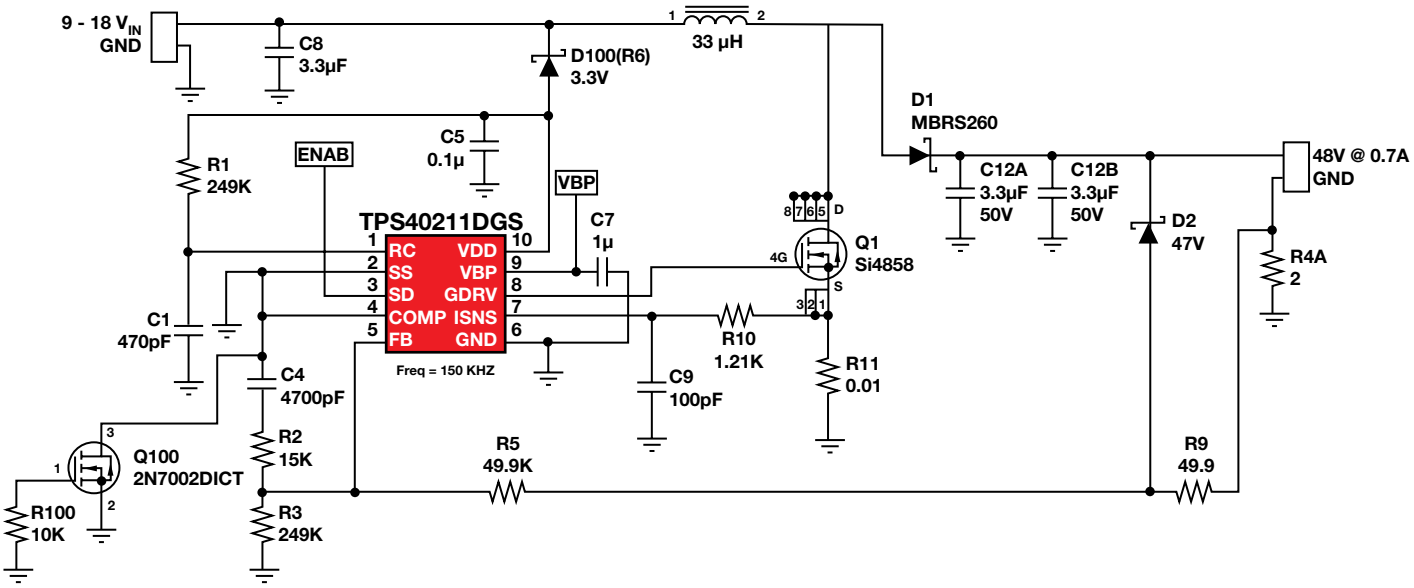
Web Links

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

Design Specifications

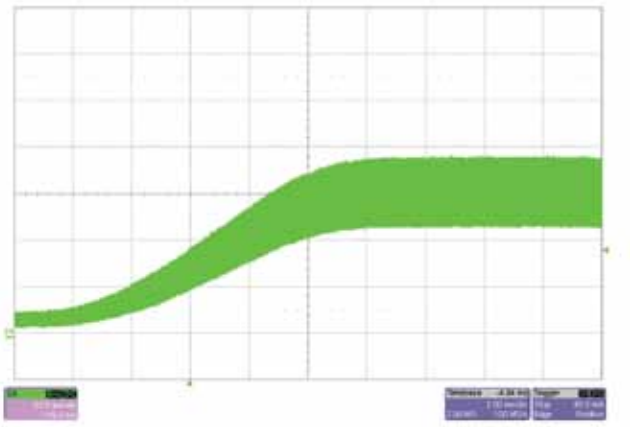
Parameter	Minimum	Typical	Maximum	Unit
Input voltage	9	—	16	V_{DC}
Output voltage	—	—	40	Volts
Output current	—	0.700	—	Amp
Switching frequency	—	150	—	kHz

PMP4026 Schematic



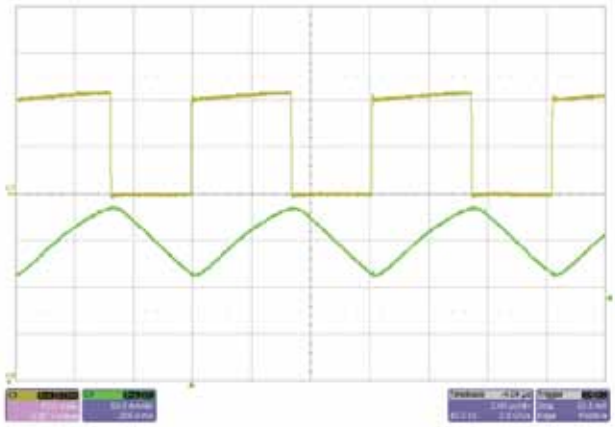
For more reference designs, see: www.ti.com/powerreferencedesigns

Startup



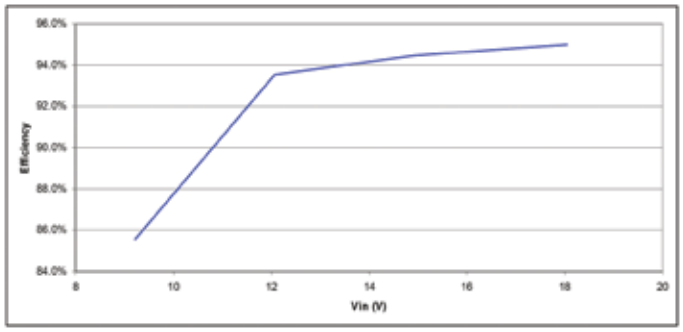
The input voltage was set at 12 V, with 0.15 (LED) + 1 (resistor) A load on the outputs.

Output Ripple Current



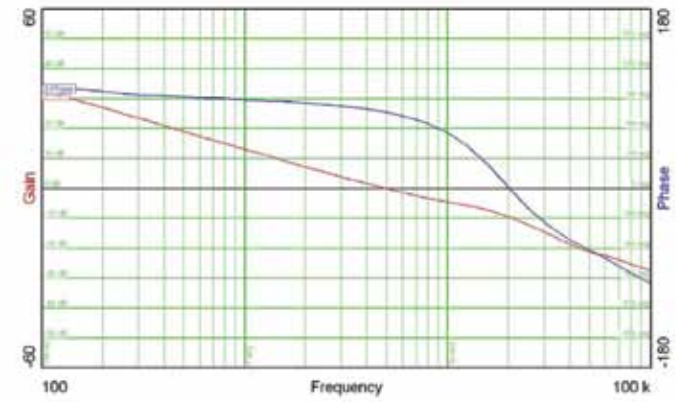
The image was taken with a 1.15 A/20 V load. Top waveform is FET drain, bottom is LED current.

Efficiency

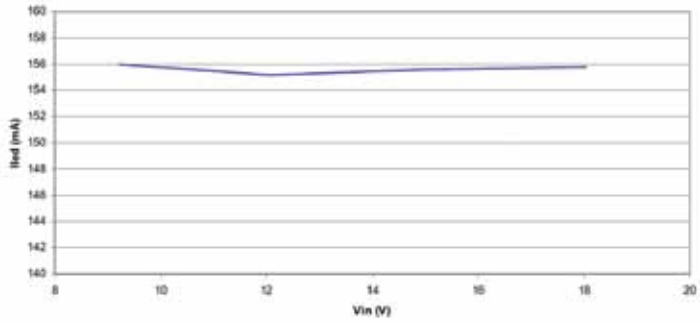


Total output current was 1.15 A, output voltage was 20 volts.

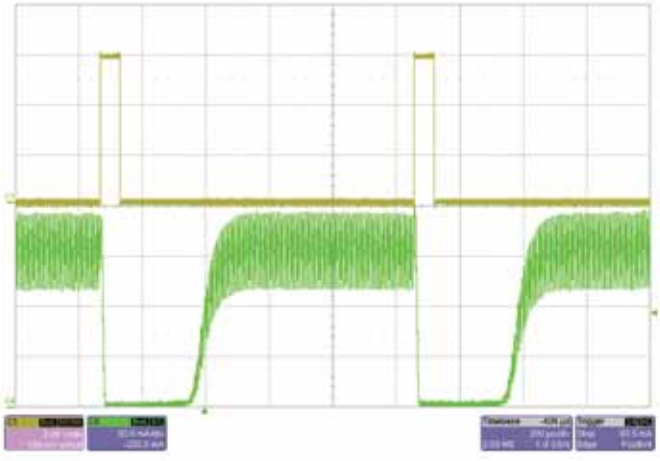
Control Loop Frequency Response: 12 V input; 1.15 A Load



Load Regulation of Outputs



Load Transients



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

Wide Input DC Voltage Range SEPIC Driver

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**

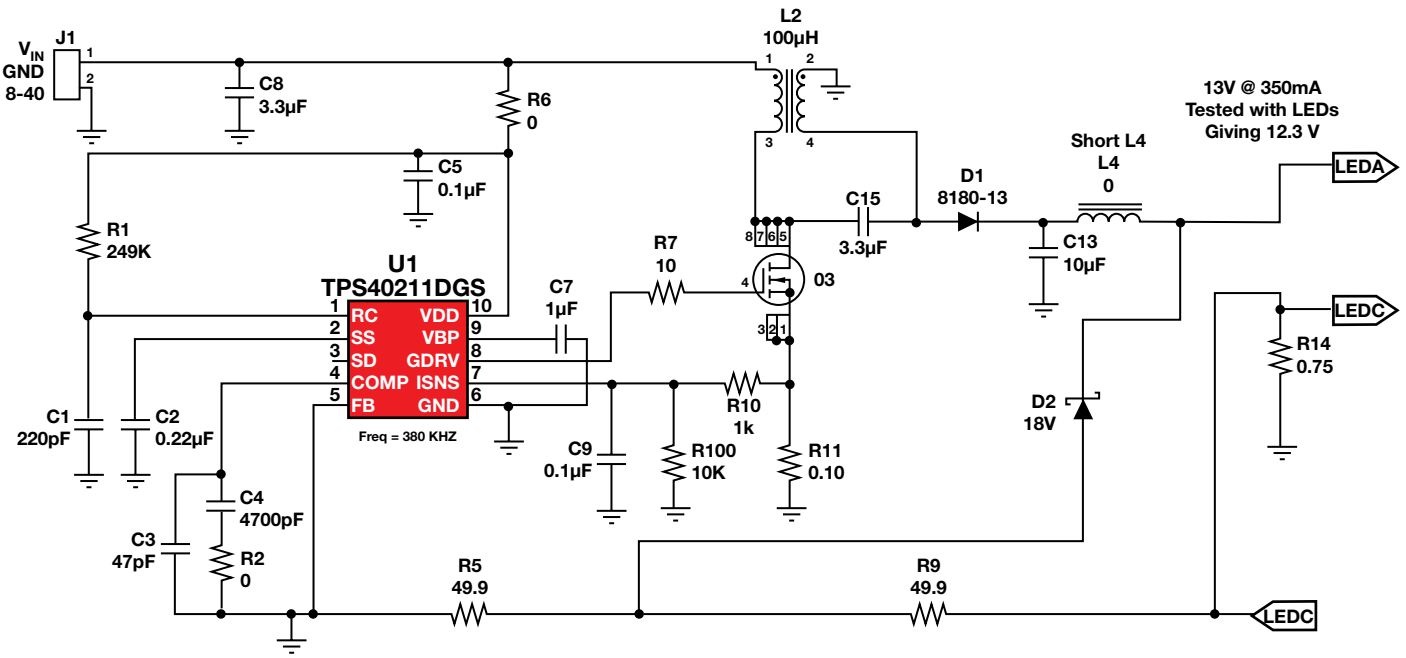
Web Links

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

Design Specifications

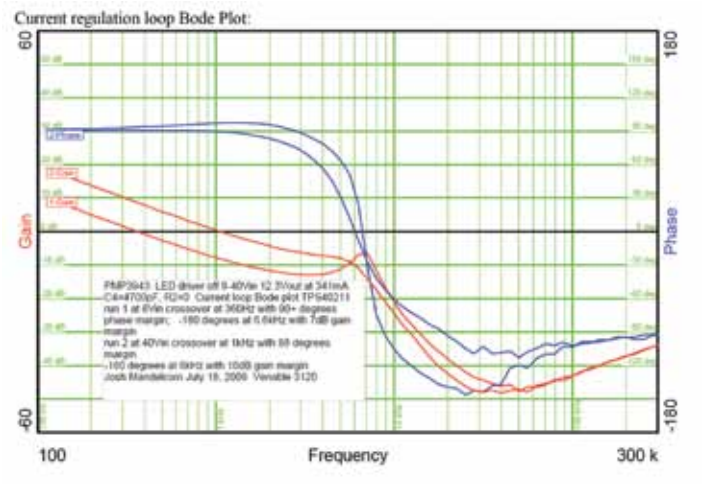
Parameter	Minimum	Typical	Maximum	Unit
Input voltage	8	—	40	Volts
Output voltage	—	13	—	Volts
Output current	—	0.350	—	Amp
Switching frequency	—	300	—	kHz

PMP3943 Schematic



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

Current Loop Frequency Response



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

V_{IN} Volts	I_{IN} mA	V_{OUT1} Volts	I_{OUT1} mA	Efficiency %
40.22	123.6	12.27	341.8	84.4
20.11	238.5	12.27	341.3	87.3
7.93	619.4	12.27	341.3	85.3

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

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

V_{IN} Volts	I_{IN} mA	V_{OUT1} Volts	I_{OUT1} mA
40.42	8.79	18.44	0
20.08	10.75	18.41	0
8.00	19.12	18.40	0

Short Circuit: Output Current Holds Steady

V_{IN} Volts	I_{IN} mA	V_{OUT1} Volts	I_{OUT1} mA
40.14	21.24	0.694	341.6
20.06	34.20	0.694	341.5
8.00	77.70	0.694	341.4

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_{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 whos total power input does not exceed 3 W.

Web Links

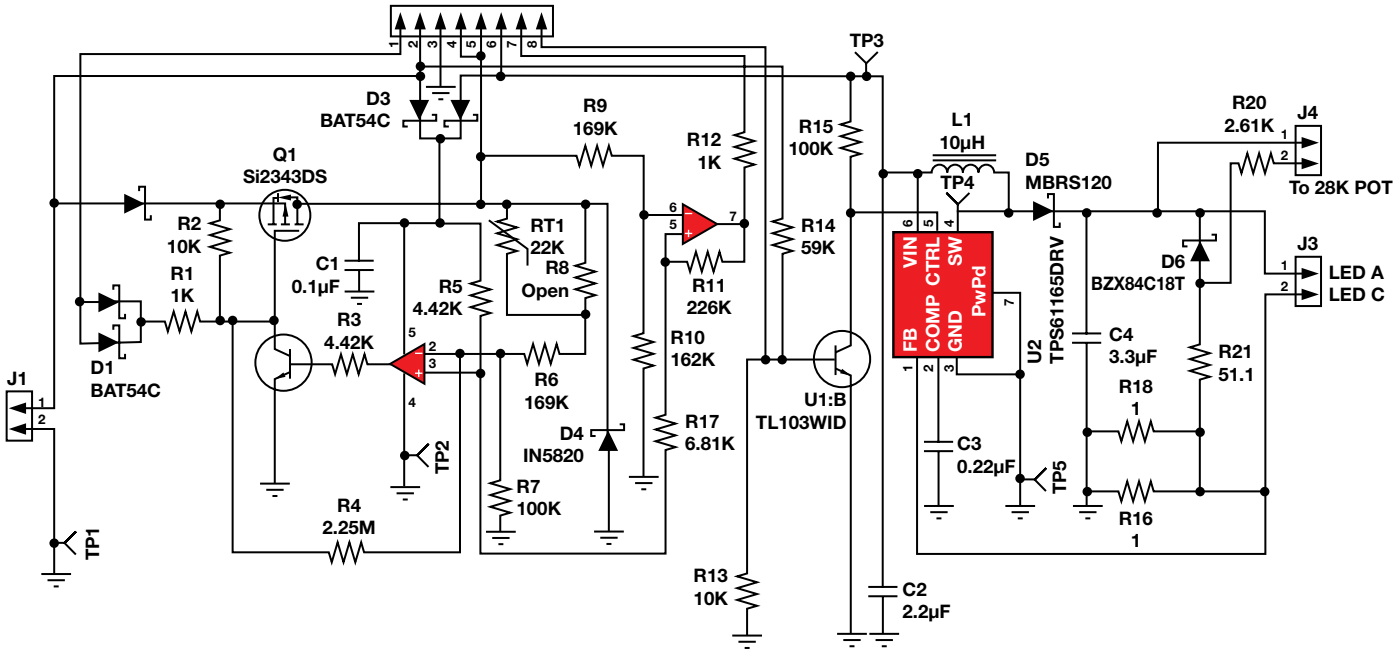
Reference designs:
www.ti.com/**powerreferencedesigns**

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

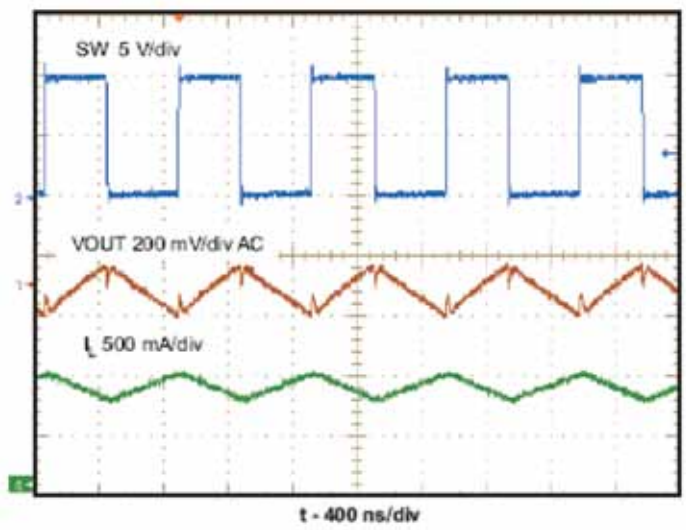
Design Specifications

Parameter	Minimum	Typical	Maximum	Unit
Input Voltage	4.5	6	7.4	Volts
Output Voltage	10.45	10.5	10.65	Volts
Output Ripple	—	—	50	mV pp
Output Current	0	—	350	mA
Switching Frequency	—	1200	—	kHz

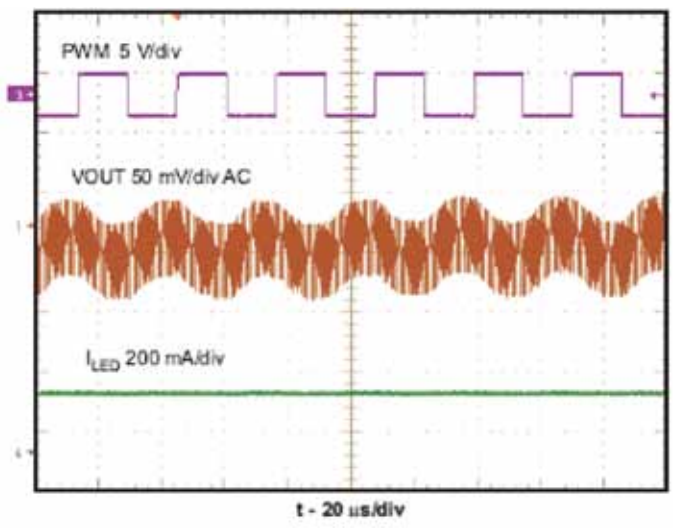
PMP3598 Schematic



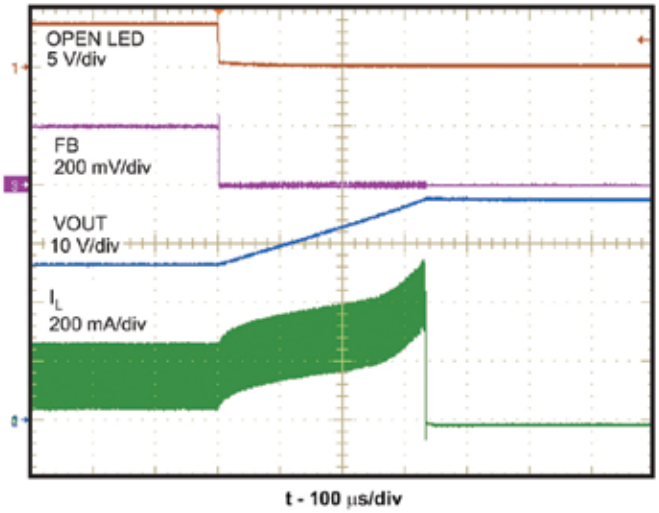
Switching Waveform



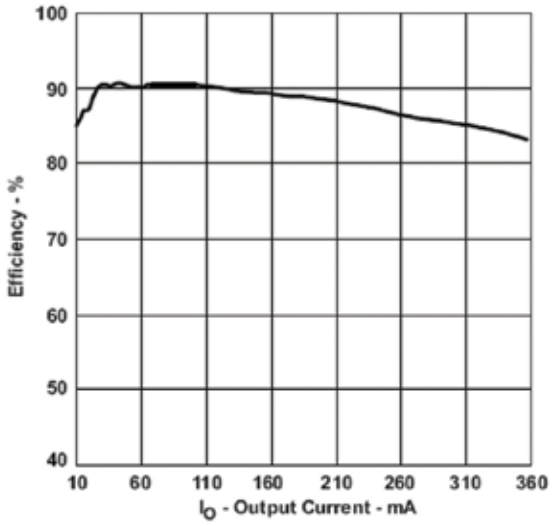
Output Ripple



Open LED Protection



Efficiency



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