Using the TPS92210-PMP6002

Reference Design

Literature Number: SLUU460A
October 2010–Revised December 2010

120-VAC to 32-V, 350-mA Dimmable LED Driver

1 Introduction

This reference design is a single stage power factor corrected TRIAC dimmable LED lighting driver using TPS92210. The driver will work with AC mains from 90 V_{RMS} to 145 V_{RMS} and provide a constant 350-mA current to drive ten high-brightness (HB) LEDs.

2 Description

Based on a TPS92210 control chip, this LED lighting driver design is capable of providing high power factor, load protection and extended life in a small volume at low cost. It employs constant “on-time” and critical, or discontinuous, conduction mode in an isolated flyback configuration. Intended for low power lighting applications, it can be packaged in a variety of ways including individual lamp designs and generic PCB form for many types of luminaries. This driver also preserves dimmer holding current and features dimmer conduction angle detection circuits to improve dimming linearity when used with common TRIAC based phase control dimmers.

2.1 Typical Applications

- Light Bulb Replacement (LBR)

2.2 Features

- 90V_{RMS} to 145-V_{RMS} Offline Operation
- Power Factor Correction
- Constant Current Control
- Output Isolation
- TRIAC Dimming Compatible
- Dimmer Conduction Angle Detection
- Triac Holding Current Augmentation

3 Electrical Performance Specifications

Table 1. PMP6002 Electrical Performance Specifications

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
Input Characteristics					
Voltage range		90		145	Vrms
PF			0.98		
THD				8	%
Output Characteristics					
Output voltage, V_{OUT}	Output current = 350 mA		32		V
Output load current, I_{OUT}			350		mA
Systems Characteristics					
Efficiency		80			%

4 Schematic

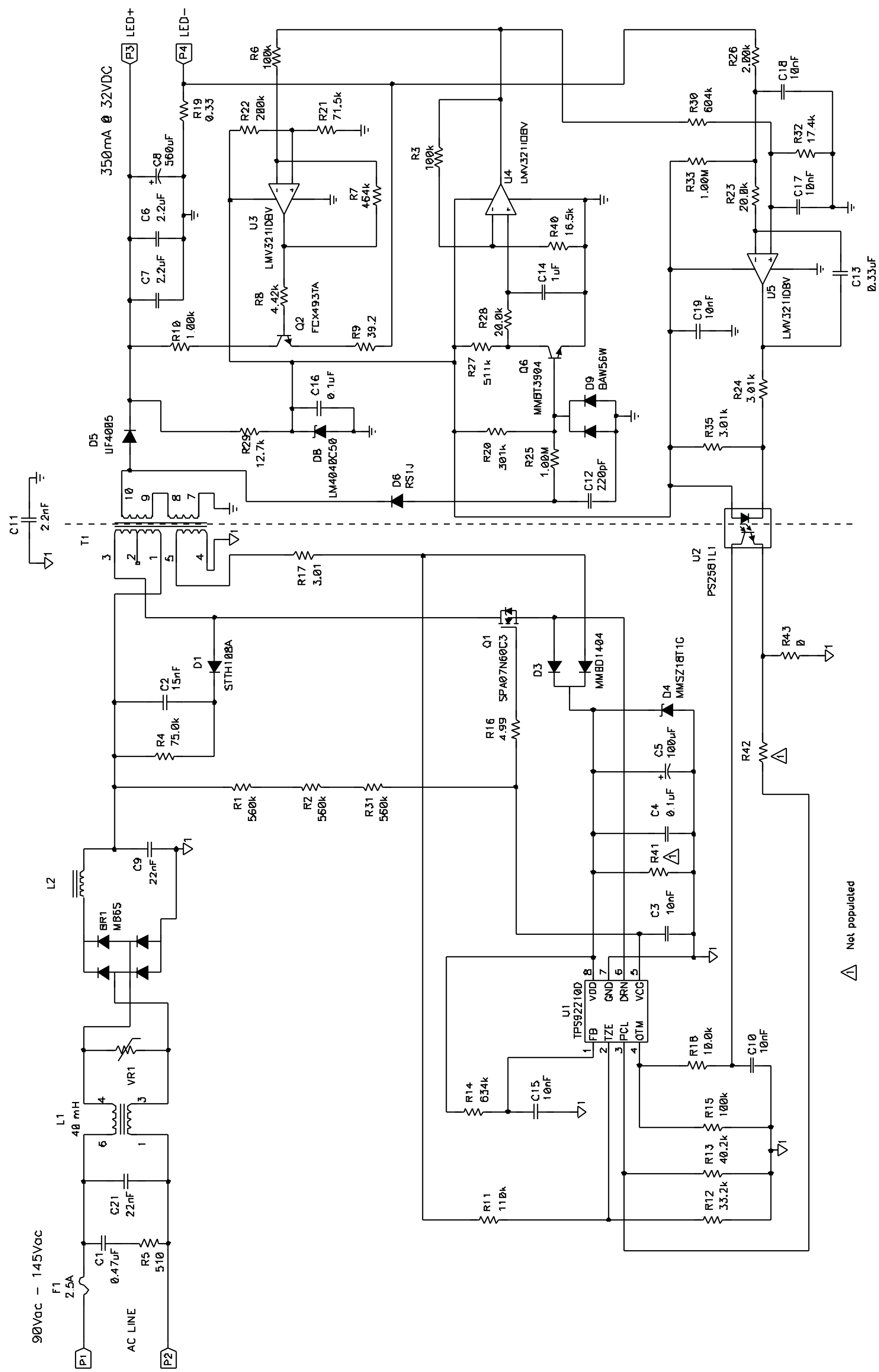

Figure 1. PMP6002 Schematic

5 Theory of Operation

5.1 Single Stage Power

Any single stage AC/DC converter topology that can be coerced into drawing a sinusoidal current from the AC line can be considered a single stage power factor corrected converter.

Referring to Figure 2, the TPS92210 controller can be programmed to operate at a fixed frequency with a constant on-time for the internal switch which drives the primary power FET. Configured in a CASCODE arrangement, the TPS92210 output driver provides current control without an external sense resistor.

Because the on-time of the cascode switch is constant, peak inductor current that is reached during each switching cycle will depend on the primary inductance and the instantaneous supply voltage. Primary inductance is fixed, and the power switch on-time is constant, so the peak current each cycle will be directly proportional to source voltage.

$$I_{prim\_peak} = \frac{V_{BULK} \times t_{ON}}{L_{prim}} = \frac{V_{BULK}}{k} \quad \text{where} \quad k = \frac{L_{prim}}{t_{ON}} \tag{1}$$

The variable k has the units Henrys/seconds which is equivalent to Ohms. Under these conditions the power stage will have the same transfer function as a resistor, and a power factor of 1. Variations in primary inductance or on-time of the cascode switch may lead to degradation in power factor.

C_{BULK}, in Figure 2, is reduced to a switching frequency bypass role providing no DC support. Consequently, the source voltage has the form of a rectified sine wave and input current will track input voltage with very good fidelity, yielding a high power factor. Notice also in the diagram of Figure 2, there are no “hard” edges in the input current waveform and consequently few significant harmonics.

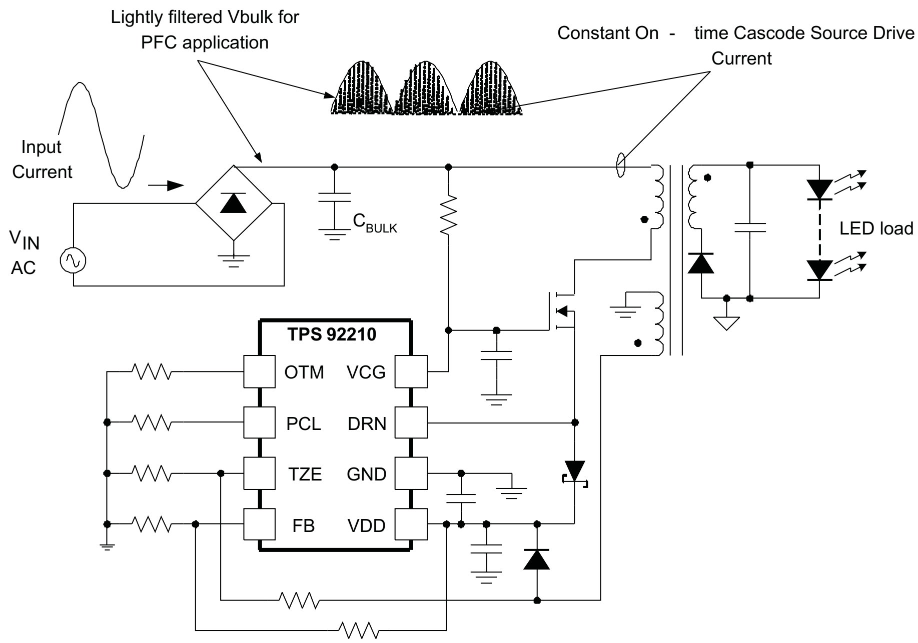

Figure 2. Input Current Tracks Input Voltage in Constant On-Time Flyback

NOTE: V_{BULK} in Figure 2 represents the source voltage during each switching cycle

Figure 2 shows the TPS92210 operating as a fixed on-time, fixed frequency, flyback controller with no feedback, resulting in a power stage with very high power factor, very low THD, and unconditional stability resulting from the elimination of control loop dynamics. In the absence of feedback the load voltage and current are not regulated but instead the total power delivered to the secondary load is directly proportional to the rms line voltage and is a function of the programmed on-time, PWM frequency, primary inductance, and power stage conversion efficiency. The TPS92210 frequency error is trimmed to less than 5%, the on-time modulation accuracy is specified as less than 10%, and so with a 10% tolerance primary inductance, output power control with such a minimum system can be held to within about 25% with additional variations due to line voltage. Although the controller is running open loop in this example, programmable isolated output over-voltage protection is still available, and power limiting and overload protection is still active.

If high load ripple current at twice the line frequency is tolerable, then the circuit in this example can easily be constructed with no electrolytic capacitors. Without electrolytic capacitors and an opto-coupler, the circuit in this example has the potential for very high reliability if components are carefully chosen and properly de-rated for voltage, current, and operating temperature.

5.2 TPS92210 Controller

Operation and features of the TPS92210 are detailed in the T.I. data sheet for that controller. Briefly, the device features of interest here are associated with programming it to provide fixed frequency, adjustable maximum current (sensing the power inductor current) and flyback period sensing to assure discontinuous operation.

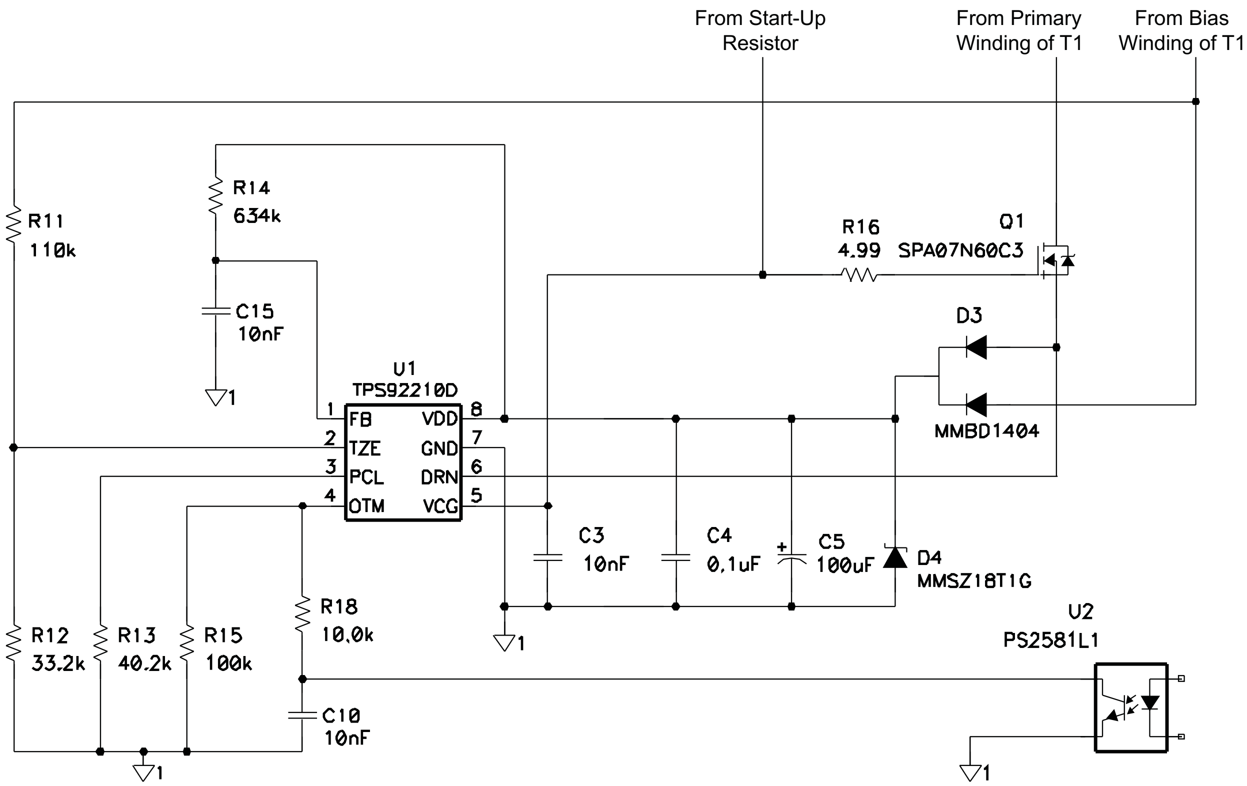

Figure 3. TPS92210 Control Chip, Driving Q1 With Programmable On-Time

Drive to the main power switch, Q1, uses a CASCODE arrangement in which an internal drive transistor switches source current in Q1 allowing inductor current to be measured within the TPS92210 without the need for an external current sense resistor. Note that Q1 gate and source connections are made directly to the controller. Power for the controller (VDD) comes from an auxiliary winding on the power inductor through D3 filtered and limited by D4, C4 and C5.

VDD is also used to program fixed frequency operation by injecting current into the FB (Feedback) pin on the TPS92210, through R14. In this design, the programming current is approximately 18V / 634 kΩ = 28 µA, yielding an operating frequency of 110 kHz.

A non-rectified signal from the inductor auxiliary winding is routed via a divider, R11 and R12 to the TZE pin where it is used to detect demagnetization of the transformer by observing the zero crossing of the signal. By re-enabling another forward drive pulse to Q1 after the flyback period has ended the controller insures that discontinuous switching mode prevails so that all the energy stored in the power inductor is transferred to the load on each cycle. Enabling on the downward slope of the signal allows for smaller switching loss per cycle.

In the configuration of this reference design, PCL the current modulation input to the TPS92210 is not used, so it is terminated to ground via R13 which programs the peak current value at which the controller cuts off drive to Q1, beyond the normal operating range. This is ordinarily the point where current sensing is done in converters using current mode control. Instead, maximum on-time is programmed at pin 4 (OTM) by R15. OTM supplies a current that is used to program an internal voltage (R15) that sets maximum on-time. Notice that the primary-side opto-coupler transistor can divert some of the current from the OTM pin through R18 thereby reducing the maximum on time according to the output current sensed on the secondary side. Maximum on-time modulation provides the feedback scheme for LED current control.

5.3 Secondary-Side Current Feedback

The main output channel on the driver secondary side is a conventional flyback configuration consisting of D5 and several filter capacitors, C6, C7, and C8. Current sense resistor R19 converts LED load current to a ground referenced voltage.

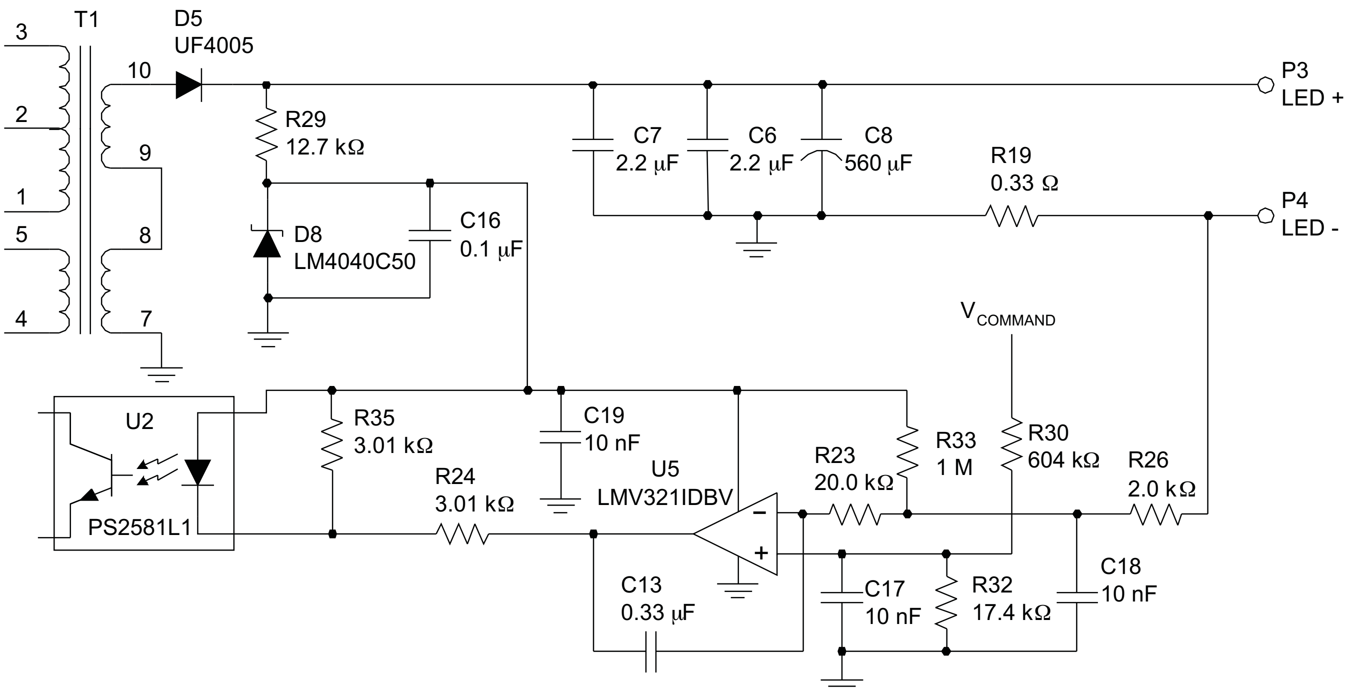

Figure 4. Secondary-Side Load Current Channel

LED current amplitude information taken from R19 is compared by integrator U5 to a reference formed by R30 and R32, amplifies the difference and drives the LED half of the opto-coupler U2 used to control maximum main switch on-time. The voltage divider R33 and R26 provide a small positive offset to the measured LED current, allowing the LED current command to actually go below zero thus insuring that the LED can be dimmed to zero current. This configuration yields closed loop current regulation for the load LEDs. Increasing load current forces U5 to increase opto-coupler drive which reduces the resistance at OTM on the TPS92210. Lower net resistance at the OTM pin causes the on-time to narrow thus reducing power to the secondary to counteract the increase in load current.

5.4 Dimmer conduction angle detection

The TPS92210 reference design is compatible with both leading-edge and trailing-edge phase-cut dimmers. It reconstructs the rectified line voltage at the secondary winding of the transformer in order to directly measure the conduction angle of the dimmer while providing good rejection to changes in line voltage.

As illustrated in Figure 5, D6-C12 reconstructs the inverted line voltage while Q6, R27, R28, and C14 act as a voltage comparator and switched-capacitor filter with a logarithmic duty-cycle to output voltage transfer function.

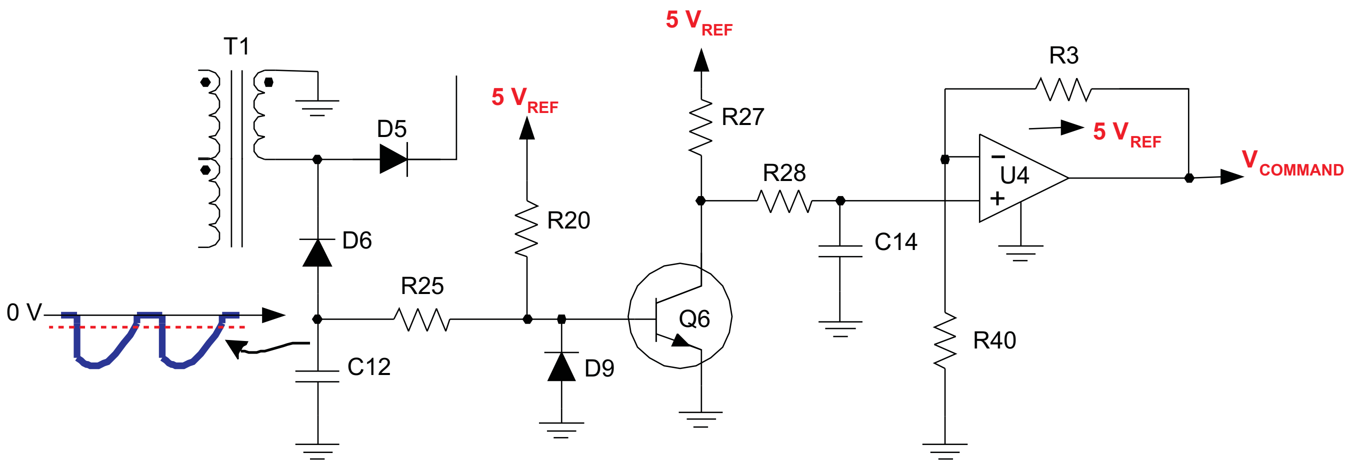

Figure 5. Dimmer Conduction Angle Detector

Operational amplifier U4 buffers and adds gain to the logarithmic output of Q6 to create the LED current command voltage. When not operating with a dimmer, or when the dimmer is set to maximum intensity, the output of U4 will saturate to the positive supply rail and provide a 5-V reference as the LED command voltage. As the conduction angle of the dimmer decreases, the output of U4 will decrease in a logarithmic fashion accurately over more than one decade as illustrated in Figure 6.

The ratio of R27 and R28 determine the logarithmic characteristic of the filter while the values of R28 and C14 determine the time constant. The time constant of the filter should be much greater than the frequency of the AC line to avoid reduction of power factor and to effectively filter any jitter that may be present on the phase angle of the dimmer. Too large a time constant will result in a noticeable delay in response to changes in the dimmer setting.

R3 and R40 set the gain of U4 which determines the dimmer conduction angle that saturates U4 and consequently produces maximum LED current. Most Triac dimmers are incapable of producing 100% conduction angle and are prone to noise and asymmetrical behavior at conduction angles below 20%, and so limiting the range of conduction angles that correspond to 0% and 100% LED current is desirable and has been done in this EVM.

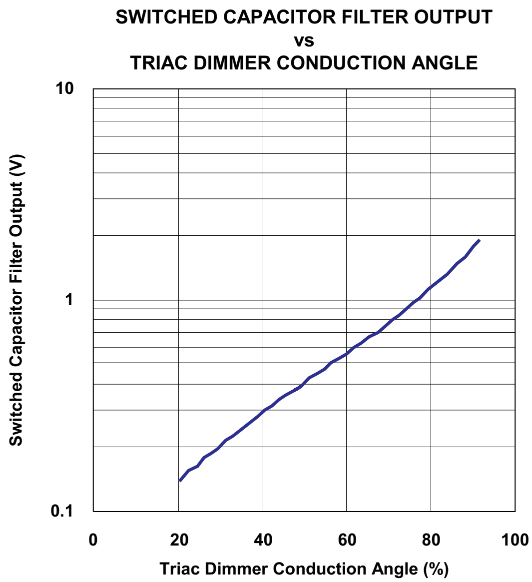

Figure 6. Response of Log Dimmer Conduction Angle Detection

5.5 Triac Holding Current Augmentation

Most triac dimmers are intended for incandescent loads of 40 W or more and consequently the very low AC line current requirements of a deeply dimmed LED are insufficient to meet the holding current requirements of the triac. If the triac holding current requirements are not met the triac will regain blocking (turn off) in a random manner resulting in visible flickering of the LED.

The TPS92210 Reference Design attempts to solve this problem by adding an additional load to the line when the LED current is too low to satisfy the holding current requirements of the triac. The additional load is actually added at the secondary as this avoids interfacing with the high voltage rectified AC line, helps keep the auxiliary supply charged, and allows the load to be drawn from the relatively fixed and know voltage of the LED. The holding current augmentation is accomplished by redirecting current around the LED so that the LED continues to dim while the AC line current remains fixed.

As illustrated in the graph of Figure 7, operational amplifier U3 monitors the LED current command voltage from U4 and when the commanded current falls below the threshold programmed by R21 and R22, U3 begins to turn on emitter follower Q2 and diverts current through R10 and around the LED load directly into the LED current metering resistor R19. R6 and R7 set the gain of U3 which determines how much current is diverted for a particular LED current.

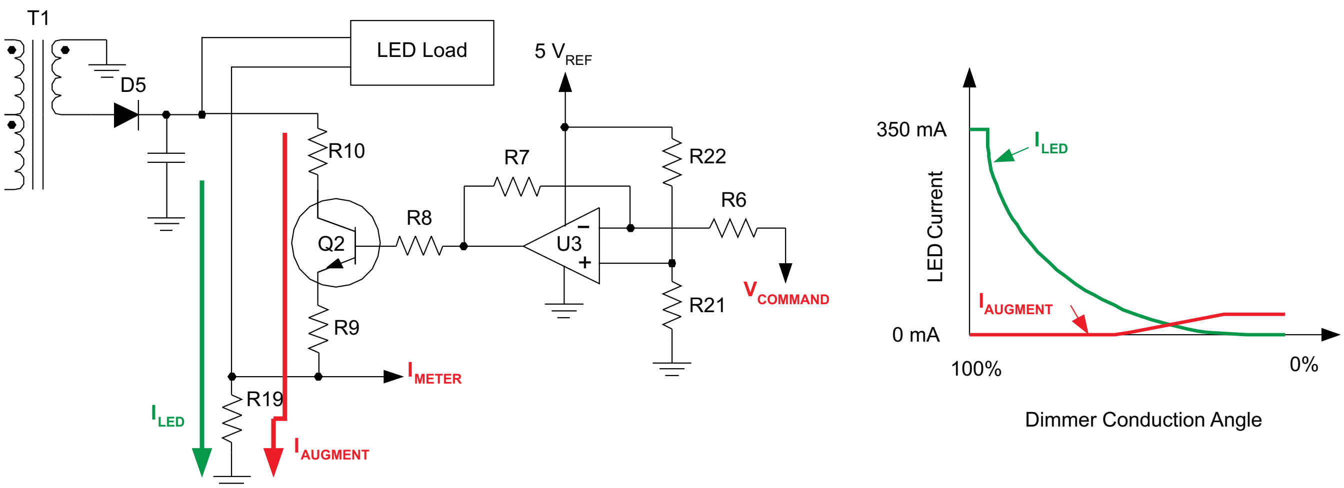

Figure 7. Triac Holding Current Augmentation

6 PCB Layout

6.1 Top Side of PMP6002 PCB Layout

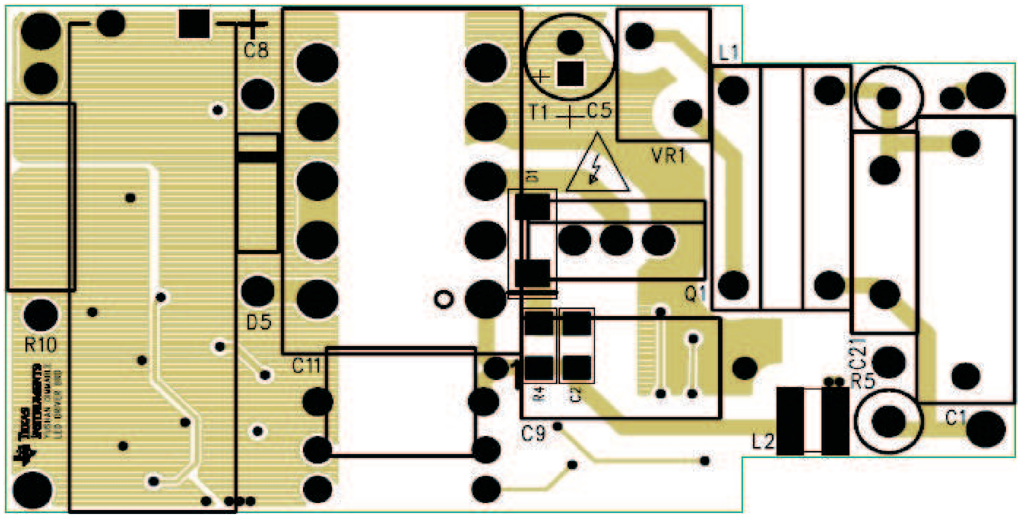

Figure 8. Top Side

6.2 Bottom Side of PMP6002 PCB Layout

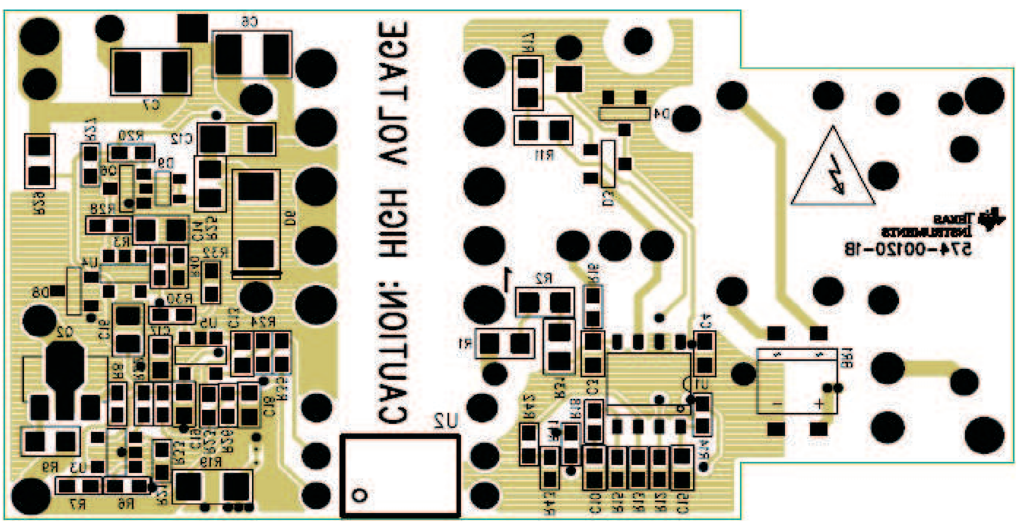

Figure 9. Bottom Side

7 Performance Data and Typical Characteristic Curves

Figure 10 to Figure 15 present typical performance curves for PMP6002 32-V, 350-mA Dimmable LED Driver.

7.1 Power Factor (PF)

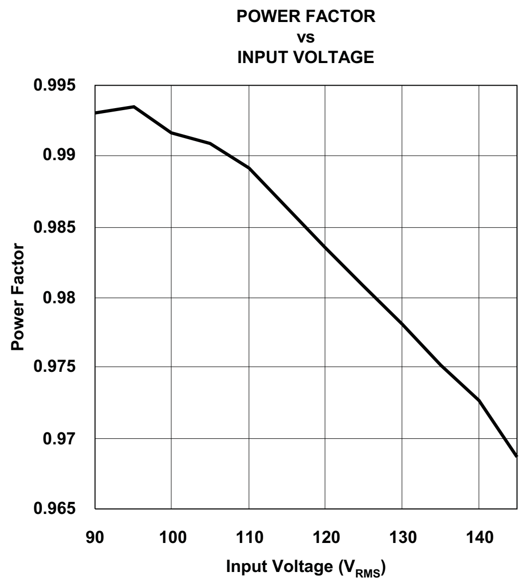

Figure 10.

7.2 Total Harmonic Distortion (THD)

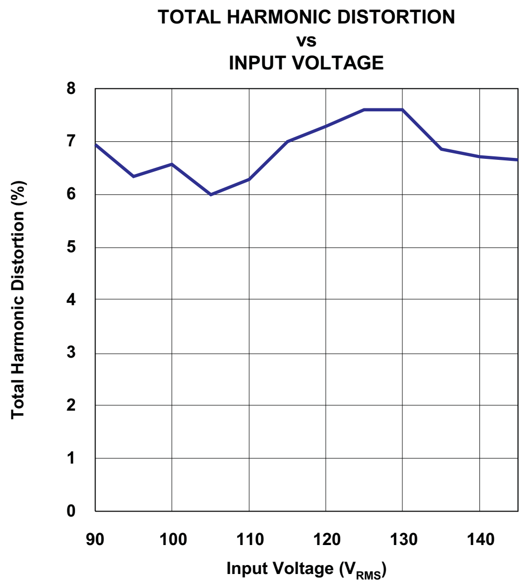

Figure 11.

7.3 Output Current (I_{OUT})

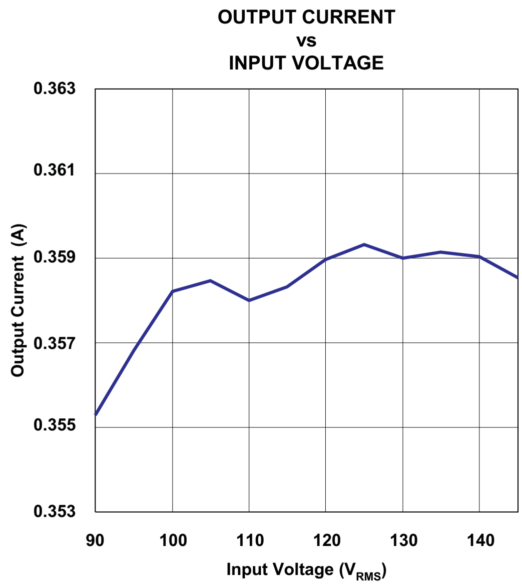

Figure 12.

7.4 Output Voltage (V_{OUT})

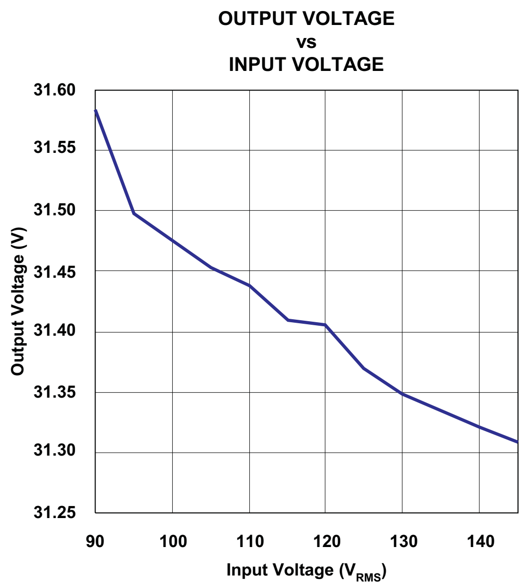

Figure 13.

7.5 Output Power (P_{OUT})

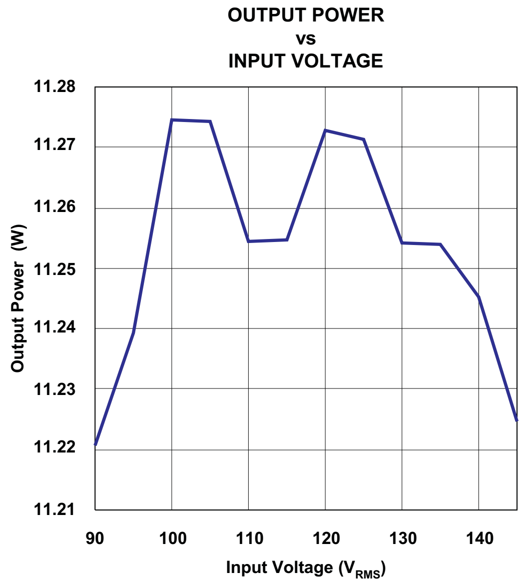

Figure 14.

7.6 Efficiency

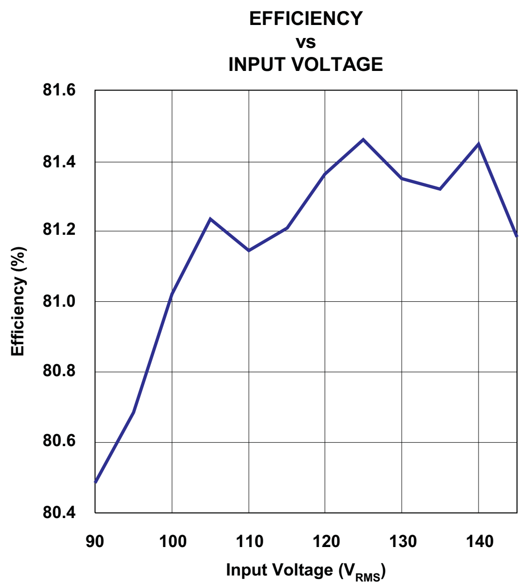

Figure 15.

8 List of Materials

Table 2. List of Materials

QTY	REFDES	DESCRIPTION	MFR	PART NUMBER
1	BR1	Rectifier, bridge, 0.5 A, 600 V, 4-pin SOIC	Diodes	MB6S
1	C1	Capacitor, metal poly, 0.47 µF, 400 VDC	Panasonic	ECQ-E4474KF
1	C2	Capacitor, ceramic, 15000 pF, 250 V, X7R, 1206	Std	Std
1	C3	Capacitor, ceramic, 10000 pF, 50 V, X7R,0603	Std	Std
1	C4	Capacitor, ceramic, 0.1 µF, 50 V, X7R ,10%, 0603	Std	Std
1	C5	Capacitor, aluminum electrolytic, 100 µF, 25 V	Std	Std
2	C6,C7	Capacitor, ceramic, 2.2 µF, 100 V, X7R, 1210	Std	Std
1	C8	Capacitor, aluminum electrolytic, 560 µF, 50 V	Std	Std
1	C9	Capacitor, metal poly, 0.022 µF, 630 VDC	Panasonic	ECQ-E6223KF
5	C10,C15,C17,C18,C19	Capacitor, ceramic, 10000 pF, 25 V, X7R, 0603	Std	Std
1	C11	Capacitor, ceramic, 2.2 nF, X1/Y1 radial	muRata	DE1E3KX222M
1	C12	Capacitor, ceramic, 220 pF, 630 VDC, U2J, 1206	Std	Std
1	C13	Capacitor, ceramic, 0.33 µF, 16 V, X7R, 0603	Std	Std
1	C14	Capacitor, ceramic, 1 µF, 16 V, X7R, 0805	Std	Std
1	C16	Capacitor, ceramic, 0.1 µF, 25 V, 0805	Std	Std
1	C21	Capacitor, 0.022 µF, 305 VAC, X2, metal polypro	Epcos	B32921C3223M
1	D1	Diode, ultra fast, 800 V, 1A, SMA	ST	STTH108A
1	D3	Diode, ultra fast, 200 V, SOT-23	Fairchild	MMBD1404
1	D4	Diode, ZENER, 18 V, 225 mW, SOT-23	Std	Std
1	D5	Diode,GPP fast,1 A, 600 V, DO-41	Std	UF4005
1	D6	Diode, GPP fast, 1 A, 600 V, SMA	Std	RS1J
1	D8	Shunt regulator, 5.0 V, SOT-23	TI	LM4040C50
1	D9	Diode, switching, 70 V, SC-70	Std	BAW56W
1	F1	Fuse, pico fast, 2.5 A , 250 V, AXIAL	Littelfuse	026302.5WRT1L
1	L1	Ind common mode choke, 40 mH	Wurth	750311650
1	L2	Jumper, res, 0.0 Ω, 1206	Std	Std
1	Q1	MOSFET, N-channel, 650 V, 7.3 A, TO-220FP	Infineon	SPA07N60C3
1	Q2	Transistor, NPN, 100 V, 1 A, SOT-89	Diodes	FCX493TA
1	Q6	Transistor, NPN, GP, 40 V, SOT23	Std	MMBT3904

Table 2. List of Materials (continued)

QTY	REFDES	DESCRIPTION	MFR	PART NUMBER
3	R1,R2,R31	Resistor, 560 kΩ, 1/4 W, 1%, 0805, SMD	Std	Std
3	R3,R6,R15	Resistor, 100 kΩ, 1/10 W, 1%, 0603, SMD	Std	Std
1	R4	Resistor, 75.0 kΩ, 1/4 W, 1%, 1206, SMD	Std	Std
1	R5	Resistor, 510 Ω, metal film, 2 W, 5%	Std	Std
1	R7	Resistor, 464 kΩ, 1/10 W, 1%, 0603, SMD	Std	Std
1	R8	Resistor, 4.42 kΩ, 1/10 W, 1%, 0603, SMD	Std	Std
1	R9	Resistor, 39.2 Ω, 1/8 W, 1%, 0805, SMD	Std	Std
1	R10	Resistor, 1.0 kΩ, metal film, 2 W, 5%	Std	Std
1	R11	Resistor, 110 kΩ, 1/8 W, 1%, 0805, SMD	Std	Std
1	R12	Resistor, 33.2 kΩ, 1/10 W, 1%, 0603, SMD	Std	Std
1	R13	Resistor, 40.2 kΩ, 1/10 W, 1%, 0603, SMD	Std	Std
1	R14	Resistor, 634 kΩ, 1/10 W, 1%, 0603, SMD	Std	Std
1	R16	Resistor, 4.99 Ω, 1/10 W, 1%, 0603, SMD	Std	Std
1	R17	Resistor, 3.01 Ω, 1/8 W, 1%, 0805, SMD	Std	Std
1	R18	Resistor, 10.0 kΩ, 1/10 W, 1%, 0603, SMD	Std	Std
1	R19	Resistor, 0.33 Ω, 1/4 W, 1%, 1206, SMD	Std	Std
1	R20	Resistor, 301 kΩ, 1/10 W, 1%, 0603, SMD	Std	Std
1	R21	Resistor, 71.5 kΩ, 1/10 W, 1%, 0603, SMD	Std	Std
1	R22	Resistor, 200 kΩ, 1/10 W, 1%, 0603, SMD	Std	Std
2	R24, R35	Resistor, 3.01 kΩ, 1/10 W, 1%, 0603, SMD	Std	Std
2	R25, R33	Resistor, 1.00 MΩ, 1/10 W, 1%, 0603, SMD	Std	Std
1	R26	Resistor, 2.00 kΩ, 1/10 W, 1%, 0603, SMD	Std	Std
1	R27	Resistor, 511 kΩ, 1/10 W, 1%, 0603, SMD	Std	Std
2	R28, R23	Resistor, 20.0 kΩ, 1/10 W, 1%, 0603, SMD	Std	Std
1	R29	Resistor, 12.7 kΩ, 1/8 W, 1%, 0805, SMD	Std	Std
1	R30	Resistor, 604 kΩ, 1/10 W, 1%, 0603, SMD	Std	Std
1	R32	Resistor, 17.4 kΩ, 1/10 W, 1%, 0603, SMD	Std	Std
1	R40	Resistor, 16.5 kΩ, 1/10 W, 1%, 0603, SMD	Std	Std
0	R41	Not populated		
0	R42	Not populated		
1	R43	Resistor, 0.0 Ω, 1/20 W, 5%, 0603, SMD	Std	Std
1	T1	Transformer flyback EE20/10/6	Wurth	750811148
1	U1	PWM controller cascode, 8-SOIC	TI	TPS92210
1	U2	Opto isolator transistor output	CEL/NEC	PS2581L1
3	U3,U4,U5	OPAMP, GP, R-R, 1MHZ, SGL, SOT23-5	TI	LMV321IDBVR
1	VR1	Sur absorber, 7 mm, 430 V, 1250 A, ZNR	Panasonic	ERZ-V07D431

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