Application Report
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7-W Single Stage PFC LED Lighting Design with TRIAC Dimming

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ABSTRACT

This report describes a reference design of 7-W AC/DC LED lighting driver with TRIAC dimming. The solution adopts single-stage power factor correction (PFC) flyback topology with primary side constant power control. A thorough analysis and design of the power converter are presented. Finally, the experimental results obtained on 7-W application are provided. The design can be easily modified to be suitable for other applications.

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1 Introduction

The reference design, PMP4304A, is a single-stage power factor corrected LED driver with TRIAC dimming using Texas Instrument's TPS92210 LED lighting power controller. The LED application focuses on PAR Bulb replacement with a small form factor, low cost, high PF and high TRIAC dimming performance.

The solution adopt single stage power factor correction (PFC) flyback converter with primary side constant power control. It realizes primary side constant power control in the single stage flyback topology without opto-coupler. The driver can work with highline AC or low-line AC. The output provides a constant current of 350 mA to drive typically 6 LEDs in series.

2 Theory of Operation

2.1 Single-Stage Flyback Converter with Power Factor Correction

This single-stage power factor corrected converter is an isolated flyback AC/DC topology that rectifies the AC input line to a DC output with an input sinusoidal current. The single-stage flyback topology is widely used as an isolated LED solution because this solution has a very low BOM cost and high efficiency.

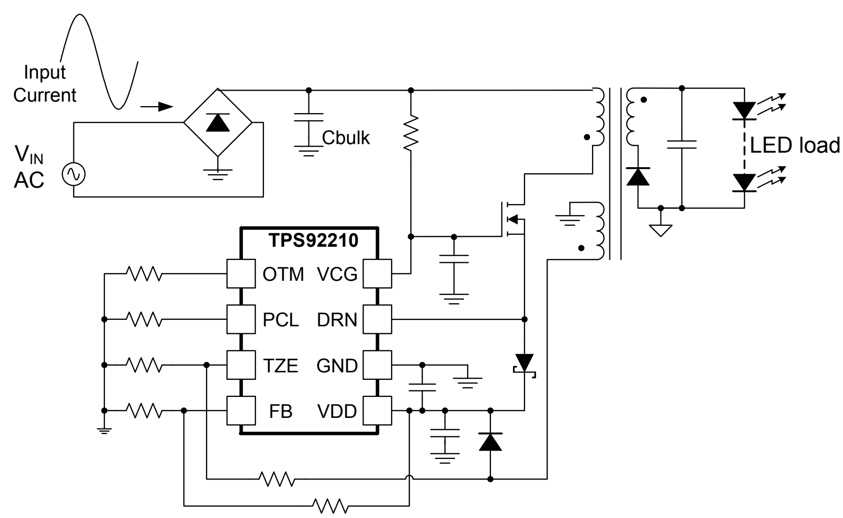


Figure 1. Single-Stage Flyback Converter

Conventional single-stage flyback solution adopt transition mode to regulate the constant on time to implement the PFC function. However, the flyback topology with transition mode is unnatural PFC because the duty cycle and the frequency always changes. So the PF and THD is not highly accurate at this condition.

However, the primary side constant power single-stage flyback is a natural PFC.

First, the input voltage can be set as below:

$$V_{in}(wt) = \sqrt{2} * V_{rms} * \sin(wt) \tag{1}$$

Then the average input current can be calculated as Equation 2.

$$I_{avg}(wt) = \sqrt{2} * V_{rms} * \sin(wt) * \frac{T_{on}}{L} * \frac{1}{2} * T_{on} * f \tag{2}$$

By Equation 1 and 2, the input power can be calculated as below.

$$Pin = \left. \frac{\int_0^{\pi/w} \sin^2(wt) * dt}{L} * V_{rms}{}^2 * T_{on}{}^2 * f \middle/ \pi / w \right. = \frac{1}{2} * \frac{V_{rms}{}^2 * T_{on}{}^2}{L} * f \tag{3}$$

In the primary side constant power scheme:

$$V_{rms} * T_{on} = K \tag{4}$$

In Equation 4, K is a constant and the value of K depends the system total power.

When the RMS of Vin changes, the duty on time changes reversely. And when the RMS of Vin is defined, the duty on time will not be changed again. So when the system is steady, the duty on time and duty are constant.

At the same time, in order to keep the constant power, the system is kept in the same switching frequency.

Because the T_{on}, L, f, and V_{in} are all constant, the input current is a natural sinusoidal from Equation 2.

From the other side, the input power is also constant from Equation 3.

In conclusion, it is seen that the primary side constant power single-stage scheme has some advantage with the conventional scheme in this application. First, the primary side constant power scheme is a natural PFC, its PF and THD are all better than conventional scheme. Second, as its name implies, the primary side constant power scheme can be controlled only on primary side. By this, the opto-coulper can be excluded, allowing for a low-cost BOM.

2.2 TPS92210 Controller and System Operation

For the TPS92210 controller, there is an OTM pin, which can control the ton time by the resistor connected to it; the details are shown below.

$$R_{OTM} = t_{ON} \times \left(2 \times 10^{10} \frac{\Omega}{s} \right) \tag{5}$$

In order to realize the primary side constant power control, the following circuit is used as Figure 2.

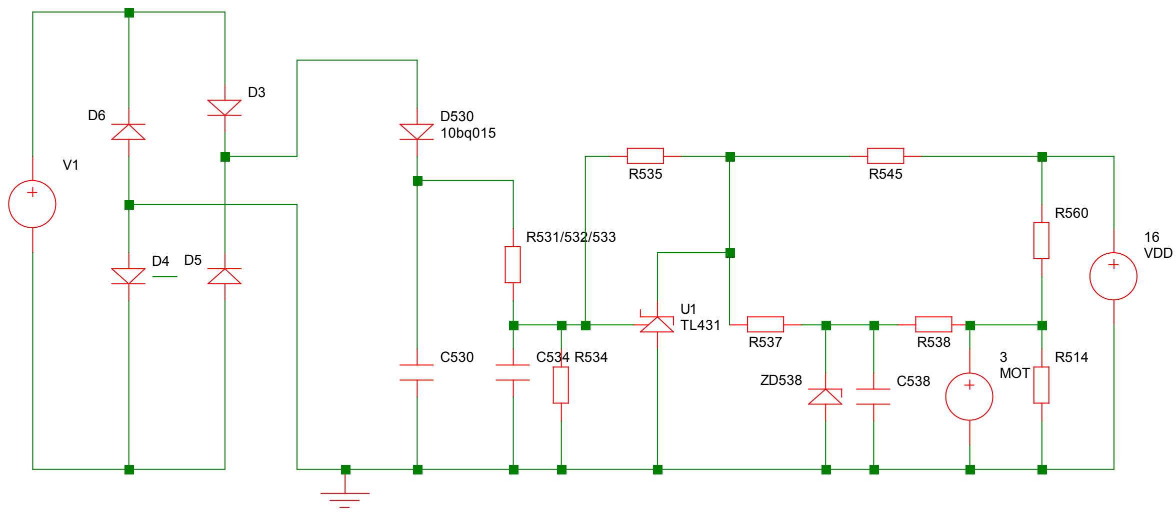


Figure 2. Feedforward Circuit for Primary Side Constant Power Control

Assuming Vin_rms = x, the relationship between Ton and Vin_rms can be calculated as below.

$$\mathrm{Ton}(x) := \frac{\dfrac{3}{\left(2\cdot 10^{10}\right)}}{\dfrac{3}{\mathrm{R514}} - \left(\dfrac{\mathrm{Vdd}-3}{\mathrm{R560}}\right) - \dfrac{\mathrm{Vf} + \dfrac{\mathrm{Vf}\cdot \mathrm{R535}}{\mathrm{R534}} - \dfrac{\left(\sqrt{2}\,x - 35\right)\cdot \mathrm{R535}}{3\cdot 10^{6}} - 3}{\mathrm{R538}+\mathrm{R537}}} \tag{6}$$

If :

$$A = \frac{3}{R514} - \frac{Vdd-3}{R560} - \frac{Vf + \dfrac{Vf\cdot R535}{R534} + \dfrac{35\cdot R535}{3\cdot 10^{6}} - 3}{R538+R537}$$

$$B = \frac{\dfrac{\sqrt{2}\cdot R535}{3\cdot 10^{6}}}{R538+R537}$$

$$C = \frac{3}{2\cdot 10^{10}}$$

Then the formula becomes the simple calculation shown in Equation 7.

$$Ton(x) = \frac{C}{A + B * x} \tag{7}$$

To meet the requirements of primary side constant power control (Vrms * Ton = K), B = 0 is chosen. At the same time, A and C can be chosen according to the input power.

Figure 3 is a simulation result after the calculation in the 7-W example. The Ton time becomes small when the input voltage becomes high. At the same time, the input power must be kept constant.

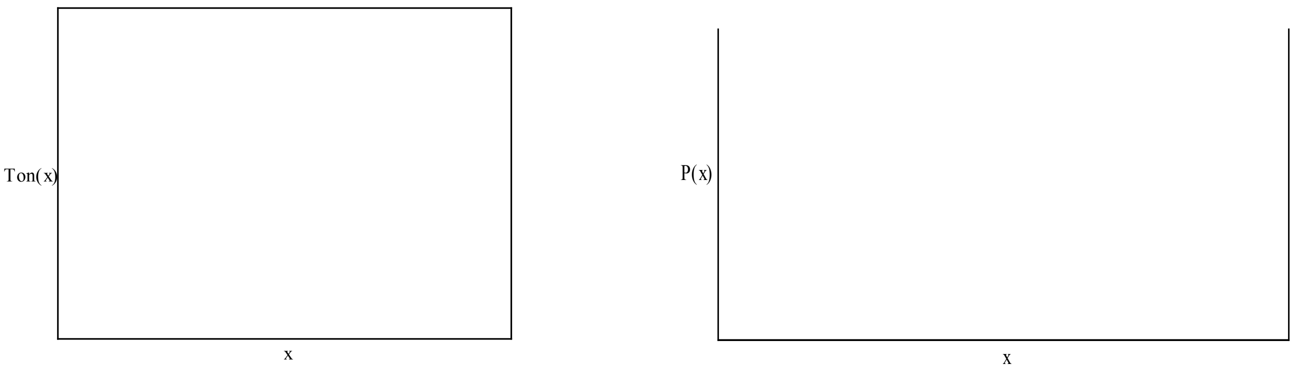


Figure 3. T_{on} Time vs. Vin_rms and Input Power vs. Vin_rms

3 7-W Off-Line Constant Power LED Lighting Driver Design

3.1 Design Specification

Table 1. Electrical Design Specification

Specification Items	Min	Typical	Max
Input AC voltage	180 V_{ac}	220 A_{ac}	265 V_{ac}
Output current Tolerance	347 mA	356 mA	372 mA
Number of LED		6	
Power Factor	0.975	0.944	0.902
Efficiency without TRIAC dimming	80.90%	81.50%	81.20%

3.2 Schematic

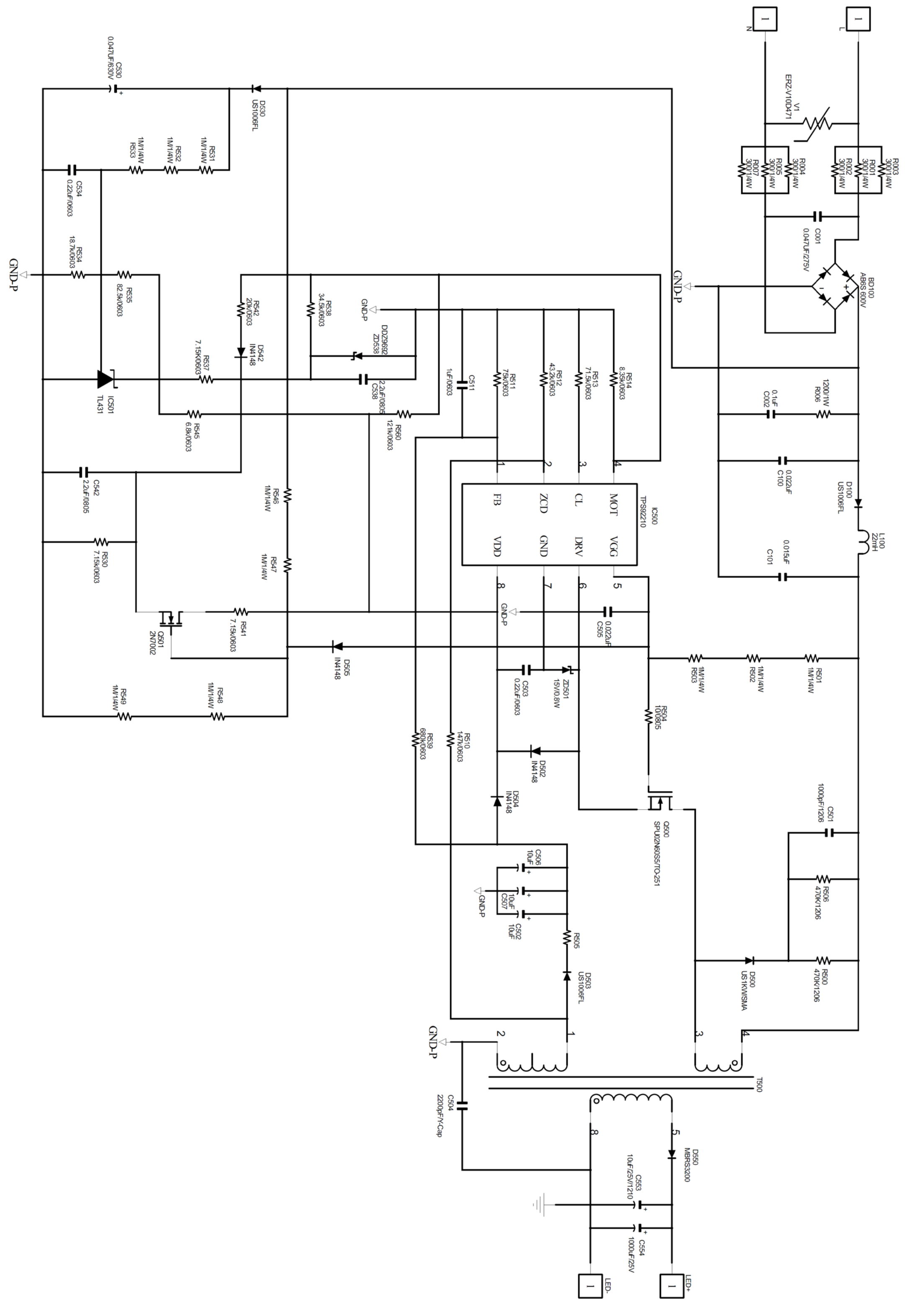


Figure 4. PMP4304A Schematic

3.3 PCB Layout

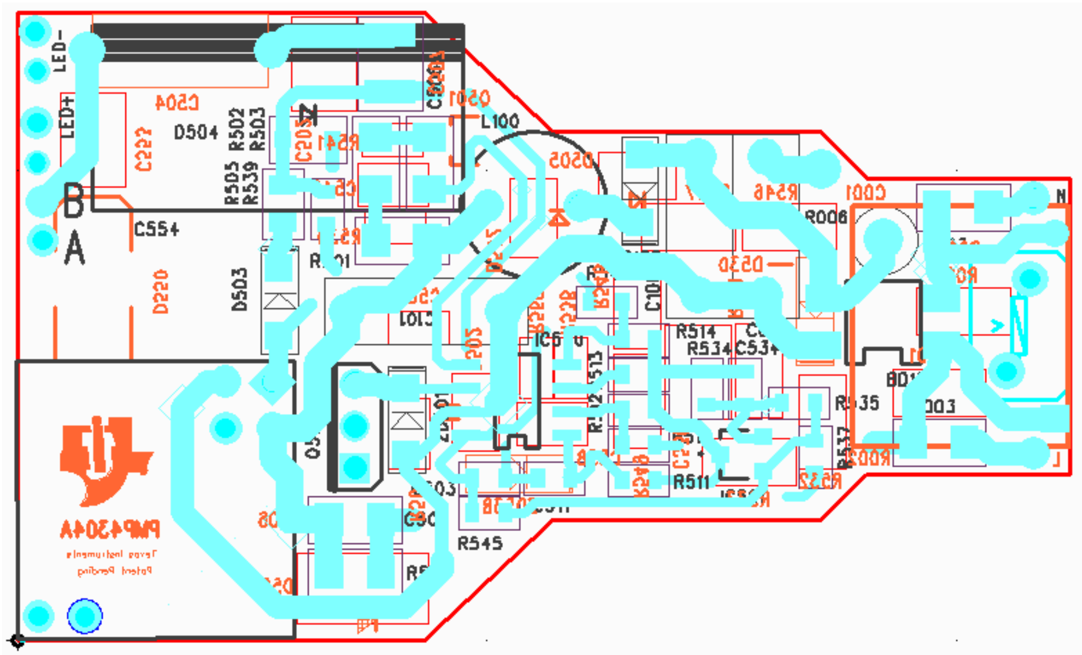


Figure 5. Circuit Board Assembly Drawing — Layer 1

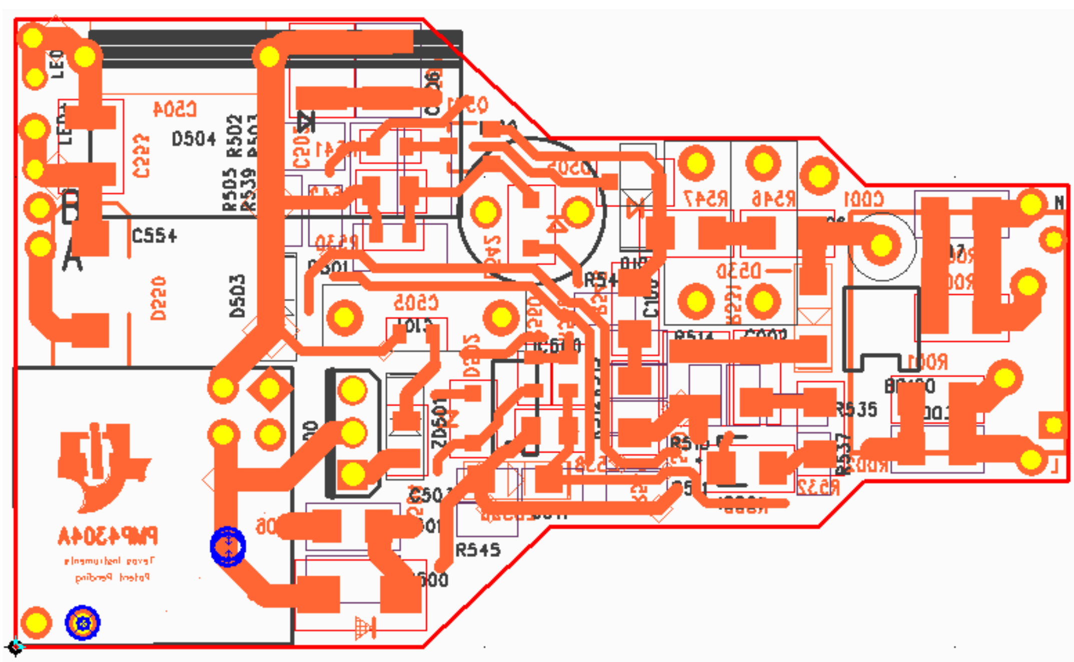


Figure 6. Circuit Board Assembly Drawing — Layer 2

3.4 Efficiency

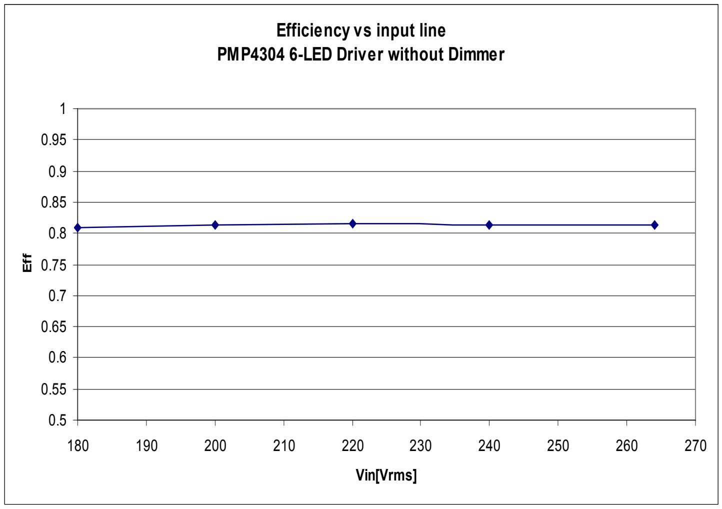


Figure 7. Efficiency vs. Input Voltage

3.5 Line Regulation

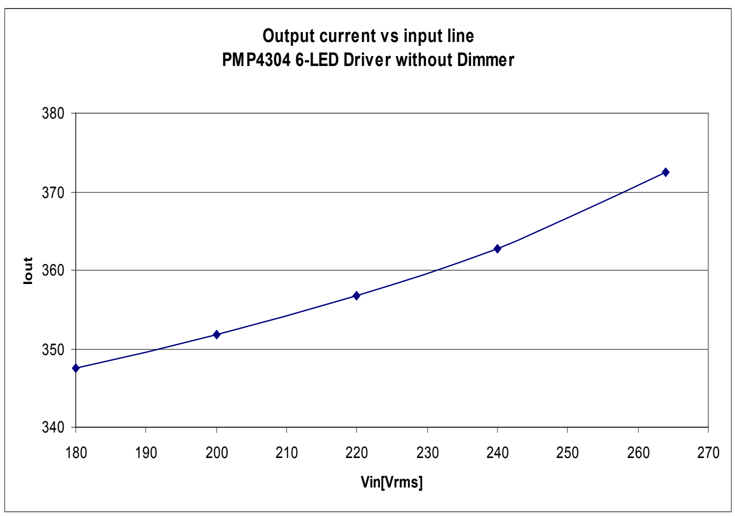


Figure 8. Output Current vs. Input Voltage

3.6 Power Factor

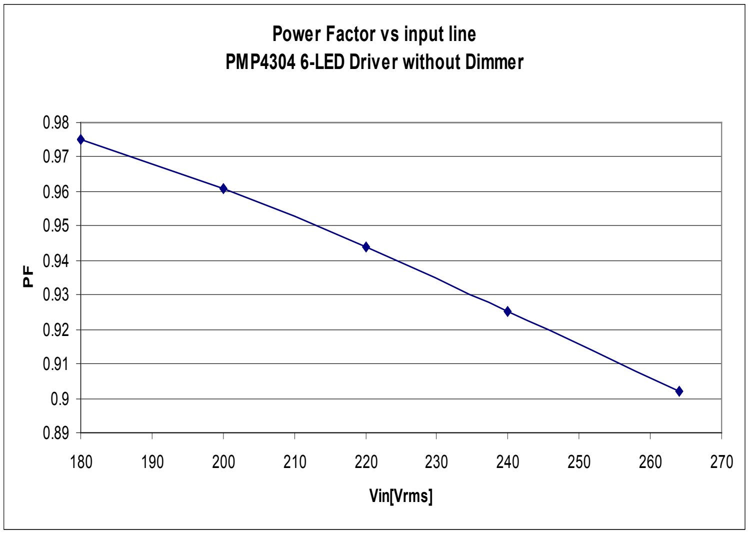


Figure 9. Power Factor vs. Input Voltage

3.7 TRIAC Dimming Performance

Table 2. Output Current with Different Dimmer Conduction Angle

Vin	Io [mA]	T/2 [mS]	Ton [mS]	Angle
220	20	8.333	1.92	41.47366
220	54.79	8.333	2.64	57.02628
220	81.04	8.333	3.24	69.9868
220	107.09	8.333	3.9	84.24337
220	138.8	8.333	4.6	99.36397
220	182.3	8.333	5.2	112.3245
220	236	8.333	5.8	125.285
220	270.71	8.333	6.32	136.5175
220	303.62	8.333	6.8	146.8859
220	333.25	8.333	7.28	157.2543
220	350.66	8.333	7.76	167.6227

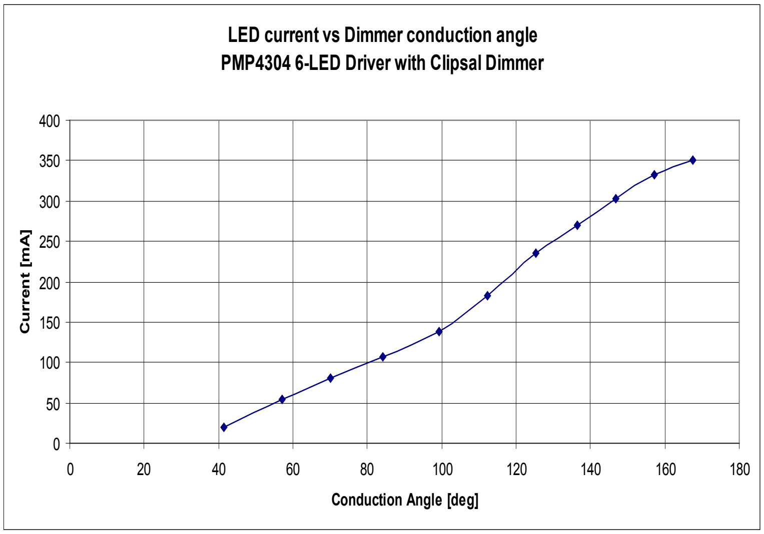
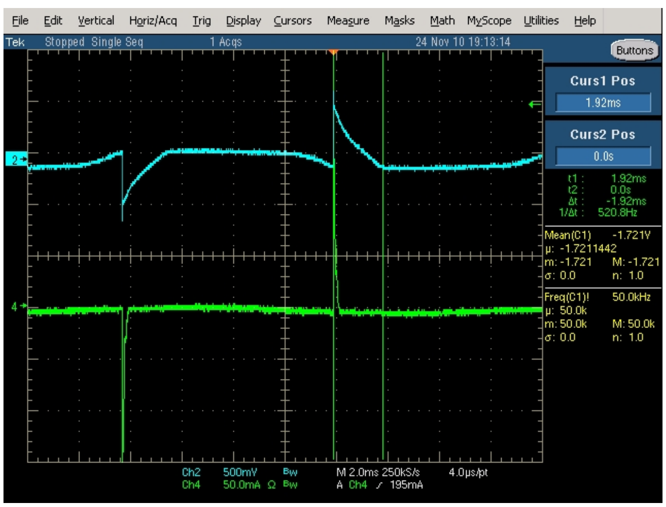
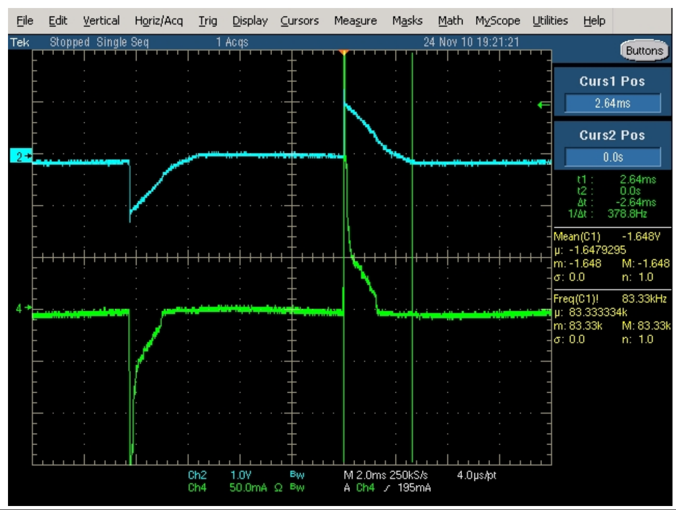
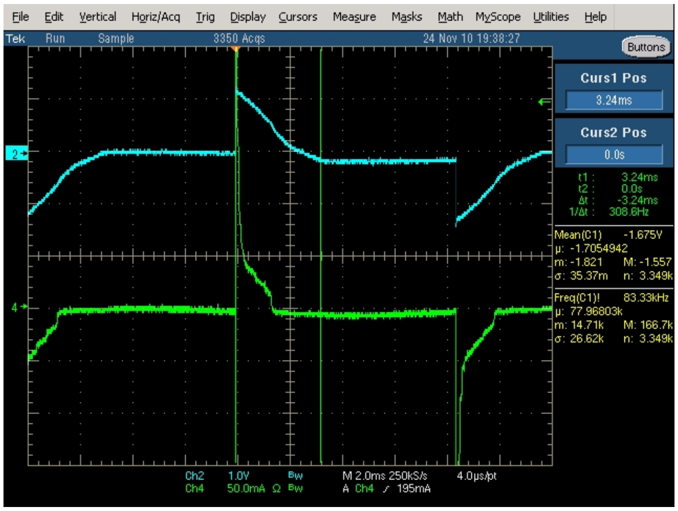


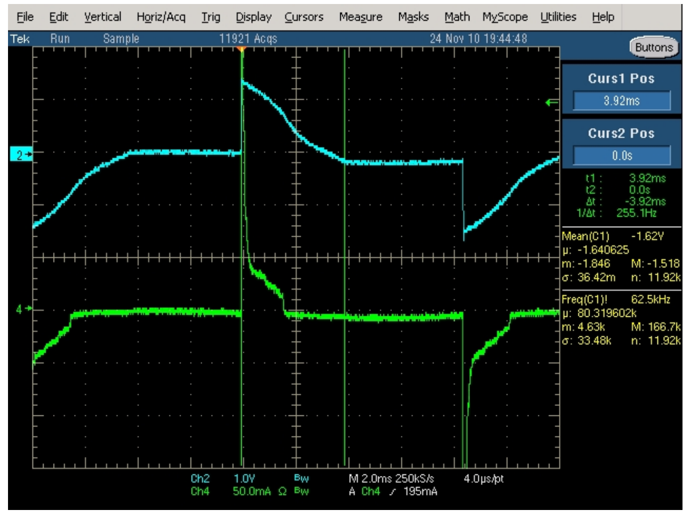
Figure 10. Output Current vs Dimmer Conduction Angle

	
Vin = 220 Vac, Phase = 41.5 deg Upper: Vin / Lower: Iin	Vin = 220 Vac, Phase = 57 deg Upper: Vin / Lower: Iin



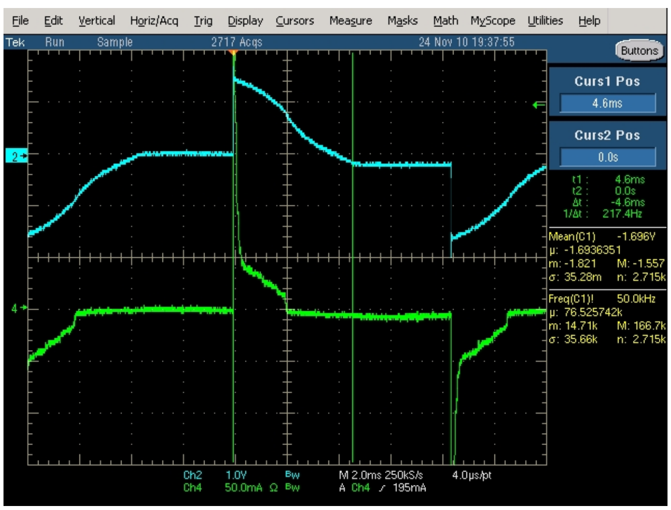
Vin = 220 Vac, Phase = 70 deg

Upper: Vin / Lower: Iin



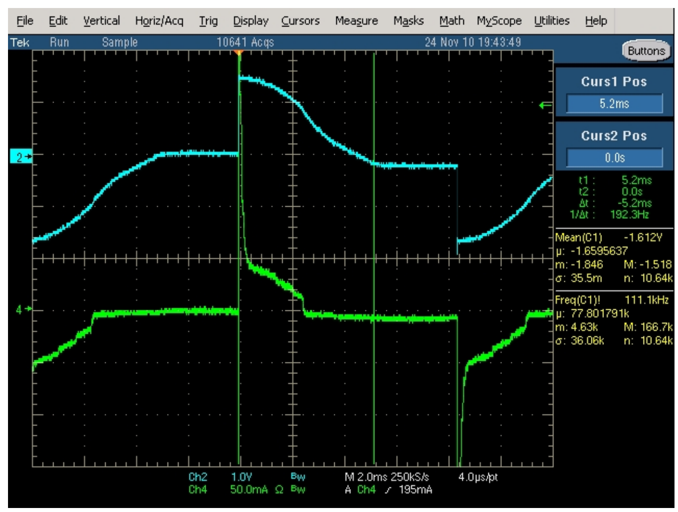
Vin = 220 Vac, Phase = 84 deg

Upper: Vin / Lower: Iin



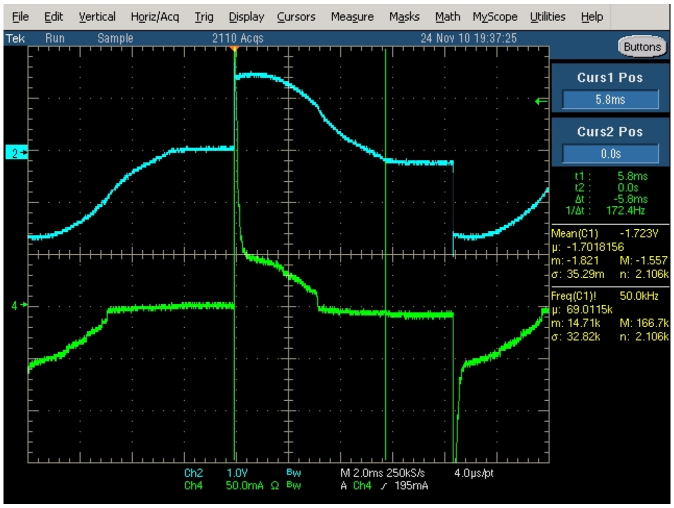
Vin = 220 Vac, Phase = 99 deg

Upper: Vin / Lower: Iin



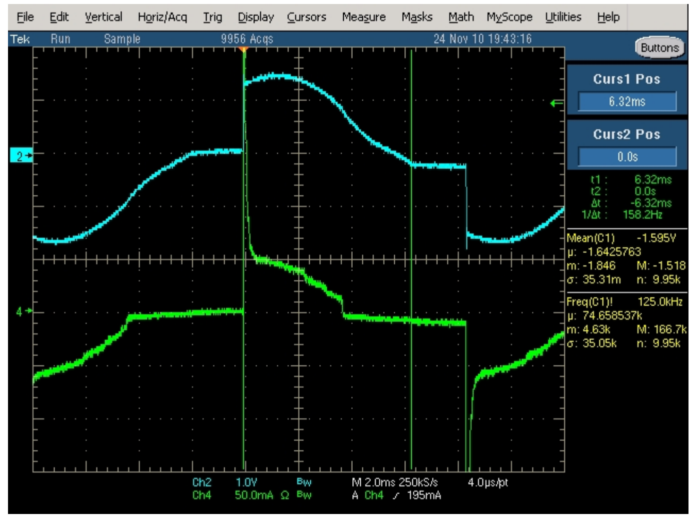
Vin = 220 Vac, Phase = 112 deg

Upper: Vin / Lower: Iin



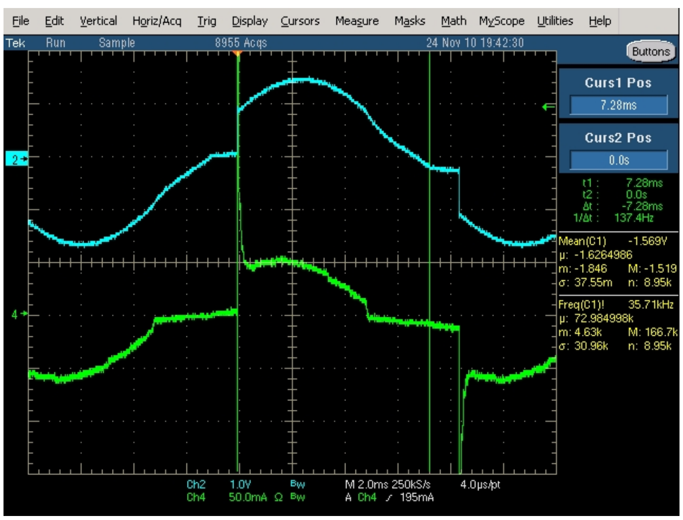
Vin = 220 Vac, Phase = 125 deg

Upper: Vin / Lower: Iin



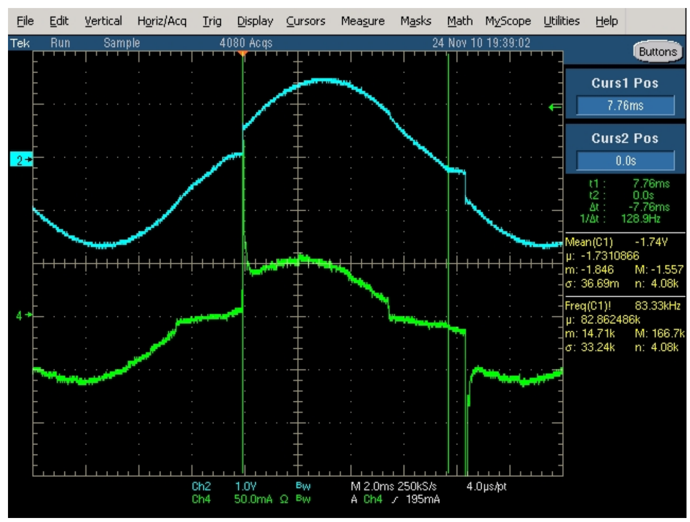
Vin = 220 Vac, Phase = 137 deg

Upper: Vin / Lower: Iin



Vin = 220 Vac, Phase = 157 deg

Upper: Vin / Lower: Iin



Vin = 220 Vac, Phase = 168 deg

Upper: Vin / Lower: Iin

Figure 11. Input Current vs. Input Voltage at Different Conduction Angle

4 Conclusion

This document shows the analysis of the primary side constant power controlled single stage flyback LED driver, and the benefit of using the primary side control based on the TPS92210. Meanwhile, a practical 7-W design has been implemented. It shows the TPS92210 solution benefits with small form factor, low cost, high PF, and high TRIAC dimming performance.

Reference

1. TPS92210 Datasheet, LED LIGHTING POWER CONTROLLER

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