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.

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:

\[ V_{in}(wt) = \sqrt{2} \cdot V_{rms} \cdot \sin(wt) \]  

(1)
Then the average input current can be calculated as Equation 2.

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

(2)

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

$$P_{in} = \frac{\pi}{w} \cdot \int_{0}^{\pi/w} \text{sin}^2(wt) \cdot dt \cdot \frac{V_{rms}^2 \cdot T_{on}^2 \cdot f}{\pi / w} = \frac{1}{2} \cdot \frac{V_{rms}^2 \cdot T_{on}^2}{L} \cdot f$$

(3)

In the primary side constant power scheme:

$$V_{rms} \cdot T_{on} = K$$

(4)

In Equation 4, K is a constant and the value of K depends on 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.

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

(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 $V_{in_{-rms}} = x$, the relationship between $T_{on}$ and $V_{in_{-rms}}$ can be calculated as below.

$$T_{on}(x) = \frac{3}{\left(2 \times 10^6\right)} \frac{3}{R_{514}} \left(\frac{V_{dd} - 3}{R_{560}}\right) - \frac{V_{f} + V_{f} \cdot R_{535}}{R_{534}} - \frac{\sqrt{2} \cdot R_{535}}{R_{538} + R_{537}} - 3$$

(6)

If:

$$A = \frac{3}{R_{514}} - \frac{V_{dd} - 3}{R_{560}}$$

$$B = \frac{3 \cdot 10^6}{R_{538} + R_{537}}$$

$$C = \frac{3}{2 \cdot 10^6}$$

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

$$T_{on}(x) = \frac{C}{A + B \cdot x}$$

(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. Ton Time vs. Vin_rms and Input Power vs. Vin_rms](image)

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

#### 3.1 Design Specification

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

![Efficiency vs. Input Voltage](image)

Figure 7. Efficiency vs. Input Voltage

3.5 Line Regulation

![Output Current vs. Input Voltage](image)

Figure 8. Output Current vs. Input Voltage
3.6 Power Factor

![Power Factor vs input line](image)

Figure 9. Power Factor vs. Input Voltage

3.7 TRIAC Dimming Performance

<table>
<thead>
<tr>
<th>Vin</th>
<th>Io [mA]</th>
<th>T/2 [mS]</th>
<th>Ton [mS]</th>
<th>Angle</th>
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<tr>
<td>220</td>
<td>20</td>
<td>8.333</td>
<td>1.92</td>
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<td>220</td>
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<td>220</td>
<td>350.66</td>
<td>8.333</td>
<td>7.76</td>
<td>167.6227</td>
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</table>
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: lin

Vin = 220 Vac, Phase = 84 deg
Upper: Vin / Lower: lin

Vin = 220 Vac, Phase = 99 deg
Upper: Vin / Lower: lin

Vin = 220 Vac, Phase = 112 deg
Upper: Vin / Lower: lin
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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