PMP6022
120 VAC, 7W, PFC, Wall Dimmable AC Linear
TPS92411 Floating Switch LED Driver Test Report

July, 2014
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Floating Switch LED Driver Test Report

1 Introduction

The TPS92411 reference design is a discrete linear Power Factor Corrected current regulator utilizing three TPS92411s using no magnetics. Unlike other linear solutions the TPS92411 design utilizes energy storage capacitors to achieve low flicker, high LED utilization. The TPS92411 determines if there is enough voltage available to supply current to its LED string or, if there isn’t enough voltage, bypass it. If the three LED stack voltages are setup as a ratio of four, two, and one there will be eight different switch states which relate to eight different total string voltages the current regulator sees. The highest voltage the current regulator will see is the lower stack voltage plus the designed headroom for the current regulator. This design uses LEDs with a Vf of 22 volts at an input power of approximately 8.7 watts, power factor is above 0.9 and THD below 20%.

2 Description

This reference design has an input voltage range from 85-135 VAC though a more optimal range is 108 to 132 VAC. The current regulator is a discrete circuit that provides power factor correction, input line regulation and triac detect with a DC offset circuit to prevent triac dimmer misfire. It uses 22 volt LEDs in series/parallel combinations to satisfy the current requirement and provide the necessary stack voltages. The lower stack consists of three 22 volt LEDs in parallel. The middle stack has twice as many LEDs to double the stack voltage, 44 volts, and the upper stack utilizes 12 22 volt LEDs creating a stack voltage of 88 volts. This gives the four, two, and one ratio desired for this design, though not necessary.

2.1 Typical Applications

This design is suitable for a variety of light bulbs, can lights or other LED lighting application using an AC input. It can be adjusted for higher or lower output power to suit different power levels.

2.2 Features

2.2.1 Feature description

This section describes certain features of the reference design board and some considerations of each.

2.2.1.1 Rsns pin

The Rsns pin tells the TPS92411 when to close its internal MOSFET bypassing the current going to its LED stack and energy storage capacitor. The internal current source is 4 uA and internal trip threshold is 0.210 volts. A 1 Mohm Rsns resistor will cause the TPS92411 to close as it crosses 3.79 volts from its common to the system common. The threshold voltage is set high enough to prevent the current regulator from dropping out, it is the voltage headroom for the current regulator. It has a negative effect on efficiency if set too high and can cause interruptions in the power factor corrected current waveform if set too low. The Rsns pin functions as the voltage source to the TPS92411 is falling.
2.2.1.2 **Rset pin**

The Rset pin tells the TPS92411 when to open its internal MOSFET allowing current to flow to its LED stack and energy storage capacitor. It uses half the current through the Rsns resistor to trip an internal 1.25 volt threshold. When the Rset voltage rises and crosses the 1.25 volt internal threshold, because the Rsns current is high enough, the TPS92411 MOSFET opens allowing current to flow to the LEDs and storage capacitor. The Rset pin functions as the voltage source to the TPS92411 is rising.

2.2.1.3 **Slew controlled drain connection**

This is the connection to the internal MOSFET that allows the TPS92411 to bypass its LED section, MOSFET closed, or allows the current to power its LED stack and charge the energy storage capacitor, MOSFET open. The MOSFET state is set by the Rsns and Rset thresholds via an internal RS latch. The drain connection is slew rate controlled to reduce conducted EMI. The MOSFET also closes faster than it opens to prevent the current regulator from dropping out.

2.2.1.4 **Over Voltage Protection**

The TPS92411 used on this design has built in over voltage protection. If the LED section opens the current regulator will continue to charge the energy storage capacitor beyond the LED section voltage. When the voltage reaches 100 volts the TPS92411 closes bypassing the open LED section. As the energy storage capacitor discharges the TPS92411 will open again until reaching the 100 volt threshold. The hysteresis is four volts.

2.2.1.5 **Power factor correction**

A simple current regulator using a MOSFET, Q1, a current sense resistor, R15 and a transistor, Q2 to regulate current from the rectified AC. The reference to this regulator is a resistor divider from rectified AC, R8 and R13. Note that Q2 collector and emitter are in this divider but will be a fixed voltage which is the Vgs threshold of Q1 plus the Vbe of Q2. The Vgs is small compared to the rectified AC voltage so it will have little effect. The Vbe drop of Q2 will add some DC offset however the line regulation circuit actually overcompensates for that.

2.2.1.6 **Line regulation**

The TPS92411 reference design uses a circuit that averages the rectified AC input and forces the current set point lower as the input voltage rises. A zener diode is part of the circuit to prevent the circuit from interfering with dimming.

2.2.1.7 **Leading edge dim detect and DC offset**

A damper RC is used to prevent the triac from mis-firing when the rising edge of the dimmer occurs. Without a rising edge the maximum voltage on the capacitor is less than four volts. When a triac, leading edge, dimmer is present the voltage across the capacitor is much higher during the rising edge of the dimmer. Some of the energy from the dimmer pulse is stored in another capacitor providing a low DC voltage. This is applied to the PFC current reference which prevents the current from dropping below the triac hold current. This circuit prevents triac mis-fire at the end of each half cycle by keeping current flow through the triac dimmer.
2.2.1.8 EMI control

A capacitor, C7, across the discrete current regulator MOSFET, Q1, along with the TPS92411 slew control allows the reference design to pass conducted EMI with 8dB of margin with only a 0.1 uF capacitor, C2, across rectified AC. Radiated EMI is not an issue with this topology. C2 value could be reduced if less margin is acceptable, or the output power could be increased by lowering R15. The EMI capacitor value is proportional to the input current. Doubling the power would require doubling the capacitor, C2 and the triac damper capacitor would also need to double.

3 Electrical Performance Specifications

Table 1: TPS92411 discrete linear Electrical Performance Specifications

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<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
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<td>Voltage range</td>
<td>Normal operation</td>
<td>108</td>
<td>120</td>
<td>132</td>
<td>V</td>
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<td>Maximum range</td>
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<td>135</td>
<td></td>
<td>V</td>
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<td>A rms</td>
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<td>watts</td>
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<td><strong>Output Characteristics</strong></td>
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<td>Output voltage, upper stack</td>
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<td>V</td>
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<td></td>
<td>V</td>
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<td>Output voltage lower stack</td>
<td>At maximum output</td>
<td>22</td>
<td></td>
<td></td>
<td>V</td>
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Figure 1: TPS92411 discrete linear Schematic
Figure 1: TPS92411 discrete linear Schematic
5 Performance Data and Typical Characteristic Curves
Figures 2 through 23 present typical performance curves for TPS92411 discrete design.

5.1 Efficiency

![Efficiency Graph](image1)

Figure 2: Efficiency

5.2 Line Regulation

![Line Regulation Graph](image2)

Figure 3: Line Regulation
5.3 **Drain voltage of current regulator**

![Figure 4: Current regulator drain waveform (yellow), input current (green)](image)

5.4 **Current sense**

![Figure 5: Voltage at current sense resistor, R15 (yellow)](image)
Figure 6: PFC command, R13 voltage

Figure 7: Current regulator drain voltage during power on, storage capacitors charging
Figure 8: Current regulator drain voltage when forward phase dimming

Figure 9: Voltage on DC offset circuit, C4 holding command up when forward phase dimming
Figure 10: Current reference with DC offset, R13

Figure 11: Current sense voltage while forward phase dimming, R15
Figure 12: Input averaging voltage used for line regulation, C6

Figure 13: Rectified AC, reference for next oscilloscope plots
Figure 14: Upper TPS92411 drain waveform

Figure 15: Middle TPS92411 drain waveform
Figure 16: Lower TPS92411 drain waveform

Figure 17: Series load voltage for linear regulator MOSFET (sum of the LED stacks)
Figure 18: Open upper stack voltage during Over Voltage Protection

Figure 19: Over voltage protection, hysteresis when TPS92411 opens and closes
Figure 20: Upper stack current ripple (10 mV equals 1 mA)

Figure 21: Middle stack current ripple (10 mV equals 1 mA)
Figure 22: Current ripple lower stack (10 mV equals 1 mA)
### 5.5 EMI Performance

The conducted EMI scan peak and average, Quasi-peak measures -8.1 dB for both line and neutral at 150 KHz.

**Figure 23:** Conducted EMI scan peak and average, Quasi-peak measures -8.1 dB for both line and neutral at 150 KHz.
5.6  *TPS92411 test hardware, designed for A19 bulb*

Figure 24: When used in bulb the test point section is removed, right angle connector connects component board to LED board. 0.031" FR4 with copper spreader for heatsinking on LED section

Figure 25: FR4 SMT section including three TPS92411
The following figures (Figure 26 through Figure 27) show the design of the TPS92411 printed circuit board.

Figure 26: Top Layer and Top Overlay (Top view)

Figure 27: Bottom Layer and Bottom Overlay (Bottom view)
## 7 Bill of Materials

Table 2: The TPS92411 discrete linear components list according to the schematic shown in Figure 1

<table>
<thead>
<tr>
<th>REFERENCE DESIGNATOR</th>
<th>QTY</th>
<th>VALUE</th>
<th>DESCRIPTION</th>
<th>SIZE</th>
<th>MFR</th>
<th>PART NUMBER</th>
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<td>0.33µF</td>
<td>Cap, Film, 0.33µF, 250V, +/-10%, Radial</td>
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<td>UHE2A470MPD</td>
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<td>10µF</td>
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<td>Texas Instruments</td>
<td>TPS92411PDBV</td>
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Only those TI components that TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components that have not been so designated is solely at Buyer's risk, and Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.