Application Report
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Line Undervoltage and Overvoltage Protection for TPS92210-Based LED Drivers

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Power Management

ABSTRACT

Increasing demands for electric power have caused existing power grids to become overloaded. Overloading, inadequate power generation, and inadequate distribution systems are the main causes of line voltage fluctuations. This application report describes implementation of the line undervoltage and overvoltage protection circuit for TPS92210-based LED lighting driver designs. Basic circuit operation and component value modifications required to set desired undervoltage and overvoltage cut-off limits are described here.

Line undervoltage and overvoltage protections, which can be realized using ultra-low-cost discrete components or low-power operational amplifiers, are required to protect the LED driver from high input currents when operating at low input voltage, and significant voltage stress on power MOSFET during operation at high input voltage. It is necessary to disable the driver when the line AC input goes outside a normal operating range, using one of the control pins on the TPS92210.

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1 Need for Undervoltage and Overvoltage Protection

Output power of an LED Driver is given by:

$$P_{OUT} = V_{OUT} \times I_{OUT}$$

where

- P_{OUT} = Output Power
- V_{OUT} = Voltage across the LED String
- I_{OUT} = Current through the LEDs (1)

Assuming similar system efficiency at constant output power across different line inputs, a decrease in input voltage corresponds to an increase in input current and vice-versa. Hence, when line input voltage drops, the input current to the LED driver increases, while maintaining the same output power. This increased input current may result in heating of components or even permanent damage (when this current exceeds device current rating) and reduced lifetime of the device.

Similarly, electronic devices and components (like MOSFETs, diodes, capacitors, and so forth) are rated for a maximum voltage. Operation beyond these limits may reduce the lifetime or may even cause permanent damage to the device. In an LED driver, maximum voltage stress on power MOSFET, as given in Equation 2, is the sum of peak input voltage, output voltage reflected from secondary during Toff, and voltage spike due to leakage inductance of transformer primary-side winding.

$$V_{FET(max)} = V_{in(rms)} \times \sqrt{2} + N \times (V_{out} + V_D) + V_{leakage} \tag{2}$$

With leakage inductance ringing assumed to be approximately 100 V maximum, voltage on primary-side FET drain may exceed its specifications in the event of an overvoltage on the universal line input. In such cases, input undervoltage and overvoltage protection is needed to prevent permanent damage to the components. It is required to inhibit switching/power transfer to the load when operating outside the safe operating range.

2 About TPS92210

The TPS92210 is a natural power factor correction (PFC) light-emitting diode (LED) driver controller with advanced energy features to provide high efficiency control for LED lighting applications. This controller has the following salient features:

- Flexible operation modes
  - Constant on-time enables single-stage PFC implementation
  - Peak primary current
- Cascoded MOSFET configuration
  - Fully-integrated current control without sense resistor
  - Fast and easy startup
- Discontinuous conduction mode or transition mode operation
- Transformer zero energy detection
  - Enables valley switching operation
  - Helps to achieve high efficiency and low EMI
- Open LED detection
- Advanced overcurrent protection
- Output overvoltage protection
- Line surge ruggedness
- Internal over-temperature protection

The TPS92210 cascode architecture enables low switching loss in the primary side and when combined with the discontinuous conduction mode (DCM) operation ensures that there is no reverse recovery loss in the output rectifier. These innovations result in efficiency, reliability, or system cost improvements over a conventional flyback architecture.

Figure 1 shows a typical application of a TPS92210 based LED driver.

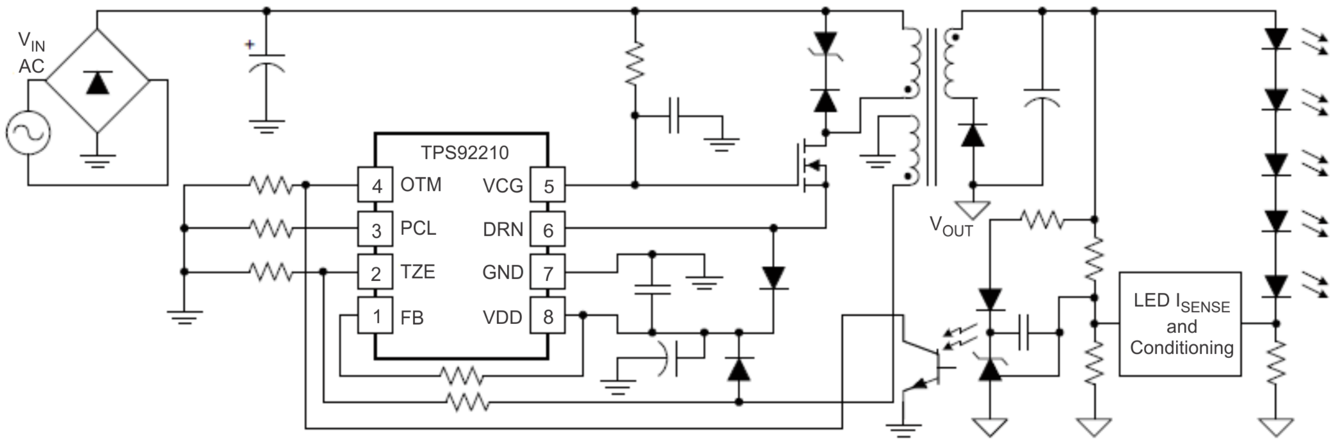

Figure 1. Typical Application Schematic for TPS92210 Based LED Driver

2.1 *Transformer Zero Energy Detection*

The TPS92210 operates in discontinuous mode with the next switching cycle initiated only when the transformer has been completely reset or when its energy is zero. The TZE pin is connected through a resistor divider to the primary-side auxiliary winding for zero energy detection. The transformer zero energy is detected by monitoring the current sourced out of the TZE pin when the primary bias winding of the flyback converter goes negative with respect to ground. It is possible to align the turn-on of the primary switch with the resonant valley of the primary winding waveform to minimize switching losses and optimize efficiency.

When the power MOSFET turns off, the transformer secondary runs out of energy after some time, and ringing is observed on the primary MOSFET drain, as shown in Figure 2. The TZE pin detects this zero cross at the primary auxiliary winding and aligns the next switching cycle with the resonant valley. Figure 2 shows the waveform on the high-voltage MOSFET drain, the voltage at the TZE pin and the primary transformer current.

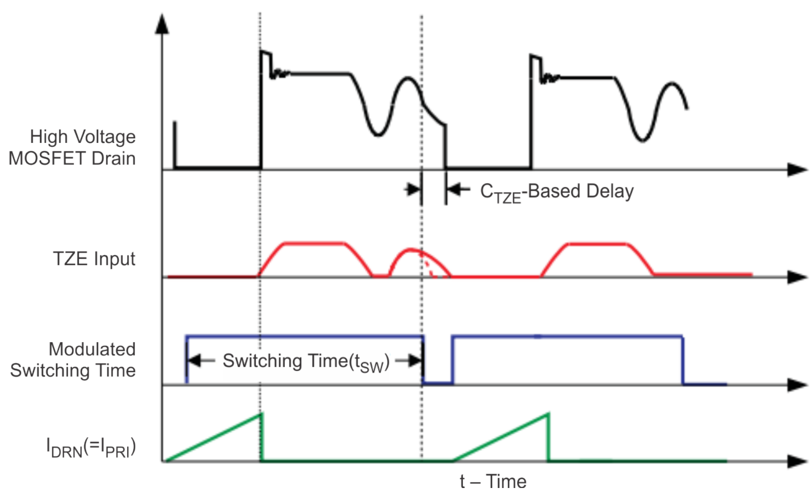

Figure 2. TZE and HVMOSFET Drain Voltages for Valley Switching

It is required to fulfill the following three conditions before initiating a new switching cycle:

- The time since the last turn-on edge must be equal to or greater than the time that is requested by the feedback processor as determined by the feedback current, I_{FB}.
- The time since the last turn-on edge must be longer than the minimum period that is built into the device (nominally 7.5 µs which equals 133 kHz).
- Immediately following a high-to-low zero crossing of the TZE pin voltage, or, it has been longer than $t_{WAIT,TZE}$ since the last zero crossing of the current has been detected.

This application report describes a circuit which violates the third condition to prevent initiation of the next switching cycle in an event of undervoltage or overvoltage at the input.

3 Application Schematic

Figure 3 shows the circuit for undervoltage and overvoltage protection in TPS92210-based LED driver controllers, using low-power op amp TLC27L4:

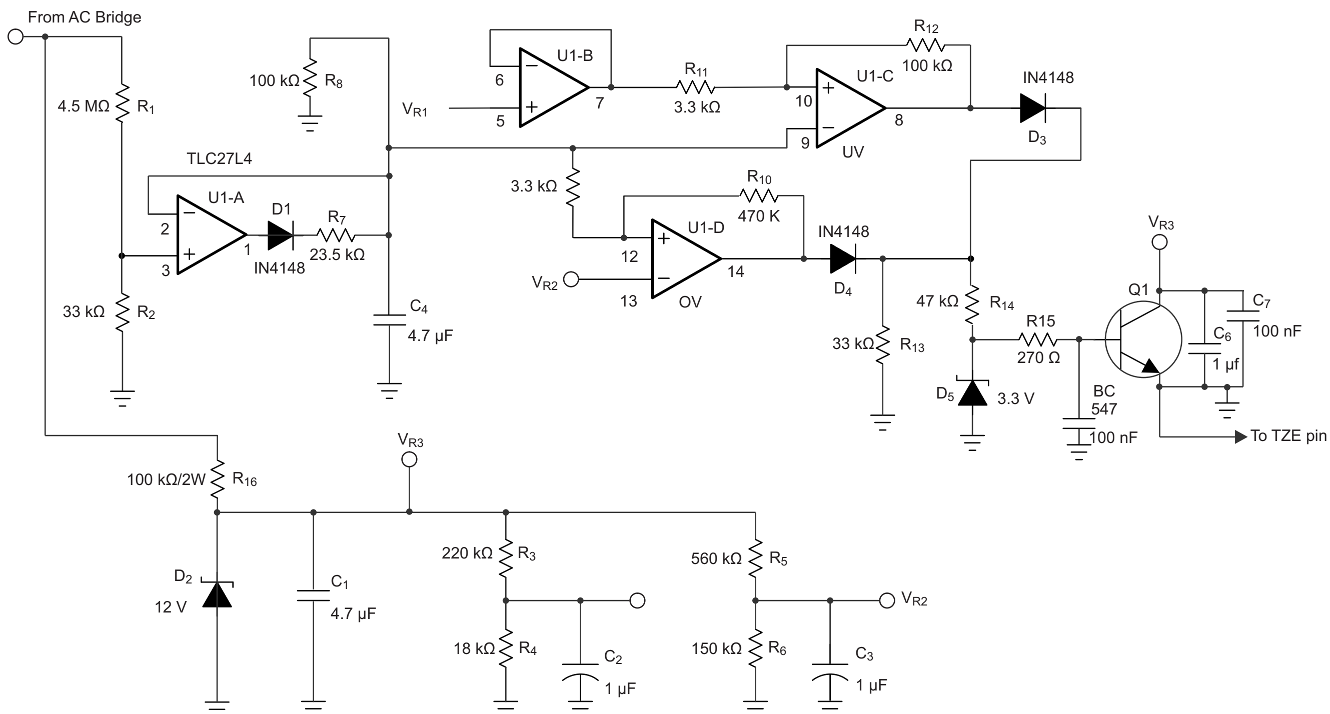

Figure 3. Schematic for Input Undervoltage and Overvoltage Protection

In case the line input is outside the safe operating range, this circuit forces a DC voltage on the TZE pin to prevent the occurrence of next zero crossing, thereby violating a necessary condition (third condition) and successive switching cycle. Hence, no power is transferred to the Load (LEDs). When in safe operating range (say, 90–265 VAC input voltage), this circuit does not output this DC voltage on the TZE pin, and there are usual occurrence of zero crosses and switching cycles to deliver power to the output.

4 Circuit Operation

Figure 3 shows the schematic for this protection circuit. Line input voltage at bridge rectifier output (pulsating DC) is input to this protection circuit. This pulsating input is clamped at 12 V with zener D2, and further reduced proportionately using resistors R3 and R4 (for undervoltage protection) and R5 and R6 (for overvoltage protection). The 12-V bias also powers up TLC27L4 (U1), a precision quad single supply micro-power operational amplifier used in this circuit. It is required to use a micro-power opamp, since this circuit is powered up from 12-V zener voltage, which is current limited at low-line inputs. If this opamp is replaced with a greater supply current device, it is possible to observe erratic on-off cycles at low input voltages (30–50 VAC). U1-A works as a peak detector, generating a DC voltage on capacitor C4, which is proportional to $V_{in(rms)}$. U1-B buffers this DC voltage and U1-C outputs an error signal at the moment the peak detector voltage goes below undervoltage reference (VR1). Similarly, U1-D compares peak detector output with overvoltage reference (VR2) to provide a HIGH output as an error signal when $V_{in(rms)}$ exceeds the overvoltage trigger threshold. Outputs of U1-C and U1-D are clamped at 3.3 V with zener D_5, and then buffered with BJT Q1 before being fed to the TZE pin. Hysteresis of approximately 5 V (input RMS voltage) is introduced using resistors R10 and R12, to prevent false triggering at boundary limits. Due to use of small input capacitor C4 in this LED driver, this hysteresis becomes even more important at undervoltage cut-off points, as input current is larger at lower AC mains, and the action of switching the LED driver ON/OFF immediately changes DC bus voltage. This is also the reason why we use a smaller R_{12} (as compared with R_{10}) to add a greater hysteresis at the undervoltage trip point.

5 Calculations

Assume the RMS line input undervoltage and overvoltage trip points as $V_{in(uv)}$ and $V_{in(ov)}$, respectively.

For RMS line input voltage $V_{in(rms)}$, peak voltage at non-inverting input (pin 3) of U1-A is given by:

$$V_{in(U1-A)} = \frac{V_{in(rms)} \times \sqrt{2} \times R_2}{R_1 + R_2} \tag{3}$$

Due to negative feedback, the same voltage is generated at the output of peak detector. Values of R_7 and C_4 are selected such that transients at input are rejected, while peak detecting the 100-Hz input voltage.

From the 12 V generated using D_2, R_3, and R_4 determine the undervoltage trigger threshold, while R_5 and R_6 determine the overvoltage trigger threshold. These thresholds are set at 1 V and 2.5 V, respectively. Thus, at undervoltage trigger point,

$$V_{UV} = 1\,V = \frac{12\,V}{R_3 + R_4} R_4 \tag{4}$$

And at overvoltage trigger point:

$$V_{OV} = 2.5\,V = \frac{12\,V}{R_5 + R_6} R_6 \tag{5}$$

For these values of undervoltage and overvoltage cut-off thresholds, we get resistor values as R_3 = 220 kΩ, R_4 = 18 kΩ, R_5 = 560 kΩ and R_6 = 150 kΩ.

These trip thresholds are inputs to U1-C and U1-D, such that when peak detector output deviates from normal operating range voltage, opamp outputs are triggered HIGH, indicating error, and hence force a DC voltage on TPS92210's TZE pin through transistor Q1 in emitter-follower configuration. Since TZE input of TPS92210 is continuously being scanned for valley transitions, forcing of this DC voltage inhibits next switching cycles, until input voltage returns to within normal operating range.

6 Modes of Operation

Table 1 lists the different operating conditions of an LED driver using a protection circuit.

Table 1. Different Operating Conditions of LED Driver with use of Protection Circuit

Input Range of Operation	AC Input (V)	U1–C Output	U1–D Output	TZE Pin Input	LED Driver Status
Undervoltage	< 85	High	Low	DC voltage forced	Off
Normal operating range	85–260	Low	Low	Normal operation	On
Overvoltage	> 260	Low	High	DC voltage forced	Off

7 References

- TPS92210 Constant-On Time Driver Controller with Cascoded MOSFET for LED Lighting datasheet (SLUS989).
- TLC27L4 Quad Precision Single Supply µPower Operational Amplifier datasheet (SLOS053).

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