AND8462/D

Tips and Tricks for Optimizing NCL30000 based LED Drivers

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APPLICATION NOTE

The NCL30000 is a flexible critical conduction mode (CrM) flyback controller intended for LED Lighting applications where high power factor is required. There are several demo boards available from ON Semiconductor which illustrate how the NCL30000 can be used in practical power supply applications. Some LED driver power supply designs have special requirements or need additional features not covered in the existing demo boards and application notes. This document covers some ideas to enhance performance in practical LED driver solutions.

Tip 1: Overload and Transformer Leakage Inductance

Under certain application situations, an offline LED driver may inadvertently have the outputs shorted together. This may also occur as part of a safety qualification regime. Depending on the transformer parameters, a short circuit may result in high component stress.

LED drivers based on the NCL30000 controller operating in CrM rely on information derived from the bias winding to signal when it is time to start the next switching cycle. The NCL30000 maintains CrM operation by monitoring the bias winding via the Zero Current Detection (ZCD) input. Typically the voltage at this pin falls to a low level at the end of a switching cycle when the transformer has demagnetized and the power switch is turned on once again. Depending on the design of the transformer and the magnitude of the leakage current, it may be necessary to add a minimum off time delay circuit to further limit the power under a short circuit condition.

Leakage inductance, or uncoupled flux, associated with the transformer secondary winding slows the rate of rise of current as a function of the load on the winding. Under short circuit conditions the bias winding is lightly loaded compared to the main secondary winding and as such experiences a higher rate of voltage rise. The leakage inductance between these two secondary windings introduces a resonant behavior due to the difference in relative voltage. As the windings normalize a ringing waveform can appear on the bias winding where the amplitude is dependant on leakage inductance.

Figure 1 below shows the bias winding voltage of a low leakage inductance transformer with the LED driver under a short circuit condition. The negative voltage shown corresponds to the on-time of the power FET which then becomes positive after the FET turns off. The transformer does not demagnetize due to the shorted output and the bias winding voltage remains above 2 V which is above the ZCD threshold. Since no ZCD event is detected, after approximately 170 μs, the start timer within the NCL30000 initiates a new switching cycle. So normally under a short circuit event, the controller effectively operates in a skip mode resulting in a low duty cycle and reduced component stress. If and when the short is removed, the controller returns to normal operation.

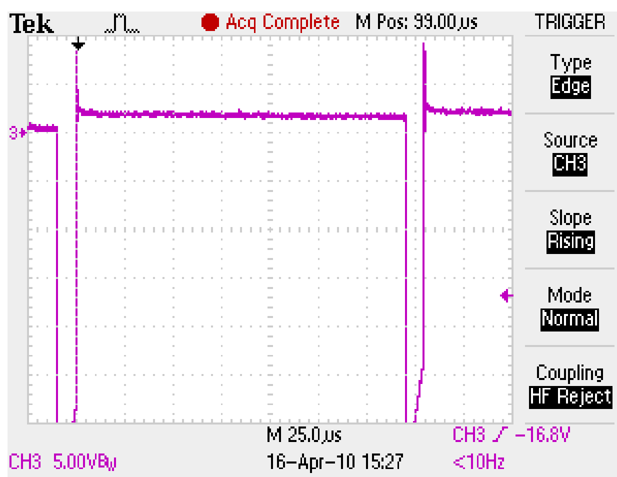

Figure 1. Bias Winding Voltage for Low Leakage Inductance Transformer.

If the transformer leakage inductance is high, the ringing on the bias winding could be interpreted as transformer demagnetization by the ZCD pin thus initiating another switching cycle. Since the transformer is not actually demagnetized the current in the power switch will rise rapidly to the over current threshold. When the current limit function turns the power switch off the transfer of energy to the secondary begins at a higher level stimulating ringing in the bias winding. The cycle repeats itself at a very high rate. The high current and fast switching rate results in increased power dissipation. Figure 2 shows the bias winding voltage of a high leakage inductance transformer under short circuit. Note the higher switching frequency.

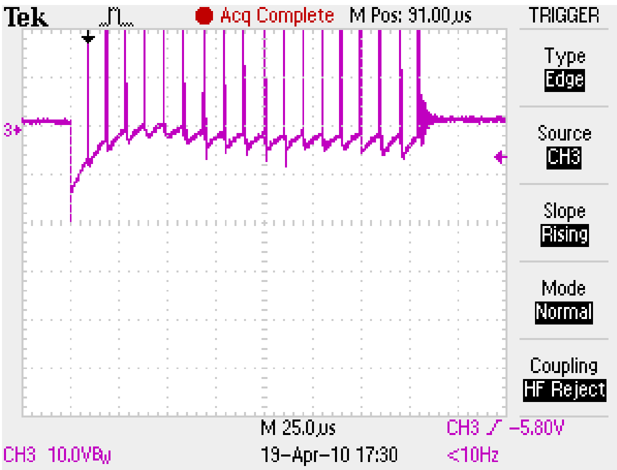

Figure 2. Bias Winding Voltage for High Leakage Inductance Transformer

Low transformer leakage inductance minimizes the resonance and allows the bias winding to dampen very quickly without improperly triggering the ZCD function. Unfortunately producing a transformer with low leakage inductance is not always possible. In these circumstances, some measure to prevent the power switch from turning back on prematurely can ensure proper CrM operation by allowing proper detection of transformer demagnetization.

The circuit shown in Figure 3 below performs a masking or minimum off-time function which blocks the ZCD function during the ringing on the bias winding immediately after the power switch turns off. Capacitor Ca charges quickly through resistor Ra and the lower Da diode while power switch Q3 gate drive signal is on. When the gate drive turns off, capacitor Ca retains charge and keeps the voltage on the ZCD above the trigger threshold during the period when there may be ringing on the bias winding. The capacitor quickly discharges through resistor Rb and restores normal bias winding monitoring of transformer demagnetization.

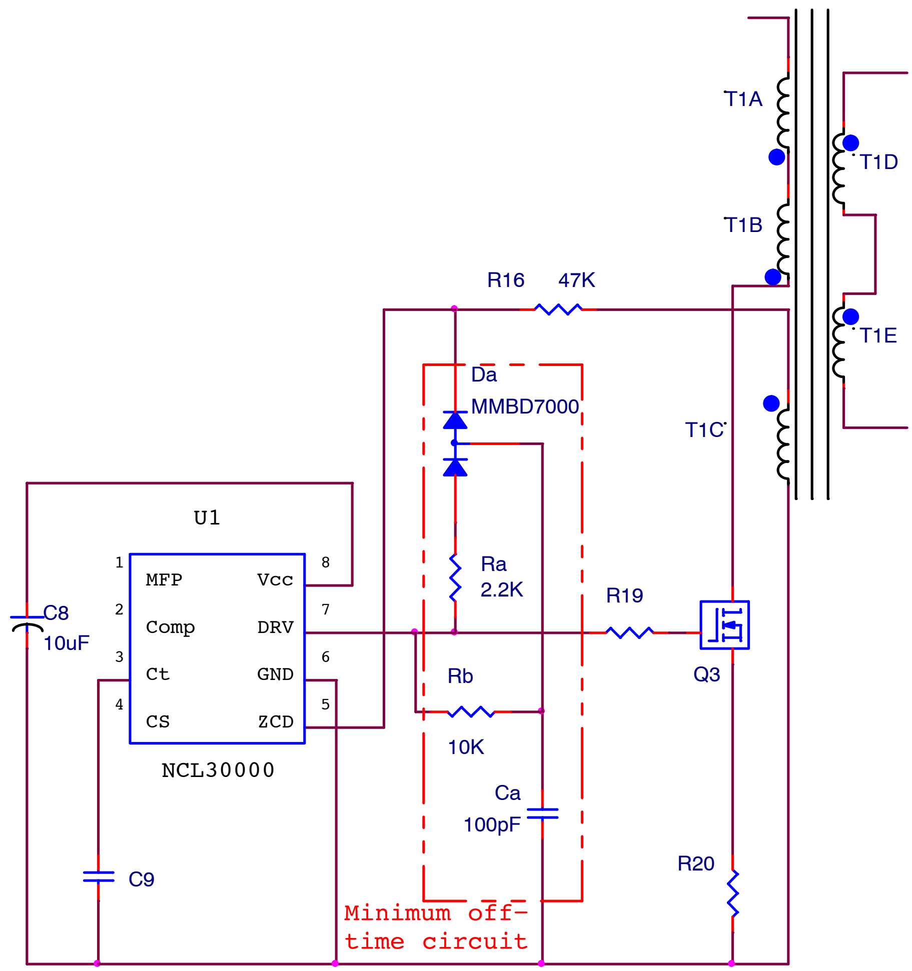

Figure 3. Minimum Off-Time Circuit

Typical masking time is 1 to 4 μs which is well within operating times of LED drivers based on the NCL30000. Values in the circuit can be adjusted to fit particular transformer leakage characteristics. Figure 4 shows the same high inductance transformer operating in short circuit with the minimum off-time circuit shown above. Note the ringing does not erroneously activate the ZCD function and the converter operates at a lower switching frequency with lower dissipation.

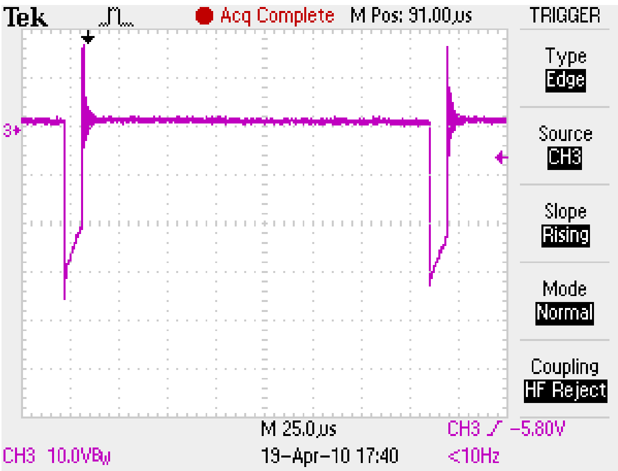

Figure 4. High Leakage Inductance with Minimum Off-Time

Tip 2: Enhanced Over Voltage Protection

A constant current source LED driver requires some way to limit the output voltage at no load. The NCL30000 application circuit includes protection in the event the output is left open or if the output opens due to a fault in the LED string. The open load protection utilizes the current feedback opto-coupler. In some circumstances, additional protection may be required in the event the opto-coupler fails. Note that isolation is required for redundant over voltage protection. A second opto-coupler could be used, but there is another alternative.

The bias winding voltage is proportional to the output voltage. Coupling the bias winding to the Multi Function Pin through a zener diode will provide redundant over voltage protection in the event of feedback opto-coupler failure. The zener diode should be selected such that it not interfere with normal operating voltages and yet provide a limit on output voltage to avoid damaging the output filter capacitor or other components.

The partial schematic from the NCL30000 demonstration board in Figure 5 below shows the connection for the over voltage protection zener in the dashed line box. Inserting a 51 volt zener (BZX84C51LT1G) in the 'R8' position on the PCB limits the output voltage to about 63 volts in the event of failure of the open load protection function.

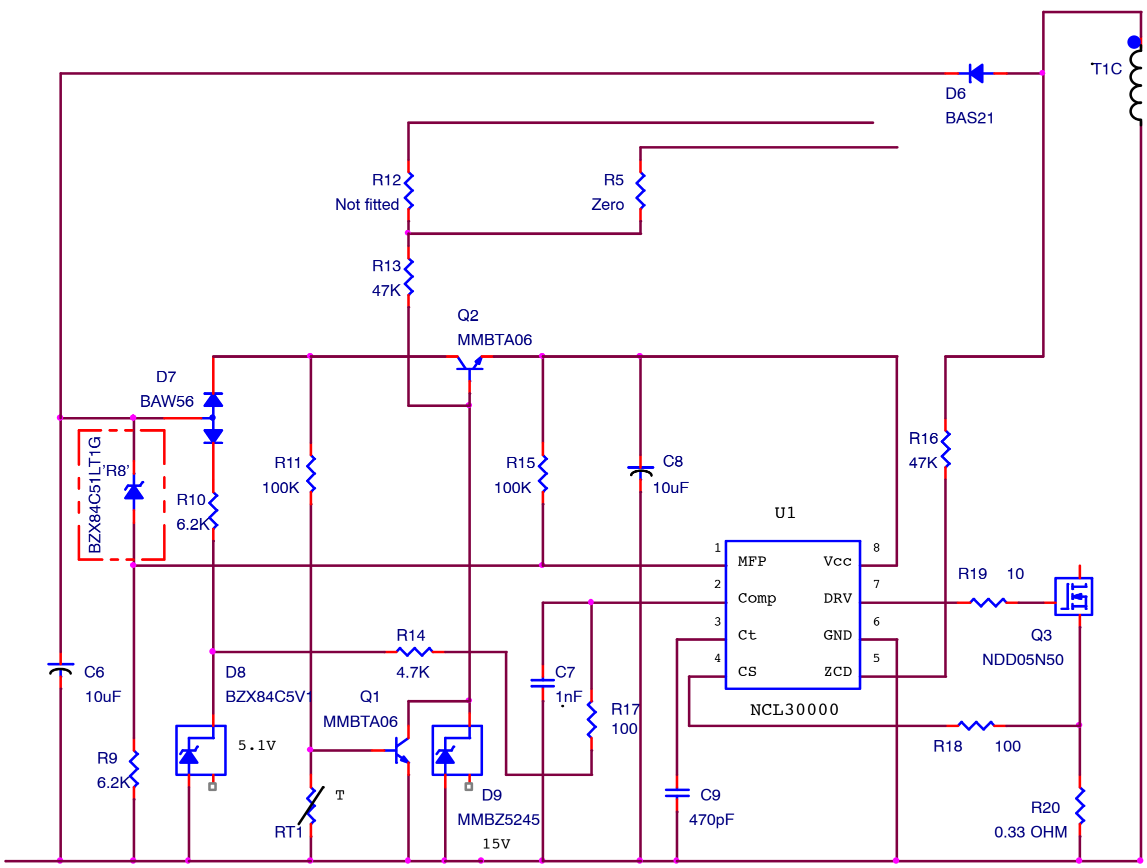

Figure 5. Primary Side Circuitry with OVP and Thermal Shutdown

Tip 3: Thermal Shutdown

Unlike incandescent bulbs, an LED's lumen output drops with increasing junction temperature and above certain junction temperatures, the LED lifetime is reduced. Traditional lighting fixtures are designed to protect internal wiring from excessive temperatures by not transferring heat from the bulb to the enclosure. This is not the preferred situation for LED applications where the drive electronics are enclosed with the LEDs in the same housing and the heat generated from the LEDs couples into the driver. In fact for integral LED bulbs such as PAR bulb the LEDs and power electronics share the same heat sink and are thermally coupled together.

In these types of applications, a thermal shutdown will protect the bulb in the event of misuse or high ambient temperature. Referring to Figure 5, by adding a simple circuit consisting of a positive temperature coefficient (PTC) thermistor (RT1), a bipolar transistor (Q1), and a resistor (R11), a thermal shutdown circuit can be incorporated into the driver to provide enhanced thermal protection.

At a predetermined temperature the thermistor abruptly increases resistance. This biases Q1 on which in turn shuts off the primary bias to the NCL30000 stopping all switching. When the driver cools off the thermistor resistance reduces and Q1 turns off restoring bias power and resuming driver operation.

Shutdown temperature is controlled by selecting a thermistor with a specific transition temperature. Thermistors are available in a wide range of temperatures to match requirements of a particular application.

Tip 4: Improving PF for 277 Vac Applications

The wide range demo board NCL30000LED3GEVB features an input range of 90-305 Vac. The upper boundary extends beyond the normal universal AC range of 90-265 Vac to support 277 Vac commercial lighting applications. Since the standard demo board was designed to meet EMI performance across the entire line voltage range some tradeoffs were made to the filter design. Modifications can be made for applications specifically intended for 277 Vac input to optimize the power factor (PF). In particular, the X capacitors can be reduced and the constant on-time threshold lowered. The differential mode inductors are adjusted to provide similar EMI performance with the smaller X capacitors.

Power factor at 277 Vac increased from typical 0.936 to 0.954 with these changes. The schematic in Figure 6 below shows the changes to the EMI filter and component selection.

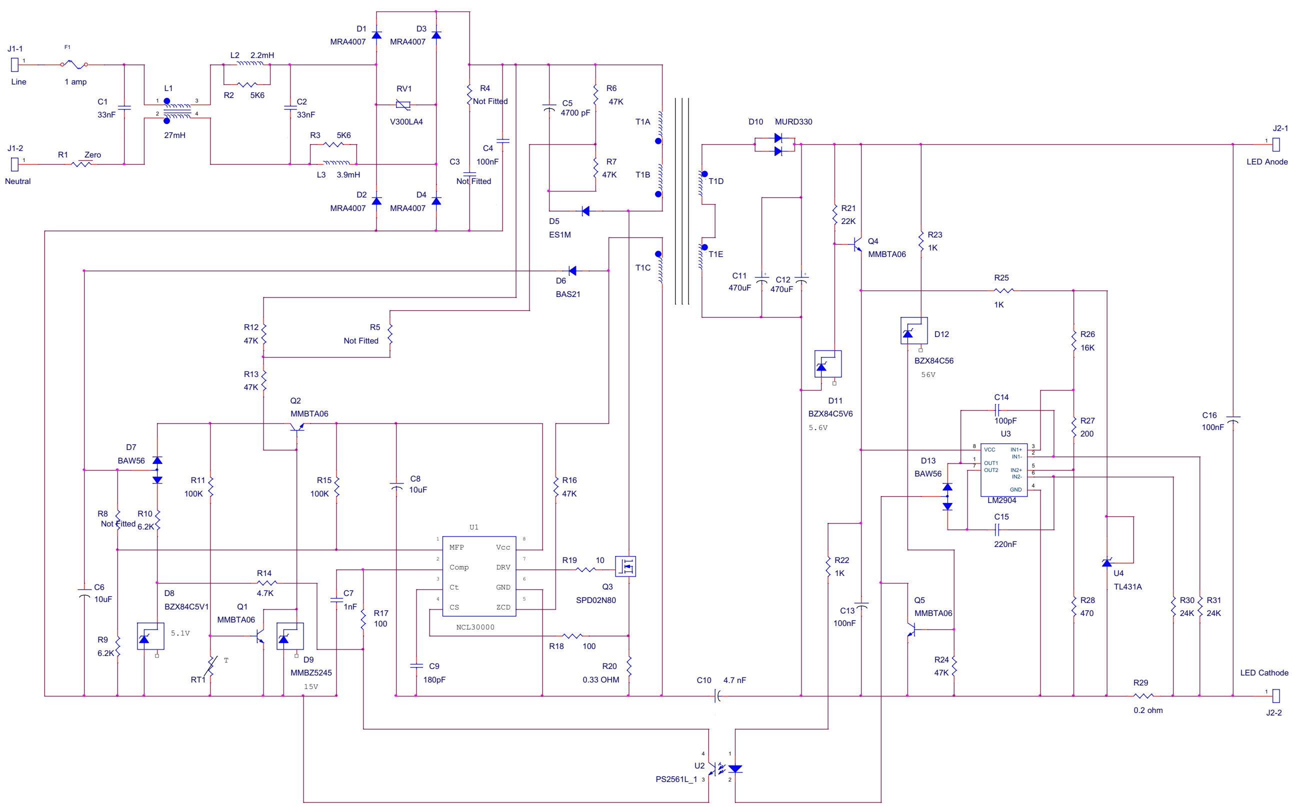

Figure 6. Schematic for 277 Vac optimized EMI filter

Tip 5: Alternate Transformer Bobbin for Isolation

Transformers used in off-line power converters present certain design challenges. Safety guidelines require physical spacing between primary and user accessible secondary circuits. Transformer cores are often deemed 'primary connected' by examiners and as such the secondary bobbin pins and secondary connected components must be spaced some distance from the core which can be difficult in compact designs.

The NCL30000 demonstration boards were designed to provide maximum flexibility for customer use. The transformer secondary winding was configured as two identical windings allowing a series connection for high voltage/lower current or a parallel connection for low voltage/higher current applications. Self or 'flying' leads were used to allow alternate configurations and termination of the secondary connections in optimal locations on the PCB away from the transformer core.

Transformers without flying leads are often preferred in mass production. Designing a transformer for a specific LED driver application can simplify secondary terminations to one configuration. Specially designed transformer bobbins are available which provide the required spacing between primary and secondary connections. Extra distance and barriers support safety agency requirements without needing flying leads. This ensures a robust design and simplifies the power supply assembly process.

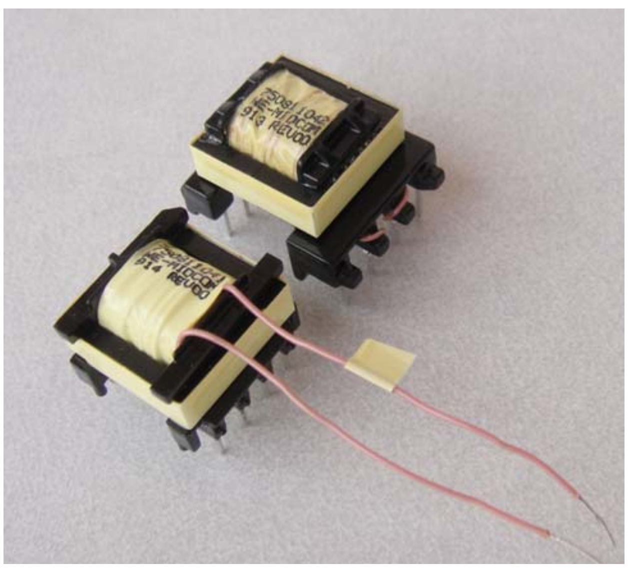

Figure 7. Example comparing a transformer with flying leads and special bobbin

Figure 7 illustrates a transformer with flying leads and one with an optimized bobbin which provides proper spacing and does not require the extra assembly step of manually placing and soldering the flying leads. Both transformers in this figure where provided by Wurth-Midcom (www.we-online.com).

Tip 6: ZCD and Dimming Flicker

The NCL30000 operates in Critical Conduction Mode (CrM) where turn on of the power switch is controlled by the transformer flux level. The Zero Current Detect (ZCD) control block monitors the transformer bias winding to determine when the energy stored in the transformer is depleted and the power switch should be turned back on. The signal on the bias winding is first qualified as a valid pulse after the power switch is turned off and then when the signal falls below a set level indicating the transformer is discharged, the gate drive signal is turned back on initiating a new switching cycle.

If the ZCD signal is not detected for 165 μs (nominal), an internal timer will automatically start a new switching cycle. This occurs when power is first applied to the controller or if a ZCD event is not detected. If ZCD is not operating properly this may result in LED flicker or flutter. Due to the way the human eye responds to light, this is most noticeable when a phase−cut dimmer is used on the AC input and is at very low conduction angles. If flicker is observed, verify that the signal on pin 5 is sufficient to activate the ZCD function.

Resistor R16 couples the signal from the transformer bias winding to the ZCD function. Depending on the voltage present on the bias winding, the value of R16 may need to be adjusted to provide adequate signal to the controller. Care should be taken to not overdrive the ZCD input. Consult the NCL30000 datasheet for details on ZCD operation.

Another possible cause for improper ZCD operation is if the turns ratio of the transformer bias winding is too low to provide sufficient voltage to activate the ZCD function or power the primary bias. Make certain the bias winding provides at least 14 volts when the LED output is operating at minimum voltage.

Phase cut dimmers gate the AC input delivered to the power converter and when the dimmer TRIAC is not on, the rectified bulk falls to a low voltage. If the voltage falls too low as the FET is switching, the bias winding will not generate sufficient signal to activate the ZCD and may also result in LED flicker. 100 nF is a typical bulk capacitor (C4) value for a 12 to 15 watt LED load when the controller is operating in the 35 to 65 kHz region. C4 should be scaled appropriately for higher power levels. For example, in a 25 watt application C4 should be at least 220 nF. Note increasing C4 too high will degrade the Power Factor. Sizing C4 too small degrades regulation due to excessive switching frequency ripple on the bulk capacitor and may complicate EMI compliance.

Shown below in Figure 8 are the AC line current (Blue trace) when the TRIAC turns on and the switching FET drain voltage (Purple trace). Note the FET is still switching during the period before the dimmer TRIAC turns on but with very low amplitude due to the low bulk voltage. The switching is sufficient to activate the ZCD function and maintain continuous operation without activating the 165 μs start-up timer.

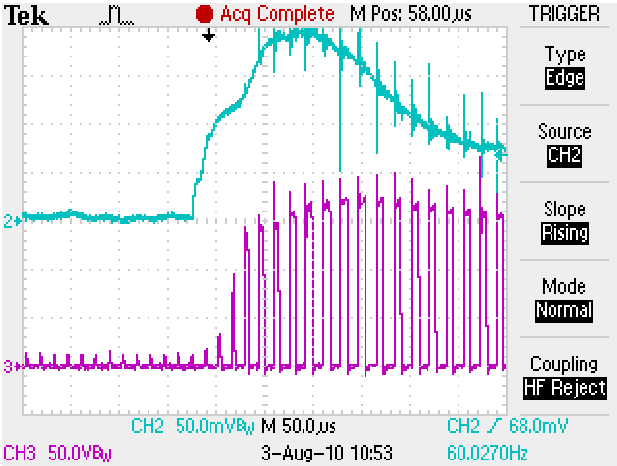

Figure 8. Switching waveforms after TRIAC turns on

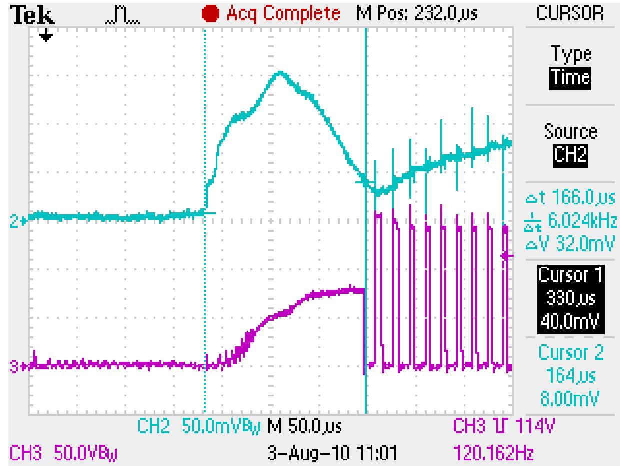

Figure 9. No switching after TRIAC turns on

Some designs may have different bulk capacitance or transformer characteristics such that during the dimmer TRIAC off times, there is insufficient signal on the transformer bias winding to continuously activate the ZCD block. Figure 9 shows an instance where the FET was not switching while the TRIAC was off and the start-up timer initiated a switching cycle about 165 µs after the dimmer TRIAC turned on. Because the delay is random, it can cause LED flicker. AC line current is shown in blue and FET drain switching is shown in purple.

If the bulk voltage falls too low and causes LED flicker, connect a 6.8 kΩ resistor from the primary bias capacitor C6 to bulk capacitor C4 to provide additional voltage on the bulk. A diode is required to prevent the bulk voltage from powering the primary bias when the bulk voltage is high. Operating without a diode would reduce efficiency and could place excessive voltage on C6.

A partial schematic of the NCL30000LED1GEVB demo board is shown below in Figure 10. The added resistor and diode are indicated in the box labeled “ZCD Support”. Reference the full schematic for further details.

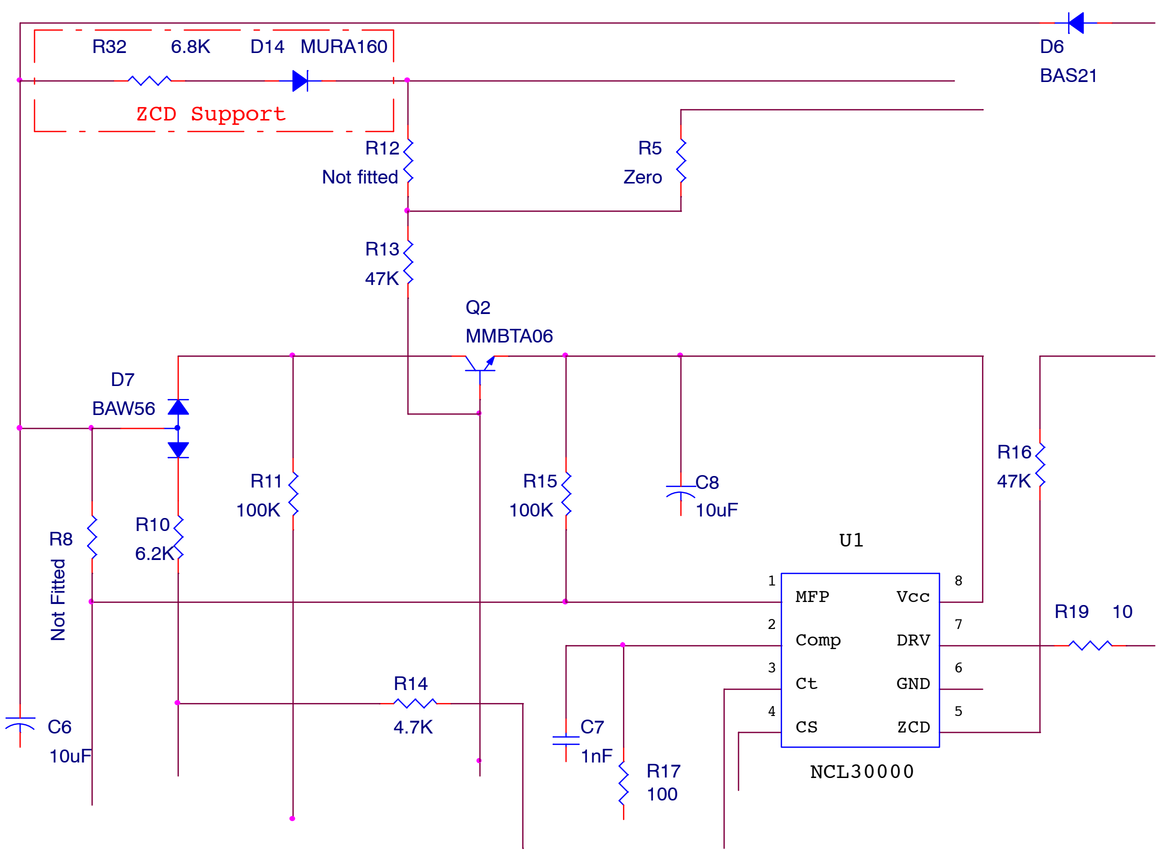

Figure 10. Partial Schematic Showing ZCD Support Circuit

This circuit corrects performance in a system where the absence of continuous ZCD pulses was causing flicker in the LED. Some adjustment to the resistor value may be necessary in particular circuits displaying flicker issues. Monitoring the FET gate drive signal during dimming will indicate if missing ZCD pulses are causing flicker.

Tip 7: Thermal Foldback

While Tip 3 describes a thermal shutdown circuit, an alternate circuit that can protect the LEDs in the event of high temperature is a thermal foldback. This reduces the LED current proportionally at higher temperature thus reducing thermal stress but still provides illumination.

A simple modification to the open load protection is made to realize thermal foldback by introducing a positive temperature coefficient (PTC) thermistor into the resistor divider network. The thermistor is inserted in series with the lower divider resistor. The original resistor value should be reduced by the nominal thermistor impedance at a target (room temperature) value to maintain open load protection threshold.

The partial schematic shown in Figure 11 details the thermal foldback configuration. The application shown is similar to the NCL30000 PAR 30 lamp described in AND8463/D.

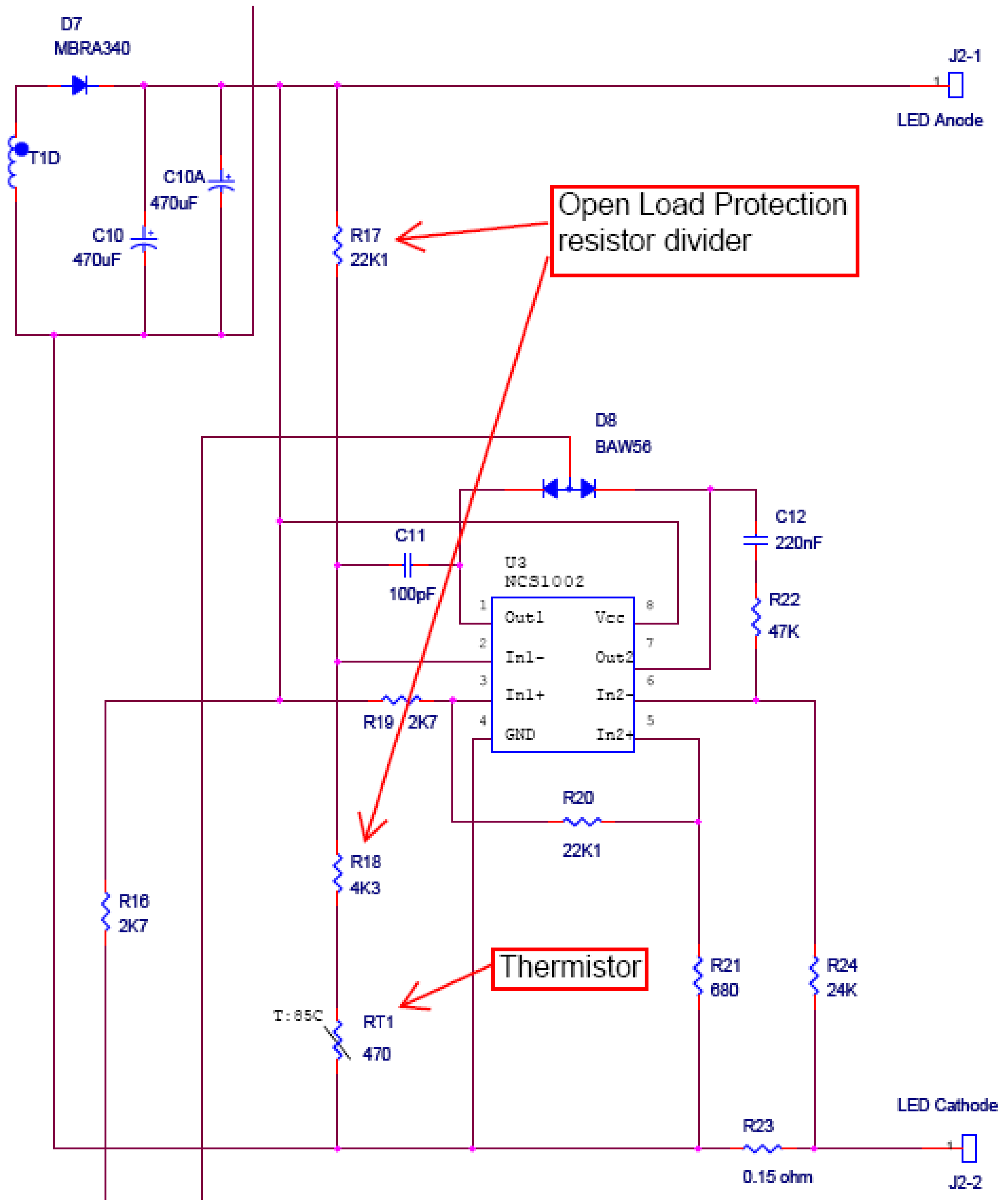

Figure 11. Thermal Foldback Configuration

When the positive thermal coefficient thermistor RT1 reaches transition temperature the impedance will increase rapidly. Raising the impedance of the lower divider resistor will activate the open load protection feature. As a result, the pulse width of the switching controller will cut back reducing the current delivered to the LED load. The reduced current will lower dissipation and allow the LEDs to cool down.

Since the thermistor is located on the secondary side, it can be closely coupled to the LEDs for direct sensing of the LED heat sink. If it is not possible to locate the thermistor near the LEDs similar foldback performance may be possible by placing the thermistor near the output rectifier.

The circuit will control the temperature by reducing the LED current as required and yet still provide some current to the LEDs avoiding a ‘no light’ situation. If the conditions causing the over temperature are removed, the circuit will automatically restore normal operation. This foldback characteristic can ensure the lamp does not experience excessive temperature due to external environmental conditions or improper installation such as being installed in an enclosed space.

For additional information on the NCL30000, please refer to onsemi.com for the data sheet, application notes and demo board manuals which give further information on this product and the available demo boards.

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