

# NCP1370BGEVB

## NCP1370 Evaluation Board User's Manual

The NCP1370 is a primary side constant current controller. It features a built in control algorithm that allows to precisely regulate the output current of a Flyback converter from the primary side. This eliminates the need for an opto-coupler and associated circuitry. The control scheme also support non-isolated topology such as Buck-Boost and SEPIC. The output current regulation is within  $\pm 2\%$  over a line range of 85 – 265 V rms.

The power control uses a Critical Conduction Mode (CrM) approach with valley switching to optimize efficiency and EMI filtering. The controller selects the appropriate valley for operation which keeps the frequency within a tighter range than would normally be possible with simple CrM operation.

This manual covers the specification, testing and construction of the NCP1370 demonstration board. The board demonstrates a 50-W LED driver for TV backlighting. A dimming circuitry is also provided to show the dimming performances of the NCP1370.

The board allows building 2 different power converters:

- 200-V Output Voltage with an Output Current of 250 mA
- 100-V Output Voltage with an Output Current of 500 mA

### Specifications

The board is designed to meet the specifications of Table 1.

**Table 1. LED Driver Specifications**

| Description                                           | Symbol          | Value | Units |
|-------------------------------------------------------|-----------------|-------|-------|
| Minimum Input Voltage                                 | $V_{IN,Min}$    | 120   | V dc  |
| Maximum Input Voltage                                 | $V_{IN,Max}$    | 375   | V dc  |
| Minimum Output Voltage                                | $V_{OUT,Min}$   | 175   | V     |
| Nominal Output Voltage                                | $V_{OUT,Nom}$   | 200   | V     |
| Maximum Output Voltage                                | $V_{OUT,Max}$   | 215   | V     |
| Output Voltage at which the OVP is Activated          | $V_{OUT(OVP)}$  | 340   | V     |
| Output Current (Nominal)                              | $I_{OUT}$       | 250   | mA    |
| Input Voltage for Brown-In                            | $V_{IN(Start)}$ | 110   | V dc  |
| Switching Frequency at $P_{OUT,Max}$ and $V_{IN,Min}$ | $F_{SW}$        | 100   | kHz   |

### Description of the Board

The board has been designed using the method described in the application note AND9131/D [1].

Figure 2 shows the schematic of the 200-V, 250 mA LED driver which is the default board version. Figure 3 portrays the schematic of the 100-V, 500 mA LED driver.

The resistor R12 connected to pin 1 (ILIM) of the controller sets the peak current limit threshold  $V_{ILIMIT}$  to 2.4 V. A resistor divided formed by R34 and R35 is used to limit the voltage and current in ZCD pin.

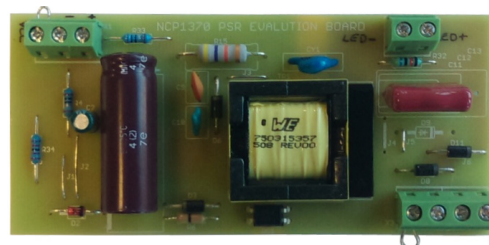
R16 is the line feedforward resistor that compensates the output current variation caused by the propagation delays.



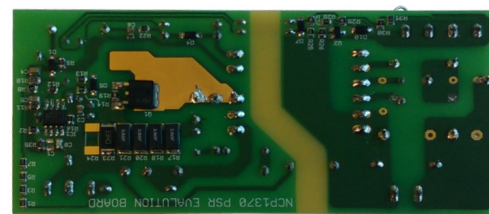
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## EVAL BOARD USER'S MANUAL



Top View



Bottom View

**Figure 1. NCP1370 Evaluation Board**

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R1, R3, R5, R7, R8 and R10 are the brown-out resistors which have been calculated to start operating at  $V_{IN} = 110$  V dc.

The controller is supplied by an external power supply. In order to start, the controller needs at least 12 V on VCC pin.

The output current is set to 250 mA by the sense resistors R17, R18, R20, R21 and R23.

R23 is used to adjust the output current exactly to 250 mA. A small output capacitor of 470 nF is used in order to have a square output current waveform when PWM dimming is used.

The board has a low profile and its height does not exceed 15 mm.

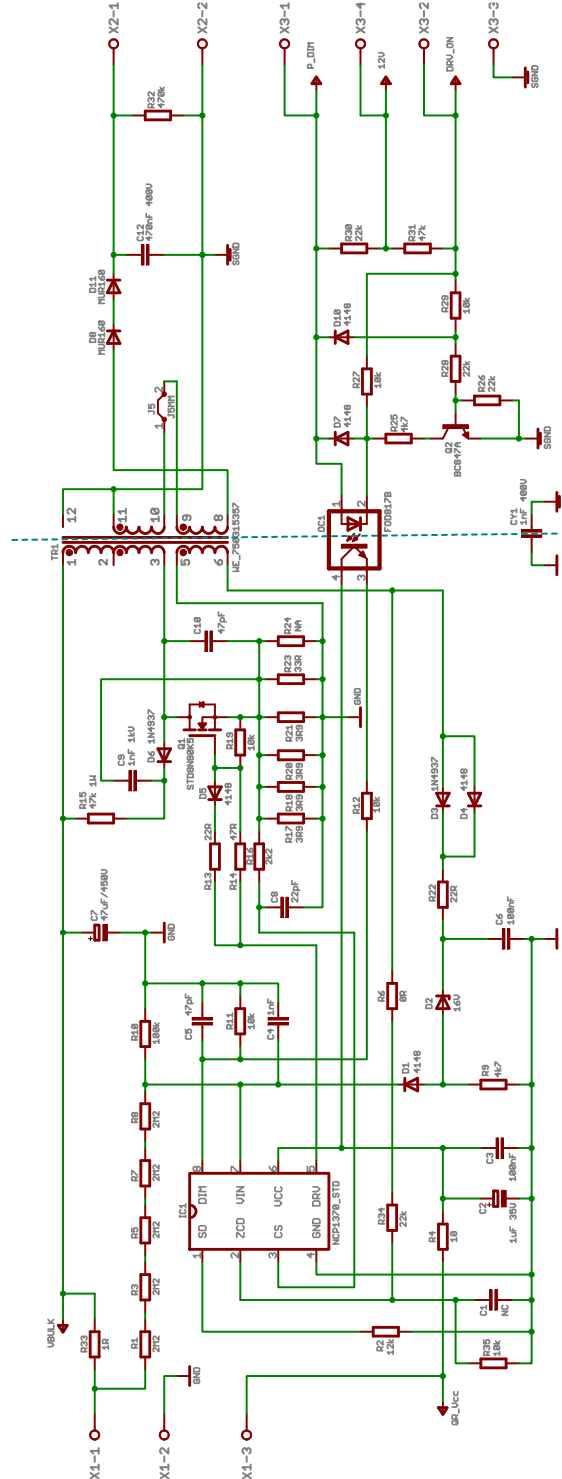
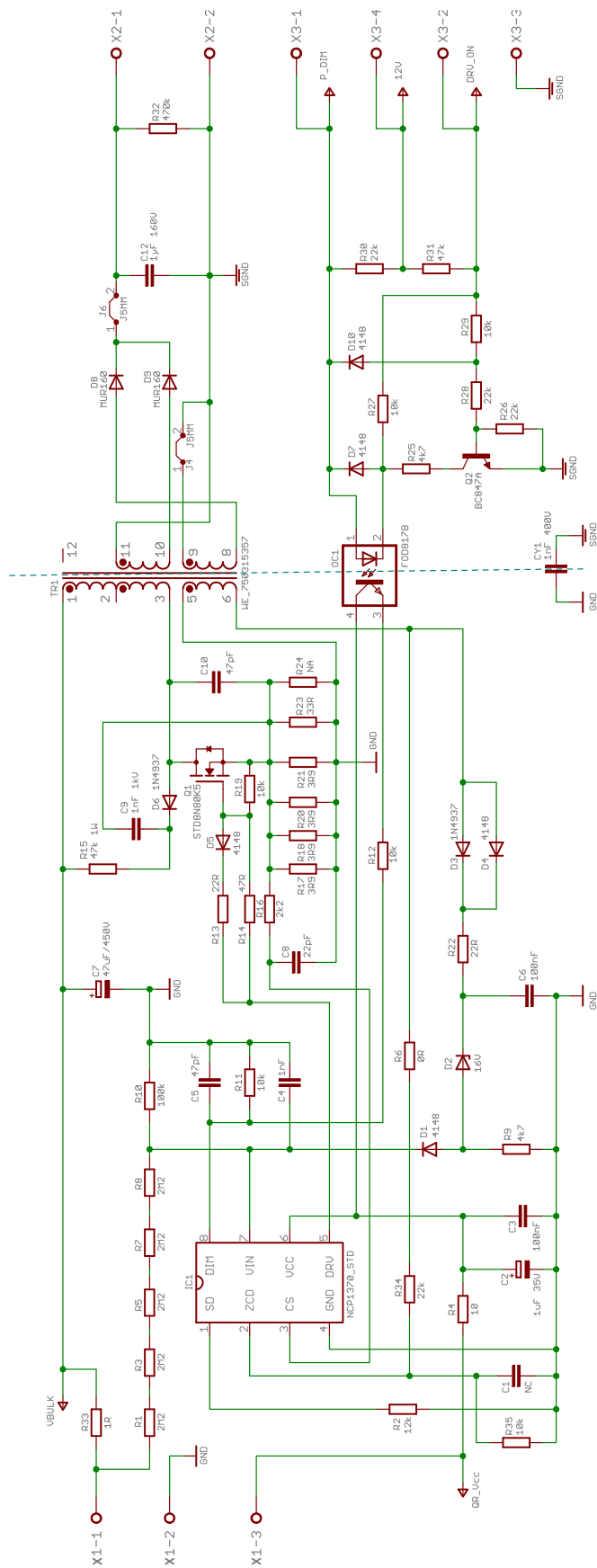


Figure 2. Evaluation Board with 200-V/250-mA Output

**NCP1370BGEVB**



### Figure 3. Evaluation Board wit 100-V/500-mA Output

**NCP1370BGEVB**

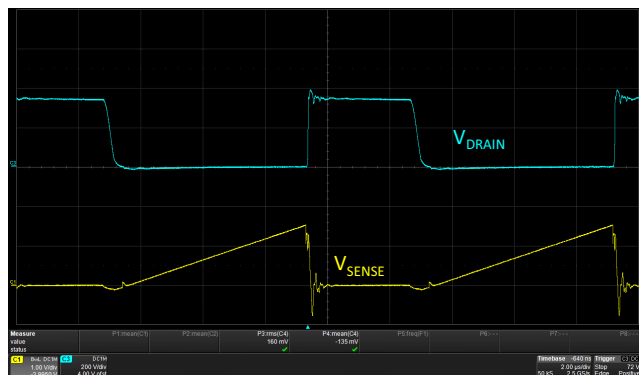
## Valley Switching and Valley Lockout

The NCP1370 implements a current-mode, quasi-resonant architecture which optimizes the efficiency over a wide load range by turning on the MOSFET when its drain-source voltage is minimal (valley).

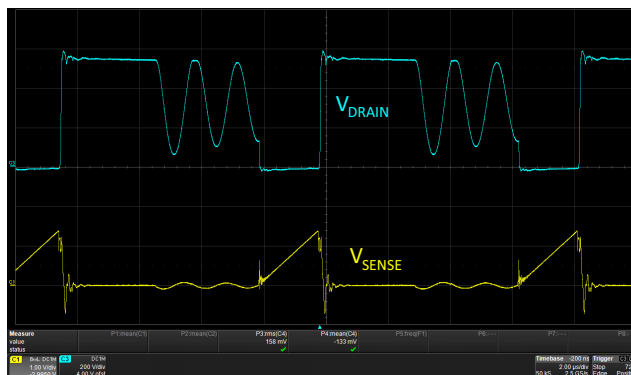
Depending on the power supply design, it is possible to achieve almost zero voltage switching as shown by Figure 4.

When the light is dimmed, the controller selects a following valley to reduce the switching frequency and

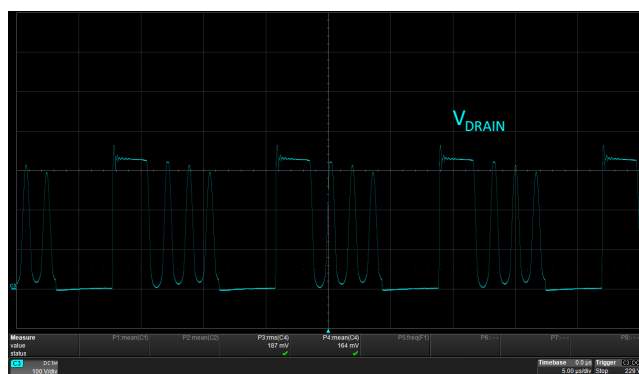
keep the switching losses low. For stable operation, the valley at which the MOSFET is switch-on remains locked until the light demand is changed. Practically, the NCP1370 transitions from quasi-resonant operation to the 2<sup>nd</sup> valley at low line and from 3<sup>rd</sup> valley to 4<sup>th</sup> valley at high line when the LED driver load goes below 80% of its nominal value. A table summarizing the valley transitions can be found in the NCP1370 data sheet [2].



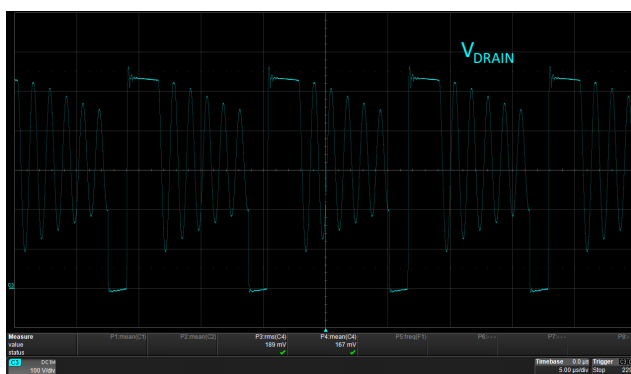
**Figure 4. 1<sup>st</sup> Valley Operation at Low Line, Full Load**



**Figure 5. 3<sup>rd</sup> Valley Operation at Low High, Full Load**



**Figure 6. 4<sup>th</sup> Valley Operation at 50% Nominal Output  
Current, Low Line**



**Figure 7. 6<sup>th</sup> Valley Operation at 50% Output Current, High Line**

### Output Current Regulation

The output current value is set by the sense resistor  $R_{SENSE}$  formed by R17, R18, R20, R21 and R23 on the board. The sense resistor value can be calculated with:

$$R_{\text{SENSE}} = \frac{V_{\text{REF}}}{2 \cdot N_{\text{SP}} \cdot I_{\text{OUT}}} \quad (\text{eq. 1})$$

Where:

- $N_{SP}$  is the transformer turn ratio: secondary turns divided by primary turns
- $I_{OUT}$  is the targeted output current
- $V_{REF}$  is the reference voltage for constant current regulation

In order to compensate the current variation caused by the propagation delays, line feedforward is needed. The resistor in series with the CS pin R16 adjust the voltage offset on the current sense signal as a function of the input voltage.

The capacitor on CS pin C8 must be kept small in order to avoid delaying the current-sense signal and thus increasing the propagation delays. Here a capacitor value of 22 pF was chosen.

Because of the line feedforward and also for reason inherent to the constant current algorithm, the obtained output current is slightly lower than the targeted output current. Thus, it may be necessary to adjust slightly the sense resistor by decreasing it. That's why we added  $R23 = 33\ \Omega$  in parallel of the other four  $3.9\ \Omega$  sense resistors.

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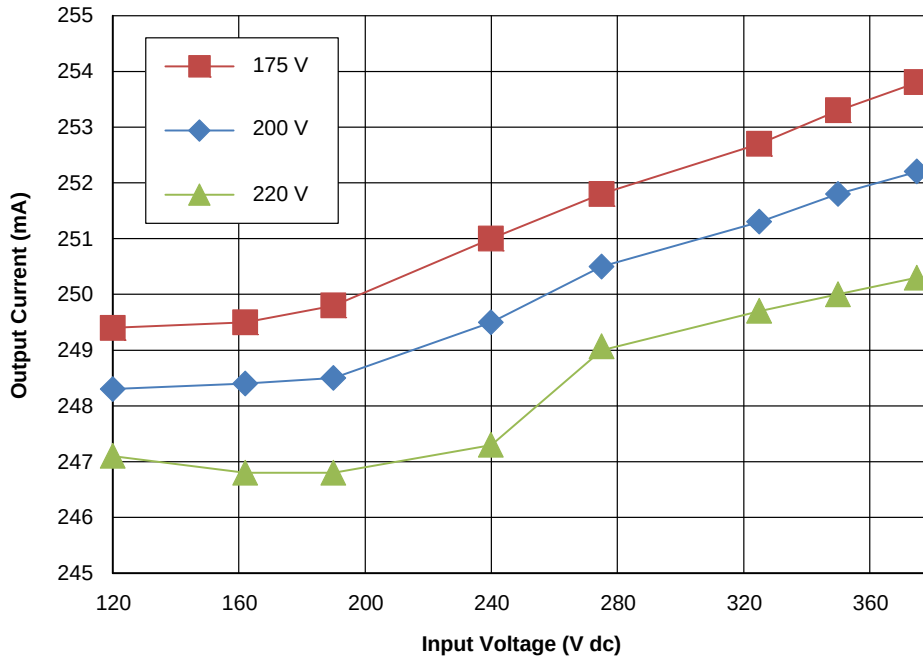


Figure 8. Output Current Variation for  $V_{LED} = 175\text{ V to }220\text{ V}$

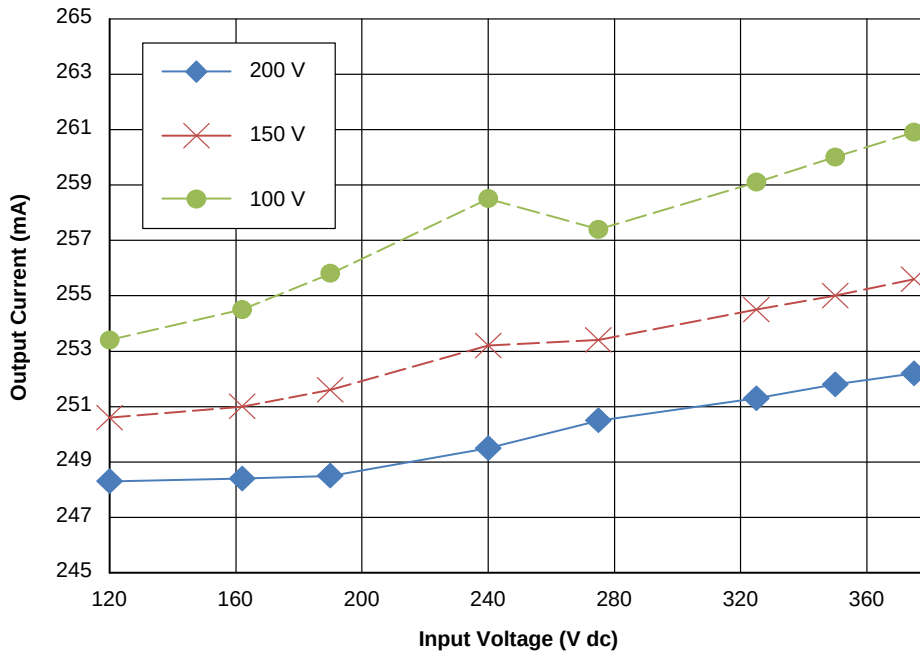


Figure 9. Output Current Variation for  $V_{LED} = 100\text{ V to }200\text{ V}$

Figure 8 and Figure 9 shows the output current measured when the input voltage is varied from 120 V dc to 375 V dc for different LED string voltages. A Chroma electronic load in LED mode is used to emulate the LED string voltage variation.

Looking at Figure 8 where the LED voltage is varied from 175 V to 220 V (roughly  $200\text{ V} \pm 11\%$ ), we can calculate the mean output current value and the current regulation.

The mean output current is calculated by considering the maximum and the minimum value measured over the output voltage and the input voltage range:

$$I_{OUT,Mean} = \frac{I_{OUT,Max} + I_{OUT,Min}}{2} \quad (\text{eq. 2})$$

$$= \frac{253.8 + 246.8}{2} = 250.3 \text{ mA}$$

The output current regulation is then calculated as follows:

$$\frac{\Delta I_{OUT}}{I_{OUT}} = 100 \cdot \frac{I_{OUT,Max} - I_{OUT,Min}}{I_{OUT,Mean}} \quad (\text{eq. 3})$$

$$= 100 \cdot \frac{253.8 - 246.8}{250.3} = 1.4\%$$

The output current regulation is thus  $\pm 1.4\%$  for a LED string voltage varying from 175 V to 220 V and for the input voltage varying from 120 V dc to 375 V dc.

Figure 9 portrays the current variation when the LED voltage is decreased down to 100 V (the nominal voltage being 200 V) in order to simulate the case where several LEDs are shorted.

We can see that the current regulation is still good. We have 254.6 mA  $\pm 2.5\%$

$$I_{OUT2,Mean} = \frac{I_{OUT2,Max} + I_{OUT2,Min}}{2} \quad (\text{eq. 4})$$

$$= \frac{260.9 + 248.3}{2} = 254.6 \text{ mA}$$

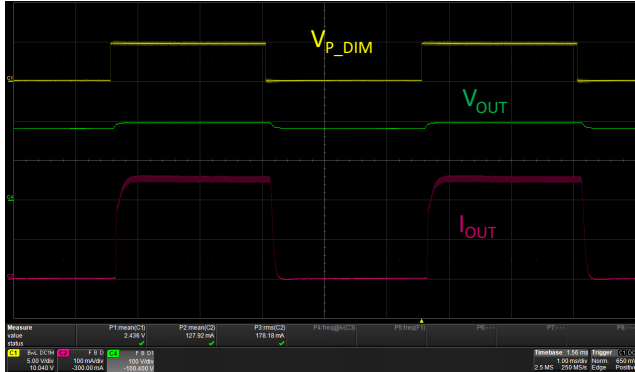


Figure 10. 50% PWM Dimming

$$\frac{\Delta I_{OUT2}}{I_{OUT2}} = 100 \cdot \frac{I_{OUT2,Max} - I_{OUT2,Min}}{I_{OUT2,Mean}} \quad (\text{eq. 5})$$

$$= 100 \cdot \frac{260.9 - 254.6}{254.6} = 2.5\%$$

### Dimming

A circuit made of the opto-coupler OC1, the transistor Q2 and some resistors is used to send the digital dimming signal from the secondary side to the DIM pin of the controller on the primary side.

By default at start-up, the controller is in OFF mode. In OFF mode, the controller consumes less than 50  $\mu\text{A}$ . The controller leaves the OFF mode when  $V_{CC} > V_{CC(on)}$  and  $V_{DIM} > V_{DIM(EN)}$ . During normal operation, the OFF mode is entered when  $V_{DIM}$  stays below  $V_{DIM(EN)}$  for 4 seconds.

Back to the evaluation board, in order to start, a voltage of at least 3.3 V must be applied on P\_DIM connector. For digital or PWM dimming, apply 3.3 V on DRV\_ON and apply a square signal varying between 5 V to 0 V with a 200-Hz frequency on P\_DIM.

By varying the duty-cycle of this signal, the output current will also vary. Figure 10 shows the output voltage and current when dimming with 50% duty-cycle. Figure 11 shows the dimming pin voltage  $V_{DIM}$  and the drain voltage in addition to the output current when the dimming signal has a duty-cycle of 10%. The resistors R12 and R11 with the capacitor C4 adds in an extra soft-stop which delays the LED turn-off and compensates the internal soft-start of the NCP1370 and also the time needed for the output voltage to be high enough to turn-on the LED.

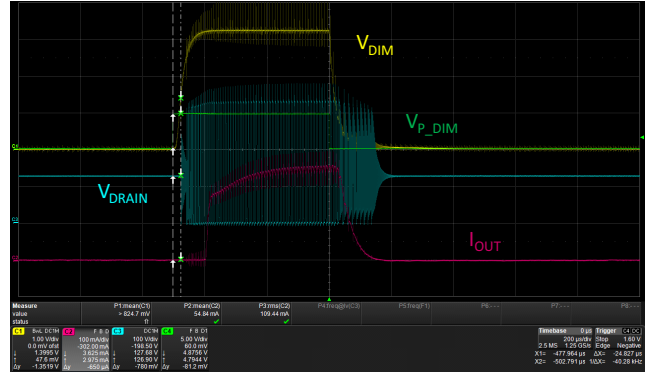


Figure 11. 10% PWM Dimming

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Figure 12 and Figure 13 show the output current as a function of the PWM dimming signal duty-ratio. The tests were made at 162 V dc. We can observe that the output

current is nicely controlled by the DIM pin and the measured current matches the expected value even at low duty-ratio dimming thanks to the soft-stop.

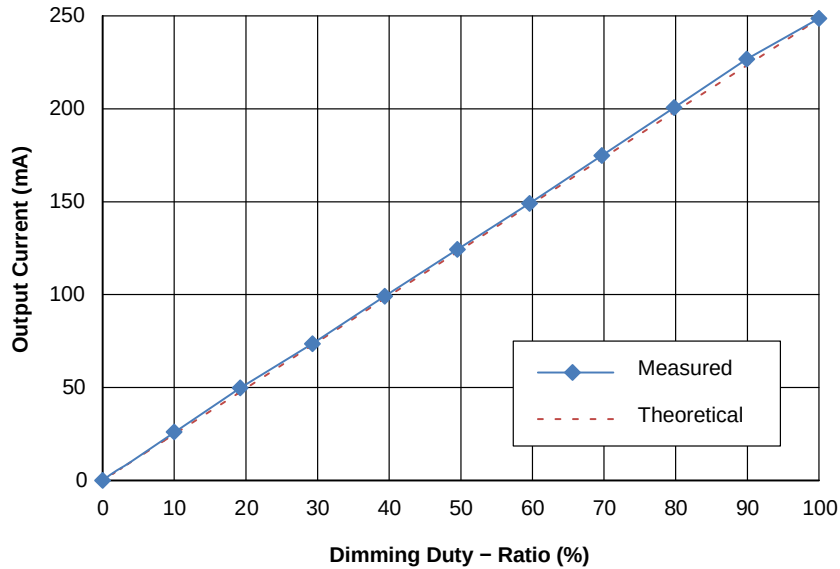


Figure 12. Output Current vs. PWM Dimming Duty-Ratio

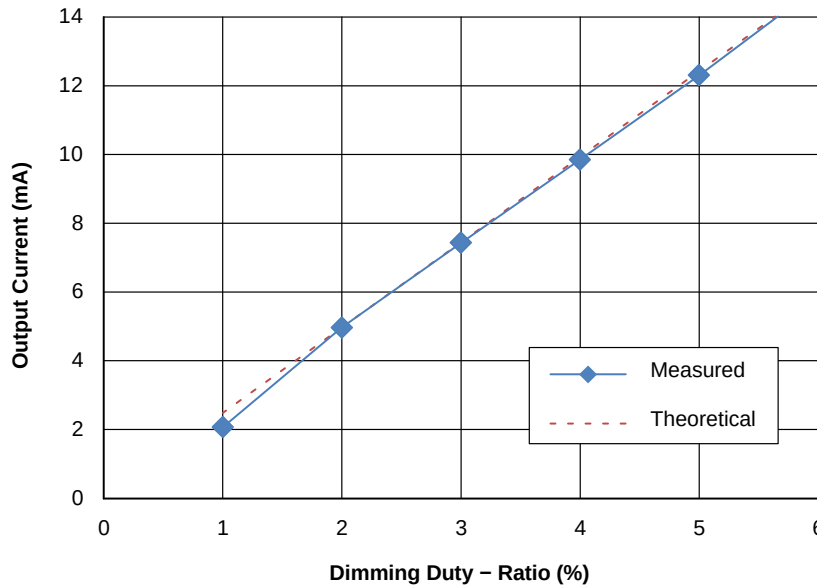


Figure 13. Output Current Variation for PWM Dimming Duty-Ration between 1% to 5%

## Over Voltage Protection/Open LED Protection

By monitoring the auxiliary winding voltage through D3, D4, R22 and C6, we have an image of the output voltage. By connecting a zener diode from C6 to the VIN pin, we can trigger the over voltage protection (OVP). When pin VIN voltage exceeds 5 V, the controller stops and restarts switching after 1 second. In order to reach 5 V on VIN pin, a current of approximately 900  $\mu$ A must be injected inside the pin by the zener diode.

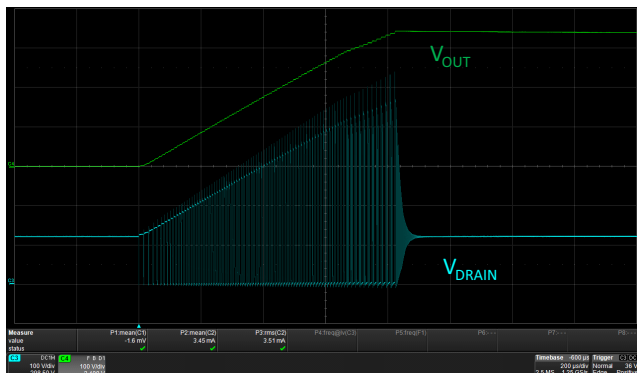


Figure 14.  $V_{OUT}$  Waveform in Case of Open LED

In order to decrease the maximum voltage reached on the output connector in case no LEDs are connected to board, the circuit shown in Figure 16 can be used. The maximum

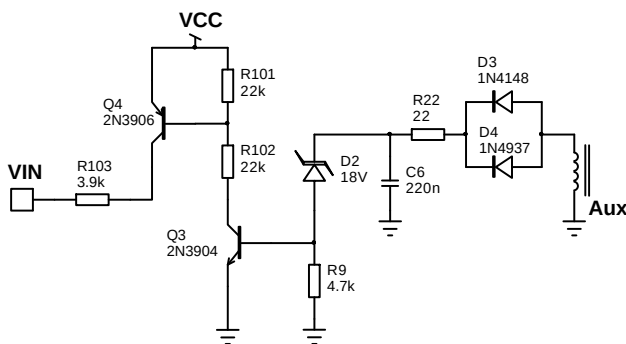


Figure 16. Alternative Circuit for OVP on VIN Pin

As soon as the zener diode starts conducting, the transistor Q3 is turned on and then bias Q4 which allow pulling the VIN pin high above 5 V immediately. In this case, we need

We chose a 16-V zener diode. As the OVP threshold is 5 V, the comparator will trigger when the voltage on capacitor C6 exceeds  $16\text{ V} + 5\text{ V} + 0.6\text{ V} = 21.6\text{ V}$  (0.6 V being the forward voltage drop of diode D1).

Figure 14 and Figure 15 show the output voltage waveform in case of open LED. The maximum output voltage is 345 V. On Figure 15, we can see that the output capacitor is discharged down to 0 V after the 1 second timer has elapsed thanks to the dummy output resistor R32.

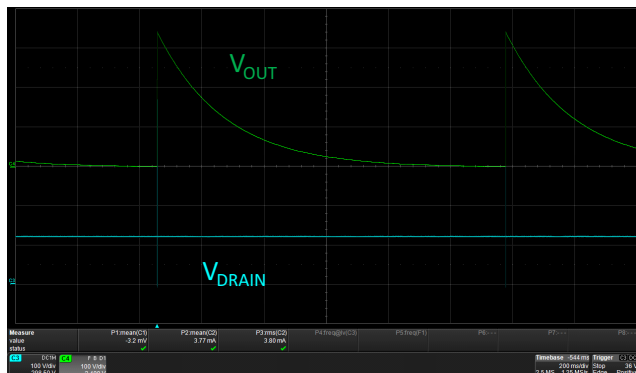


Figure 15.  $V_{OUT}$  Waveform in Case of Open LED after the OVP Timer Has Elapsed

voltage reached on the board when no LED was connected was 300 V with this circuit.

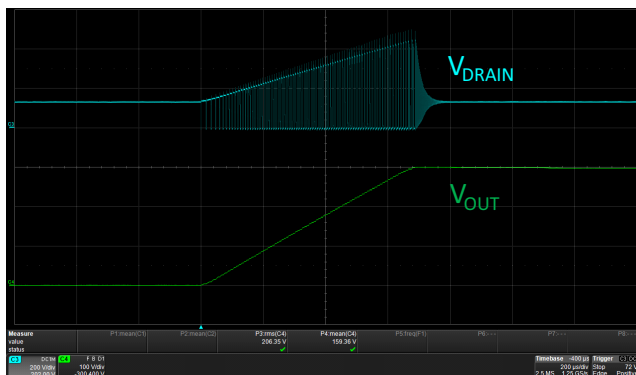


Figure 17. Open LED with New OVP Circuit on VIN Pin

to use an 18-V zener diode instead of a 16-V to avoid triggering the protection during the normal operating range.



## NCP1370BGEVB

### Test Procedure

#### Equipment Needed:

- High voltage dc source: 100 to 375 V dc, minimum 500 W capability
- Two dc sources, 30 V
- DC Voltmeter – 300 V dc minimum, 0.1% accuracy or better
- DC Ammeter – 1 A dc minimum, 0.1% accuracy or better
- LED load between 175 V to 215 V at 250 mA.  
A constant voltage Electronic load is an acceptable substitute as long as it is stable

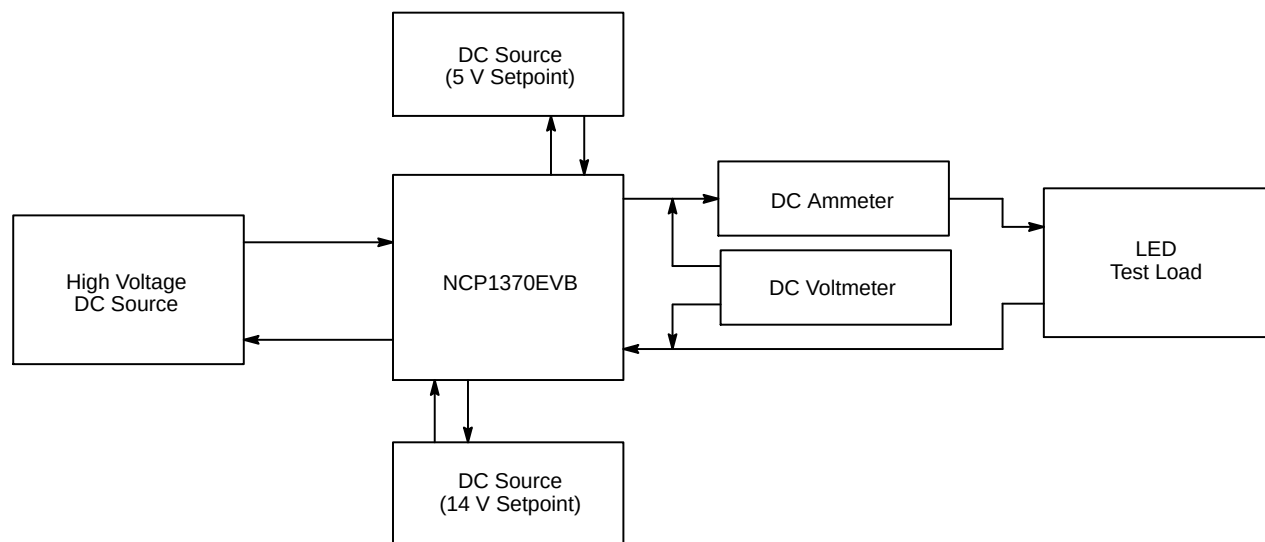


Figure 18.

#### Test Connections:

- Connect the high voltage source between inputs “+” and “-” of X1 connector.
- Connect a dc power supply between inputs “VCC” and “-” of X1 connector
- Connect a dc power supply between inputs 1 and 3 of X3 connector
- Connect the ammeter to “LED+” output of X2 connector and then connect the LED load positive terminal to the ammeter and its negative terminal to the “LED-” output of X2 connector

#### Functional Test Procedure:

- Set the load at 200 V output
- Set the input voltage to 162 V dc
- Measure the output current: its value should be within  $\pm 2\%$  of 250 mA.

# NCP1370BGEVB

## Flyback Inductor Specification

more than you expect



### ELECTRICAL SPECIFICATIONS @ 25° C unless otherwise noted:

| PARAMETER          | TEST CONDITIONS                            | VALUE             |
|--------------------|--------------------------------------------|-------------------|
| D.C. RESISTANCE    | 9-8 @20°C                                  | 0.267 ohms ±10%   |
| D.C. RESISTANCE    | 5-6 @20°C                                  | 0.027 ohms ±20%   |
| D.C. RESISTANCE    | 11-10 @20°C                                | 0.288 ohms ±10%   |
| D.C. RESISTANCE    | 1-3 @20°C                                  | 0.343 ohms ±10%   |
| INDUCTANCE         | 1-3 10kHz, 100mV, Ls                       | 400µH ±10%        |
| SATURATION CURRENT | 1-3 20% rolloff from initial @100°C        | 1.8A              |
| LEAKAGE INDUCTANCE | 1-3 tie(5+6, 8+9+10+11), 100kHz, 100mV, Ls | 3.0µH max.        |
| DIELECTRIC         | 1-11 tie(3+5, 9+10), 4000VAC, 1 second     | 4000VAC, 1 minute |
| URNS RATIO         | (1-3):(5-6)                                | 14.67:1, ±1%      |
| URNS RATIO         | (1-3):(11-8), tie(9+10)                    | 1:1, ±1%          |

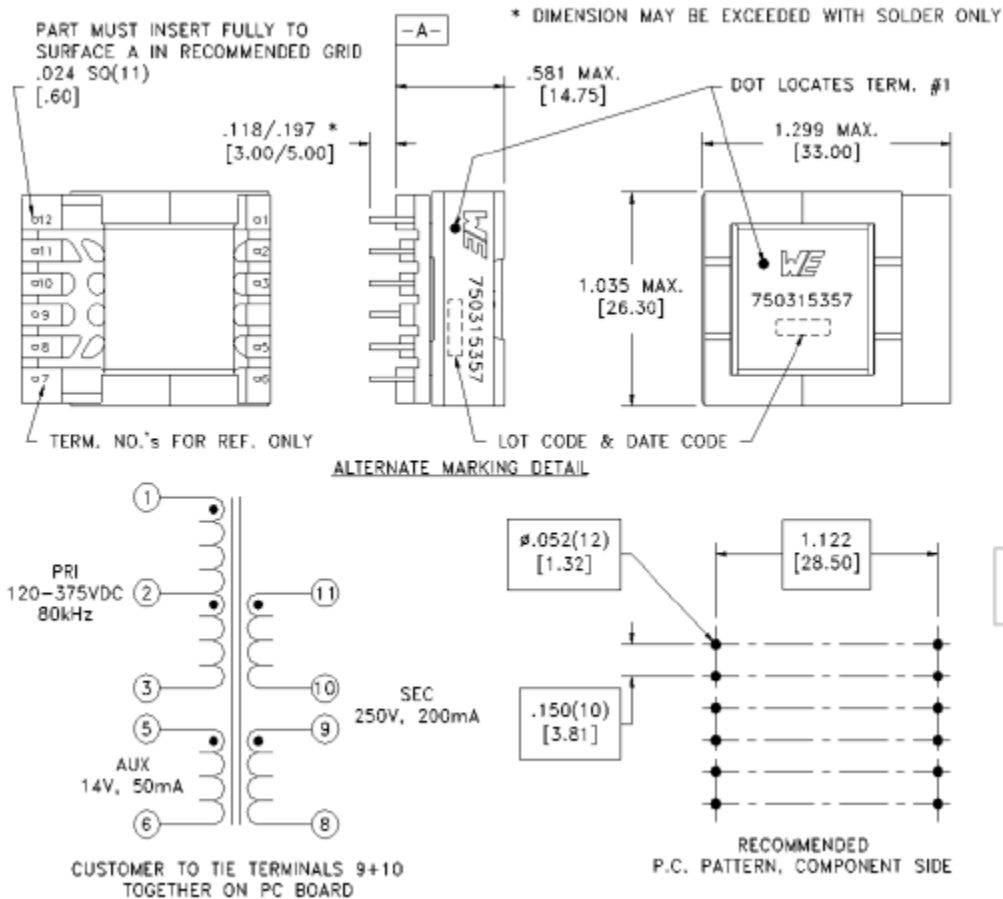


Figure 19. Flyback Inductor Specification

# NCP1370BGEVB

## Bill of Materials

**Table 2. NCP1370 BILL OF MATERIALS**

| Qty | Reference                       | Description             | Value          | Tolerance/<br>Constraint | Package/<br>Footprint | Manufacturer        | Manufacturer<br>Part Number |
|-----|---------------------------------|-------------------------|----------------|--------------------------|-----------------------|---------------------|-----------------------------|
| 1   | C1                              |                         | NC             |                          | SMD0805               |                     |                             |
| 1   | C10                             | Ceramic Capacitor       | 47 pF          | 5%, 1 kV                 | Through-Hole          | Standard            | Standard                    |
| 1   | C12                             | Film Capacitor PET      | 470 nF         | 400 V                    | Through-Hole          | Panasonic           | ECQE4474JF                  |
| 1   | C2                              | Electrolytic Capacitor  | 1 $\mu$ F      | 35 V                     | Through-Hole          | Standard            | Standard                    |
| 2   | C3, C6                          | SMD Capacitor           | 100 nF         | 50 V                     | SMD0805               | Standard            | Standard                    |
| 1   | C4                              | SMD Capacitor           | 1 nF           | 50 V                     | SMD0805               | Standard            | Standard                    |
| 1   | C5                              | SMD Capacitor           | 47 pF          | 50 V                     | SMD0805               | Standard            | Standard                    |
| 1   | C7                              | Electrolytic Capacitor  | 47 $\mu$ F     | 450 V                    | Through-Hole          | Rubycon             | 12X35                       |
| 1   | C8                              | SMD Capacitor           | 22 pF          | 50 V                     | SMD0805               | Standard            | Standard                    |
| 1   | C9                              | Ceramic Capacitor       | 1 nF           | 1 kV                     | Through-Hole          | Standard            | Standard                    |
| 1   | CY1                             | Y1 Capacitor            | 1 nF           | 400 V                    | Through-Hole          | Standard            | Standard                    |
| 5   | D1, D4, D5,<br>D7, D10          | Standard Diode          | 1N4148         | 100 V                    | SOD-123               | ON Semiconductor    | MMSD4148                    |
| 1   | D2                              | Zener Diode             | BZX85-C16      | 16 V                     | DO-41                 | Fairchild           |                             |
| 2   | D3, D6                          | Fast Recovery Rectifier | 1N4937         | 1 A, 600 V               | DO-41                 | ON Semiconductor    | 1N4937                      |
| 1   | D8, D11                         | Ultra-Fast Diode        | MUR160         | 1 A, 600 V               | DO-41                 | ON Semiconductor    | MUR160                      |
| 1   | IC1                             | PSR Controller          | NCP1370B       |                          | SO-08                 | ON Semiconductor    | NCP1370B                    |
| 1   | OC1                             | Opto-Coupler            | FOD817B        |                          | DIL-04W               | Fairchild           | FOD817B                     |
| 1   | Q1                              | Power MOSFET            | STD8N80K5      | 8 A, 800 V               | DPACK                 | ST Microelectronics | STD8N80K5                   |
| 1   | Q2                              | NPN Transistor          | BC847A         |                          | SOT-23                | ON Semiconductor    | BC847AL                     |
| 5   | R1, R3, R5,<br>R7, R8           | Resistor                | 2.2 M $\Omega$ | 1%, 125 mW               | SMD0805               | Standard            | Standard                    |
| 1   | R10                             | Resistor                | 100 k $\Omega$ | 1%, 125 mW               | SMD0805               | Standard            | Standard                    |
| 6   | R11, R12, R19,<br>R27, R29, R35 | Resistor                | 10 k $\Omega$  | 5%, 125 mW               | SMD0805               | Standard            | Standard                    |
| 2   | R13, R22                        | Resistor                | 22 $\Omega$    | 5%, 125 mW               | SMD0805               | Standard            | Standard                    |
| 1   | R14                             | Resistor                | 47 $\Omega$    | 5%, 125 mW               | SMD0805               | Standard            | Standard                    |
| 1   | R15                             | Resistor                | 47 k $\Omega$  | 5%, 1 W                  | Axial                 | Standard            | Standard                    |
| 1   | R16                             | Resistor                | 2.2 k $\Omega$ | 1%, 125 mW               | SMD0805               | Standard            | Standard                    |
| 4   | R17, R18, R20,<br>R21           | Resistor                | 3.9 $\Omega$   | 1%, 1 W                  | SMD2512               | Standard            | Standard                    |
| 1   | R2                              | Resistor                | 12 k $\Omega$  | 1%, 125 mW               | SMD0805               | Standard            | Standard                    |
| 1   | R23                             | Resistor                | 33 $\Omega$    | 1%, 0.5 W                | SMD2512               | Standard            | Standard                    |
| 1   | R24                             | Resistor                | NC             |                          | SMD2512               |                     |                             |
| 3   | R26, R28,<br>R30                | Resistor                | 22 k $\Omega$  | 5%, 125 mW               | SMD0805               | Standard            | Standard                    |
| 1   | R31                             | Resistor                | 47 k $\Omega$  | 5%, 125 mW               | SMD0805               | Standard            | Standard                    |
| 1   | R32                             | Resistor                | 470 k $\Omega$ | 5%, 250 mW               | Axial                 | Standard            | Standard                    |
| 1   | R33                             | Resistor                | 1 $\Omega$     | 5%, 250 mW               | Axial                 | Standard            | Standard                    |
| 1   | R34                             | Resistor                | 22 k $\Omega$  | 5%, 250 mW               | Axial                 | Standard            | Standard                    |
| 1   | R4                              | Resistor                | 10 $\Omega$    | 5%, 250 mW               | Axial                 | Standard            | Standard                    |
| 1   | R6                              | Resistor                | 0 $\Omega$     | 5%, 250 mW               | Axial                 | Standard            | Standard                    |
| 2   | R9, R25                         | Resistor                | 4.7 k $\Omega$ | 5%, 125 mW               | SMD0805               | Standard            | Standard                    |
| 1   | TR1                             | Flyback Inductor        |                |                          | Through-Hole          | Würth               | 750315357                   |
| 1   | X1                              | Input Connector         |                |                          | Through-Hole          | Standard            | Standard                    |
| 1   | X2                              | Output Connector        |                |                          | Through-Hole          | Standard            | Standard                    |
| 1   | X3                              | Dimming Connector       |                |                          | Through-Hole          | Standard            | Standard                    |

# NCP1370BGEVB

## References

- [1] Stéphanie Cannenterre, Application note  
[AND9131/D](#), “Designing a LED Driver with the  
NCL30080/81/82/83”
- [2] Data Sheet NCP1370/D

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