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 ±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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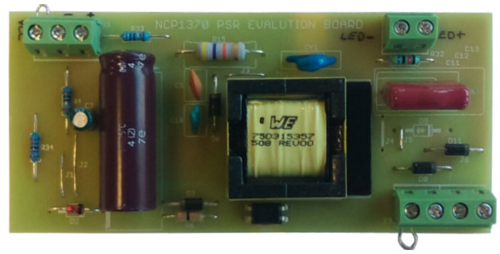
EVAL BOARD USER'S MANUAL



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.

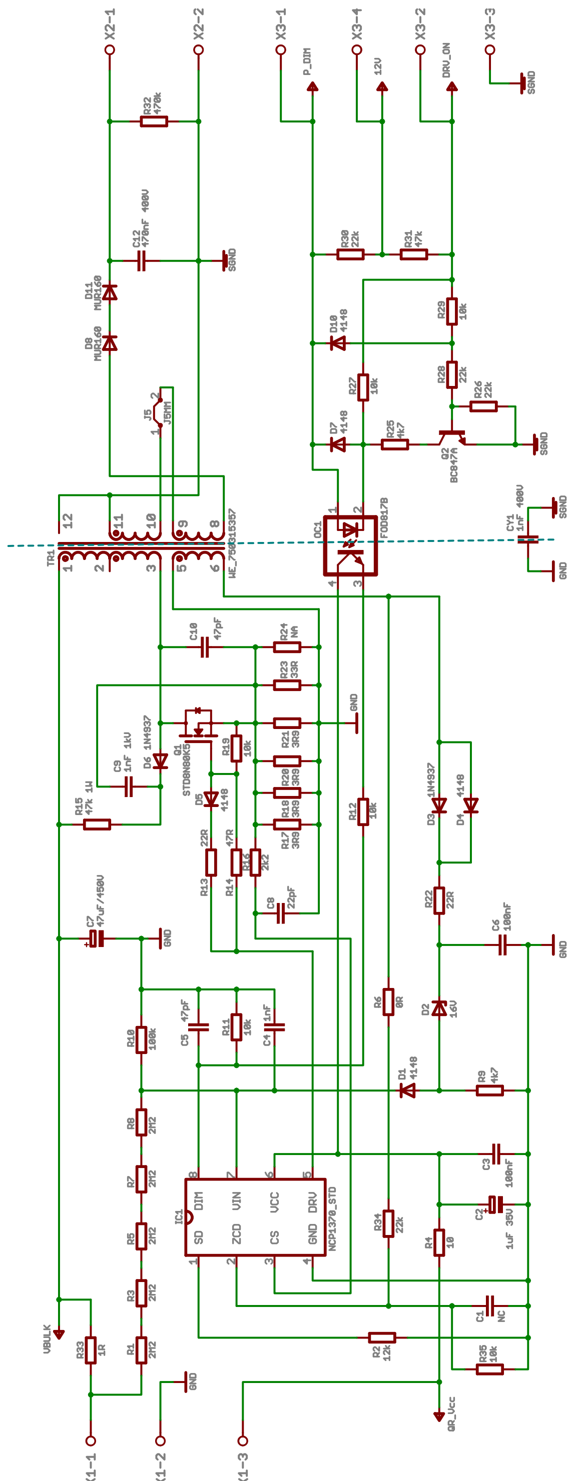

Figure 2. Evaluation Board wit 200-V/250-mA Output

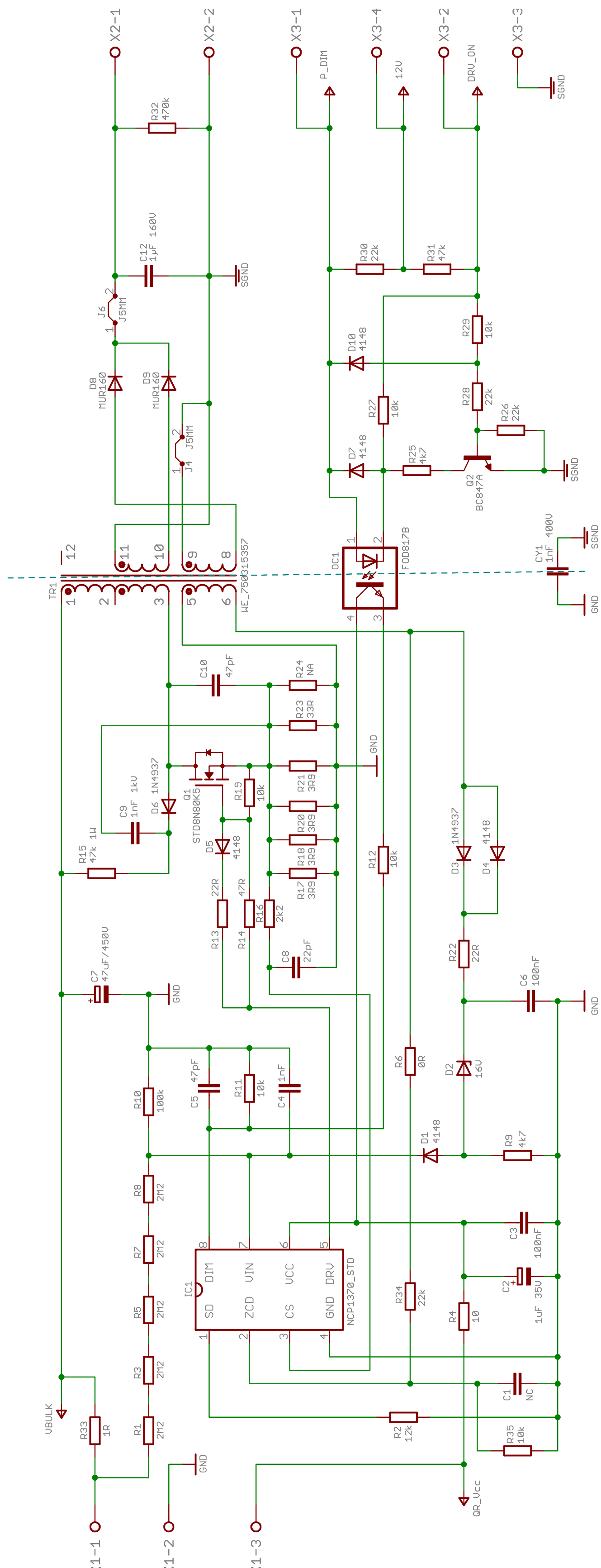

Figure 3. Evaluation Board wit 100-V/500-mA Output

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 2nd valley at low line and from 3rd valley to 4th 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].

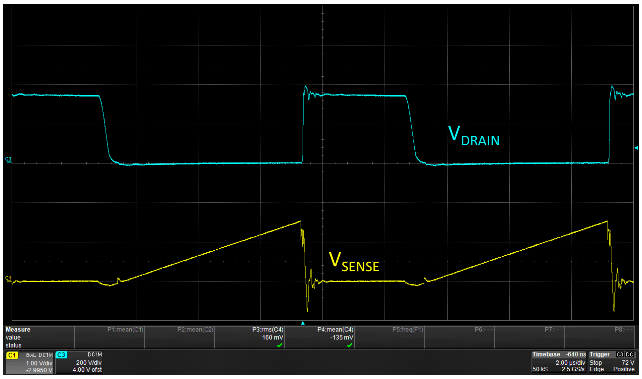

Figure 4. 1st Valley Operation at Low Line, Full Load

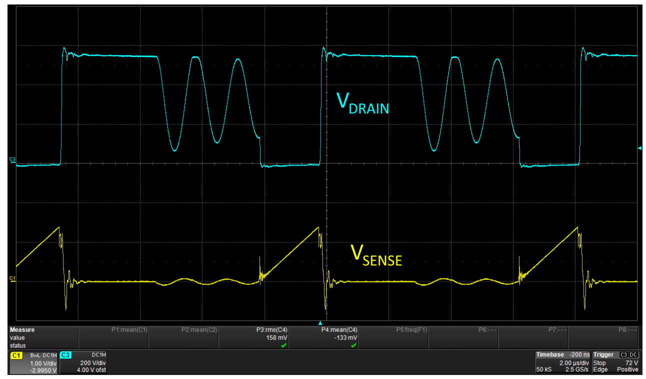

Figure 5. 3rd Valley Operation at Low High, Full Load

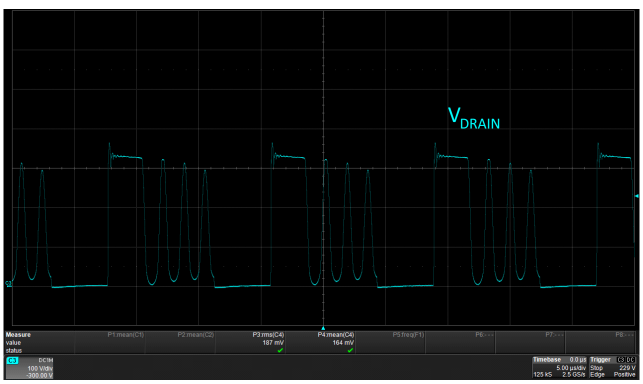

Figure 6. 4th Valley Operation at 50% Nominal Output Current, Low Line

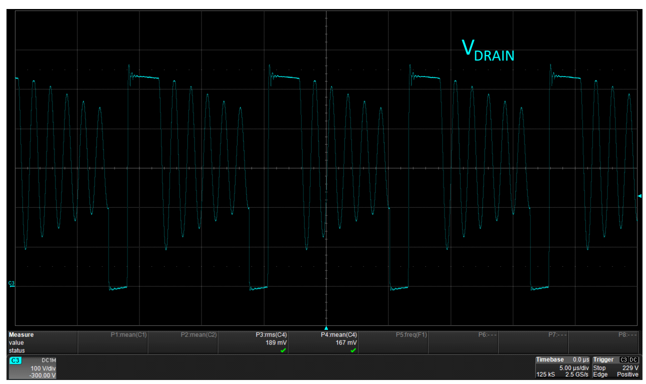

Figure 7. 6th Valley Operation at 50% Output Current, High Line

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:

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

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 Ω in parallel of the other four 3.9 Ω sense resistors.

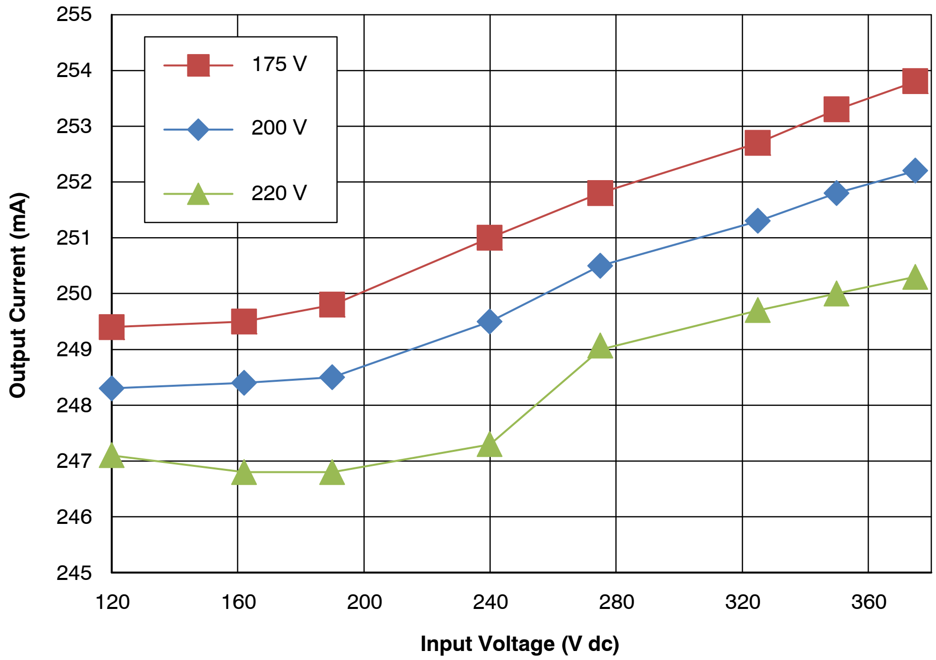

Figure 8. Output Current Variation for V_{LED} = 175 V to 220 V

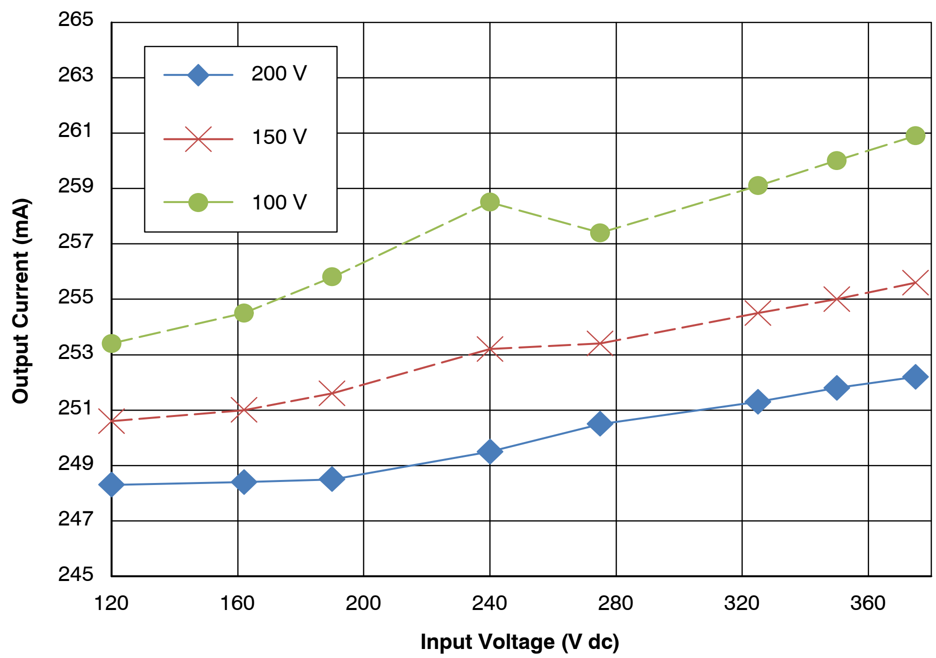

Figure 9. Output Current Variation for V_{LED} = 100 V to 200 V

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 V ±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:

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

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

The output current regulation is thus ±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 ±2.5%

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

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

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

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

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 μA. 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.

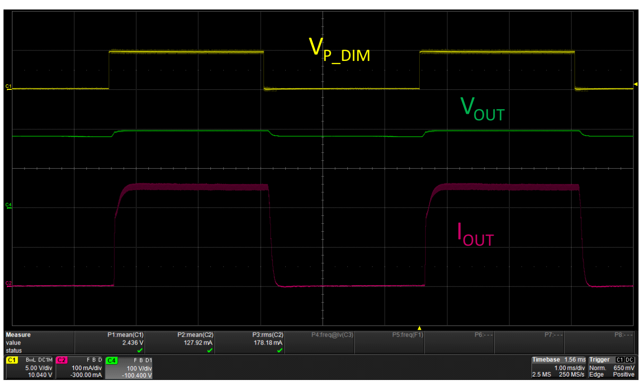

Figure 10. 50% PWM Dimming

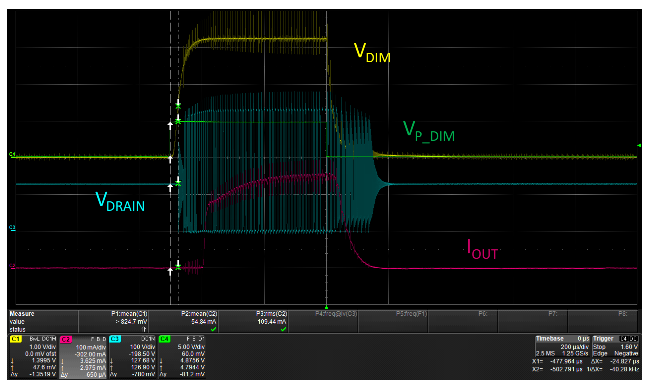

Figure 11. 10% PWM Dimming

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.

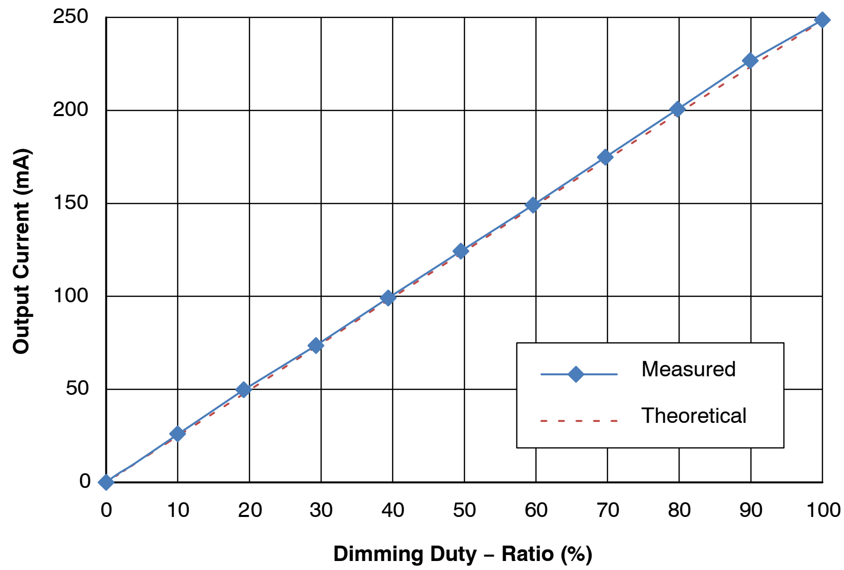

Figure 12. Output Current vs. PWM Dimming Duty-Ratio

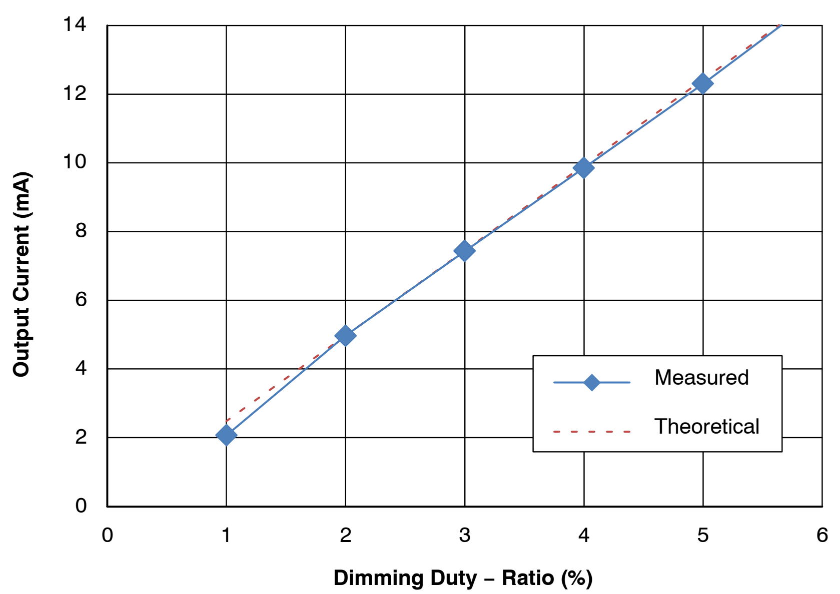

Figure 13. Output Current Variation for PWM Dimming Duty-Ration between 1% to 5%

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 µA must be injected inside the pin by the zener diode.

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 V + 5 V + 0.6 V = 21.6 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.

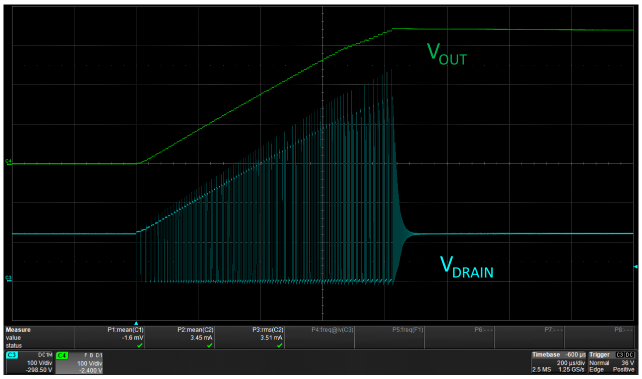

Figure 14. V_{OUT} Waveform in Case of Open LED

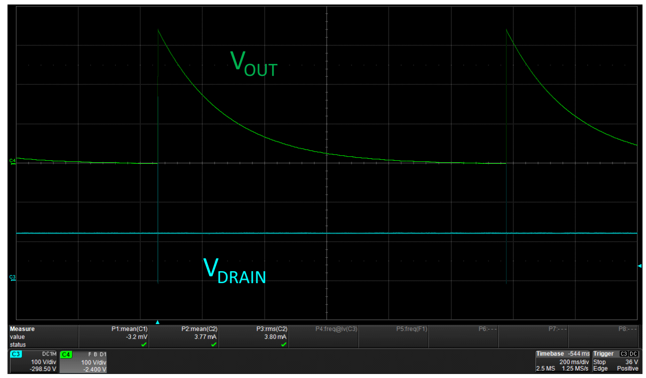

Figure 15. V_{OUT} Waveform in Case of Open LED after the OVP Timer Has Elapsed

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

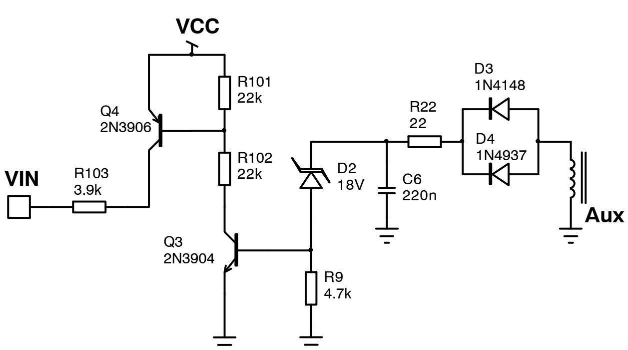

Figure 16. Alternative Circuit for OVP on VIN Pin

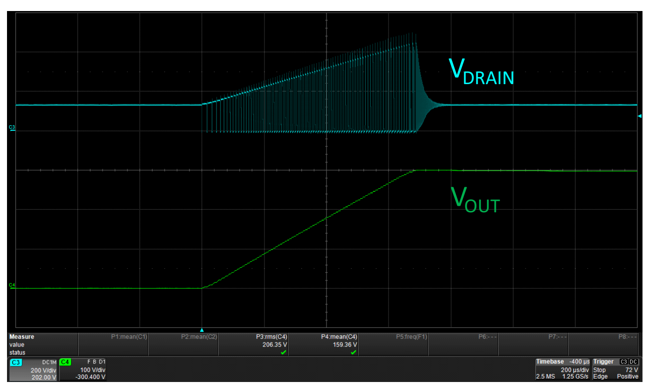

Figure 17. Open LED with New OVP Circuit on VIN Pin

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

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

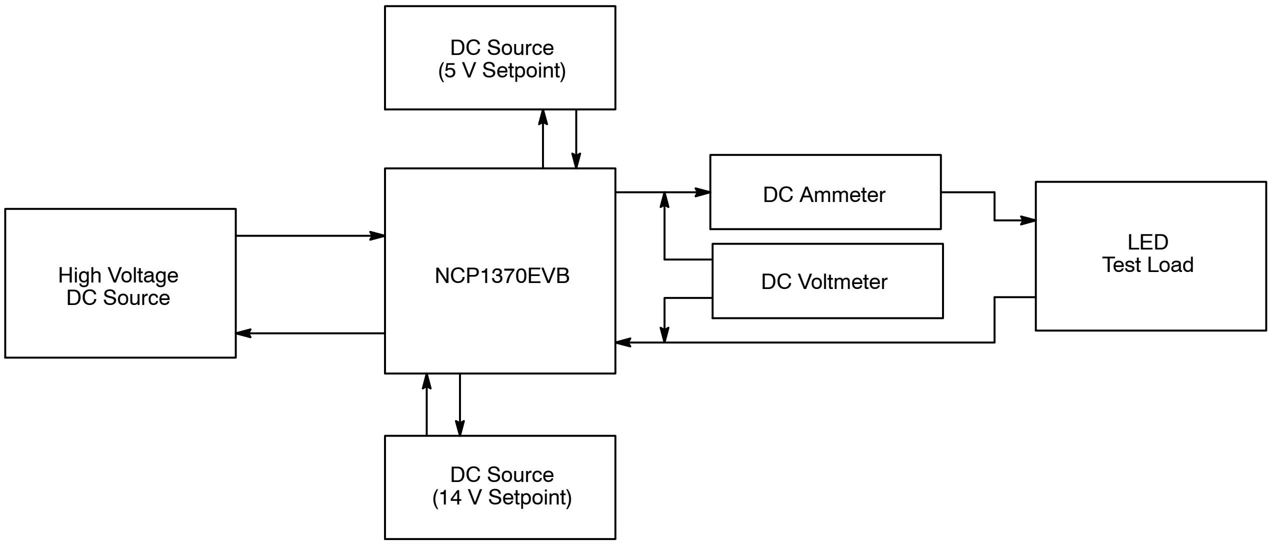

Figure 18.

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 ±2% of 250 mA.

Flyback Inductor Specification

more than you expect

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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
TURNS RATIO		(1-3):(5-6)	14.67:1, ±1%
TURNS RATIO		(1-3):(11-8), tie(9+10)	1:1, ±1%

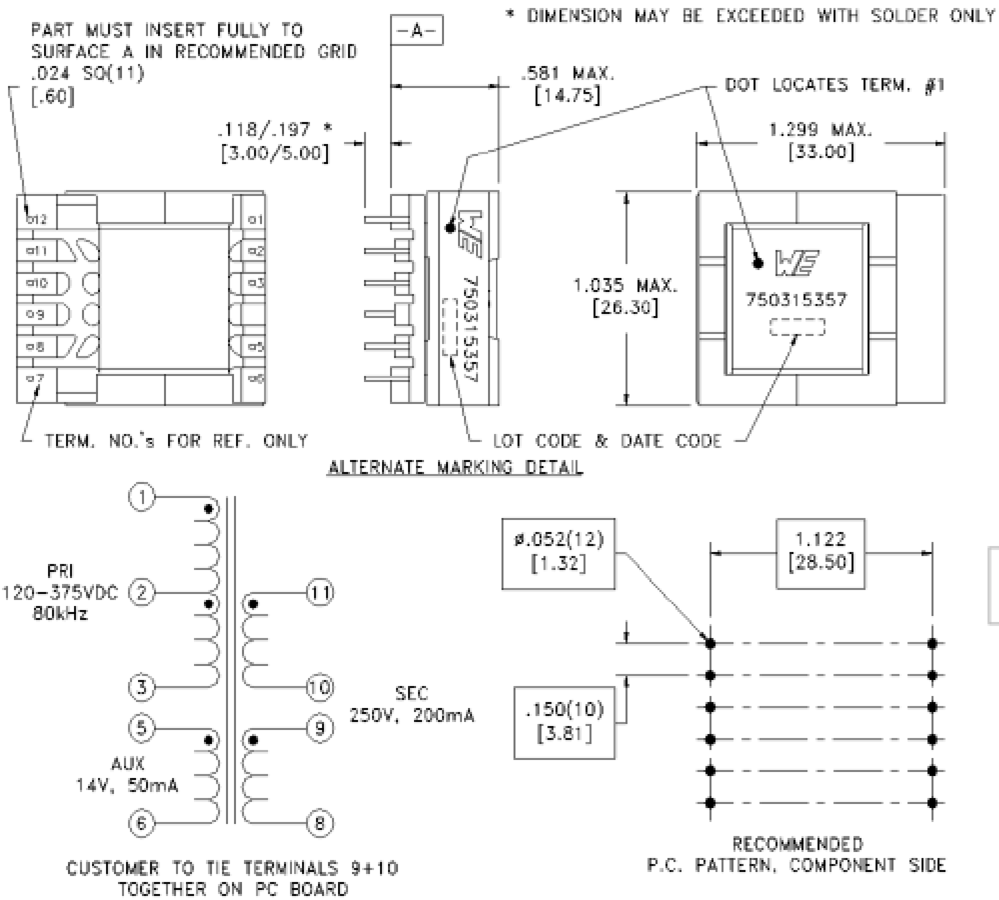

Figure 19. Flyback Inductor Specification

Bill of Materials

Table 2. NCP1370 BILL OF MATERIALS

Qty	Reference	Description	Value	Tolerance/ Constraint	Package/ Footprint	Manufacturer	Manufacturer 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	Electrolitic Capacitor	1 μF	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	Electrolitic Capacitor	47 μF	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, D7, D10	Standard Diode	1N4148	100 V	SOD−123	ON Semicondutor	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 Semicondutor	1N4937
1	D8, D11	Ultra-Fast Diode	MUR160	1 A, 600 V	DO−41	ON Semicondutor	MUR160
1	IC1	PSR Controller	NCP1370B		SO−08	ON Semicondutor	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 Semicondutor	BC847AL
5	R1, R3, R5, R7, R8	Resistor	2.2 MΩ	1%, 125 mW	SMD0805	Standard	Standard
1	R10	Resistor	100 kΩ	1%, 125 mW	SMD0805	Standard	Standard
6	R11, R12, R19, R27, R29, R35	Resistor	10 kΩ	5%, 125 mW	SMD0805	Standard	Standard
2	R13, R22	Resistor	22 Ω	5%, 125 mW	SMD0805	Standard	Standard
1	R14	Resistor	47 Ω	5%, 125 mW	SMD0805	Standard	Standard
1	R15	Resistor	47 kΩ	5%, 1 W	Axial	Standard	Standard
1	R16	Resistor	2.2 kΩ	1%, 125 mW	SMD0805	Standard	Standard
4	R17, R18, R20, R21	Resistor	3.9 Ω	1%, 1 W	SMD2512	Standard	Standard
1	R2	Resistor	12 kΩ	1%, 125 mW	SMD0805	Standard	Standard
1	R23	Resistor	33 Ω	1%, 0.5 W	SMD2512	Standard	Standard
1	R24	Resistor	NC		SMD2512		
3	R26, R28, R30	Resistor	22 kΩ	5%, 125 mW	SMD0805	Standard	Standard
1	R31	Resistor	47 kΩ	5%, 125 mW	SMD0805	Standard	Standard
1	R32	Resistor	470 kΩ	5%, 250 mW	Axial	Standard	Standard
1	R33	Resistor	1 Ω	5%, 250 mW	Axial	Standard	Standard
1	R34	Resistor	22 kΩ	5%, 250 mW	Axial	Standard	Standard
1	R4	Resistor	10 Ω	5%, 250 mW	Axial	Standard	Standard
1	R6	Resistor	0 Ω	5%, 250 mW	Axial	Standard	Standard
2	R9, R25	Resistor	4.7 kΩ	5%, 125 mW	SMD0805	Standard	Standard
1	TR1	Flyback Inductor			Through-Hole	Wurth	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

References

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

ADDITIONAL INFORMATION

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