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AND9715/D

Performances of a LED Driver Controlled by the NCL30386/88

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APPLICATION NOTE

Description

This paper focuses on the experimental results of a LED driver controlled by the NCL30386/88.

Introduction

The NCL30386 [1] and NCL30388 [2] are power factor corrected controllers with primary side constant voltage (CV) and constant current (CC) control suitable for flyback, buck−boost or SEPIC converters. The NCL30386 is housed in an SOIC 10 package and provides analog dimming of the output current with two dedicated dimming control input pins: ADIM and PDIM. The NCL30388 is housed in an SOIC 8 package and targets high−performance LED drivers. These controller integrate a proprietary circuit for power factor correction and constant current control allowing to achieve a power factor above 0.95 and total harmonic distortion below 10% for universal mains input. The output current and the output voltage regulation are typically within ± 2% for an input voltage varying from 85 V rms to 265 V rms. The current−mode, quasi−resonant architecture of these controllers optimizes the efficiency by turning on the MOSFET when the drain−source voltage is minimal (valley). The valley lockout and frequency foldback circuitry maintains high−efficiency performance in dimmed conditions or in light load during constant−voltage regulation.

In addition, the circuit contains a set of powerful protections to ensure a robust LED driver design:

- Output over voltage protection
- Cycle−by−cycle peak current limit
- Winding and output diode short circuit protection
- Output short circuit protection
- V_{CC} pin over voltage protection
- Floating/short pin detection: the circuit can detect most of these situations which is of great help to pass safety tests.

Table 1. LED DRIVER SPECIFICATION

Description	Symbol	Value	Units
LED Driver Specification			
Minimum input voltage	$V_{in,min}$	85	V rms
Maximum input voltage	$V_{in,max}$	265	V rms
Power factor	PF	> 0.9	
Minimum output voltage	$V_{out,min}$	20	V
Output voltage for constant voltage regulation	$V_{out,max}$	40	V
Output voltage level to activate the over voltage protection	$V_{out(OVP)}$	54	V
Output current (nominal)	I_{out}	0.5	A
Output rectifier voltage drop (estimated)	V_f	0.6	V
Startup time	$t_{startup}$	≤ 0.5	s
Other Parameters			
Estimated efficiency	η	85	%
Estimated lump capacitor	C_{lump}	50	pF
Switching frequency at $P_{out,max}$, V_{in} = 115 V rms	F_{sw}	65	kHz

The LED driver is designed to meet the specifications of Table 1.

Description of the Board

The 20−W LED driver has been designed using the guidelines provided in the application notes AND9200/D [3] and AND9714/D [4]. Figure 1 shows the schematic of the board with the NCL30386 implanted and Figure 2 shows the schematic with the NCL30388.

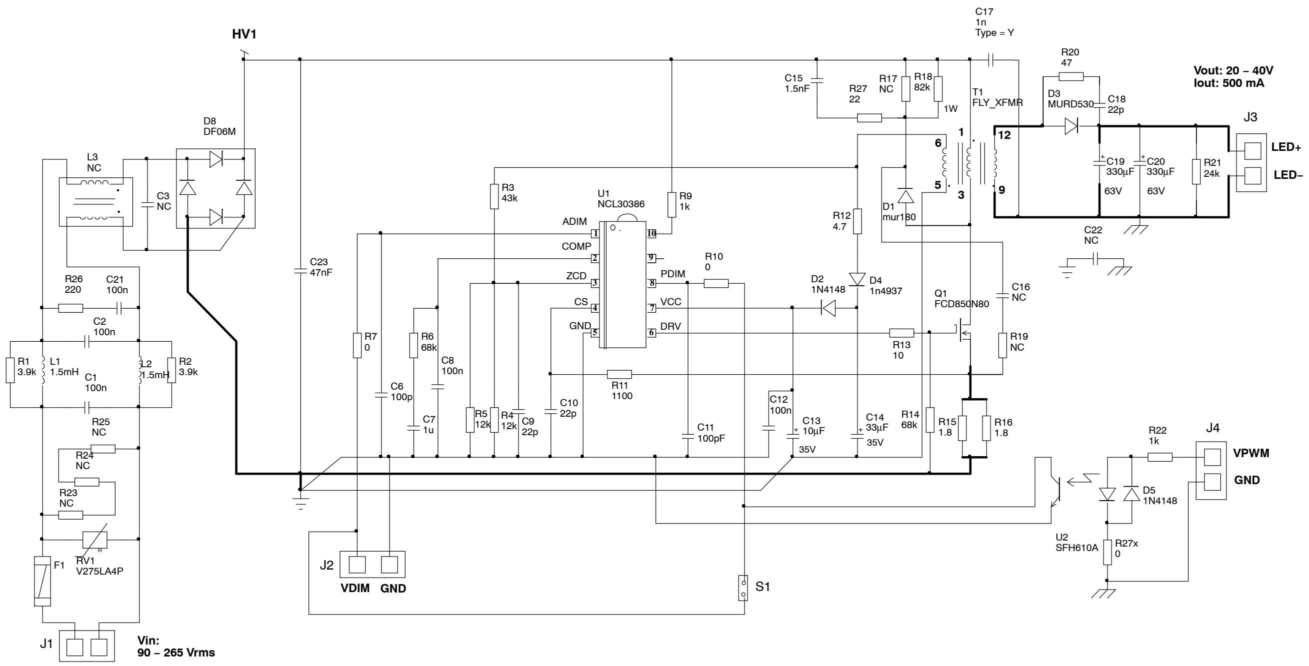


Figure 1. Evaluation Board Schematic for the NCL30386

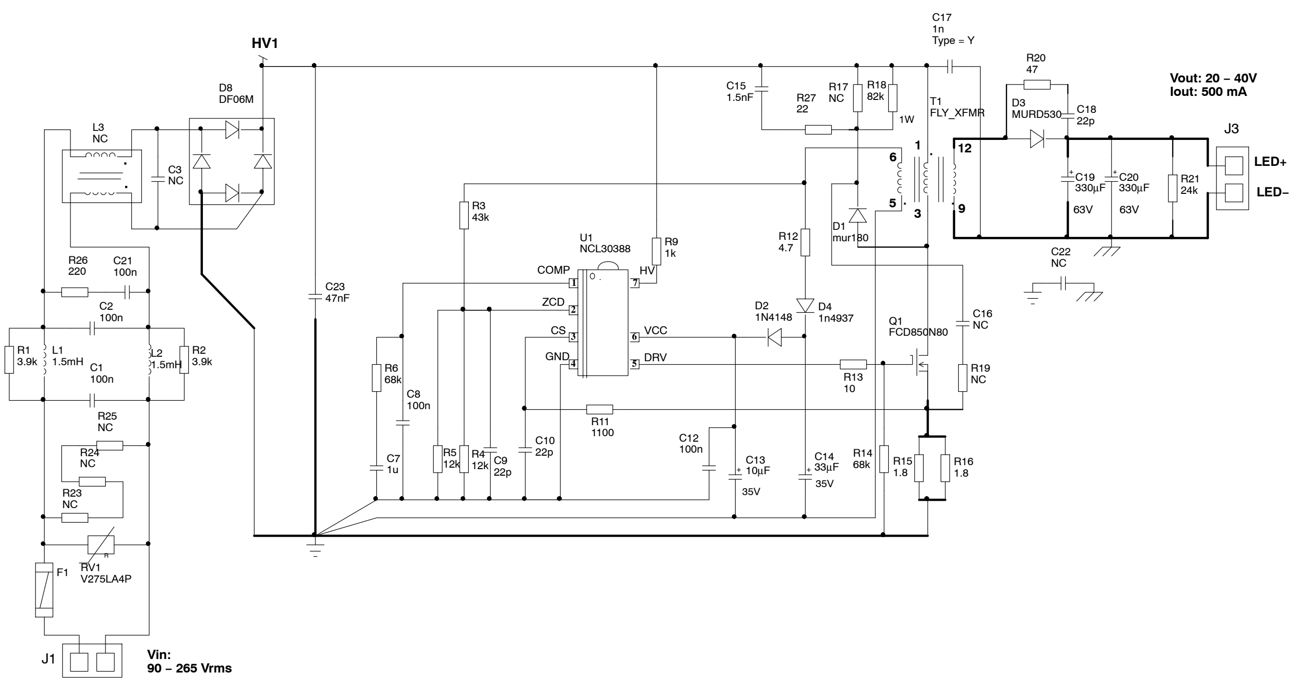


Figure 2. Evaluation Schematic for the NCL30388

The varistor RV1 protects the power supply in case of line surge.

The resistors R1 and R2 damp the oscillation caused by the self−resonant frequency of the coils L1 and L2. This is only for EMI filtering purpose.

The damper circuit formed by R26 and C21 reduces the peaking of the output impedance of the L−C EMI filter composed of L1, L2 and C2.

R6, C7 and C8 are connected to the output of the OTA for the constant voltage loop compensation. They were chosen to set the voltage loop crossover frequency around 8 Hz.

R3, R4 and R5 set the output voltage regulation to 40 V as specified in Table 1. Also, these resistors together with C9 capacitor delay the zero−voltage crossing event and help to tune the turn−on instant when the drain voltage is in the valley.

R11 is the line feedforward resistor that compensates the output current variation caused by the propagation delays.

R9 limits the voltage on HV pin in case of surge.

R15 and R16 are the current sense resistors calculated to set the output current to 500 mA.

R18, R27 and C15 clamp the drain voltage excursion when the MOSFET turns off.

R21 is the dummy−load resistor and provide a minimum output load for the converter in standby to keep the output voltage regulated.

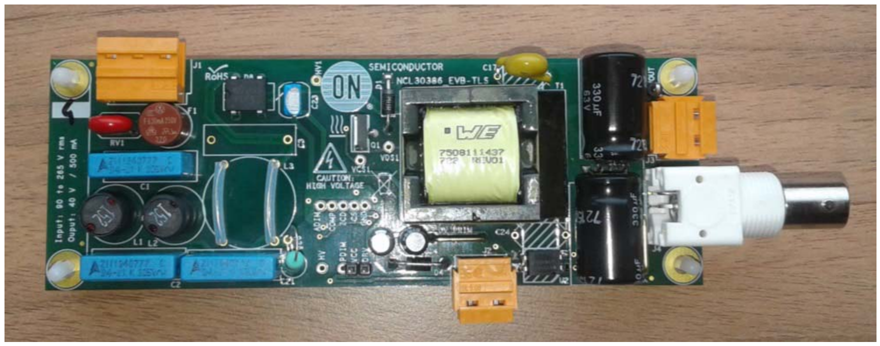


Figure 3. Photograph of the EVB Top Side

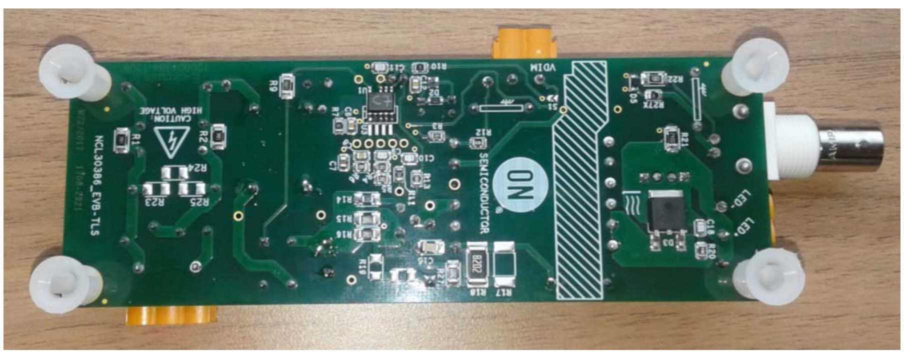


Figure 4. Photograph of the EVB Bottom Side

Figure 5. EVB Side Picture

Output Current Regulation

The output current is measured as the input voltage and the output load vary. The output load is varied by changing the number of LEDs connected to the board output. The LEDs used are the XLamp CXA1304 series from Cree for the 38 V output setpoint and the WL−SWTP series from Wurth for the 24 V output setpoint. The Cree LEDs are specified to have a forward voltage of 9 V at 400 mA, the maximum current being 1 A. Four Cree LEDs in series where used to set the output voltage around 38 V for the test. The Wurth LED load consists in an arrangement of series / parallel LEDs to set the output voltage around 24 V as the minimum output voltage for the test. The input voltage is varied from 85 to 265 V rms.

The output current regulation is estimated by calculating the median value of the output current $I_{out(mean)}$ considering the maximum and the minimum value measured:

$$I_{out(mean)} = \frac{I_{out(max)} + I_{out(mean)}}{2} \qquad \textit{(eq. 1)}$$

Then, we calculate the gap from the maximum value to the median value to deduce the current regulation expressed as a percentage of $I_{out(mean)}$:

$$\delta\, I_{out} = 100\frac{\Delta I_{out}}{I_{out(mean)}} = 100\frac{I_{out(max)} - I_{out(mean)}}{I_{out(mean)}} \qquad \textit{(eq. 2)}$$

For the measurements shown in Figure 6, we have the following results:

$I_{out(mean)}$ = 505.7 mA
$I_{out(max)}$ = 513.1 mA
$I_{out(min)}$ = 498.3 mA
δI_{out} = ± 1.5 %

The output current regulation is ± 1.5 % with line and load variation included.

We can also measure the output current regulation when the ambient temperature varies. The board is placed in a stove and the temperature is varied from 70°C to 25°C. The LEDs are placed outside the stove. The current circulating in the LEDs is measured with an electronic multimeter. The results are plotted in Figure 7.

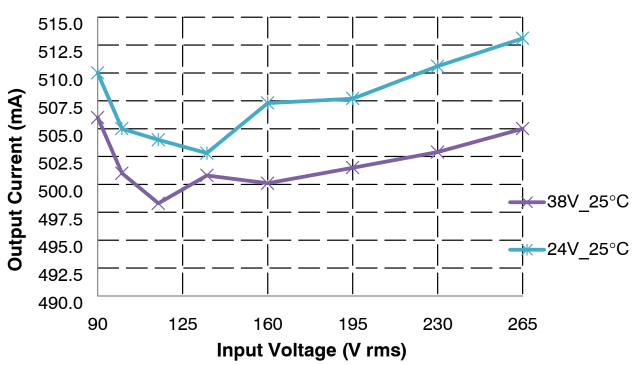


Figure 6. Line and Load Regulation for an Ambient Temperature of 25°C

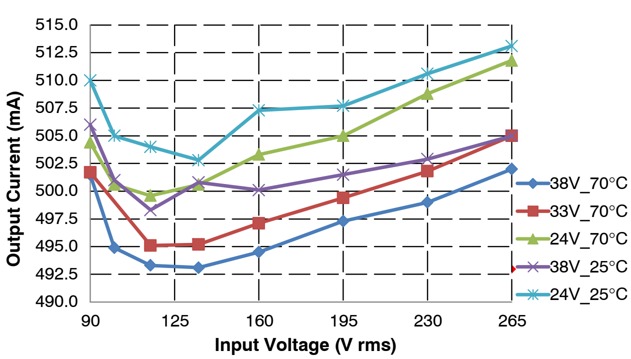


Figure 7. Output Current Regulation with Temperature

The output current variations with temperature are not caused by the controller alone. The output rectifier plays a significant role in the output current variation. From the measurements on Figure 7, we have the following results:

$I_{out(mean)}$ = 503.1 mA
$I_{out(max)}$ = 513.1 mA
$I_{out(min)}$ = 493.1 mA
δI_{out} = ± 2%

The output current regulation is within ± 2% of the mean value with the ambient temperature variation included on top of the line and load variation.

Output Voltage Regulation

An electronic load in constant resistance mode is used to obtain the CC/CV characteristic of the flyback converter (output voltage versus output current) controlled by the NCL30386/88. The CC/CV curve is plotted for various input voltage: 90, 115, 230 and 265 Vrms.

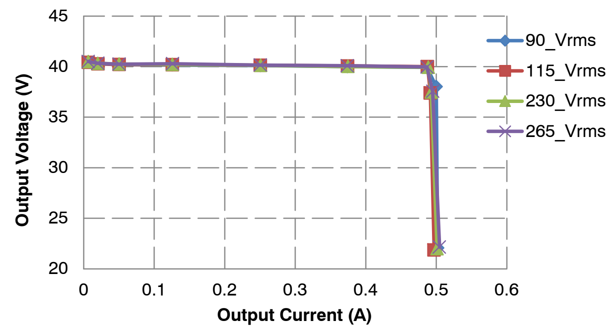


Figure 8. CC/CV Curves of the NCL30386/88

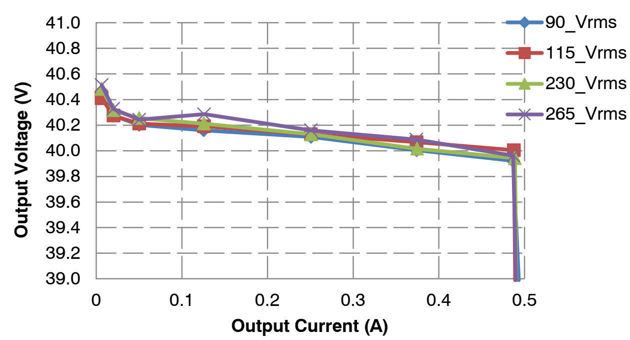


Figure 9. Constant Voltage Regulation at Different Input Voltage

The output voltage varies from 39.9 V at maximum output load to 40.9 V in standby when the electronic load is disconnected from the board output.

Using the same method described in the previous paragraph for the output current regulation, we can estimate the output voltage regulation:

$V_{out(mean)}$ = 40.4 V
$V_{out(max)}$ = 40.9 V (obtained when the load is disconnected from the board)
$V_{out(min)}$ = 39.9 V (obtained for maximum output load)
δV_{out} = ± 1.2 %

The constant voltage regulation is ± 1.2% over the input voltage range.

Efficiency, Power Factor and Total Harmonic Distortion

The measurements were made after the board was operated during 5 minutes at maximum output load (20 W), low line, with an open frame and at ambient temperature.

The input power, the PF and the THD were measured with the power meter 66202 from Chroma.

The output current and the output voltage were measured using the electronic load with the output voltage sensed at the board output. The electronic load was used in constant resistance mode and programmed to draw 100%, 75%, 50% and 25% of the board maximum output power. Figure 10, Figure 11 and Figure 12 summarizes the measurements results.

With an average efficiency of 88.3% at 115 V rms and 88.1% at 230 V rms, the board exceed the Tier 2 of the Code of Conduct on Energy Efficiency of External Power Supplies.

The THD is also excellent and stays below 10% down when the output load is 25% of the maximum rated power over the line range.

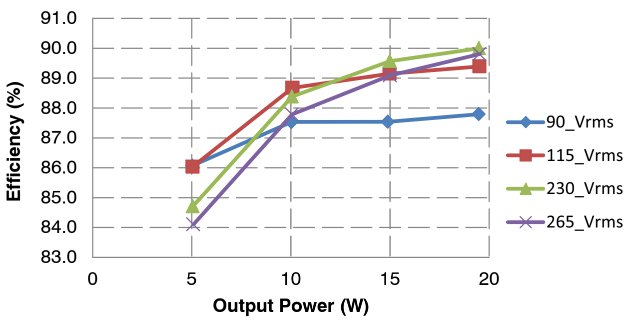


Figure 10. Efficiency

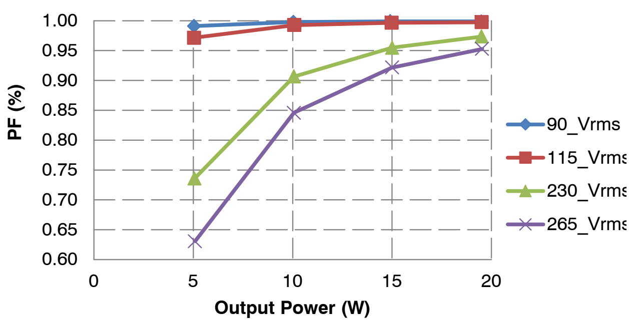


Figure 11. Power Factor

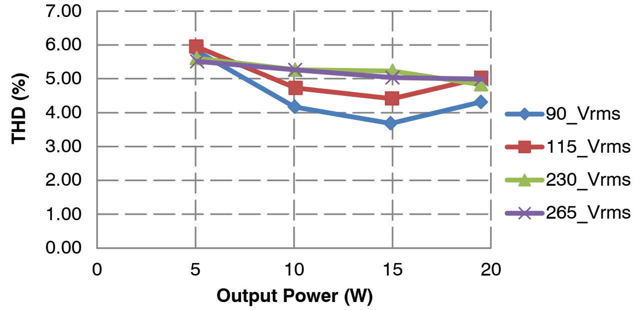


Figure 12. THD for V_{in} = 90 to 265 V rms

Dimming with the NCL30386

The NCL30386 provides two pins to dim the output current.

The ADIM pin receives an analog signal and dim the output current in an analog way.

The pin PDIM reads the duty−cycle of a PWM signal and translates this duty−cycle into the corresponding current setpoint internally. As a result, the output current is dimmed in an analog fashion. The frequency of the dimming signal can vary from 1 kHz to 250 Hz.

To summarize, both pins provides an analog dimming of the output current.

The NCL30386 features a linear dimming curve or a square dimming curve depending on the option.

Figure 13 and Figure 14 shows the measured output current as a function of the duty ratio of the PWM signal applied to PDIM pin through the optocoupler U2. The signal has a frequency of 700 Hz and its duty ratio is varied from 100% to 1%.

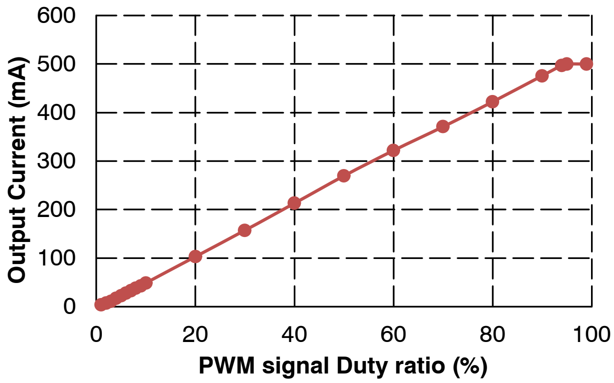


Figure 13. Output Current with Linear Dimming Response Using PDIM Pin

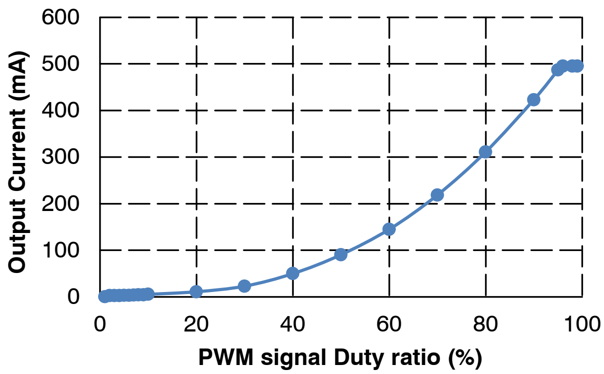


Figure 14. Output Current with Square Dimming Response Using PDIM Pin

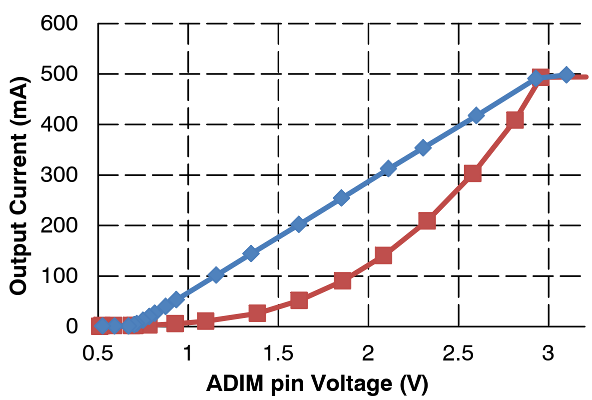


Figure 15. Output Current with Linear Dimming Response (blue) and Square Dimming (red) Using ADIM Pin

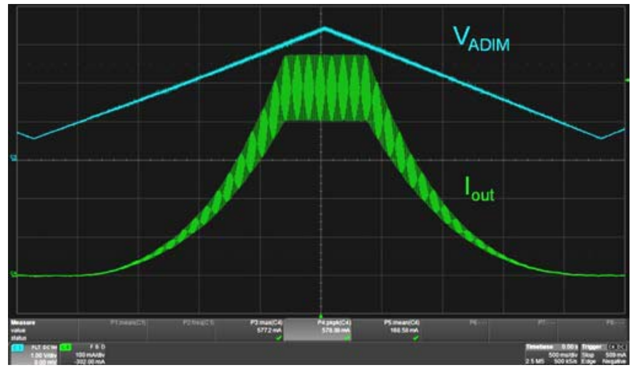


Figure 16. Output Current Waveform with Square Dimming Response Using ADIM Pin

Figure 15 portrays the measured output current as a function of the voltage applied on ADIM pin. The blue curve is the linear dimmed response while the red curve is the square dimming response. The maximum output current is reached when $V_{ADIM} \geq 3$ V.

When 0.5 V < $V_{ADIM} \leq 0.7$ V, the output current is clamped to a minimum value. Below 0.5 V, the controller is disabled.

Transient Load Step

Since PFC has low loop bandwidth, abrupt changes in the load may cause excessive over or under−shoot. The NCL30386/88 features circuitry to limit the output voltage variation during load transient. The slow Over Voltage Protection contains the output voltage when it exceeds 115% of its regulation level. In addition, the NCL30386 speeds up the constant voltage regulation loop when the output voltage goes below 80% of its regulation level.

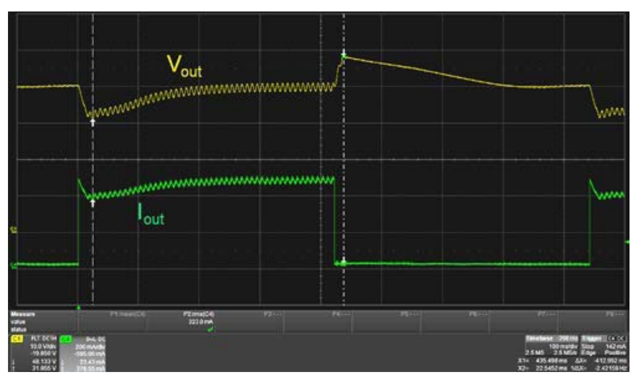


Figure 17. Transient Load Step Response with Electronic Load in Constant Resistance Mode

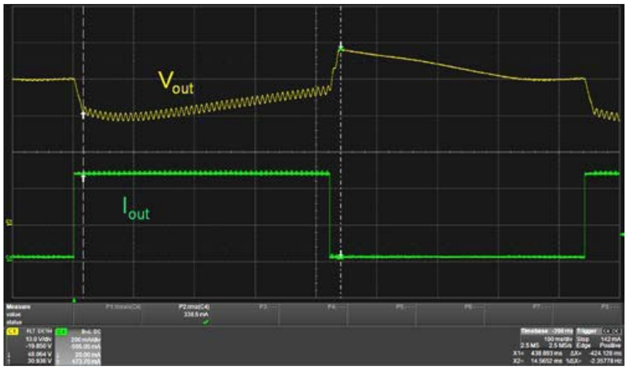


Figure 18. Transient Load Step Response with Electronic Load in Constant Current Mode

Figure 18 shows the output voltage and the output current variation when the output load is varied from 480 mA to 20 mA abruptly, the load being in constant current mode. Figure 17 shows the output voltage and the output current variation when the output load is varied from 80 Ω to 2.1 kΩ abruptly, the electronic load being in constant resistance mode and V_{in} = 115 V rms. For both conditions, the output voltage overshoot is contained at 48 V and the voltage undershoot is at 31 V, which represents respectively 20% and −23% of the output voltage regulation level.

Protections

Fast Over Voltage Protection

If ZCD voltage exceeds 130% of $V_{REF(CV)}$ (2.5 V) for 4 consecutive switching cycles (slow OVP not triggered) or for 2 switching cycles if the slow OVP has already been triggered, the controller detects a fault and shutdown. The controller initiates a new startup sequence after waiting for 4 seconds.

Figure 19 shows the fast OVP at work. In order to trigger the fast OVP, the dummy load R_{21} at the board output is removed at time t_1. The slow OVP is first triggered and the controller reduces its switching period around 1.4 ms. The output voltage continues increasing until the fast OVP triggers at t_2: V_{out} = 58 V. The controller stops switching during 4 s and VCC hiccups. At t_3, the controller restarts switching (V_{out} = 57.4 V). The output voltage increases and the fast OVP is triggered again at t_4.

For this design, when the fast OVP is triggered, the output voltage varies between 58 V and 57.4 V.

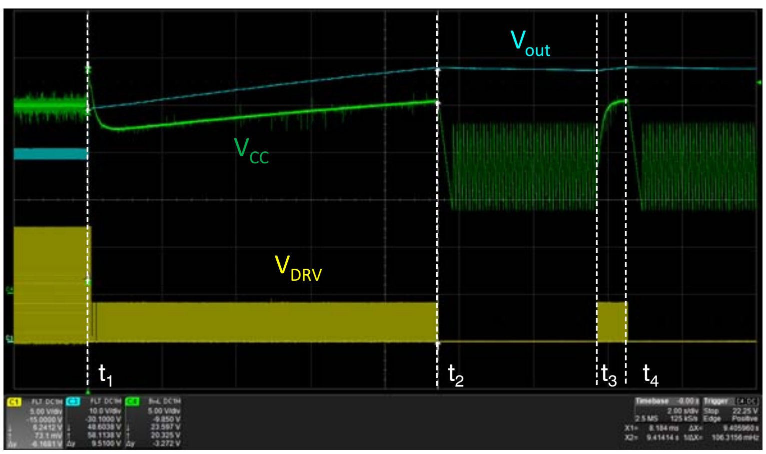


Figure 19. Fast OVP at Works

Output Short Circuit Protection

Figure 20 illustrates the behavior of the short circuit protection. At t_1, the output is shorted. As a result, V_{ZCD} < 1 V and the short circuit timer start counting. After 100 ms at t_2, the controller stops switching and V_{CC} hiccups. When the 4−s auto−recovery timer elapses, the controller restarts switching at t_3.

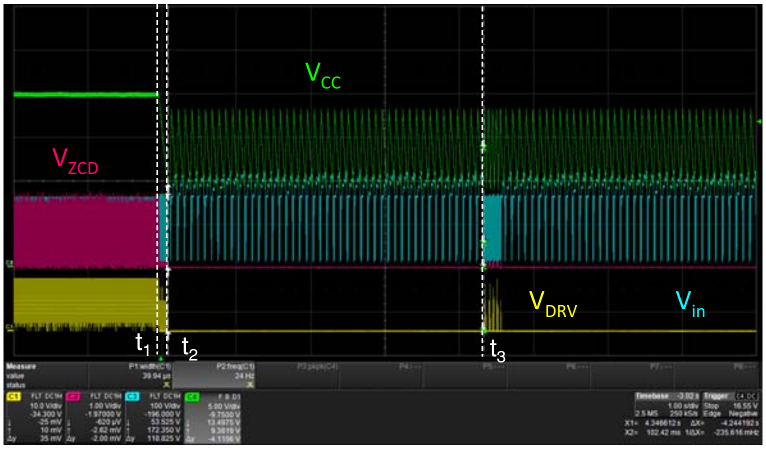


Figure 20. Output Short Circuit Protection

Output Diode Short

The LED driver stops operating as soon as V_{CS} exceeds $V_{CS(stop)}$ (140% of maximum peak current limit) during 4 consecutives DRV pulses. The NCL30386/88 tries to resume operation when the 4–s auto–recovery delay is elapsed.

This is illustrated by Figure 21 where the output diode of the LED driver has been shorted.

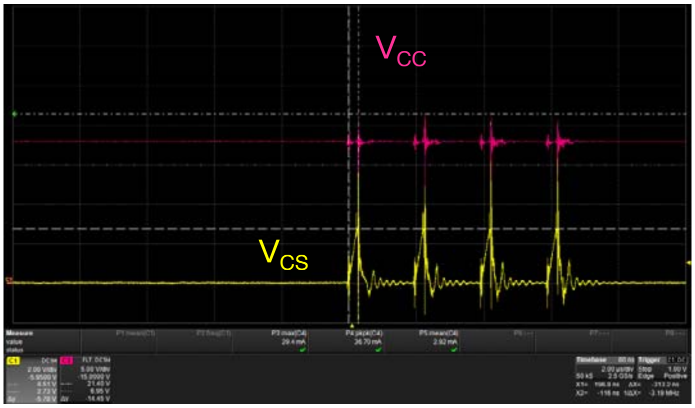


Figure 21. The Winding or Output Diode Short Circuit Protection Triggers as soon as 4 Consecutive Faulty DRV Pulses are Detected

Conclusion

This application note has shown the experimental results of a LED driver controlled by the NCL30386/88.

This new family of controllers provides a very good regulation of the output current and the output voltage from the primary side of a flyback controller: ± 1.5 % achieved with the evaluation boards for constant current regulation and ± 1.2% for constant voltage regulation.

BILL OF MATERIAL

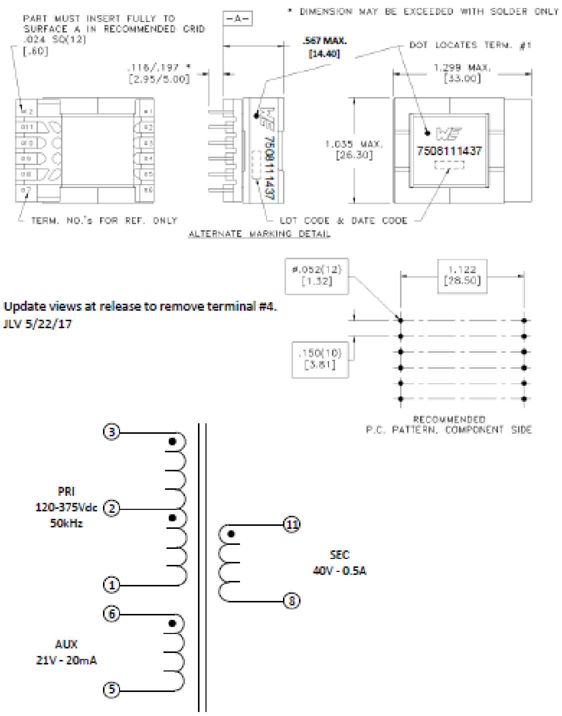
Table 2. BOM FOR NCL30386/88 EVB

Reference	Qty	Description	Value / Tolerance	Footprint	Manufacturer	Manufacturer Part Number
RV1	1	Varistor	275 V	Through hole	Littelfuse	V275LAP
F1	1	Fuse	1 A	Through hole	Standard	Standard
C1, C2, C21	3	X2 capacitor	100 nF, 300 V ac	Through hole	VISHAY	BFC233840104
C3	0	Capacitor	Not connected			
L1, L2	2	Radial coil	1.5 mH, 340 mA	Through hole	Coilcraft	RFB0810
L3	0	Common Mode choke	Not connected			
D8	1	Diode bridge	1.5 A, 600 V	Through hole	ON Semiconductor	DF06M
D1	1	Ultra−fast diode	MUR180	Axial	ON Semiconductor	MUR180E
D2, D5	2	Diode	1N4148	SOD−323	ON Semiconductor	1N4148WS
D3	1	Ultra−fast rectifier	MURD530	DPAK	ON Semiconductor	MURD530T4G
D4	1	Diode	1N4937	Axial	ON Semiconductor	1N4937G
Q1	1	MOSFET	6 A, 800 V	TO−251	ON Semiconductor	FCU850N80Z
C23	1	Ceramic capacitor	47 nF, 400 V	Through hole	TDK/EPCOS	B32559C6473+
C9, C10, C18	3	Ceramic capacitor	22 pF	SMD 0805	Standard	Standard
C7	1	Ceramic capacitor	1 μF	SMD 0805	Standard	Standard
C8	1	Ceramic capacitor	100 nF	SMD 0805	Standard	Standard
C12	1	Ceramic capacitor	100 nF	SMD 0805	Standard	Standard
C11	1	Ceramic capacitor	47 pF	SMD 0805	Standard	Standard
C6	1	Ceramic capacitor	100 pF	SMD 0805	Standard	Standard
C13	1	Electrolytic capacitor	10 μF, 35 V	Radial	Standard	Standard
C14	1	Electrolytic capacitor	33 μF, 35 V	Radial	Standard	Standard
C15	1	Ceramic capacitor	2.2 nF, 1 kV	SMD1206	Standard	Standard
C16	0	Ceramic capacitor	Not connected			
C17	1	Y capacitor	1 nF	Through hole	Standard	Standard
C19, C20	2	Electrolytic capacitor	330 μF, 63 V, 1.58 A	Radial	Panasonic	EEUFR1J331B
R1, R2	2	Resistor	3.9 kΩ	SMD 1206	Standard	Standard
R3	1	Resistor	43 kΩ, 1%	SMD 0805	Standard	Standard
R4, R5	2	Resistor	12 kΩ, 1%	SMD 0805	Standard	Standard
R6	1	Resistor	68 kΩ	SMD 0805	Standard	Standard
R7, R10, R27x	3	Resistor	0 Ω	SMD 0805	Standard	Standard
R9	1	Resistor	1 kΩ	SMD 1206	Standard	Standard
R11	1	Resistor	1.1 kΩ	SMD 0805	Standard	Standard
R12	1	Resistor	4.7 Ω	SMD 0805	Standard	Standard
R13	1	Resistor	10 Ω	SMD 0805	Standard	Standard
R14	1	Resistor	68 kΩ	SMD 1206	Standard	Standard
R15, R16	2	Resistor	1.8 Ω, 1%	SMD1206	Standard	Standard
R17	0	Resistor	Not connected			
R18	1	Resistor	82 kΩ, 1W	SMD2512	Standard	Standard
R19	0	Resistor	Not connected	SMD1206		

Table 2. BOM FOR NCL30386/88 EVB

Reference	Qty	Description	Value / Tolerance	Footprint	Manufacturer	Manufacturer Part Number
R20	1	Resistor	47 Ω	SMD 0805	Standard	Standard
R21	1	Resistor	47 kΩ	SMD 1206	Standard	Standard
R22	1	Resistor	1 kΩ	SMD1206	Standard	Standard
R26	1	Resistor	220 Ω, 1W	Axial	Standard	Standard
R23, R24, R25	0	Resistor	Not connected			
R27	1	Resistor	22 Ω	SMD 1206	Standard	Standard
T1	1	Flyback Transformer		Through hole	Wurth	7508111437r01
U1	1	Controller	NCL30386 NCL30388	SOIC9 SOIC7	ON Semiconductor	
U2	1	Optocoupler	SFH6106−3	SMD	Standard	Standard
J1	1	Input connector male		Through hole	WEIDMULLER	SL 5.08/3/90B4.5
J1a	1	Input connector female			WEIDMULLER	BLZ 5.08/3
J2, J3	2	Input connector male		Through hole	WEIDMULLER	SL 5.08/2/90B4.5
J2a, J3a	2	Input connector female			WEIDMULLER	BLZ 5.08/2
J4	1	BNC connector		Through hole	Standard	Standard

TRANSFORMER SPECIFICATION



ELECTRICAL SPECIFICATIONS @ 25° C unless otherwise noted:

PARAMETER		TEST CONDITIONS	VALUE
D.C. RESISTANCE	3-1	@20°C	0.818 ohms ±10%
D.C. RESISTANCE	5-6	@20°C	0.142 ohms ±10%
D.C. RESISTANCE	8-11	@20°C	0.144 ohms ±10%
INDUCTANCE	3-1	10kHz, 100mV, Ls	850µH ±10%
SATURATION CURRENT	3-1	20% rolloff from initial	1.95A
LEAKAGE INDUCTANCE	3-1	tie(4+5, 8+11),100kHz, 100mV, Ls	7µH typ., 12µH max.
DIELECTRIC	1-11	tie(3+5), 3750VAC, 1 second	3000VAC, 1 minute
DIELECTRIC	1-6	625VAC, 1 second	
TURNS RATIO		(3-2):(2-1)	1:1, ±1%
TURNS RATIO		(3-1):(6-5)	5.47:1, ±1%
TURNS RATIO		(3-1):(11-8)	2.83:1, ±1%

GENERAL SPECIFICATIONS:

OPERATING TEMPERATURE RANGE: -40°C to +125°C including temp rise.

Designed to comply with the following requirements as defined by IEC60950-1, EN60950-1, UL60950-1/CSA60950-1 and AS/NZS60950.1:

- Reinforced insulation for a primary circuit at a working voltage of 265Vrms, 400Vpeak, Overvoltage Category II.

REFERENCES

[1] NCL30386 Datasheet,

[2] NCL30388 Datasheet,

[3] Joel Turchi, "4 Key Steps to Design a NCL30088−Controlled LED Driver", AND9200/D

[4] Stéphanie Cannenterre, "Designing a LED driver with the NCL30386/88", AND9714/D

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