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## Performances of a LED Driver Driven by the NCL30080/81/82/83

### Introduction

As LED lighting finds its way into low wattage applications, lamp designers are challenged for a variety of conflicting requirements. Size is often dictated by the incumbent lamp and fixture size whether it's A19, GU10, etc. Thermal performance, reliability, safety, and EMC requirements also present design challenges. The NCL3008X family of controllers incorporates all the features and protection needed to design compact low wattage LED drivers with a minimum of external components.

Table 1. PRODUCT MATRIX

| Product     | Package | Thermal Foldback | Analog/Digital Dimming | 5 Step LOG Dimming |
|-------------|---------|------------------|------------------------|--------------------|
| NCL30080A/B | TSOP6   | No               | No                     | No                 |
| NCL30081A/B | TSOP6   | No               | No                     | Yes                |
| NCL30082A/B | Micro-8 | Yes              | Yes                    | No                 |
| NCL30083A/B | Micro-8 | Yes              | Soft-start             | Yes                |

In the A versions of the NCL3008X, some protections are latched. In the B versions, all faults are auto-recoverable.

The controllers have 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 optocoupler and associated circuitry. The control scheme also support Buck-boost and SEPIC topology. 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

### Overview

The NCL3008X is a family of 4 controllers in 2 different packages (Micro 8 and TSOP6). The 8 pin packaged parts have 2 extra pins for Dimming and thermal / over voltage protection. The 6 pin package parts have all the basic control and protection feature required to make a low parts count LED driver.

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 application note focuses on the experimental results of a LED driver controlled by the NCL30080-81-82-83.

### LED Driver Specification

The LED driver is designed to meet the specifications of Table 2.

Table 2. 12 W LED DRIVER SPECIFICATION

| Description                                  | Symbol         | Value | Units |
|--|----------------|-------|-------|
| <b>LED driver specification</b>              |                |       |       |
| Minimum input voltage                        | $V_{in,min}$   | 85    | V rms |
| Maximum input voltage                        | $V_{in,max}$   | 265   | V rms |
| Power factor (valley fill version only)      | PF             | > 0.7 |       |
| Minimum output voltage                       | $V_{out,min}$  | 12    | V     |
| Maximum output voltage                       | $V_{out,max}$  | 24    | V     |
| Output voltage at which the OVP is activated | $V_{out(OVP)}$ | 28    | V     |
| Output current (nominal)                     | $I_{out}$      | 0.5   | A     |

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**Table 2. 12 W LED DRIVER SPECIFICATION**

| Description                               | Symbol          | Value      | Units |
|---|-----------------|------------|-------|
| Output rectifier voltage drop (estimated) | $V_f$           | 0.6        | V     |
| Input voltage for brown-in                | $V_{in(start)}$ | 72         | Vrms  |
| Startup time                              | $t_{startup}$   | $\leq 1.5$ | s     |

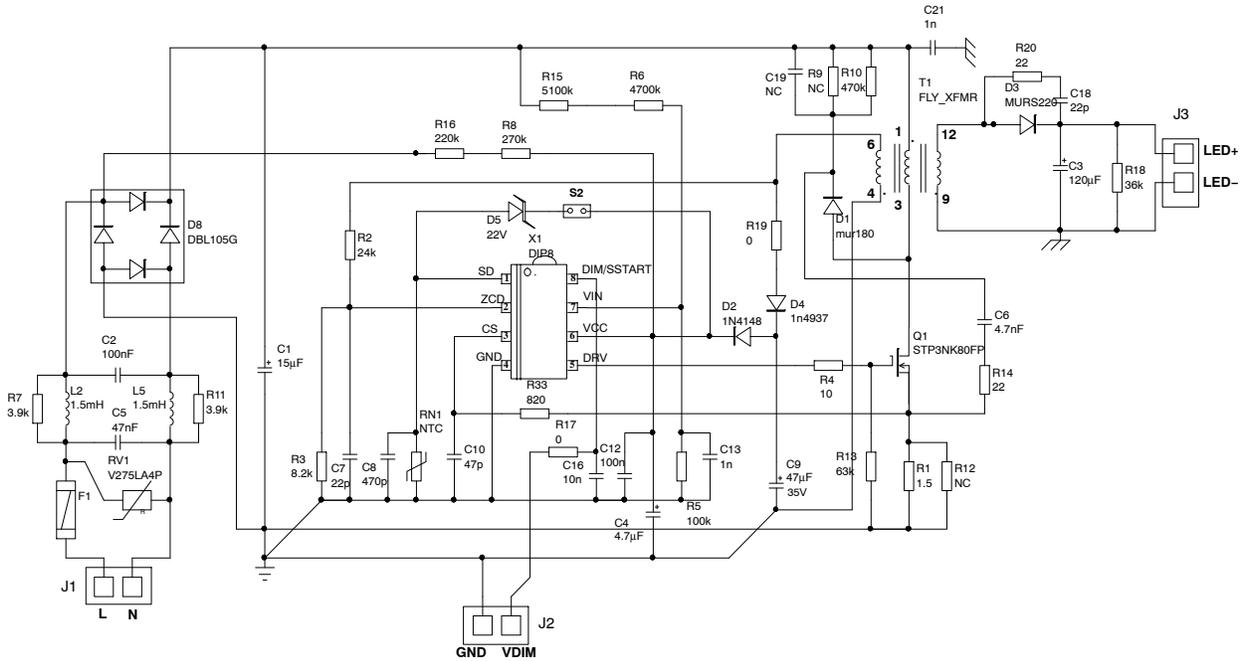
**Other parameters**

|   |              |    |     |
|---|--------------|----|-----|
| Estimated efficiency                                | $\eta$       | 85 | %   |
| Estimated lump capacitor                            | $C_{lump}$   | 50 | pF  |
| Switching frequency at $P_{out,max}$ , $V_{in,min}$ | $F_{sw}$     | 45 | kHz |
| Estimated bulk voltage ripple                       | $V_{ripple}$ | 30 | V   |

**Description of the Board**

The 12 W LED driver has been designed using the method described in the application note AND9131/D [1]. Figure 1

shows the schematic of the default board version and Figure 2 shows the schematic with the valley fill circuit to provide passive power correction.



**Figure 1. Default Evaluation Board Schematic**

The evaluation board (EVB) supports all 4 controllers the NCL30080, NCL30081, NCL30082 and NCL30083 thanks to a small daughter board.

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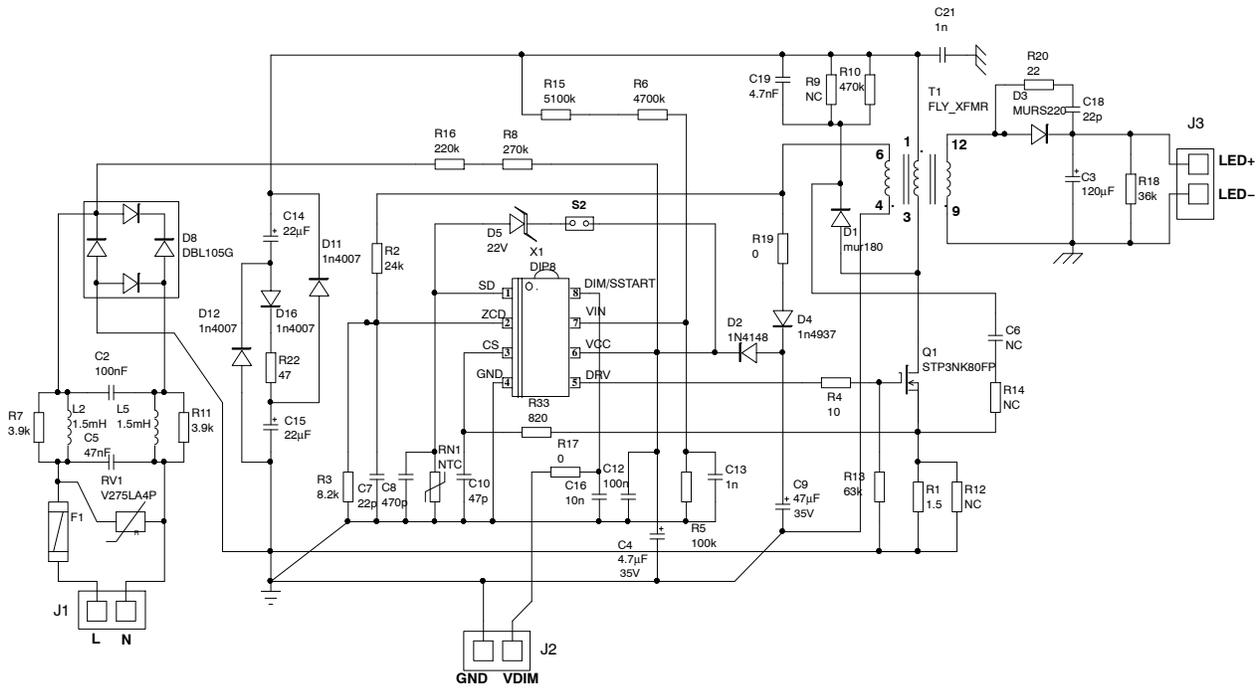


Figure 2. Evaluation Board with Valley Fill

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

The resistors R7 and R11 damp the oscillation caused by the self resonant frequency of the coils L2 and L5. This is only for EMI filtering purpose.

R16 and R8 are the startup resistors connected to the half-wave in order to decrease the power losses in the startup network. They were sized to provide a startup time of 1.5 s at 85 V rms.

R2 and R3 limit the current flowing in the ZCD pin. Also, these resistors together with C7 capacitor delay the zero

voltage crossing event and helps to tune the turn-on instant when the drain voltage is in the valley.

RN1 is a NTC chosen to provide a thermal foldback starting point at 75°C and an over temperature trip point at 95°C. We selected a NTC with  $B_{25/85} = 4220$  and a resistance at 25°C  $R_{25} = 100 \text{ k}\Omega$ .

R33 is the line feedforward resistor that compensates the output current variation caused by the propagation delay.

R15, R6 and R5 are the brown-out resistors which have been calculated to start operating at  $V_{in} = 71 \text{ V rms}$ .



Figure 3. Photograph of the Top Side of the Valley Fill EVB

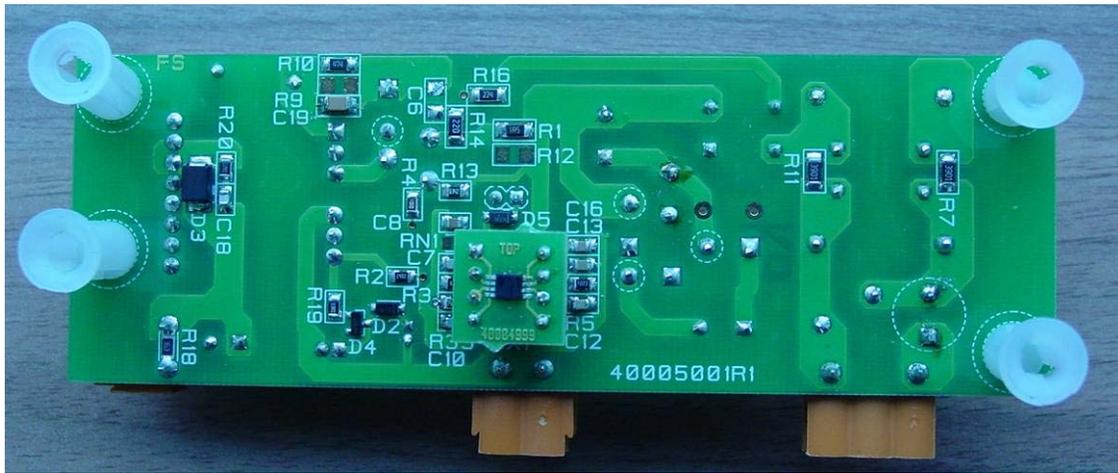


Figure 4. Photograph of the Bottom Side of the Valley Fill EVB

**Output current regulation**

The output current is measured as the input voltage and the output load vary. The output load varied by changing the number of LEDs connected to the board output. The LEDs used are Xlamp MX-6 LEDs from Cree with have a forward

voltage drop around 3.6 V at 480 mA. The number of LEDs is varied from 3 to 6, fixing an output voltage from 10.9 V to 21.7 V. The input voltage is varied from 85 to 265 V rms for the default EVB or from 90 V rms to 265 V rms for the Valley Fill EVB.

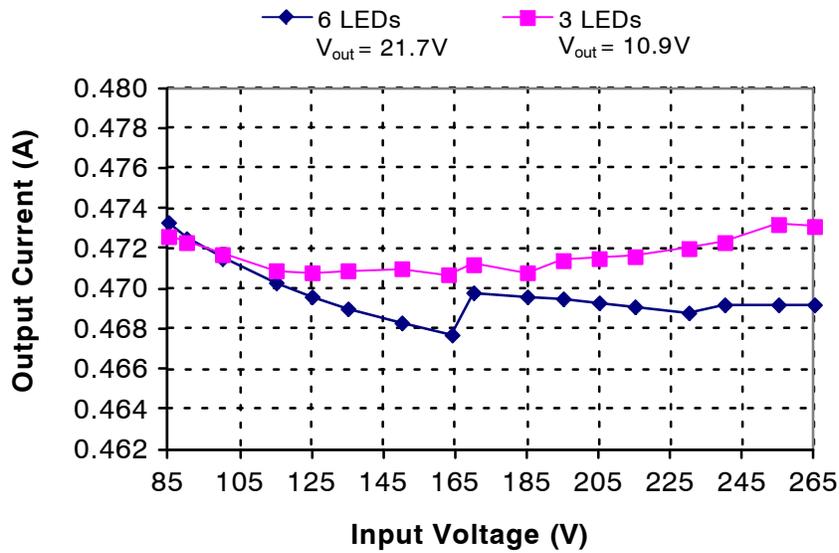


Figure 5. Line and Load Regulation with the NCL30080B (Normal EVB)

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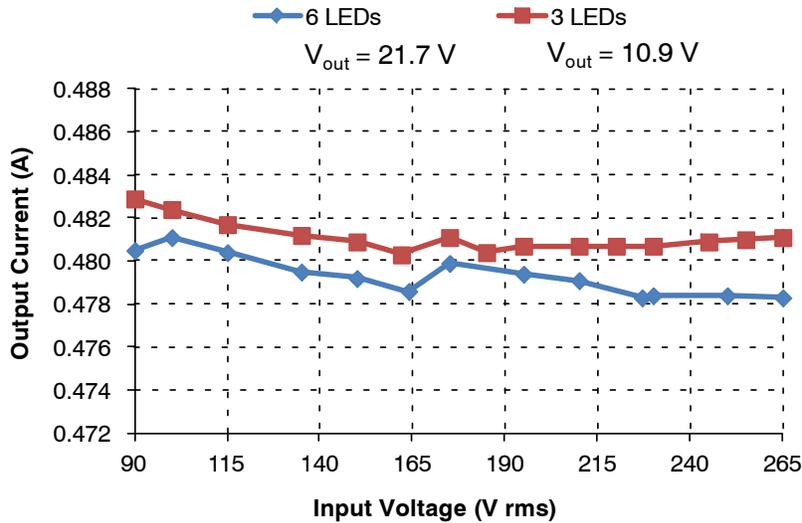


Figure 6. Line and Load Regulation with Valley Fill EVB (NCL30083B)

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:

$$I_{out(mean)} = \frac{I_{out(max)} + I_{out(min)}}{2} \quad (\text{eq. 1})$$

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

$$\delta I_{out} = 100 \frac{\Delta I_{out}}{I_{out(mean)}} = 100 \frac{I_{out(max)} - I_{out(min)}}{I_{out(mean)}} \quad (\text{eq. 2})$$

For the measurements shown in Figure 5, we have the following results:

$$\begin{aligned} I_{out(mean)} &= 470.5 \text{ mA} \\ I_{out(max)} &= 473.2 \text{ mA} \\ I_{out(min)} &= 467.7 \text{ mA} \\ \delta I_{out} &= \pm 0.6\% \end{aligned}$$

The output current regulation is  $\pm 0.6\%$ .

For the Valley Fill EVB (Figure 6), we have the following results:

$$\begin{aligned} I_{out(mean)} &= 480.6 \text{ mA} \\ I_{out(max)} &= 482.9 \text{ mA} \\ I_{out(min)} &= 478.3 \text{ mA} \\ \delta I_{out} &= \pm 0.5\% \end{aligned}$$

The output current regulation is  $\pm 0.5\%$  with valley fill circuit for power factor correction. The valley fill circuit does not decrease the precision of the current regulation.

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  $80^{\circ}\text{C}$  to  $-20^{\circ}\text{C}$ . The LEDs are placed outside the stove. The current circulating in the LEDs is measured with an electronic multimeter. The measurements are plotted in Figure 7.

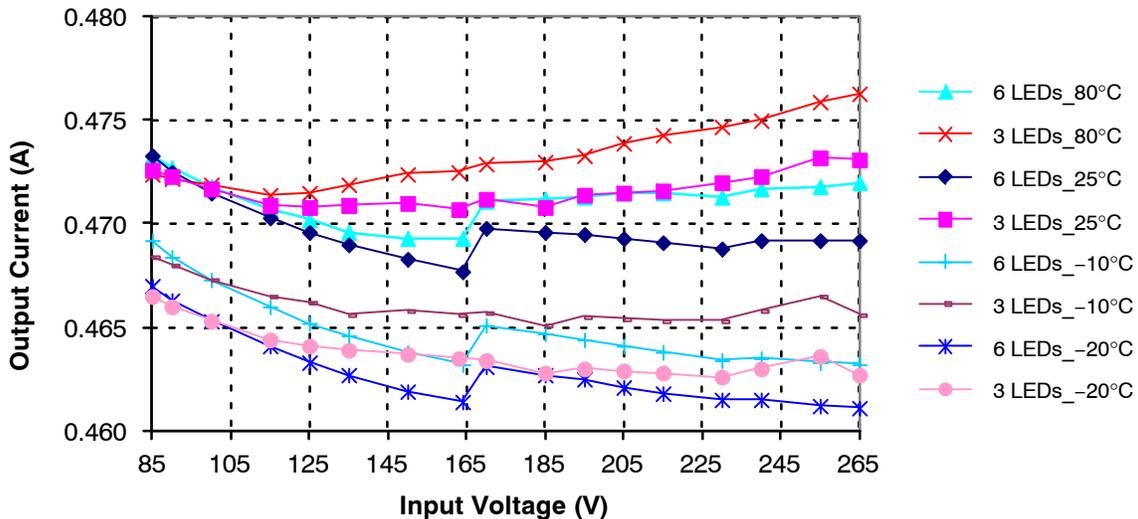


Figure 7. Output Current Regulation with Temperature (NCL30080B, Normal EVB)

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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 6, we have the following results:

$$I_{out(mean)} = 468.7 \text{ mA}$$

$$I_{out(max)} = 476.3 \text{ mA}$$

$$I_{out(min)} = 461.1 \text{ mA}$$

$$\delta I_{out} = \pm 1.6\%$$

The output current regulation is  $\pm 1.6\%$  from  $80^{\circ}\text{C}$  to  $-20^{\circ}\text{C}$ .

### Step Dimming Results

The NCL30081 and NCL30083 can dim the LED current to 5 discrete levels sequentially. Interrupting the mains briefly will step the LED current down one level until returning back to full light. Figure 8 shows the output current evolution for each dimming step. Table 3 summarizes the output current regulation for each dimming step when the input voltage is varied from 85 to 265 V rms and the output load from 6 LEDs to 4 LEDs.

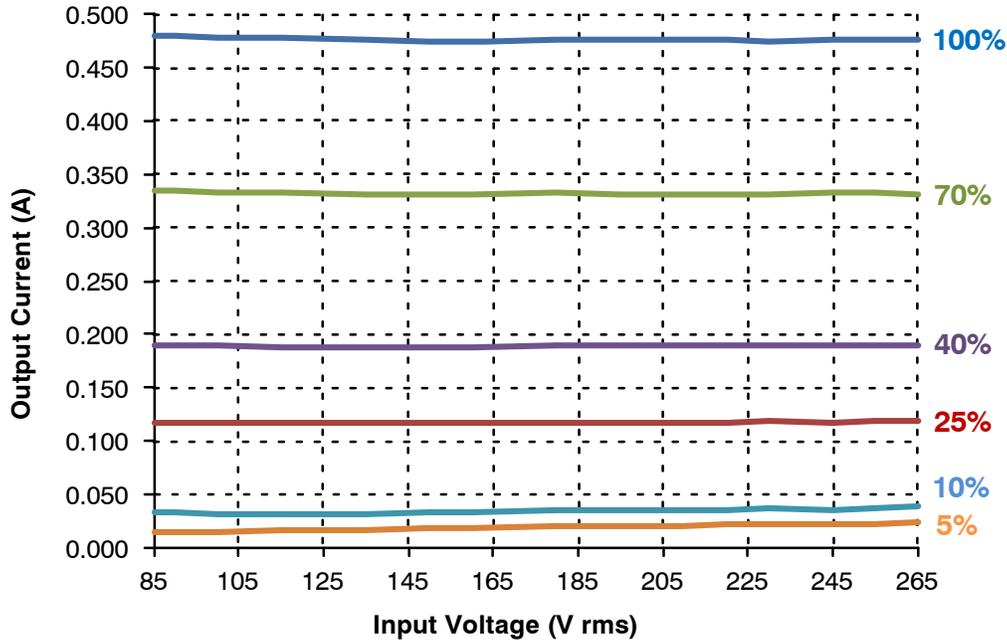


Figure 8. Dimming with the NCL30081 (Normal EVB)

Table 3. LINE AND LOAD REGULATION FOR EACH DIMMING STEP WITH THE NCL30081 (NORMAL EVB)

| Dimming Step |      | $I_{out(mean)}$ (mA) | $I_{out(min)}$ (mA) | $I_{out(max)}$ (mA) | $\delta I_{out}$ (%) | $\delta I_{out}$ (mA) |
|--------------|------|----------------------|---------------------|---------------------|----------------------|-----------------------|
| ON           | 100% | 478.5                | 480.6               | 474.5               | 0.64%                | 6.1                   |
| 1            | 70%  | 333.2                | 330.9               | 335.5               | 0.7%                 | 4.6                   |
| 2            | 40%  | 191.2                | 187.9               | 194.5               | 1.7%                 | 6.6                   |
| 3            | 25%  | 115.5                | 110.5               | 120.6               | 4.4%                 | 10.1                  |
| 4            | 10%  | 37.7                 | 32.3                | 43.1                | 14%                  | 10.8                  |
| 5            | 5%   | 24.6                 | 15.0                | 34.2                | 39%                  | 19.2                  |

The current regulation decrease for the last dimming step (5%) because the line-feedforward offset is removed for the NCL30081.

For the NCL30083, the line-feedforward offset is removed for the 10% and the 5% step.

### Efficiency and Power Factor

The measurements were made after the board was operated during 10 mn at full load (6 LEDs), low line, with an open frame and at ambient temperature.

The input power and the PF were measured with the power meter WT210A from Yokogawa.

The output current and the output voltage were measured using the digital multimeter 34401A from HP.

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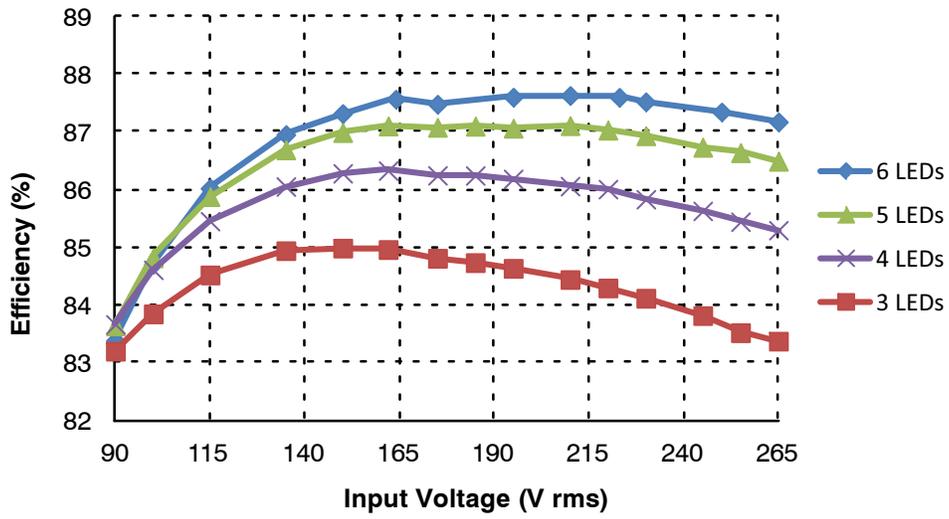


Figure 9. Valley Fill EVB Efficiency for 6, 5, 4 and 3 LEDs Connected at the Output

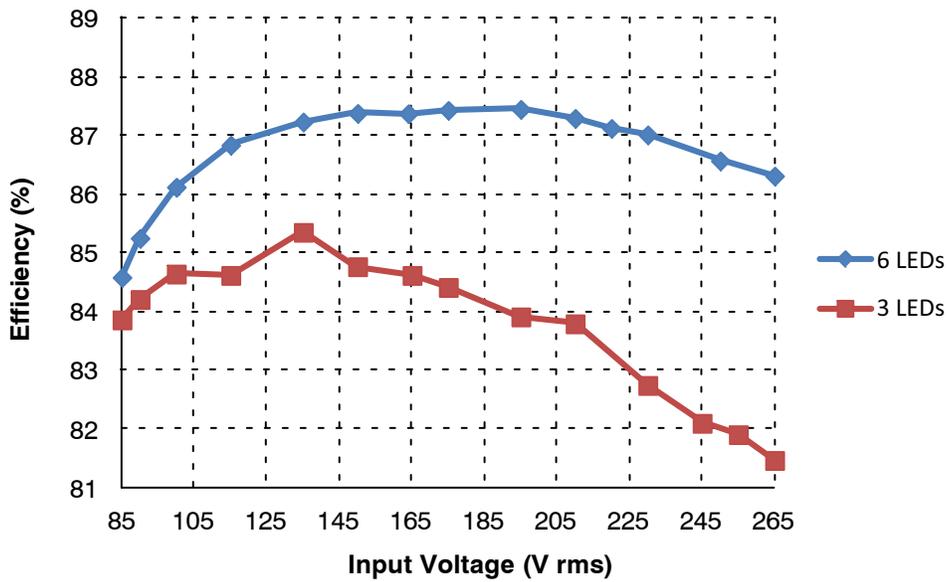


Figure 10. Efficiency for Default EVB with 6 LEDs and 3 LEDs

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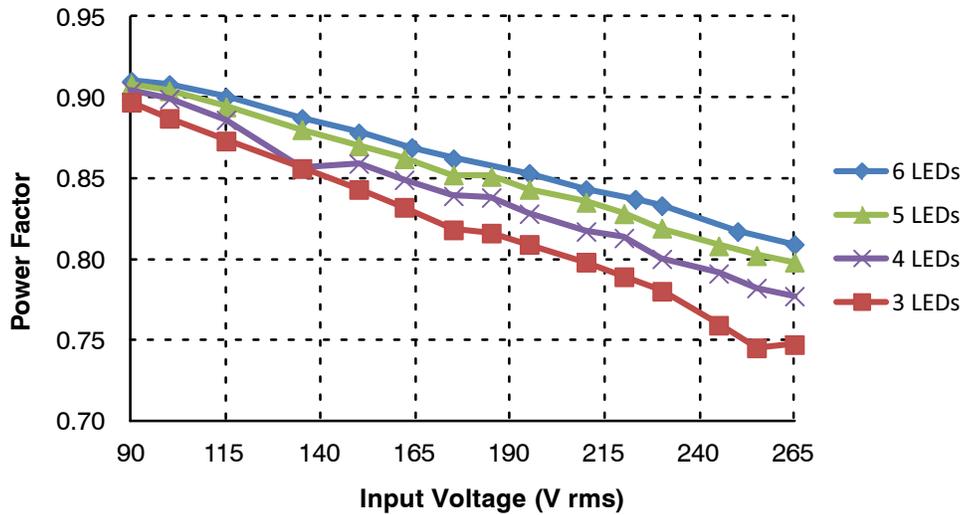


Figure 11. Power Factor with Valley Fill EVB

### Startup Waveforms

The startup resistors have been calculated to provide a maximum startup time of 1.5 s at 85 V rms. Figure 12 and Figure 13 shows the startup waveforms at 115 V rms and 230 Vrms. No overshoot is observed on the output current.



Figure 12. Startup Waveforms 115 V rms

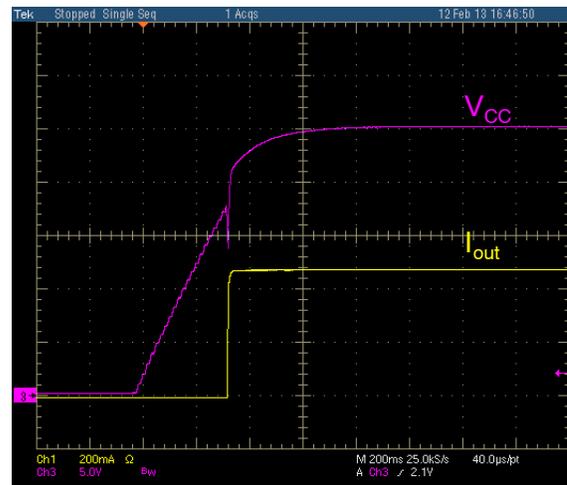


Figure 13. Startup Waveforms 230 V rms

### Open LED protection

When  $V_{CC}$  increases above 28 V, the controller detects an open LED condition and shuts down during 4 s. When the 4-s timer has elapsed, the controller tries to restart. This forces a low duty cycle burst operation which allows decreasing the power consumed by the LED driver if no load is connected to its output. Table 4 shows the no load power consumption of the Evaluation board. Figure 11 shows the output voltage variation when no output load is connected to board. The maximum output voltage reached is 37 V.



Figure 14. Output Voltage Variation with No Output Load

Table 4. NO LOAD POWER CONSUMPTION

|               | 115 Vrms      | 230 Vrms      |
|---------------|---------------|---------------|
| $P_{out}$ (W) | $P_{in}$ (mW) | $P_{in}$ (mW) |
| 0             | 24            | 66            |

**EMI Tests**

After operating the board during 15 mn at full load in order to warm it up, conducted electromagnetic emission measurements were made in quasi-peak mode using a Rohde & Schwarz EMI Test Receiver following the CISPR22 standard. The EMI signature is shown in Figure 15.

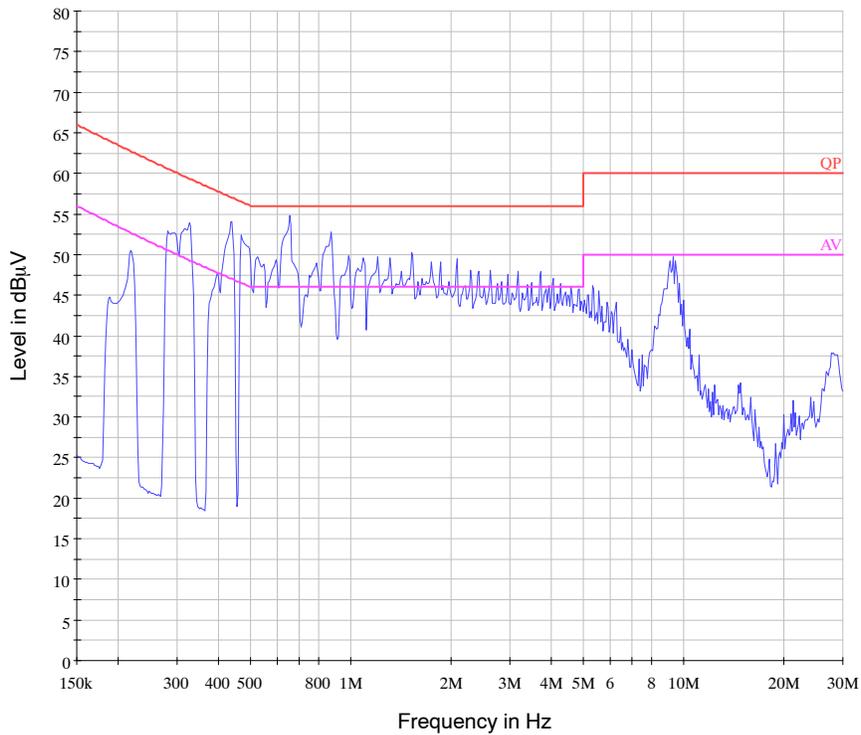


Figure 15. EMI Signature in Quasi-peak, 6 LEDs, Low Line

**Conclusion**

This application note has shows the experimental results of a LED driver controlled by the NCL30080-81-82-83.

This new family of controllers provides a very good regulation of the output current from the primary side of a flyback controller:  $\pm 0.6\%$  achieved with the evaluation boards. The controllers support Valley Fill operation

without degrading the output current precision and offer a wide range of features to implement reliable LED drivers.

**References**

[1] Stéphanie Cannenterre, “Designing a LED driver with the NCL30080-81-82-83”, AND9131/D

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## Bill of Material

**Table 5. BILL OF MATERIAL**

| Ref      | Qty | Description            | Value   | Tolerance/<br>Constraint | Package/<br>Footprint | Manufacturer     | Part Number                                     | S | VF |
|----------|-----|------------------------|---|--------------------------|-----------------------|------------------|---|---|----|
| T1       | 1   | QR transformer         |   |                          |                       | WURTH            | 750871144                                       | X | X  |
| X1       | 1   | Controller             | NCL30080,<br>NCL30081,<br>NCL30082,<br>NCL30083 |                          | TSOP6<br>Micro8       | ON Semiconductor | NCL30080,<br>NCL30081,<br>NCL30082,<br>NCL30083 | X | X  |
| X1b      | 1   | DIP8 support           |   |                          | DIP8                  | Standard         | Standard  | X | X  |
| R1       | 1   | Ceramic resistor, SMD  | 1.5 Ω   | 1%                       | SMD 1206              | Standard         | Standard  | X | X  |
| R12      | 1   | Ceramic resistor, SMD  | NC  |                          |                       |                  |   |   |    |
| R4       | 1   | Ceramic resistor, SMD  | 10  | 5%                       | SMD 0805              | Standard         | Standard  | X | X  |
| R22      | 1   | Axial resistor, 1W     | 47 Ω  | 1 W, 500 V               | through-hole          | TE Connectivity  | EP1WS47RJ                                       |   | X  |
| R6       | 1   | Ceramic resistor, SMD  | 4.7 MegΩ  | 200 V,1%                 | SMD 1206              | Standard         | Standard  | X | X  |
| R15      | 1   | Ceramic resistor, SMD  | 5.1 MegΩ  | 200 V, 1%                | SMD 1206              | Standard         | Standard  | X | X  |
| R3       | 1   | Ceramic resistor, SMD  | 8.2 kΩ  | 5%                       | SMD 0805              | Standard         | Standard  | X | X  |
| R2       | 1   | Ceramic resistor, SMD  | 24 kΩ   | 5%                       | SMD 0806              | Standard         | Standard  | X | X  |
| R16      | 1   | Ceramic resistor, SMD  | 220 kΩ  | 200 V, 5%                | SMD 1206              | Standard         | Standard  | X | X  |
| R5       | 1   | Ceramic resistor, SMD  | 100 kΩ  | 1%                       | SMD 0805              | Standard         | Standard  | X | X  |
| R7, R11  | 2   | Ceramic resistor, SMD  | 5.6 kΩ  | 5%                       | SMD 1206              | Standard         | Standard  | X | X  |
| R8       | 1   | Ceramic resistor, SMD  | 270 kΩ  | 200 V, 5%                | SMD 1206              | Standard         | Standard  | X | X  |
| R33      | 1   | Ceramic resistor, SMD  | 820 Ω   | 1%                       | SMD 0805              | Standard         | Standard  | X | X  |
| R13      | 1   | Ceramic resistor, SMD  | 63 kΩ   | 5%                       | SMD 0805              | Standard         | Standard  | X | X  |
| R14      | 1   | Ceramic resistor, SMD  | 22 Ω  | 5%                       | SMD 1206              | Standard         | Standard  | X |    |
| R18      | 1   | Ceramic resistor, SMD  | 36 kΩ   | 5%                       | SMD 1206              | Standard         | Standard  | X | X  |
| R20      | 1   | Ceramic resistor, SMD  | 22 Ω  | 5%                       | SMD 0805              | Standard         | Standard  | X | X  |
| R9       | 1   | Ceramic resistor, SMD  | NC  |                          |                       |                  |   |   |    |
| R10      | 1   | Ceramic resistor, SMD  | 470 kΩ  | 5%, 200 V                | SMD 1206              | PANASONIC        | ERJP08F4703V                                    | X | X  |
| R17      | 1   | Ceramic resistor, SMD  | 0 Ω   |                          | SMD 0805              | Standard         | Standard  | X | X  |
| R19      | 1   | Ceramic resistor, SMD  | 33 Ω  | 5%                       | SMD 0805              | Standard         | Standard  | X | X  |
| C7       | 1   | Ceramic resistor, SMD  | 22 pF   | 25 V                     | SMD 0805              | Standard         | Standard  | X | X  |
| C10      | 1   | Ceramic capacitor, SMD | 47 pF   | 25 V                     | SMD 0805              | Standard         | Standard  | X | X  |
| C8       | 1   | Ceramic capacitor, SMD | 470 pF  | 25 V                     | SMD 0805              | Standard         | Standard  | X | X  |
| C13      | 1   | Ceramic capacitor, SMD | 1 nF  | 25 V                     | SMD 0805              | Standard         | Standard  | X | X  |
| C16      | 1   | Ceramic capacitor, SMD | 10 nF   | 25 V                     | SMD 0805              | Standard         | Standard  | X | X  |
| C6       | 1   | Ceramic capacitor, SMD | 4.7 nF  | 1000 V                   | SMD 1206              | Standard         | Standard  | X |    |
| C12      | 1   | Ceramic capacitor, SMD | 100 nF  | 50 V                     | SMD 0805              | Standard         | Standard  | X | X  |
| C19      | 1   | Ceramic capacitor, SMD | 4.7 nF  | 1000 V                   | SMD 1206              | Standard         | Standard  |   | X  |
| C18      | 1   | Ceramic capacitor, SMD | 22 pF   | 100 V                    | SMD 0805              | Standard         | Standard  | X | X  |
| C5       | 1   | X2 capacitor           | 47 nF   | 300 Vac                  | through-hole          | Standard         | Standard  | X | X  |
| C2       | 1   | X2 capacitor           | 100 nF  | 300 Vac                  | through-hole          | Standard         | Standard  | X | X  |
| C4       | 1   | Electrolytic capacitor | 4.7 μF  | 35 V                     | through-hole          | Standard         | Standard  | X | X  |
| C14, C15 | 2   | Electrolytic capacitor | 22 μF   | 250 V                    | through-hole          | PANASONIC        | EEUEE2E220                                      |   | X  |
| C1       | 1   | Electrolytic capacitor | 15 μF   | 400V                     | through-hole          | PANASONIC        | EEUEE2G150                                      | X |    |

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**Table 5. BILL OF MATERIAL**

| Ref           | Qty | Description                       | Value       | Tolerance/<br>Constraint | Package/<br>Footprint | Manufacturer     | Part Number     | S | VF |
|---------------|-----|-----------------------------------|-------------|--------------------------|-----------------------|------------------|-----------------|---|----|
| C9            | 1   | Electrolytic capacitor            | 47 $\mu$ F  | 35 V                     | through-hole          | Standard         | Standard        | X | X  |
| C3            | 1   | Electrolytic capacitor            | 120 $\mu$ F | 50 V                     | through-hole          | PANASONIC        | EEUFR1H121L     | X | X  |
| C21           | 1   | Y2 capacitor                      | 1 nF        | 500 V ac                 | through-hole          | Standard         | Standard        | X | X  |
| D1            | 1   | Diode, axial, ultra fast recovery |             | 1 A, 800 V               | through-hole          | ON Semiconductor | MUR180EG        | X | X  |
| D3            | 1   | Diode, SMD, ultra fast recovery   |             | 2 A, 200 V               | SMB                   | ON Semiconductor | MURS220T3G      | X | X  |
| D11, D12, D16 | 3   | Diode, axial, 1 A, 1000 V         |             | 1A, 1000 V               | through-hole          | ON Semiconductor | 1N4007G         |   | X  |
| D2            | 1   | Diode, SMD, 100 V                 |             | 100 V                    | SOD-123               | ON Semiconductor | MMSD4148T1G     | X | X  |
| D4            | 1   | Diode, SMD, 250 V                 |             | 250 V                    | SOT-723               | ON Semiconductor | BAS21LT3G       | X | X  |
| D5            | 1   | Zener 22V                         |             | 22 V                     | SOD-123               | ON Semiconductor | MMSZ5251BT1G    | X | X  |
| Q1            | 1   | MOSFET, 3A, 800 V                 |             | 3 A, 800 V               | TO220FP               | ST Micro         | STP3NK80FP      | X | X  |
| RN1           | 1   | NTC thermistor                    |             | 100 k $\Omega$ , 5%      | SMD 0805              | AVX              | NB12P00104JB B  | X | X  |
| RVI           | 1   | Varistor                          |             | 275 V                    |                       | Littelfuse       | V275LA4P        | X | X  |
| J1            | 1   | Male connector                    |             |                          | through-hole          | WEIDMULLER       | SL5.08/3/90 4.5 | X | X  |
| J1a           | 1   | Female connector                  |             |                          | through-hole          | WEIDMULLER       | BL5.08/3        | X | X  |
| L2, L5        | 2   | Radial coil 1.5 mH                | 1.5 mH      |                          | through-hole          | COILCRAFT        | RFB0810         | X | X  |
| D8            | 1   | Diode bridge, 1 A, 600 V          |             | 1A, 600 V                | through-hole          | Taiwan Semi      | DBL105G         | X | X  |
| F1            | 1   | Fuse, 360 mA, 250 V               | 630 mA      | 250 V ac                 | through-hole          | SCHURTER         | 34.6012         | X | X  |
| J2,J3         | 2   | Male Connector                    |             |                          | through-hole          | WEIDMULLER       | SL5.08/2/90B4.5 | X | X  |
| J2a, J3a      | 2   | Female connector                  |             |                          | through-hole          | WEIDMULLER       | BL5.08/2        | X | X  |

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