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APPLICATION NOTE

Product Preview

Secondary Side Regulated LED Driver with the NCL30488

Description

This paper focuses on the experimental results of a LED driver controlled by the secondary side regulated version of the NCL30488.

Introduction

The NCL30488 [1] is a power factor corrected controller with primary side constant voltage (CV) and constant current (CC) control suitable for flyback, buck−boost or SEPIC converters. The NCL30488 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 0.9 and total harmonic distortion below 10% for universal mains input. This controller is normally primary side regulated, but the version *(TBD)* is compatible with secondary side regulation. In this version, the COMP pin features a pullup resistor to the internal reference voltage rail and allows directly connecting an optocoupler collector to the pin. The current−mode, quasi−resonant architecture of this controller optimizes the efficiency by turning on the MOSFET when the drain−source voltage is minimal (valley). The valley lockout and frequency foldback circuitry maintain high−efficiency performance in 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.

LED DRIVER SPECIFICATION

Table 1. LED DRIVER SPECIFICATION

Description	Symbol	Value	Units
LED DRIVER SPECIFICATION			
Minimum input voltage	$V_{in,min}$	85	V rms
Maximum input voltage	$V_{in,max}$	277	V rms
Power factor	PF	> 0.9	
Minimum output voltage	$V_{out,min}$	24	V
Output voltage for constant voltage regulation	$V_{out,max}$	40	V
Output voltage level to activate the over voltage protection	$V_{out(OVP)}$	52	V
Output current (nominal)	I_{out}	0.5	A
Output rectifier voltage drop (estimated)	V_f	0.6	V
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.

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DESCRIPTION OF THE BOARD

This secondary side regulated LED driver has been designed using the guidelines provided in the application notes AND9200/D [2] and ANDXXXX/D [3]. Figure 1 shows the schematic of the board with the NCL30488 implanted.

There are specific considerations for secondary side design.

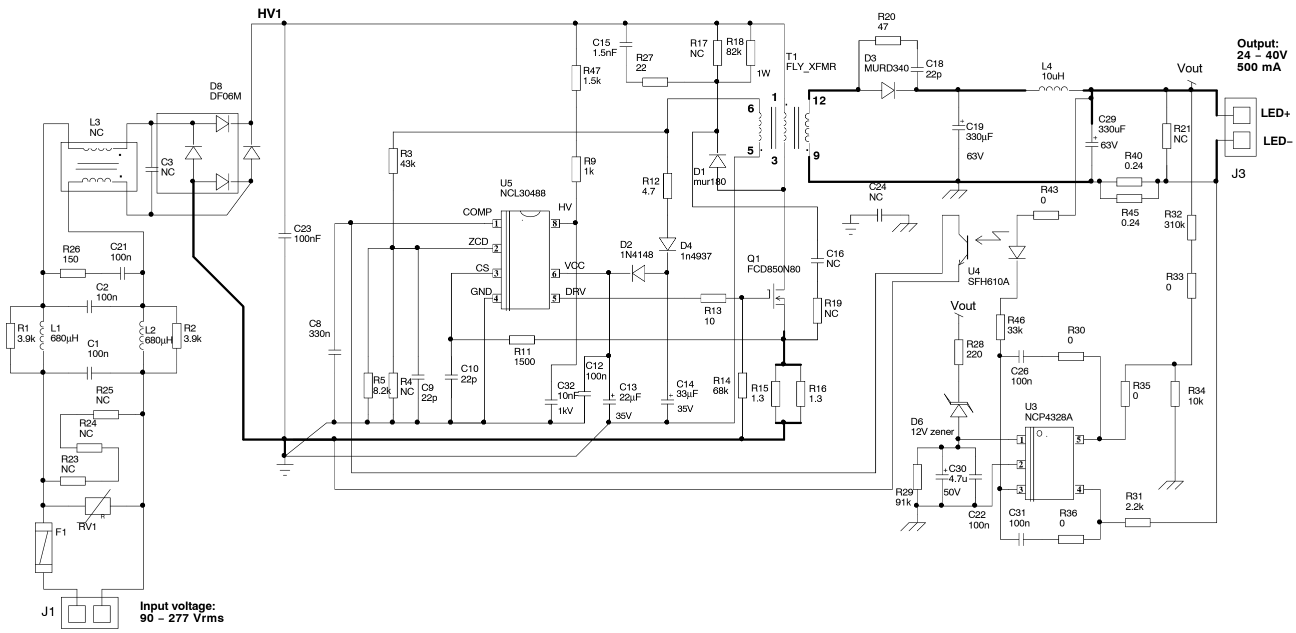


Figure 1. Evaluation Board Schematic for the NCL30 488

The MOSFET current sense resistors R15 and R16 set the output current limit from the primary side. This current limit must be set higher than the output nominal current. If not, the primary side current control implemented in the NCL30488 will take over the regulation and limit the output current. For this design, the maximum output current is set to:

$$I_{out} = \frac{V_{REF}}{2N_{sp}R_{sense}} \quad \text{(eq. 1)}$$

With:

- V_{REF}: constant current reference voltage of the NCL30488 (see datasheet)
- N_{sp}: secondary to primary turns ratio: $N_{sp} = N_s / N_p$
- R_{sense}: MOSFET current sense resistors

$$I_{out} = \frac{0.33}{2 \times 0.469 \times 0.65} = 546\text{ mA} \quad \text{(eq. 2)}$$

The NCP4328A is chosen for the secondary side Constant Voltage (CV) and Constant Current (CC) regulation. This part has a very low threshold voltage for CC operation: this helps decreasing the power dissipated in the secondary side sense resistors R40 and R45.

The output current for CC regulation is set to $I_{out,nom}$ = 500 mA. The secondary side sense resistors are calculated with:

$$R_{sense,sec} = \frac{V_{REF(CC)}}{I_{out,nom}} = \frac{0.0625}{0.5} = 0.125\ \Omega \quad \text{(eq. 3)}$$

With:

- $R_{sense,sec}$: secondary side current sense resistor
- $V_{REF(CC)}$: NCP4328 voltage reference for the constant current operation

The output voltage $V_{out,nom}$ is set to 40 V by R_{32}, R_{33} and R_{34}.

R_{34} chosen value is 10 kΩ to have small current in the resistor bridge (125 µA). Then R_{33} and R_{34} values are calculated:

$$R_{32} + R_{33} = \left(\frac{V_{out,nom}}{V_{REF(CV)}} - 1\right) R_{34} \quad \text{(eq. 4)}$$

With

- $V_{REF(CV)}$: NCP4328 voltage reference for the CV operation

A type 2 compensator is built around the NCP4328 to stabilize the power supply. R_{46} set the mid−band gain of the compensator to have a crossover frequency f_c around 10 Hz. The internal pullup resistor of the NCL30488 R_{pullup} forms a pole with C_8 to filter the line frequency. This pole is set to 26 Hz in this design. This pole is common to both the CC and the CV loop.

The zeroes of the CV loop and the CC loop are selected to provide enough phase boost to have a phase margin above 45° over the load range.

The document “Designing a type 2 compensator with the NCP4328/4352” [5] explains how to calculate the compensation network for the NCP4328. The Zener diode D_6 limits the voltage supplied to the NCP4328 as the max rating for this controller is 35 V.

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.

R3, R4 and R5 set the output overvoltage fast protection to 52 V. 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 (for primary side constant current control).

R9 and R47 limit the voltage on HV pin in case of surge.

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

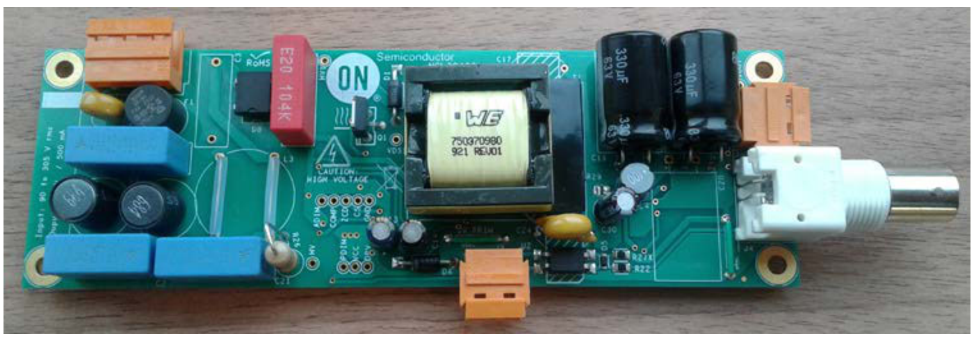


Figure 2. Photograph of the EVB Top Side

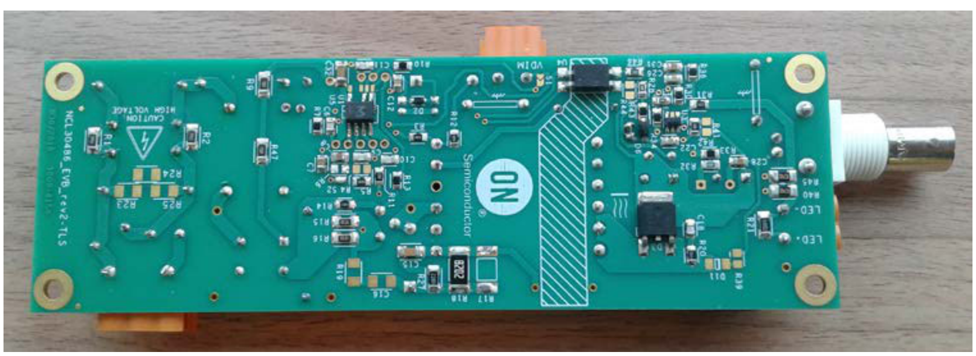


Figure 3. Photograph of the EVB Bottom Side

Figure 4. EVB Side Picture: Board Height is 15 mm

OUTPUT VOLTAGE AND CURRENT 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 NCL30488. The CC/CV curve is plotted for various input voltage: 100, 120, 230 and 277 Vrms.

Thanks to the secondary side controller, the output voltage and output current are regulated very precisely.

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:

$$I_{out(mean)} = \frac{I_{out(max)} + I_{out(mean)}}{2} \qquad \text{(eq. 5)}$$

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

$$\delta I_{out} = 100\,\frac{\Delta I_{out}}{I_{out(mean)}} = 100\,\frac{I_{out(max)} - I_{out(mean)}}{I_{out(mean)}} \qquad \text{(eq. 6)}$$

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

$I_{out(mean)}$ = 510.4 mA

$I_{out(max)}$ = 512 mA

$I_{out(min)}$ = 508.8 mA

δI_{out} = ±0.3 %

The output current regulation is ±0.3 % with line and load variation included.

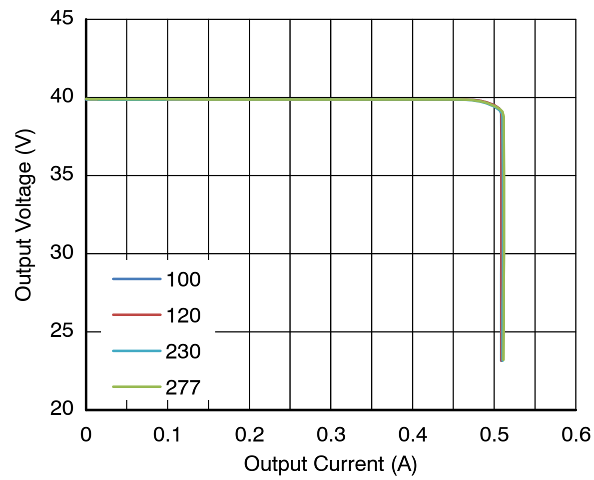


Figure 6. Line and Load Regulation for I_{out}

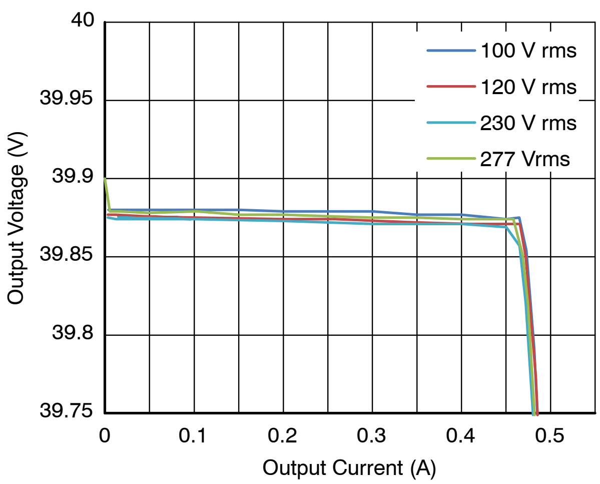


Figure 5. CV Curve Zoom for V_{in} = 100 to 277 V rms

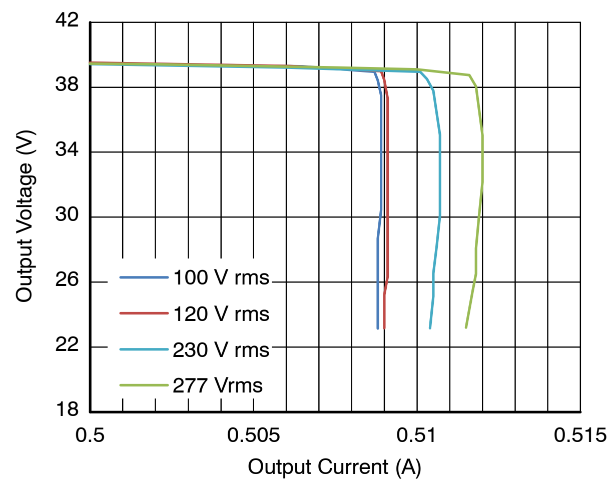


Figure 7. CC Curve Zoom for V_{in} = 100 to 277 V rms

In the same way, we can estimate the output voltage regulation:

$V_{out(mean)}$ = 39.88 V

$V_{out(max)}$ = 39.90 V

$V_{out(min)}$ = 39.86 V

δV_{out} = 0.05%

The constant voltage regulation is ±0.05% 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 8, Figure 9 and Figure 10 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.

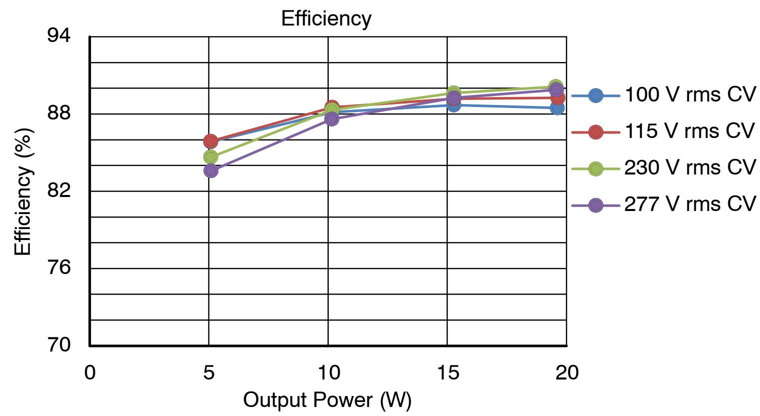


Figure 8. Efficiency

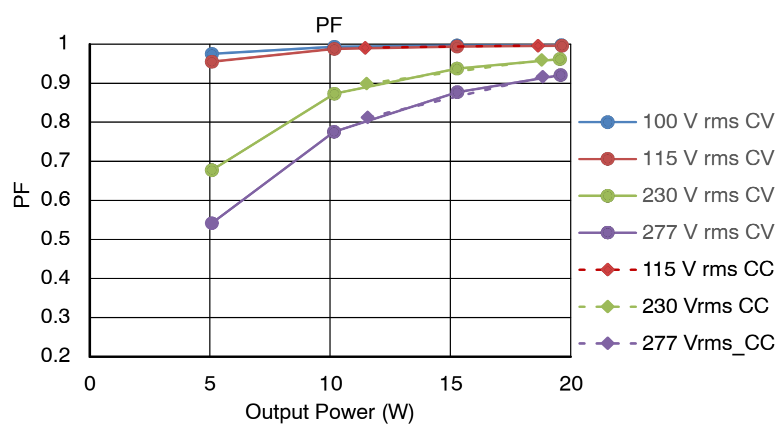


Figure 9. Power Factor

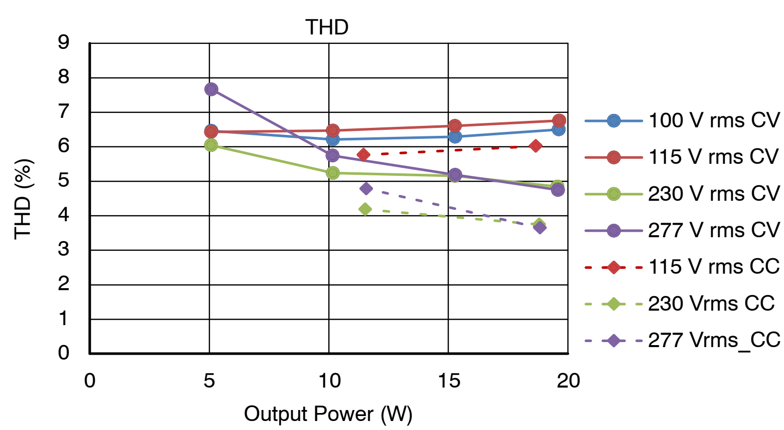


Figure 10. THD for V_{in} = 100 to 277 V rms

TRANSIENT LOAD STEP

Figure 11 and Figure 12 show the output voltage and the output current variation when the output load is varied abruptly from 100% to 25% and from 100% to 50% of the maximum output load (20 W), the electronic load being in constant resistance mode. For the 100% to 25% output load variation, the output voltage overshoot is contained at 46.2 V and the voltage undershoot is at 33.4 V, which represents respectively 15.5% and −16.5% of the output voltage regulation level.

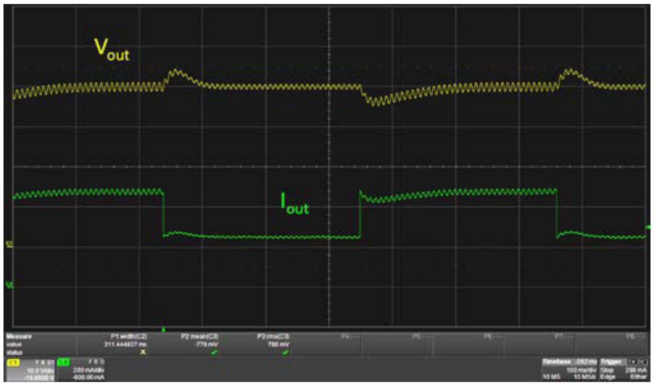


Figure 11. Transient Load Step Response from 100% to 50% Output Load

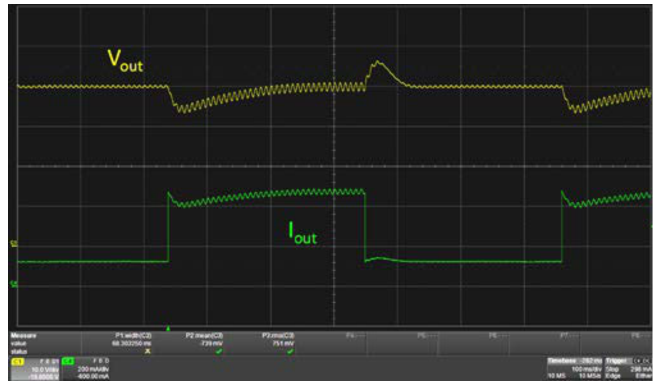


Figure 12. Transient Load Step Response from 100% to 25% Output Load

STANDBY POWER CONSUMPTION

Thanks to the standby mode featured by the NCL30488, the power consumption when no load is connected to the board is small. Table 2 summarizes the results obtained.

Table 2. STANDBY POWER MEASUREMENT

Input Voltage (V rms)	Input Power (mW)
277	127
230	113

CONCLUSION

This application note has shown the experimental results of a LED driver controlled by the NCL30488 secondary side regulation compatible version.

A very good regulation of the output current and the output voltage is obtained as well as excellent THD.

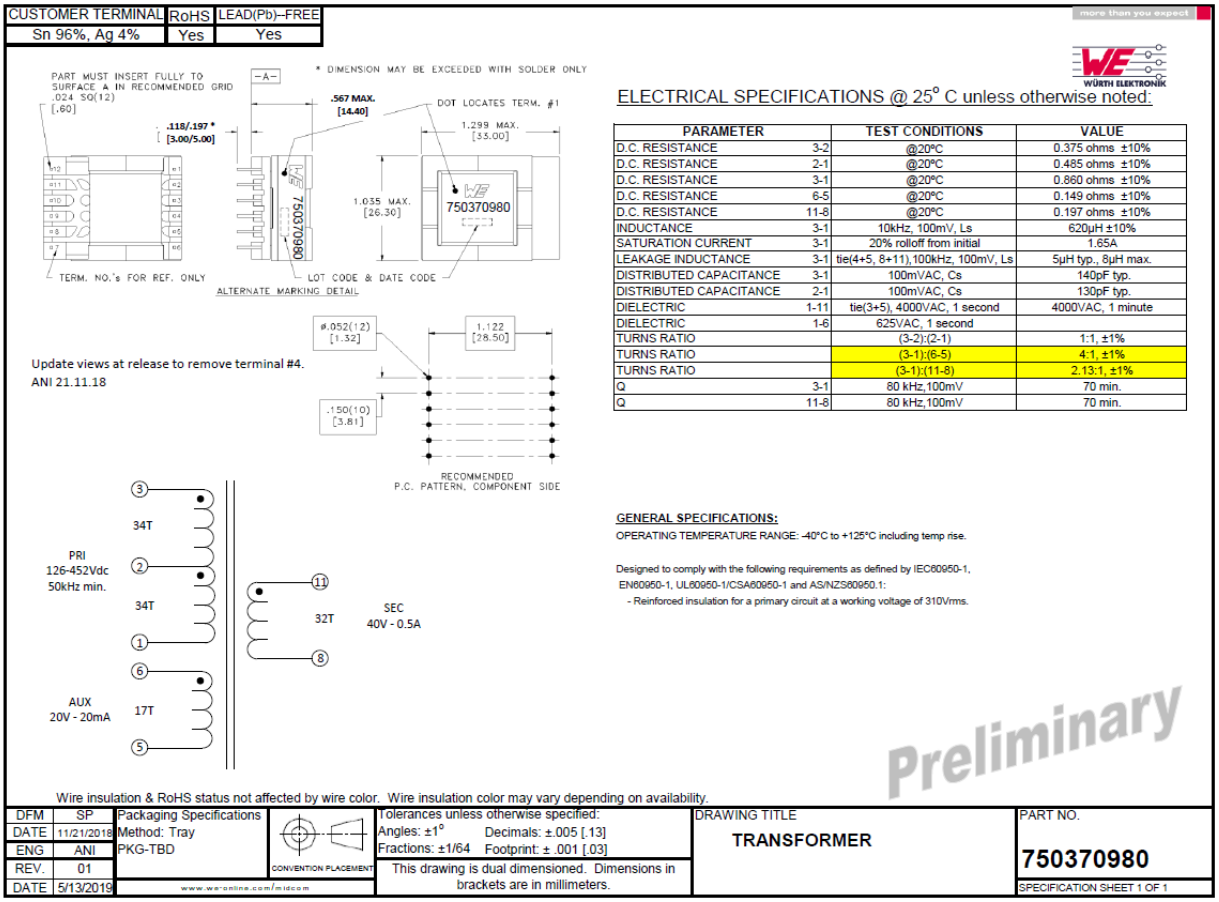
Table 3. BOM FOR NCL30488 20 W SSR EVB

Reference	QTY	Description	Value / Tol	Footprint	Manufacturer	Manufacturer Part Number
RV1	1	Varistor	420 V	through hole	Wurth	820474211
F1	1	Fuse, 300 Vac	1 A			
L1, L2	3	Radial coil	680 μH, 340 mA	through hole	Coilcraft	RFB1010−152L
L3	0	common mode choke	Not connected	through hole	Wurth	7446622002
L4	1	Inductor	10 μH	through hole	Wurth	744779100
D1	0	Ultra fast diode	MUR180	axial	ON Semiconductor	MUR180E
D2, D5	1	Diode	1N4148	SOD−323	ON Semiconductor	1N4148WS
D3	1	Ultrra fast rectifier	MURD340	DPAK	ON Semiconductor	
D4	2	Diode	1N4937	axial	ON Semiconductor	1N4937G
D6	1	Zener diode	12 V, 0.5 W	SMD	ON Semiconductor	MMSZ12T1G
D8	1	Diode bridge	1.5 A, 600 V	through hole	ON Semiconductor	DF06M
D11	1	Diode fast	Not connected		ON Semiconductor	ES1JFL
Q1	1	MOSFET	6 A, 800 V, 0.85 Ω	TO−251 (IPAK)	ON Semiconductor	FCU850N80Z
C1, C2, C21	3	X2 capacitors	100 nF, 330 V ac	through hole	EPCOS	B32912A3104
C6	1	Capacitor	100 pF	SMD 0805		
C8	2	Capacitor	330 nF	SMD 0805		
C9, C10, C11, C18	4	Capacitor	22 pF	SMD 0805		
C12, C22, C26, C31	4	Capacitor	100 nF	SMD 0805		
C11	1	Capacitor	47 pF	SMD 0805		
C13	1	Electrolytic capacitor	22 μF, 35 V	radial	Panasonic	EEUFC1V220
C14	1	Electrolytic capacitor	33 μF, 35 V	radial	Panasonic	EEUFM1V330
C15	1	Ceramic capacitor	1.5 nF, 1 kV	SMD1206		
C17, C24	1	Y capacitor	1 nF			
C19, C29	2	Electrolytic capacitor	330 μF, 63 V, 1.58 A	radial	Panasonic	EEUFR1J331B
C23	1	Capacitor	100 nF, 630 V	through hole	Wurth	890303422005CS
C30	1	Electrolytic capacitor	4.7 μF, 63 V	through hole	Nichicon	UPW1J4R71TD
R1, R2	2	Resistor	3.9 kΩ	SMD1206		
R3	1	Resistor	43 kΩ	SMD0805		
R5	1	Resistor	8.2 kΩ	SMD 0805		
R7, R10, R30, R33, R36, R27x, R44	7	Resistor	0 Ω	SMD 0805		
R9	1	Resistor	1 kΩ	SMD 1206		
R11	1	Resistor	1.5 kΩ, 1%	SMD 0805		
R12	1	Resistor	4.7 Ω	SMD 0805		
R14, R21	1	Resistor	68 kΩ	SMD 1206		
R15, R16	1	Resistor	1.3 Ω, 1%, 0.33 W	SMD1206		
R18	1	82 kΩ, 1W	82 kΩ, 1W	SMD2512		
R20	1	Resistor	47 Ω	SMD1206		
R21	1	Resistor	43 kΩ	SMD1206		
R22	1	Resistor	1 kΩ	SMD0805		

Table 3. BOM FOR NCL30488 20 W SSR EVB (continued)

Reference	QTY	Description	Value / Tol	Footprint	Manufacturer	Manufacturer Part Number
R26	1	Resistor	150 Ω, 2 W	axial		
R27	1	Resistor	22 Ω	SMD 1206		
R28	1	Resistor	220 Ω	SMD 0805		
R29	1	Resistor	36 kΩ	SMD 0805		
R31	1	Resistor	2.2 kΩ	SMD 0805		
R32	1	Resistor	310 kΩ	SMD 0805		
R34	1	Resistor	10 kΩ	SMD 0805		
R40, R45	2	Resistor	0.24 Ω, 1%, 0.5 W	SMD 1210		
R43	1	Resistor	0 Ω	SMD 0805		
R46	1	Resistor	33 kΩ	SMD0805		
R47	1	Resistor	1.5 kΩ	SMD0805		
U1	1	NCL30488	NCL30488	SOIC8	ON Semiconductor	NCL30488
U4	1	Optocoupler	SFH6106−3	SMD		SFH6106−3
U3	1	CC/CV controller	NCP4328A	TSOP 6	ON Semiconductor	NCP4328A
J1	1	Input connector male		through hole	WEIDMULLER	SL5.08/3/90 4.5
J1a	1	Input connector female			WEIDMULLER	BL5.08/3
J2, J3	1	Input connector male		through hole	WEIDMULLER	
J2a, J3a	1	Input connector female			WEIDMULLER	
J4	1	BNC connector				
T1	1	Flyback Transformer		through hole	Wurth	750370980

TRANSFORMER SPECIFICATION



PARAMETER		TEST CONDITIONS	VALUE
D.C. RESISTANCE	3-2	@20ºC	0.375 ohms ±10%
D.C. RESISTANCE	2-1	@20ºC	0.485 ohms ±10%
D.C. RESISTANCE	3-1	@20ºC	0.860 ohms ±10%
D.C. RESISTANCE	6-5	@20ºC	0.149 ohms ±10%
D.C. RESISTANCE	11-8	@20ºC	0.197 ohms ±10%
INDUCTANCE	3-1	10kHz, 100mV, Ls	620µH ±10%
SATURATION CURRENT	3-1	20% rolloff from initial	1.65A
LEAKAGE INDUCTANCE	3-1	tie(4+5, 8+11),100kHz, 100mV, Ls	5µH typ., 8µH max.
DISTRIBUTED CAPACITANCE	3-1	100mVAC, Cs	140pF typ.
DISTRIBUTED CAPACITANCE	2-1	100mVAC, Cs	130pF typ.
DIELECTRIC	1-11	tie(3+5), 4000VAC, 1 second	4000VAC, 1 minute
DIELECTRIC	1-6	625VAC, 1 second	
TURNS RATIO		(3-2):(2-1)	1:1, ±1%
TURNS RATIO		(3-1):(6-5)	4:1, ±1%
TURNS RATIO		(3-1):(11-8)	2.13:1, ±1%
Q	3-1	80 kHz,100mV	70 min.
Q	11-8	80 kHz,100mV	70 min.

Figure 13. Transformer Specification

REFERENCES

1. NCL30488 Datasheet
2. Joel Turchi, "4 Key Steps to Design a NCL30088−Controlled LED Driver", AND9200/D
3. Stéphanie Cannenterre, "Designing a LED driver with the NCL30486/88", ANDXXXX
4. NCP4328 Datasheet
5. Christophe Basso, "Designing a type 2 compensator with the NCP4328 / NCP4352"

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