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AND8136/D

Offline LED Driver

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APPLICATION NOTE

This application note provides a simple approach to designing an LED driver utilizing the ON Semiconductor NCP1014 self−supplied monolithic switcher. The easy−to−follow, step−by−step procedure guides the user into designing the different blocks that constitute the power supply, mainly the input block, the power stage, the magnetics, the snubber, the output block, and the feedback loop. The circuit diagram, bill of material, and PCB layout are also included at the end of the application note. This power supply is specifically designed to drive three LED's. It meets IEC and UL requirements. EMI is minimal and a 70% achievable efficiency or greater is possible.

The NCP1014 integrates a fixed−frequency current mode controller and a 700 V MOSFET. This device is housed in a PDIP−7 package and features soft−start, frequency jittering, short−circuit protection, skip−cycle, and a dynamic self−supply (no need for an auxiliary winding).

Design Parameters

The first step in designing a power supply is to define and predetermine the input and output parameters.

Universal Input Voltage Range:

$$V_{ac(min)} = 85\text{ Vac},\ V_{ac(max)} = 265\text{ Vac}$$

Output Specifications:

$$V_{out} \approx 11.75\text{ V} \pm 2\%,\ I_{out} = 350\text{ mA}$$

Input Power:

$$P_{in} = \frac{P_{out}}{\eta}, \text{ where } \eta = 78\% \text{ estimated efficiency}$$

$$P_{out} = V_{out} \cdot I_{out} = 11.75 \cdot 0.350 \approx 4.1\text{ W}$$

$$\therefore P_{in} = \frac{4.1}{0.78} = 5.25\text{ W}$$

DC Rail Voltages at Low Line and High Line:

$$V_{dc(min)} = V_{ac(min)} \cdot \sqrt{2} = 85 \cdot \sqrt{2} = 120\text{ Vdc}$$
$$V_{dc(max)} = V_{ac(max)} \cdot \sqrt{2} = 265 \cdot \sqrt{2} = 375\text{ Vdc}$$

Average Input Current:

$$I_{in(avg)} = \frac{P_{in}}{V_{dc(min)}} \approx \frac{5.25}{120} \approx 44\text{ mA}$$

Input Peak Current:

$$I_{peak} = 5 \cdot I_{in(avg)} = 220\text{ mA}$$

Circuit Description

Input Block

The input block of the power supply consists of a fuse, an EMI filter, a diode bridge rectifier, and an input bulk capacitor.

Fuse

The fuse F1 is protecting the circuit from current surges occurring at turn on. In this application, F1 is rated for 2.0 A, 125 Vac.

EMI Filter

The EMI filter suppresses common mode and differential mode noise and is very dependent upon board layout, component selection, etc. An X capacitor C1 and a common mode choke L1 are placed across the AC lines to attenuate differential mode noise, see Figure 1. The EMI inductor is slowing down any transient voltage surge to reduce high frequency noise. Both the capacitor and choke should be placed before the diode bridge and as close to the ac line input as possible to minimize RFI.

Diode Bridge Rectifier

In order to choose the right diode bridge rectifier, the values of the forward and surge currents and DC blocking voltage must be considered. The surge current can reach values up to five times that of the average input rms current. It is therefore necessary to select a rectifier capable of handling such large currents.

DC Blocking Voltage is calculated at high line:

$$V_R \geq V_{dc(max)} = 375\text{ Vdc}$$

Forward Current:

$$I_F \geq 1.5 \cdot I_{in(avg)} = 1.5 \cdot 0.044 = 66\text{ mA}$$

Surge Current:

$$I_{FSM} \geq 5 \cdot I_F = 5 \cdot 0.066 = 330\text{ mA}$$

Input Bulk Capacitor

The purpose of the input bulk capacitor C2 is to hold up the rectified line voltage and also to filter out common mode noise. It is placed between the bridge rectifier output and ground. The size of the bulk capacitor depends on peak rectified input voltage and the ripple voltage magnitude. A larger capacitor will lower the ripple voltage on the dc input line, but will induce a larger surge current when the supply is powered up. Assuming a ripple magnitude of about 20% of the peak rectified voltage at low line, C_{bulk} can then be calculated using:

$$C_{bulk} = \frac{P_{in}}{fac \cdot (V_{peak(min)}{}^2 - V_{in(min)}{}^2)}$$

$$= \frac{4.1}{60 \cdot (120^2 - 96^2)} = 13\ \mu F$$

In this case, we chose a 33 μF aluminum electrolytic due to availability.

Power Stage

At the heart of the power stage is the ON Semiconductor NCP1014. The NCP1014 is a current−mode controller with a high voltage power MOSFET in a monolithic structure. The NCP1014 features soft−start, frequency jittering, short circuit protection, a maximum peak current set point, and a dynamic self−supply. It operates in skip−cycle mode below ¼ of the maximum peak current limit, thus no acoustic noise is present. For more information on this device, please go to www.onsemi.com.

Magnetics Calculations

The next step is the design of the flyback transformer. The design of the magnetics block is the most important and delicate part of the whole design process because it will determine how well the power supply will perform. The flyback−mode transformer functions by first conducting current in the primary winding, thus storing energy in the core of the transformer. The core energy is then transferred to the secondary winding when the primary side is turned off. The core and bobbin are standard EFD20 sizes.

In order for the regulator to operate in discontinuous mode under worse case conditions and to maximize power, the maximum on time is 48% of the full period, therefore the maximum primary inductance is calculated based on a maximum duty cycle of 48%. Using a larger inductance than calculated will cause the power supply output to fall out of regulation.

Let $f_{op} = 100$ kHz (operating frequency)

$\partial max = 48\%$ (maximum duty cycle)

$V_{in(min)} = V_{dc(min)} - 20\% \approx 96$ V (minimum input voltage)

$P_{out} = 4.1$ W (output power)

$\eta = 78\%$ (estimated efficiency)

$I_{peak} = 220$ mA (input peak current)

$$L_{pri} = \frac{V_{in(min)} \cdot \partial max}{I_{peak} \cdot f_{op}} = \frac{96 \cdot 0.48}{0.220 * 100\ kHz} = 2.09\ mH$$

Primary to secondary turns ratio:

$$\frac{N_{pri}}{N_{sec}} = \frac{V_{in(min)} \cdot \partial max}{V_{out} + V_F \cdot (1 - \partial max)}$$

$$= \frac{120 \cdot 0.48}{11.75 + 0.875 \cdot (1 - 0.48)} \approx 7\ turns$$

An easy way to check if the power capability of the transformer is large enough to supply the output is with the following equation:

$$P_{in(core)} = \frac{L_{pri} \cdot I_{peak}{}^2}{2} \cdot f_{op} > P_{out}$$

$$P_{in(core)} = \frac{2.09\ mH \cdot 0.220^2}{2} \cdot 100\ kHz = 5.05 > 4.1\ W$$

Input Snubber

Because of the high dv/dt characteristic of the power transistor drain voltage and of the transformer leakage inductance, voltage spikes and ringing occur at the drain when the power switch is turned off. Resistor R1, C3, D5 compromise an RCD snubber. In parallel to the primary winding are R2 and C4 which compromise an RC ringing damper which slows down the dv/dt and reduces the peak voltage therefore decreasing the ringing due to high frequency noise. Since $i = C \cdot \frac{dv}{dt}$, increasing the capacitance will also reduce the magnitude of the voltage ripple. The snubber and ringing damper act together to protect the IC from voltage transients greater than 700 V and reduce radiated noise.

Output Block

The output block or secondary side in Figure 1 consists of two main diodes, D6 (forward diode) and D10 (flyback diode), an optocoupler, resistors, zener diodes and storage capacitors. Diode D6 operates in the forward mode and conducts while the internal switch is turned on. Resistor R3 limits the forward current and diode D7 limits the voltage to 5.1 V. This also acts as the auxiliary supply on the secondary side and provides power to the optocoupler IC2 and the TLV431 labeled as IC3.

During the flyback mode, the energy stored in the transformer T1 is released to the secondary load capacitor C6 via D10. Capacitor C6 smoothes out the current pulses and establishes an effectively constant dc voltage for the LEDs. The current is controlled and limited by using feedback. The LED current is converted to a voltage by using a 3.6 Ω resistor R6. The control reference is IC3.

There are two fault conditions that can occur; open circuit and short circuit. An open circuit fault condition occurs when there are no LEDs connected or there is no LED current flowing. In order to limit the secondary voltage during this fault condition, and over−voltage zener diode, D9 is added. If the secondary flyback voltage rises above 47 V, D9 starts conducting and causes the optocoupler to conduct current as well, which then informs the NCP1014 on the primary side to reduce the energy transferred through the transformer. During this time, there is 47 V on C6 and 5.1 V on C5 which totals 52 V on the secondary side.

Under a short circuit fault conditon, all LEDs are shorted. This can occur if only one LED is shorted or if the LEDs are supplied with current through a cable. The wires on the cable are either twisted together or are shorted together. The LED secondary current is limited by resistor R6 which develops a 1.25 V voltage drop. When the voltage across R6 is greater than 1.25 V, IC2 conducts and causes the NCP1014 to reduce the energy transferred to the secondary side. This is identical to the open circuit fault condition previously discussed.

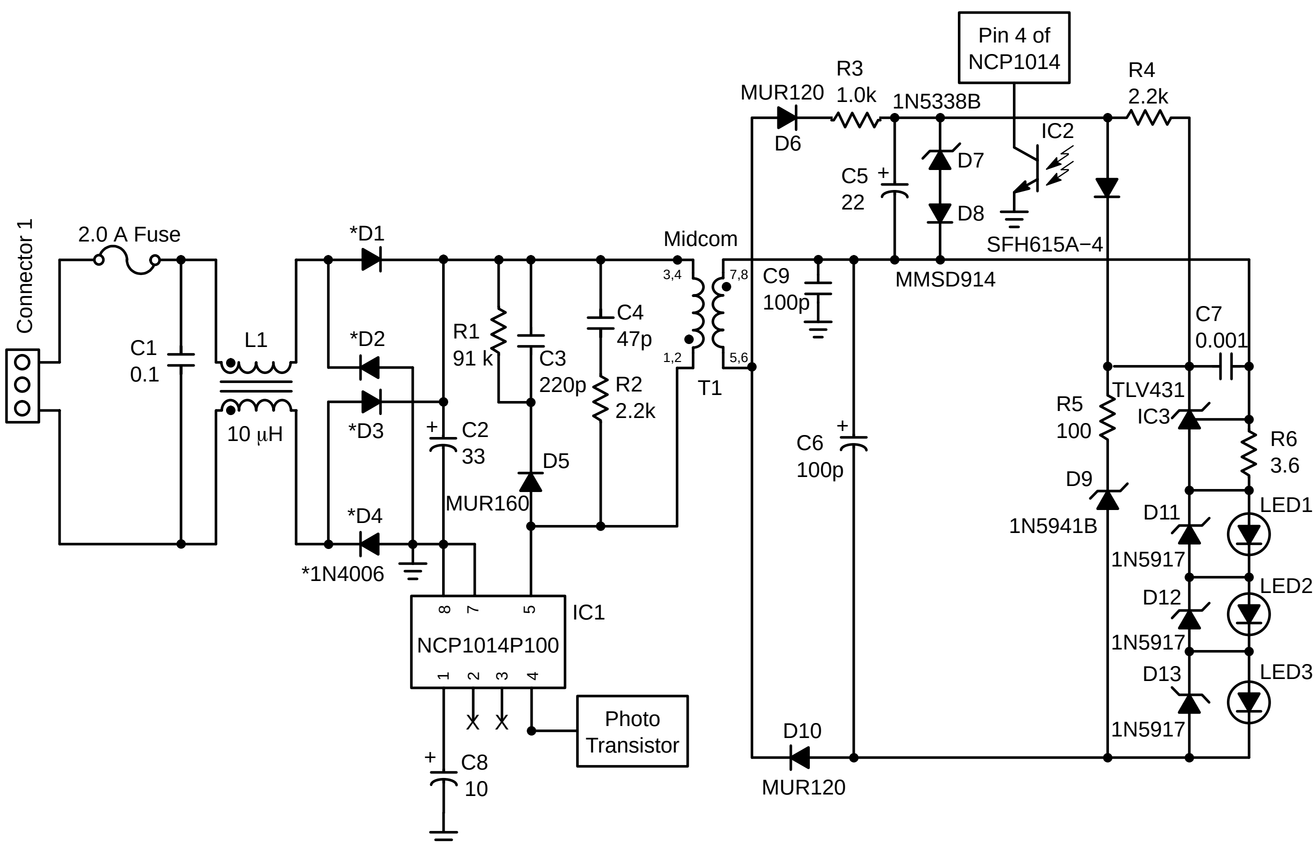

Figure 1. Circuit Diagram

Table 1. Bill of Materials

Ref.	Component Value	Qty	Part Number	Manufacturer
IC1	450 mA, 100 kHz, PDIP−7	1	NCP1014AP100	ON Semiconductor
IC2	Opto Coupler, Dip	1	SFH615A−4	Isocom
IC3	1.25 V Shunt Reg., TO−92	1	TLV431ALP	ON Semiconductor
D1−4	1.0 A, 800 V, Gen Purp	4	1N4006	ON Semiconductor
D5	1.0 A, 600 V, Ultrafast	1	MUR160	ON Semiconductor
D6,D10	1.0 A, 200 V, Ultrafast	1	MUR120	ON Semiconductor
D7	5.1 V, 5.0 W, Zener	1	1N5338B	ON Semiconductor
D8	1.0 V, Switching diode	1	MMSD914	ON Semiconductor
D9	47 V, 3.0 W, Zener	1	1N5941B	ON Semiconductor
D11,12,13	4.7 V, 3.0 W, Zener	3	1N5917	ON Semiconductor
T1	Flyback Transformer	1	31842	Midcom
L1	Choke, Common Mode, 10 mH	1	40479	Midcom
C1	0.1 mF, film, radial	1	R46104M275BIS	Nissei
C2	33 mF, 400 V, radial	1	KME400VB33RM16X31LL	United Chem−Con
C3	220 pF, 1 kV, 10%, disc	1	NCD221K1KVY5F	NIC Components
C4	47 pF, 1 kV, 10%, disc	1	NCD470K1KVSL	NIC Components
C5	22 uF,radial	1	ECA−1HHG220	Panasonic
C6	100 uF,radial	1	ECA−1HHG101	Panasonic
C7	0.001mF, ceramic	1	SR155C102KAA	AVX
C8	10 mF, 16 V, 20%, radial	1	SME16VB10RM5X11LL	United Chem−Con
C13*	1 mF, 16 V, radial	1	SR215E105MAA	AVX
C9	100 pF, 1 kV, 10%, disc	1	NCD101K1KVY5F	NIC Components
R1	91 kW, 1 W	1	RS−1W−91K−5	SEI
R2	2.2 kW, 1/2 W, 5%	1	CF−1/2W−2.2K−5	SEI
R3	1 kW, 1/4 W, 5%	1	CF−1/4W−1k−5	SEI
R4	2.2 kW, 1/4 W, 5%	1	CF−1/4W−2.2K−5	SEI
R4*	2 kW, 1/4 W, 5%	1	CF−1/4W−2K−5	SEI
R5	100,1/4,5%	1	RN−1/4W−T1−100−5	SEI
R7*	0.5 W, 1 W	1	RS−1−R5−5TR	SEI
R8*	1.2 W, 1 W	1	RS−1−1R2−5TR	SEI
R9*	22 W, 1/4 W, 5%	1	CF−1/4W−22R−5	SEI
R10*	220 W 1/4W, 5%	1	CF−1/4W−221−5	SEI
R6	3.6,1W,5%	1	CF−1W−3.6−5	SEI
LED1−3	Luxeon Star	3	LXHL−MW1C	Luxeon
F1	2A, axial	1	251002TR1	LittleFuse
Connector 1		1	1715035	Phoenix Contact

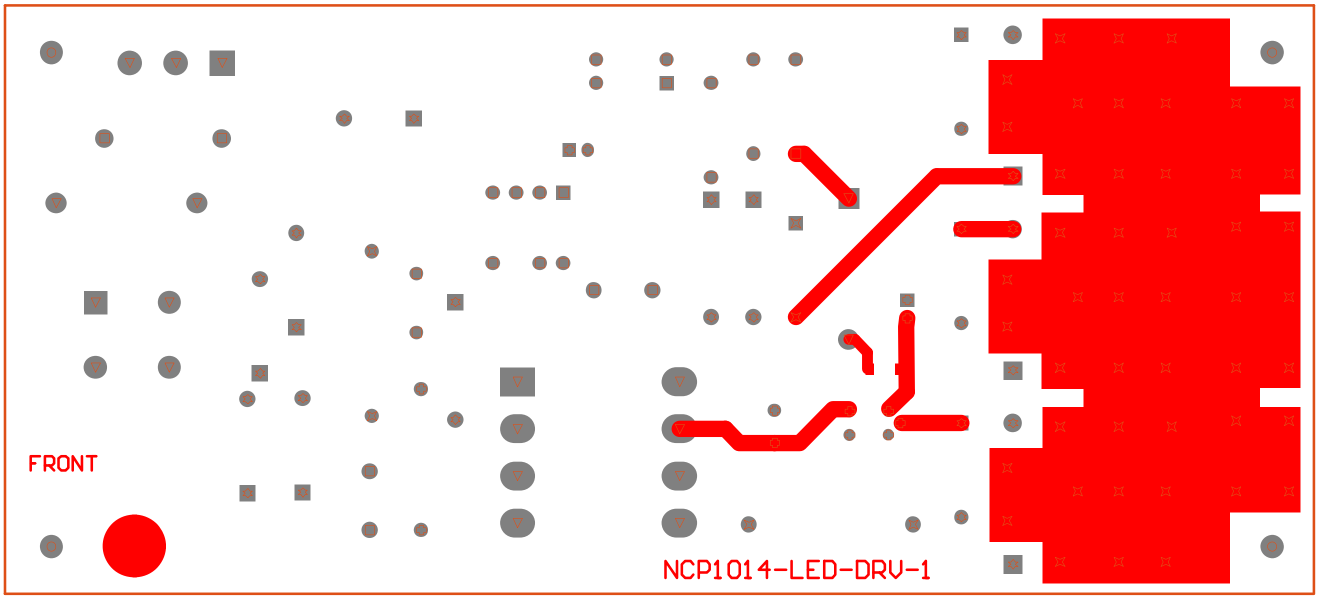

Figure 2. PCB Metal Layer (front)

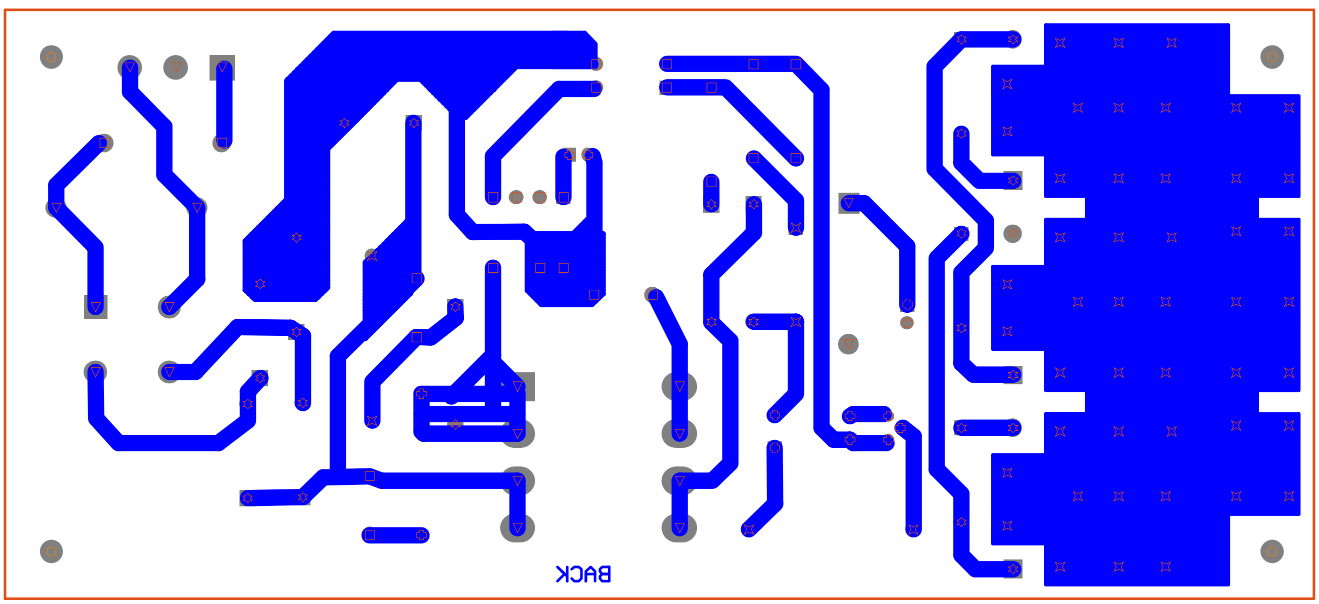

Figure 3. PCB Metal Layer (back)

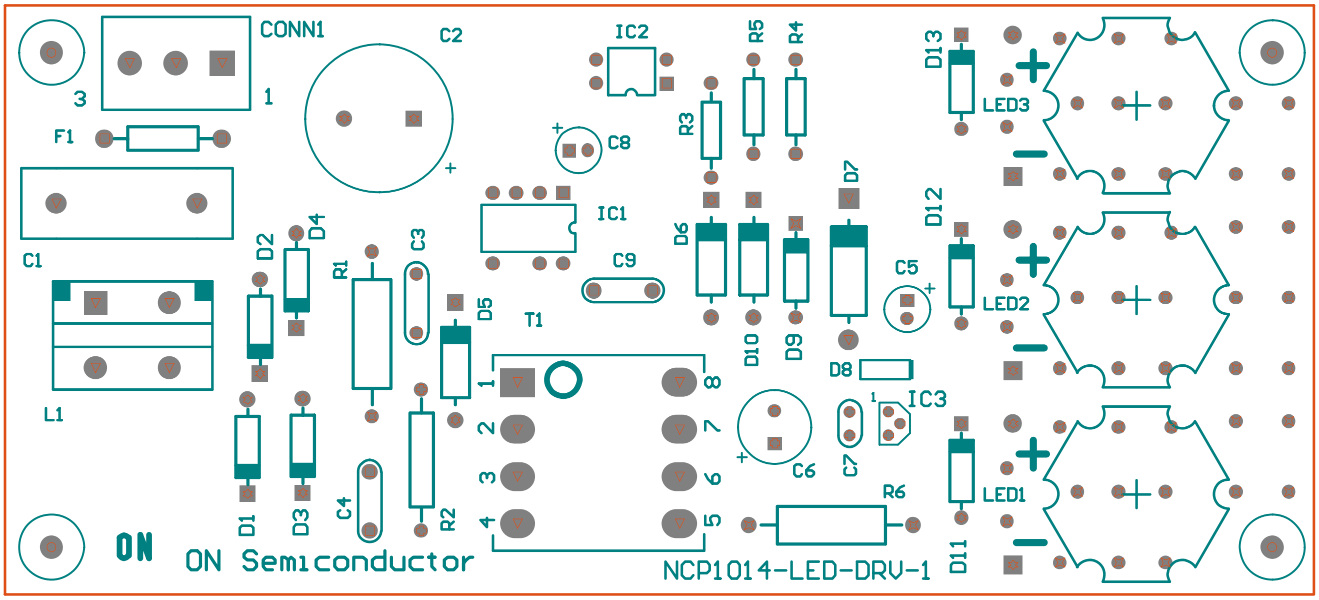

Figure 4. PCB Silk Screen

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