TND373/D
Rev. 0, Oct - 2009

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1 W to 5 W LED Driver for MR16 LED

Reference Design Documentation Package

TND373/D

1 W to 5 W LED Driver for MR16 LED

ON Semiconductor®

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TECHNICAL NOTE

Introduction

The market for High-Brightness LED's (HB-LED) continues to rise rapidly. Over the last few years LED efficacy (lm/W) has more than doubled while flux per package continues to rise rapidly making them more useful for many new applications. We have seen revolutionary new products in handheld flashlights, architectural lighting and street lighting. The challenge continues to be making a more cost effective system versus incandescent and compact fluorescent bulbs.

In many applications this challenge involves powering the HB-LED's from a wide input-voltage range source. This is especially true in general illumination applications like track lighting where the power source is a 12 Vac or +12 Vdc source that can be very loosely regulated. The LED's need to be driven by a current source rather than a voltage source since the forward voltage (3.4 V nominal) can vary more than ±20% over process tolerance and temperature. Moreover given the flux of current 1 W warm white power LEDs, it is common to need 3-4 LEDs to replace the light output of a 20 W incandescent. To obtain predictable and matched luminosity and chromaticity it is also desirable to drive the LED's with a constant current. The buck-boost topology meets this requirement from an architectural perspective but it not as common as the standard buck or boost topologies. Once understood, the buck-boost topology can offer many advantages for cost effective HB LED lighting when V_{in} overlaps V_f.

Overview

This reference document describes a built and tested, GreenPoint® solution for a 1 to 5 W LED driver for MR16 LED replacement. The circuit is proposed for driving HB-LED (high-brightness LED) in a variety of lighting applications but is configured in size and features for an MR16 LED replacement. Configurations like this are found in 12 Vac / 12 Vdc track lighting applications, automotive applications, and low voltage AC landscaping applications as well as task lighting such as under-cabinet lights and desk lamps that might be powered from standard off-the-shelf Vac wall adapters.

The circuit is based around the ON Semiconductor NCP3065 operating at ~150 kHz in a non-isolated configuration. A key consideration in this design was achieving flat current regulation across input line variation and output voltage variation with a 12 Vac input. It also features an auto-detect circuit in combination with the NCP3065 which allows input from a 12 Vdc or 12 Vac supply and still maintain targeted output current regulation.

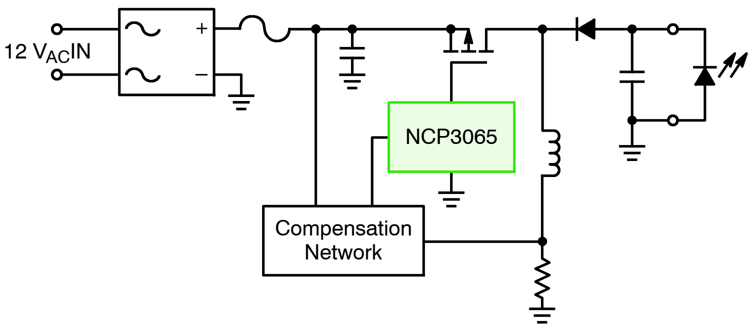
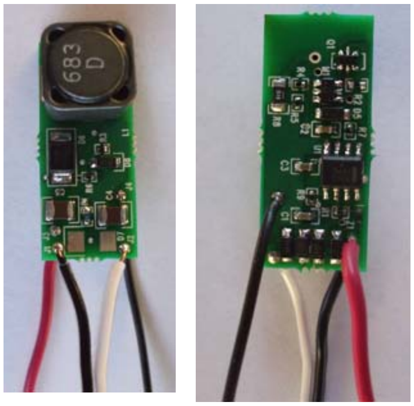


Figure 1. Simplified Block Diagram



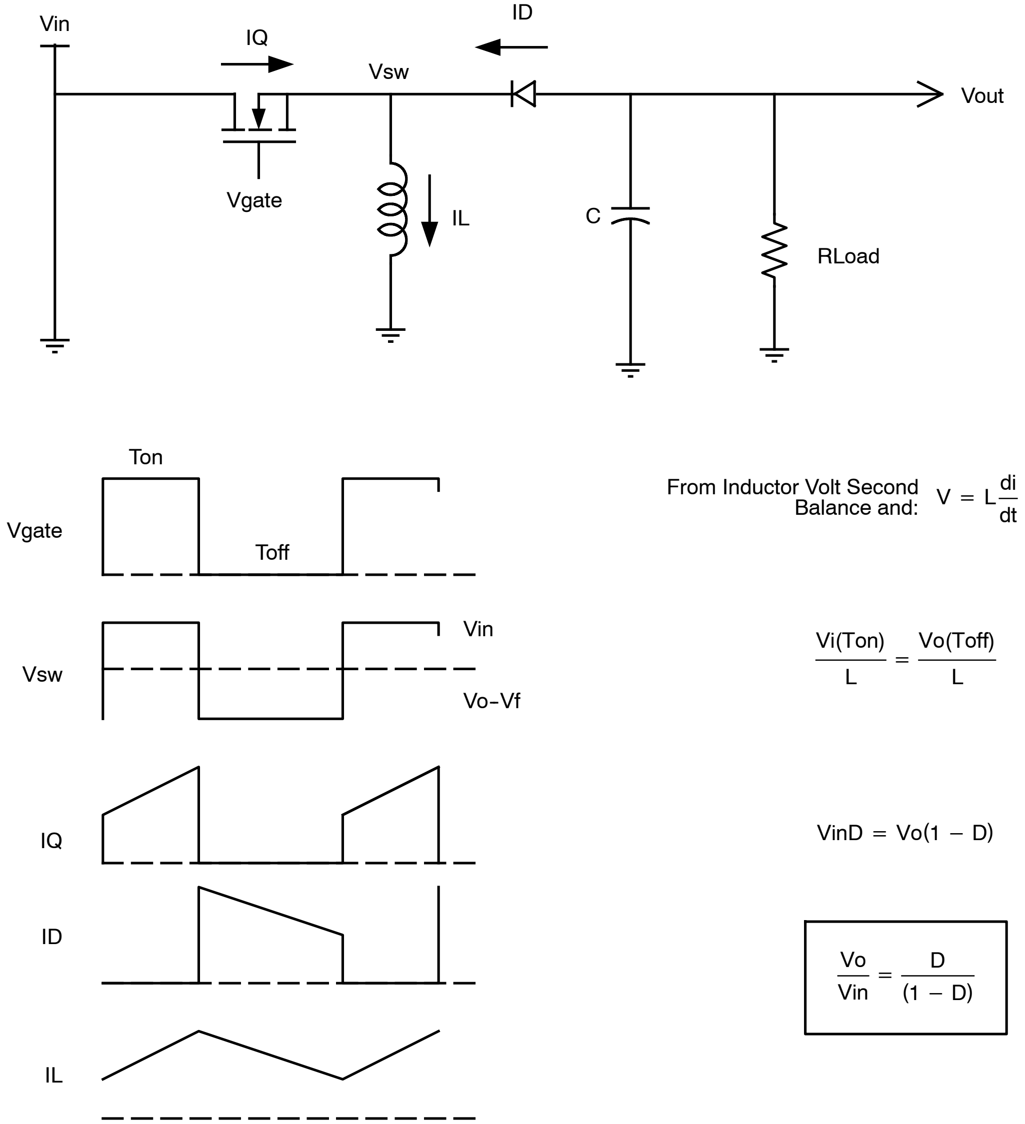
Actual Size

Basic Power Topology

The principle of the Buck-Boost converter is fairly simple (see Figure 2):

While in the On-state, the input voltage source is directly connected to the inductor (L). This results in accumulating energy in L. In this stage, the capacitor C supplies energy to the output load;

While in the Off-state, the inductor is connected to the output load and capacitor through the Output Diode, so energy is transferred to the load.



$$V = L\frac{di}{dt}$$

$$\frac{Vi(Ton)}{L} = \frac{Vo(Toff)}{L}$$

$$VinD = Vo(1 - D)$$

$$\boxed{\frac{Vo}{Vin} = \frac{D}{(1 - D)}}$$

Figure 2. Buck-Boost Operation

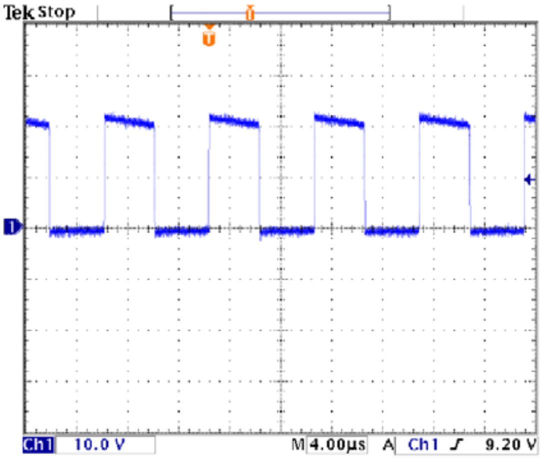


Figure 3. V_{switch} Node Waveform

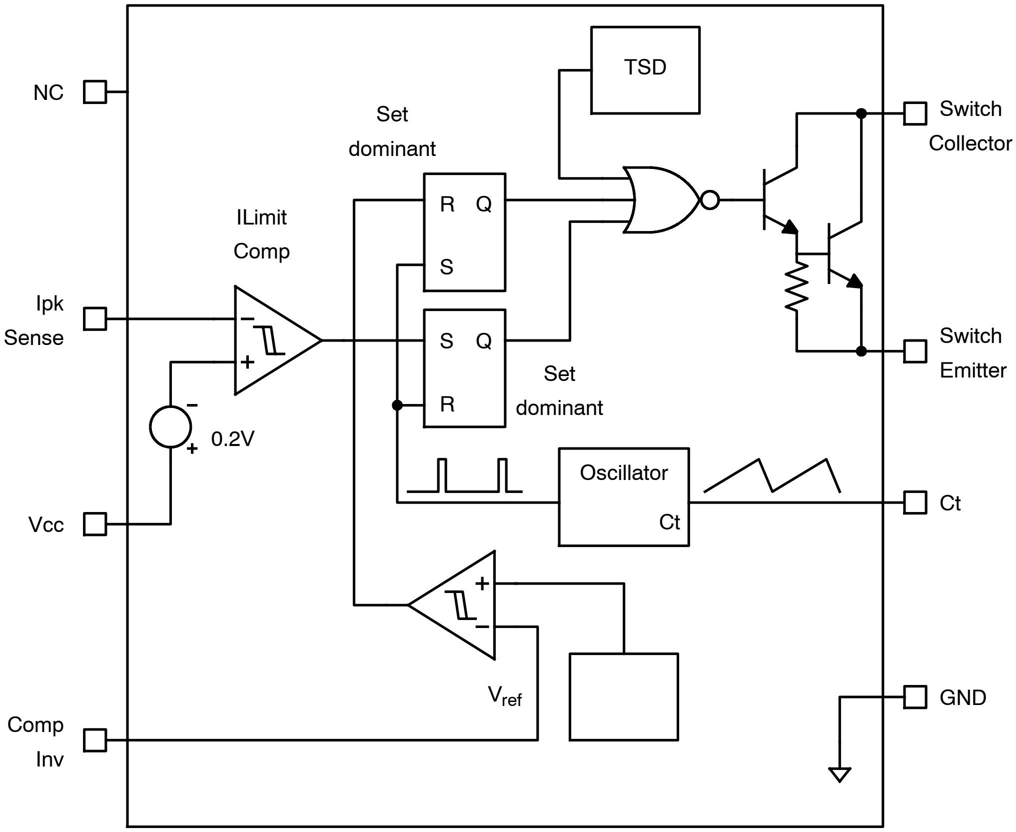


Figure 4. NCP3065 Burst Mode Controller

Burst Mode Control

The basic control loop consists of a 235 mV internal Reference, a Feedback Comparator, and two Set-Dominant RS Latches. Basically the NCP3065 allows the Power FET for the Buck-Boost stage to switch ON as the Feedback Voltage falls below the reference voltage. The Power FET will be then be forced OFF unconditionally during Ct Ramp down.

R8 is used to sense the inductor current and is fed to the FB pin of the NCP3065.

This application produces OFF time instantaneous (I_{valley}) inductor current control (see Figure 5). A cycle of switch ON time is only allowed to start once the OFF time Inductor current crosses the V_{ref} threshold.

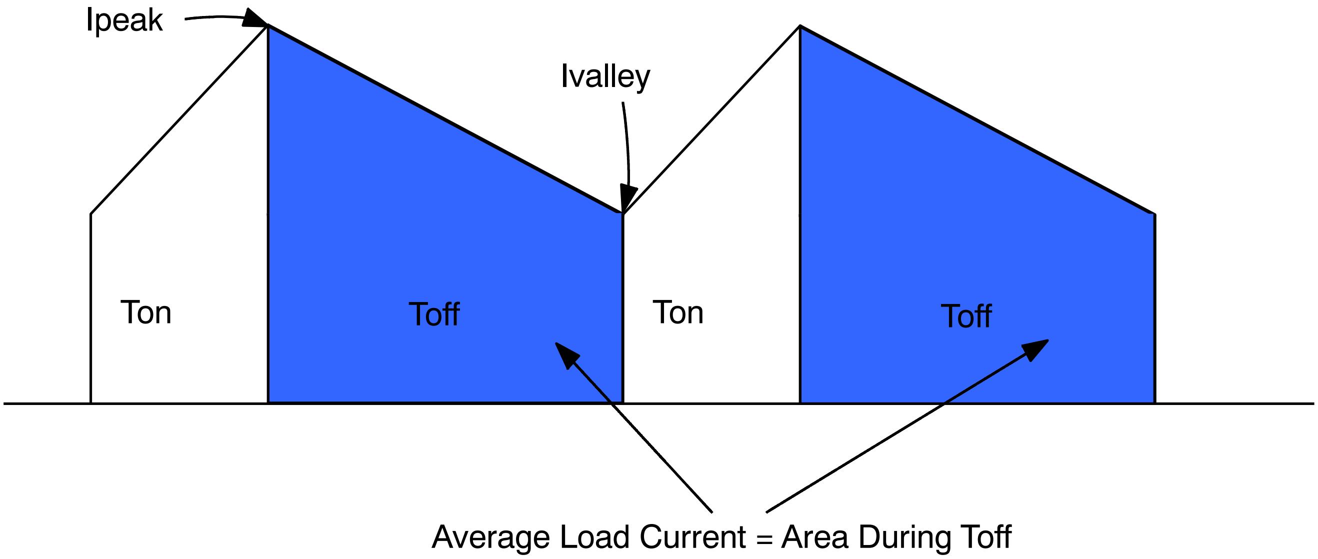


Figure 5. Buck-Boost Inductor Current

Since the controller does not provide integral PWM control and utilizes only a comparator trip point for feedback, the peak to average load current is not in direct proportion as in a Buck Converter, but rather follows the following formula:

$$I_{ave} = \left\{ I_{valley} + \frac{1}{2}\left[\left(\frac{V_o}{L}\right) 1 - \frac{\frac{V_o}{V_o+V_{in}}}{F}\right]\right\}\left(1 - \frac{V_o}{V_o + V_{in}}\right)$$

Where, I_{valley} is the lowest inductor current point. Plotting I_{ave} vs V_{in} shows a dramatic curve which would cause a significant change in light output of the LED (see Figure 6).

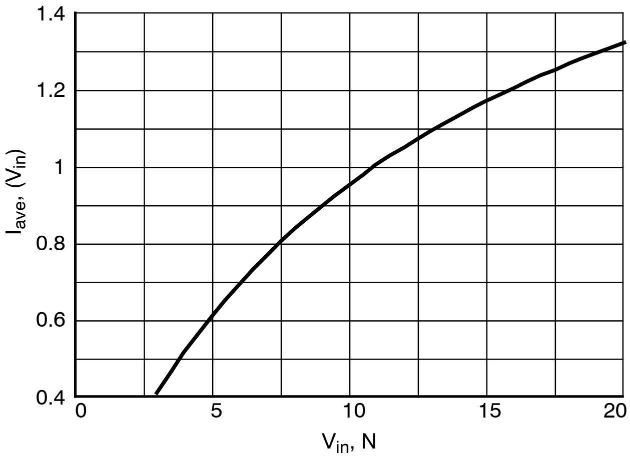


Figure 6. Average LED Current vs V_{in} DC (Without V_{in} Compensation)

Therefore an input voltage feed-forward compensation network is used to reduce the error due to the nonlinear response of the I_{out} vs V_{in} curve.

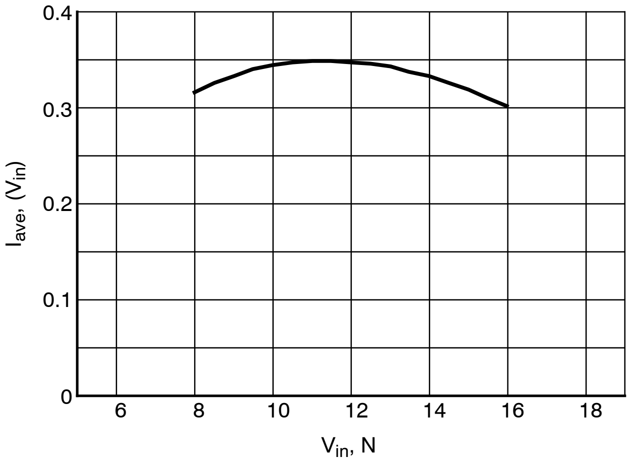


Figure 7. Average LED Current vs Vin DC (With Vin Compensation)

A resistive divider network consisting of R3, R5 and summing resistor R4 are used to add V_{in} proportional voltage to the FB pin in order to reduce the load current as V_{in} is increased. This has the effect of flattening the curve of Figure 6 and reduces the overall current error (see Figure 7). This average line can be DC shifted with R8 and the ends can be aligned by adjusting R5, R3 and R4.

R9 and C6 are used to limit the gate to source voltage on the external switch at high input voltage. The resistor divider network of R9 and R2 are used to program and gate to source maximum.

$$V_{gs} = V_{in} - \left(\frac{V_{in} \cdot R9}{R9 + R2}\right) \qquad \text{(eq. 1)}$$

Pulsed Feedback Resistor

R7 and D5 are used to reduce the possibility of pulse skipping (see Figure 8). Since burst mode control involves only one feedback voltage, cross-detection per cycle and does not involve the use of a window comparator, it is possible to have skipped pulses which do not effect the DC regulation but could be visible as flicker in an LED application if the pulsing had a low frequency component. R7 and D5 add current to the Ct timing capacitor C2. This effectively limits the maximum achievable duty cycle of the NCP3065. When conditions warrant low duty cycle, R7 and D5 make higher than desired duty cycles unavailable. D7 is necessary to block voltage during the OFF time, since this is Buck-Boost Topology. More information on Pulsed Feedback compensation is available in the NCP3065 data sheet.

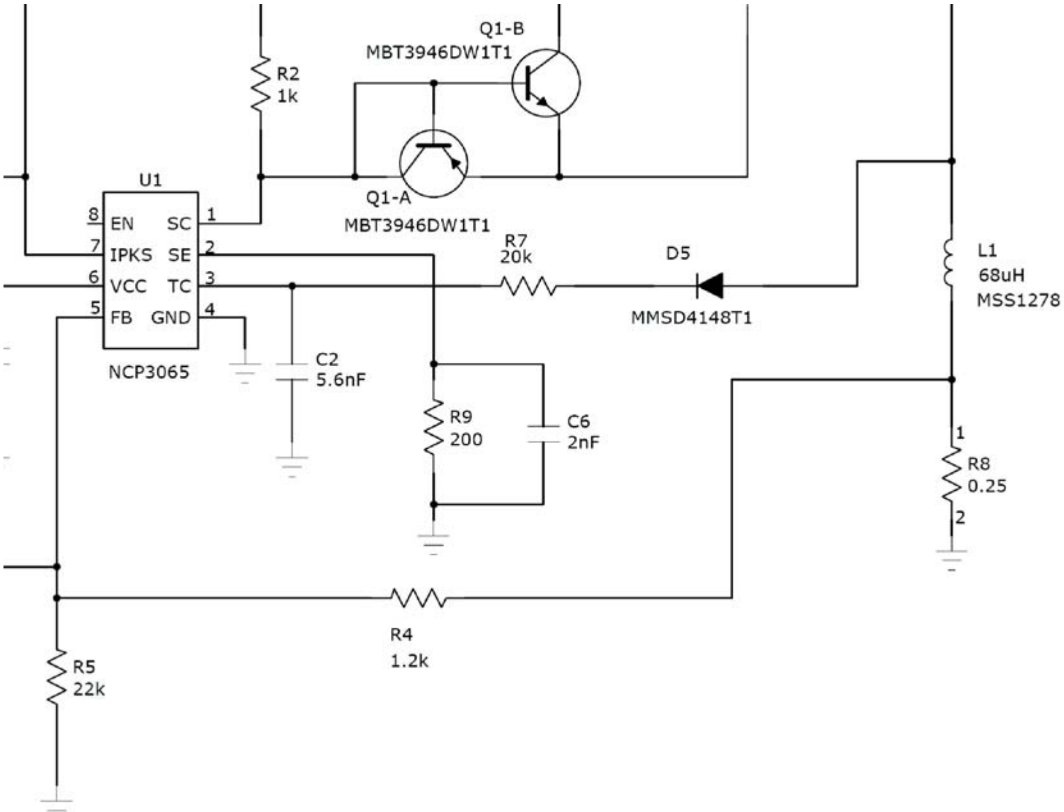


Figure 8. Pulsed Feedback Resistor

AC Operation vs DC

Since there is a half sine wave input to the Buck-Boost stage, there is a different operating point as compared with pure DC input. Since small size is a goal for this design very little input capacitance is used past the full bridge rectifier. As a result the line voltage can drop to as little as 3 V depending on the input capacitance selection. Therefore, the input to the converter is a full wave rectified sine wave. Since the regulator is non-functional below ~4 V there are dead spots in the regulation. So we end up with regulation for some finite portion ~80% of the 120 Hz line cycle, and then no output for ~20%. This has the effect of reducing the average current by ~20% when operating with AC input. Thermal consideration should be taken when running with > 12 Vac. In most applications the module is potted to increase thermal dissipation.

An additional AC compensation network is added to the V_{in} Compensation to account for the different operating point (see Figure 9).

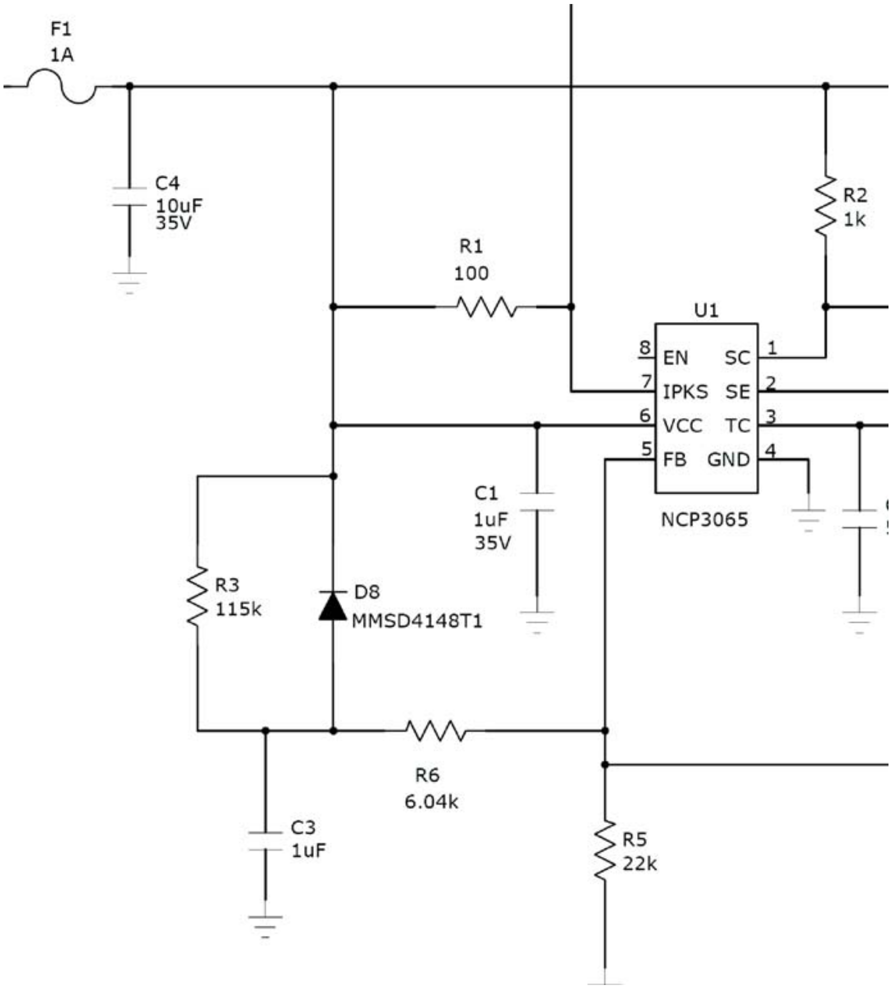


Figure 9. Pulsed Feedback Resistor

Protection

Z1 and R1, along with the Current limit function of the NCP3065, are used for open circuit protection. In the event of an open circuit at the load, the loop will try to increase the output voltage in order to satisfy the current demand which feeds back zero current. When (V_{in} + V_{out}) exceeds the voltage of Z1, current will flow in R1 which triggers the current limit function of the NCP3065.

Short circuit protection is handled with a fuse, F1, on the input. Surge protection from inductive loads is an important consideration specifically in transformer fed systems that carry significant source inductance such as found with magnetic transformers used in landscape lighting applications. The surge device needs to be selected to a voltage that will never exceed the gate to source voltage of the power FET with reasonable voltage margin. This may require some trial and error to select since the clamp voltage will stretch depending on how much energy needs to be absorbed.

Increasing Output Current

The reference design is configured for 350 mA average LED current. Increasing the current regulation point on the reference board is as simple as cutting the current sense resistor R8 in half from 250 mΩ to 125 mΩ. Also, the input fuse must be increased to accommodate the increased input current draw. Heat sinking may be required depending on the implementation of the housing and the environmental characteristics when moving to the higher power design.

PC BOARD

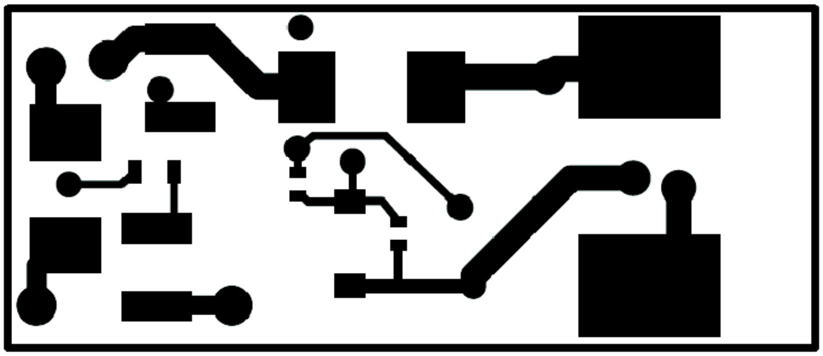


Figure 10. Component Placement (Top)

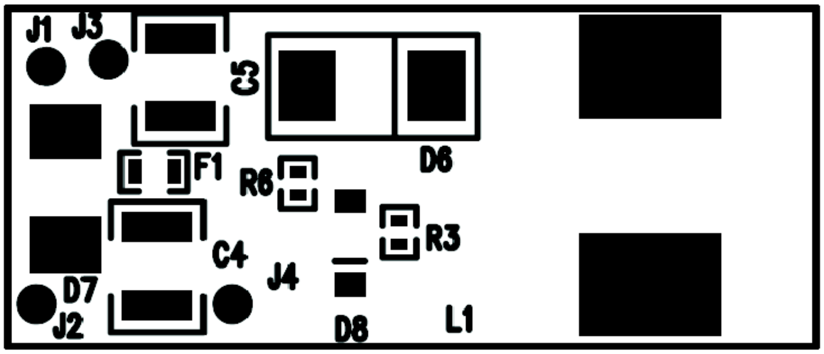


Figure 11. Traces (Top View)

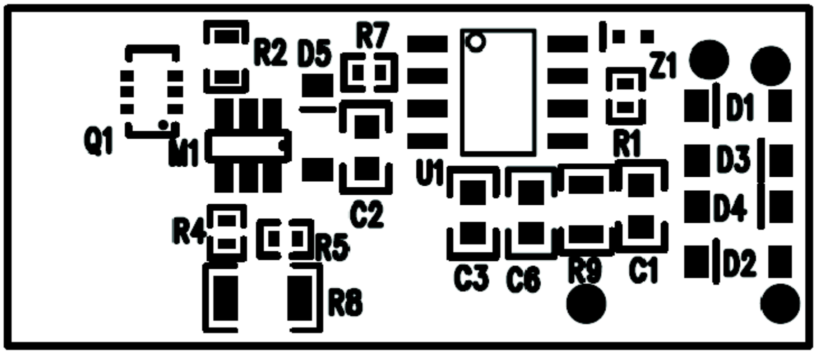


Figure 12. Component Placement (Bottom)

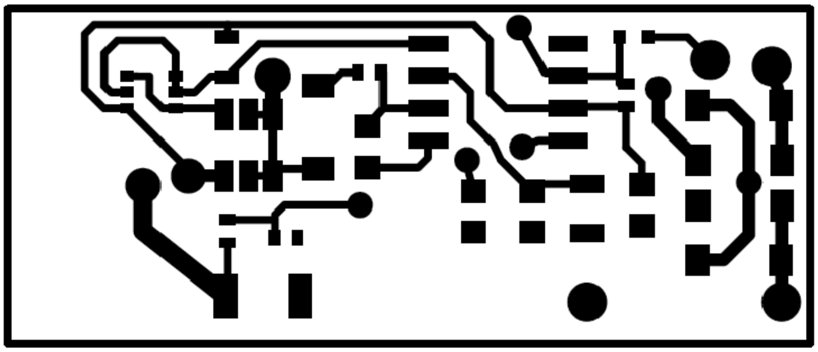


Figure 13. Traces (Bottom View)

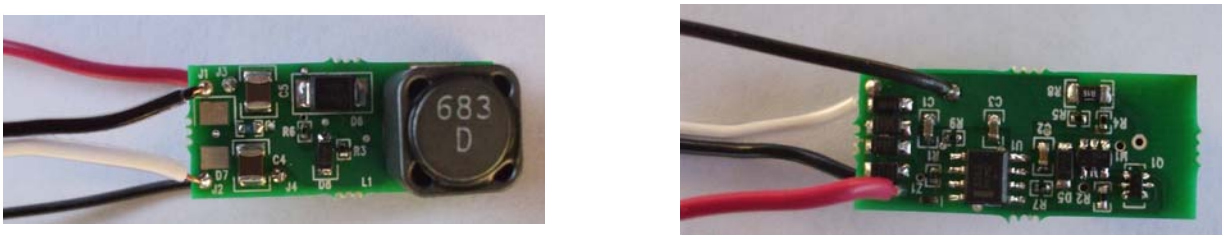


Figure 14. Reference Design
0.457” x 1.148” (11 mm x 29 mm)

Remember this is an inverting output. So the negative output will connect to the anode of the LED, and the positive output will connect to the cathode of the LED.

Also note, when trying to make measurements with a scope probe, that ground is NOT ground. The scope will need to be floating (ground connection removed from the AC wall source) or there will be a ground loop / short circuit that will cause the device to turn off.

SCHEMATIC

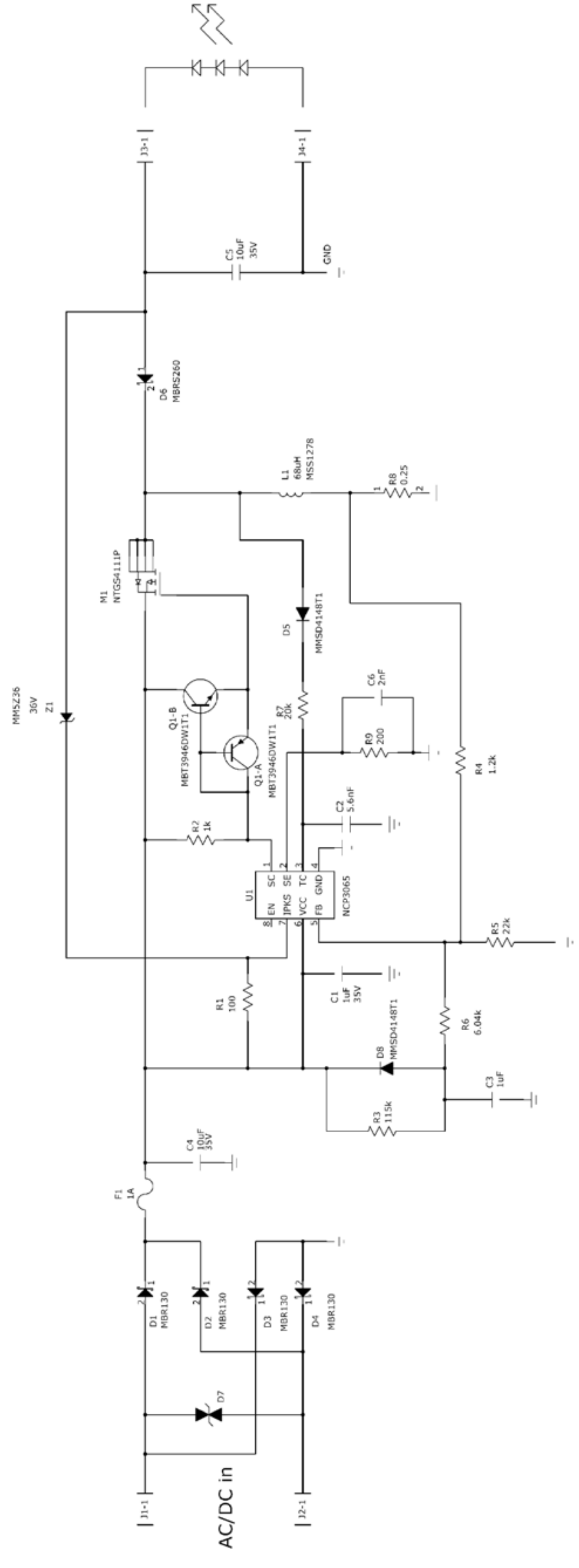


Figure 15.

Table 1. BILL OF MATERIALS

Qty	Ref	Value	Part Number	Description	Manufacturer
1	F1	4 A	0457004.NR	Fuse	LittleFuse
1	C3	10 μF	GRM31MF51A106ZA01L	Ceramic Chip Capacitor	Murata
1	C6	1 nF	GRM188R71H102KA01D	Ceramic Chip Capacitor	Murata
1	C1	1 μF	GRM188R61E105KA12D	Ceramic Chip Capacitor	Murata
1	C2	5.6 nF	GRM188R71H562KA01D	Ceramic Chip Capacitor	Murata
1	C4	10 μF	GRM32NF51E106ZA01L	Ceramic Chip Capacitor	Murata
1	C5	10 μF	GRM32NF51E106ZA01L	Ceramic Chip Capacitor	Murata
1	D1	1 A, 30 V	MBR130T1G	DIODE, SCHOTTKY	ON Semiconductor
1	D2	1 A, 30 V	MBR130T1G	DIODE, SCHOTTKY	ON Semiconductor
1	D3	1 A, 30 V	MBR130T1G	DIODE, SCHOTTKY	ON Semiconductor
1	D4	1 A, 30 V	MBR130T1G	DIODE, SCHOTTKY	ON Semiconductor
1	D6	2 A, 60 V	MBRS260T3	DIODE, SCHOTTKY	ON Semiconductor
1	Q1	PNP	MBT3946DW1T1	General Purpose NPN Transistor	ON Semiconductor
1	D5	0.2 A, 100 V	MMSD4148T1	Diode, Small Signal	ON Semiconductor
1	D8	0.2 A, 100 V	MMSD4148T1	Diode, Small Signal	ON Semiconductor
1	Z1	36 V	MM5Z36VT1	DIODE, ZENER	ON Semiconductor
1	L1	68 μH	MSS1278-683MLD	INDUCTOR, SM	Coilcraft
1	U1	40 V 1.5 A	NCP3065DR2G	Switching Regulator	ON Semiconductor
1	M1	P-FET	NTGS4111PT1G	MOSFET, P	ON Semiconductor
1	R4	1.2k	CRCW04021K20FKED	Resistor	Vishay / Dale
1	R1	100	CRCW0402100RFKED	Resistor	Vishay / Dale
1	R3	162k	CRCW0402162KFKED	Resistor	Vishay / Dale
1	R6	196	CRCW0402196RFKED	Resistor	Vishay / Dale
1	R7	22k	CRCW040222K0FKED	Resistor	Vishay / Dale
1	R5	22k	CRCW040222K0FKED	Resistor	Vishay / Dale
1	R2	1k	CRCW04021K00FKED	Resistor	Vishay / Dale
1	R9	200	CRCW0402200RFKED	Resistor	Vishay / Dale
1	R8	0.25	CSR1/20.25FICT-ND	Resistor	Vishay / Dale
1	D7		P6SMB22CAT3	ZENER, BACK TO BACK	ON Semiconductor

MEASUREMENTS

(12 Vac Data)

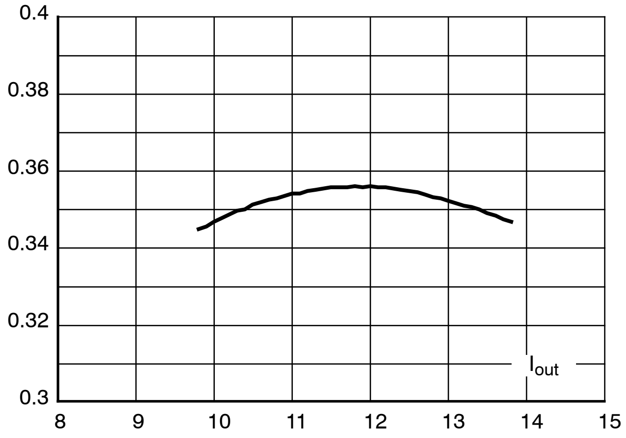


Figure 16. I_{out} vs Vac

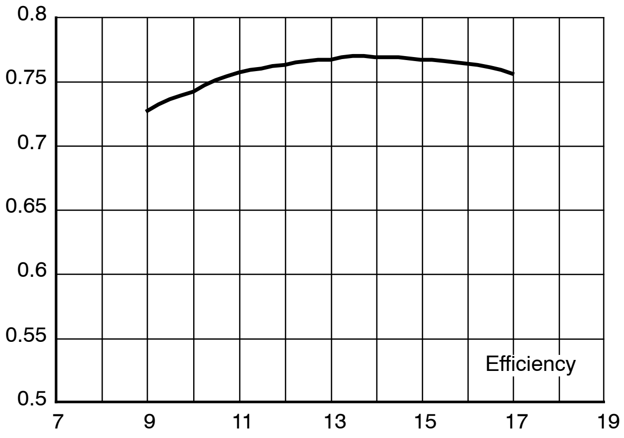


Figure 17. Efficiency vs Vdc

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