AND8289

LED Driving with NCP/V3063

Prepared by: Petr Konvicny, Bernie Weir
ON Semiconductor

ON Semiconductor®

Introduction

Improvements in high brightness LEDs present the potential for creative new lighting solutions that offer an improved lighting experience while reducing energy demand. LEDs require constant current driver solutions due to their wide forward voltage variation and steep V/I transfer function.
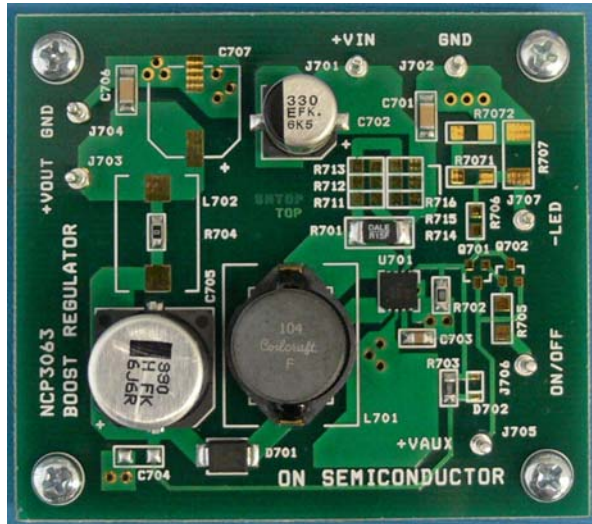

Figure 1. NCP/NCV3063 DFN Demo Board

This application note describes how the NCP3063/NCV3063 can be configured in a boost topology to drive strings of LEDs: be it traditional low power LEDs or high brightness power LEDs such as the Lumileds Luxeon™ series, the CREE XLAMP™ 4550 or XR−E or the OSRAM TopLED™ or Golden Dragon™. Configurations like this are found in 12 V_{DC} 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 5 V_{DC} and 12 V_{DC} wall adapters.

Key considerations in this design were achieving high conversion efficiency in the mid− 80% range and having flat current regulation across input line variation and output voltage variation.

Boost Converter Topology

The Boost topology is illustrated in Figure 2. When the low side power switch is turned on, current drawn from the input begins to flow through the inductor and the current I_{ton} rises up as shown in Figure 2. When the low side switch is turned off, the current (I_{toff}) circulates through diode D to the output capacitor and load. At the same time the inductor voltage is added with the input power supply voltage and as long as this is higher than the output voltage, the current continues to flow through diode. Provided that the current through the inductor is always positive, the converter is operating in Continuous Conduction Mode (CCM). On the next switching cycle, the process is repeated.

When operating in CCM the output voltage is equal to:

$$V_{OUT} = V_{IN} \cdot \frac{1}{1 - D} \qquad \text{(eq. 1)}$$

The duty cycle is defined as:

$$D = \frac{t_{ON}}{t_{ON} + t_{OFF}} = \frac{t_{ON}}{T} \qquad \text{(eq. 2)}$$

The input ripple current is defined as:

$$\Delta I = V_{IN} \frac{D}{f * L} \qquad \text{(eq. 3)}$$

The load voltage must always be higher than the input voltage. This voltage is defined as:

$V_{LOAD} = V_{SENSE} + n * V_f$; Where V_f = LED forward voltage, V_{SENSE} is the converter reference voltage, and n = # of LED's in cluster.
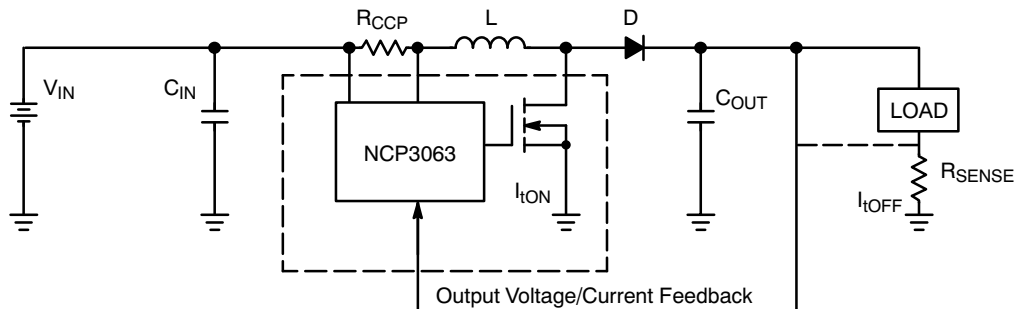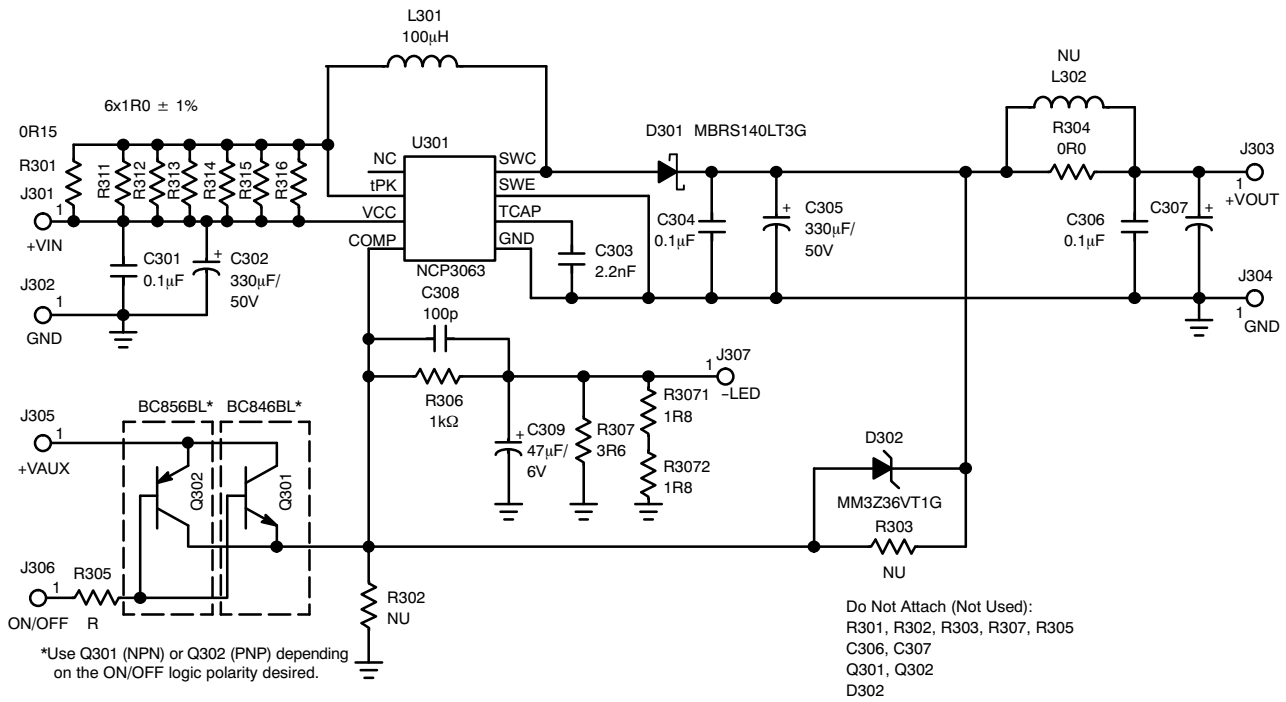

Figure 2. "Semi−Ideal" Boost Converter

Figure 3. NCP3063/NCV3063 Demo Board — Application circuit

Since the converter needs to regulate current independent of load voltage variation, a sense resistor is placed across the feedback voltage. This drop is calculated as: $V_{SENSE} = I_{LOAD} * R_{SENSE}$. The V_{SENSE} corresponds to the internal voltage reference or feedback comparator threshold.

Simple Boost 350 mA LED driver

The NCP/NCV3063 boost converter is configured as a 350 mA LED driver is shown in Figure 3. It is well suited to automotive or industrial applications where limited board space and a high voltage and high ambient temperature range might be found. The NCP3063 also incorporates safety features such as peak switch current and thermal shutdown protection. The schematic has an external high side current sense resistor that is used to detect if the peak current is exceeded. In the constant current configuration, protection is also required in the event of an open LED fault since current will continue to charge the output capacitor causing the output voltage to rise. An external zener diode is used to clamp the output voltage in this fault mode. Although the NCP3063 is designed to operate up to 40 V additional input transient protections might be required in certain automotive applications due to inductive load dump.

The main operational frequency is determined by external capacitor C303. The t_{on} time is controlled by the internal feedback comparator, peak current comparator and main oscillator. The output current is configured by an internal feedback comparator with negative feedback input. The positive input is connected to an internal voltage reference of 1.25 V with 1.5% precision. The nominal LED current is setup by a feedback resistor. This current is defined as:

$$I_{OUT} = \frac{1.25}{R_{SENSE}} \qquad \text{(eq. 4)}$$

R_{SENSE} correspond to R307 (or R3071 and R3072) in the schematic. For a nominal 350 mA operation a 3.6 Ω resistor should be used. By changing the R_{SENSE} resistor other values of current can be achieved.

There are two approaches to implement LED dimming. Both use the negative comparator input as a shutdown input. When the pin voltage is higher than 1.25 V the switch transistor is off. You could connect an external PWM signal to pin ON/OFF and a power source to pin $+V_{AUX}$ to realize the PWM dimming function. When the dimming signal exceeds the turn on threshold of the external PNP or NPN transistor, the comp pin will be pulled up. A TTL level input can also be used for dimming control. The range of the dimming frequency is from 100 Hz to 1 kHz, but it is recommended to use frequency around 200 Hz as this is safely above the frequency where the human eye can detect the pulsed behavior, in addition this value is convenient to minimize EMI. There are two options to determine the dimming polarity. The first one uses the NPN switching transistor and the second uses a PNP switching transistor. The switch on/off level is depending on chosen dimming topology. The external voltage source (V_{AUX}) should have a voltage ranging from +5 V_{DC} to $+V_{IN}$. Figure 13 illustrates average LEDs current dependency on the dimming input signal duty cycle.

For cycle by cycle switch current limiting a second comparator is used which has a nominal 200 mV threshold.

The value of resistor R301 determines the current limit value and is configured according to the following equation.

$$I_{pk(SW)} = \frac{0.2}{0.15} = 1.33 \text{ A} \qquad \text{(eq. 5)}$$

The maximum output voltage is clamped with an external zener, D302 with a value of 36 V which protects the NCP3063/NCV3063 output from an open LED fault.

The demo board has a few options to configure it to your needs. You can use one 150 mΩ (R301) or a combination of parallel resistors such as six 1 Ω resistors (R311 — R316) for current sense. To set I_{LED} a single 3.6 Ω resistor (R307) or two 1.8 Ω resistors in series (R3071/2) can be used.

To evaluate the functionality of the board, high power LEDs with a typical $V_f = 3.42$ V @ 350 mA were connected in several series combinations (4, 6, 8 LED's string).

Number of LEDs	String Forward Voltage at 25°C		
	Min	**Typ**	**Max**
4	11.16	13.68	15.96
6	16.74	20.52	23.94
8	22.32	27.36	31.92

The efficiency was calculated by measuring the input voltage and input current and LED current and LED voltage as showed in Figure 4. The load regulation graph shows behavior of the NCP3063 boost converter across a broad input voltage range. The output current is dependent on the peak current, inductor value, input voltage and voltage drop value and of course on the switching frequency.

$$I_{OUT} = \left(D - D^2\right) * \left(\frac{I_{pk(SW)}}{D} - \frac{V_{IN} - V_{SWCE}}{2 * L * f}\right) \dots \dots [A] \qquad \text{(eq. 6)}$$

$$D = \frac{V_{OUT} + V_F - V_{IN}}{V_{OUT} + V_F - V_{SWCE}} \dots \dots [-] \qquad \text{(eq. 7)}$$

V_{OUT} Output Voltage
V_{IN} Input Voltage
V_F Schottky Diode Forward Voltage
V_{SWCE} Switch Voltage Drop
$I_{pk(SW)}$ Peak Switch Current

D   Duty Cycle
L   Inductor Value
f   Switching Frequency

This curve illustrates three distinct regions; in the first region, the peak current to the switch is exceeded tripping the overcurrent protection and causing the regulated current to drop, Region 2 is where the current is flat and represents normal operation, Region 3 occurs when V_{IN} is greater than V_{OUT} and there is no longer constant current regulation. Region 3 and 1 are included here for illustrative purposes as this is not a normal mode of operation.

The data is plotted for three values of inductors, 47 μH, 68 μH and 100 μH to illustrate efficiency and output current regulation variation. The Coilcraft RFB0810 series was utilized in this testing. As one would expect, since this design is optimized for CCM operation, lower values of inductor value would result in higher peak currents. Figure 5 illustrates this point clearly as at low V_{IN} and low inductor value (47 μH), the current limit of 1.33 A is reached at an input of slightly below 7.5 V and the circuit starts to fall out of current regulation. With high values of inductance, the circuit remains in current regulation. Similar behavior is illustrated in Figures 7 and 9 for longer strings of LEDs.

Figure 12 illustrates the additional circuitry required to support 12 V_{AC} input signal which includes the addition of a bridge rectifier and input filter capacitor. The rectified dc voltage is

$$V_{INDC} = \sqrt{2} * V_{AC} \approx 17 \text{ }V_{DC} \qquad \text{(eq. 8)}$$

Conclusion

LEDs are now being used to replace traditional incandescent and halogen lighting sources in architectural, industrial, residential and the transportation lighting. The key challenge in powering LED's is providing a constant current source. The demo board for the NCP3063/NCV3063 can be easily configured for a variety of constant current boost LED driver applications. In addition there is an EXCEL tool at the ON Semiconductor website for calculating inductor and other passive components if the design requirements differ from this specific application voltages and currents illustrated in this example.
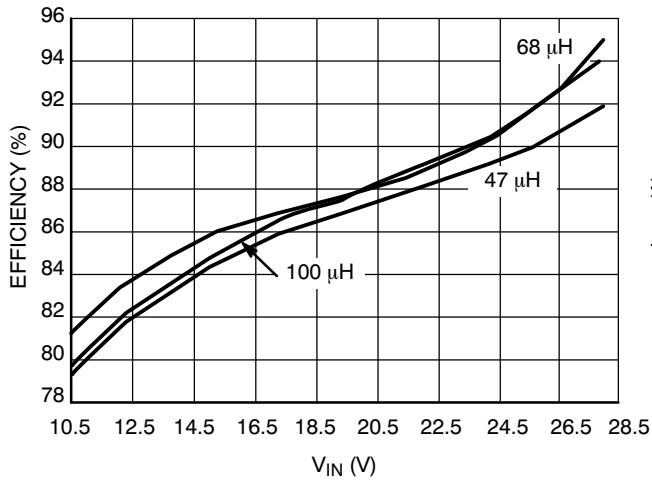
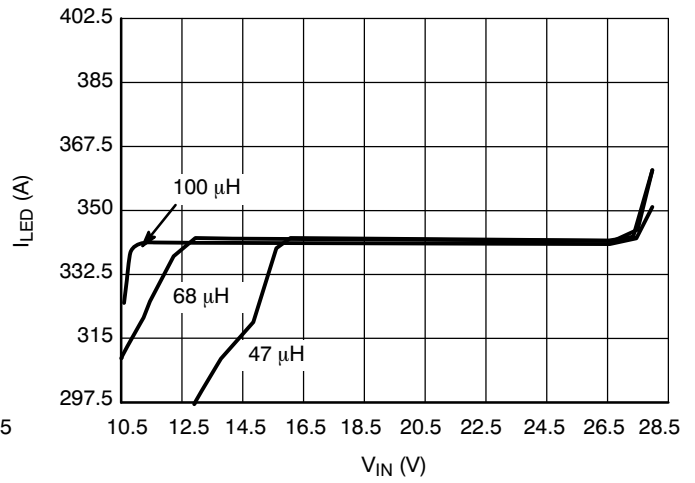**Figure 4. Boost Converter Efficiency with NCP3063 for 8 LEDs Cluster**

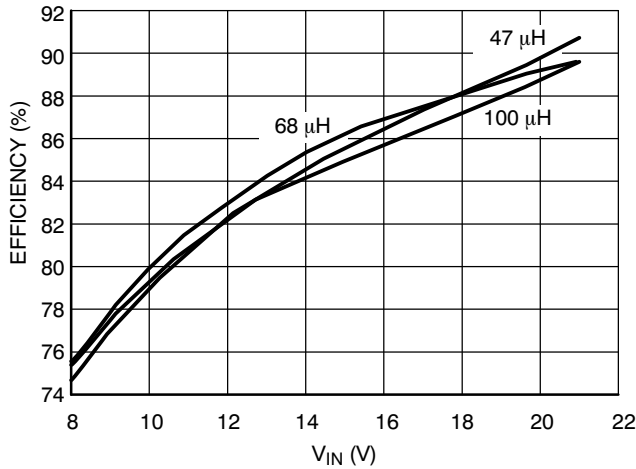**Figure 5. Current Regulation on the Input Voltage for 8 LEDs Cluster**

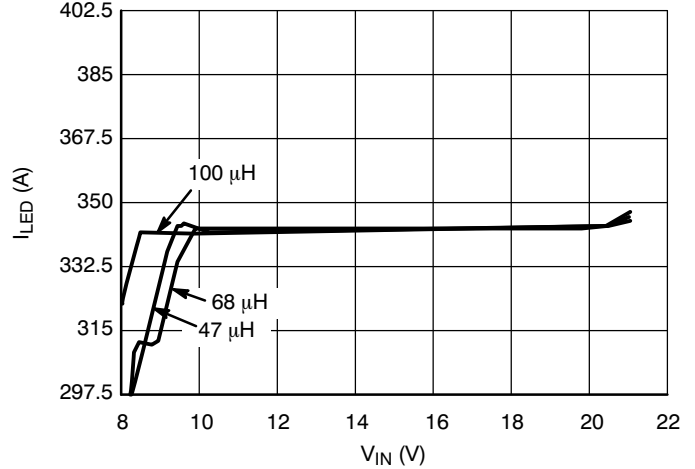**Figure 6. Converter Efficiency for 6 LEDs Cluster**

Figure 7. Current Regulation on the Input Voltage for 6 LEDs Cluster
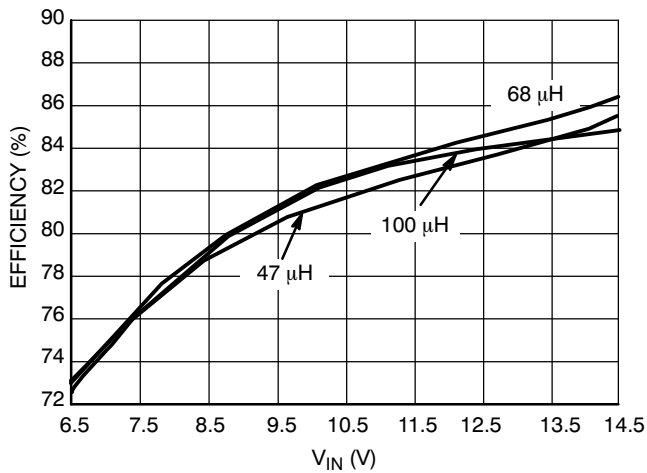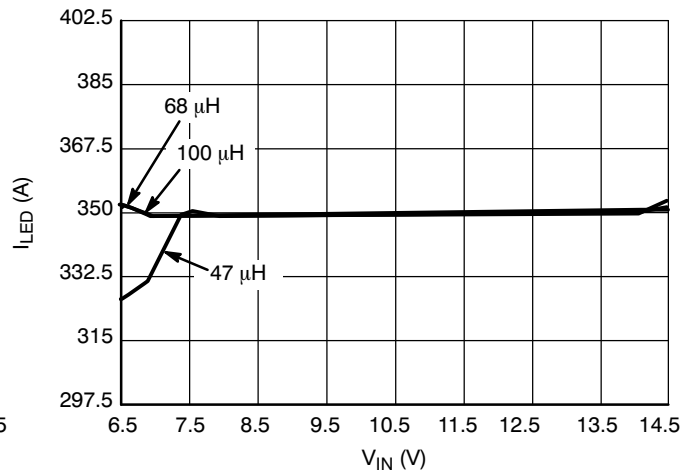
Figure 8. Converter Efficiency for 4 LEDs Cluster

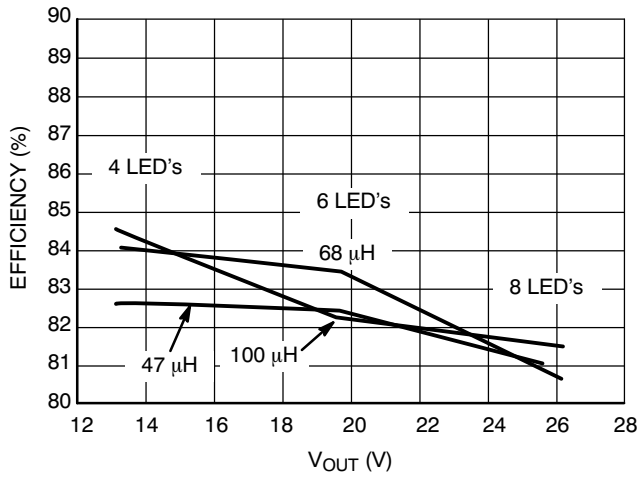**Figure 9. Current Regulation on the Input Voltage for 4 LEDs Cluster**

Figure 10. NCP3063 Boost LED Configuration – Efficiency versus Output Voltage /# of LED's/ for Input Voltage 12 V$_{DC}$
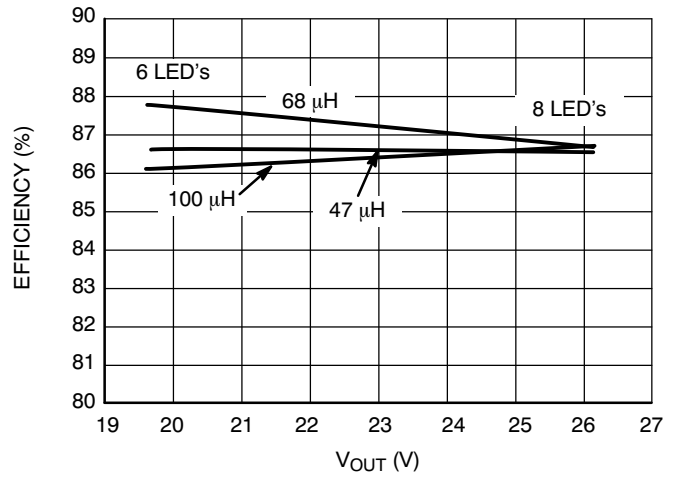
Figure 11. NCP3063 Boost LED Configuration – Efficiency versus Output Voltage /# of LED's/ for Input Voltage 12 V$_{AC}$
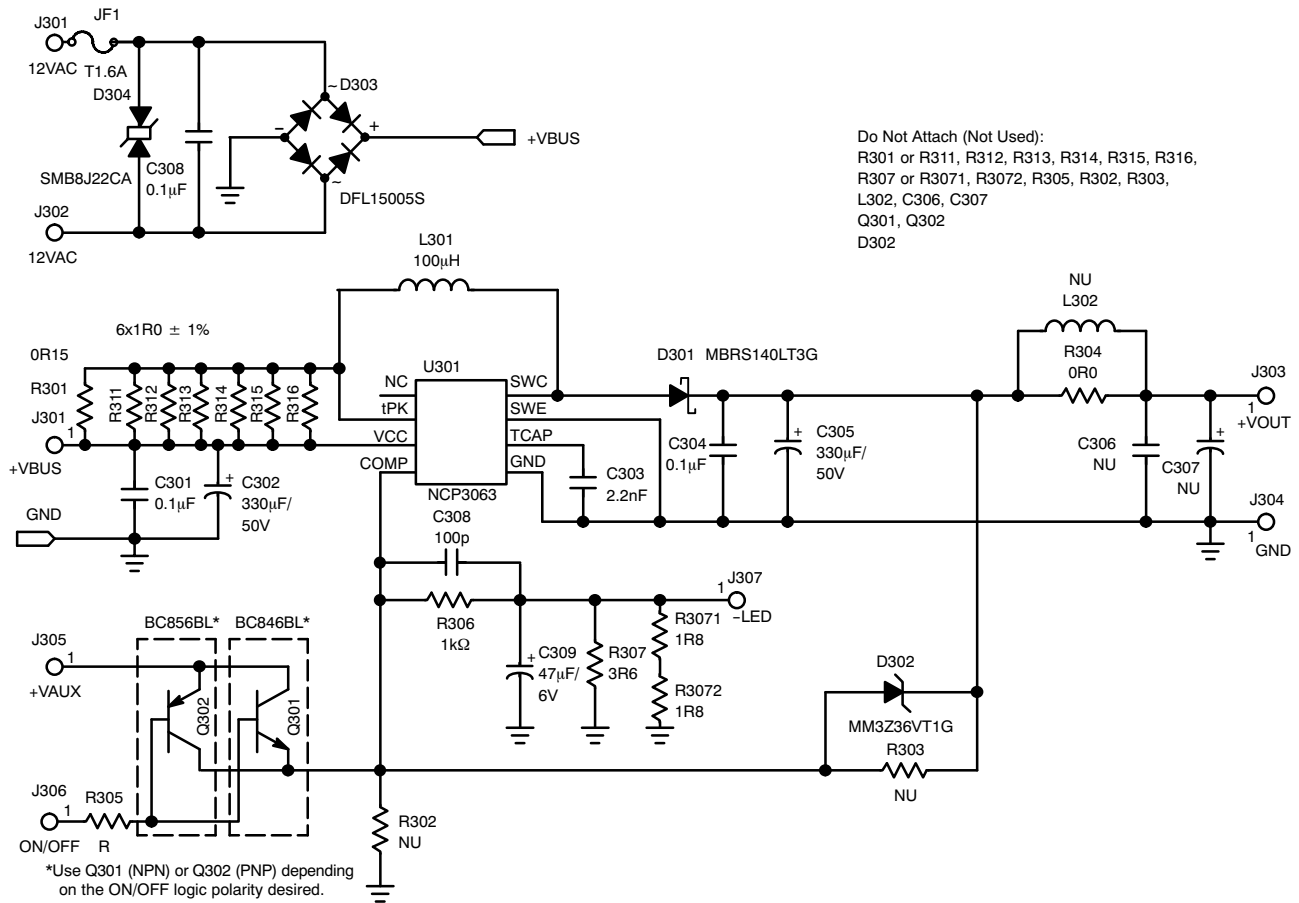
Figure 12. NCP3063 Boost LED Configuration Power from 12 V$_{AC}$ Line
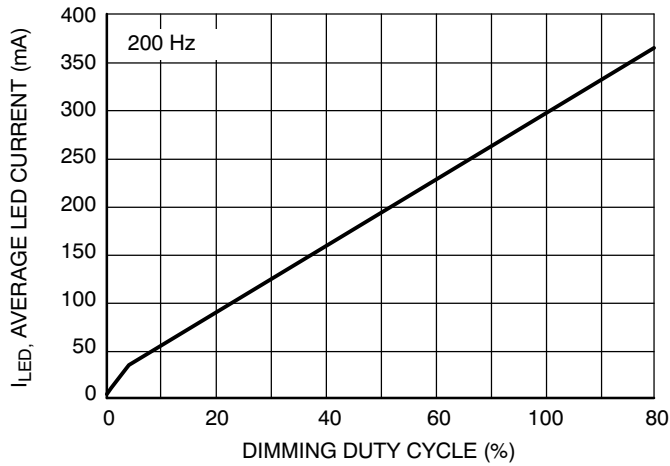
Figure 13. LED Average Current versus Dimming Duty Cycle, Dimming Frequency 200 Hz