AND8306/D

700 mA/1 A Buck Boost LED Driver using FETs, High Side Current Sensing and a NCP3063 Controller

ON Semiconductor®

http://onsemi.com

Prepared by: DENNIS SOLLEY
ON Semiconductor

INTRODUCTION

This application note and associated demo board will focus on driving 3 to 6 LEDs, at a regulated 700 mA/1 A, from low voltage DC or AC sources commonly used in lighting applications at power levels to 20 W. This note is an extension of Application Note AND8305/D.

LED Characteristics

By combining LED manufacturer's data, taken from several product families, it is possible to come up with minimum and maximum forward voltage drops for a "generic" LED, operating at a specified current. This voltage variation is presented in Table 1, and extended to include 3 to 6 LED combinations at 700 mA.

Table 1. Output Voltage Variation for a "Generic" 700 mA LED

Generic LED # String	Current (A)	V_{MIN} (V) @ $T_{J(max)}$°C (Note 1)	V_{MAX} (V) @ 25°C
1 LED	0.70	2.41	4.41
3 LEDs	0.70	7.22	13.23
4 LEDs	0.70	11.50	17.64
5 LEDs	0.70	12.03	22.05
6 LEDs	0.70	14.43	26.46

1. $T_{J(max)}$ based on LED manufacturer's maximum rating

Driver Definition

A typical automotive input requirement may require continuous operation between 9 V and 16 V, excursions between 18 V and 19 V for one hour, a double battery jump start to 26 V for one minute and finally a load dump to 70 V (typically absorbed by avalanching alternator rectifiers or by a transient suppressor). Similar requirements apply in AC situations. Depending on the illumination required, a particular application may require a driver to supply 700 mA to a series string of 3 to 6 LEDs. From Table 1, the driver must support output variations between 7 volts and 26 volts. Therefore, a constant current converter with both a wide input (9−19 V) and wide overlapping output ranges (7−26 V), is preferred. This application note targets a current regulated, non inverting buck boost converter. In automotive applications (e.g. emergency vehicles), a high side current sensing scheme can simplify wiring by returning the LED string to chassis ground.

The basic buck boost topology, consisting of a buck and boost converter cascaded together, is illustrated in Figure 1.

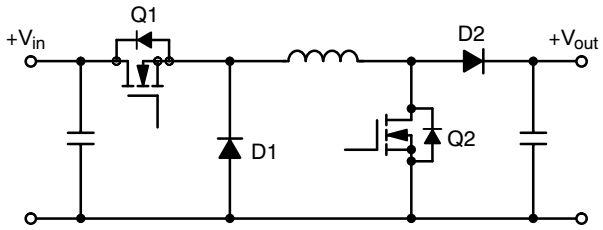

Figure 1. Buck Boost Converter

Either FETs or BJTs can be selected as the primary switches Q1/Q2. In the 20 W power range FETs are the preferred choice. Application Note AND8305/D covers a 7 W application using BJTs.

Theory of Operation

To minimize power dissipation in the power circuit, low ripple current is required. So the converter is run in continuous current mode (CCM). For this analysis, all power components are assumed ideal. During the first switching interval $D*T_{SW,}$ Q1 and Q2 are turned ON by the controller across the input source V_{in} and allow energy to be stored in the inductor. During the second switching interval $(1-D)*T_{SW,}$ switches Q1 and Q2 are turned off by the controller, allowing diodes D1 and D2 to conduct and deliver the energy stored in the inductor to the load.

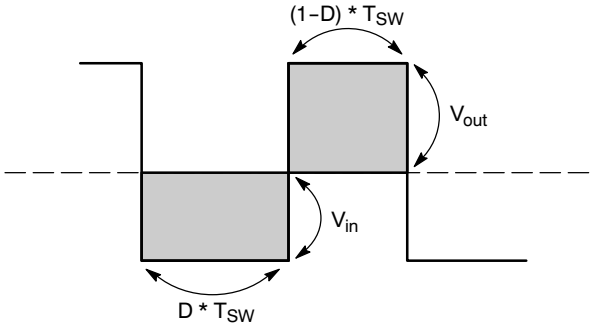

Figure 2. Voltage Waveform Across the Inductor

For the inductor flux (V*μs) to remain in equilibrium each switching cycle, the V*μs product across the inductor during each switch interval must balance (see Figure 4).

$$V_{in} \cdot D \cdot T_{SW} = V_{out} \cdot (1 - D) \cdot T_{SW} \quad \text{(eq. 1)}$$

Rearranging Equation 1 the voltage gain of buck boost is given by:

$$V_{out} = V_{in} \cdot \frac{D}{1 - D} \quad \text{(eq. 2)}$$

Varying the duty cycle will vary the output. When D is below 0.5, the converter is in buck mode, when D is above 0.5, the converter is in boost mode and when D equals 0.5, the voltage gain V_{out}/V_{in} is unity.

The ripple current in the inductor is given by expression

$$\Delta I_{L1} = \frac{V_{in} \cdot D \cdot T_{SW}}{L1} \quad \text{(eq. 3)}$$

For a typical design case, where V_{in} = 12 V and D^*T_{SW} = 0.5*5 μs, a value for L1 of 47 μH (Equation 3) will maintain ±30% ripple current in a 700 mA application, thereby ensuring CCM operation.

Key Component Selection

NTMS5P02 and NTMS4705N were selected from ON Semiconductor's portfolio of FETs for Q1 and Q2 respectively. NTMS5P02 is a −20 V, 5.4 A SO−8 satisfying the 16 V input requirement with a 26 mΩ $R_{DS(on)}$ at −4.5 V. Its gate charge characteristic is shown in Figure 3. NTMS4705N is a 30 V, 12 A SO−8 satisfying the 26 V output requirement with a 10.5 mΩ $R_{DS(on)}$ at 4.5 V. Its gate charge characteristic is shown in Figure 4.

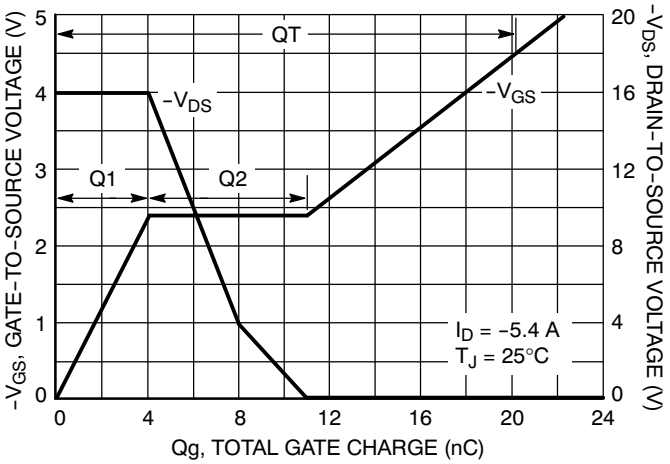

Figure 3. Gate charge characteristic of NTMS5P02

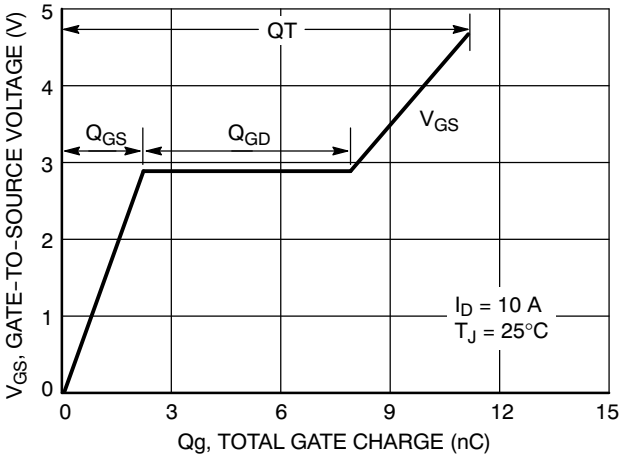

Figure 4. Gate Charge Characteristic

The controller used is ON Semiconductor's NCP3063. A functional block diagram is shown in the Figure 5.

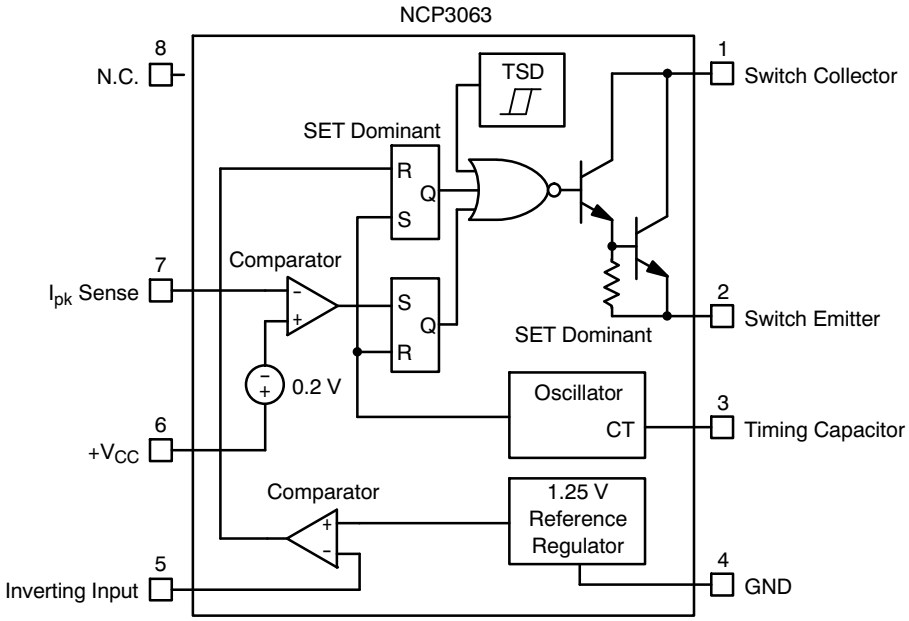

Figure 5. Block Diagram of NCP3063

This device consists of a 1.25 V reference, comparator, oscillator, an active current limit circuit, a driver and a high current output switch. In its traditional operating mode, the NCP3063 is a hysteretic, regulator that uses a gated oscillator to control the output. Voltage feedback from the output is sensed at pin 5, and gates the oscillator on/off to regulate the output. The oscillator frequency and off−time of the output switch are programmed by the value selected for the timing capacitor; C_T. C_T is charged and discharged by a 1 to 6 ratio internal current source and sink, generating a ramp at pin 3. The ramp is controlled by two comparators whose levels are set 500 mV apart. In normal operation, D is fixed at 6/7 or 0.86. In this application, the "gated oscillator" mode is only used to protect the LED string if a LED fails "open".

The NCP3063 can also operate as a conventional PWM controller, by injecting current into the CT pin. The control current may be developed either from the input source, providing voltage feedforward or from the output current sensing circuit. In either case, the slope of the oscillator ramp changes causing D to be modulated as shown in Figure 6.

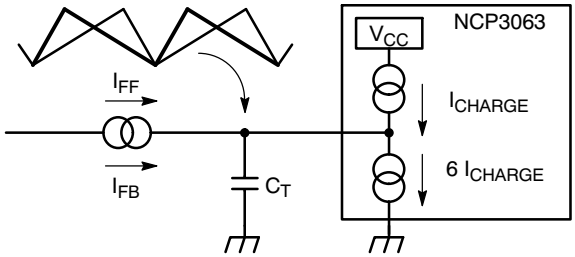

Figure 6. Current Injection into C_T Pin Providing Continuous Duty Cycle Modulation

Schottky Diode Selection

Schottky diodes have reverse leakage current which increases with reverse voltage and temperature. Hence it is important to select a device and package that will maintain the device temperature in the particular application to avoid thermal runaway. The effect is shown in Figure 7.

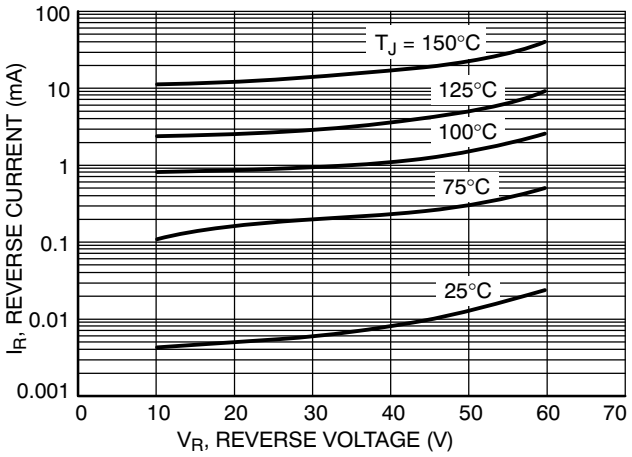

Figure 7. Reverse Leakage Characteristic of MBRD360

When the driver is in boost mode driving multiple LEDs, maximum power (20 watts) is delivered through diodes D1 and D2. Under these conditions D2 also has a high reverse voltage across it. In order to process 20 watts on a 1.5 in. x 2 in. demo board, MBRD340 was selected for D2.

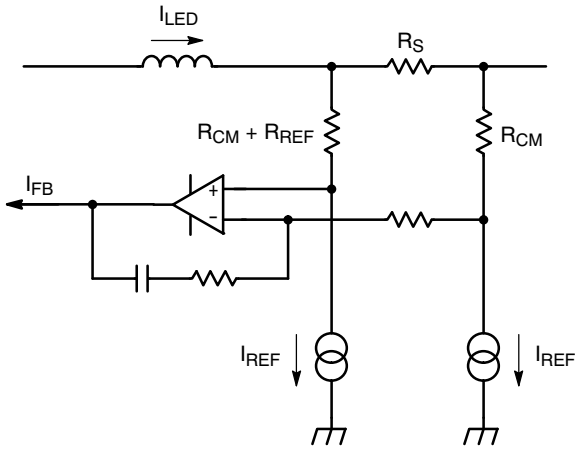

Figure 8. High Side Sensing Scheme

Referring to Figure 8, R_S is the high side current sensing resistor. Two equal currents generated by the current sinks designated I_{REF}, flow through resistors (R_{CM} + R_{REF}) and R_{CM}. The voltage I_{REF}*R_{CM} creates a level shift to satisfy the common mode input requirements of the operational amplifier inputs, whose supply is tied to V_{out}. The additional voltage drop I_{REF}* R_{REF} appearing at the non inverting input, creates a reference V_{REF} for the current sense circuit.

The output of the operational amplifier provides current injection into the Ct pin of controller U1. The operational amplifier may be compensated to provide a high closed loop gain to "force" I_{LED} to be equal to V_{REF} / R_S with high accuracy.

Power Stage Schematics

The schematic of the power stage is shown in Figure 9. When the output Darlington switch within U1 is turned on each switching cycle, the gate source terminals of Q1 and Q2 are connected in series across V_{in}. As illustrated in Figures 3 and 4, the gate charge characteristics of Q1 and Q2 will be different. Hence the gate to source voltages $V_{GS1/2}$ appearing at Q1 and Q3 will be defined by balancing the charge across each device. Hence V_{GS1}*Q_{T1} equals V_{GS2}*Q_{T2}. As this is dependent on device characteristics, a zener diode D1 is used to define the V_{GS1} of Q1. Then the V_{GS2} of Q2 is defined approximately by (V_{in}–V_{D1}) ignoring the drop in the output Darlington pair in U1. The gate losses in Q2 will increase with V_{in}, but this is preferable as the N channel device Q2 has half the total charge Q_T of the P channel device Q1. At the end of each switching cycle when the output switch within U2 turns off, small signal transistors Q2 and Q4 are activated to discharge the gate charge within 50 ns.

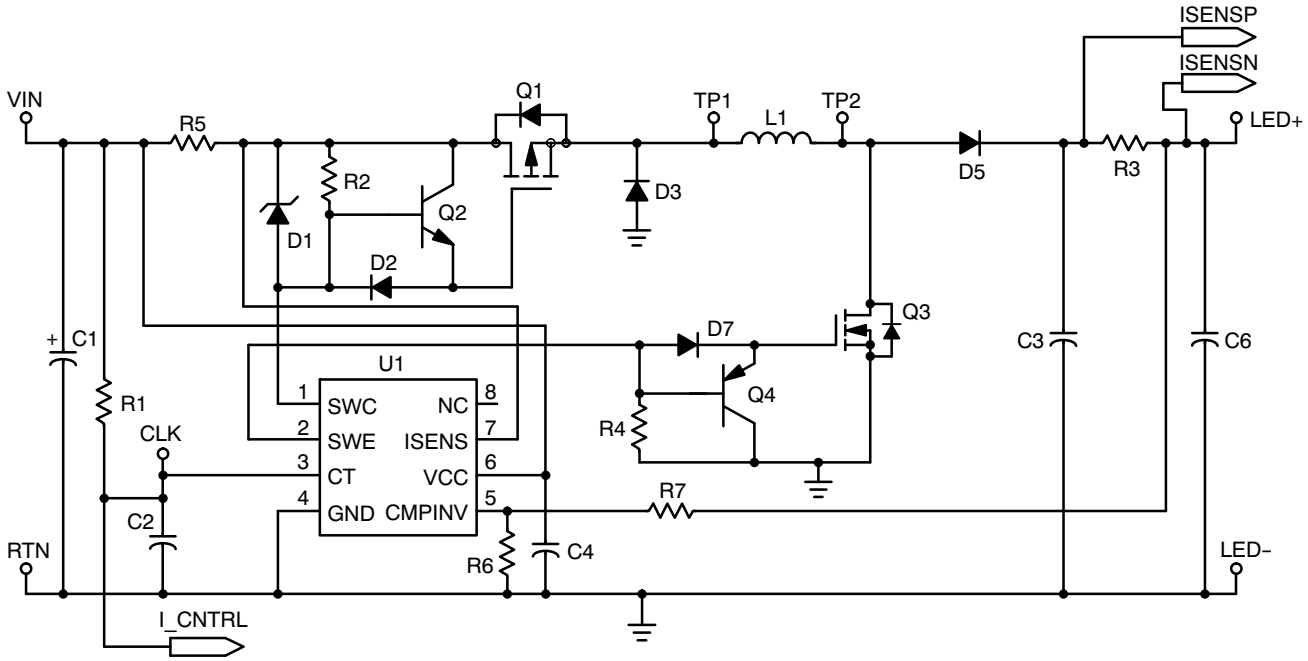

Figure 9. Schematic of Power Stage

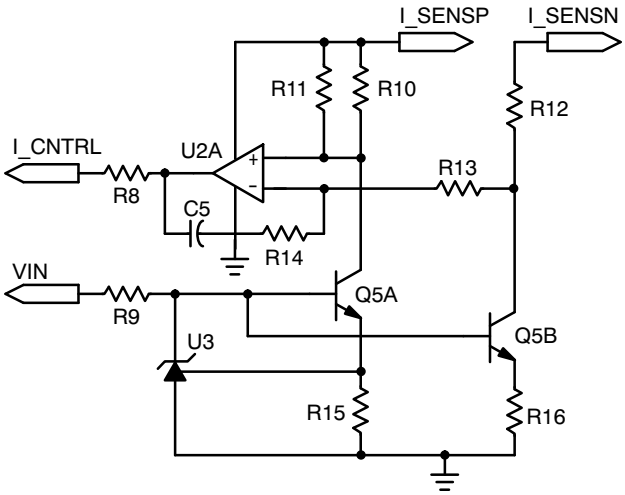

Figure 10. High Side Current Sensing Control Circuit

Note the parallel combination of R10 and R11 sets the V_{REF} for 700 mA operation. If the converter is required to regulate at a 1 A constant current, R11 is removed.

Converter Waveforms

The voltage waveforms at both the input (upper trace) and output (lower trace) of the inductor L1 were measured while the difference waveform (middle trace) gives the voltage across the inductor. Figure 11 shows the converter operating in buck mode, while Figure 12 illustrates boost operation.

The waveform shapes in Figures 11 and 12 are caused by the gate turn off delay associated with switch Q1. (Refer to application note AND8305/D for details.)

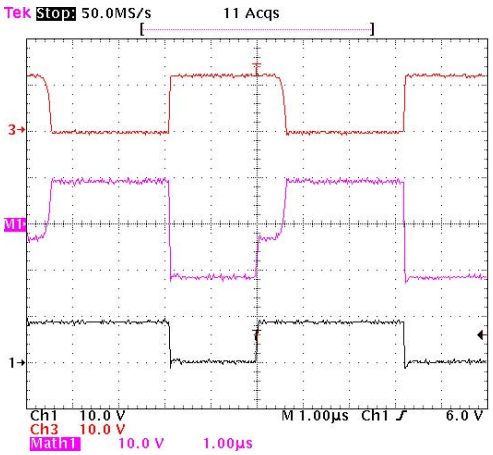

Figure 11. Buck Mode from 12 V_{in} to 8 V_{out}

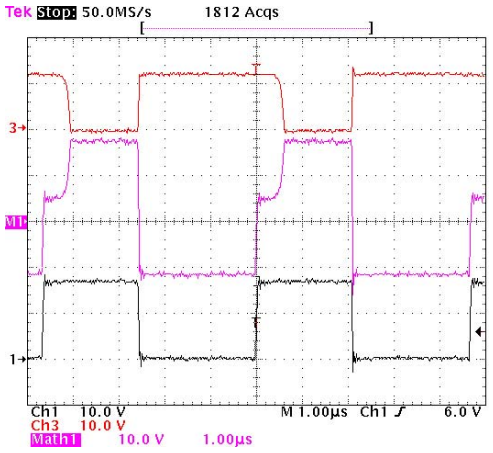

Figure 12. Boost Mode from 12 V_{in} to 16 V_{out}

Demo Board

The top side component layout of the NCP3063 buck boost demo board is shown in Figure 13.

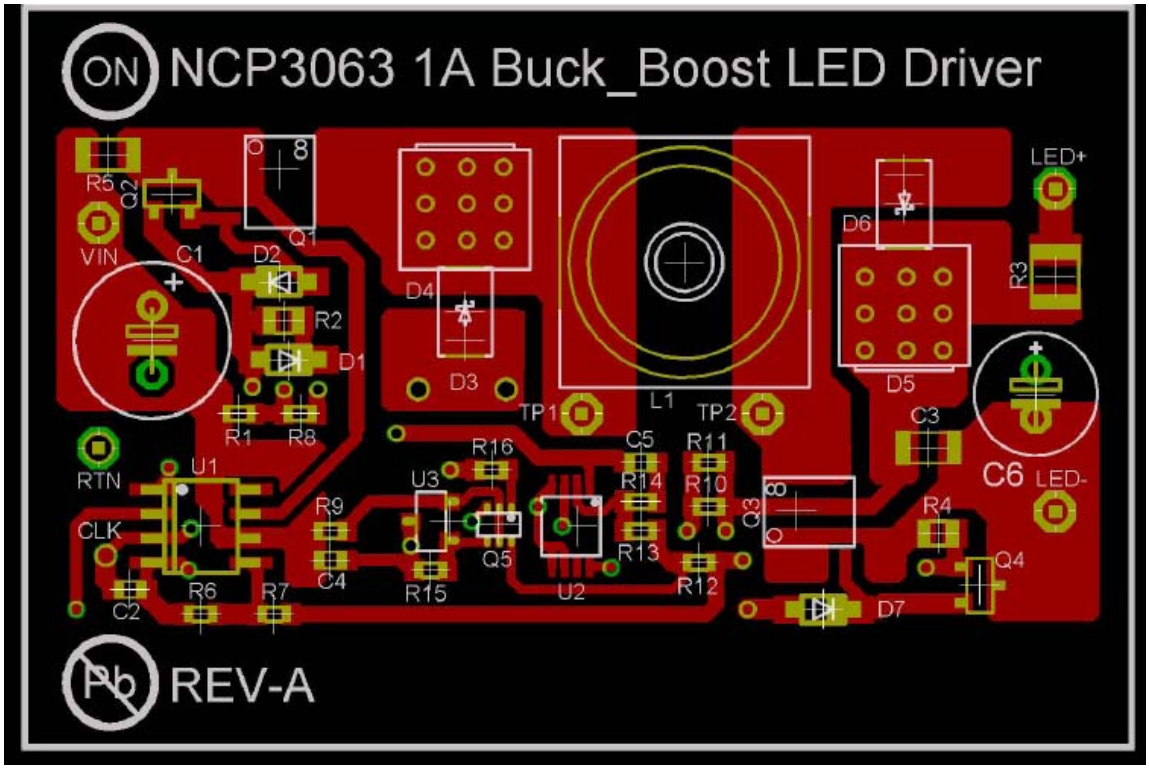

Figure 13. Top Side Component Layout

The bottom side copper layout is shown in Figure 14. Note that the copper pours mounting the power components Q1, Q2, D1, D2 and L1 have been maximized within the 1.5 in. x 2 in. footprint of the board. Also additional heat sinking for D1 and D2 has been created using bottom side copper islands and thermal vias.

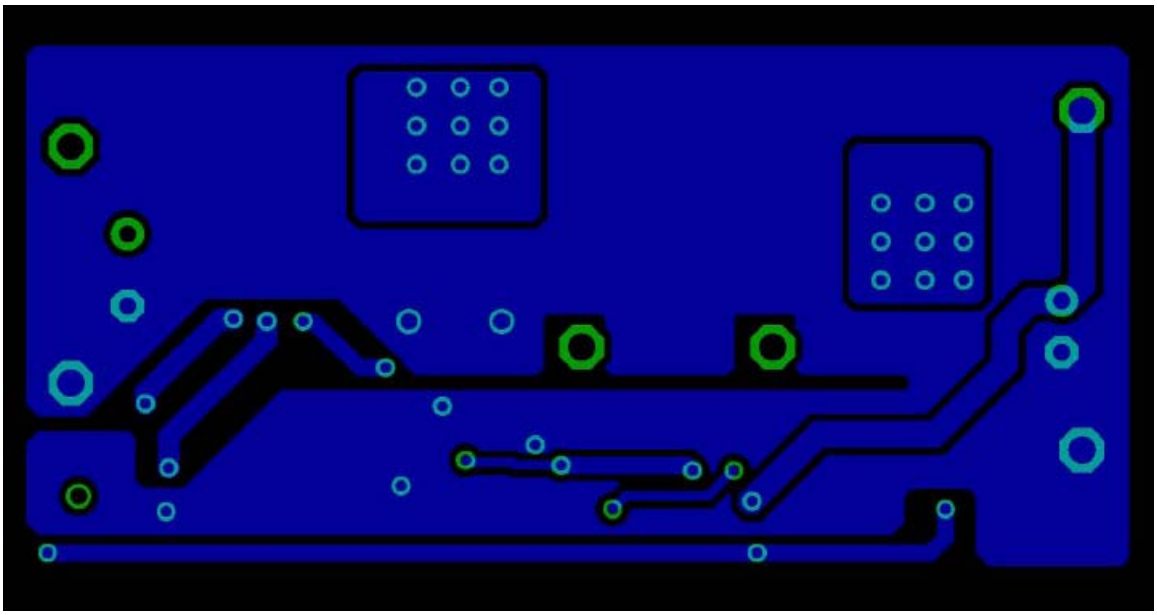

Figure 14. Bottom Side Copper

Test Data

A 12 V source is connected between VIN (positive) and RTN (negative) and the LED string, consisting of 3 to 6, 700 mA rated devices are connected across LED+ and LED−.

Efficiency data, measured over an extended overlapping input and output voltage range, is shown in Figure 15.

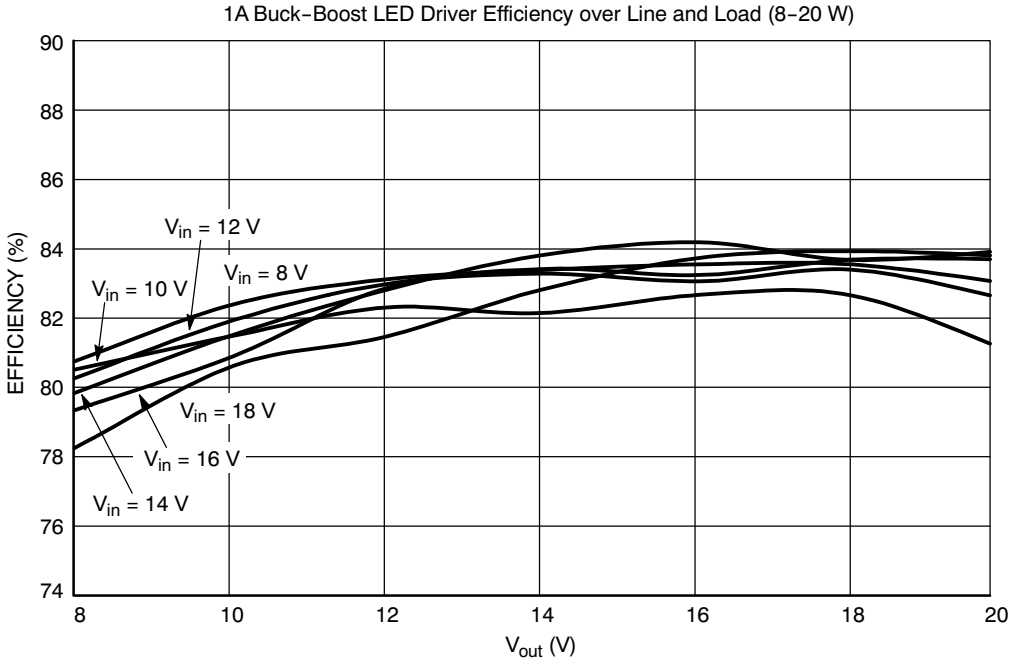

Figure 15. Efficiency Data Over Extended Input and Output Voltage Range

The BOM for the NCP3063 buck_boost demo board is given in Table 2. Generic resistors and capacitors are referenced by Digi−Key part numbers.

Table 2. BOM for NCP3063 1 A Buck_boost LED Driver

Designator	Quantity	Manufacturer	Manufacturer Part Number
U1	1	ON Semiconductor	NCP3063DR2G
U2	1	ON Semiconductor	NCV2904DMR2G
U3	1	ON Semiconductor	TLV431ASN1T1G
Q1	1	ON Semiconductor	NTMS5P02
Q2	1	ON Semiconductor	MMBT3904LT1G
Q4	1	ON Semiconductor	MMBT2907ALT1G
Q3	1	ON Semiconductor	NTMS4705NR2G
Q5	1	ON Semiconductor	MBT3904DW1T1G
D1	1	ON Semiconductor	MMSZ4686T1G0SCT−ND
D2/D7	1	ON Semiconductor	MMSD914T1G
D4/D6	1	ON Semiconductor	MBRD340T4G
C1	1	330 μF/16 V	493−1042−ND
C2	1	3900 pF/50 V	478−1222−2−ND
C3	2	10 μF/25 V	490−3373−2−ND
C4	1	1 μF/25 V	587−1248−2−ND
C5	1	0.22 μF/50 V	490−1569−2−ND
C6	1	47 μF/25 V	P834−ND
R1	0	Do not insert	NA
R3	1	IRC	LRC−LR1206−01−R200−F
R4	1	3.32 k/0603	P3.32KHTR−ND
R5	1	IRC	LRC−LR1206−01−R050−F
R2/R6/R15/R16	4	1.21 k/0603	P1.21KHTR−ND
R7	1	24.3 k/0603	P24.3KHTR−ND
R8	1	2.00 k/0603	P2.00KHTR−ND
R9/R13/R14	3	4.75 k/0603	P4.75KHTR−ND
R10	1	4.42 k/0603	P4.42KHTR−ND
R11	0	324 k/0603	P324KHTR−ND
R12	1	4.22 k/0603	P4.22KHTR−ND
L1	1	TDK	SLF12575T−680M2R0−PF

PUBLICATION ORDERING INFORMATION

LITERATURE FULFILLMENT:
Literature Distribution Center for ON Semiconductor
P.O. Box 5163, Denver, Colorado 80217 USA
Phone: 303−675−2175 or 800−344−3860 Toll Free USA/Canada
Fax: 303−675−2176 or 800−344−3867 Toll Free USA/Canada
Email: orderlit@onsemi.com

N. American Technical Support: 800−282−9855 Toll Free USA/Canada
Europe, Middle East and Africa Technical Support:
Phone: 421 33 790 2910
Japan Customer Focus Center
Phone: 81−3−5773−3850

ON Semiconductor Website: **www.onsemi.com**

Order Literature: http://www.onsemi.com/orderlit

For additional information, please contact your local Sales Representative