ON Semiconductor

Design Note – DN06018/D

12V or 24Vin DC, Constant Current LED Driver

Device	Application	Input Voltage	Output Power	Topology	I/O Isolation
CS51411 NCV51411	Constant Current LED Driver	12 V or 24 V DC	Up to 4 W	Buck	None

Other Specifications				
	Output 1	Output 2	Output 3	Output 4
Output Voltage	3.6 V nom	N/A	N/A	N/A
Ripple	20 mV	N/A	N/A	N/A
Nominal Current	700 mA	N/A	N/A	N/A
Max Current	1 A	N/A	N/A	N/A
Min Current	N/A	N/A	N/A	N/A

PFC (Yes/No)	No
Cooling Method/Supply Orientation	Convection

Circuit Description

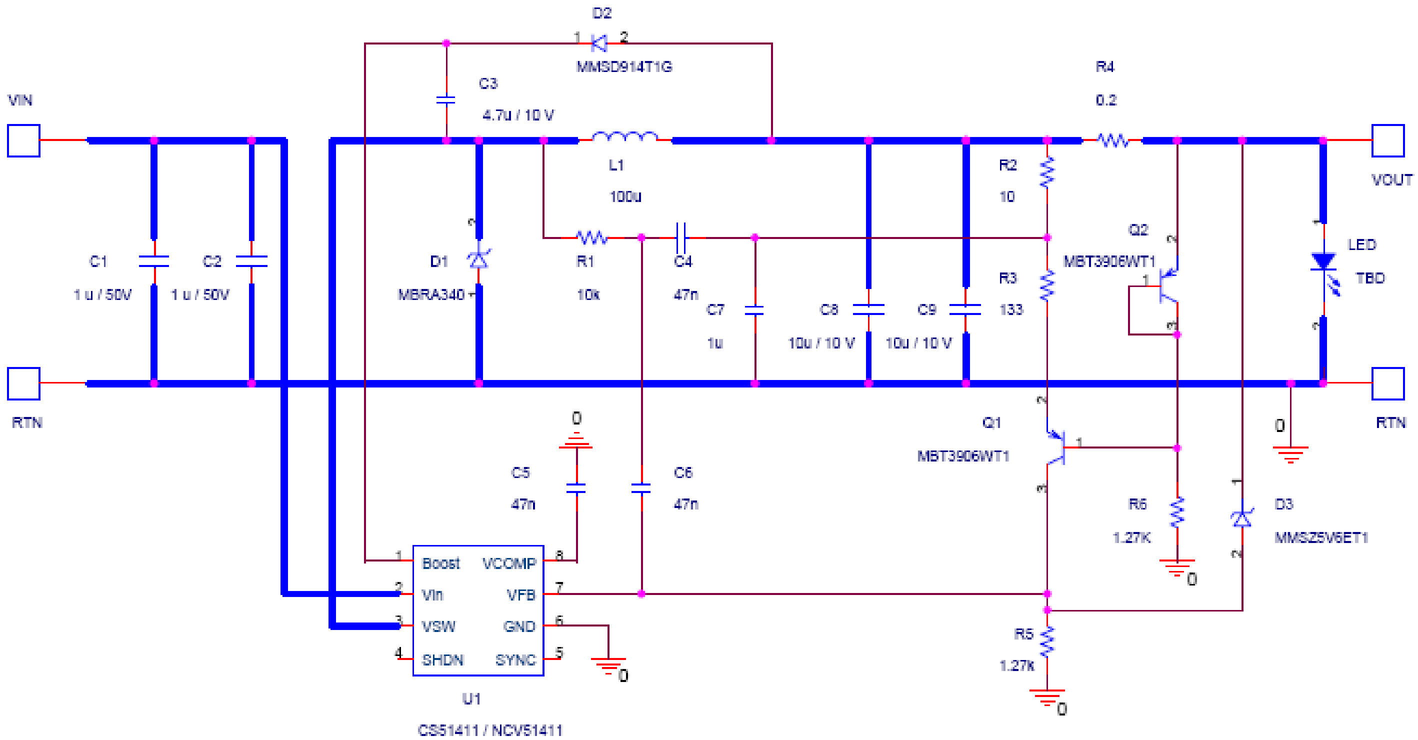
ON Semiconductor's latest monolithic NCV51411 (CS51411) converter is to be used in a buck topology optimized to drive a single LED at a constant current between 350 mA to 1 Amp.
A high side, low drop, current sensing scheme has been implemented, targeted for automotive and other high efficiency applications.
DCR Inductor current sensing is used to generate the control ramp required for the V2 controller.

Key Features

- Constant current output with voltage clamp
- Low drop high side current sensing
- High frequency (260 kHz / 520kHz*) operation to enable cost effective magnetic and capacitive (e.g. MLCC) filter components
- Minimal ripple current through LED
- High side sensing allows LED cathode to be directly connected to system ground

*CS51413 supports 520 kHz operation

Schematic



Design Notes

This design note targets a constant current (350mA to 1 A) driver suitable for driving a single LED (1 watt or 3 watts) from a nominal 12 V or 24 V dc source. The output voltage range assumes a single White/Blue/Green LED with a forward voltage of 3.6 +/- 35%. The converters used in the design are from ON Semiconductor's CS5141x family; the CS51411 in a SOIC-8 and is offered in two ambient temperature ranges (0-70 C or -40-85C) while the NCV51411 is specifically intended for automotive applications and is specified for junction temperatures up to 125 C. The schematic above shows the pin out of the SOIC-8. Refer to the data sheet at the On Semiconductor web site for the pin out for other package options such as the NCV51411 DFN package.

Theory of Operation

For low ripple current in the inductor and through the LED, this design is based around Continuous Conduction Mode (CCM) operating mode. The switch within the controller turns on for time D*Ts (D duty cycle, Ts switching period) charging inductor L1 through the voltage differential (VIN–VOUT). When the switch is turned off by the feedback signal, diode D1 conducts and delivers the energy stored in the inductor to the output VOUT.
For the inductor flux (volt microsecond) to remain in equilibrium each switching cycle, (VIN-VOUT)*D*Ts must equal VOUT*(1-D)*Ts neglecting circuit losses. Hence the voltage gain of buck is given by the expression VOUT = D*VIN.

Power Components

The NCV/CS51411 has a switching frequency of 260 kHz equivalent to a switching period Ts = 3.85uS
For a nominal 12 V input to 3.6 V output, the duty cycle D = 3.6 / 12 = 0.3

Output Inductor Selection

Ripple current in the inductor is obtained from the expression ∂ I (L1) = VIN*TS*D*(1-D) / L1.
A value for L1 of 47 uH will maintain +/-15% ripple current in the 700 mA application (3 watt LED) discussed below.

Freewheel Diode D1

The MBRA340 Schottky diode has a forward drop of 300 mV at a forward current of 0.7A. Power loss is (1-D)*I (L1)* VD1 This equates to a power loss of 150mW in this application.

Boost Diode D2

Diode D2 and MLCC C3, across the inductor L1, form a simple boost circuit to supply base current to drive the high side BJT in the controller. C3 is charged to VOUT during each switching period (1-D)*TS, when the freewheeling diode D1 is conducting.

Input/Output Capacitors

The input/output capacitors used for the application are MLCC capacitors in a 1206 or a 0805 SMT package. Low value MLCC capacitors (10 uF) have very small esr (2 milliohms) and esl (100 nH) values. When combined in parallel combinations they form the "perfect" capacitor. Consequently the ripple voltage across them is due only to charging and discharging of the capacitor by the inductor ripple current.
The ripple voltage across the input capacitor = 0.5*D*TS*∂ I (L1) / Cin. For Cin = 2*1 uF, input voltage ripple = 60mV p/p
The ripple developed across the output capacitors = 0.5*(1-D)*TS*∂I (L1) / Cout. For Cout = 2*10 uF, output ripple = 15mV p/p.
Note the actual value of a MLCC decreases with dc voltage applied. Therefore it is recommended to have a voltage stress de-rating factor of 50% on each component. Hence a 50 V rating is suggested for the 24V application and a 6.3 V is recommended across the 3.6 V output. Depending on the maximum Vf of the LED, this output capacitor rating should be increased to 10 V.

Current Sensing Circuitry

Driving a single LED will produce a voltage VOUT at the converter's output of approximately 3.6 volts. This voltage will vary with device and temperature effects. If a sensing scheme using a 0.6 V (BJT base emitter junction) or higher voltage reference is used, the converter's conversion efficiency can be seriously degraded. For example if a sense resistor is placed across a Vbe junction for current sensing, the efficiency will be degrade by 17%. Also in automotive applications, high side current sensing is preferred because in an automobile the chassis is used for ground returns.

In this design, low drop, cost effective, high side current sensing is achieved by the transistor pair of Q1 and Q2 and resistors R2, R3, R4, R5 and R6. The feedback pin under normal operation is maintained at 1.27 volts, equal to the controller U1's internal reference. Consequently a constant current of 1.27 V / 1.27 k or 1 mA flows through R2, R3, Q1 and R5. The voltage across R2 + R3 = (R2+R3)*1mA or 140 mV. The output LED current is sensed by sense resistor R4, which in turn develops a voltage ILED*R4 across it. The current regulation point is determined when the equation ILED = (1.27/R5)*{(R2+R4) / R5} is satisfied. For the values chosen ILED = 1mA * (140/0.2) or 700 mA. Above 700 mA, the current mirror, consisting of Q2 and R6 will cause additional current to flow in Q1. The increase in voltage at the feedback pin VFB will cause the duty cycle to reduce to limit the current at the designed set point. It is worth noting that even though the ripple current in the inductor is 200 mA, this is diverted into the output capacitor bank. The ripple current in the LED itself is an order of magnitude less determined by the ratio of the LED's dynamic impedance to the output capacitor's impedance at the 260 kHz switching frequency.

The LED current can be varied from 350mA to 1 amp by scaling the value of either R3 or R4.

Control Circuitry

The error amplifier in the V2 controller U1 is a trans-conductance amplifier having several megohms of output impedance. Adding a small capacitor C5 to ground at its output VCOMP will provide a low frequency pole at 20 Hz. This pole will filter the feedback signal providing a dc error signal to one input of the PWM inside the controller. The V2 control architecture requires a control ramp to be included with the dc feedback information on the feedback pin VFB. This signal is passed directly to the other input of the PWM. When the dc error signal and dc feedback plus ramp intersect, the switch cycle is terminated, thereby allowing modulation of the duty cycle D to occur.

In this application, this control ramp is generated from indirectly sensing the current flowing in the inductor's DCR winding resistance. When an integrating network consisting of R1, C4 is placed across the output inductor L1, the voltage developed across the integrating capacitor C4 is given by the equation below.

$\partial V (C4) = VIN*TS*D*(1-D) / R1*C4$

Assuming the inductor winding resistance is dcr, the voltage across this dcr resistance ∂V (dcr) is given by the following equation.

$\partial V (dcr) = VIN *TS*D*(1-D)*dcr / L1$

It is apparent the two expressions are equal if the integrator's time constant R1*C4 is matched to the inductor's time constant L / dcr. At this point in the design, we can select the output inductor L1 to be a TDK SLF10145T-470M1R4. This is a 47uH inductor with a dcr of 0.1 ohms and a saturation current of 1.4 Amps. Its time constant is 470 uS. If we select R1 as 10k and C4 equal to 47nF we match the 470 uS time constant. Our control ramp is the inductor current. Its amplitude is calculated from the ∂V (C4) equation as 21 mV. Alternatively a Coilcraft inductor DO3316P-473 having a larger 0.14 ohm dcr could be selected. In order not to degrade this ramp with switching ripple from the output, the filter network R2, C6 is recommended. Finally the capacitor C5 is used to ac couple the current control ramp to the feedback pin VFB.

In the event of an open circuit output condition, such as the case if the output LED failed open, zener diode D3 conducts to limit the output voltage to Vz + 1.27 volts. In the application, the voltage clamp is designed to operate at 6.9 V.

Bill of Materials

U1	Buck Controller SO-8 ON Semiconductor CS51411
	Buck Controller 18 lead DFN ON Semiconductor NCV51411
D1	1 A 40 V Schottky SOD123 ON Semiconductor MBR140SFT1G (350mA)
	3 A 40 V Schottky SMA ON Semiconductor MBRA340 (700mA)
D2	0.2 A 100 V Diode SOD 123 MMSD914T1G
D3	5.6 V Zener SOD123 ON Semiconductor MMSZ5V6ET1
L1	47 uH output inductor
	0.14 ohms 1.6 A Isat Coilcraft DO3316P-473
	0.10 ohms 1.4 A Isat TDK SLF10145T-470M1R4
Q1, Q2	-0.2 A -40V Dual PNP array SOT363 ON Semiconductor MBT3906WT1
C1, C2	1 uF 50V 1206 X7R muRata GRM31MR71H105K
C3	4.7 uF 10 V 0805 MLCC TDK C2012X%R1A475M
C4, C5, C6	47 nF 0603 MLCC Vishay VJ0603Y473KXXA
C7	1 uF 16 V 0603 MLCC TDK C1608X5R1C105M
C8.C9	10 uF 6.3 V 0805 MLCC Taiyo Yuden JMK316BJ106ML-T
R1	10k 0603 Vishay CRCW06031002F
R2	10 0603 Vishay CRCW060310R0F
R3	133 0603 Vishay CRCW05031330F
R4	0.2 1206 TT electronics IRC LRC-LR1206-01-R200-F
R5, R6	1.27k 0603 Vishay CRCW06031271F

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