Buck-Boost-based LED Drivers using the HV9910/HV9910B

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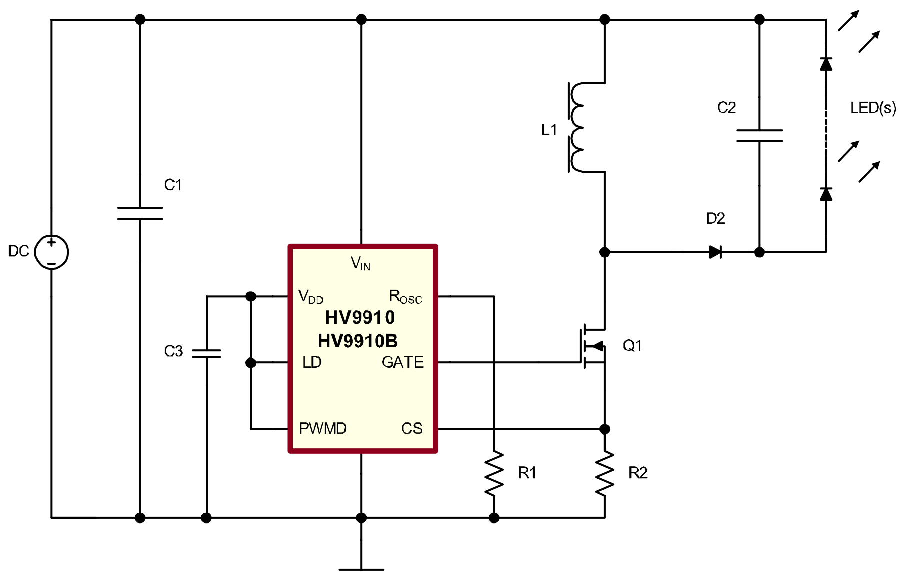
Buck-boost (or Flyback) converters are an excellent choice for LED drivers in low voltage applications as they can drive LED strings with voltages both above and below the input voltage. In the case where the nominal LED string voltage is close to the nominal input voltage, a buck-boost converter would be an good solution given that the variations in the LED forward voltages can make the string voltage either higher or lower than the input voltage. A peak-current-controlled, dis-continuous mode, buck-boost converter can inherently reject input voltage variations and maintain tight line voltage regulation over a wide input voltage range. Coupled with the fact that these converters can be easily designed to operate at efficiencies greater than 85%, the buck-boost-based driver becomes an excellent solution to drive a string of High Brightness LEDs from low input voltages, such as a battery or automotive accumulators.

The discontinuous mode buck-boost converter has two noticeable drawbacks. The topology is a constant power converter, which means that it maintains a constant input power when input voltage and/or output voltage vary. A change in the LED parameters due to any reason, such as using other types of LEDs, will reflect on the steady-state LED current. Also, an open LED condition causes excessive voltages at converter output and can damage the converter. The Appendix to this Application Note describes an optional circuit that works with the HV9910/HV9910B to correct these drawbacks.

The Supertex HV9910/HV9910B provides low-cost, low component count solutions to implement discontinuous mode buck-boost converters. They have two current sense threshold voltages – a fixed 250mV that can be overdriven by an external voltage at the LD pin, pulling down the threshold voltage below the fixed 250mV level. The low sense voltages allow the use of a low value current sense resistor. The IC operates down to 8V input, which makes it usable from any 9V or 12V input. It also has an internal linear regulator that supplies power to the IC from the input voltage, eliminating the need for an external power supply. It is capable of driving the external FET directly, without the need for additional costly driver circuitry. Linear or PWM dimming can also be easily implemented using HV9910/HV9910B.

Circuit Diagram



Input Voltage:
$V_{in,\,min}$ = 9V
$V_{in,\,max}$ = 16V

LED string voltage
(a string of 4 white 350mA LEDS)
$V_{o,\,min}$ = 10V
$V_{o,\,max}$ = 16V

LED Current:
$I_{o,\,max}$ = 350mA

Expected Efficiency:
$\varkappa$ = 0.85

This Application Note discusses the design of a buck-boost-based LED driver using HV9910/HV9910B in 12V DC input voltage design example.

Step 1: Switching Frequency and resistor (R1)
The switching frequency determines the size of the inductor L1. A larger switching frequency will result in a smaller inductor, but will increase the switching losses in the circuit. A typical switching frequency $f_S = 100kHz$ is a good compromise. From the HV9910 datasheet, the oscillator resistor needed to achieve this is $228k\Omega$.

Step 2: Choose the Inductor (L1)
The inductor value should be computed based on the worst case conditions – minimum input voltage and maximum output power.

At minimum input voltage, the average input current is:

$$\overline{I_{in,\max}} = \frac{V_{o,\max} \times I_{o,\max}}{V_{in,\min} \times \eta} \quad (1)$$

The inductor L1 can then be computed using:

$$L1 = \frac{0.32 \times V_{in,\min} \times V_{o,\max}^2}{\overline{I_{in,\max}} \times \left(V_{in,\min} + V_{o,\max}\right)^2 \times f_s} \quad (2)$$

In this example,

$$\overline{I_{in,\max}} = 0.732A \quad and \quad L1 = 16.11\mu H.$$

The closest typical inductor value is 15μH. However, before an inductor is chosen, it is better to compute the peak and rms currents through the inductor.

Step 3: Compute the currents in the circuit
The maximum on-time of the switch is given by:

$$t_{on,\max} = \sqrt{\frac{2 \times \overline{I_{in,\max}} \times L1}{f_s \times V_{in,\min}}} \quad (3)$$

The peak inductor is:

$$I_{pk} = \frac{V_{in,\min} \times t_{on,\max}}{L1}. \quad (4)$$

The off-time is given by:

$$t_{off} = \frac{L1 \times I_{pk}}{V_{o,\max}} \quad (5)$$

The rms value of the inductor current can be computed as:

$$I_{rms} = I_{pk} \times \sqrt{\frac{(t_{on,\max} + t_{off}) \times f_s}{3}} \quad (6)$$

For this example, $t_{on,\max} = 4.94\mu s$, $t_{off} = 2.78\mu s$, $I_{pk} \approx 3A$ and $I_{rms} = 1.5A$

Note: *If the circuit given in the Appendix (Page 4) has not been implemented, compute $t_{off,\max}$ using equation (5) and substituting $V_{o,\max}$ by $V_{o,\min}$. Make sure that $(t_{on,\max} + t_{off,\max}) \times f_s$ < 1. If not, the design would not work properly in the condition of low input voltage and low output voltage. Reducing the value of the inductor and re-computing equations (3) – (6) till the condition is met enables the circuit to function properly. However, the output current at the minimum output voltage is now 560mA. The external circuit described in the Appendix controls the current to be held at 350mA.*

Choose a 15μH, 3.3A(peak), 2A(rms) inductor.

Step 4: FET (Q1) and Diode (D2)
The peak voltage seen by the FET is equal to the sum of maximum input and output voltage. Using a 20% safety rating,

$$V_{FET} = 1.2 \times \left(V_{in,max} + V_{o,max}\right) = 38V \quad (7)$$

The maximum rms current through the FET is:

$$I_{FET} = I_{pk} \times \sqrt{\frac{t_{on,\max} \times f_s}{3}} = 1.2A \quad (8)$$

Typically a FET with about 3 times the current is chosen to minimize the resistive losses in the switch.

For this application, chose a 40V, 3A FET.

The peak voltage rating of the diode is the same as the FET. Hence,

$$V_{diode} = V_{FET} = 38V \quad (9)$$

The average current through the diode is:

$$I_{diode} = 0.5 \times I_{pk} \times t_{off,max} \times f_s = 0.417A. \quad (10)$$

Choose a 50V, 1A schottky diode.

Step 5: Sense Resistor (R2)
The sense resistor value is given by:

$$R2 = \frac{0.25}{I_{pk}} \quad (11)$$

if the internal voltage threshold is being used. Otherwise, substitute the voltage at the LD pin instead of the 0.25V in equation (11).

For this design, R2 is a parallel combination of two 0.18Ω, 1/4W resistors**.**

Note: *Capacitor C3 is a bypass capacitor. A typical value of 1µ to 2.2µF, 16V is recommended.*

Step 6: Choose the Output Capacitor C2
The output current of the buck-boost converter is not continuous like the buck topology. Hence, to assure continuous current via the LED string, it needs to be filtered. Before the output filter capacitor can be chosen, the dynamic impendence of the LED string must be known.

When using most common 350mA high-brightness LEDs, the approximate dynamic resistance of the LED string $R_{LED} = 4\Omega$.

Assuming a peak-to-peak LED current ripple of about 40% of $I_{o,\max}$, the required capacitance is:

$$C2 = \frac{I_{pk} \times t_{off,\max}}{2 \times R_{LED} \times 0.4 \times I_{o,\max}} \quad (12)$$

The voltage rating of the capacitor should be greater than the maximum LED string voltage.
Note: The capacitors chosen should be low ESR capacitors. In case of multi layered ceramic capacitors, the capacitance value drops with the bias voltage. X7R capacitors drop by only 20% at full rated value and are a good choice for this application.

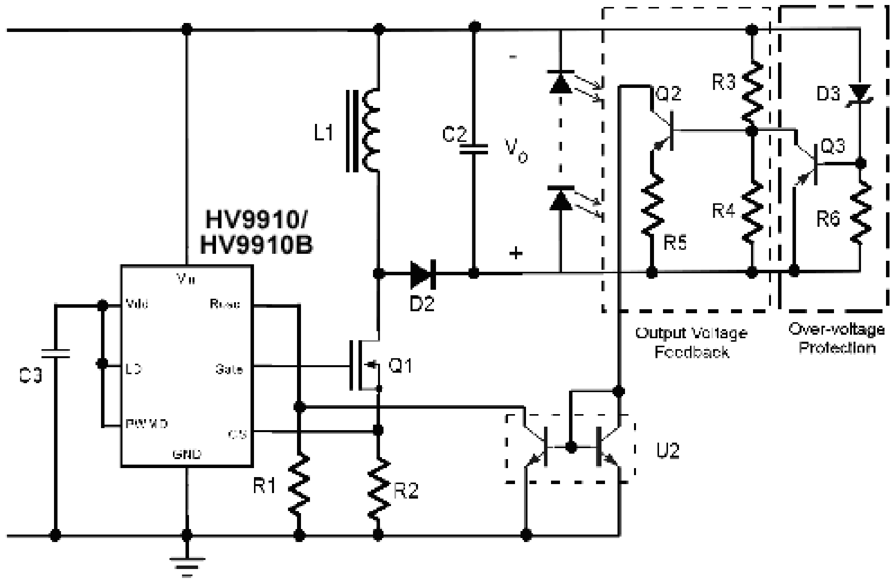
In this case, $C2 = 7.45\mu F$. Use a parallel combination of two 4.7µF ceramic capacitors, rated at 25V.

Step 7: Choose the Input Capacitor C1
To compute C1, assume a peak-to-peak ripple in the input voltage of $V_{in,pp} = 1V$. Then, the capacitance required is:

$$C1 = \frac{I_{pk} \times t_{on,\max}}{2 \times V_{in,pp}} \quad (13)$$

In this case, C1 is a 10µF, 25V ceramic capacitor.

Appendix



In a Buck-boost converter without the output voltage feedback, the output current is proportional to the ratio of the switching frequency to the output voltage. The feedback circuit makes the switching frequency proportional to the output voltage making the LED current constant over varying LED string voltages.

1. Set R1 to be 10MΩ. This sets the minimum operating frequency to be about 2.5kHz, and the circuit will draw about 0.2W at no load.

2. Set R3=R4=10kΩ. Thus, the voltage at the midpoint of the divider formed by R3 and R4 will be between 5-8V.

3. At 16V output voltage, the required switching frequency is 100kHz (to obtain maximum power output). Thus, the current drawn from the R_{osc} pin of the IC must be

$$I_{osc} = \frac{6.4}{\frac{25000}{f_{osc}[kHz]} - 22}[mA]$$

In this case, $I_{osc} = 28\mu A$

4. U2 is a 1:1 current mirror formed by using a matched transistor pair. R5 sets the current drawn from R_{osc} and should be designed accordingly.

$$R5 = \frac{\frac{V_{o,max}}{2} - V_{be}}{I_{osc}}$$

Here, $R5 = 235k\Omega$.

5. In case of an open LED condition, D3 conducts, biasing Q3. This makes the current through R5 zero causing the converter to operate at its lowest frequency of 2.5kHz. Using a 22V, 350mW zener diode (the power rating of the diode must be greater than the minimum power of 0.2W), the current through D3 will be $I_{D3} = 9mA$. R6 must be designed such that the voltage drop across R3 at 9mA will bias Q3.

$$R6 = \frac{V_{be}}{I_{D3}}$$

For this circuit, R6=82Ω.

6. With this additional circuit, the converter switching frequency will vary from 100kHz at 16V output to about 60kHz at 10V output. The circuit will also have an open circuit protection limiting the output voltage to about 23V.

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