Buck Converter
12S - 5V at 3A

We are required to create a buck converter that steps down voltage from the 12S range (36V to 50.4V) to 5V at 3A.

This is a high voltage input. Therefore, I will be using LMR16030SDDAR as the IC. This IC functions as a high-speed on/off switch which is needed for a buck converter. This is mainly used for the calculation of the Duty Cycle, which is a percentage of time the switch is on.

2 Calculate the Maximum Switch Current

The first step to calculate the switch current is to determine the duty cycle, D, for the maximum input voltage. The maximum input voltage is used because this leads to the maximum switch current.

$$\text{Maximum Duty Cycle: } D = \frac{V_{OUT}}{V_{IN(\max)} \times \eta}$$

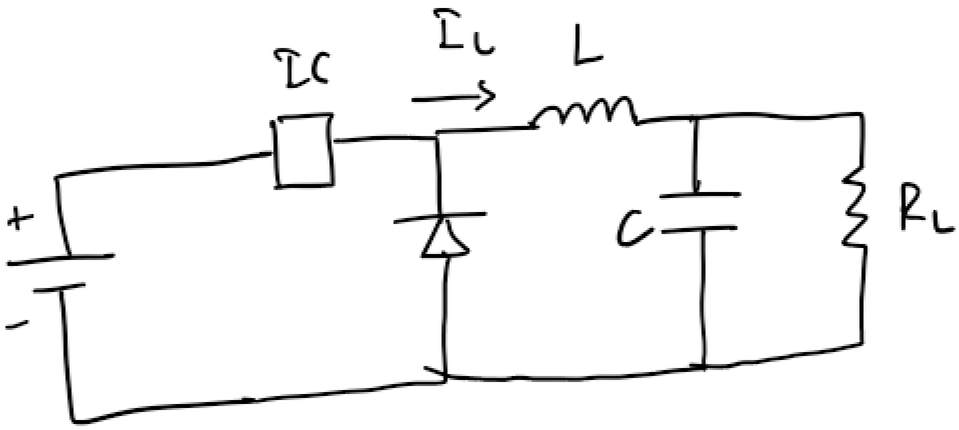
$V_{IN(max)}$ = maximum input voltage
V_{OUT} = output voltage

[1] 'Basic calculation of a Buck Converter's Power Stage' by Texas Instruments.

Efficiency of the converter is estimated to be 90%. [1]
$V_{out} = 5V$
$V_{in} = 50.4V$ (max)

$$D = \frac{5}{50.4 \cdot 0.9} = 0.11$$

Duty Cycle = 0.11



Buck Converter Topology

ΔI_L = 30% of max output (3A)

$\therefore \Delta I_L = (0.3)(3) = 0.9A$

3 Inductor Selection

Data sheets often give a range of recommended inductor values. If this is the case, choose an inductor from this range. The higher the inductor value, the higher is the maximum output current because of the reduced ripple current.

In general, the lower the inductor value, the smaller is the solution size. Note that the inductor must always have a higher current rating than the maximum current given in Equation 4; this is because the current increases with decreasing inductance.

For parts where no inductor range is given, the following equation is a good estimation for the right inductor:

$$L = \frac{V_{OUT} \times (V_{IN} - V_{OUT})}{\Delta I_L \times f_S \times V_{IN}}$$

2. Image from ‘Basic calculation of a Buck Converter’s Power Stage’ by Texas Instruments. [1]

F_{sw} = 500kHz (for the specific IC)

$$L = \frac{5 \cdot (50.4 - 5)}{(0.9)(500 \times 10^3)(50.4)}$$

$\therefore L = 10\mu H$

$\therefore$ We will use $15\mu H$ (higher end)

4 Rectifier Diode Selection

To reduce losses, use Schottky diodes. The forward current rating needed is equal to the maximum output current:

$$I_F = I_{OUT(max)} \times (1 - D) \tag{7}$$

I_F = average forward current of the rectifier diode
$I_{OUT(max)}$ = maximum output current necessary in the application

Schottky diodes have a much higher peak current rating than average rating. Therefore the higher peak current in the system is not a problem.

$$I_F = 3 \cdot (1 - 0.11)$$

$\therefore I_F = 2.67$

$I_F = 2.67A$

5 Output Voltage Setting

Almost all converters set the output voltage with a resistive divider network (which is integrated if they are fixed output voltage converters).

With the given feedback voltage, V_{FB}, and feedback bias current, I_{FB}, the voltage divider can be calculated.

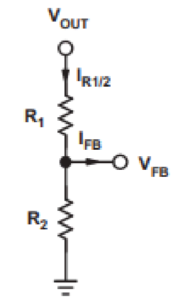


Figure 2. Resistive Divider for Setting the Output Voltage

The current through the resistive divider needs to be at least 100 times as big as the feedback bias current:

$$I_{R1/2} \geq 100 \times I_{FB} \tag{9}$$

$I_{R1/2}$ = current through the resistive divider to GND
I_{FB} = feedback bias current from data sheet

This adds less than 1% inaccuracy to the voltage measurement and for the calculation of the feedback divider, the current into the feedback pin can be neglected. The current also can be a lot higher. The only disadvantage of smaller resistor values is a higher power loss in the resistive divider, but the accuracy is increased a little.

With the preceding assumption, the resistors are calculated as follows:

$$R_2 = \frac{V_{FB}}{I_{R1/2}} \tag{10}$$

$$R_1 = R_2 \times \left(\frac{V_{OUT}}{V_{FB}} - 1 \right) \tag{11}$$

R_1,R_2 = resistive divider, see Figure 2.
V_{FB} = feedback voltage from the data sheet
$I_{R1/2}$ = current through the resistive divider to GND, calculated in Equation 9
V_{OUT} = desired output voltage

From the Datasheets of the IC,
$V_{FB} = 0.75V$

$$R_1 = R_2 \cdot \left[\frac{V_{out}}{V_{FB}} - 1 \right]$$

$R_2 = 10k\Omega$ (known)

$$\therefore R_1 = 10k \left[\frac{5}{0.75} - 1 \right]$$

$$\therefore R_1 = 56.7k\Omega$$

$\therefore$ closest R_1 value $= 56.2k\Omega$ which gives V_{out} as $4.965V$

8.2.2.7 Input Capacitor Selection

The LMR16030 device requires high frequency input decoupling capacitor or capacitors and a bulk input capacitor, depending on the application. The typical recommended value for the high frequency decoupling capacitor is 4.7 µF to 10 µF. A high-quality ceramic capacitor type X5R or X7R with sufficiency voltage rating is recommended. To compensate the derating of ceramic capacitors, a voltage rating of twice the maximum input voltage is recommended. Additionally, some bulk capacitance can be required, especially if the LMR16030 circuit is not located within approximately 5 cm from the input voltage source. This capacitor is used to provide damping to the voltage spike due to the lead inductance of the cable or the trace. For this design, two 2.2-µF, X7R ceramic capacitors rated for 100 V are used. 0.1 µF for high-frequency filtering and place it as close as possible to the device pins.

[2].

We can use two 4.7uF X7R at 100V ceramic capacitors connected in parallel (=9.4uF in total).

We are using the high-end of the range due to our high voltage.

$$C_{OUT} > \frac{3 \times (I_{OH} - I_{OL})}{f_{SW} \times V_{US}}$$

[2].

$$C_{out} = \frac{3 \times (3)}{500 \times 10^3 \cdot 0.25}$$

$$\therefore C_{out} = 72\mu F$$

$C_{out} > 72uF$

Therefore, we can use two 47uF at 16V capacitors in parallel (=94uF) which is greater than the min for C_{out}.

$R_T = 49.9k\Omega$ [2]. - Taken from the datasheet

$C_{BOOT} = 0.1uF$ [2]. - Taken from the datasheet

C_{SS}:

The LMR16030S has an external soft-start pin for programmable output ramp-up time. The soft-start feature is used to prevent inrush current impacting the LMR16030 and its load when power is first applied. The soft-start time can be programed by connecting an external capacitor C_{SS} from SS pin to GND. An internal current source (typically I_{SS} = 3 μA) charges C_{SS} and generates a ramp from 0 V to V_{REF}. The soft-start time can be calculated by Equation 4:

$$t_{SS}(ms) = \frac{C_{SS}(nF) \times V_{REF}(V)}{I_{SS}(\mu A)} \qquad (4)$$

The internal soft start resets while the device is disabled or in thermal shutdown.

We can pick a start time of about 4ms. V_{REF} is 0.75V. I_{SS} is given as 3uA.

$$4 = \frac{C_{ss} \cdot 0.75}{3}$$

$$\therefore C_{ss} = \frac{12}{0.75} = \frac{12}{3/4} = \frac{4 \cdot 12}{3} = \frac{48}{3} = 16nF$$

We can choose the next best actual capacitor value - 22nF. Using this will give us a time between 5 and 6ms.

The LMR16030 only requires a few external components to convert from wide voltage range supply to a fixed output voltage. A schematic of 5-V / 3-A application circuit is shown in Figure 8-1. The external components have to fulfill the needs of the application, but also the stability criteria of the control loop of the device.

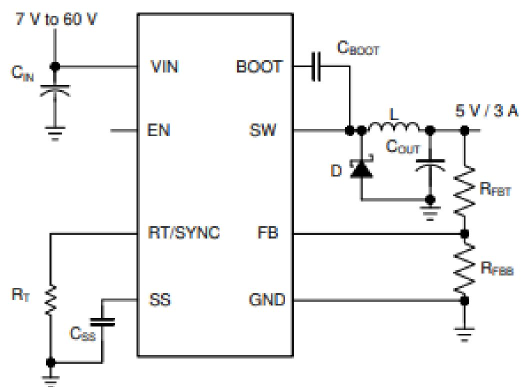
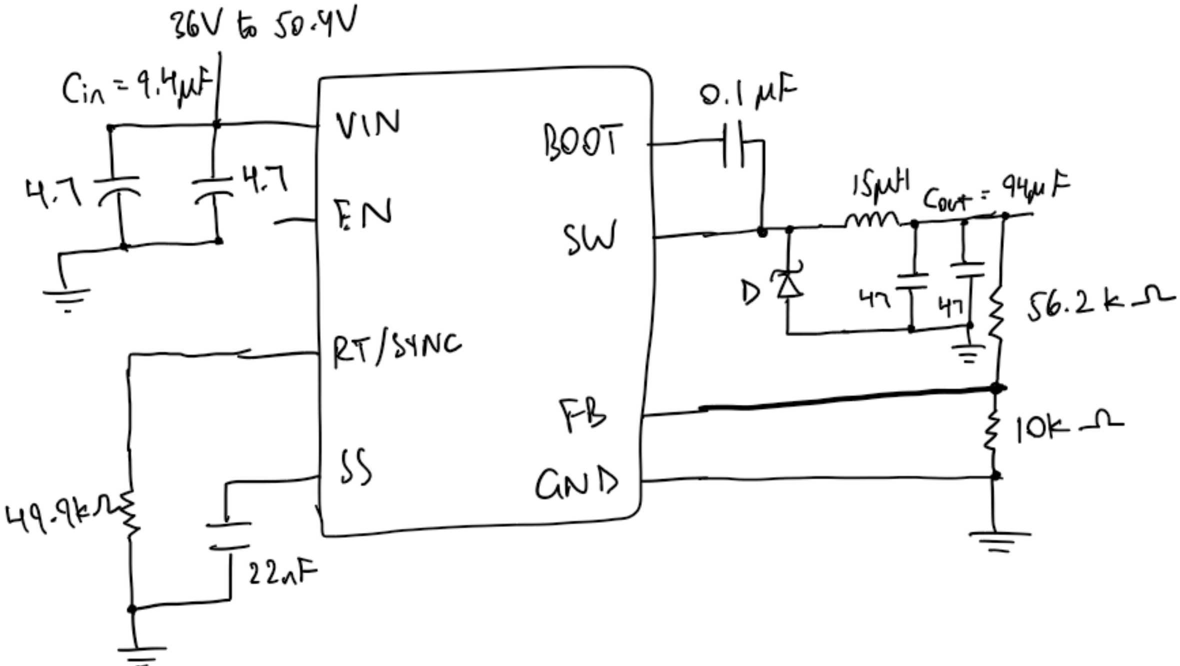


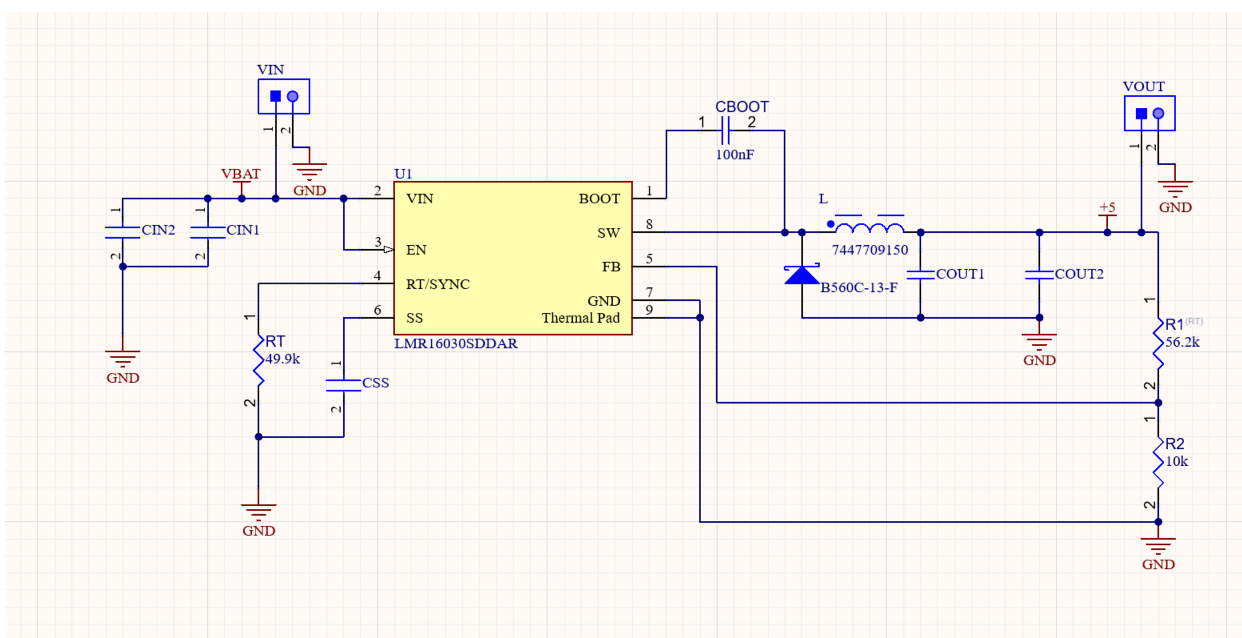
Figure 8-1. Application Circuit, 5-V Output

Now, we can finally get to building something similar to this catered to our requirements.

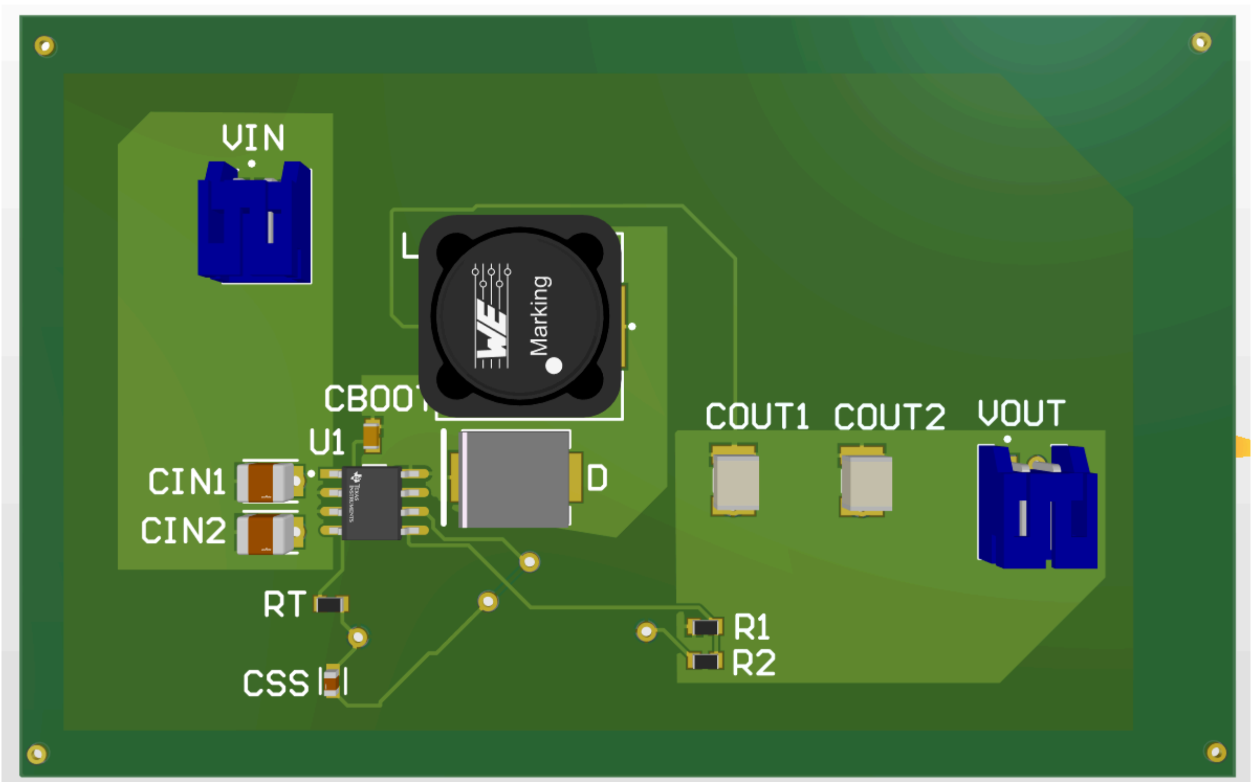
Primary Sketch:



Final Schematic:



Final PCB:


VIN
L
Marking
CBOOT
U1
CIN1
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COUT1
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VOUT
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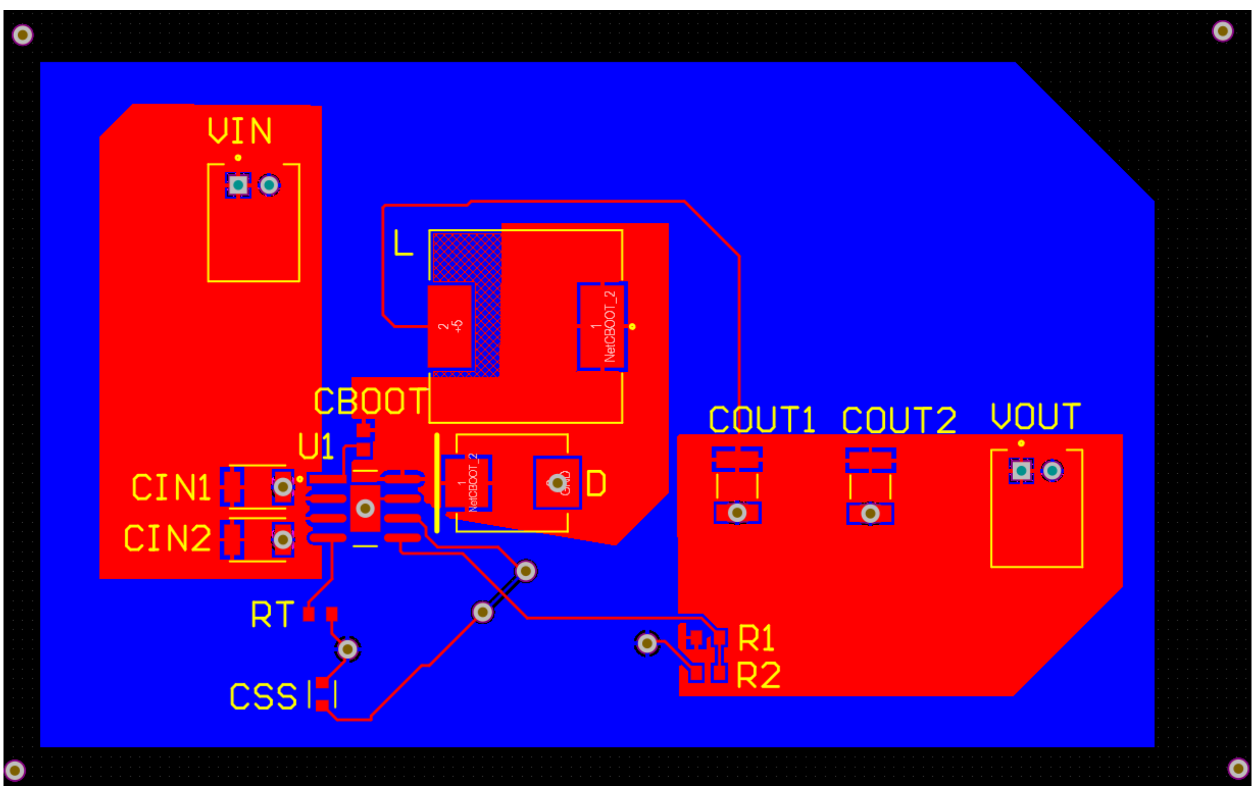
VIN
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CIN2
D
COUT1
COUT2
VOUT
RT
CSS
R1
R2

References

[1]. B. Hauke, "Basic Calculation of a Buck Converter's Power Stage," Application Report SLVA477B, Texas Instruments, Dallas, TX, USA, Aug. 2015. [Online]. Available: https://www.ti.com/lit/an/slva477b/slva477b.pdf

[2]. LMR16030 SIMPLE SWITCHER® 60-V, 3-A Step-Down Converter With 40-µA IQ datasheet (Rev. B) SNVSAH9B, Texas Instruments, Dallas, TX, USA, Mar. 2021. [Online]. Available: https://www.ti.com/lit/ds/symlink/lmr16030.pdf