Wide-Input, High Voltage Buck Converter

National Semiconductor
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Introduction

When the DC input voltage to a buck converter has a wide range, it becomes important to not only select a suitable switching regulator IC for the application, but to select the power components to handle the worst-case input voltage. For a given component, the worst-case may be the maximum input voltage or the minimum input voltage, but in fact may also be somewhere in between. A typical design scenario is presented, using the high voltage SIMPLE SWITCHER® IC, the LM2593HV. The IC is rated for an input of 4.5V to 60V for a 2A load and switches at 150kHz. Considerations reflecting the higher than usual maximum input voltage are also highlighted.

Component Selection

We set the specifications of the converter to be

$V_{IN\_MAX} = 60V$

$V_{IN\_MIN} = 7V$

$V_O = 5V$

$I_O = 2A$

Inductor

The inductor design for a buck converter must be done at the maximum input voltage V_{IN_MAX}. This represents the worst-case for all the key inductor parameters: the core loss, the peak/RMS inductor current, the copper loss, the temperature rise, the energy it must handle, and the peak flux density.

We define 'D' as the Duty Cycle and 'r' the ripple current ratio $\Delta I/I_O$. See Application Note AN-1197 for more details on the terms and equations used here.

We choose 'r' to be 0.3 here as per the design procedure inductor nomographs in the LM2593HV datasheet as well as the guidelines in the referenced Application Note. 'r' is related to the inductance through the equation

$$r = \frac{Et}{L \bullet I_{DC}}$$

where 'Et' is the applied Voltμsecs, I_{DC} is the maximum rated load in Amps, and L is the inductance in μH.

The Duty Cycle is

$$D = \frac{V_O + V_D}{V_{IN} - V_{SW} + V_D}$$

where V_D is the diode forward voltage drop ($\approxeq$ 0.5V), and V_{SW} is the drop across the switch when it is ON, plus any parasitics ($\approxeq$1.5V). So at maximum input

$$D = \frac{5 + 0.5}{60 - 1.5 + 0.5} = 0.093$$

In general it should be ensured that the minimum duty cycle is indeed achievable by the controller. For the LM2593HV, the minimum duty cycle before start of pulse skipping is typically about 5-8%.

The switch ON-time is

$$t_{ON} = \frac{D}{f} = \frac{0.093}{150000} \times 10^6 = 0.62\ \mu s$$

So the Voltμseconds 'Et' is

$$Et = (V_{IN} - V_{SW} - V_O) \times t_{ON} = (60 - 1.5 - 5) \times 0.62 = 33.17V\mu secs$$

Estimated inductance is therefore

$$L = \frac{Et}{r \times I_O} = \frac{33.17}{0.3 \times 2.0} = 55.3\ \mu H$$

The first pass selection of the inductor is usually on the basis of the inductance calculated above and the max load current.

Note that if the maximum load current was less than 2A, say 1A, and the input voltage is greater than 40V, we may still need to size the inductor for 2A current rather than the maximum load of 1A. This is because during a typical (hard) startup/power-up, the feedback loop is ineffective in limiting the duty cycle, and the peak switch current hits the current limit of the controller. For low input voltages, this is usually not a problem, as the controller can nevertheless still protect itself by limiting the current to the set current limit. But if the input voltage exceeds 40V, it is empirically seen that a typical inductor can saturate so rapidly that the current limit cannot be 'enforced' by the controller. This will cause destruction of the switch. Exculpatory factors are the use of substantial soft-start, and paying attention to the material of the core. Powdered iron cores for example, despite other inherent limitations, do not saturate as 'sharply' as do most ferrites, and survive such momentary overloads much better. Ferrites with 'open' magnetic structures like drums/rods (possessing a large inherent air gap in the closed magnetic path) also fare quite well. In general, for all high voltage devices like the LM2593HV, we recommend a careful evaluation of the inductor to ensure that the converter withstands damage during power-up, and also if the outputs are overloaded/shorted (in which case soft-start cannot help either). In our particular example, any standard 56μH/2A inductor should work.

Input Capacitor

The input capacitor of a buck converter sees the maximum ripple current when the duty cycle is 50% (or closest point within range to this). The input voltage corresponding to D=0.5 is $V_{0.5}$ below

$$V_{0.5} - (2 \times V_O) + V_{SW} + V_D \text{ Volts}$$

$$V_{0.5} - (2 \times 5) + 1.5 + 0.5 = 12 \text{ Volts}$$

Input Capacitor (Continued)

In our case the input voltage range does include this point. But in a more general case, if the input voltage range did not include this point, we would take either V_{IN_MAX} or V_{IN_MIN} whichever happens to be closer to $V_{0.5}$. And we would need to calculate the duty cycle at that input voltage for the ripple current calculation below.

The ripple current is (for small 'r')

$$I_{RMS\_IN} = I_O \cdot \sqrt{D \cdot [1\text{-}D]}\ A$$

$$I_{RMS\_IN} = 2 \cdot \sqrt{0.5 \cdot [1\text{-}0.5]} = 1.0\ A$$

The voltage rating of the input capacitor must obviously be higher than the DC Input. Tantalum capacitors were not considered suitable here due to their 50V maximum rating, and their inherent surge current limitations (which are always of concern especially at high input voltages). We recommend at the bare minimum a 63V aluminum electrolytic (preferably 100V) sized to handle 1A RMS current as calculated above. A suitable candidate is Part Number EEVFC1J680Q from Panasonic. This is a 68µF/63V/1.02A SMT Al capacitor. Note that Aluminum electrolytics are quite tolerant of surge voltages provided they do not last 'long'. Further there seems to be no modern statistical evidence to suggest anymore that voltage derating leads to significantly lower failure rates or higher life in such capacitors, as was believed in the past. But please validate these general statements with specific vendors, before relying on them fully.

Output Capacitor

For the output capacitor, the worst-case is again the highest input voltage. The basic selection is based on the ripple current and output ripple.

The ripple current is

$$I_{RMS\_OUT} = I_O \cdot \frac{r}{\sqrt{12}}\ A$$

$$I_{RMS\_OUT} = 2 \cdot \frac{0.3}{\sqrt{12}} = 0.17\ A$$

A suitable candidate is Part Number EEVFC0J221P from Panasonic. This is a 220µF/6.3V/0.23A SMT Al capacitor.

A confirmation of the output voltage ripple is required here. The peak to peak current in the output capacitor is

$I_{PP} = I_O \times r = 0.6$

So with the chosen capacitor, which has an ESR of 0.4 ohms, the output ripple will be 0.6*0.4=0.24V. This is equivalent to ±120mV. If this is considered excessive, a lower ESR capacitor should be selected. However, too low an ESR could lead to instability in the feedback loop particularly when using voltage mode controllers like the LM2593HV.

Catch Diode

The voltage rating of the diode must be higher than the input voltage. We have picked a 100V Schottky diode here. The average current in the catch diode is

$$I_{AVG\_D} = I_O \times (1\text{-}D)$$

The diode conducts during the OFF-time, so minimum duty cycle (or highest input) is again the worst-case here. Therefore

$$I_{AVG\_D} = 2 \times (1\text{-}0.093) = 1.81A$$

We can use a 3A/100V Schottky diode from any vendor.

Additional Information

power.national.com

www.national.com/pf/LM/LM2593HV.html

www.national.com/an/AN/AN-1197.pdf

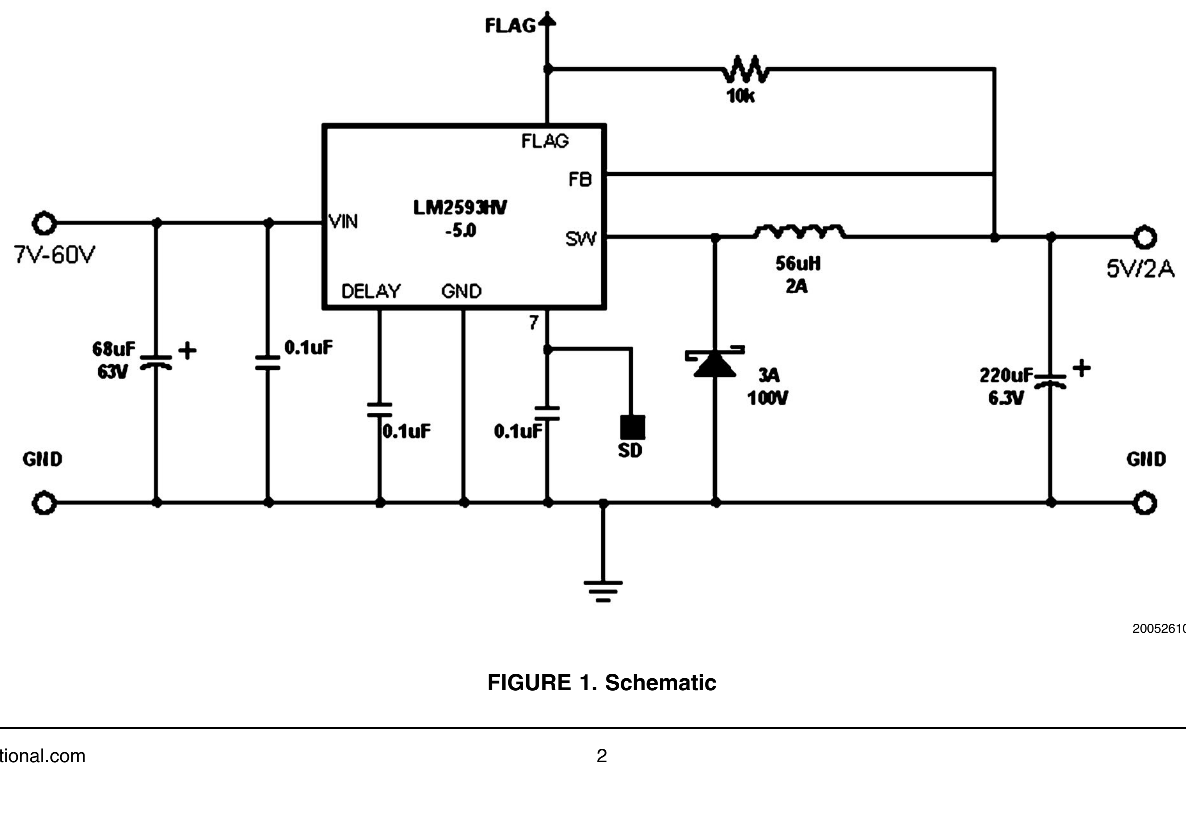

FIGURE 1. Schematic

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