Buck Converter

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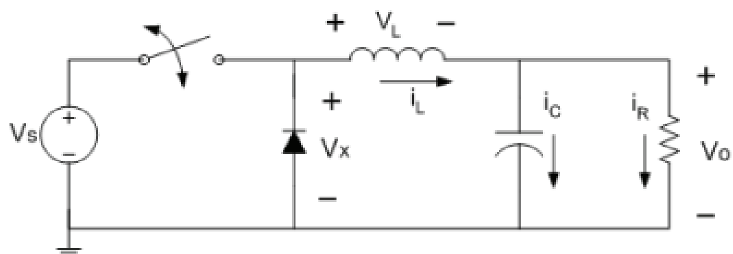
Assignment 1

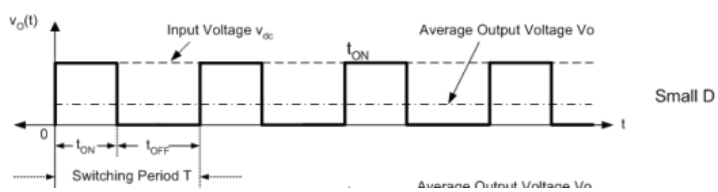
1 Theory

Buck converter is a type of DC-DC converter whose circuit employees a switching network that converts DC voltage from a higher level to a lower level.

Basic Topology of the circuit is as follows:



The switching creates the following waveform at the input of inductor



To obtain the average values we pass this waveform through a low pass filter here LC filter.
To obtain the output voltage to load we can use the fact that average voltage of inductor is zero.
Therefore, $V_L = v_{Lon}t_{on} + v_{Loff}t_{off} = 0$
$v_{Lon} = V_s - V_o$

where V_s and V_o are source voltage and output voltage respectively.
As $I_{steadyState} = \frac{V_o}{R_{Load}}$ so voltage accross inductor as switch is opened, will be such that current is not reduced to zero but a current of V_o/R is maintained.
So , $v_{Loff} = -V_o$
Therefore, $(V_s - V_o)DT + (-V_o)(1-D)T = 0$
$V_o = DV_s$
here D is fraction of time T for which switch was on referred to as Duty Cycle.

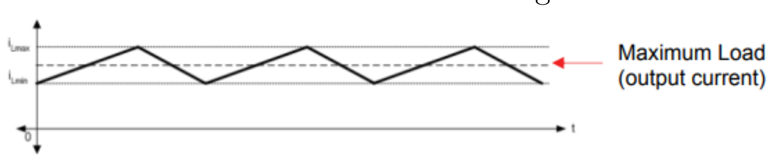
1.1 CCM and DCM

CCM stands for continous conduction mode, DCM stands for Discontinous Concuduction mode.
In CCM mode inductor current remains positive through out the cycle while DCM inductor becomes zero for sometime in switching period.
CCM has slower response as compared to DCM.
DCM have higher efficiency than CCM.

2 Design

2.1 Calculating the inductor value

We want to remain in CCM mode, so $I_{Lmin} = 0$
Maximum and minimum current through inductor can be wrriten as

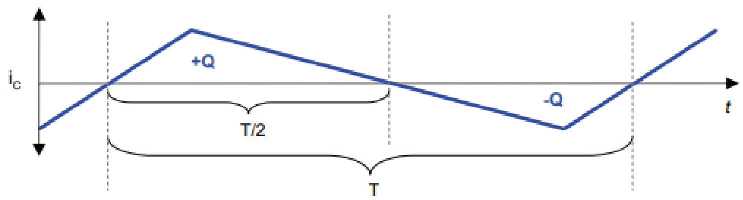


$I_{Lmin} = I_L - \frac{|\Delta i_L|}{2}$
where I_L is average current through inductor.
When switch is off
$v_L = -V_o = L\frac{di_L}{dt}$
$\frac{di_L}{dt} = \frac{-V_o}{L}$
$\Delta i_{Loff} = \frac{-V_o}{L}\Delta t_{off}$
$\Delta i_{Loff} = \frac{-V_o}{L}(1-D)T$
$I_{Lmin} = \frac{V_o}{R} - \frac{V_o(1-D)}{2Lf}$
For $I_{Lmin} = 0$

$L_c = \frac{(1-D_{max})R_{max}}{2f}$
Choose $L > 1.05L_c$

2.2 Choosing C

Through capacitor ripple current will flow.
Total Charge in interval T/2



$q = C\Delta V_o$ $C = \frac{q}{\Delta V_o} = \frac{1-D}{8Lf^2(\Delta V_o/V_o)}$
Capacitor voltage rating
$V_{cmax} = V_o + \frac{\Delta V_o}{2}$

2.3 Diode Selection

Schottky diode is used because of its low losses.
$V_{RRM} = V_{inmax}$
V_{RRM} is peak inverse voltage of diode.
for V_{RRM} we take 20% safety factor
Current Rating of Diode(I_F) $> I_L(1-D)$

3 Implementation and Results

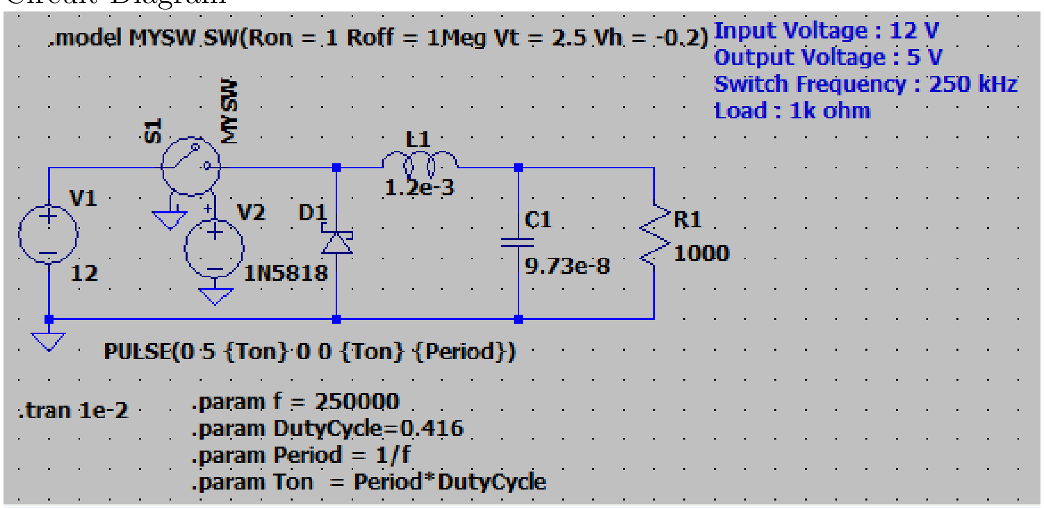
3.1 Buck Converter Specification

Input Voltage = 12 V
Output Voltage = 5 V
Switch Frequency = 250 kHz
$D = \frac{V_o}{V_s} = \frac{5}{12} = 0.416$
$L_c = \frac{(1-D_{max})R_{max}}{2f}$
$L_c = \frac{(1-0.416)1000}{2\times 250^3}$
$L = 1.05 \times 1.168mH$
$L = 1.226mH$

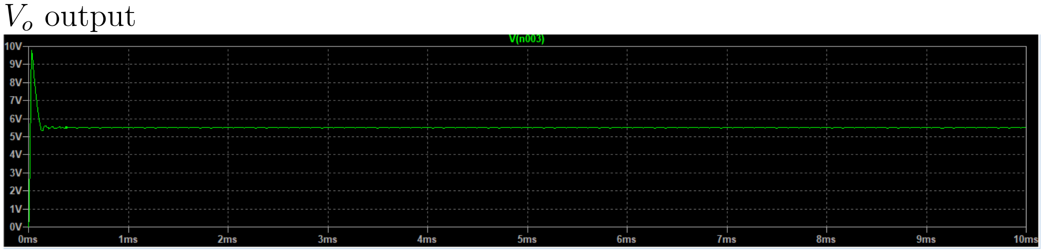
$C = \frac{1-D}{8Lf^2(\Delta V_o/V_o)}$
$\Delta V_o = 0.01$ (arbitarily choosing)
$C = \frac{1-0.416}{8\times1.2\times10^{-3}\times(250kHz)^2\times(0.01)}$
$Therefore C = 9.73 \times 10^{-8}$ Imax = 9.8 mA
$V_{RMM} > 12V$ for diode
$I_F > 2.92mA$
Diode Choosen : 1N5818

3.2 Circuit Diagram and Results

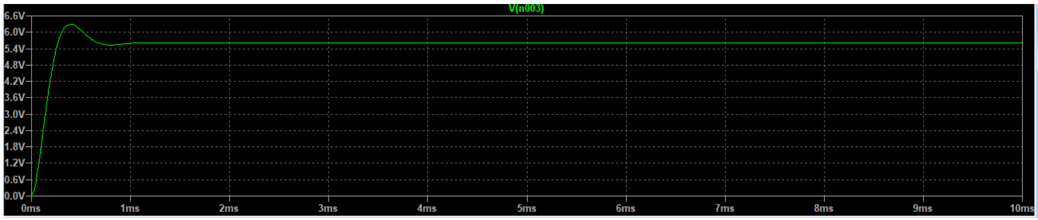
Circuit Diagram



V_o output



Steady State Error = 0.4 V
Maximum Peak = 10 V
To reduce Peak overshoot we can increase L
So increasing L to 1.2e-1 Henry



So peak overshoot decreases but time to reach steady state increases.

To make system better that is to reduce steady state error, peak overshoot, t_{ss} we can add a PID controller to improve the same.

4 References

- Tutorial on Buck Converter
- Article from all about Ciruits