TEAM MUSE

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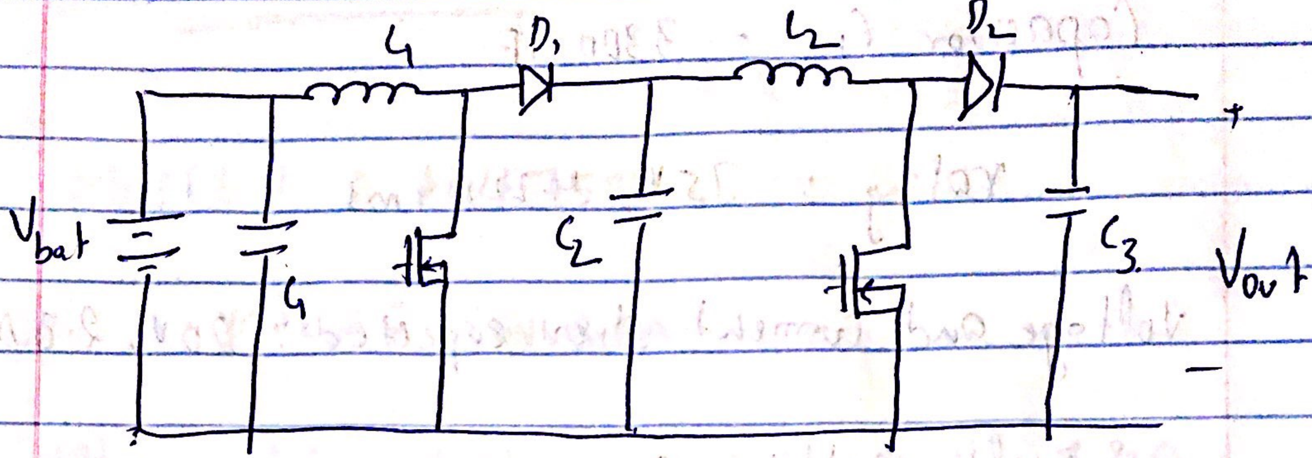
Pre lab Exp 4



1. Converter design

(a) for output voltage equal 120V.

$V_{bat} = 12V$

~~Consider both MOSFETS are given same control pulse.~~
~~Duty cycle of both stages is constant~~.

So for first boost stage output across capacitor C_2 is 43V

So for 12V to 43V

duty cycle $D_1 = 1 - \frac{V_{bat}}{V_{c2}}$

$$D_1 = 1 - \frac{12}{43} = 0.72$$

for second stage
43V to 120V

duty cycle $D_2 = 1 - \frac{V_{c2}}{V_{out}}$

$$= 1 - \frac{43}{120}$$

$$= \cancel{0.713} = 0.6416$$

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Capacitor C_2 is ~~ch~~ selected as → UVR1J222MHD

max $i_{rms} = 2.3A$

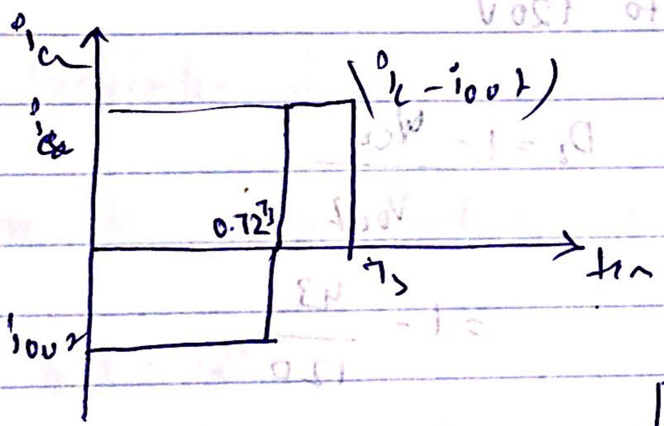
Stage-1

12 – 43 ; 85W

$$I_{out} = \frac{85}{43} = 1.97A$$

$$I_L = 7.083A$$

current across capacitor C_2



$$\cancel{i_{c\,rms} = \sqrt{\frac{1}{T}\left(i_{out}^2 \times 0.72 + i_{c}^2 \times 0.28\right) T_s}}$$

$$i_{c\,rms} = \sqrt{\frac{i_{out}^2 \times DT_s + (i_L - i_{out})^2 D' T_s}{T_s}}$$

$$= 7.18\,rms$$

this current rating exceeds the rating of

capacitor max rms current, so placing two capacitor in paired

Now max rms current we can manage is $= 2.3 \times 2$
$= 4.6\,A$

for Rms current calculation

$$i_{rms} = \sqrt{i_x^2 \times 0.72 + \left(\frac{P_{max}}{12} - I_x\right)^2 (1 - 0.72)}$$

and $I_x \times 43 = P_{max}$

$\boxed{P_{max} \approx 125\,W}$

~~$I_x = 2.9\,A$~~ $I_x = 2.9\,A$

$I_{crms} = 4.6\,A$

current across each capacitor $= 2.3\,A$

Selecting MOSFET → STP70N170

R_{on} of MOSFET = 1.60×10^{-2} ohm.

Stage-1 conduction loss for max power

$I = 10.41$

$D = 0.72$

$P_{cond_1} = I^2 R \times D$

$= 1.25W$

Stage-2

$I = 2.907$

$D = 0.641$

$P_{cond_2} = I^2 R \times D$

$= 8.68 \times 10^{-2}$

$P_{cond\ total} = P_1 + P_2 = 1.34\ W$

(b) for output voltage equal 200V

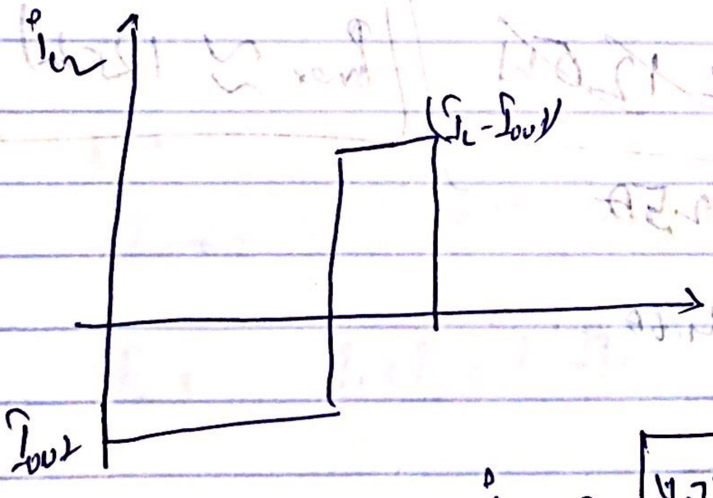
first ~~stage~~ stage

12V to 50V , 85W

$I_{out} = 1.7$ duty cycle $= 1 - \frac{12}{50} = 0.76$

$I_L = 7.083$

Current across capacitor C_2



$i_{rms} = \sqrt{(1.7)^2 \times 0.76 + (7.083 - 1.7)^2 \times (0.24)}$

$= 3.02$

two capacitor in parallel are placed.

Capacitor C_2 → UVR1J222MHD

$I_{rm} = 2.3A$

Now Capacitors placed in parallel so

$I_{max\,rm} = 4.6A$

for max power

$$I_{max\,rm} = \sqrt{I_x^2 \times 0.76 + \left(\frac{P_{max}}{12} - I_x\right)^2 \times 0.24}$$

$I_x \times 50 = P_{max}$

$\boxed{\cancel{P_{max} \simeq 120W}}$ $\boxed{P_{max} \simeq 125W}$

$I_x = 2.5A$

$I_{rm} = 4.6A$

for stage - 2

50V to 200V

$$D_2 = 1 - \frac{50}{200} = 0.75$$

MOSFET → STP70N17D

R_{on} of MOSFET = 1.6×10^{-2} ohm

at P_{max} = 125W

Stage-1 conduction loss

$I_1 = 16.4$ A

$D = 0.76$

$P_{cond_1} = I^2 R \times D = 1.32$ W

Stage-2

$I = 2.5$

$D = 0.76$

$P_{cond_2} = I^2 R \times D = 7.5 \times 10^{-2}$ W

$P_{total} = P_1 + P_2 = 1.39$ W

For 120V

	Stage-1. 12V to 43V	Stage-2 43V to 120V
Duty cycle	0.72	0.64
Pmax.	125W.	
Mosfet conduction loss	1.34W.	

For 200V

	Stage-1. 12V to 50V	Stage-2 50V to 200V
Duty cycle	0.76	0.75
Pmax	125V	
Mosfet conduction loss	1.39W	

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2. <u>Inductor design</u>

Inductor is designed for 12V to 200V.
and $P_1 = P_{max} = 125W$

<u>Stage-2</u> (~~12V to 50V~~) (50 to 200V)

$f_s = 60\ kHz$

$D = 0.75$

$\Delta I = 15\%$

$I_{max} = I + \Delta I = 2.875$

$$L = \frac{V_{out} \times D' T_s}{2\Delta I} = 8.33 \times 10^{-4}\ H$$

$P_{loss} = 1W. \Rightarrow R = 0.16\ ohm$

$B_{max} = 0.37$

Fill factor $= k_u = 0.4$

$$kg \geq \frac{L^2 I_{max}^2 \rho}{B_{max}^2 \times R \times k_u} \times 10^8$$

$$kg \geq 0.171$$

a ferrite core PQ 32/20 with $kg = 0.203$ is selecte

from PQ 32/20 data sheet

$A_C = 1.7 cm^2$

$W_A = 0.471 cm^2$

$MLT = 6.71 cm$

air gap $l_g = \frac{\mu_0 \times L \times I_{max}^2}{B_{max}^2 \times A_C} \times 10^4$

$$\boxed{l_g = 0.5\cancel{7}6 \text{ mm}}$$

Number of turns $n = \frac{L \times I_{max} \times 10^4}{B_{max} \times A_C}$

$$\boxed{n = 47}$$

$$A_W \le \frac{K_U W_A}{n}$$

$$A_W \le 4.01 \times 10^{-3}$$

Use $AWG = \#22$

~~For Stage-2 (50V to 200V)~~

~~$f_s = 60\ kHz$~~

For Stage-1 (12V to 50V)

$f_s = 60kHz$

$D = 0.76$

$\Delta I = 15\%$

$I_{max} = I + \Delta I = 11.979\ Amp$

$$L = \frac{V_{out} \times D' \times T_s}{2\Delta I} = 48.6\ \mu H$$

$P_{loss} = 1W \Rightarrow R = 9.22\ m\ ohm$

$B_{max} = 0.3$

$k_u = 0.4$

$$k_g \geq \frac{L^2 I_{max}^2 \rho}{B_{max}^2 \times R \times k_u} \times 10^8$$

$k_g \geq 0.176$

a ferrite core PQ 32/20 is selected with $k_g = 0.207$

$A_c = 1.7\ cm^2$

$W_A = 0.471\ cm^2$

$MLT = 6.71\ cm$

air gap $l_g = \frac{\mu_0 L I_{max}^2}{B_{max}^2 \times A_c} \times 10^4$

$l_g = 0.566\ mm$

Number of turns $n = \frac{L \times I_{max} \times 10^4}{B_{max} \times A_L}$

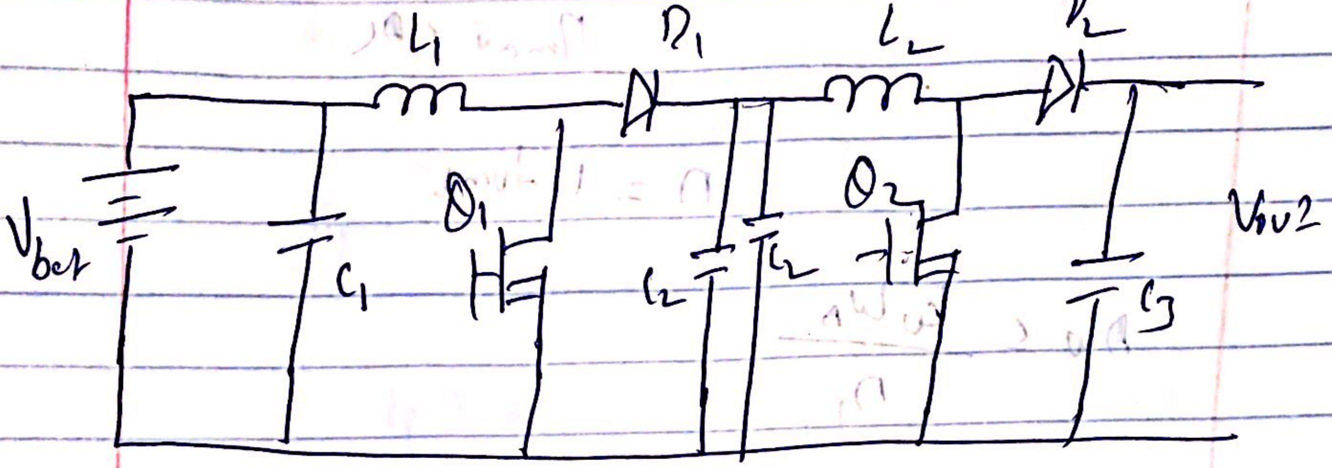
$n = 11$ turns

$A_w \le \frac{K_u W_A}{n_1}$

$A_w \le 16.5 \times 10^{-3}\ cm^2$

Use AWG # 16

7. Loss Budget



Capacitor C_1 = 330μF

rating ~~24V~~ 25V 0.865 Arms

Capacitor C_2 = 2200μF.

rating 63V → 2.3 Arms

Capacitor C_3 ⇒ 22μF

rating 200V 0.5 Arms.

MOSFET

Q_1 and Q_2 ⇒ STP70N17.0
100V, 65A

Diode D1 → FES16BT.
100V, 16A

Diode D2 → MUR 440
400V, 4A

Conduction loss for 125 W!

for MOSFET. ~~Ron = 19 $\times 10^{-2}$ ohm~~
$R_{on} = 19.5 \, m\Omega$

at stage-1

$i_{in} = 10.41 \, A$

$D_1 = 0.76$

$P_1 = I_1^2 R D$

$= 1.6W$

at stage-2

$I = 2.5A$

$D_2 = 0.75$

$P_2 = I_2^2 R D_2$

$= 91.4 \, mW$

$= \cancel{75 \times 10^{-3} W}$

$P_{total} = P_1 + P_2 = \cancel{1.9W}$

$= \cancel{2.3W}$

$P_{Total} = 1.69W$

for Diode - FES16BT

~~Vf~~ forward voltage $V_f = 1$

Current $I_1 = 10.41$

$D = 0.76$

$P_1 = V_f \times I \times D'$

$= 2.4984 \, W$

for Diode MUR440

forward voltage $V_f = 1$

current $I = 2.5$

$D = \cancel{0.6} \, 0.75$

$P_2 = V_f \times I \times D'$

$= 0.625$

Total diode conduction losses $= P_1 + P_2$

$= 3.123 W$

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Switching loss

from MOSFET specs

turn on delay = 30ns   turn off delay t_h = 65ns

rise time t_r = 20ns   fall time t_f = 20ns

from Diode FES16BT

Reverse recovery time = 35ns

$I_{RR} = 0.25$ A

from Diode MUR440

reverse recovery time = 50ns

$I_{rr} = 0.25$ A

Stage-1 Switching loss

during MOSFET Turn ON - Diode Turn off

$$P_1 = \frac{1}{2}(t_r + t_{rr}) \times V_{bat} \times (I_{L_1} + I_{RR}) \times f_s$$

$$= 0.211\ W$$

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during MOSFET Turn off - Diode turn ON

$$P_2 = \frac{1}{2}(t_n + t_f) V_{bat} \times I_4 \times f_s$$

$$= 0.31 W$$

Stage-2

During MOSFET turn ON - Diode turn Off

$$P_3 = \frac{1}{2}(t_{rt} t_{rr}) \times V_2 \times (I_{L2} + I_{rr}) f_s$$

$$= 0.288 W$$

During MOSFET turn Off and diode turn ON

$$P_4 = \frac{1}{2}(t_n + t_f) V_2 \times I_{L2} \times f_s$$

$$= 0.318 W$$

total switching loss $= P_1 + P_2 + P_3 + P_4$

$$= 1.127 W$$

Inductor loss

Core loss

for stage-1

$\Delta I = 1.5625\,A$

$\Delta B = 40\,mT \approx 50\,mT$

from ferrite material "TDK PC44" Data sheet

Power density $= 5\times10^{3}\,W/m^{3}$

according to core spec

$A_c = 1.66\times10^{-4}\,m^2$

$l_m = \underbrace{l_c}_{\text{core length}} + \underbrace{l_g}_{\text{air gap}} = 2.12\times10^{-2}\,m$

loss $\Rightarrow P_1 =$ Power density $\times A_c \times l_m$

$P_1 = 1.76\times10^{-2}\,W$

for stage-2

$\Delta I = 0.375 A$

$\Delta B = 40 mT \approx 50 mT$

from 'PC44' Data Sheet

Power density $= 5\times10^3 \, W/m^3$

Area of core $= A_c \, 1.66\times10^{-4} \, m^2$

effective height $= l_m = 2.12\times10^{-2} \, m$

Power loss $=$ Power density $\times A_c \times l_m$

$P_2 = 1.76\times10^{-2} W$

~~Pa~~

Copper loss

for stage-1

Stage-1 inductor has wire AWG = #16

effective $R_{ohm} = 1.01 \times 10^{-2}$ ohm

$I = 10.41$

Copper loss = $P_3 = I^2 R$

$= 1.1W$

for stage-2

inductor has wire of AWG = #22

effective $R_{ohm} = 1.68 \times 10^{-1}$ ohm

$I = 2.5A$

Copper loss = $P_4 = I^2 R = 1.05W$

Proximity loss is negligible

Total inductor loss = $P_1 + P_2 + P_3 + P_4 = 2.16W$

Loss Budget

Operating point $V_{in} = 12V$ $V_{out} = 200V$

~~$P_{out} = 125W$~~

$P_{in} = P_{max} = 125W.$

$f_s = 60kHz$

MOSFET conduction loss = 1.39W

Diode conduction loss = 3.123W

Switching loss = 1.127W

Inductor loss = 2.16W

Total loss = 7.8W

Predicted efficiency 93.76%.