(1) Given,

$V_{in} = 300V$ $\quad$ $C_1 = C_2 = 4.7\mu F$

$L = 35\mu H$ $\quad$ $V_o = 12V$

$C = 220\mu F$ $\quad$ $n = 9$

$f_s = 50kHz$ $\quad$ $L_p = 2.7mH$

(a) $V_o = \dfrac{d V_{in}}{n}$

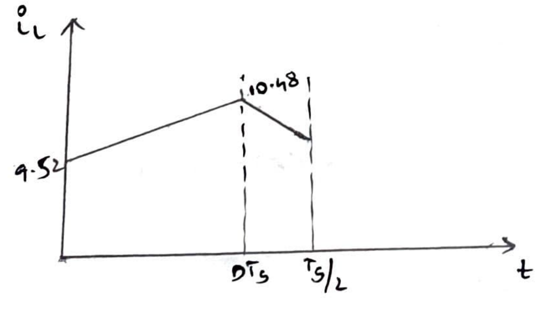
$12 = \dfrac{d \times 300}{9} \Rightarrow d = 0.36$

$\bar{i}_L = I_o = 10A$

$\Delta i_{L_{pp}} = \dfrac{V_o(0.5 - D)}{f_s L} = \dfrac{12(0.5 - 0.36)}{35\times10^{-6} \times 50\times10^{3}} = 0.96A$

$i_{L_{min}} = c = I_o - \dfrac{\Delta i_{L_{pp}}}{2} = 9.52A$

$i_{max} = b = I_o + \dfrac{\Delta i_{L_{pp}}}{2} = 10.48A$




secondary current → 9.52A - 10.48A

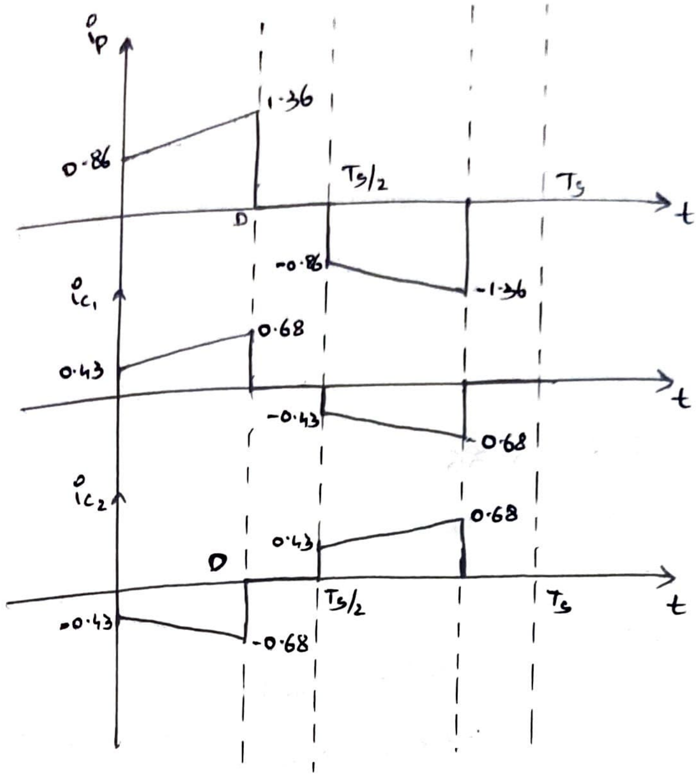
Reflected secondary current → $\dfrac{i_L}{n}$ → 1.06A - 1.16A

magnetizing current → $a = \dfrac{V_{in}}{2 L_{pm}} DT_s \times \dfrac{1}{2} = \dfrac{300}{2\times2.7\times10^{-3}} \times 0.36 \times \dfrac{1}{2\times50K}$

$a = 0.2A$

$\therefore$ $i_p$ varies b/w $\dfrac{c}{n} - a \leftrightarrow \dfrac{b}{n} + a$ → 0.86A - 1.36A

$$i_{c_1} = \frac{i_p}{2} \quad , \quad i_{c_2} = \frac{-i_p}{2}$$




(b) $L_p = 2.7mH$

$L_l = 30\%$ of $L_p = 0.03 L_p = 8.1\times10^{-5} H$

$$V_o = \frac{DV_{in}}{n} - \frac{3}{2}\frac{f_s L_l I_o}{n^2}$$

$$12 = \frac{D\times300}{9} - \frac{3}{2}\times\frac{50\times10^3\times8.1\times10^{-5}\times10}{9^2}$$

$$12 = \frac{100\times D}{3} - 0.75$$

$$\boxed{D = 0.3825}$$

② (i) Given,

| | |
|---|---|
| input | 250V - 400V |
| output | 12V |
| $I_o$ | 2A - 5A |
| $f_s$ | 100KHz |

→ Flyback converter is an indirect energy transfer converter. when the switch is on, the primary inductance will store energy but the secondary diode is reverse biased. so, current wont fly to secondary

→ when the switch is off, the stored energy in the inductor is given to switch capacitance and output capacitance

→ As there is no load the capacitor cannot discharge and for every cycle the energy keeps on increasing in capacitance and this leads to blown up capacitor and switch.

→ for CCM,

$$I_{P_{min}} - I_{P_{max}} = \frac{V_{in}}{L_P} DT_s$$

$$E = \frac{1}{2} L I^2 = \frac{1}{2} L \left(I_{P_{max}} - I_{P_{min}}\right)^2$$

This the power transferred for one cycle

Average power transfered.

$$P_o = \frac{1}{2} L \left(I_{P_{max}} - I_{P_{min}}\right)^2$$

$P_o = V_o I_o$

$V_o I_o = \frac{1}{2} L (IP_{max} - IP_{min})^2 \times f_s$

$$V_o = \frac{D^2 V_{in}^2}{2 f_s L_p I_o}$$

but $I_o = 0A$

$$V_o = \frac{D^2 V_{in}^2}{2 f_s L_p I_o} \approx \infty$$

→ This is the reason why capacitor will be blown

(ii) NO, Her professor didnt teach her wrong, flyback converter should be tested with less duty cycle and less value of load

→ so that energy stored in primary inductance will be less and is given to the output or secondary side when the switch is off.

3

Given,

$A_c = 266\,mm^2$

$A_w = 537\,mm^2$

$A_p = A_c A_w = 142842\,mm^2$

$I = 30A \pm 3A$

$I_{max} = 33A, \quad I_{min} = 27A$

$k_i = \frac{I_{max}}{I} = \frac{33}{30} = 1.1$

$k_s = 0.36$

$J = 4A/mm^2$

$B_{max} = 0.2\,wb/m^2 = 0.2\times10^{-6}\,wb/mm^2$

$$A_p \geq \left(\frac{1}{2} L I^2\right)\left(\frac{2k_i}{k_s B_{max} J}\right)$$

$$L_{max} = \frac{A_p k_s J B_{max}}{k_i I^2}$$

$$= \frac{142842 \times 0.36 \times 4 \times 0.2\times10^{-6}}{1.1\times30^2}$$

$$\boxed{L_{max} = 41.55\mu H}$$

$$N = \frac{L k_i I}{A_c B_{max}} = \frac{41.55\times10^{-6}\times1.1\times30}{266\times0.2\times10^{-6}}$$

$N = 25.77$

$$\boxed{N \approx 26}$$

$$L = \frac{\mu_i N^2 A_c}{l_e + 2g\frac{\mu_i}{\mu_o}}$$

$$g = \frac{\mu_o N^2 A_c}{2L} - \frac{\mu_o l_e}{2\mu_i}$$

$$g = \frac{4\pi\times10^{-7}\times26^2\times266\times10^{-6}}{2\times41.55\times10^{-6}} - \frac{148\times10^{-3}}{2\times2200}$$

$$\boxed{g = 2.68mm}$$

(4) Given,

$V_{in} = 108V - 135V$

$V_o = 12V$

$I_o = 2A - 5A$

$\Delta i_L < 1A$

$\Delta V_o < 1\%$ of $V_o$

$f_s = 40KHz$

$D_{max} = 0.45$

$$V_o = \frac{DV_{in}}{n}$$

$$12 = \frac{D_{max}\times V_{in\,min}}{n}$$

$$n = \frac{0.45\times108}{12} \approx 4.05 \approx 4$$

$$V_o = \frac{D_{min}\times V_{in\,max}}{n} \Rightarrow 12 = \frac{D_{min}\times135}{4} \Rightarrow D_{min} = 0.36$$

$$\Delta i_L = \frac{(1-D)V_o}{L} \times DT_s$$

$$\Delta i_L = \frac{(1-D_{min})V_o}{f_s L}$$

$$L = \frac{(1-0.36)\times 12}{40000 \times 1}$$

$$\boxed{L = 192\,\mu H}$$

$$\Delta i_L = \frac{(1-D_{max})V_o}{f_s L}$$

$$\Delta i_L = \frac{(1-0.45)\times 12}{40000 \times 192 \times 10^{-6}} = 0.859$$

$$I_{L\,min} = I_o - \frac{\Delta i_L}{2} = 4.57A$$

$$I_{L\,max} = I_o + \frac{\Delta i_L}{2} = 5.429A$$

$$k_i = \frac{I_{L\,max}}{I} = \frac{5.429}{5} = 1.0859$$

$$A_p = \left(\frac{1}{2} L I^2\right)\left(\frac{2k_i}{K_s B_{max} J}\right)$$

$$A_p = \left(\frac{1}{2} \times 192 \times 10^{-6} \times 5^2\right)\left(\frac{2 \times 1.0859}{0.4 \times 3 \times 0.2 \times 10^{-6}}\right)$$

$$A_p = 21718\,mm^4$$

Sel, EE 40/16/12

$$A_c = 149\,mm^2$$

$$A_w = 2 \times 10.5 \times \left(\frac{28.6 - 12.5}{2}\right) = 169\,mm^2$$

$A_p = A_c A_w$

$A_p = 25188\,mm^2$

$\therefore$ we choose EE40/16/12 core

Mean turn length $= 4 \times \left(12.5 + \frac{28.6 - 12.5}{2}\right)$

$L_m = 82.2\,mm$

RMS value of current $\approx 5A$

copper area $= \frac{I}{J} = \frac{5}{3} = 1.667\,mm^2$

for SWG 16,

Cu area $\rightarrow 2.075\,mm^2$

Cu dia $\rightarrow 2\sqrt{\frac{2.075}{\pi}} = 1.625\,mm$

dia $\rightarrow 1.709\,mm$

$\therefore$ we choose SWG 16 wire

$N\phi = LI$

$N = \frac{LI}{\phi} = \frac{L\,I_{max}}{A_c\,B_{max}}$

$N = \frac{192 \times 10^{-6} \times 5.429}{149 \times 0.2 \times 10^{-6}}$

$N = 35.5 \approx 36$ turns $\rightarrow$ 40 turns

window height $= 2 \times 10.5 = 21\,mm$

useful window $= 21 - (2 \times 1 + 2 \times 2) = 15\,mm$

No. of turns/layer $= \frac{15}{1.709} = 8.77$

for 40 turns

wind 8 turns per layer for 5 layers

$$P = 5$$

$$h = 0.866 \times d = 0.866 \times 1.625 = 1.407$$

$$F_l = \frac{N \times d}{W} = \frac{8 \times 1.625}{15} = 0.866$$

$$\Delta = 0.31\,mm \ @ \ 40\,kHz$$

$$\rightarrow \frac{h\sqrt{F_l}}{\Delta} = \frac{1.407\sqrt{0.866}}{0.31} = 4.22$$

$$F_r = \frac{2P^2+1}{3} \times \frac{h\sqrt{F_l}}{\Delta}$$

$$F_r = \frac{2 \times 5^2+1}{3} \times \frac{1.407\sqrt{0.866}}{0.31} = 71.74$$

$$\frac{R_{ac}}{R_{dc}} = 71.74$$

$$R_{dc} = \frac{82.2 \times 15}{1000} \times 0.0083 \times 1.2$$

$$R_{dc} = 12.2\,m\Omega$$

$$R_{ac} = R_{dc} \times F_r = 12.2\,m\Omega \times 71.74 = 0.88\,\Omega$$

$$\text{Cu loss} = I_{dc}^2 R_c + I_{ac}^2 R_{ac}$$

$$P_{cu} = 12.2 \times 10^{-3} \times 5^2 + 0.88 \times \left(\frac{0.429}{\sqrt{3}}\right)^2$$

$$P_{cu} = 0.305 + 0.0539$$

$$P_{cu} = 0.358\,W$$

core loss,

B changes b/w $0.2\ Wb/m^2$ &

$0.2 \times \frac{4.57}{5.429} = 0.168$

$\Delta B_m = \frac{0.2 - 0.168}{2} = 15.8\ mWb/m^2$

$\Delta B_m \simeq 16\ wb/m^2$

Relative core loss for $\Delta B_m$ @ 40KHz

$\simeq 1.8\ mW/cc$

core volume $\simeq$ 11.5 cc

core loss $= P_c = 1.8 \times 11.5 \times 10^{-3}$

$P_c = 0.0207\ W$

Total loss $= 0.358 + 0.0207$

$\boxed{P_T = 0.378\ W}$

| | |
|---|---|
| Diode peak current. | MOSFET peak current = |
| Diode RMS current = | MOSFET peak voltage = |
| Diode peak voltage. | MOSFET RMS current : |

for capacitance,

ESR×1 = 0.12

ESR = 0.12 Ω

$C = \frac{40 \times 10^{-6}}{0.12} = 333.3\ \mu F$

$C = 30 \times 10^{-6} / 0.48 = 62.5\ \mu F$

(5)

Given,

$V_{in} = 200V - 280V$

$V_o = 24V$

$I_o = 2A - 5A$

$\Delta v_o < 2\%$ of $V_o$

$\Delta i_L < 1A$

$f_s = 75kHz$ , $D_{max} = 0.45$

$$V_o = \frac{2DV_{in}}{n}$$

$$V_o = \frac{2 \times D_{max} \times V_{in\,min}}{n}$$

$$n = \frac{2 \times 0.45 \times 200}{24} = 7.5$$

$$n \simeq 8$$

$$D_{min} = \frac{n \times V_o}{2 \times V_{in\,max}} = \frac{24 \times 8}{2 \times 280} = 0.34$$

$$\Delta i_L = \frac{V_o(0.5 - D)\,T_s}{L}$$

$$\therefore L = \frac{24(0.5 - 0.34)}{75000 \times 1} = 51.2\mu H$$

$$\boxed{L = 51.2\mu H}$$

for capacitance,

$$ESR \times 1 = 0.48$$

$$ESR = 0.48\Omega$$

$$C = 30 \times 10^{-6} / 0.48 = 62.5\mu F$$

$$\Delta i_L = \frac{24(0.5-0.45)}{10^{-6} \times 75000 \times 51.2}$$

$$\Delta i_L = 0.3125 A$$

$$I_{Lmin} = I_o - \frac{\Delta i_L}{2} = 4.8437 A$$

$$I_{Lmax} = I_o + \frac{\Delta i_L}{2} = 5.1562 A$$

$$k_i = \frac{I_{Lmax}}{I} = \frac{5.1562}{5} = 1.0312$$

$$k_s = 0.4$$

$$A_p = \left(\frac{1}{2} L I^2\right)\left(\frac{2 k_i}{0.4 \times 3 \times 0.2 \times 10^{-6}}\right)$$

$$A_p = \left(\frac{1}{2} \times 51.2 \times 10^{-6} \times 5^2\right)\left(\frac{2 \times 1.0312}{0.4 \times 3 \times 0.2 \times 10^{-6}}\right)$$

$$A_p = 6284.19 mm^4$$

for EE 30/15/7

$$A_c = 60 mm^2$$

$$A_w = 2 \times 9.7 \times \left(\frac{19.5 - 7.2}{2}\right) = 119.31 mm^2$$

$$A_p = A_c A_w = 7158.6 mm^4$$

$$\text{Mean turn length} = 4 \times \left(7.2 + \frac{19.5 - 7.2}{2}\right)$$

$$l_m = 53.4 mm$$

RMS value of current $\approx 5A$

$$\text{copper area} = \frac{I}{J} = \frac{5}{3} = 1.667 mm^2$$

SWG 16.

Cu area = 2.075 mm²

Dia = 1.709 mm²

Cu dia = 1.625 mm²

$$N = \frac{L I_{max}}{A_c B_{max}} = \frac{51.2 \times 10^{-6} \times 5.1562}{60 \times 0.2 \times 10^{-6}}$$

$N = 21.8 \approx 24$

window height = $2 \times 9.7 = 19.4$ mm

utilized window height = $19.4 - (2\times1 + 2\times2)$

= 13.4 mm

wire dia = 1.709 mm

Number of turns / layer = $\frac{13.4}{1.709} = 7.84$

choose 6 turns for 4 layers → 24 turns

$h = 0.866 \times 1.625$

$h = 1.407$ mm

$$F_l = \frac{6 \times 1.625}{13.4} = 0.727$$

$\Delta = 0.25$ @ 75KHz

$$\frac{h\sqrt{F_l}}{\Delta} = \frac{1.407 \times 0.727}{0.25} = 4.095$$

$$F_r = \frac{2p^2+1}{3} \times \frac{h\sqrt{F_l}}{\Delta}$$

$F_r = 45.045$

$$R_{DC} = \frac{53.2 \times 13.4}{1000} \times 0.0083 \times 1.2$$

$$R_{DC} = 7.1\,m\Omega$$

$$R_{AC} = 7.1\,m\Omega \times 45.045 = 0.32\,\Omega$$

Copper loss, $I_{DC}^2 R_{DC} + I_{ac}^2 R_{ac} = P_{cu}$

$$P_{cu} = 7.1 \times 10^{-3} \times 5^2 + 0.32 \times \left(\frac{0.156}{\sqrt{3}}\right)^2$$

$$P_{cu} = 0.18\,W$$

Core loss,

$B_m$ varies from $0.2\ Wb/m^2 \rightarrow 0.2 \times \frac{4.843}{5.156}$

$0.2\ Wb/m^2 - 0.187\ Wb/m^2$

$$\Delta B_m = \frac{0.2 - 0.187}{2} = 6.5 \times 10^{-3}$$

$$\Delta B_m = 7\,m\,Wb/m^2$$

$$cl = 2\,mW/cc$$

$$P_c = 4 \times 2 = 8\,mW$$

$$P_T = P_{cu} + P_c$$

$$P_T = 0.18 + 0.008$$

$$\boxed{P_T = 0.188\,W}$$

For transformer,

$$P_o = (1.47\,\eta\, B_{max}\, J\, f_s\, k_s)\,(A_p)$$

let $\eta = 90\%$

$$A_p = \frac{P_o}{1.47\,\eta\, B_{max}\, J\, f_s\, k_s}$$

$$A_p = \frac{24 \times 5}{1.47 \times 0.9 \times 0.2 \times 10^{6} \times 3 \times 75000 \times 0.35}$$

$A_p = 5758.9\,mm^4$

$\therefore$ for EE 30/15/7

$A_p = 7158.6\,mm^4$

$\therefore$ we choose EE 30/15/7 core

(6) Given,

$V_{in} = 250-400V$

$V_o = 12V$

$I_o = 5A-20A$

$\Delta V_o < 2\%\ p\text{-}p$

$\Delta i_L < 4A\ p\text{-}p$

$f_s = 50kHz$

$D_{max} = 0.45$

$$V_o = \frac{DV_{in}}{n}$$

$$n = \frac{D_{max} V_{in\,min}}{V_o} = \frac{0.45 \times 250}{12}$$

$$n = 9.32 \approx 9$$

$$\therefore D_{min} = \frac{nV_o}{V_{in(max)}} = \frac{9 \times 12}{400} = 0.27$$

D values from 0.27 to 0.45

$$\Delta i_L = \frac{V_o(0.5 - D)T_s}{L}$$

$$\Delta i_L = \frac{12(0.5 - 0.27)}{4 \times 50 \times 10^3}$$

$$\boxed{L = 13.8\mu H}$$

Capacitance, ESR $\times 4 = 0.24$

$ESR = 0.24/4 = 0.06\Omega$

$C = 50 \times 10^{-6}/0.06 = 833.3\mu F$

$$\Delta i_L = \frac{V_o(0.5 - 0.45)}{50\times10^3 \times 13.8\times10^{-6}}$$

$\Delta i_L = 0.869A$

$i_{L_{max}} = 20.43A$

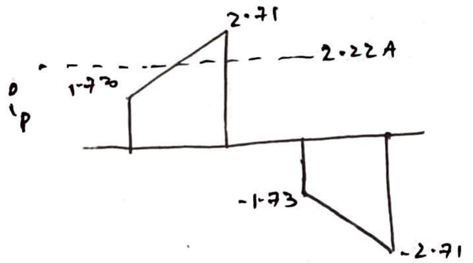
$i_{L_{min}} = 19.56A$

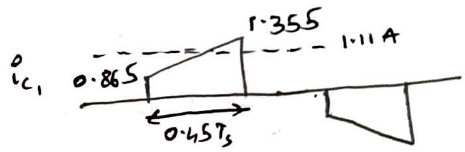
Reflected secondary currents, 2.174 - 2.270A

$\therefore$ primary current varies b/w $(2.17 - 0.44)A$ to

$(2.27 + 0.44)A$

$\rightarrow$ 1.73A to 2.71A




Charge contained in +ve half cycle $= \frac{1.11 \times 0.45}{50\times10^3} = 9.99\mu C$

5% P-P ripple is allowed in $C_1$ & $C_2$

$\therefore \left(\frac{V_{in}}{2}\right) \times 0.05 \times C = 9.99\mu C$

$C_1 = C_2 = 1.6\mu F \rightarrow$ paper capacitor

charge contained in one half cycle of $i_p = 2.22 \times 0.45 \times 20\times10^{-6}$

$= 19.98\mu C$

$\therefore \frac{250}{2} \times 0.05 \times C_b = 19.98\mu C$

$\boxed{C_b = 3.3\mu F}$

switch peak current = 2.71A

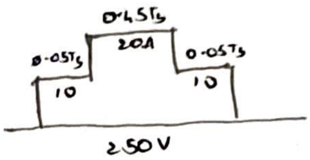
switch avg current = $(i_p)_{av}$ = 2.22A

switch RMS current = $(i_p)_{rms}$ for $T_s/2$ : $2.2\sqrt{0.45} = 1.475A$

o/p diode peak current = $20 + \underset{\text{ripple}}{2} = 22A$

o/p diode avg current = $\frac{(I_L)_{avg}}{2} = \frac{20}{2} = 10A$

o/p diode RMS current = secondary RMS.




$$\rightarrow \sqrt{\frac{20^2 \times 0.45 \times 20 \times 10^{-6} + 10^2 \times 2 \times 0.05 \times 20 \times 10^{-6}}{20 \times 10^{-6}}}$$

$$= \underline{\underline{13.78A}}$$

<u>Transformer:</u>

primary RMS = $\frac{I_o}{n}\sqrt{2D_{max}}$

secondary RMS = $\frac{I_o}{2}\sqrt{2D_{max}+1}$

$$K_s A_w = n_p \times \frac{I_o}{n}\frac{\sqrt{2D_{max}}}{J} + \frac{I_o}{2J}\sqrt{2D_{max}+1} \times 2n_s$$

$$D_{max} = 0.45$$

$$K_s A_w = 2.33 n_s \frac{I_o}{J}$$

$$A_w = \frac{2.33 n_s I_o}{K_s J}$$

$\rightarrow n V_o T_s = 2 B_m A_c n_p$

$$A_c = \frac{n V_o T_s}{2 n_p B_m} = \frac{V_o}{2 f_s B_m n_s}$$

$$A_c A_w = \frac{2.33 V_o I_o}{k_s J B_m f_s} = \cancel{5.8\times}$$

$\therefore A_p = 26628.57 \text{ mm}^4$

for EE42/21/~~15~~

$A_c = \cancel{\phantom{00}}\ 178 \text{ mm}^2$

$$A_w = (2\times 14.8)\times\left(\frac{29.5-12.2}{2}\right) = 256.04 \text{ mm}^2$$

$A_p = \cancel{59913.36}\ 45568 \text{ mm}^4$

Hence we choose EE42/21/~~15~~ core for Tf

$$n_s = \frac{1}{\frac{2 f_s B_m A_c}{V_o}} = \frac{V_o}{2 f_s B_m A_c} = 3.37$$

$n_s \approx 4$

$n_p = n \times n_s = 9 \times n_s$

$n_p = 9\times 4 = 36$

Inductor,

RMS value of $I_L \approx 20A$

copper area $= \frac{I}{J} = \frac{20}{3} = 6.667 \text{ mm}^2$

$\therefore$ SWG 11 has

cu area $\rightarrow 6.818 \text{ mm}^2$

cu dia $\rightarrow 2.946$ mm

dia $\rightarrow 3.068$ mm

Calculated $L = 13.8\mu H$

$$K_i^p = \frac{I_{max}}{I} = \frac{20.43}{20} = 1.0215$$

$K_s = 0.35$

$$A_p = \frac{1}{2} L I^2 \frac{2K_i^p}{K_s J B_{max}}$$

$$A_p = \frac{1}{2} \times \frac{13.8\times10^{-6}\times20^2\times2\times1.0215}{0.35\times3\times0.2\times10^{-6}}$$

$A_p = 26850.85 mm^4$

$\therefore$ EE 42/20/15 core is selected

Mean turn length $= 4\times\left(12.2 + \frac{29.5-12.2}{2}\right)$

$l_m = 83.4mm$

$$N = \frac{L I_{max}}{A_c B_{max}} = \frac{13.8\times10^{-6}\times 20.43}{178\times0.2\times10^{-6}} = 7.91$$

$N = 7.91 \approx 8$

window height $= 2\times14.8 = 29.6mm$

utilize height $= 29.6 - 6 = 23.6mm$

Number of turns/layer $= \frac{23.6}{3.068} = 7.69$

$\therefore$ $4\times2$ layer $= 8$ turns

$h = 0.866\times d = 0.866\times 2.946$

$= 2.5512mm$

$$F_l = \frac{N \times d}{W} = \frac{4 \times 2.946}{23.6} = 0.496$$

$\Delta = 0.141\ mm$ @ 50 kHz

$$\therefore \frac{h\sqrt{F_l}}{\Delta} = 12.74$$

$$\therefore F_r = \frac{2p^2+1}{3}\,\frac{h\sqrt{F_l}}{\Delta} = \frac{2 \times 2^2 + 1}{3} \times 12.74$$

$$F_r = 38.22$$

$$R_{DC} = \frac{83.4 \times 23.6}{1000} \times 0.0025 \times 1.2$$

$R_{DC} = 5.9\ m\Omega$ @ $70°C$

$$R_{AC} = 5.9\,m\Omega \times 38.22 = 0.225\,\Omega$$

$$\text{Cu loss} = 20^2 \times 5.9 \times 10^{-3} + \left(\frac{0.43}{\sqrt{3}}\right)^2 \times 0.225$$

$$\text{Cu loss} = 2.36 + 0.0139$$

Cu loss = 2.37 watt

Bm changes from $0.2\ wb/m^2 \longrightarrow 0.2 \times \frac{19.56}{20.43}$

$$\Delta B_m = \frac{0.2 - 0.19}{2} = 5\,mT$$

$\therefore$ core loss at 50 kHz $= 0.6\ mW/cc$

core volume $= 17.3\ cc$

$P_c = 17.3 \times 0.6\ mW = 10.38\ mW$

$P_T = P_{cu} + P_c = 2.384\ W$

(7) Given,

$V_{in} = 250 - 400V$ MOSFET - 900V $(V_R)$

$V_o = 12V$ $J = 3A/mm^2$

$I = 2-5A$ $B_m = 0.25wb/m^2$

$\Delta V_o = 2\%$ P-P

$f_s = 100KHz$

from MOSFET voltage rating find 'n'

$$1.3\left(V_{in_{max}} + n(V_o + V_\gamma)\right) \leq 0.8 \times V_R$$ $V_\gamma = 1V$ for silicon

$$1.3\left(400 + n(12+1)\right) \leq 0.8 \times 900$$

$$n : 11.83 \approx 12 \text{ turns}$$

use n to find $D_{max}$

$$D_{max}\left(1 + \frac{V_{in_{min}}}{n(V_o+V_\gamma)}\right) \leq 0.8$$

$$D_{max} = \frac{0.8}{1 + \frac{250}{12(12+1)}} = 0.31$$

$$D_{max} = \sqrt{\frac{2\, l_p\, P_{o_{max}}\, f_s}{V_{in_{max}}^2}}$$

$$0.31 = \sqrt{\frac{2 \times l_p \times 12 \times 5 \times 100 \times 10^3}{250^2}}$$

$$l_p = \frac{(0.31 \times 250)^2}{2 \times 60 \times 100 \times 10^3} = 500.5 \mu H$$

leakage inductance $\rightarrow$ 4% of $L_p$

$$L_l = 20.02\ \mu H$$

$$\rightarrow \quad V_{in} + n(V_o + V_\gamma) = 250 + 12(12+1) = 406$$

$$V_{in} + V_c > 406$$

If we want $V_{in} + V_c = 600$

$$V_c = 600 - 406 = 194V$$

$$R_c = \frac{2V_c\left(V_c - n\left(V_o + V_\gamma\right)\right)}{f_s L_l I_p^2}$$

$$I_p = \frac{V_{in\,max} D_{max}}{L_p f_s} = \frac{250 \times 0.31}{500.5 \times 10^{-6} \times 100 \times 10^3}$$

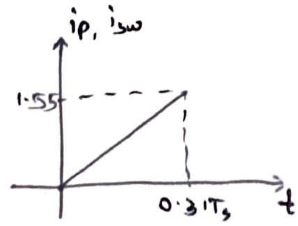
$$I_p = 1.55A$$

$$R_c = \frac{2 \times 194\left(194 - 12\left(12+1\right)\right)}{100 \times 10^3 \times 20 \times 10^{-6} \times 1.55^2}$$

$$R_c = 3068.4\ \Omega$$

$$C_c > \frac{1}{2\pi f_s R_c} = 518.69 pF$$

primary RMS current =




$$i_p = \frac{1.55t}{0.31T_s}$$

$$(i_p)_{rms} = \sqrt{\frac{1}{T_s}\int_0^{0.31T_s}\left(\frac{1.55t}{0.31T_s}\right)^2 dt} = 0.492A$$

flux linkage in primary = $L_p \times I_p$

$= 500.5 \times 10^{-6} \times 1.55$

$= 775.7 \mu Wb\cdot T$

$775.7 = A_c \times n_p \times B_m$

$$A_c = \frac{775.7 \times 10^{-6}}{0.2 \times 10^{-6} \times n_p}$$

$$K_s A_w = n_p \times 0.24\, mm^2 + n_s \times 2.67\, mm^2$$

$$A_w = n_p \left( 0.24 + \frac{2.67}{12} \right)$$

$$A_w = \frac{0.4625}{0.35} n_p = 1.32\, n_p$$

$\therefore A_c A_w = 5119.62\, mm^2$

we choose E 30/15/7 core $\rightarrow A_p = 7100\, mm^2$

$A_c = 59.7\, mm^2$

$A_w = 119\, mm^2$

$$A_c = \frac{775.7}{0.2\, n_p} \Rightarrow n_p = \frac{775.7}{0.2 \times 59.7}$$

$n_p = 64.9 \approx 65$ turns

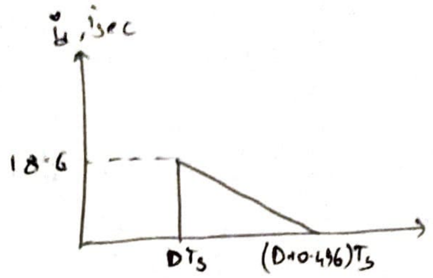
$$n_s = \frac{n_p}{n} = \frac{65}{12} = 5.4 \approx 6 \text{ turns}$$

for DCM.

$T_s = DT_s + t_\gamma + t_d$

diode conducts during $t_\gamma$

$$t_\gamma = \frac{D_{max} V_{in\,min} T_s}{n(V_o + V_\gamma)} = \frac{0.31 \times 250}{12 \times 13} T_s = 0.496 T_s$$




$i_d = nI_p = 18.6$

$$i_d = \frac{18.6\,t}{0.496 T_s} = \frac{37.5t}{T_s}$$

$$i_{sec(rms)} = \sqrt{\frac{1}{T_s} \int_0^{0.496T_s} \left(\frac{37.50\,t}{T_s}\right)^2 dt}$$

$$i_{sec(rms)} = 7.81\,A$$

Diode RMS current = 7.81A

Diode peak current = 18.6A

Mosfet RMS current = ~~1.55A~~ 0.492 A

Mosfet peak current = 1.55A

$$\text{primary wire} = \frac{I}{J} = \frac{0.492}{3} = 0.164\,mm^2 \rightarrow SWG24$$

size = $0.245\,mm^2$

$$\text{secondary wire} = \frac{I}{J} = \frac{7.81}{3} = 2.436\,mm^2 \rightarrow SWG15$$

size = $2.67\,mm^2$

Transformer,

with $L_p = 500.5\mu H$

$n = 12$

8

$$1.3\left[V_{in_{max}} + n(V_o + V_\gamma)\right] \le 0.8 V_B$$

$$V_\gamma = 1V \qquad (L_p)_{min} = \frac{n(V_o+V_\gamma)V_{in_{max}}}{n(V_o+V_\gamma)+V_{in_{max}}} \times \frac{1}{2 f_s P_{o_{min}}}$$

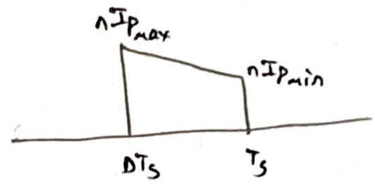
$$1.3\left[400 + n(12+1)\right] \le 720$$

$$n = 11.83 \approx 12$$

$$L_{p_{min}} = \left(\frac{12\times13\times400}{12\times13+400}\right)^2 \times \frac{1}{2\times100\times10^3\times24}$$

$$L_{p_{min}} = 2.33\,mH$$

**Secondary RMS**




$$D_{min} = \frac{n(V_o+V_\gamma)}{n(V_o+V_\gamma)+V_{in_{max}}} = \frac{12(13)}{12(13)+400} = 0.28$$

$$D_{max} = \frac{n(V_o+V_\gamma)}{n(V_o+V_\gamma)+V_{in_{min}}} = \frac{12\times13}{12\times13+250} = 0.384$$

$$I_{P_{max}} + I_{P_{min}} = \frac{2 I_o}{n(1-D_{min})} = \frac{2\times5}{12(1-0.28)} = 1.157 \quad \text{—(1)}$$

$$I_{P_{max}} - I_{P_{min}} = \frac{n(V_o+V_\gamma)}{f_s L_p}(1-D) = \frac{12(13)(1-0.28)}{2.33\times10^{-3}\times100\times10^3}$$

$$I_{P_{max}} - I_{P_{min}} = 0.482 \quad \text{—(2)}$$

from (1) & (2)

$$I_{P_{max}} = 0.8195A$$

$$I_{P_{min}} = 0.3375A$$

$$I_{sec} \approx \left( \frac{n I_{P_{max}} + n I_{P_{min}}}{2} \right) \sqrt{1 - D_{min}}$$

$$I_{sec_{rms}} = \left( \frac{12 \times 0.8195 + 12 \times 0.3375}{2} \right) \sqrt{1 - 0.28}$$

$$I_{sec_{rms}} = 5.89A$$

$$I_{avg} = I_o = \frac{P_o}{V_o} = 5A$$

$$I_{d\,peak} = n I_{P_{max}} = 12 \times 0.8195 = 9.834A$$

$$I_{d\,avg} = \left( \frac{n I_{P_{max}} + n I_{P_{min}}}{2} \right) (1 - D_{min}) = 4.9 \approx 5A$$

Primary RMS:

$$I_{P_{max}} + I_{P_{min}} = \frac{2 I_{O_{max}}}{n(1 - D_{max})} = \frac{2 \times 5}{12(1 - 0.384)} = 1.3528 \quad \text{— (3)}$$

$$I_{P_{max}} - I_{P_{min}} = \frac{n(V_o + V_\gamma)(1 - D_{max})}{L_p f_s} = \frac{12(13)(1 - 0.384)}{2.33 \times 10^{-3} \times 100 \times 10^{3}} = 0.412 \quad \text{— (4)}$$

from (3) & (4)

$$I_{P_{max}} = 0.8824A$$

$$I_{P_{min}} = 0.4704A$$

$$(i_p)_{rms} = \left( \frac{I_{P_{max}} + I_{P_{min}}}{2} \right) \sqrt{D_{max}}$$

$$(i_p)_{rms} = \left( \frac{0.8824 + 0.4704}{2} \right) \sqrt{0.384} = 0.692A$$

$$i_{avg} = \left( \frac{I_{P_{max}} + I_{P_{min}}}{2} \right) D_{max} = 0.259A$$

# Transformer

$$I_{P_{max}} = 0.8824A$$

$$L_p I_{P_{max}} = A_c n_p B_m$$

$$A_c = \frac{L_p I_{P_{max}}}{n_p B_m}$$

$$A_c = \frac{2.33 \times 10^{-3} \times 0.8824}{n_p \times 0.25 \times 10^{-6}} = \frac{8223.9}{n_p}$$

$$K_s A_w = n_p \times A_p + n_s \times A_s$$

$$A_w = \frac{n_p}{K_s}\left(A_p + \frac{n_s}{n_p} A_s\right)$$

$$A_w = \frac{n_p}{0.35}\left(0.141 + \frac{2}{12}\right)$$

$$A_p = A_c A_w = \frac{8223.9}{n_p} \times \frac{n_p}{0.35}\left(0.141 \times \frac{2}{12}\right)$$

$$A_c A_w = 7228.4 mm^2$$

∴ we choose E 32/16/11 core

→ $A_c = 97 mm^2$

$A_P = 14340 mm^4$

$$\therefore n_p = \frac{8223}{A_c} = \frac{8223}{97} = 84.77$$

$$n_s = \frac{84.77}{12} = 7.06$$

$$\therefore \boxed{n_p = 96, \quad n_s = 8}$$

↓ SWG26 ↓ SWG16

(9)

$$V_o = \frac{V_{in}}{1-D}$$

$$24 = \frac{10.8}{1-D}$$

$$1-D = 0.45$$

$$D_{max} = 0.55$$

$$24 = \frac{13.6}{1-D}$$

$$1-D = 0.566$$

$$D = 0.433$$

$$P_o = P_{in}$$

$$I_{in} = \frac{I_o}{1-D}$$

for $I_o = 1A$, $I_{in} = 2.22A$

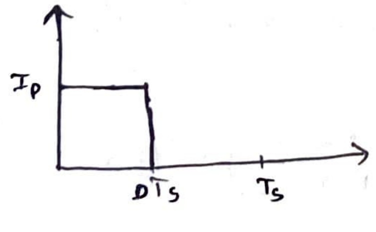
$I_o = 4A$, $I_{in} = 8.88A$

sensing gain $= 0.125 V/A$

$I = 1A$, $V = 0.125V$

$I = 8.88A$, $V = 1.11V$

Assume $x = 1\%$




$I = 8.88A$

$V = 1.11V$

$V_{fw} = 0.6V$

$D_{max} = 0.55$

$$nL_m \geq \frac{100 D_{max}(V + V_{fw})}{x f_s I}$$

$$nL_m = \frac{100 \times 0.55 (1.11 + 0.6)}{1 \times 50 \times 10^3 \times 8.88}$$

$$nL_m = 211.82 \mu H \cdot T$$

$$B_m = \frac{D_{max}(V+V_{fw})}{n f_s A_c} = \frac{0.55(1.11+0.6)}{50\times10^3 \times n \times A_c}$$

$$B_m = \frac{1.881\times10^{-5}}{n A_c}$$ , we choose $T_{32}$ core , $n = 87$

| core | $A_c$ | $A_W$ | $A_L$ | $I_s = \frac{I_{P_{rms}}}{n}$ | $B_m$ | $n$ |
|---|---|---|---|---|---|---|
| $T_{10}$ | 6.2 | 19.6 | 765 | 0.023 | 0.0108 | 276 |
| $T_{12}$ | 12 | 44.2 | 1180 | 0.036 | $8.7\times10^{-3}$ | 179 |
| $T_{16}$ | 20 | 78.5 | 1482 | 0.046 | , | 142 |
| $T_{20}$ | 22 | 95 | 1130 | 0.035 | , | 187 |
| $T_{27}$ | 42 | 165 | 1851 | 0.037 | , | 114 |
| $T_{32}$ | 61 | 165 | 2427 | 0.075 | , | 87 |
| $T_{45}$ | 93 | 616 | 2367 | 0.074 | , | 89 |

$J = 3 A/mm^2$

$$J = I/A \rightarrow A = \frac{I}{J} = \frac{0.075}{3} = 0.025 mm^2$$

$\therefore$ SWG 32 wire is selected

$$V_z = (V+V_{fw})\left(\frac{D_{max}}{1-D_{max}}\right) - V_{fw}$$

$$V_z = (1.11+0.6)\left(\frac{0.55}{1-0.55}\right) - 0.6$$

$$V_z = 1.49V$$

power rating of zener $= \frac{L_m I_m^2 f_s}{2}$

$$L_m = \frac{211.8\times10^{-6}}{87} = 2.43\times10^{-6}$$

$$P = \frac{2.43\times10^{-6}\times(0.01\times8.88)^2\times 50000}{2} = 0.479mW$$

$$R_s = \frac{V}{I/n} = \frac{1.11}{8.88/87}$$

$$\boxed{R_s = 10.875\,\Omega}$$

$$P = I_{rms}^2 R$$

$$P = (0.075)^2 \times 10.8 = 0.061W$$

10

$I = 1.11A \longrightarrow V = 0.139V$

$0.125\,V \longrightarrow 1A$

$1.11A \longrightarrow 1.11 \times 0.125 = 0.139V$

$$nL_m \geq \frac{3.2V}{I f_s}$$

$$nL_m = \frac{3.2 \times 0.139}{50 \times 10^3 \times 1.11} \approx 8.01\,\mu H \cdot T$$

$$I_m = \frac{DV}{2nL_m f_s} = \frac{0.36V}{2nL_m f_s}$$

$$I_m = \frac{0.36 \times 0.139}{2 \times 8.01 \times 10^{-6} \times 50K} = 0.0624$$

but $I_m >> 1\%$ of $I$

$1\%$ of $I = 0.011$

$$0.011 = \frac{0.36 \times 1}{2 \times 50000 \times nL_m}$$

$$nL_m = 327.27\,\mu H \cdot T$$

$$B_m = \frac{DV}{2n f_s A_c} = \frac{0.36 \times 0.139}{2 \times 50000 \times n A_c}$$

| core | $A_c$ | $A_L$ | $n$ | $B_m$ |
|---|---|---|---|---|
| $T_{10}$ | 6.2 | 765 | 427 | $1.39\times10^{-4}$ |
| $T_{12}$ | 12 | 1180 | 217 | $1.5\times10^{-4}$ |
| $T_{20}$ | 22 | 1130 | 209 | |
| $T_{32}$ | 61 | 2427 | 134 | |
| $T_{45}$ | 93 | 2367 | 138 | |

$$J = 2.5\,A/mm^2 = I/A$$

$$A = I/J = 4\times\frac{1.11}{2.5} = \cancel{0.44}\ 1.76\,mm^2 \longrightarrow SWG\ 15$$

So, we choose $T_{45}$ toroid core

138 turns of SWG 15

$$R_s = \frac{V}{I/n} = \frac{0.139}{\frac{1.11}{138}}$$

$$R_s = 17.28\,\Omega$$

$$P = I_{rms}^2 R_s = 4.44^2 \times 17.28 = 1.14$$

$$R_s = 17.28\,\Omega / 1.5\,W$$

(11)

$$V_o = \frac{2 V_{in} D}{n}$$

$$D_{max} = \frac{n V_o}{2 V_{in_{min}}} = \frac{6 \times 12}{2 \times 180} = 0.2$$

CT design parameter

$I = \frac{10}{6} = 1.67A$

$x = 1\%$

$D_{max} = 0.2$

$V = 0.5 \times 1.67 = 0.833$

$f_s = 80 kHz$

$V_{fw} = 0.6$

$I_m = 1\%$ of $I$

$$n L_m = \frac{100 D_{max} (V + V_{fw})}{x f_s I} = \frac{100 \times 0.2 (0.833 + 0.6)}{1 \times 80 \times 10^3 \times 1.67}$$

$n L_m = 0.215 mH$

| Core | n | $(I_s)_{rms}$ | $B_m$ |
|---|---|---|---|
| $T_{10}$ | 280 | $2.66 \times 10^{-3}$ | $2.06 \times 10^{-3}$ |
| $T_{12}$ | 182 | $4.1 \times 10^{-3}$ | $1.64 \times 10^{-3}$ |
| $T_{20}$ | 140 | $3.9 \times 10^{-3}$ | |
| $T_{32}$ | 88 | $8.48 \times 10^{-3}$ | |
| $T_{45}$ | 90 | $8.29 \times 10^{-3}$ | |

$T_{32}$, $n = 88$, $I_s = 8.48 \times 10^{-3}$ is choosen

$$A = \frac{8.48 \times 10^{-3}}{2.5} = 0.0033 mm^2$$

SWG 32 is choosen

$$v_z = \frac{D_{max}}{1-D_{max}}(v + v_{fw})$$

$$v_z = \frac{0.2}{0.8}(0.833+0.6) = 0.358V$$

Power rating of zener $= \frac{L_m I_m^2 f_s}{2}$

$$= \frac{2.42\times10^{-6}\times(0.01\times1.67)^2\times80\times10^3}{2}$$

$$= 27.1\,\mu W$$

$$R_s = \frac{v}{I/n} = \frac{0.833}{1.67/88} = 43.89\,\Omega$$