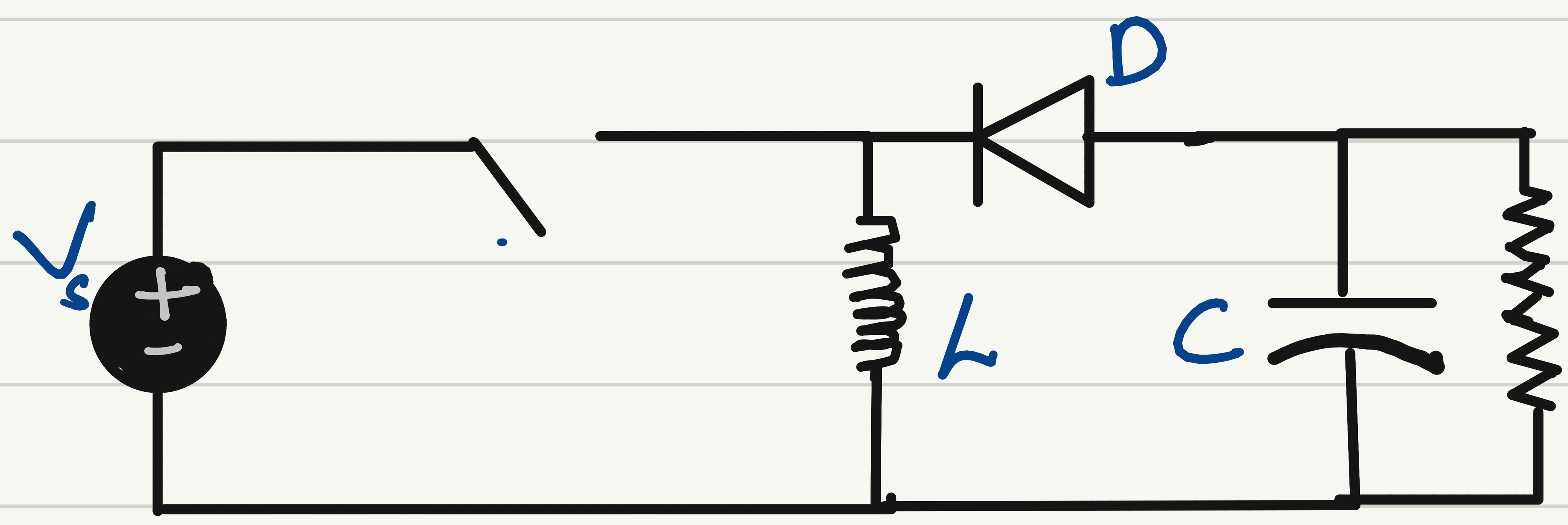
Design of magnetics : Course project 210020050

Problem statement: Design an inductor with specification for buck converter

Input voltage	10V
Output voltage	40V
Power	100W
Efficiency	88%
frequency	20khz
ΔT	45 °C
T	40 °C
voltage ripple	1%



$$D = \frac{V_o}{V_o + V_{in}} = \frac{40}{40+10} = 0.8$$

(∴ V_{in} minimum to V_{out} maximum)

$$I_{in} = \frac{P_o}{\eta V_{in}} = \frac{100}{0.88(10)} = 11.36A$$; Input power = 113.6W

$$I_{OUT} = \frac{P_o}{V_o} = \frac{100}{40} = 2.5A \text{ (minimum)}$$

$$I_{out} = \frac{P_o}{V_o} = \frac{100}{5} = 20A \text{ (maximum)}$$

$$I_{in} = \frac{P_o}{\eta V_{in}} = \frac{100}{0.88(30)} = 3.78A$$; (max voltage)

assuming 20% ripple of current

$11.36 \times 0.2 = \Delta I_L = 2.26A ;\ 0.76A$

inductance at minimum voltage and $D = 0.5$

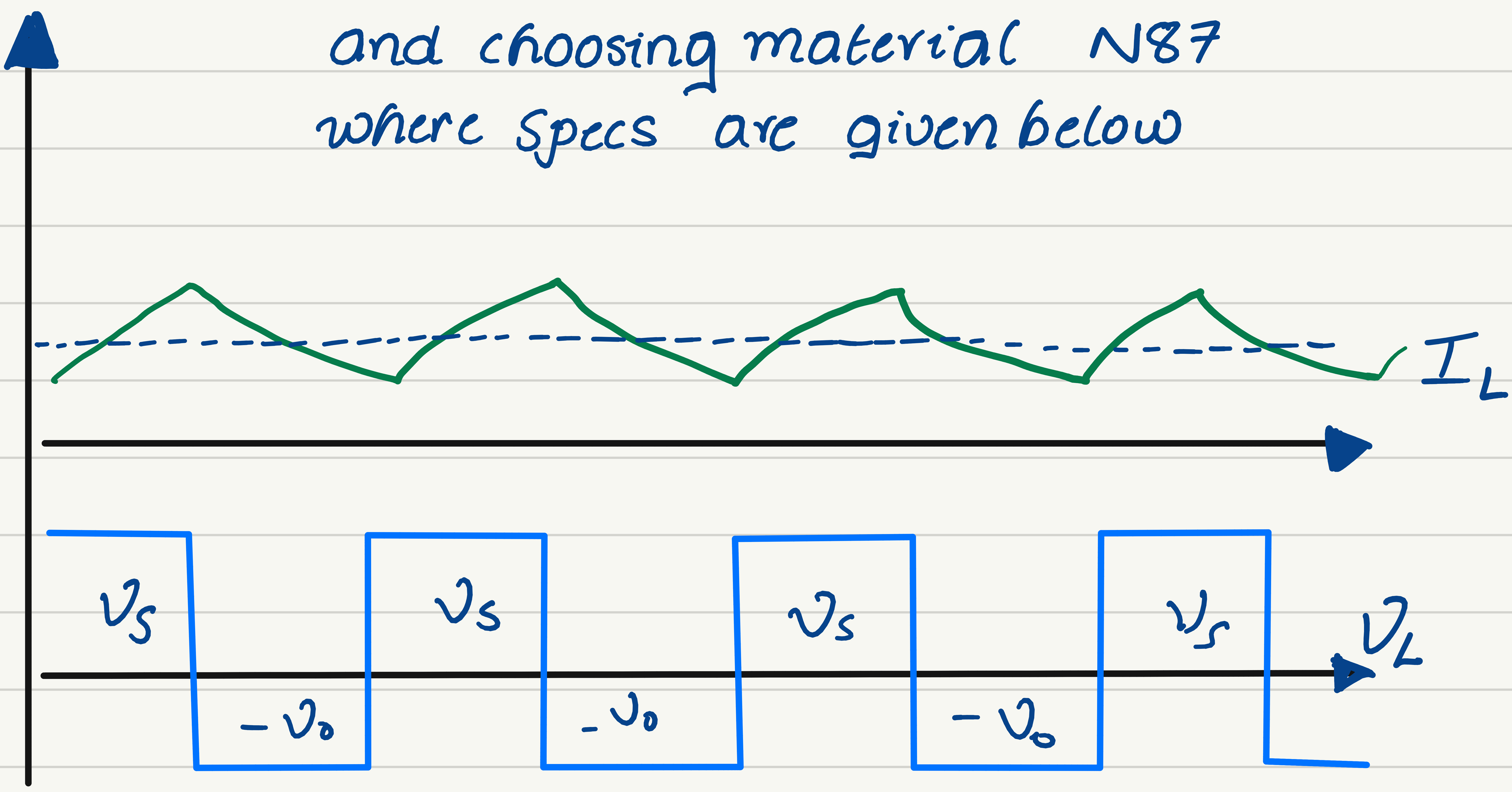
$V_{IN} = 10V ;\ V_{OUT} = 10V ;$

$$L_{min} = 10 \times 0.5 / 20 \times 10^3 \times 2.26 = 1.1mH$$

$$L_{max} = 30 \times 0.5 / 20 \times 10^3 \times 0.76 = 0.9mH$$

So 1.1mH inductance will be good enough

and choosing material N87 where specs are given below



$B_m = 0.25T ;\ K_u = 0.8 ;\ r = 0 ;\ K_i = 1$

$$I_m = 11.36 + \frac{2.26}{2} = 12.5A$$

$$A_p = \left[\frac{\sqrt{1+r}\, K_i L I^2}{B_m K_t \sqrt{K_u \Delta T}} \right]$$

$$A_p = \left[\frac{\sqrt{T}\,(1)\,110\times10^{-6}\,(12.5)^2}{0.25\,\sqrt{0.8\times45}}\right]$$

$$K_t = \sqrt{\frac{h\,k_a}{\delta_w\,k_w}} = \sqrt{\frac{10\times40}{1.72\times10^{-8}\times10}} = 48.2\times10^{3}$$

$$A_p = \frac{0.017}{0.25\times48.2\times10^{3}\times\sqrt{0.845}} = 2.65\,cm^4$$

$$P_D = \Delta T/R_\theta = 45/11 = 4.09\,W$$ (11 for core)

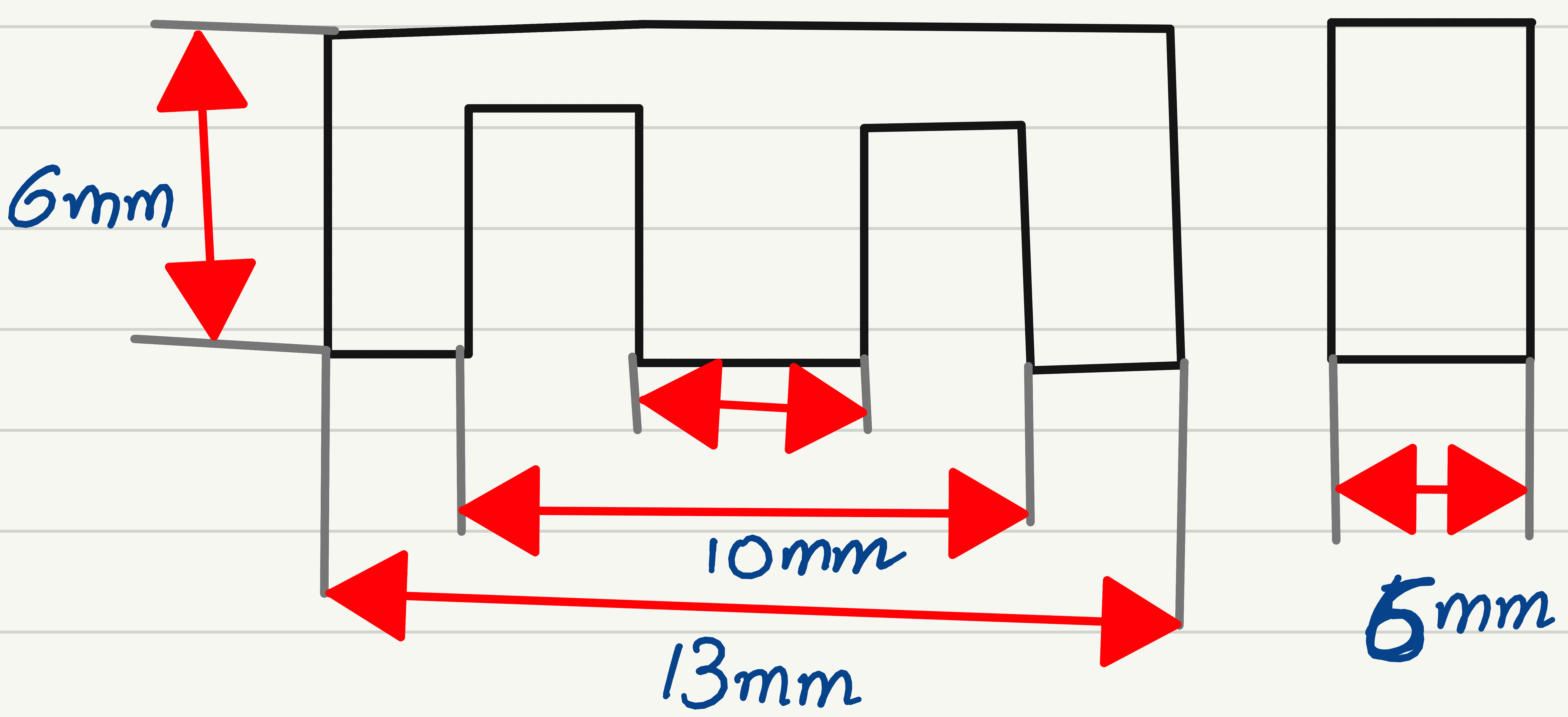
EE 13/6/5 is suitable from TDK

$A_c = 0.33\,cm^2$

$W_a = 8\,cm^2$

$A_p = 0.33\times8 = 2.64\,cm^4$

from datasheet



effective core lenght $= l_c$

$= 4.6\,cm$

Choosing core material as copper

$MLT = 2.4\,cm$

$$\mu_{eff} = \frac{B_m l_c k_i}{\mu_0 \sqrt{\frac{\rho_{cu} k_u W_a}{\delta_\omega MLT}}}$$

$$= \frac{0.25 \times (4.6 \times 10^{-2})}{4\pi \times 10^{-7} \sqrt{\frac{(2.27) \times 0.8 \times 8 \times 10^{-5}}{(1.72 \times 10^{-8}) \times (4.6 \times 10^{-2})}}}$$

$$\mu_{eff} = 6.75$$

gap lenght $\Rightarrow g = \frac{l_c}{\mu_{ef}} = \frac{4.6 \times 10^{-2}}{6.75} = 0.68\,mm$

from data sheet $A_L = 900 \times 10^{-9}$

$$N = \sqrt{\frac{L}{A_L}} = \sqrt{\frac{110 \times 10^{-6}}{900 \times 10^{-9}}} \simeq 11 \text{ Turns}$$

Analytical caluclations:

$\Rightarrow$ Copper radius

$$J_0 = k_t \frac{\sqrt{\Delta T}}{\sqrt{k_u(1+\gamma)} \sqrt[8]{A_p}}$$

$$= 48.2 \times 10^3 \frac{\sqrt{45}}{\sqrt{0.8} \sqrt[8]{2.65 \times 10^{-8}}}$$

$$= 3.2 \times 10^6 \ A/m^2$$

$$A = \frac{11.36}{3.2\times10^{6}}$$

$$A_{wire} = 3.55\times10^{-4}$$

⇒ Copper Loss

T_{max} : $85^\circ C$

$$R_{DC} = \frac{N \times MLT \times (\rho)}{A}\left(1+\alpha(T-T_0)\right)$$

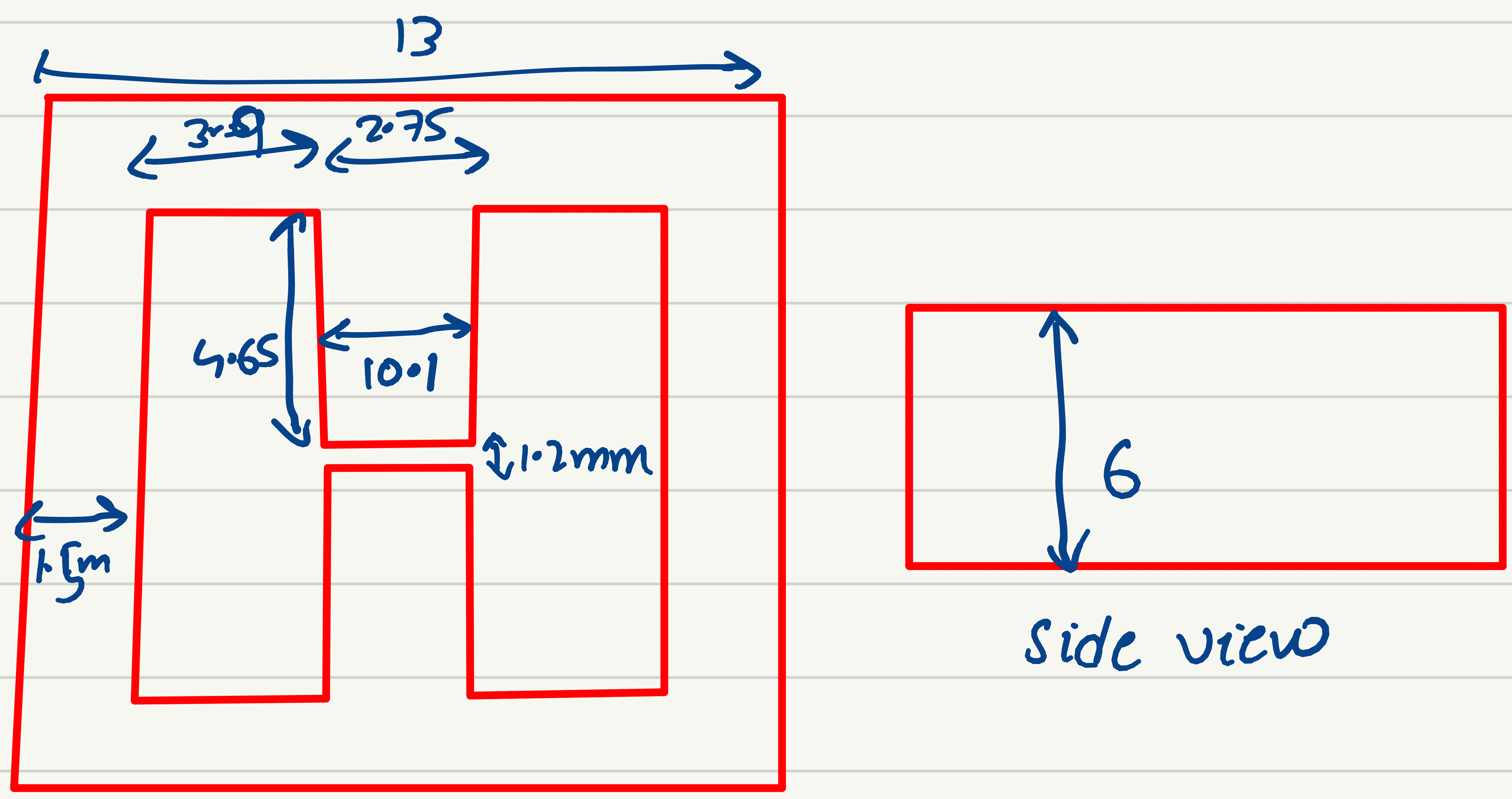
$$R_{DC} = \frac{11\times2.4\times10^{-1}\times1.72\times10^{-8}}{3.55\times10^{-4}}\left(1+0.00393(85-20)\right)$$

$$R_{DC} = 0.0127$$

$$P_{cu} = R_{DC} \times I_m^2$$

$$= 0.0127\times11.36^2$$

$$= 1.63\ W$$

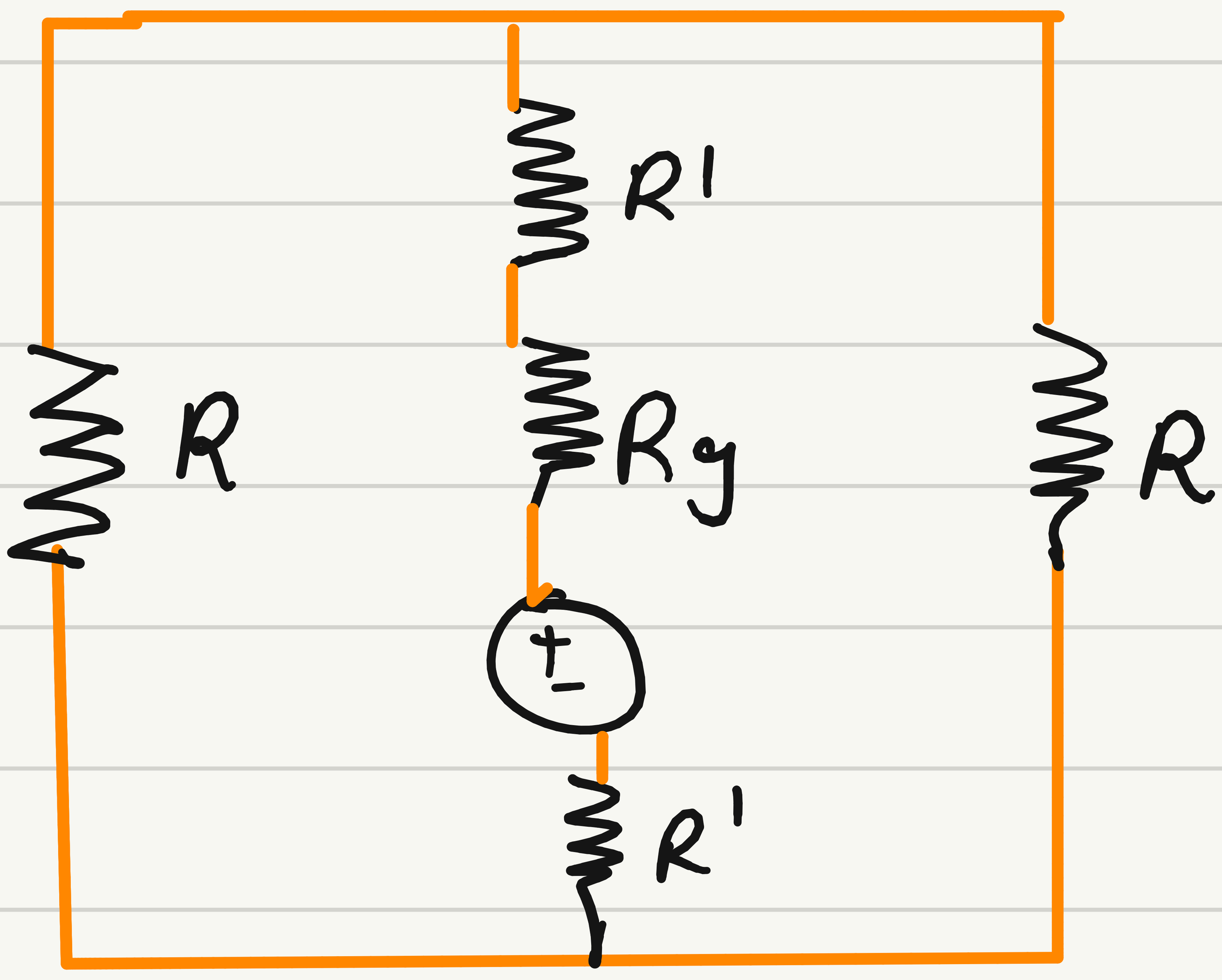


Top view

already drawn above

gap lenght must be $0.2mm$

from datasheet



$$R_g = \frac{l_g}{\mu_0 \times A_c} = \frac{0.2\times10^{-3}}{4\pi\times10^{-7}\times(2.7\times6)}$$

$$R_g = 1.2\times10^{5}$$

$$R = \frac{l}{\mu\times A_c} = \frac{4.65\times10^{-3}}{4\pi\times10^{-7}\times5000\times(2.7\times6)}$$

$$= 4.57\times10^{3}$$

$$R' = \frac{l}{\mu\times A_c} = \frac{(13+3.85+3.85)\times10^{-3}}{4\pi\times10^{-7}\times5000\times(6\times1.5)}$$

$$= 35.3\times10^{3}$$

$$R_{eff} \equiv 1.3\times10^{5}$$

$$L = \frac{N^2}{R} = \frac{11^2}{1.3\times10^{5}} = 9.5mH$$