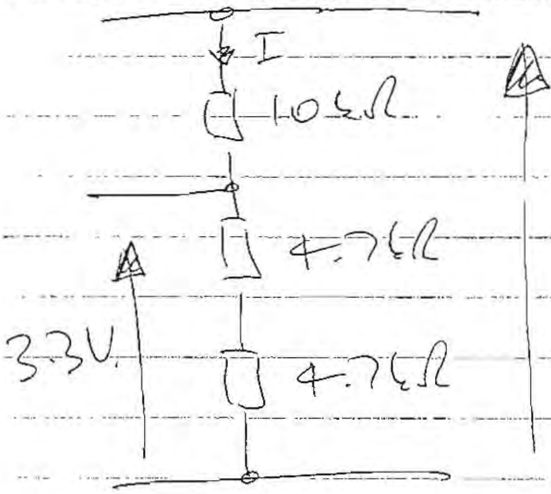
Q1

a) Output voltage range

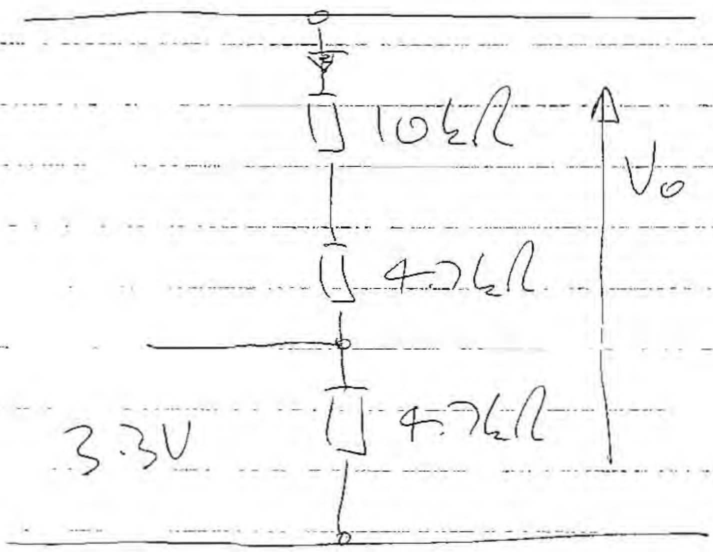
Rv wiper set to max.



$$I = \frac{3.3}{2 \times 4.7k} = 3.51 \times 10^{-4} A$$

$$V_o = R_{tot} \times I$$
$$= ((10k + 2 \times 4.7k) \times 3.51 \times 10^{-4}$$
$$= 6.81V$$

Rv wiper set to min



$$I = \frac{3.3}{4.7k} = 7.02 \times 10^{-4} A$$

$$V_o = R_{tot} \times I$$
$$= (10k + 2 \times 4.7k)$$
$$\times 7.02 \times 10^{-4}$$
$$= 13.62V$$

Max V_o = 13.62V
Min V_o = 6.81V

b) Determine max value for R

Worst case is when V_i is minimum and V_o is maximum.

$$R = \frac{V_{i\,min} - V_{o\,max}}{I_{out} + I_s} = \frac{18 - 13.61}{0.04 + 0.01}$$

$$\underline{\underline{R = 87.6\,\Omega}}$$

c) Determine power dissipated in R

For short cct all of V_i applied across R.

$$\therefore P_R = \frac{V_i^2}{R} = \frac{25^2}{87.6}$$

$$\underline{\underline{= 7.13W}}$$

For normal conditions P will be max when voltage across R is max.

$$P_R = \frac{(V_{in\,max} - V_{o\,min})^2}{R} = \frac{(25 - 6.81)^2}{87.6}$$

$$\underline{\underline{= 3.77W}}$$

d) Max power for T_1

$$P_{T_1} = I_{T_1} \times V_{T_1} = \frac{(V_i - V_o)}{R} V_o = \frac{V_i V_o}{R} - \frac{V_o^2}{R}$$

Need to find value of V_o that maximise P_{T_1}

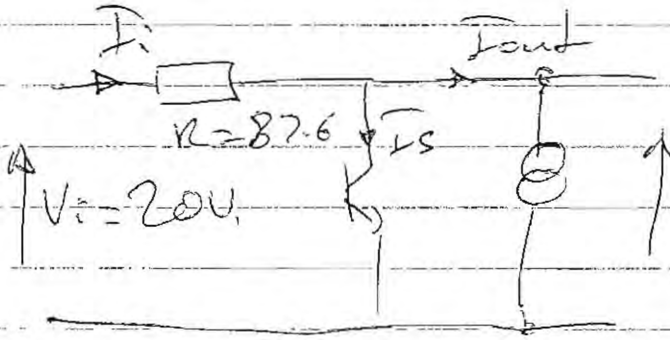
$$\frac{dP_{T1}}{dV_o} = \frac{V_i}{R} - \frac{2V_o}{R}$$

$\therefore V_o = \frac{V_i}{2}$, since P_{T1} is max when V_i is max

$$P_{T1} = \left(\frac{V_{i\,max} - V_{i\,max}/2}{R}\right)\frac{V_{i\,max}}{2}$$

$$= \frac{25 - 12.5}{87.6} \times 12.5 = \underline{\underline{1.78W}}$$

22.



$$I_i = \frac{20 - 10}{87.6} = 114.15mA.$$

$$I_{out} = \frac{10}{500} = 20mA.$$

$$I_s = I_i - I_{out} = 114.15 - 20 = 94.15mA.$$

$$P_{T1} = I_s \times V_o = 10 \times 94.15 \times 10^{-3} = 0.94W$$

$$P_R = \frac{10^2}{87.6} = 1.14W. \quad P_{out} = \frac{10^2}{500} = 0.2W.$$

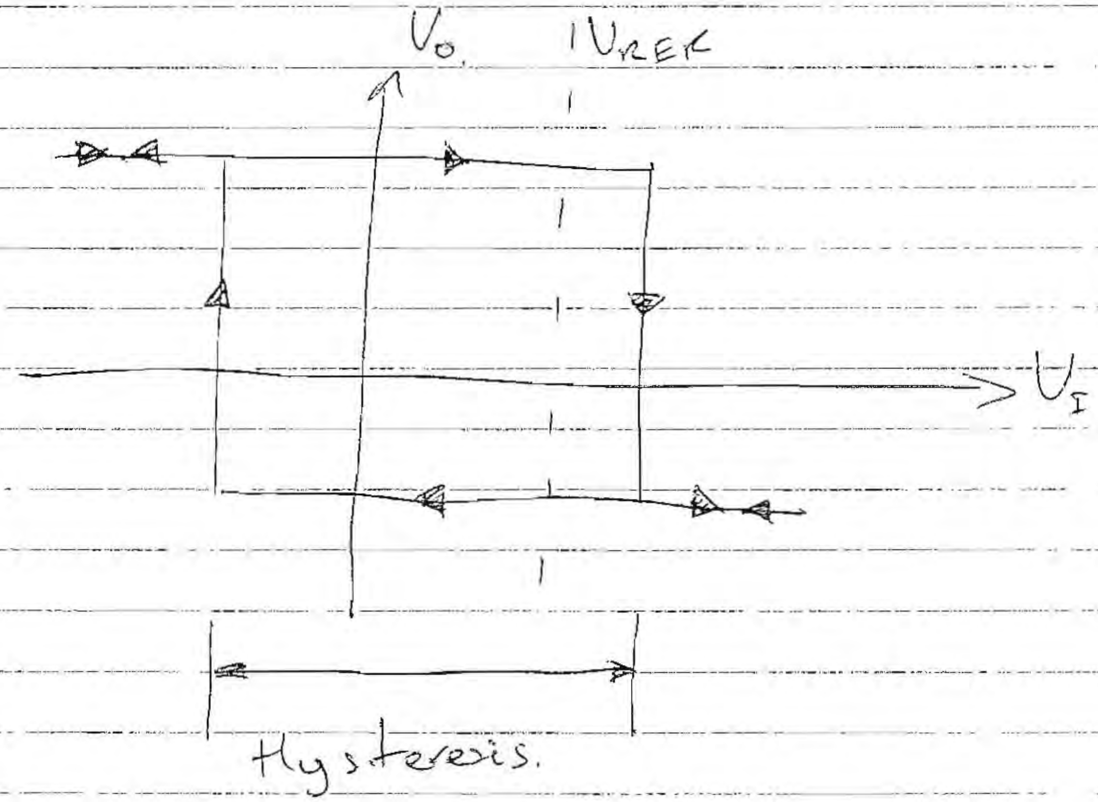
$$\text{Efficiency } \eta = \frac{P_{out}}{P_{out} + P_R + P_{T1}} = \frac{0.2}{0.2 + 1.14 + 0.94} = 8.77\%$$

4

Q2.

a) Hysteresis is used to reduce a comparator's susceptibility to noise.
Applications include waveform zero crossing detectio

b).

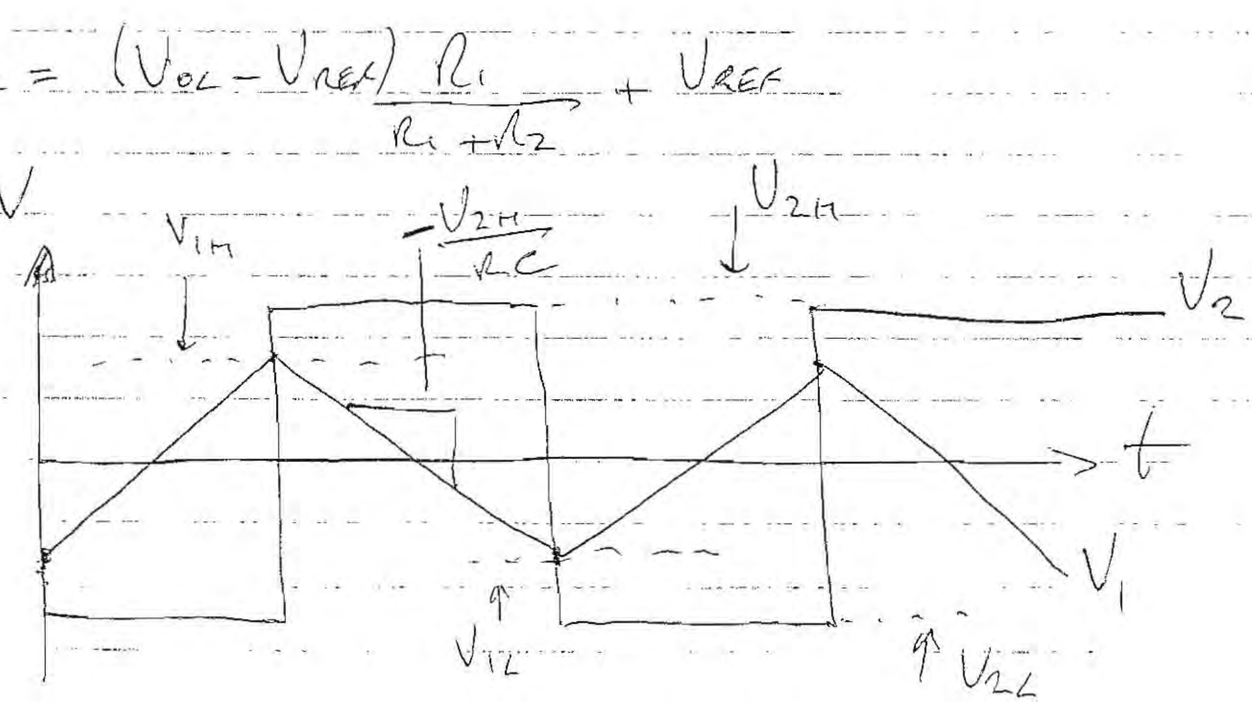


$V^+_H - V^+_L$

$$V^+_H = (V_{OH} - V_{REF})\frac{R_1}{R_1+R_2} + V_{REF}$$

$$V^+_L = (V_{OL} - V_{REF})\frac{R_1}{R_1+R_2} + V_{REF}$$

c)



d) A_1 is an inverting integrator and so V_1 travels from V_{1L} to V_{1H} at a rate of $-\frac{V_{2L}}{RC}$ $\frac{V}{S}$.

A_2 will change state when $V^+ = 0$

$$V^+ = \frac{V_2 - V_1}{R_1 + R_2} \times R_1 + V_1 = 0.$$

Thus $V_{1L} = -\frac{R_1}{R_2} V_{2H}$ or $V_{1H} = -\frac{R_1}{R_2} V_{2L}$

$V_1(t) = \frac{-V_{2L}}{RC} \cdot t$, so from 0 to V_{1H}.

$V_{1H} = \frac{-V_{2L}}{RC} t_1$ $\therefore$ $t_1 = -\frac{V_{1H}\, RC}{V_{2L}} = \frac{R_1}{R_2} RC$

The time taken for a half period $\frac{T}{2} = 2\frac{R_1}{R_2} RC$

whole period is given by $T = 4\frac{R_1}{R_2} RC$

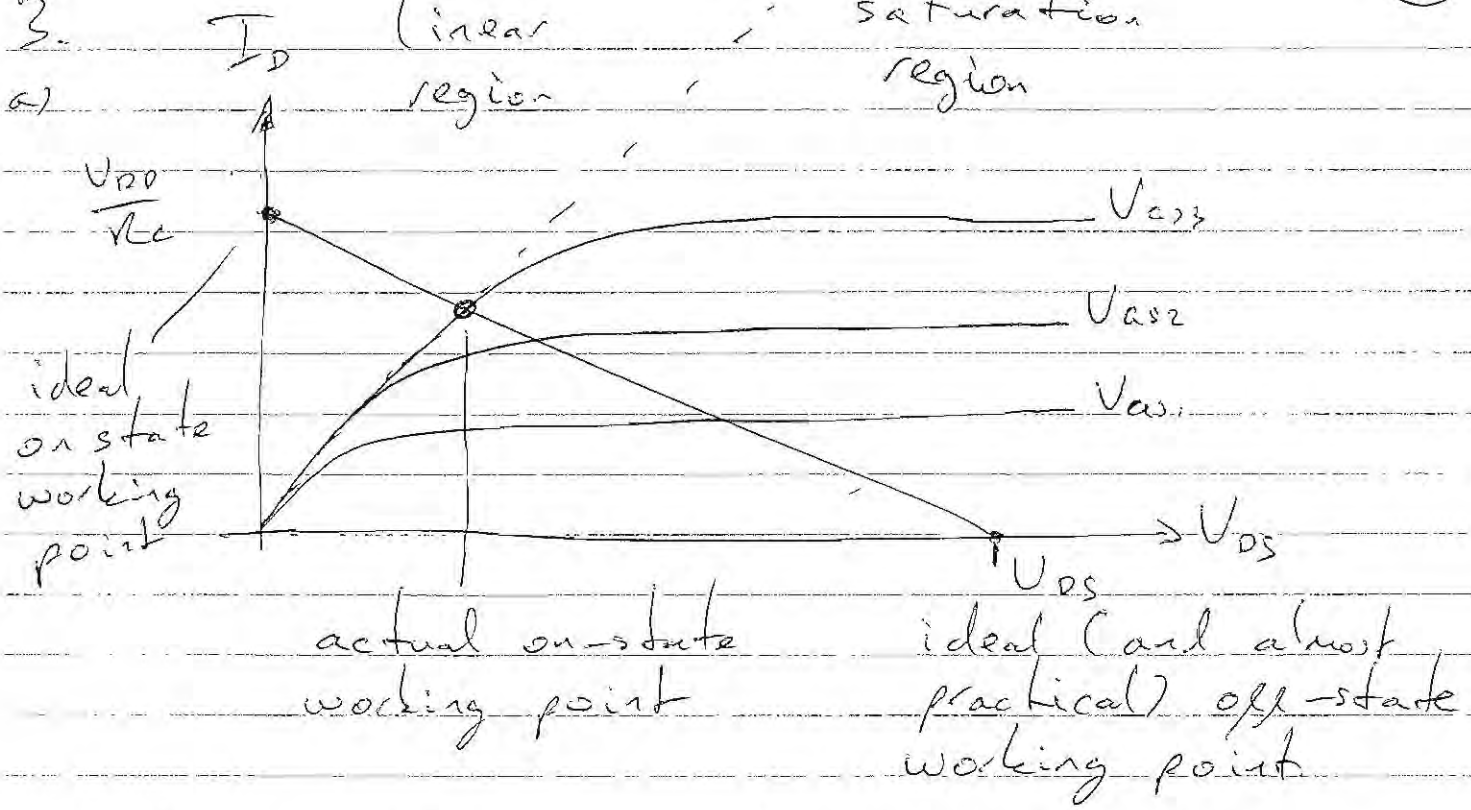
Thus the oscillation frequency is given by

$$f = \frac{R_1}{4R_2 RC}$$

With $f = 4k\,Hz$. $RC = \frac{1}{4 \times 4000} = 6.25 \times 10^{-5}$ Secon

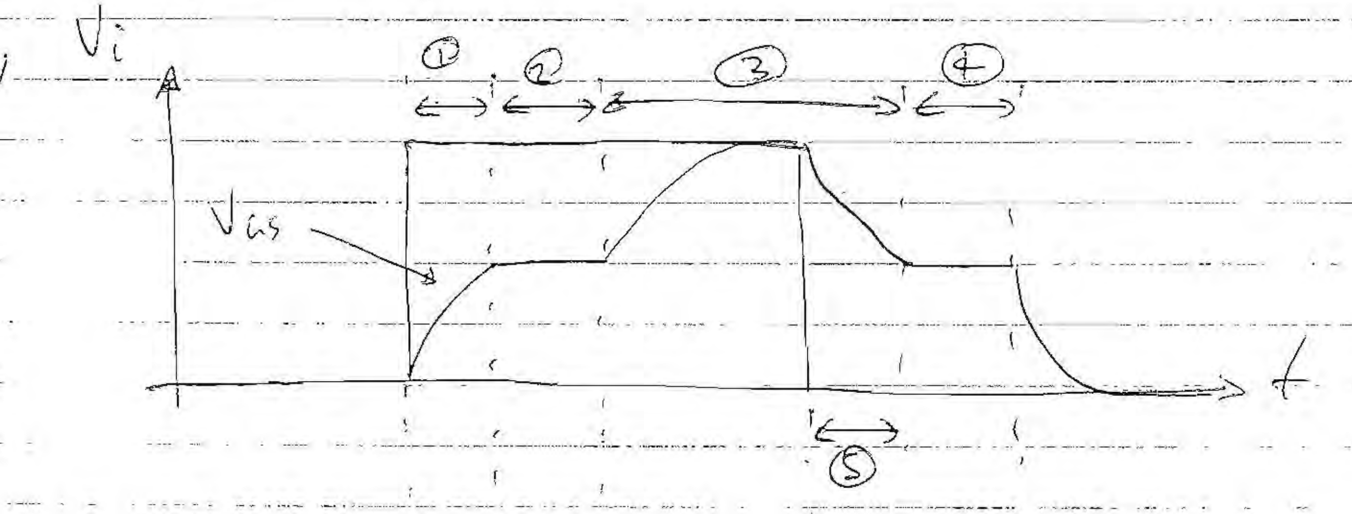
3.

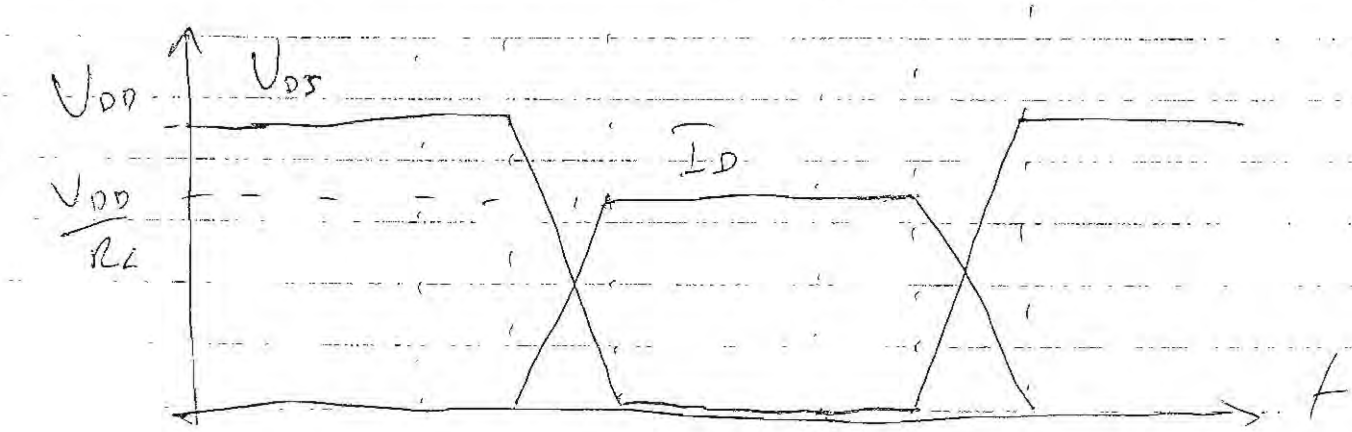
a)



1 mark for V_{GS} characteristic
3 marks for operating points
1 mark for regions

b)

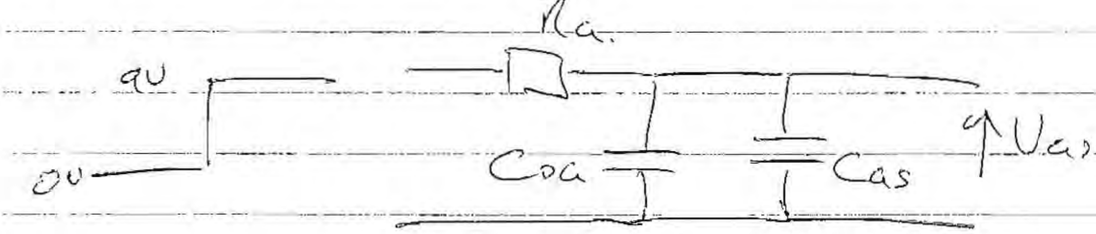




① turn-on delay t_{don}
② turn-on switching time t_{son}
③ on time t_{on}
④ turn-off switching time t_{soff}
⑤ turn-off delay t_{doff}

0.5 mark for each event time.
1 mark for each wave form.
0.5 mark for voltage and current label.

c). Turn on delay



$V_{gs}(t) = V_i\left(1 - e^{-\frac{t}{\tau}}\right)$ $\qquad \tau = R_G\left[C_{DG} + C_{GS}\right]$

$= 23.94\,ns$

$V_{gs}(t_{don}) = V_{TH} = V_i\left(1 - e^{-\frac{t_{don}}{\tau}}\right)$

$t_{don} = -\tau \ln\left[1 - \frac{V_{TH}}{V_i}\right] = \underline{14.07\,\mu s}$

turn on switching time.

$i_g = \frac{V_i - V_{TH}}{R_G} = C_{DG}\frac{dV_D}{dt} = C_{DG}\left(-\frac{V_{DD}}{t_{son}}\right)$

$\underline{t_{son} = 71.3\,ns.}$

d) The inclusion of the parallel diode resistor combination modifies the gate resistor value during turn-off.

$$R_{goff} = R_g \| R = 45\,\Omega$$

$$\tau_{off} = R_{goff}\left[C_{DG} + C_{GS}\right] = 5.99\,ns$$

$$V_{GS}(t) = V_i\, e^{-\frac{t}{\tau}}$$

$$V_{TH} = V_i \times e^{-\frac{t_{doff}}{\tau_{off}}}$$

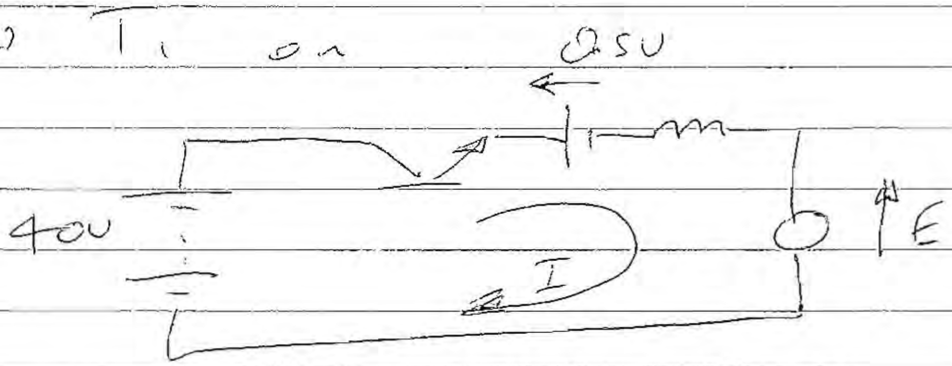
$$t_{doff} = -\tau_{off} \ln\left(\frac{V_{TH}}{V_i}\right) = 4.85\,ns$$

$$i_{goff} = \frac{V_{TH}}{R_{goff}} = C_{DG}\frac{V_{DD}}{t_{soff}}$$

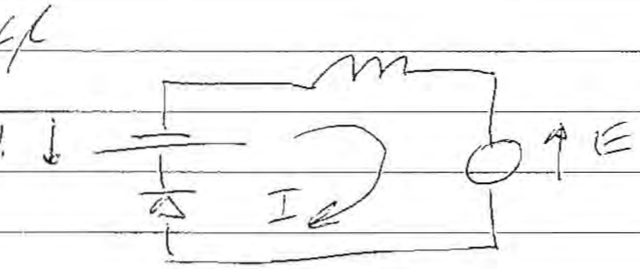
$$t_{soff} = 22.26\,ns$$

Q4

a) T_1 on



T_1 off



2.5 mark for each circuit.

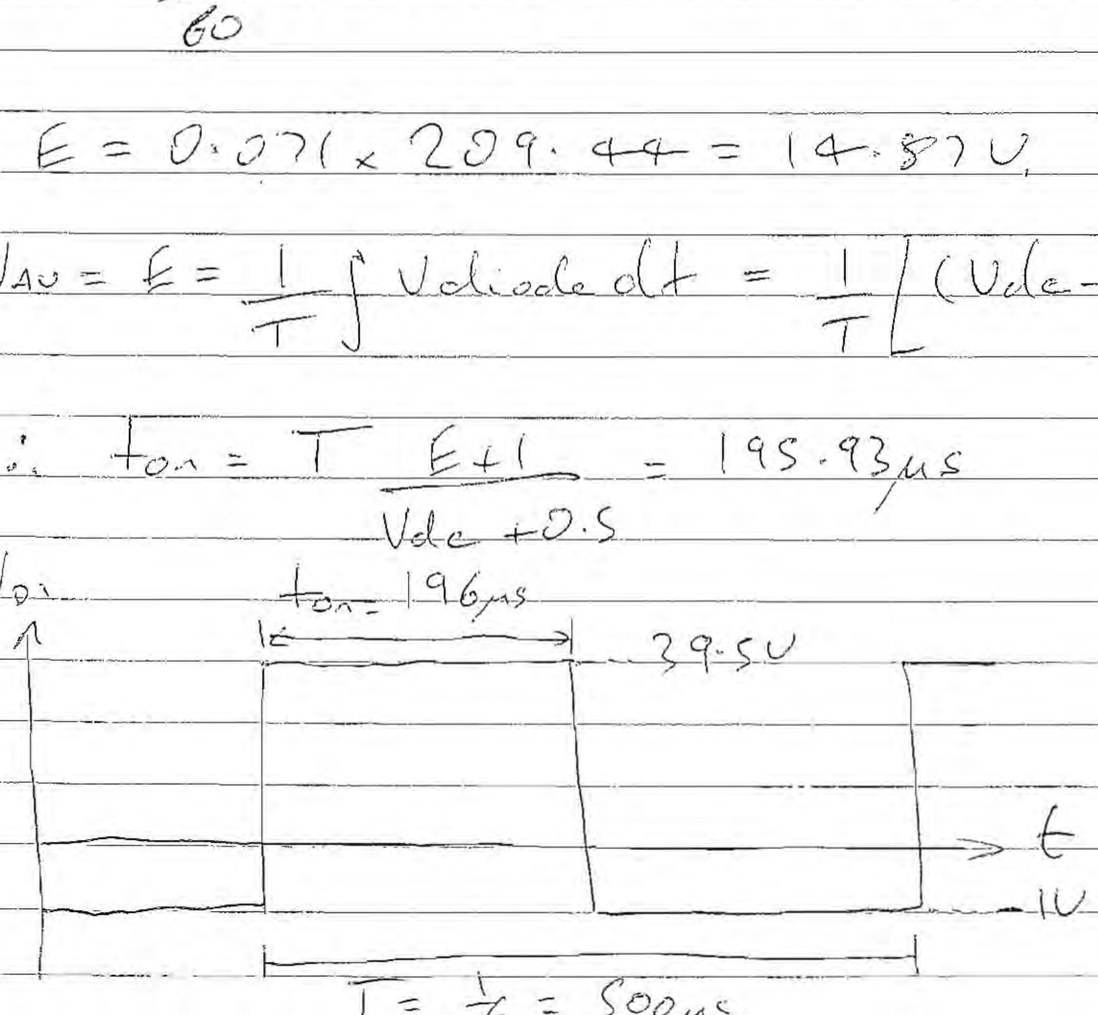
b) $E = \Psi\omega$ = average diode voltage $= V_{AV}$.

$$\omega = \frac{2\pi}{60} \times 2000 = 209.44 \text{ rad/sec}$$

$$E = 0.071 \times 209.44 = 14.87V$$

$$V_{AV} = E = \frac{1}{T}\int V_{diode}\,dt = \frac{1}{T}\left[(V_{dc}-0.5)t_{on} - (T-t_{on})\right]$$

$$\therefore t_{on} = T\,\frac{E+1}{V_{dc}+0.5} = 195.93\mu s$$



c) $T_m = \Psi I = 0.15 = 0.071 I$

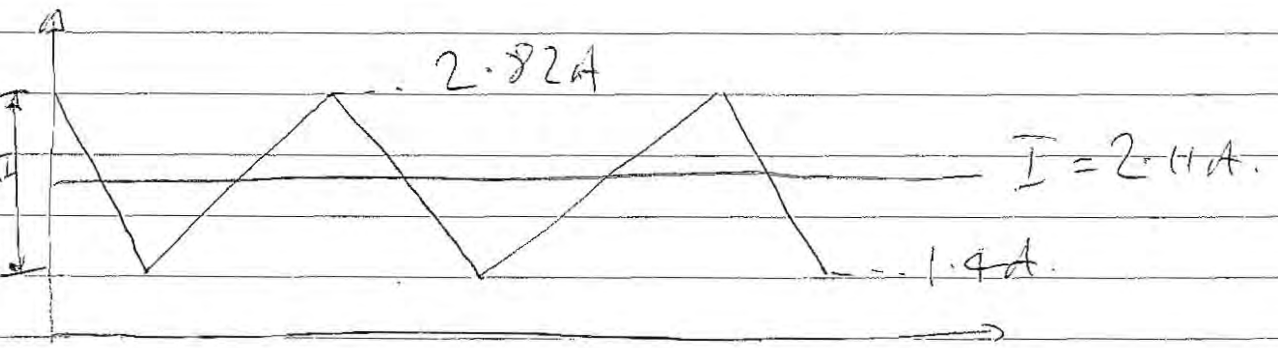
$$I = \frac{0.15}{0.071} = \underline{\underline{2.11A}} \text{ - average current}$$

The ripple superimposed on this is given by

$$v = L\frac{di}{dt} \quad , \quad V_i - E = L\frac{\Delta I}{t_{on}}$$

$$\text{Ripple} = \Delta I = \frac{t_{on}(V_i - E)}{L} = \frac{196\times10^{-6}(39.5 - 14.87)}{3.4\times10^{-3}}$$

$$= 1.419A$$



$I_{average} = 2.11A$, $I_{max} = 2.82A$, $I_{min} = 1.40A$.

d) $$E = \Psi\omega = 0.071 \times \frac{2\pi}{60} \times 1000 = 7.44V$$

$$\text{Duty } \delta = \frac{t_{on}}{T} = \frac{E}{V_i} = \frac{7.44}{40} = 0.186$$

$$V_i - E = L\frac{\Delta I}{\delta T} \quad \therefore \quad T = \frac{L\Delta}{(V_i - E)\delta} = 2.8\times10^{-4}$$

$$f = \frac{1}{T} = 3570\ Hz$$