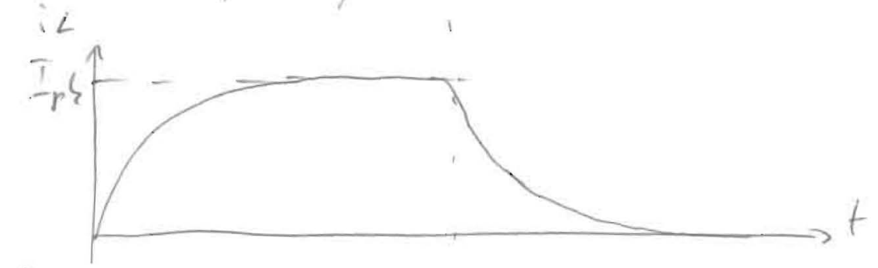
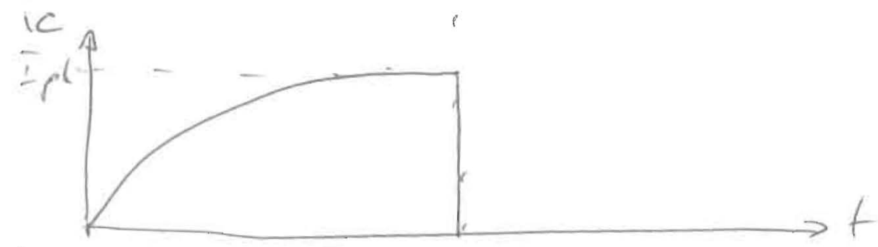
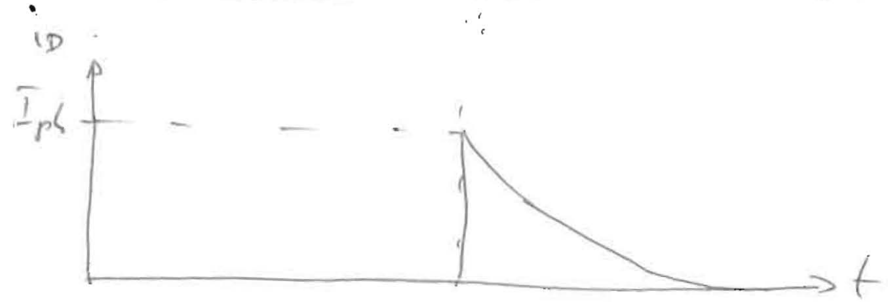
Q1

a) Waveforms for i_L, i_C and i_D.



2 marks for each waveform.
1 mark lost for each error.





b) Turn-on delay.

$i_L \geq 0.4A. = I_{LON}$

$i_L(t) = \frac{V_s}{R}(1 - e^{-\frac{t}{\tau}})$ $\qquad \tau = \frac{L}{R} = 2ms.$

$t_{don} = -\tau \ln\left(1 - \frac{i_{LON} R}{V_s}\right)$.

$= \underline{\underline{810\mu s}}$

c) Turn-off delay

$i_L \leq 0.15A$

$i_L(t) = \frac{V_s}{R} e^{-\frac{t}{\tau}} = i_{Loff}$

$t_{doff} = -\tau \ln\left(\frac{i_{Loff} R}{V_s}\right)$

$= \underline{\underline{4.15ms}}$

Q1

d) Value of R_S to make $t_{doff} = 2ms$.

$$\tau = \frac{L}{R+R_S}$$

$$t_{doff} = \frac{-L}{R+R_S} \ln\left(\frac{i_{Coff} R}{V_S}\right).$$

$$R_S = \frac{-L}{t_{doff}} \ln\left(\frac{i_{Coff} R}{V_S}\right) - R$$

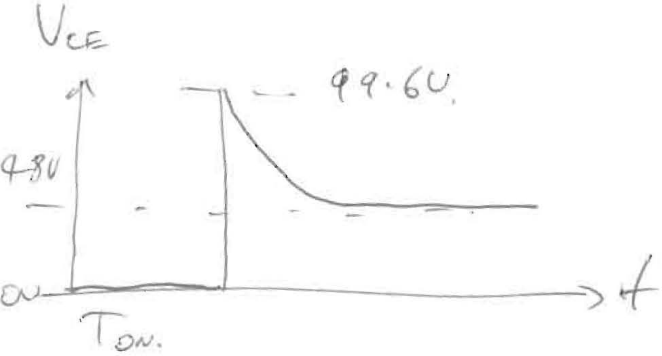
$$= 43.2\Omega.$$

e). Waveform of V_{CE} and V_{CE} rating.

At instant when diode conducts a voltage of V_{RS} is dropped across R_S so $V_{CE} = V_C = V_S + V_{RS}$

$$= V_S + \frac{V_S}{R} R_S$$

$$= V_S\left(1 + \frac{R_S}{R}\right) = 99.6V.$$



Q2

b) cont

Transistor turns on when $V_{BEON} = 0.7V$.

$$I_{lim} = \frac{V_{BEON}}{R_S}$$

$$R_S = \frac{V_{BEON}}{I_{lim}} = \underline{\underline{0.0875\Omega}}.$$

Under a short cct condition all of the supply voltage is dropped across T. Thus,

$V_{CE} = 48V$, $I_C = 8A$

$$P = VI = 384W.$$

c) Efficiency.

$$P_{out} = \frac{V_{out}^2}{R_L} = \frac{12^2}{6} = \underline{\underline{24W}}.$$

$$P_{loss} \text{ in } T = P_T = V_{CE} I_{out} = (V_{dc} - V_{out}) I_{out}$$
$$= (36-12) \times 2 = \underline{\underline{48W}}$$

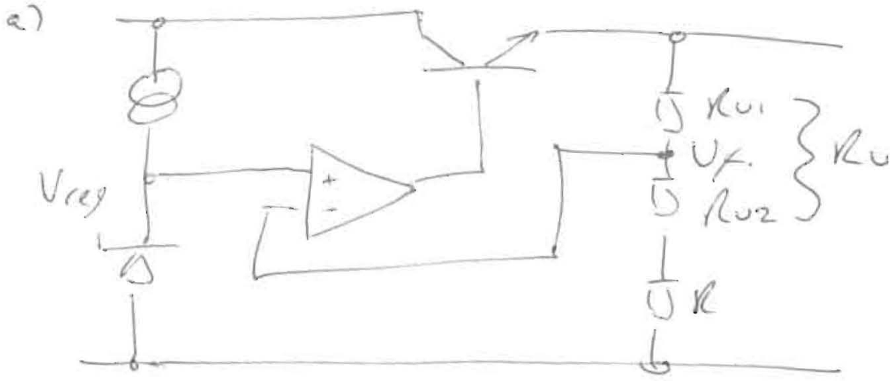
$$P_{loss} \text{ in } R_S = P_{RS} = I_{out}^2 R_S = 4 \times 0.0875 = 0.35W.$$

$$\text{Efficiency } \eta = \frac{P_{out}}{P_{in}} = \frac{P_{out}}{P_{out} + P_{loss}} = \frac{P_{out}}{P_{out} + P_T + P_{RS} + P_R}$$

$$= \frac{24}{24 + 48 + 0.35} = 33\%.$$

Q2 Series voltage regulator

a)



$A_v = \infty$, $V_{ref} = V^+$, $V_f = V^-$, $V^+ = V^-$, $V_{ref} = 4V$.

$$V_f = \frac{R_{v2} + R}{R_{v1} + R_{v2} + R} \times V_{out}$$

$$V_{out} = \frac{R_{v1} + R_{v2} + R}{R_{v2} + R} \times V_{ref}$$

If $0 \le x \le 1$ is the position of R_v's wiper.

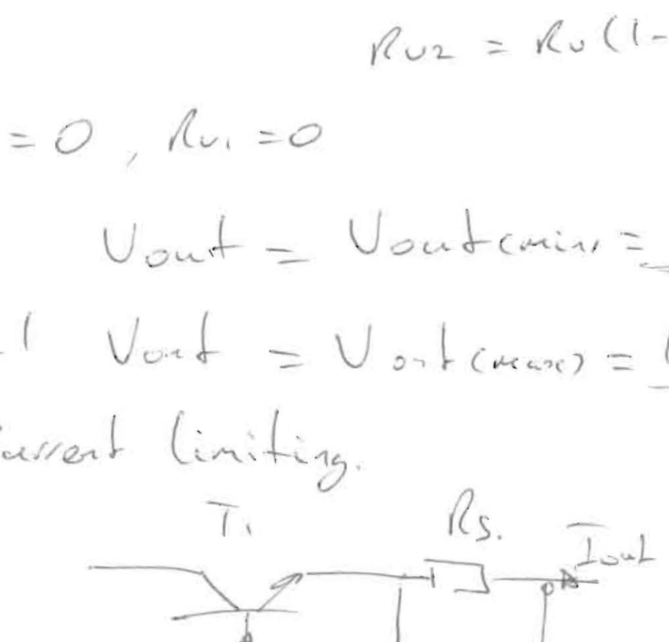
$$R_{v1} = R_v x$$
$$R_{v2} = R_v (1 - x).$$

$x = 0$, $R_{v1} = 0$

$$V_{out} = V_{out(min)} = \underline{4V}$$

$x = 1$ $V_{out} = V_{out(max)} = \underline{16.12V}$

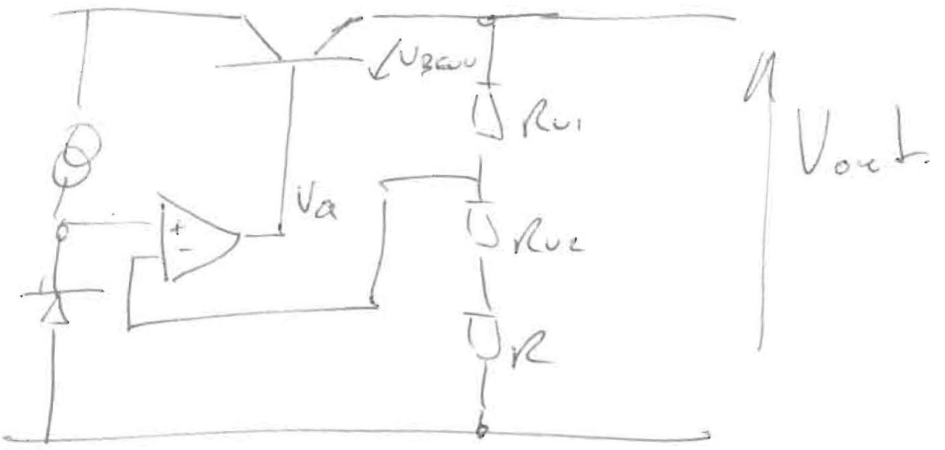
b) Current limiting.



A current sensing resistor R_s is added in series with the output to measure the current. When the voltage drop across R_s exceeds 0.7V T_2 turns on reducing the bias on T_1. As the output current increases further T_2 is driven harder providing a natural limit to I_{out}.

e) Non-ideal op-amp

$A_v = 100$



$$V_a = A_v(V^+ - V^-)$$

$$V_{out} = V_a - V_{BEON}$$

$$= A_v(V^+ - V^-) - V_{BEON}$$

$$= A_v\left(V_{ref} - \frac{R_{v2}+R}{R_{v1}+R_{v2}+R} \times V_{out}\right) - V_{BEON}$$

$$V_{out} + A_v \frac{R_{v2}+R}{R_{v1}+R_{v2}+R} V_{out} = A_v V_{ref} - V_{BEON}$$

$$V_{out}(1 + A_v k) = A_v V_{ref} - V_{BEON}$$

$$V_{out} = \frac{A_v V_{ref} - V_{BEON}}{1 + A_v k}$$

Using similar terminology as in part a).

$x = 0$ $\quad V_{out} = V_{out(min)} = \dfrac{100 \times 4 - 0.7}{101} = \underline{3.95V}$

$x = 1$ $\quad V_{out} = V_{out(max)} = \dfrac{100 \times 4 - 0.7}{1 + 100 \times 0.2481} = \underline{15.47}$

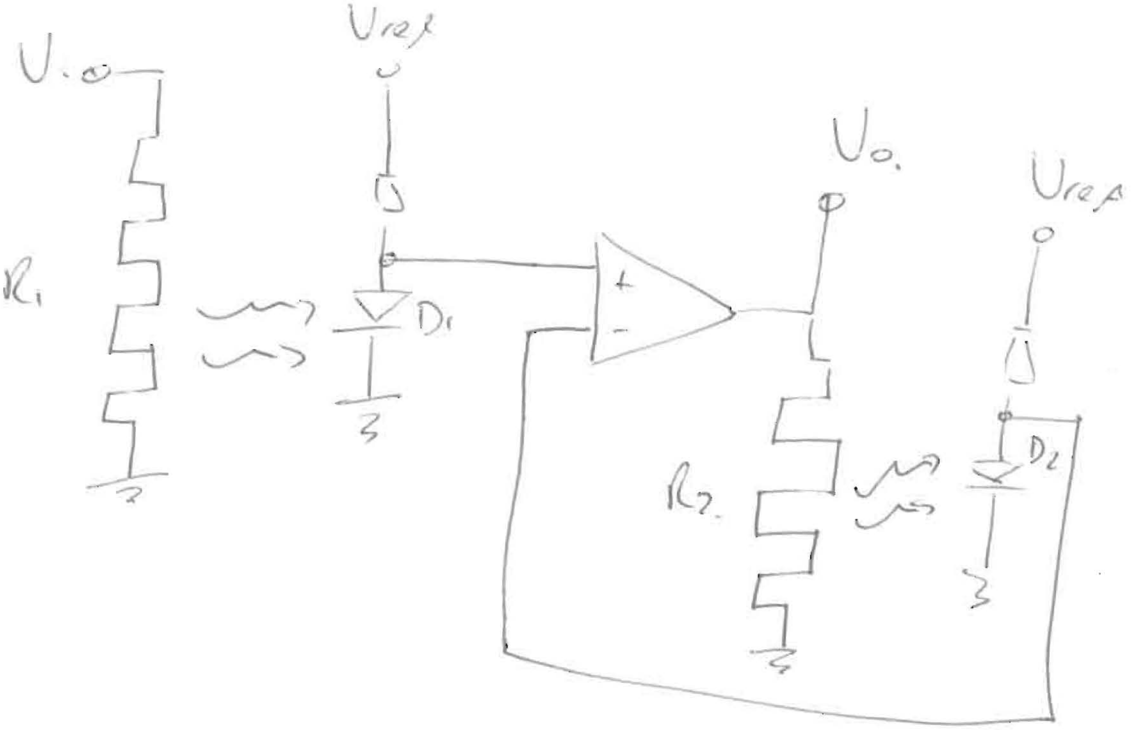
Q3c) cont.

Now $I_{C1} = \frac{V_i}{R}$ & $I_{C2} = \frac{V_{ref}}{R_2}$

$$V_o = -\alpha V_T \ln\left(\frac{V_i}{V_{ref}} \cdot \frac{R_2}{R_1}\right).$$

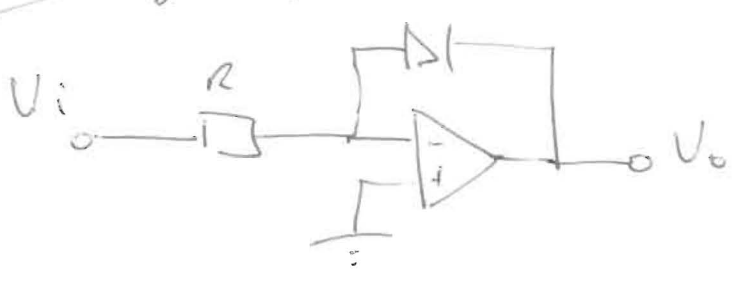
α is gain of A_2.

d) Bolometric RMS converter



V_i is converted into heat using R_1.
Temperature of R_1 is measured by D_1 and compared to the temp. of R_2 by the error amp.
Negative feedback cause V_o to vary in accordance to the RMS value of V_i.

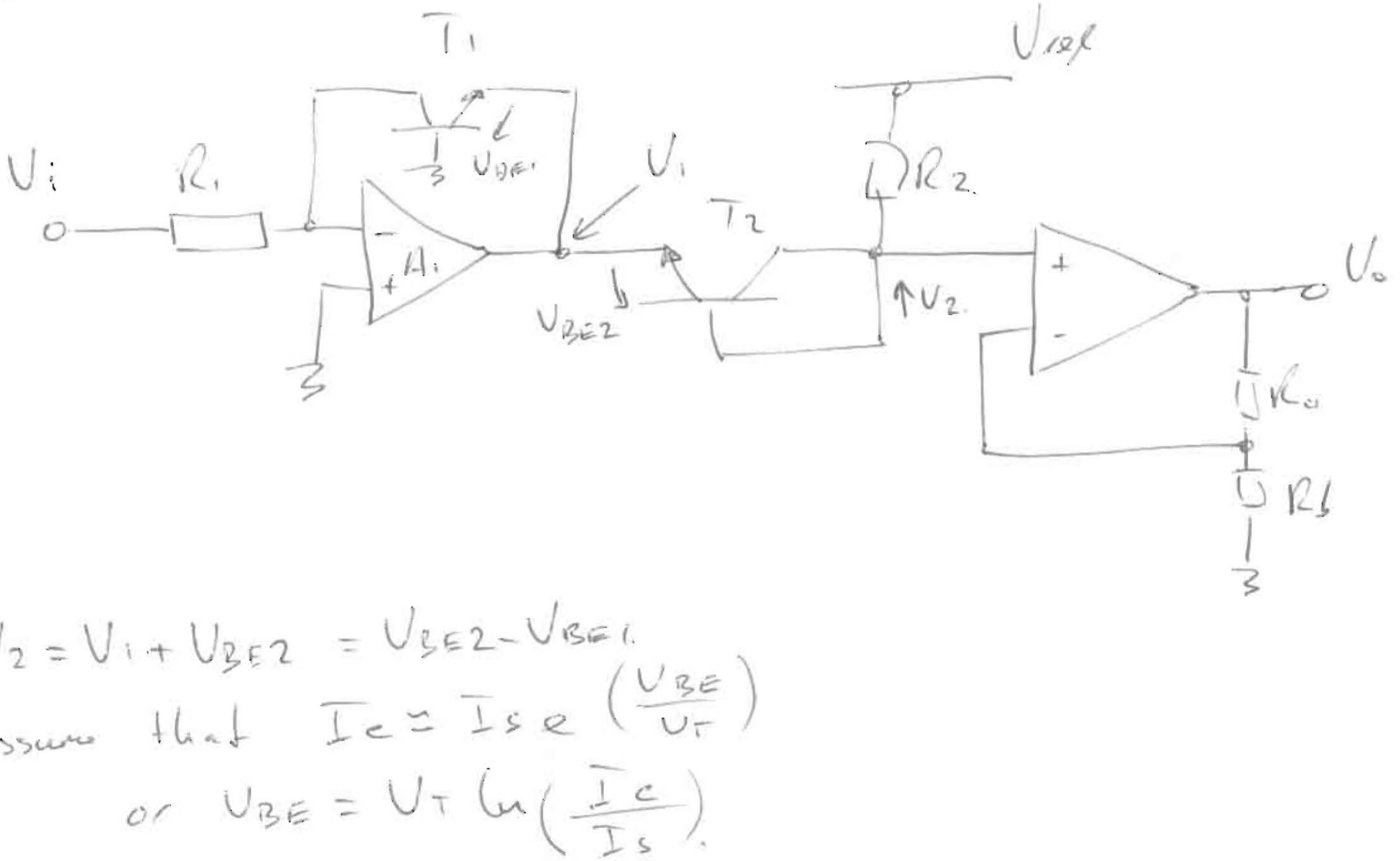
Q3b Log amp.



$$\frac{V_i}{R} = I_s e^{\frac{-V_o}{0.026}}$$

$$\therefore V_o = -0.026 \ln\left(\frac{V_i}{I_s R}\right).$$

c).



$V_2 = V_1 + V_{BE2} = V_{BE2} - V_{BE1}$

Assume that $I_c \simeq I_s e^{\left(\frac{V_{BE}}{V_T}\right)}$

or $V_{BE} = V_T \ln\left(\frac{I_c}{I_s}\right)$.

$$\therefore V_2 = V_{T2} \ln\left(\frac{I_{c2}}{I_{s2}}\right) - V_{T1} \ln\left(\frac{I_{c1}}{I_{s1}}\right)$$

Since T1 & T2 are matched

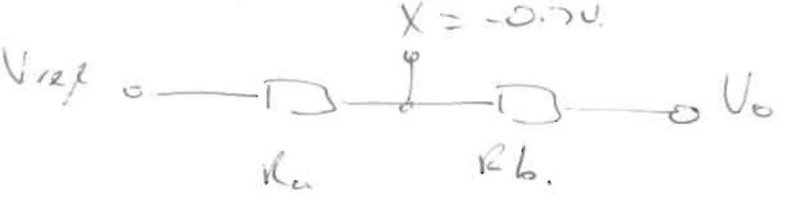
$I_s = I_{s1} = I_{s2}$ $\quad V_{T1} = V_{T2} = V_T$.

$$V_2 = V_T \ln\left(\frac{I_{c2}}{I_s}\right) - V_T \ln\left(\frac{I_{c1}}{I_s}\right) = V_T \ln\left(\frac{I_{c2}}{I_{c1}}\right).$$

Q3 a) Shaping cct.

The circuit has an incremental gain of $-\frac{R_f}{R}$ until D_1 or D_2 conduct.

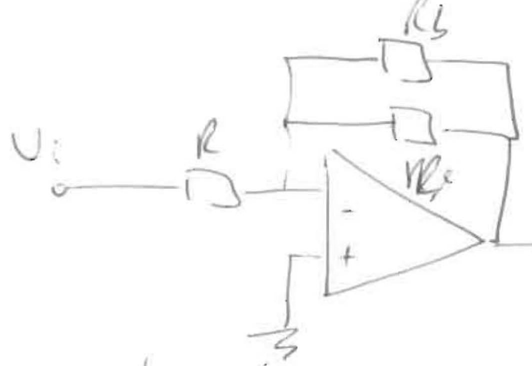
Assuming that V_i is +ve, D_1 will conduct when $X = -0.7V$.



$$\frac{V_{ref} + 0.7}{R_a} = \frac{-0.7 - V_o}{R_b}$$

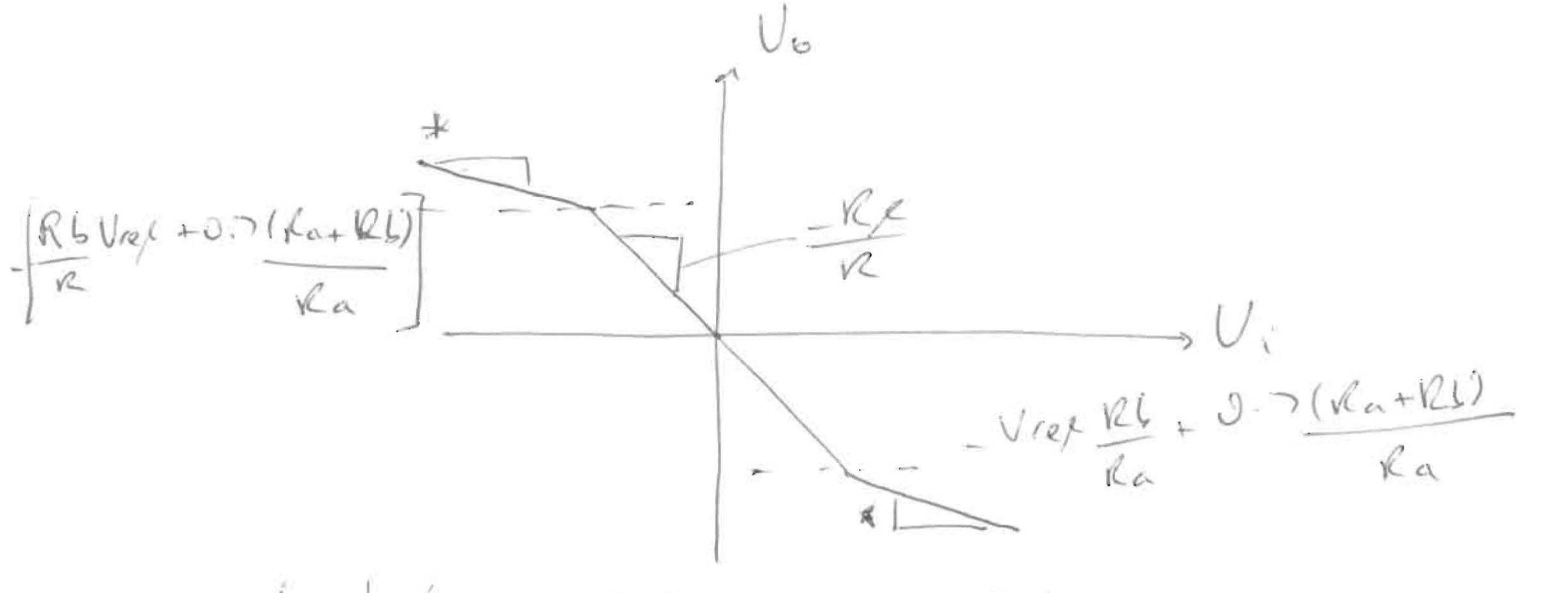
$$V_o = -\left[\frac{R_b}{R_a} V_{ref} + \frac{0.7 (R_a + R_b)}{R_a}\right]$$

After D_1 has switched on the cct become



$$\frac{V_o}{V_i} = -\frac{R_f \| R_b}{R}$$

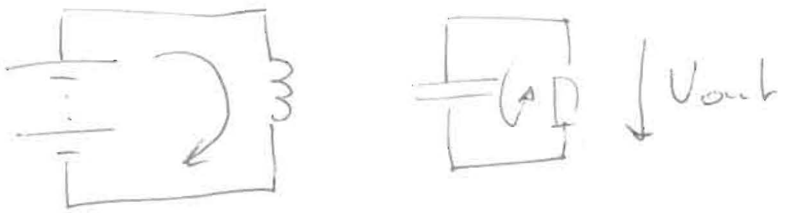
V_o/V_i characteristic is



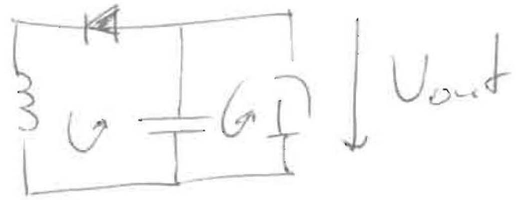
* gradient / incremental gain $= -\frac{R_f \| R_b}{R}$.

4a) Sub-circuits

i) S on D off

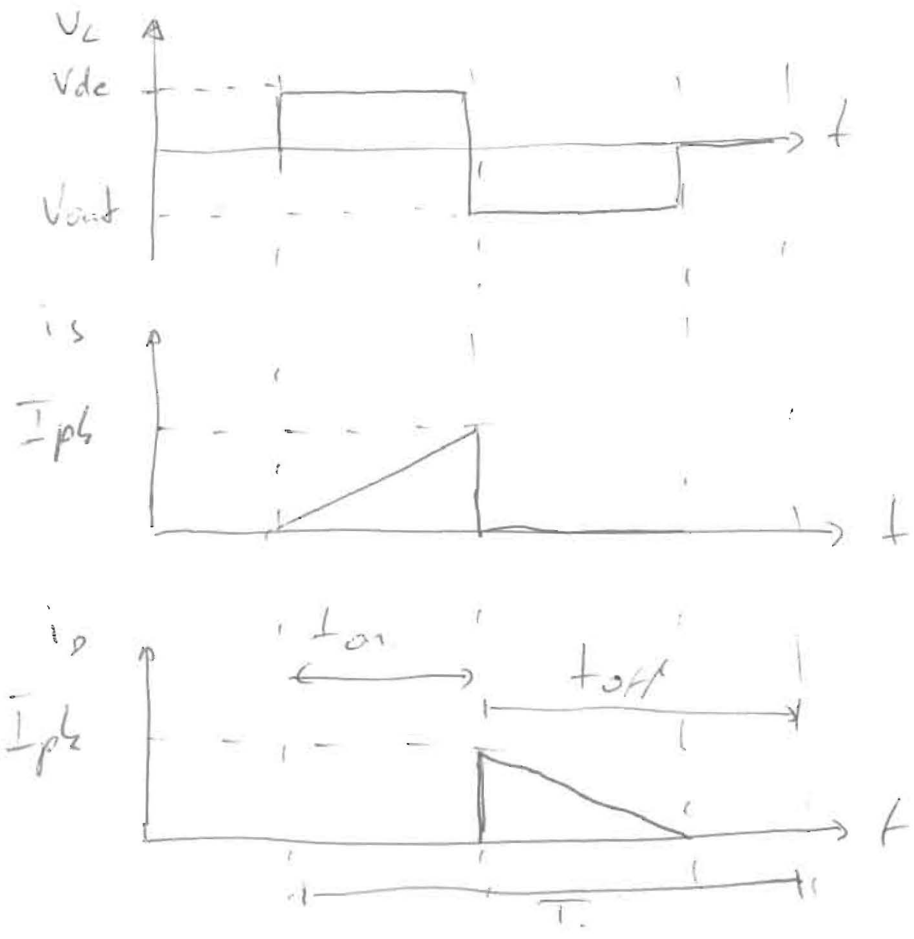


ii) S off D on



iii) S off D off

b) Waveforms



c) Output voltage

Peak energy stored in L $\quad E = \frac{1}{2} L I_{pk}^2$

when S is on $\quad V_{dc} = L \frac{I_{pk}}{t_{on}}$

$$I_{pk} = \frac{V_{dc}\, t_{on}}{L} = \frac{V_{dc}\, T}{2L}$$

$$E = \frac{1}{2} L \left(\frac{V_{dc}\, t_{on}}{L}\right)^2$$

Energy consumed by the load is $E = \frac{V_{out}^2}{R_L} \times T$.

Equating the two energies and rearranging gives

$V_{out} = \sqrt{\frac{RT}{2L}}\, \frac{V_{dc}}{2}$ $\quad$ where $t_{on} = \frac{T}{2} = \frac{1}{f_s}$.

substituting values give

$V_{out} = 400V$

d) Peak-to peak ripple voltage

Assume V_{out} is fairly constant.

$I_{pk} = \frac{V_{dc}\, T}{2L}$

$t_{fall} = \frac{I_{pk} L}{V_{out}} = \frac{V_{dc} T}{2L} \times \frac{L}{V_{out}} = \frac{V_{dc}\, T}{2V_{out}}$

$Q = It = \frac{1}{2} \times t_{fall} \times I_{pk}$

$$= \frac{1}{2} \times \frac{V_{dc} T}{2V_{out}} \times \frac{V_{dc} T}{2L} = \frac{V_{dc}^2 T^2}{8 L V_{out}}$$

$$C \Delta V = Q.$$

$$\Delta V = \frac{Q}{C} = \frac{1}{8LC} \frac{V_{dc}^2}{V_{out}} T^2$$

$$= \frac{1}{8LC f_s^2} \frac{V_{dc}^2}{V_{out}}$$

$$\underline{\underline{= 5.67V}}$$