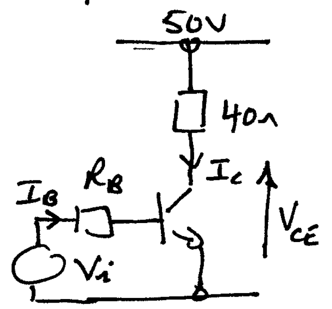
EEE103 / EEE121 / EEE141 Problem Solutions

Transistors as Switches and Amplifiers

Q1 It is important to ensure that a transistor switch is driven on and off properly in order to minimise power dissipation within the switch. When on, one wants a small voltage across the switch so that $I_{ON} V_{ON}$ is small and when off one wants a small current through the switch (ideally zero) so that $I_{OFF} V_{OF}$ is small. If the switch is only half switched on, the VI product dissipated within it is likely to destroy it.



(i) $I_{ON} = \frac{50V}{40\Omega} = \underline{\underline{1.25A}}$.

(assumes V_{CESAT} negligible).

(ii) Worst case I_B (ie largest I_B) occurs for smallest h_{FE}.

$$\therefore I_{B\,max} = \frac{I_{CON}}{h_{FE\,MIN}}$$

$$= \frac{1.25A}{70} = \underline{17.86mA}.$$

(iii) R_B must be small enough to provide the on state I_B required by a transistor with the lowest h_{FE} ... ie, the answer to part (ii).

$$\therefore R_{B\,max} = \frac{10 - 0.7}{17.86mA} \quad \left[= \frac{V_i - V_{BE}}{I_{B\,max}} \right]$$

$$= \underline{\underline{521\ \Omega}}.$$

(iv) Power lost in transistor during "on" state is

$$P_D = I_{C\,ON} \cdot V_{CE\,SAT} = 1.25A \times 0.25V$$

$$= \underline{\underline{313\,mW}}$$

Q2 In their "on" state, MOSFETs look like a resistance of $r_{DS\,ON}$ so the power dissipation is $I_{D\,ON}^2 \, r_{DS\,ON}$.

$$= 1.25^2 \times 0.25\,\Omega = \underline{390\,mW}.$$

[This assumes that the "on" resistance of the MOSFET does not significantly alter $I_{D\,ON}$ ie, that $r_{DS\,ON} \ll R_L$; clearly true here]

Since the MOSFETs dissipate more energy as heat, they are less attractive than the BJT.

Q3 (i) If S has been on for a long time..

(i) $E = \frac{1}{2} L I^2 = \frac{1}{2} \times 0.1 \times 1.25A^2 = \underline{\underline{78\,mJ}}$.

(ii) D and R provide a path by which the inductor can maintain current continuity when the switch switches off. They do it in a way that defines the maximum off state voltage across the switch.

(iii) $I_D = I_{CON} = \underline{\underline{1.25A}}$ immediately after the switch opens.

(iv) The decay time constant is $L/R_L = \frac{100mH}{40\Omega}$
$= \underline{\underline{2.5\,ms}}$.

(v) I_D will create a voltage across R with its positive end at D's cathode. This voltage, $I_D R$, will add to the 50V supply to give the switch off-state voltage.
If S can cope with 200V, $50 + I_{Dmax} R = 200$

or $R = \frac{200-50}{1.25} = \frac{150}{1.25} = \underline{\underline{120\,\Omega}}$

(vi) If the switch switches 50 times per second, Energy loss per second, which equals power is

$$P = 78\,mJ \times 50 = 3.9\,W.$$

This power is shared between R and the 40Ω internal resistance of the load and since the same I_D flows through both, power is proportional to R.

Thus $P_R = 3.9\,W \times \frac{R}{40+R} = 3.9 \times \frac{100}{140}$

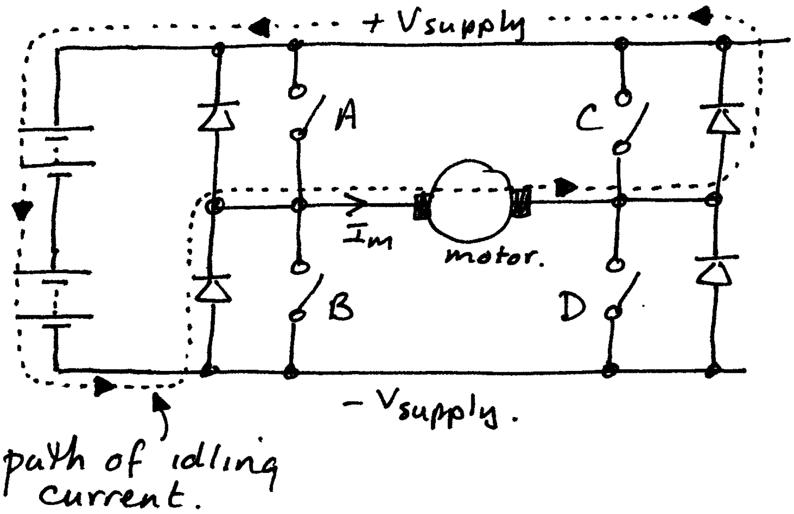
$= \underline{2.8\,W}$.

[Note that the 40Ω part of the load will also dissipate energy in the "on" state – in this case at a rate of 62.5 W – so the energy stored in L contributes only a small increment to this for the conditions of the question]

Q4 (i) switches A and D will cause clockwise motion when on.

(ii) switches C and B will cause anti-clockwise motion when on.

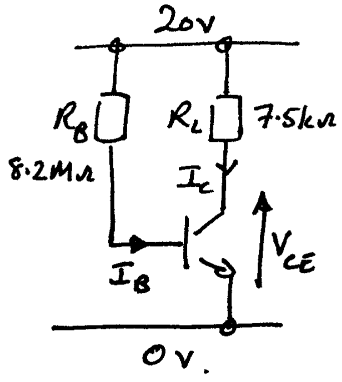
(iii)



(4)

Q5 (i) $I_B = \dfrac{20 - V_{BE}}{8.2M\Omega}$

$= \dfrac{19.3}{8.2M\Omega} = \underline{2.35\mu A}$



(ii) $I_{c\,max} = I_B h_{FEmax}$

$= 2.35\mu A \times 850$

$= 2mA.$

$I_{cmin} = I_B h_{FE\,min} = 2.35\mu A \times 100 = 235\mu A.$

$V_{CE} = 20 - I_c R_L$

$= 20 - 2mA \times 7.5k\Omega = \underline{5V}$ for $h_{FE} = 850$

$= 20 - 235\mu A \times 7.5k\Omega = \underline{18.2V}$ for $h_{FE} = 100$

(iii) The cct is a poor bias circuit because it fails to control I_c; instead it controls I_B.

(iv) From the cct, $V_{CE} = V_{cc} - I_c R_L$, and using $h_{FE} = I_c/I_B$ this can be written

$$V_{CE} = V_{cc} - h_{FE} I_B R_L . \qquad (1)$$

The normalised change in h_{FE} with temp is 0.5% ....

$$\text{ie} \quad \frac{1}{h_{FE}} \cdot \frac{dh_{FE}}{dT} = \frac{0.5}{100} \qquad (2)$$

[If you have trouble with this, put it in terms of money. If someone was to pay you 0.5% of £450 per week, how much would you get per week?]

$$\frac{dV_{CE}}{dT} = \frac{dV_{CE}}{dh_{FE}} \cdot \frac{dh_{FE}}{dT}$$

by differentiating (1)

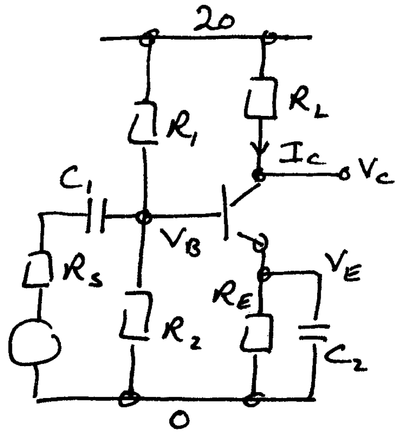
by rearranging (2)

$= -I_B R_L \cdot \dfrac{0.5\,h_{FE}}{100} = -\dfrac{2.35\mu A \times 7.5k\Omega \times .5 \times 450}{100}$

$= \underline{-40mV/^\circ C}.$

Q6 (i) $V_B = 20 \dfrac{R_2}{R_1+R_2}$

$= \dfrac{20 \;\; 39\,k\Omega}{199\,k\Omega} = \underline{3.92\,V}$



$V_E = V_B - V_{BE}$

$= 3.92 - 0.7 = \underline{\underline{3.22\,V}}.$

$I_E \approx I_c = \dfrac{3.22\,V}{R_E} = \underline{\underline{3.22\,mA}}.$

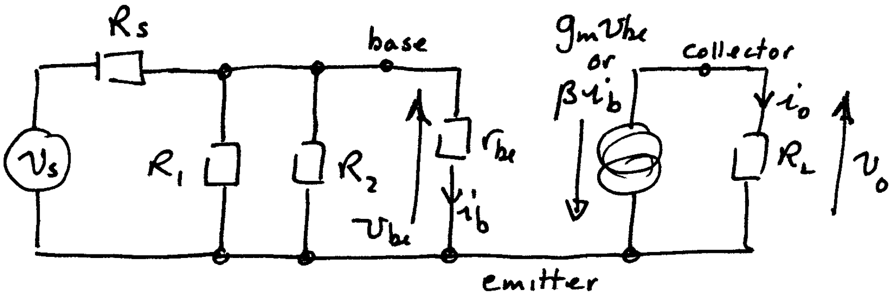
$V_c = V_{cc} - I_c R_L = 20 - 3.22 \times 2.4\,k\Omega \times 10^{-3}$

$= 20 - 7.73 = \underline{\underline{12.3\,V}}.$

(ii) $g_m = \dfrac{eI_c}{kT} = \dfrac{3.22\,mA}{.026\,V} = \underline{\underline{0.124\,A/V}}.$

$r_{be} = \beta/g_m = \dfrac{500}{0.124} = \underline{\underline{4.04\,k\Omega}}.$

(iii)



(iv) $\dfrac{v_o}{v_s} = \dfrac{v_o}{v_{be}} \times \dfrac{v_{be}}{v_s}.$

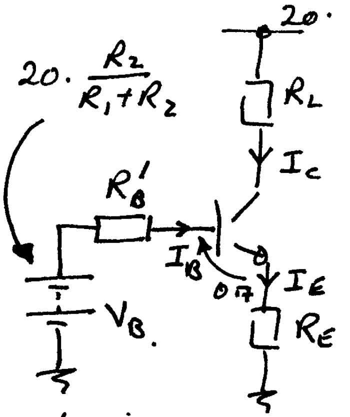
$\dfrac{v_o}{v_{be}} = -g_m R_L \quad (\text{since } i_o = -g_m v_{be} R_L).$

$\dfrac{v_{be}}{v_s} = \dfrac{R_1 \| R_2 \| r_{be}}{R_s + R_1 \| R_2 \| r_{be}}. = \dfrac{3.58\,k\Omega}{10\,k\Omega + 3.58\,k\Omega} = 0.263$

$\therefore \dfrac{v_o}{v_s} = -g_m R_L \times 0.263 = \underline{\underline{78.3}}$

(v) follow the same general process as in Q5 pt (iv).
Here the feedback makes the equations more cumbersome ....

First replace R_1 + R_2 by a Thevenin equiv (not essential but makes it a bit easier).



$$V_B = I_B R_B' + 0.7 + I_E R_E$$

but $I_E = I_B + I_C$

$$\therefore V_B = I_B R_B' + 0.7 + I_B R_E + I_C R_E$$
$$= I_B (R_B' + R_E) + 0.7 + I_C R_E$$

now I_C is the variable of interest in the question so eliminate I_B using $I_B = \frac{I_C}{h_{FE}}$

$$\therefore V_B = \frac{I_C}{h_{FE}} (R_B' + R_E) + 0.7 + I_C R_E$$

$$\text{or } I_C = \frac{(V_B - 0.7)\, h_{FE}}{R_B' + R_E + h_{FE} R_E} = \frac{3.22\, h_{FE}}{R_B' + R_E + h_{FE} R_E.} \qquad (1)$$

[one could say here $R_E + h_{FE} R_E \approx h_{FE} R_E$ if $h_{FE} \gg 1$]

As in Q5 pt (iv) ....by differentiating (1)

$$\frac{dI_C}{dT} = \frac{dI_C}{dh_{FE}} \times \frac{dh_{FE}}{dT} \text{ ....from (2) in 5pt (iv).}$$

$$\frac{dI_C}{dh_{FE}} = \frac{(R_B' + R_E + h_{FE} R_E) . 3.22 - R_E . 3.22 h_{FE}}{(R_B' + R_E + h_{FE} R_E)^2}$$

note from (1) that $(R_B' + R_E + h_{FE} R_E)^2 = \left(\frac{3.22 h_{FE}}{I_C}\right)^2$

$$\text{so } \frac{dI_C}{dh_{FE}} = \frac{3.22 (R_B' + R_E) I_C^2}{(3.22\, h_{FE})^2}$$

$$= \frac{3.22 (R_B' + R_E) \cancel{3.22^2} \times 10^{-6}}{\cancel{3.22^2} . 450^2}$$

$$\frac{dI_C}{dT} = \frac{3.22 (R_B' + R_E) \times 10^{-6}}{450^{\cancel{2}}} \cdot \frac{\cancel{450} \times 0.5}{100.} = \underline{1.16 \mu A/^oC}$$

[This gives a V_c dependency of -2.78 mV/°C]

Q7 (i) you need to find two equations with I_F and I_C as unknowns...

$$24 = (I_C + I_F)R_L + I_F(R_1 + R_2) + I_F R_3$$

or $$24 = I_C R_L + I_F(R_L + R_1 + R_2 + R_3) \quad \text{—— (1)}$$

and $$I_F R_3 = 0.7 + I_C R_E \quad \text{—— (2)}$$

(this assumes $I_E \approx I_C$).

eliminating I_F from (1) + (2) ...

$$24 = I_C R_L + \frac{0.7 + I_C R_E}{R_3}(R_L + R_1 + R_2 + R_3).$$

or $$24 = I_C \times 10k\Omega + 0.7 \times 4.467 + I_C \times 2.7 \times 10^3 \times 4.467.$$

$$= I_C(10k\Omega + 12.06k\Omega) + 3.13.$$

or $$I_C = \frac{20.87}{22.06k\Omega} = \underline{\underline{946\mu A}}$$

$\therefore$ from (2), $I_F = \underline{\underline{108\mu A}}$.

$$V_E = I_C R_E = \underline{\underline{2.55V}}$$

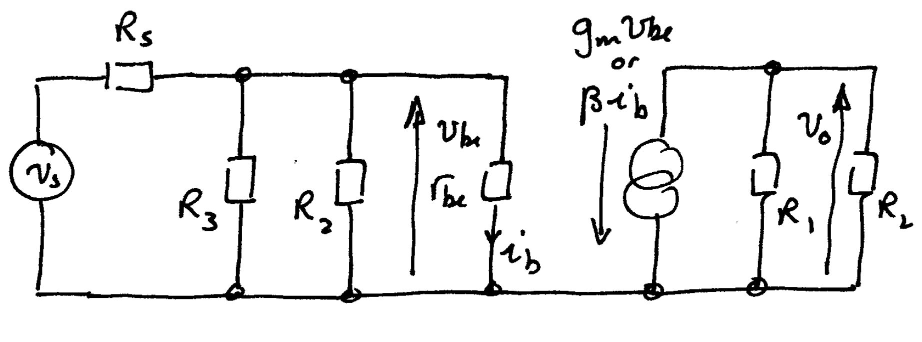
$$V_C = 24 - (I_C + I_F)R_L = 24 - 1.054mA \times 10k$$

$$= \underline{\underline{13.5V}}.$$

(ii) $$g_m = \frac{eI_C}{kT} = \frac{946 \times 10^{-6}}{.026} = \underline{\underline{36.4 mA/V}} \quad (0.0364 A/V)$$

$$r_{be} = \beta/g_m = \frac{500}{.0364} = \underline{\underline{13.7k\Omega}}$$

(iii)



(iv) if $R_s = 0$, $v_s = v_{be}$ and gain is

$$\frac{v_o}{v_s} = \frac{v_o}{v_{be}} = -g_m R_L \| R_F = \underline{\underline{-300}}.$$

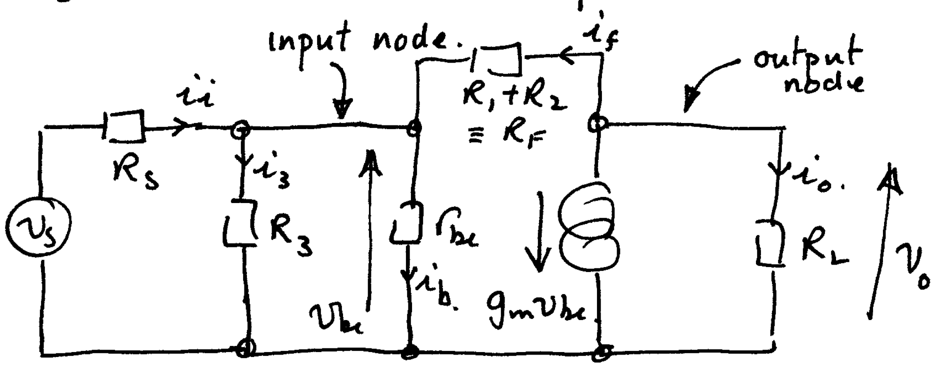
if $R_s = 10\,k\Omega$ ....

$$\frac{v_o}{v_s} = \frac{v_o}{v_{be}} \times \frac{v_{be}}{v_s}.$$

$$\frac{v_{be}}{v_s} = \frac{R_3 \| R_2 \| r_{be}}{R_s + R_3 \| R_2 \| r_{be}} = \frac{7.84\,k\Omega}{17.84\,k\Omega} = 0.439.$$

$$\therefore \frac{v_o}{v_s} = -300 \times 0.439 = \underline{\underline{-132}}$$

(v) if C_3 removed the cct changes to



Sum currents at output node ....

$$i_f + i_o + g_m v_{be} = 0$$

or $$\frac{v_o - v_{be}}{R_F} + \frac{v_o}{R_L} + g_m v_{be} = 0 \qquad \text{—— (1).}$$

Sum currents at input node ....

$$i_i + i_f = i_3 + i_b$$

or $$\frac{v_s - v_{be}}{R_s} + \frac{v_o - v_{be}}{R_F} = \frac{v_{be}}{R_3} + \frac{v_{be}}{r_{be}} \qquad \text{—— (2)}$$

v_{be} can be eliminated from (1) + (2) to give

$$\frac{v_o}{v_s} = \frac{1/R_S}{\left[\frac{R_L + R_F}{R_L(1 - g_m R_F)} \cdot \left(\frac{1}{R_S} + \frac{1}{R_F} + \frac{1}{R_3} + \frac{1}{r_{be}}\right) - \frac{1}{R_F}\right]}$$

$$= \underline{\underline{-8.85}}$$

[The big reduction of gain here occurs because there is now feedback between collector + base (via R_F) that operates on the signal.]