EC332 Devices 2

Sheet 6 (ctd.)and 7

BJT

- **Rules:**
- $I_E = I_B + I_C$

For Active Region:

- $V_{BE} = 0.7$
- $I_{E=}(\beta+1)\ I_B$
- $I_{c=}\beta\ I_B$
- $I_{c=}\alpha\ I_E$

- $\alpha = \frac{\beta}{\beta+1}$
- $\beta = \frac{\alpha}{1-\alpha}$

Sheet 6 -P3(a)

(a) Assume Active region

$V_{BE} = 0.7 \qquad \beta = 10$

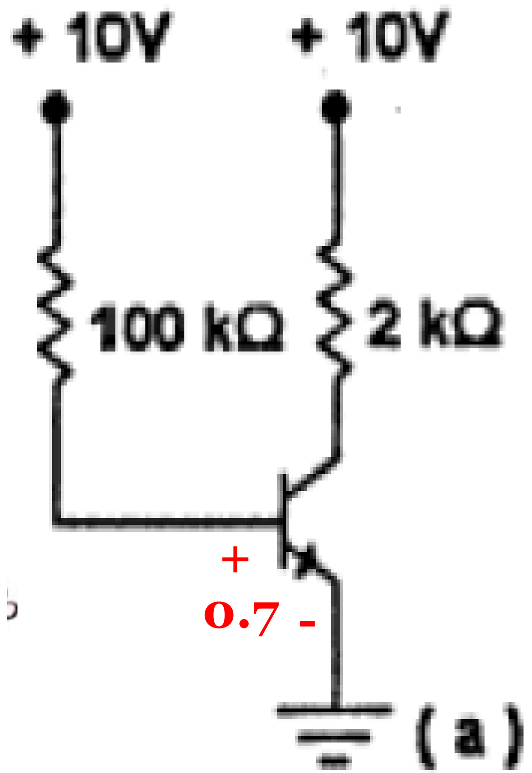
Apply KVL:

$-10 + 100k\, I_B + 0.7 = 0$

$I_B = 93\mu A$

$I_c = \beta I_B = 0.93m$

$I_E = (\beta+1) I_B = 1.023mA$



Sheet 6- P3(c)

(c) $\because V_E = 0$ & $V_{BE} = 0.7$

$\therefore V_B = 0.7$

$I_1 = \frac{10 - V_B}{100k}$ $\quad I_2 = \frac{V_B - 0}{10k}$

Apply KCL at base:

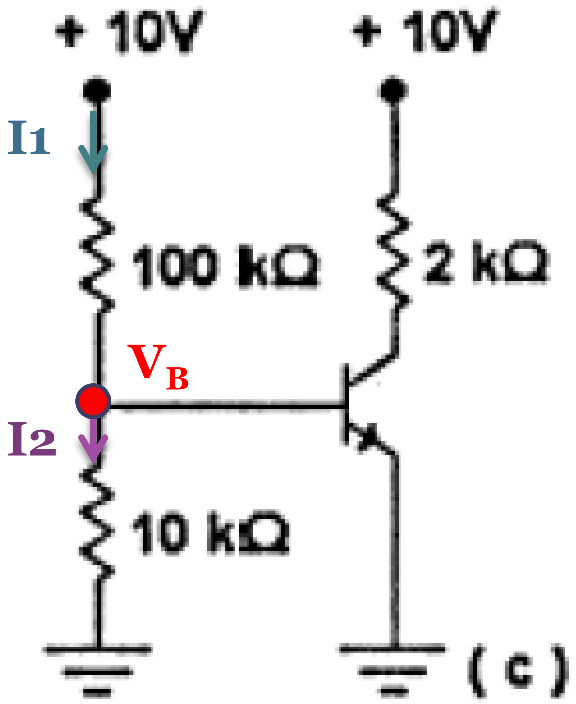
$I_1 = I_B + I_2$

$I_B = I_1 - I_2 = 23\mu A$

$I_C = \beta I_B = 0.23\ mA$

$I_E = (\beta+1) I_B = 0.253\ mA$

$\frac{10 - V_C}{2k} = I_C$ $\quad V_C = 9.54V$



Sheet 6 -P3(b)

(b) $\because V_{EB} = 0.7V$ & $V_E = 10V$

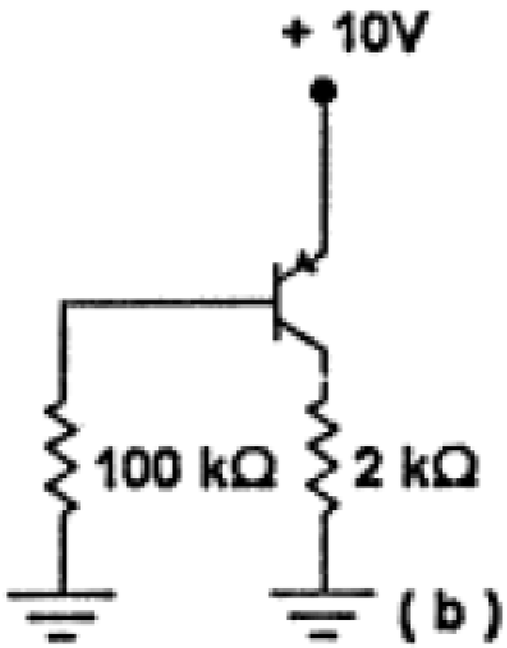
$\therefore V_B = 9.3V$

$I_B = \frac{V_B}{100k} = 93\,\mu A$

$I_C = \beta I_B = 0.93\,mA$

$I_E = (\beta + 1) I_B = 1.023\,mA$

$\frac{V_C - 0}{2k} = I_C \quad V_C = 1.86V$



Sheet 6 - P3 (d)

(d) $\because V_{EB} = 0.7$ & $V_E = 0V$

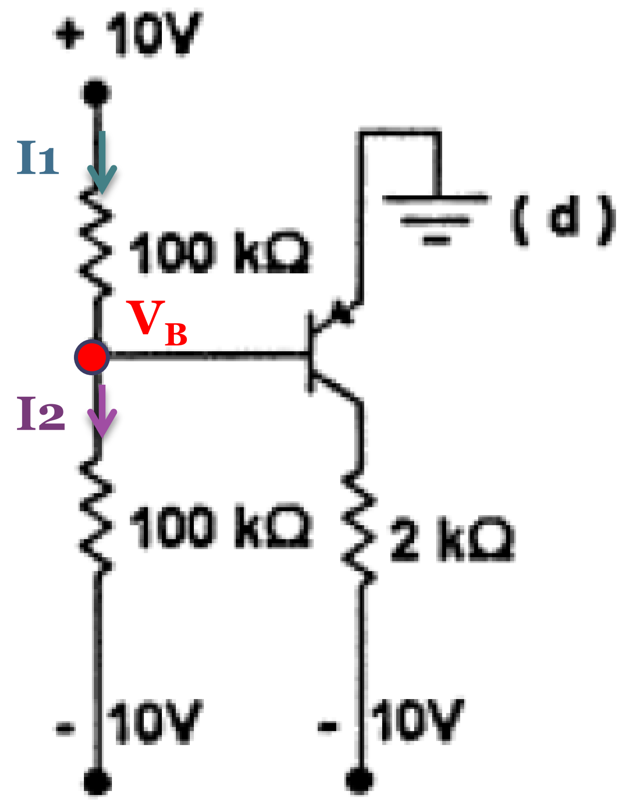
$I_1 = \frac{10 - V_B}{100k}$ $\quad I_2 = \frac{V_B - (-10V)}{100k}$

Apply KCL :

$I_2 = I_1 + I_B$ $\quad I_B = I_2 - I_1$

$I_B = -1.4 \times 10^{-5}$

Not in Active Region.



Sheet 6-P4(a)

(a) At node B:

$I_1 = I_B + 20\mu$ —— ①

At node C:

$I_2 = I_1 + I_C$

$= I_B + 20\mu + I_C$

$= I_B + 20\mu + \beta I_B$

$I_2 = (\beta+1) I_B + 20\mu$ —— ②

Apply KVL:

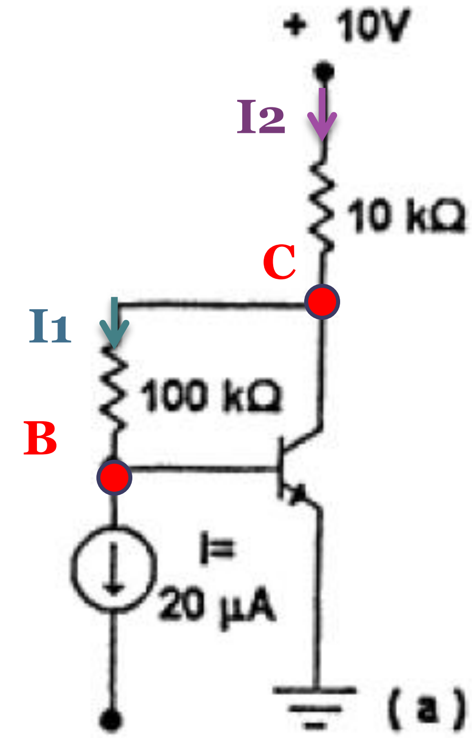
$-10 + I_2(10k) + I_1(100k) + 0.7 = 0$

$-10 + (\beta+1) I_B + 20\mu + (I_B + 20\mu)(100k) + 0.7 = 0$

$I_B = \checkmark$

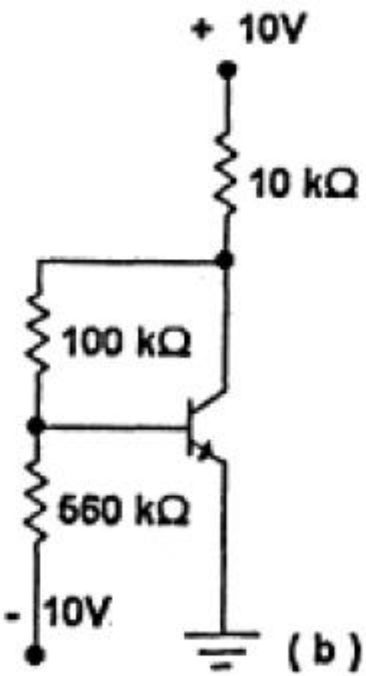
$I_C = \beta I_B = 0.582\,m$

$10 - V_C - I$ $V_C = 3.86 = V_{CE}$

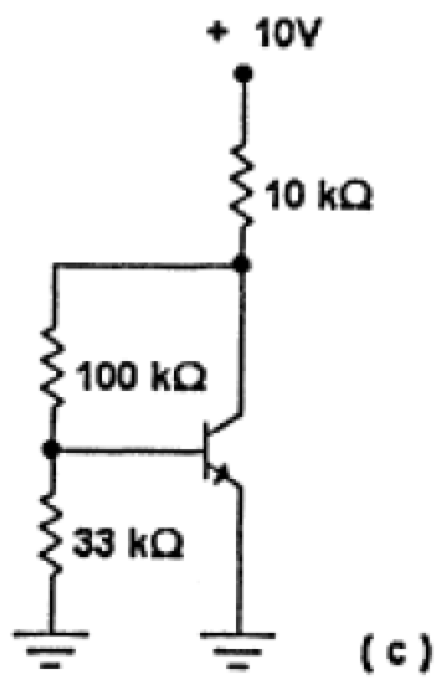


Sheet 6 –P4(b) and (c)

Similar to part (a) but..



$$I = \frac{(V_B = 0.7) - (-10)}{550k}$$



$$I = \frac{(V_B = 0.7)}{33k}$$

Sheet 6 – P4(d)

(d) Loop A:

$$-I_x(68k) + 0.7 + I_E(1k) = 0$$

$$I_x = \frac{0.7 + I_E(1k)}{68k} = \frac{0.7 + (\beta+1)I_B(1k)}{68k} \quad \text{—①}$$

At node B:

$$I_1 = I_B + I_x = I_B + \frac{0.7 + (\beta+1)I_B(1k)}{68k}$$

$$= I_B + (\beta+1)I_B\frac{(1k)}{68k} + \frac{0.7}{68k} \quad \text{—②}$$

At node C:

$$I_2 = I_1 + I_C = I_B\left(1 + (\beta+1)\frac{1k}{68k}\right) + \frac{0.7}{68k} + I_C$$

$$= I_B\left(1 + (\beta+1)\frac{1k}{68k}\right) + \frac{0.7}{68k} + \beta I_B \quad \text{—③}$$

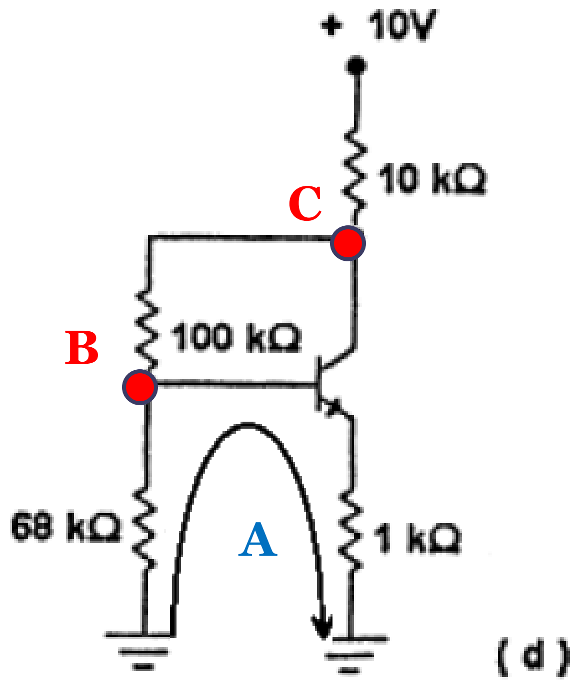
Apply KVL

$$-10 - I_2(10k) + I_1(100k) + I_x(68k) = 0$$

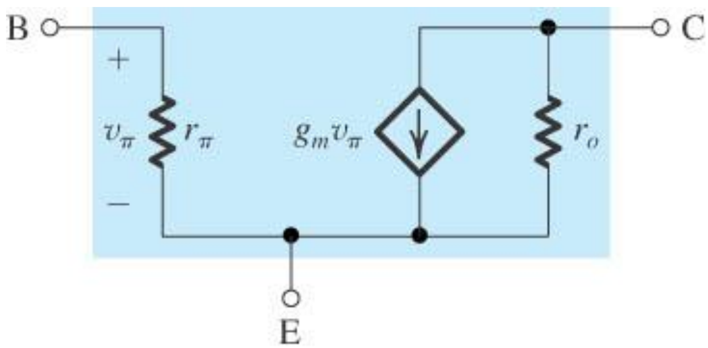
Substitute with ①, ② and ③:

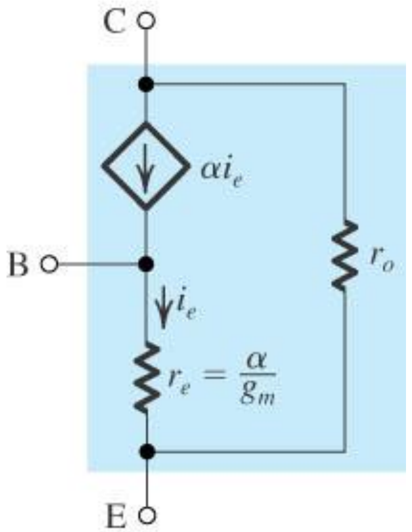
Get I_B

$I_C = 0.5\ mA$ $\quad$ $V_{CE} = 3.69V$



AC Analysis





- AC Parameters
  - $g_m = \frac{I_C}{V_t = 25mV}$
  - $r_\pi = \frac{\beta}{g_m}$
  - $r_o = \frac{V_A}{I_C}$
  - $r_e = \frac{\alpha}{g_m}$

Sheet 7 – P1

DC Analysis

Apply KVL:

$I_B(100) + 0.7 + I_E(10k) - 10V = 0$

Substitute with $I_E = (\beta+1)I_B$

$I_B(100) + 0.7 + (\beta+1)I_B(10k) - 10 = 0$

$I_B = 9.11\,\mu A$

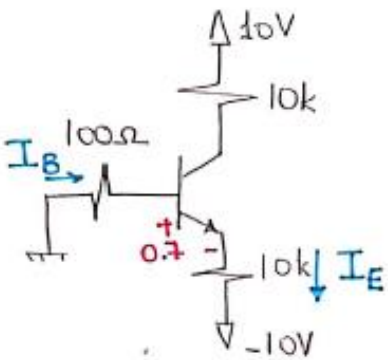
$I_C = \beta I_B = 1.36\,mA$

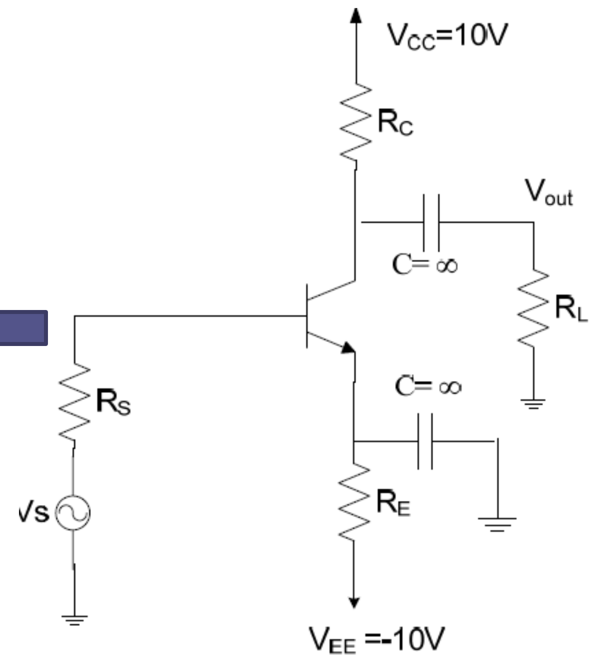
AC Parameters:

$g_m = \frac{I_C}{V_t} = \frac{1.3\,m}{25\,m} = 0.054$

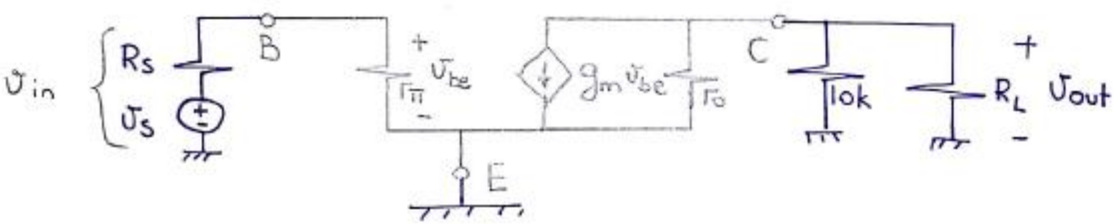
$r_\pi = \frac{\beta}{g_m} = \frac{150}{0.05} = 2.74\,k\Omega$

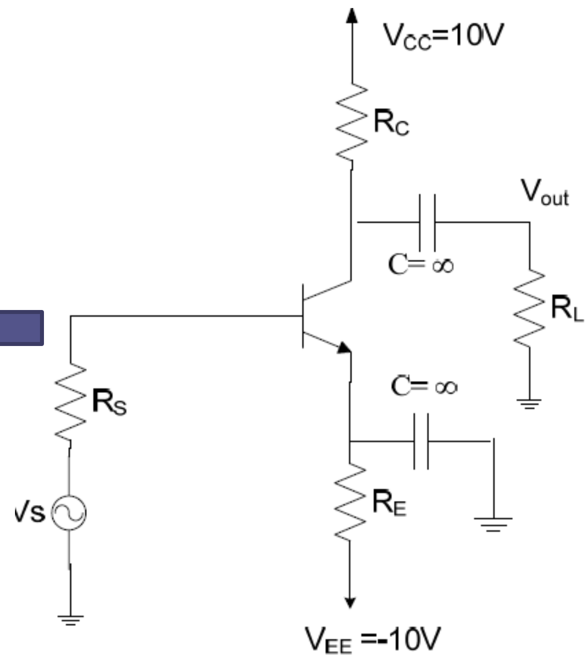
$r_o = \frac{V_A}{I_C} = \frac{200}{1.36m}$



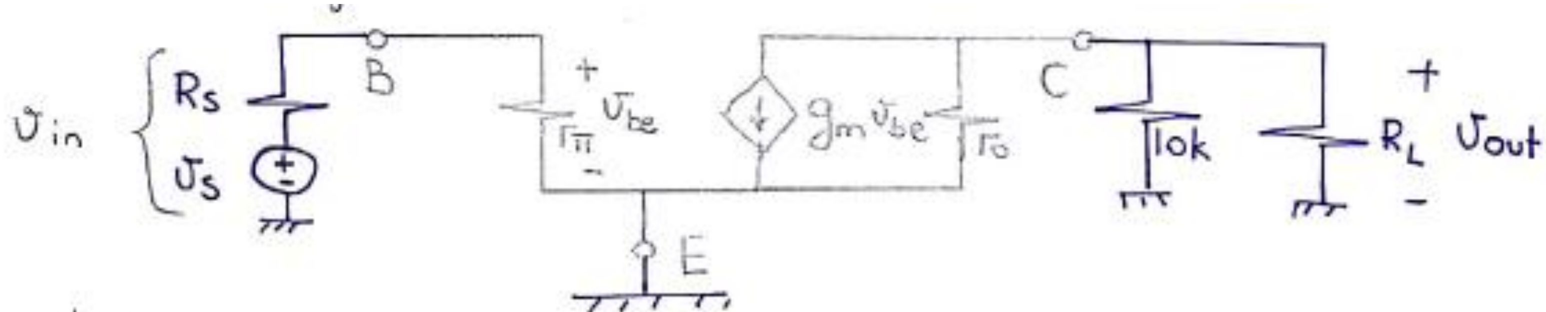


Sheet 7 – P1 (ctd.)





Sheet 7- P1 (ctd.)



To get v_o/v_s:

Applying voltage divider:

$$v_{be} = \frac{v_s r_\pi}{R_s + r_\pi} \quad \text{— (1)}$$

$$v_{out} = -g_m v_{be} \left(r_o // 10k // R_L\right) \quad \text{— (2)}$$

Substitute (1) in (2):

$$v_{out} = -g_m \frac{v_s r_\pi}{R_s + r_\pi} \left(r_o // 10k // R_L\right)$$

$$\frac{v_{out}}{v_s} = -g_m \frac{r_\pi}{R_s + r_\pi} \left(r_o // 10k // R_L\right)$$

$$R_{in} = \frac{v_{in}}{i_{in}} = r_\pi$$

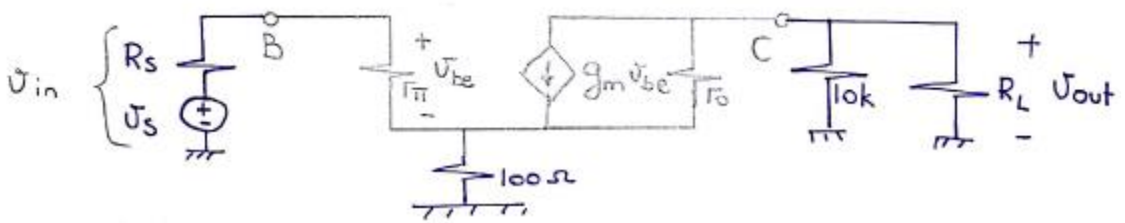
$$R_{out} = \frac{v_x}{i_x}\bigg|_{v_{in}=0} = 10k // r_o$$

Sheet7 - P2

- DC Analysis

Same as P1.

- AC Analysis



$$v_{be} = \frac{v_s \, r_\pi}{R_s + r_\pi + (\beta+1)100} \longrightarrow v_s = v_{be}\,\frac{R_s + r_\pi + (\beta+1)100}{r_\pi}$$

$$v_o = -g_m v_{be} \, (r_o // R_L // 10k)$$

$$\frac{v_o}{v_s} = \frac{-g_m \cancel{v_{be}}(r_o // R_L // 10k)}{\cancel{v_{be}} \left(\frac{R_s + r_\pi + (\beta+1)100}{r_\pi}\right)}$$

Sheet 7-P3

DC Analysis

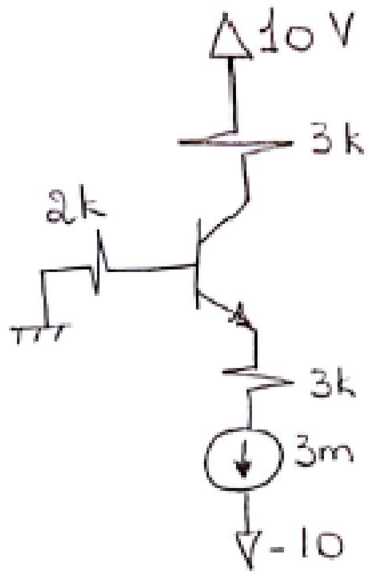
$I_E = 3mA$

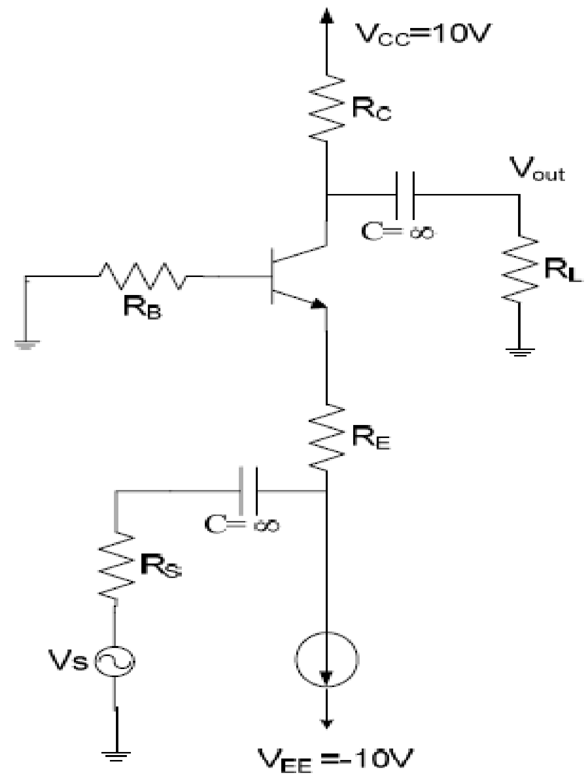
$\alpha = \frac{\beta}{\beta+1} = \frac{150}{151}$

$I_C = \alpha I_E =$

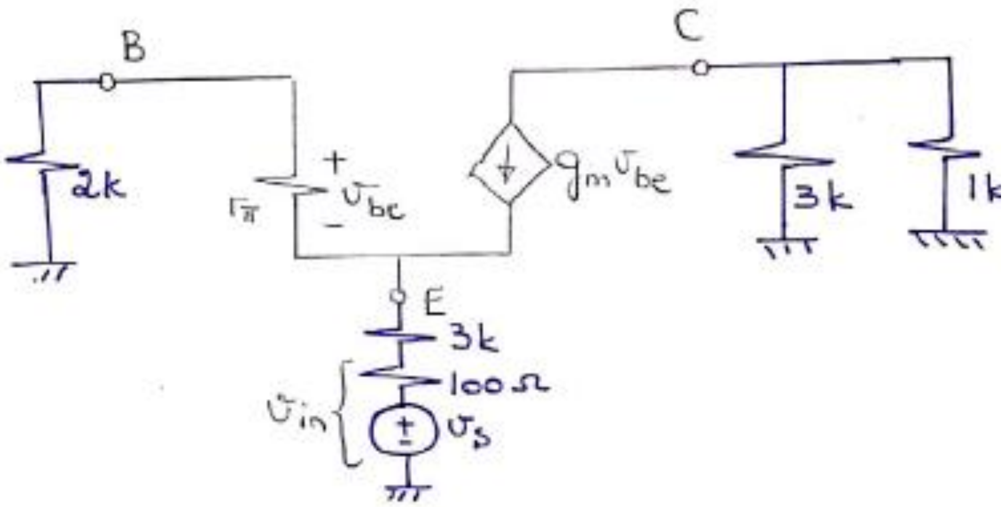
$g_m = \frac{I_c}{V_t}$

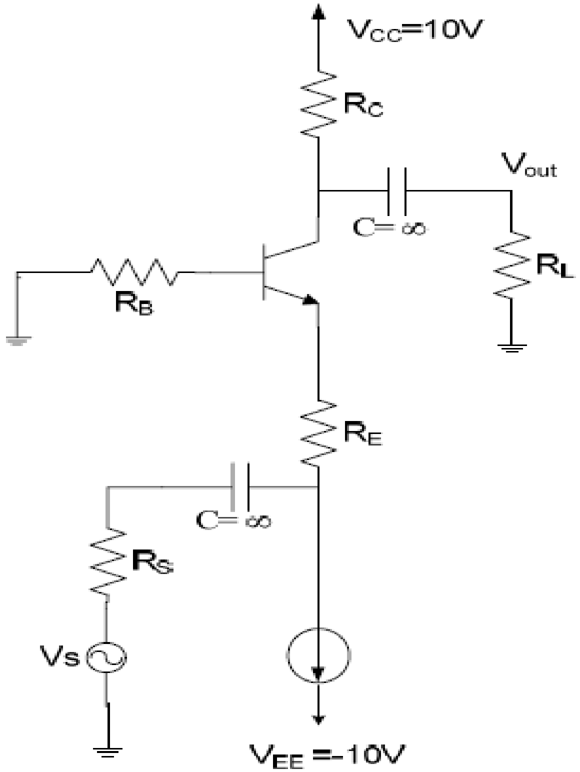
$r_\pi = \frac{\beta}{g_m}$





Sheet7-P3(ctd.)





Sheet 7 –P3 (ctd.)

To get v_o/v_s:

Apply KVL:

$$i_b(2k) + i_b(r_\pi) + i_e(3k+100) + v_s = 0$$

$$i_b(2k) + i_b(r_\pi) + (\beta+1)i_b(3k+100) + v_s = 0$$

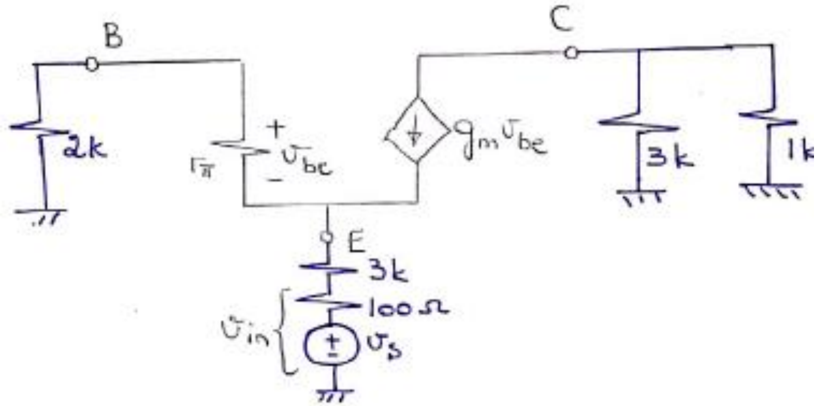
$$v_s = -i_b\left(2k + r_\pi + (\beta+1)(100+3k)\right) \text{ — } 1$$

$$v_o = -i_c(3k // 1k)$$

$$v_o = -\beta i_b(3k // 1k) \text{ — } 2$$

Divide 2 by 1:

$$\frac{v_o}{v_s} = \frac{-\beta \cancel{i_b}(3k // 1k)}{-\cancel{i_b}\left(2k + r_\pi + (\beta+1)(100+3k)\right)}$$



To get R_{in}: $i_{in} = -i_e$

$$v_{in} = i_{in}(3k) - i_b(r_\pi + 2k) = i_{in}(3k) - (\beta+1)i_e(r_\pi + 2k)$$

$$= i_{in}(3k) + i_{in}(\beta+1)(r_\pi + 2k) \quad \therefore R_{in} = 3k + (\beta+1)(r_\pi + 2k)$$

Sheet 7-P4

DC Analysis

$I_E = 0.1mA$

$\alpha = \frac{\beta}{\beta+1} = \frac{50}{51}$

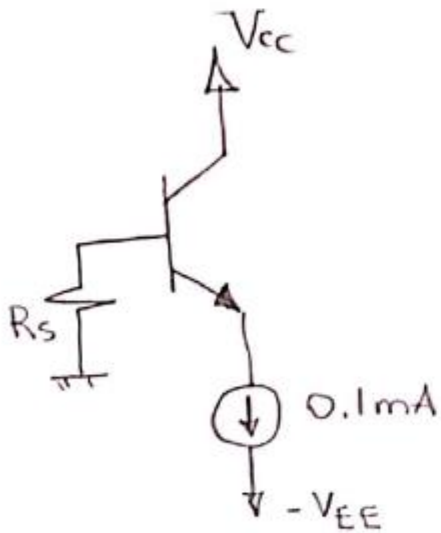
$I_C = \alpha I_E =$

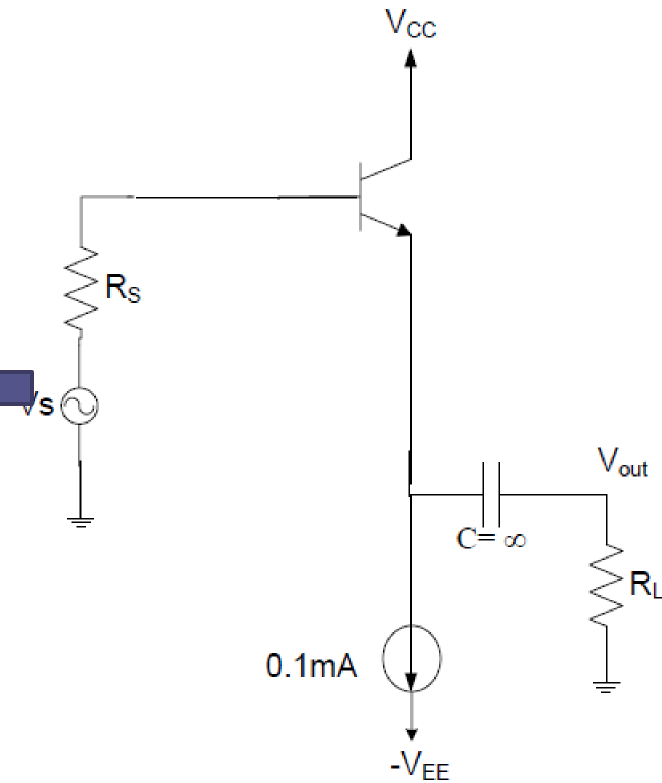
AC Parameter

$r_\pi = \frac{\beta}{g_m} =$

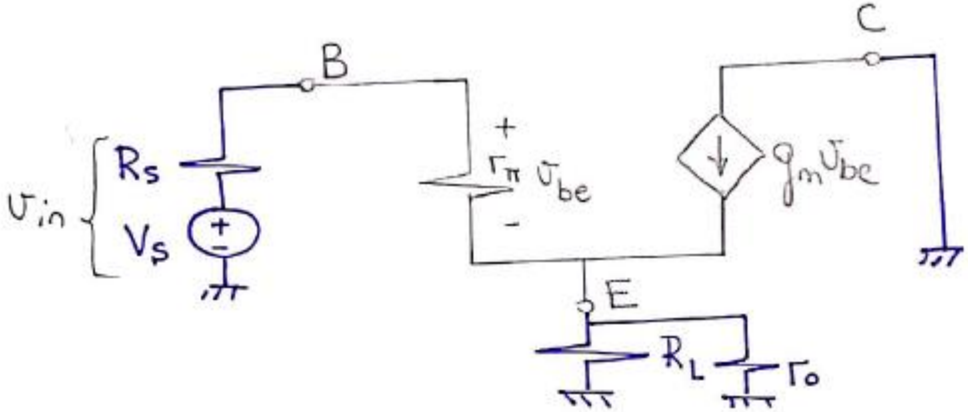
$g_m = \frac{I_C}{V_t} =$

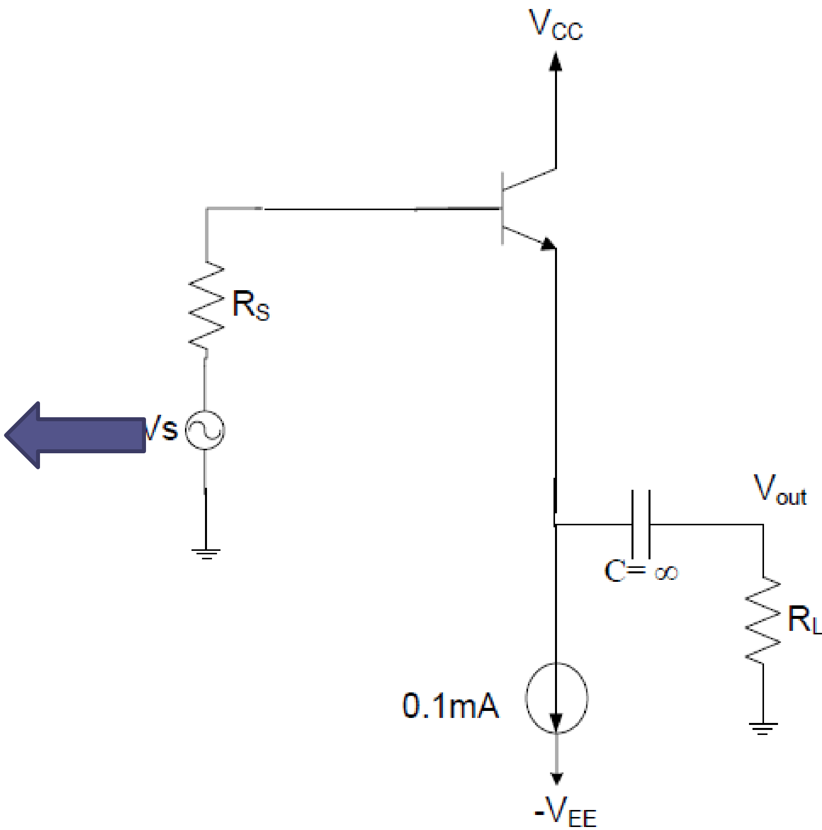
$r_o = \frac{V_A}{I_C}$





Sheet 7- P4 (ctd.)





Sheet 7- P4 (ctd.)

To get $\frac{v_o}{v_s}$

$$-v_s + i_b R_s + i_b r_\pi + i_e (R_L \| r_o) = 0$$

Substitute with $i_e = (\beta+1) i_b$

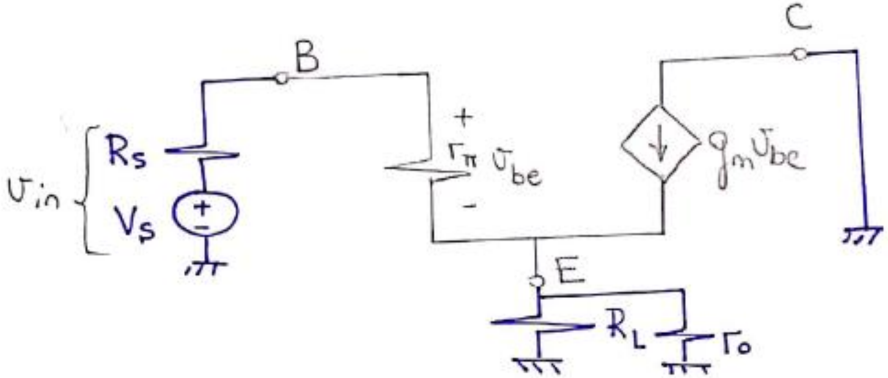
$$+v_s = i_b \left(R_s + r_\pi + (\beta+1)(R_L \| r_o)\right) \text{ --- } 1$$

$$v_o = i_e (R_L \| r_o)$$

$$v_o = (\beta+1) i_b (R_L \| r_o) \text{ --- } 2$$

Dividing 2 by 1:

$$\frac{v_o}{v_s} = \frac{(\beta+1)\cancel{i_b}(R_L \| r_o)}{\cancel{i_b}\left(R_s + r_\pi + (\beta+1)(R_L \| r_o)\right)}$$



To get R_{in}

$$i_{in} = i_b$$

$$v_{in} = i_{in} r_\pi + i_e (R_L \| r_o) = i_{in} r_\pi + (\beta+1) i_b (R_L \| r_o) = i_{in}\left(r_\pi + (\beta+1)(R_L \| r_o)\right)$$

$$R_{in} = r_\pi + (\beta+1)(R_L \| r_o)$$

Sheet 7-P3 (T Model)

To get $\frac{v_o}{v_s}$

Apply KVL at loop A:

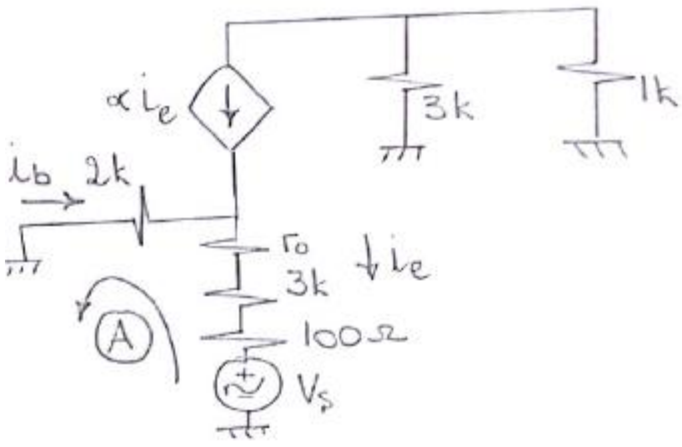
$$-v_s - i_e(100 + 3k + r_e) - i_b(2k) = 0$$

$$v_s = -i_e(100 + 3k + r_e) - \frac{i_e}{\beta+1}(2k) = -i_e\left(100 + 3k + r_e + \frac{2k}{(\beta+1)}\right) \quad (1)$$

$$v_o = -\alpha i_e (3k // 1k) \quad (2)$$

Divide (2) by (1):

$$\frac{v_o}{v_s} = \frac{-\alpha(3k//1k)}{100 + 3k + r_e + \frac{2k}{\beta+1}}$$



To get Rin

$$R_{in} = \frac{v_{in}}{i_{in}} = 3k + r_e + \frac{2k}{(\beta+1)}$$

To get Rout

$$R_{out} = 3k$$