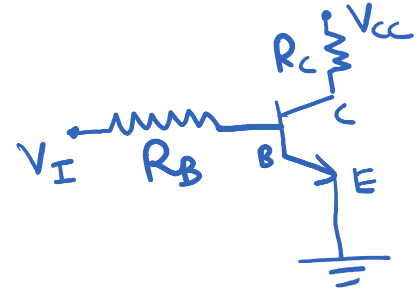
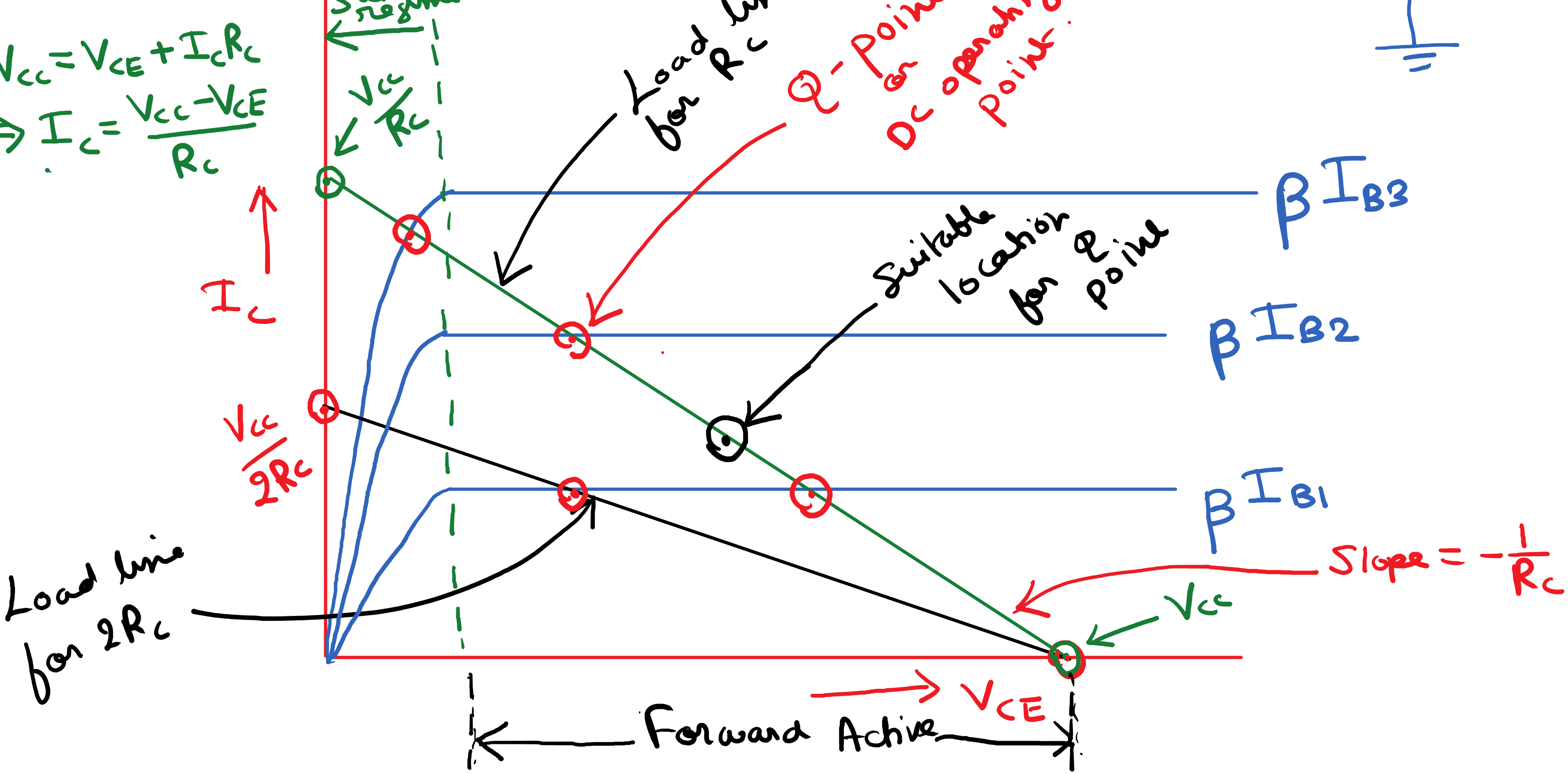
Class-20

Load lines:



$$V_{CC} = V_{CE} + I_C R_C$$

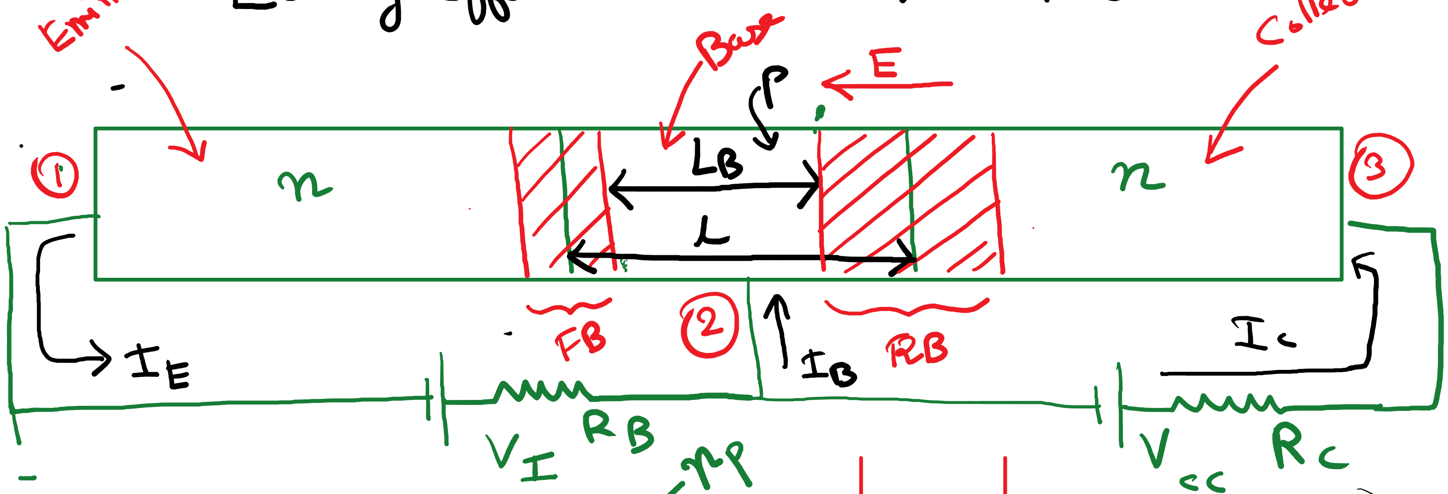
$$\Rightarrow I_C = \frac{V_{CC} - V_{CE}}{R_C}$$



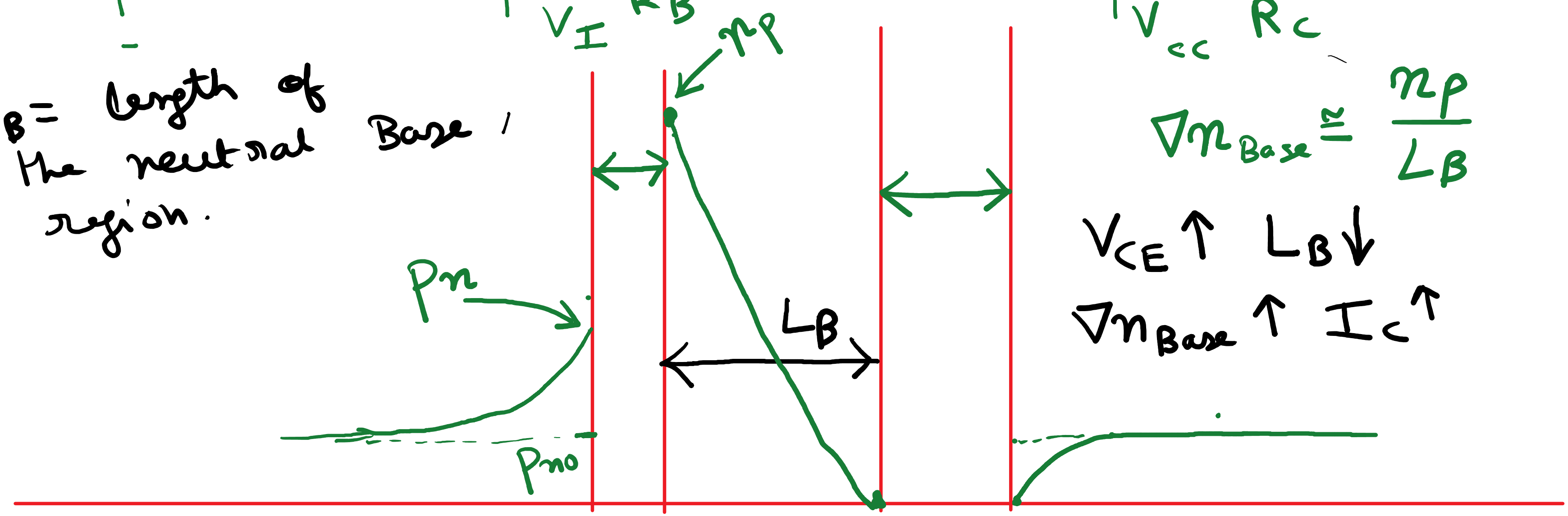
Q-point or DC operating point is the solution of the DC values of V_{CE} and I_C for a given transistor and a given set of external resistors. Q-point can be changed by changing the resistors R_B and R_C

A suitable location for Q-point is somewhere near the middle of the active regime or the middle of the load line.

Early effect or Base-width modulation



L_B = length of the neutral Base region.



$$\nabla n_{Base} \simeq \frac{n_p}{L_B}$$

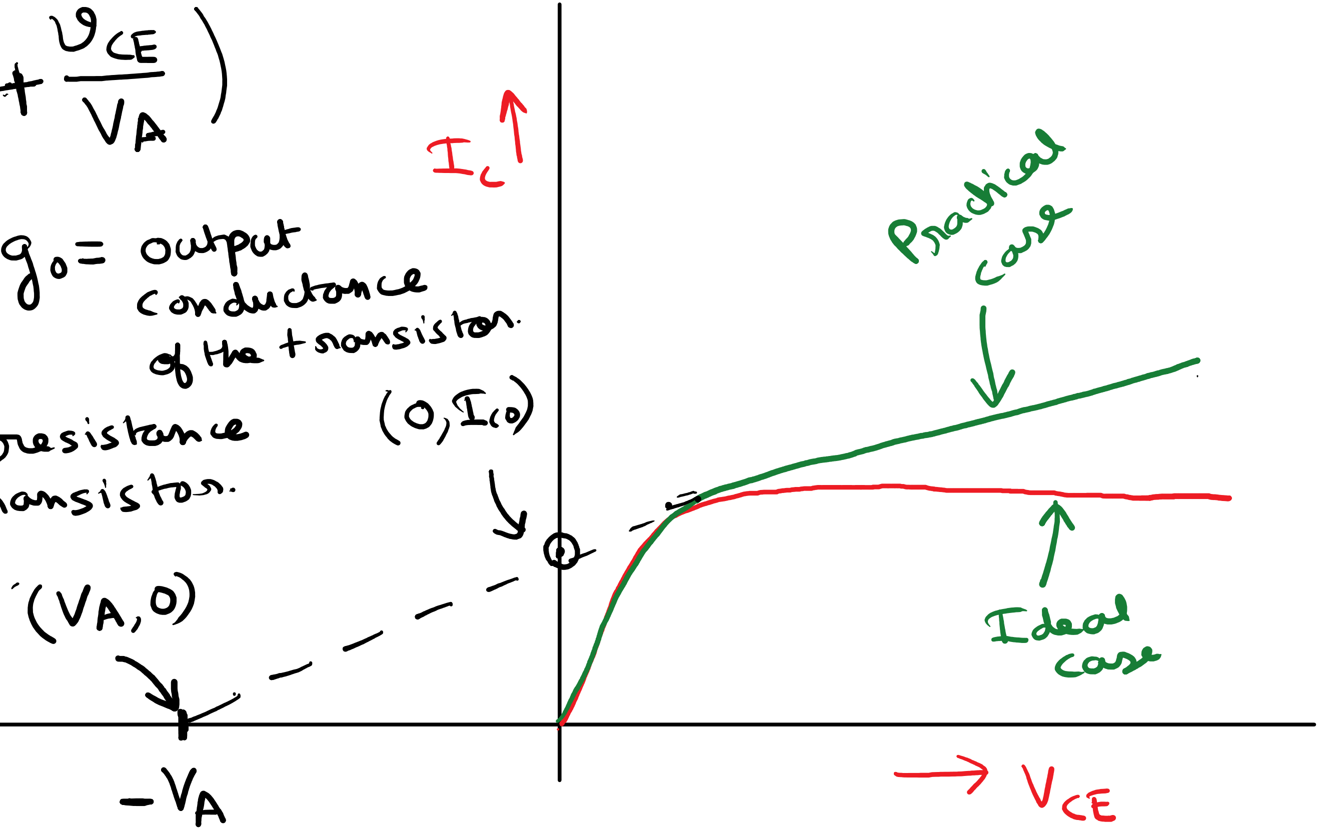
$V_{CE} \uparrow \quad L_B \downarrow$

$\nabla n_{Base} \uparrow \quad I_C \uparrow$

$$I_C = I_{C0}\left(1+\frac{v_{CE}}{V_A}\right)$$

$\dfrac{\partial I_C}{\partial v_{CE}} = \dfrac{I_{C0}}{V_A} = g_o =$ output conductance of the transistor.

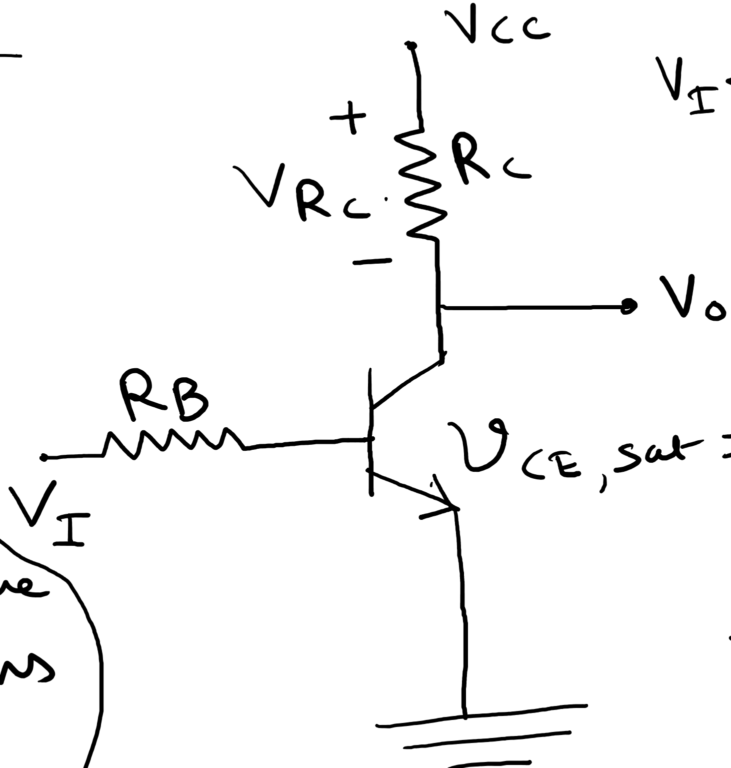
$r_o = g_o^{-1} =$ output resistance of the transistor.



$V_A =$ Early voltage.

Class - 21

V_I	V_0
Low	High
High	Low



$V_{CE,sat} = 0.2V$

If V_I is low, that is $V_I < V_{BE(ON)}$ then $I_B = 0$. So, $I_C = 0$. So, $V_{R_C} = 0$

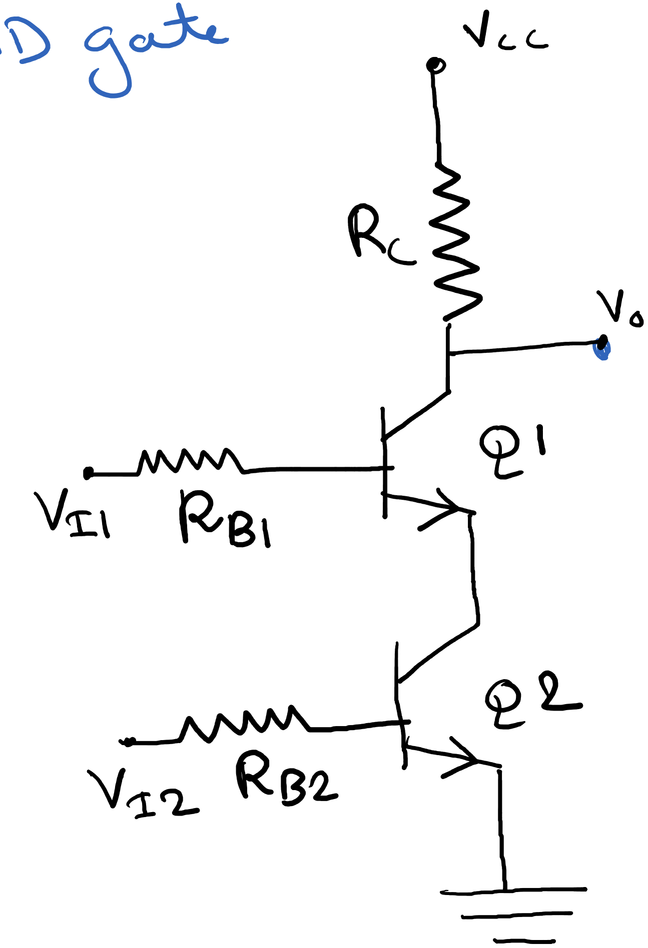
So, $V_0 = V_{CC}$.

So, this configuration acts as a NOT gate.

Here low value of V_0 means $V_0 = V_{CE,sat}$

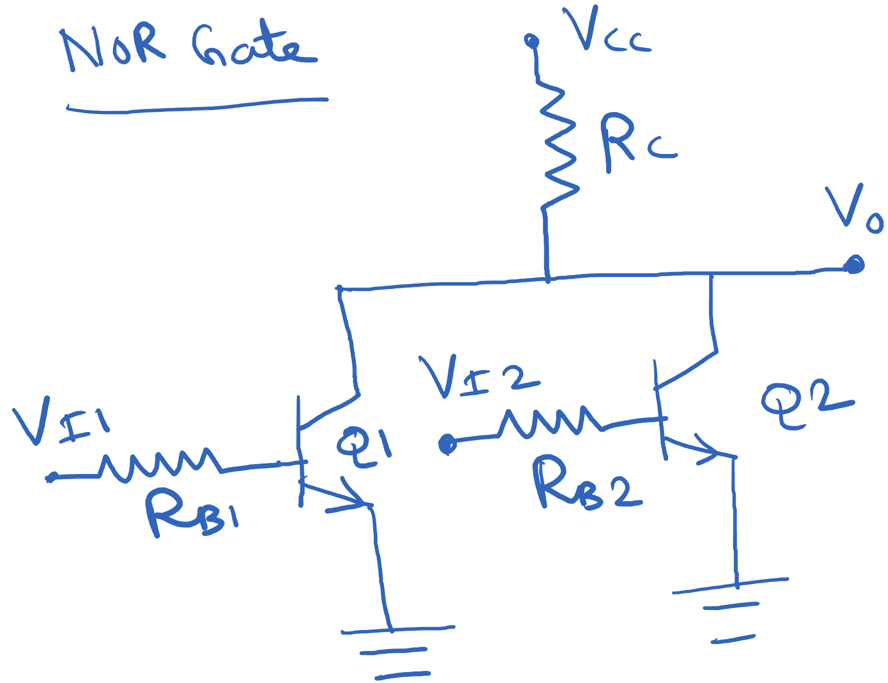
NAND gate

V_{I1}	V_{I2}	V_o
Low	Low	High
Low	High	High
High	Low	High
High	High	Low

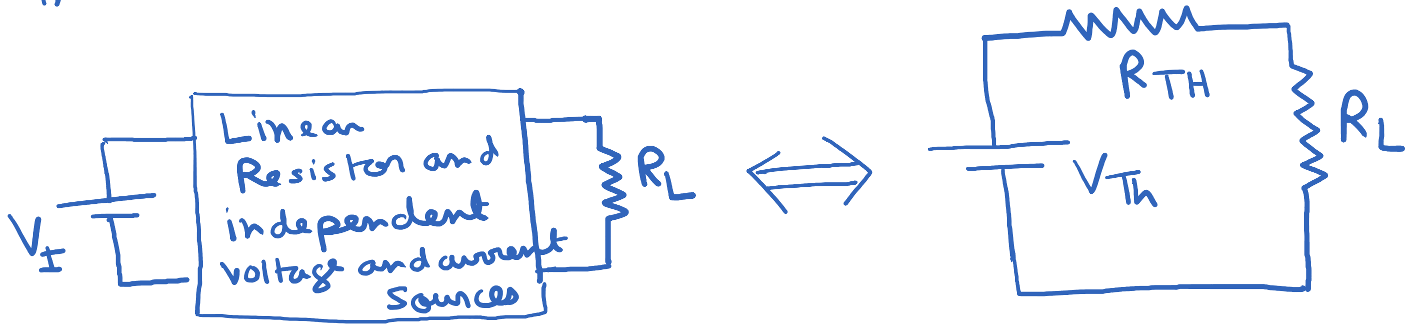


V_{I1}	V_{I2}	V_0
Low	Low	High
Low	High	Low
High	Low	Low
High	High	Low

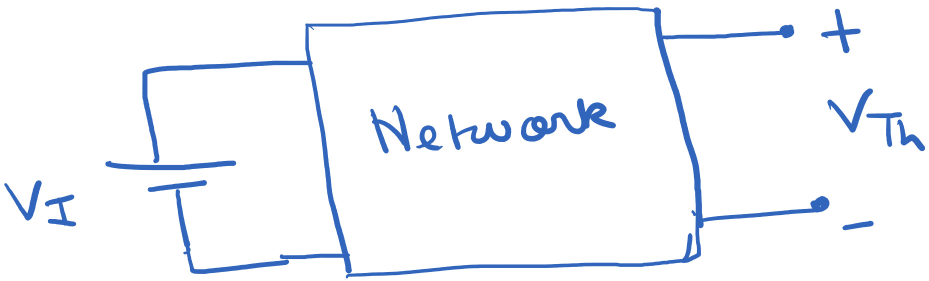
NOR Gate



Thevenin's Theorem:-

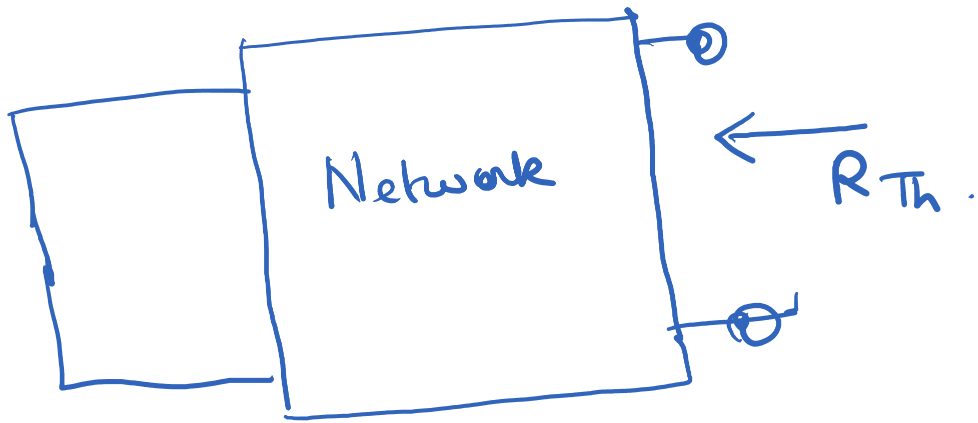


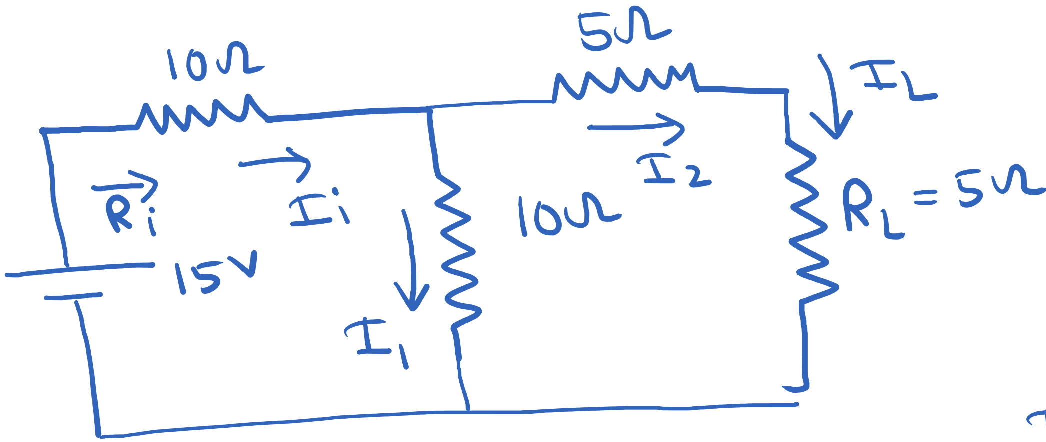
To Find V_{Th}:-



To Find R_{Th} → remove any voltage source and replace it by short circuit

→ remove any independent current source and replace by open circuit





$R_i = 10Ω + (10Ω \| 10Ω)$

$= 15Ω$

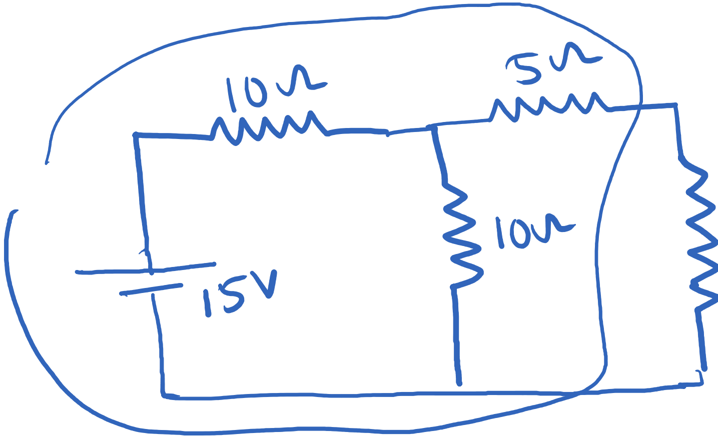
$I_i = \frac{15V}{15Ω} = 1A$

$I_1 = I_2$

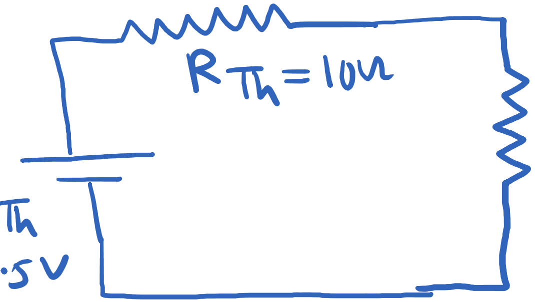
$I_1 + I_2 = I_i = 1A$

$I_1 = I_2 = \frac{I_i}{2} = 0.5A$

$I_L = I_2 = 0.5A.$



$\Longleftrightarrow$



$$V_{Th} = 15V \times \frac{10\Omega}{10\Omega + 10\Omega}$$

$$= 7.5V$$

$$R_{Th} = 5\Omega + (10\Omega \parallel 10\Omega)$$

$$= 10\Omega$$

$$I_L = \frac{V_{Th}}{R_{Th} + I_L}$$

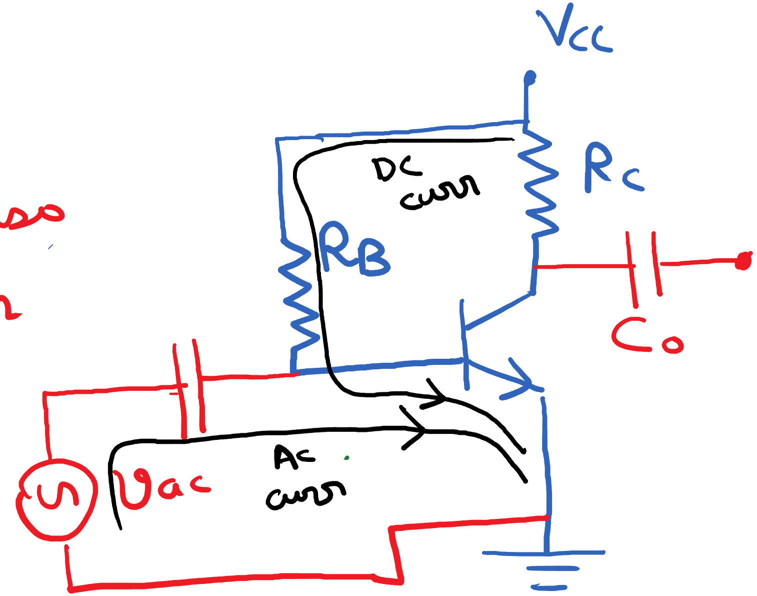
$$= \frac{7.5V}{10\Omega + 5\Omega}$$

$$= 0.5A$$

Biasing of Transistors:-

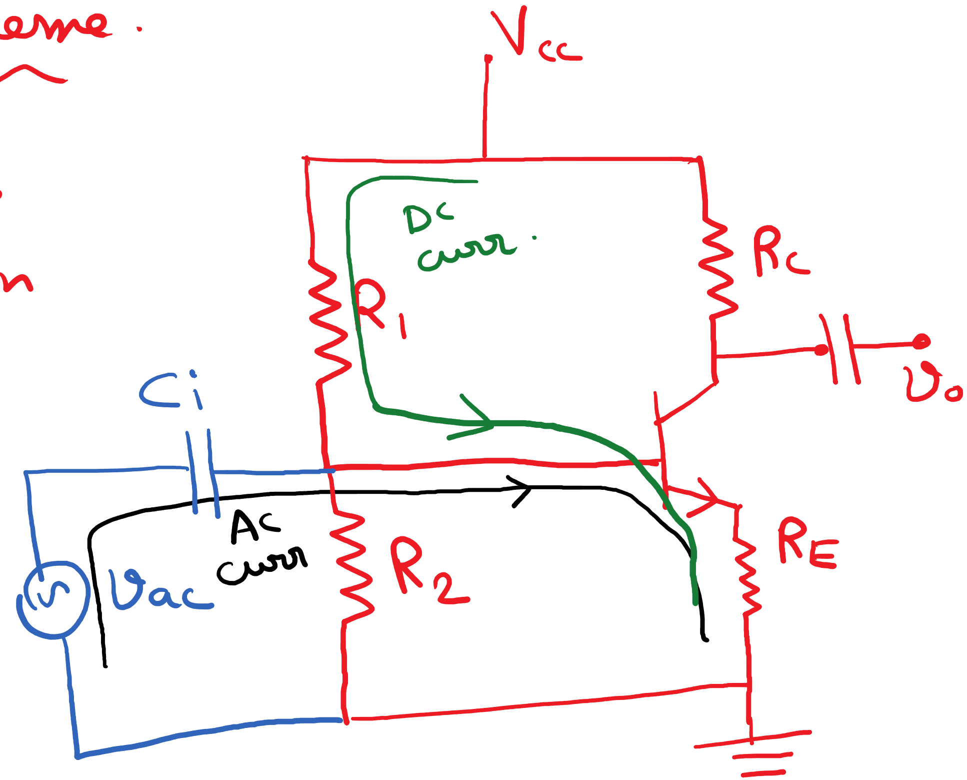
Fixed Biasing scheme.

This Biasing Scheme is also known as Single Resistor Biasing Scheme.



Voltage divider Biasing Scheme.

R_E is put to enhance biasing stability against variation in β.

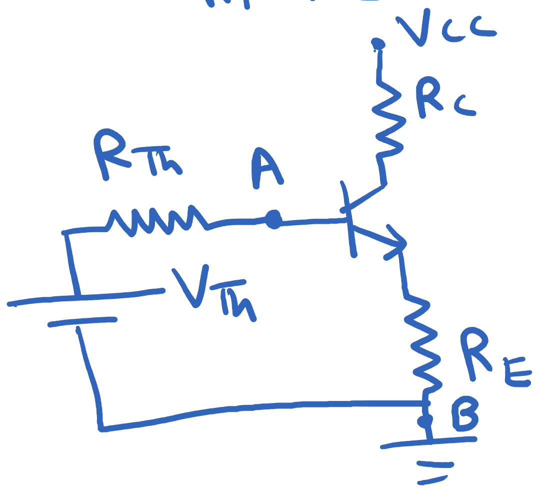


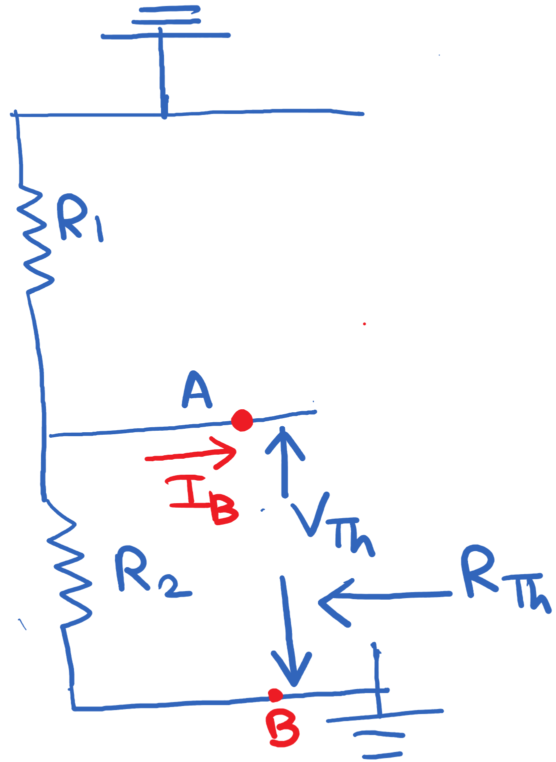
Class-22

$V_{Th}, R_{Th} = ?$

$$V_{Th} = \frac{R_2}{R_1+R_2} \times V_{cc}$$

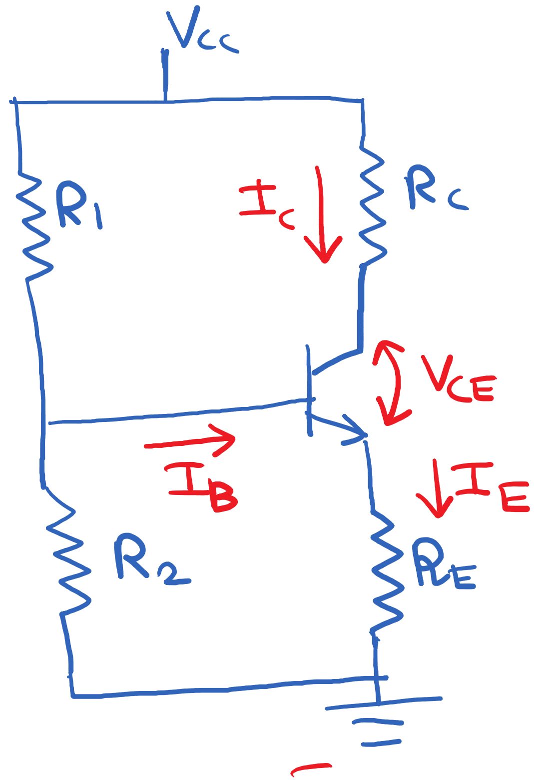
$$R_{Th} = R_1 \| R_2 = \frac{R_1 R_2}{R_1+R_2}$$





$I_C = \beta I_B$

$I_E = (\beta+1) I_B$



Vcc
R1
Ic
Rc
VCE
IB
IE
R2
RE

$$V_{Th} = I_B R_{Th} + V_{BE(ON)} + I_E R_E$$

$$= I_B R_{Th} + V_{BE(ON)} + (\beta+1) I_B R_E$$

$$\Rightarrow I_B = \frac{V_{Th} - V_{BE(ON)}}{R_{Th} + (\beta+1) R_E}$$

$$I_C = \beta \frac{V_{Th} - V_{BE(ON)}}{R_{Th} + (\beta+1) R_E}$$

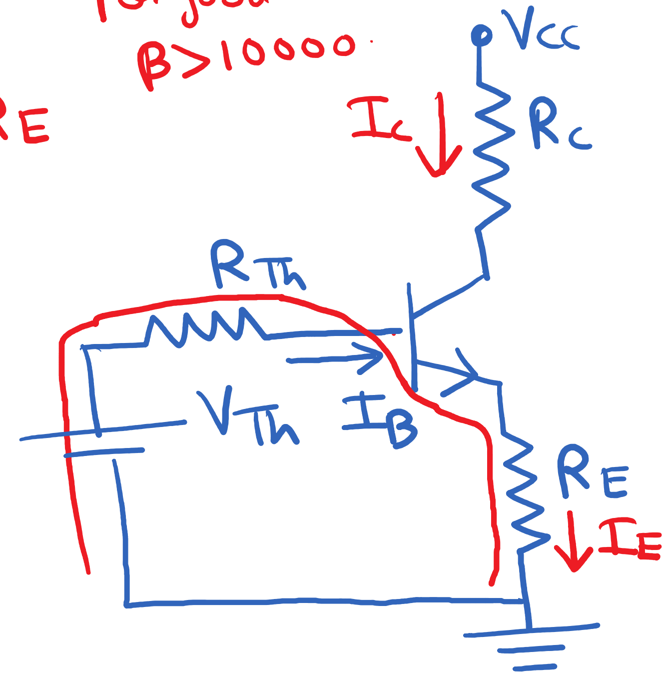
$\because (\beta+1) R_E >> R_{Th}$.

$$I_C \cong \beta \frac{V_{Th} - V_{BE(ON)}}{(\beta+1) R_E} = \frac{\beta}{\beta+1} \frac{V_{Th} - V_{BE(ON)}}{R_E}$$

$$\cong \frac{V_{Th} - V_{BE(ON)}}{R_E} \quad (\because \beta+1 \cong \beta)$$

For good transistor

$\beta > 10000$.



$I_E = (\beta+1) I_B$

β can vary due to temperature or due to ageing of transistor.

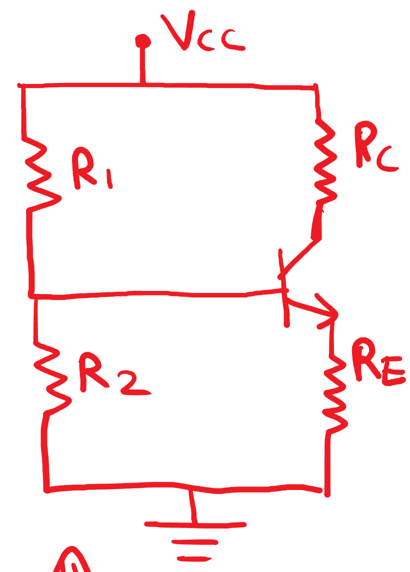
$$\approx \frac{V_{Th} - V_{BE(ON)}}{R_E} \quad (\because \beta + 1 \approx \beta)$$

to ageing of transistor.

$V_{CC} = 18V$, $R_1 = 33k\Omega$, $R_2 = 10k\Omega$, $R_C = 2.2k\Omega$

$R_E = 1k\Omega$, $\beta = 50$.

I_B, I_C , V_{CE} ?



$$V_{Th} = \frac{R_2}{R_1 + R_2} \times V_{CC} = \frac{10}{43} \times 18V = 4.186V.$$

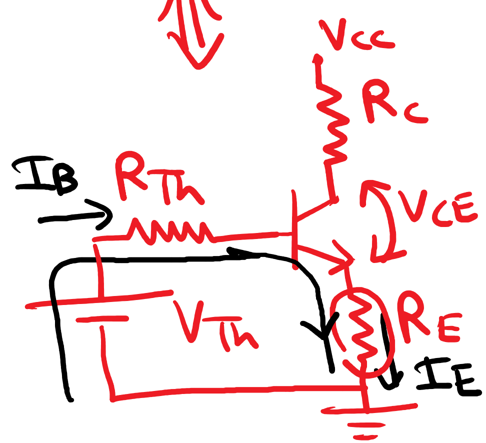
$$R_{Th} = (R_1 \| R_2) = (33k\Omega \| 10k\Omega) = 7.67k\Omega$$

$$V_{Th} = R_{Th} \times I_B + V_{BE(ON)} + I_E R_E$$

$$4.186V = 7.67 I_B + 0.7V + 51 I_B \times 1.$$

$$\Rightarrow I_B \times (7.67 + 51) = (4.186 - 0.7)$$

$$\Rightarrow I_B = \frac{3.486}{58.67} mA = 0.0594 mA$$



$$I_C = \beta I_B = 50 \times 0.0594 mA = 2.97 mA.$$

$$V_{CE} = V_{CC} - I_C R_C - I_E R_E$$

$$= 18V - 2.97 \times 2.2 - 2.97 \times 1$$

$$= 18V - 2.97 \times 3.2V$$

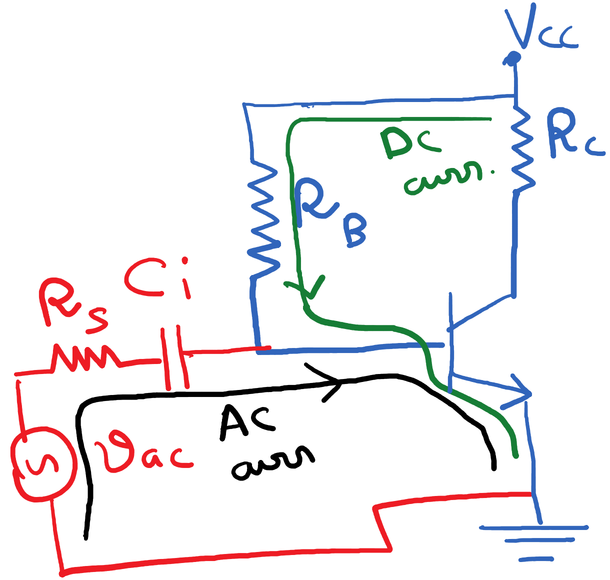
$$= 8.496V.$$

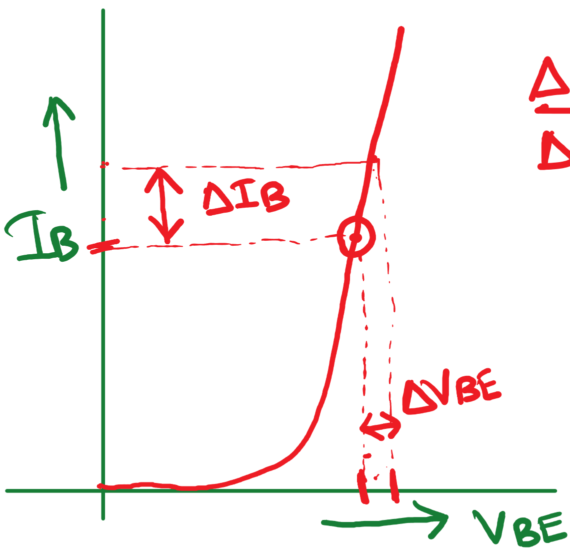
Small signal or AC model:-

$$I_E \cong I_S \exp\left\{\frac{V_{BE}}{V_T}\right\}$$

$$I_B = \frac{I_E}{\beta+1} = \frac{I_S}{\beta+1}\exp\left\{\frac{V_{BE}}{V_T}\right\}$$

$$= I_{SB} \exp\left\{\frac{V_{BE}}{V_T}\right\}$$





$\frac{\Delta I_B}{\Delta V_{BE}}$ = slope of the I_B-V_{BE} at the DC operating point

$$= \left.\frac{\partial I_B}{\partial V_{BE}}\right|_{V_{BE}=V_{BEQ}} = \frac{I_{SB}}{V_T}\exp\left\{\frac{V_{BEQ}}{V_T}\right\}$$

$$= \frac{I_{BEQ}}{V_T}$$

Small signal Base conductance

$$\left.\frac{\partial V_{BE}}{\partial I_B}\right|_{V_{BEQ}} = \left.\left(\frac{\partial I_B}{\partial V_{BE}}\right)^{-1}\right|_{V_{BEQ}} = \frac{V_T}{I_{BEQ}} = r_\pi$$

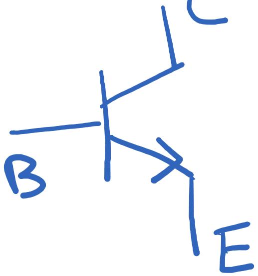
small signal Base resistance

$$\frac{\Delta V_{BE}}{\Delta I_B} = r_\pi$$

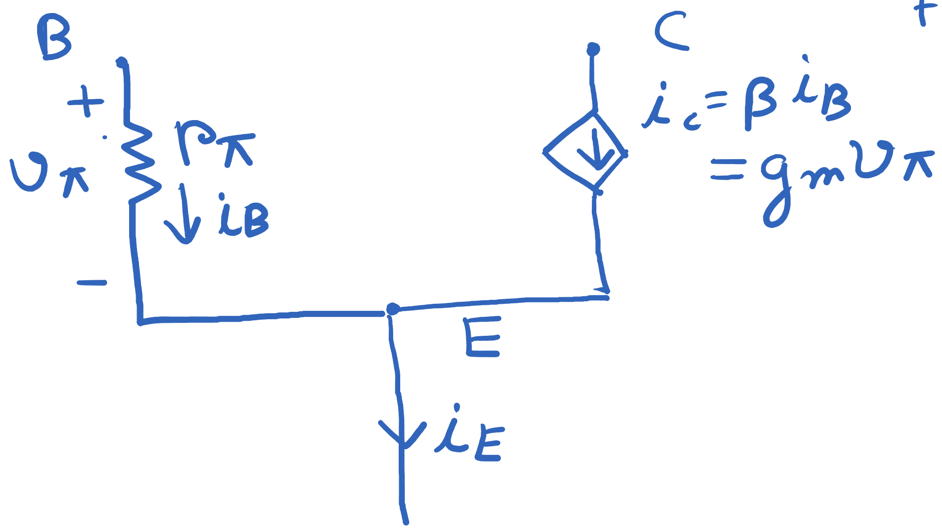
$$\Rightarrow \frac{v_{BE}}{i_B} = r_\pi$$

depends on DC biasing point

a parameter of the AC model.



Small signal model of the npn transistor.

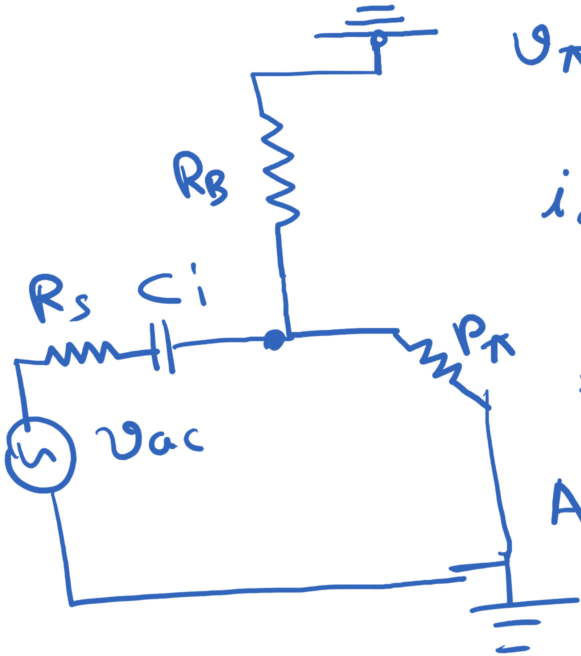


$$v_\pi = v_{be}$$

$$i_c = \beta i_B = \beta \frac{v_\pi}{r_\pi} = \frac{\beta}{r_\pi} v_\pi = g_m v_\pi$$

small-signal trans-conductance

trans-conduc



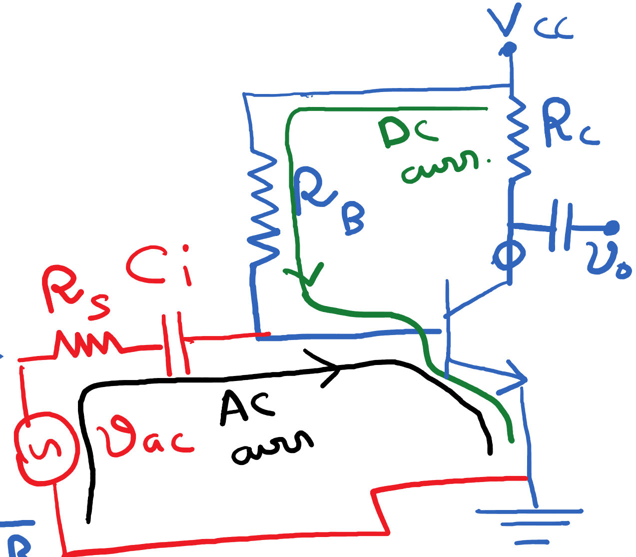
$$v_\pi = \frac{(R_B \| r_\pi)}{(R_B \| r_\pi) + R_s} \times v_{ac}$$

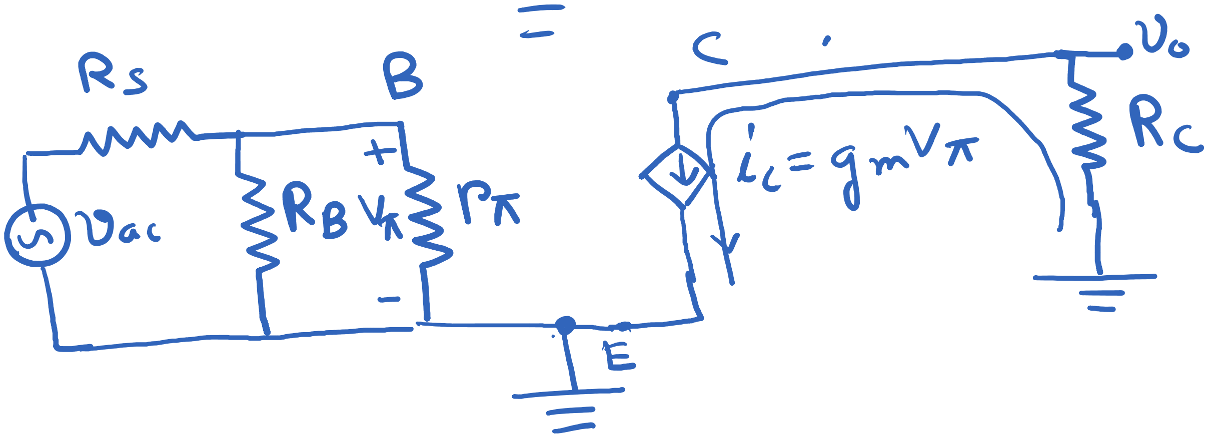
$$i_c = g_m v_\pi = \frac{\beta}{r_\pi} V_\pi$$

$$v_o = -i_c R_c$$

$$= -\frac{\beta}{r_\pi} \frac{(R_B \| r_\pi) R_c}{(R_B \| r_\pi) + R_s} \times v_{ac}$$

$$A = \frac{v_o}{v_{ac}} = -\frac{\beta R_c}{r_\pi} \frac{R_B \| r_\pi}{(R_B \| r_\pi) + R_s}$$



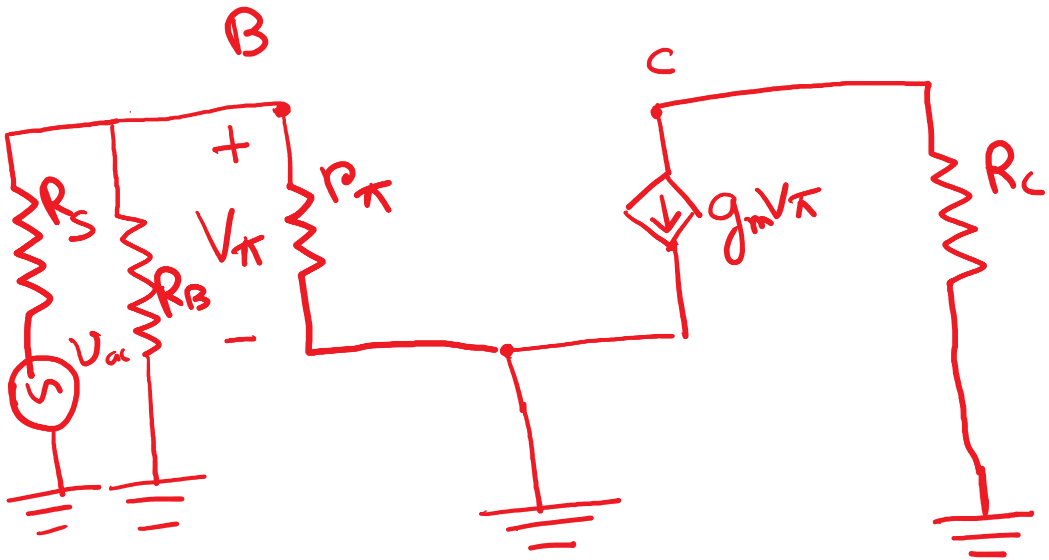


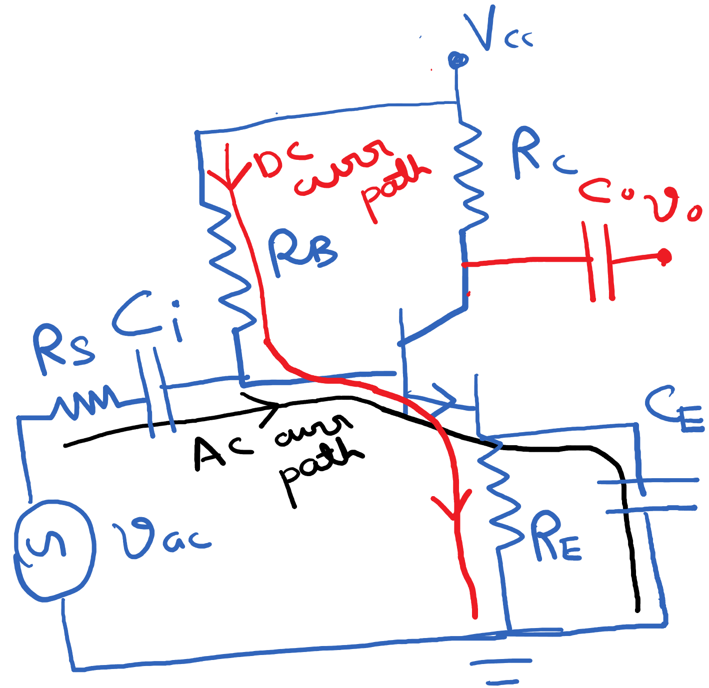
$r_\pi \rightarrow$ small signal Base resistance

$g_m \rightarrow$ small signal transconductance

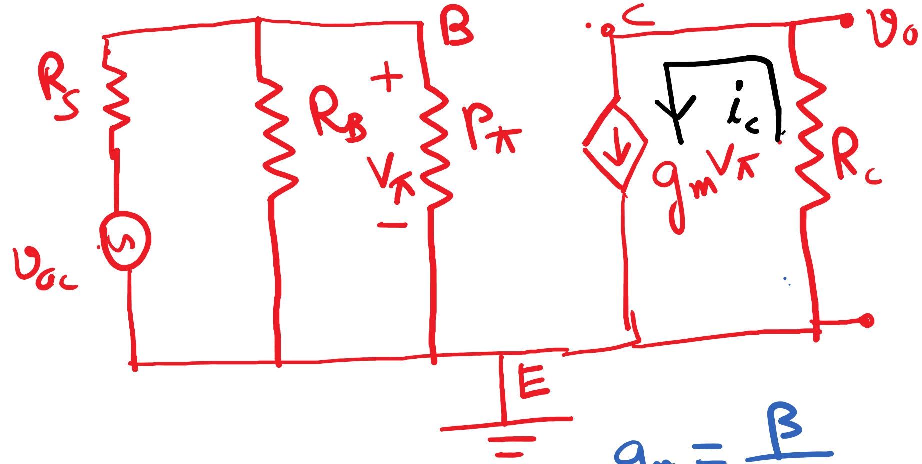
Class-23

Small-signal AC model.





$$\text{Gain} = \frac{v_o}{v_{ac}}$$



$$V_\pi = \frac{R_B \| r_\pi}{R_B \| r_\pi + R_s} \times v_{ac}$$

$$i_c = g_m V_\pi$$

$$v_o = -i_c R_c$$

$$= -g_m v_\pi R_c$$

$$= -g_m R_c v_\pi = -g_m R_c \frac{R_B \| r_\pi}{R_B \| r_\pi + R_s} v_{ac}$$

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

$$A = \frac{v_o}{v_{ac}} = -g_m R_c \frac{R_B \| r_\pi}{R_B \| r_\pi + R_s} = -\frac{\beta R_c}{r_\pi} \frac{R_B \| r_\pi}{R_B \| r_\pi + R_s}$$

AC parameters or small signal parameters:-

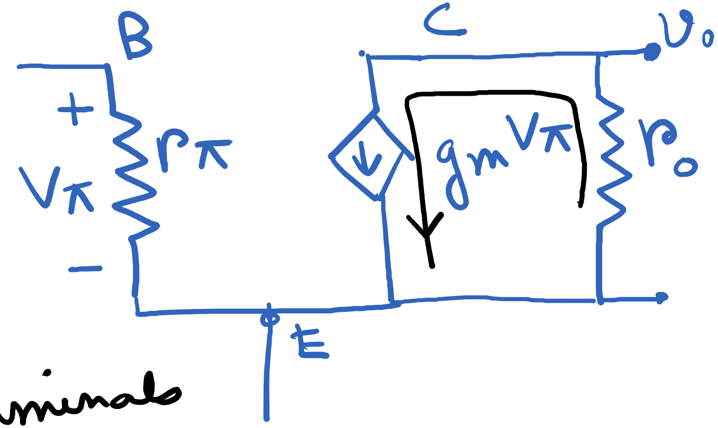
$r_\pi = \frac{V_T}{I_{BQ}}$ → small signal Base resistance

$g_m = \frac{\beta}{r_\pi}$ → small signal trans conductance.

r_o → small signal output resistance

$\hookrightarrow \frac{V_A}{I_{CQ}}$

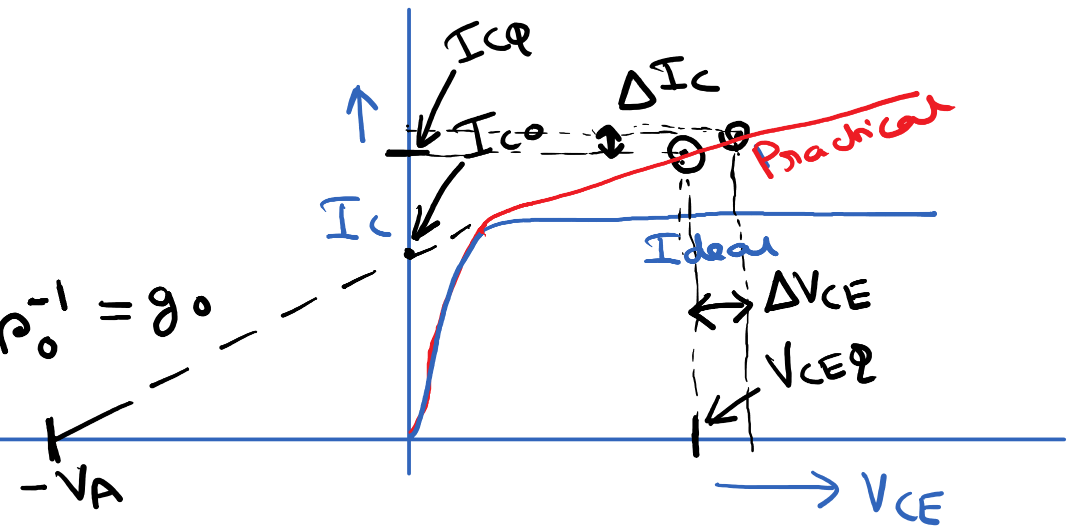
r_o is known as the small signal output resistance or simply the output resistance of a transistor. It is present between the collector and the emitter terminals



$$I_C \cong I_{CO}\left(1+\frac{v_{CE}}{V_A}\right)$$

$$\cong I_{CQ}\left(1+\frac{v_{CE}}{V_A}\right)$$

$$\lim_{\Delta V_{CE}\to 0}\frac{\Delta I_C}{\Delta V_{CE}} = \frac{I_{CQ}}{V_A} = \frac{\partial I_C}{\partial V_{CE}} = r_o^{-1} = g_o$$

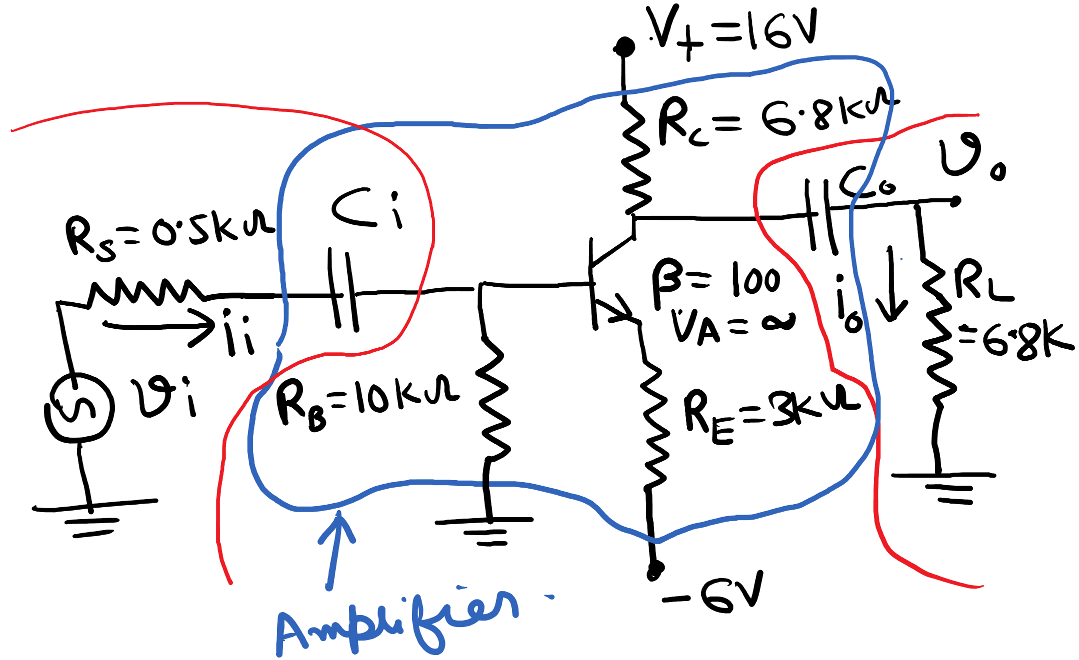


AC parameters

① $g_m, r_\pi, r_o = ?$

② $A_i = \dfrac{i_o}{i_i}$

③ $A_v = \dfrac{v_o}{v_i}$



$$g_m = \frac{\beta}{r_\pi}, \quad r_\pi = \frac{V_T}{I_{BQ}}, \quad r_o = \frac{V_A}{I_C}$$

$$0-(-6V) = I_B R_B + V_{BE(ON)} + I_E R_E$$

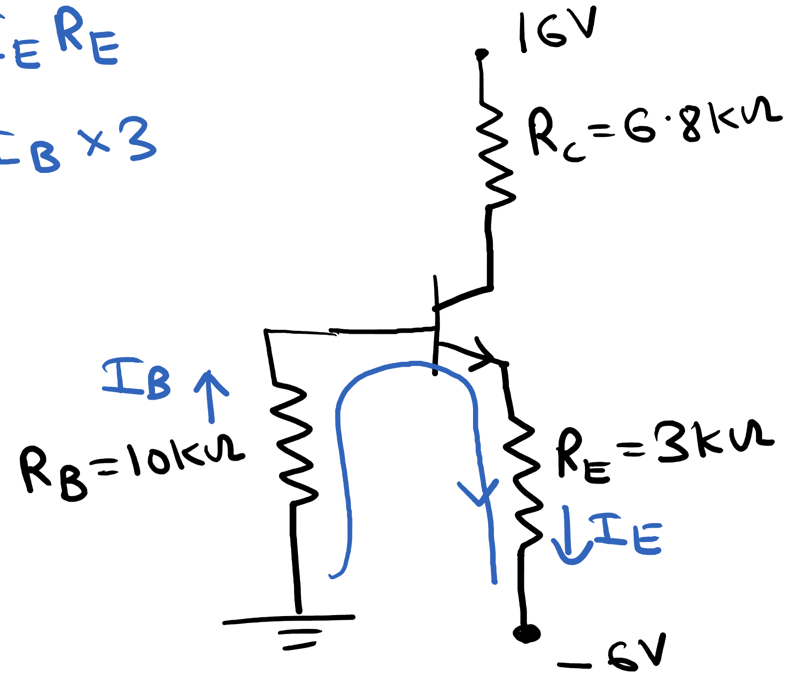
$$\Rightarrow 6V = I_B \times 10 + 0.7V + (100+1) I_B \times 3$$

$$\Rightarrow 6V - 0.7V = 10 I_B + 303 I_B$$

$$\Rightarrow 5.3V = 313 I_B$$

$$\Rightarrow I_B = \frac{5.3}{313} mA$$

$$= 0.0169 mA$$



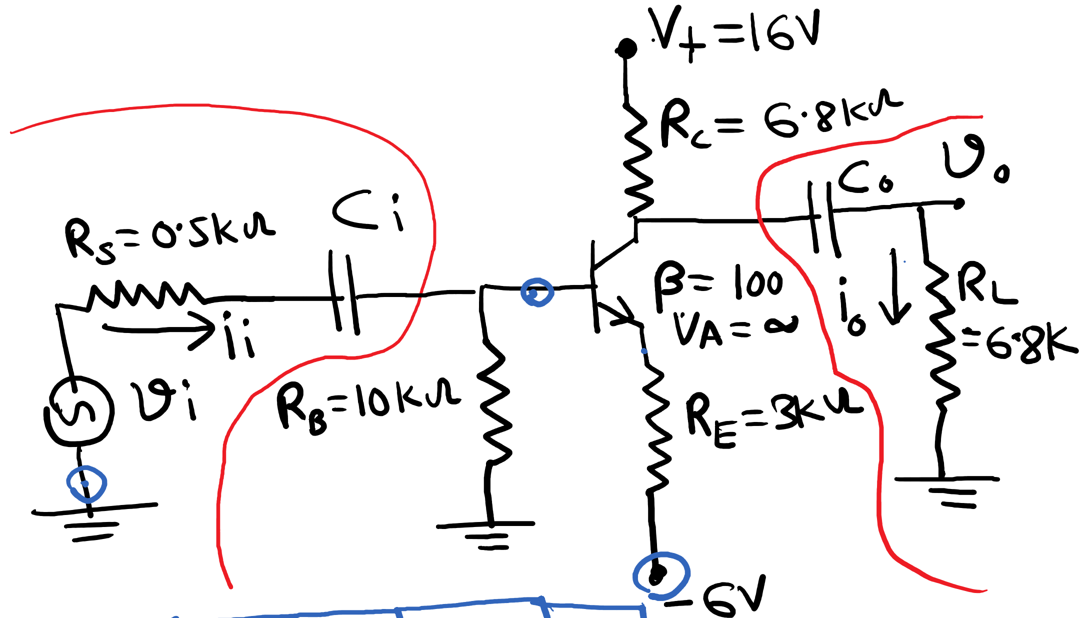
$$r_\pi = \frac{V_T}{I_B} = \frac{0.026V}{0.0169 mA} = 1.53 k\Omega$$

$$g_m = \beta / r_\pi = \frac{100}{1.53} \text{ milli-mho} = 0.065 \text{ milli-mho.}$$

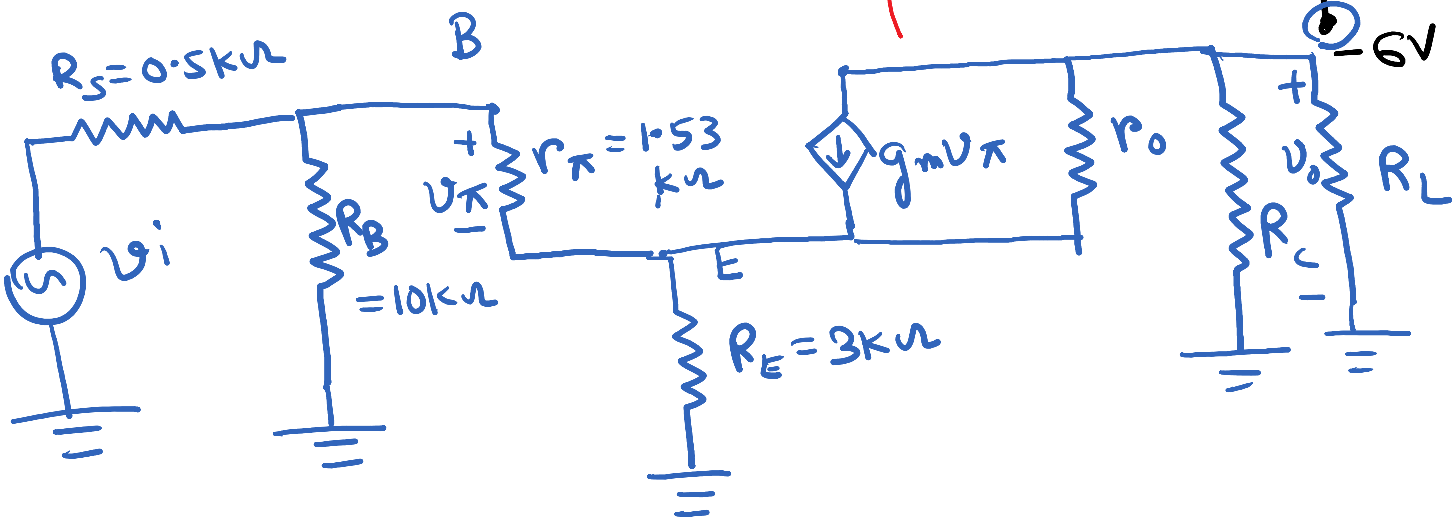
$$r_o = \frac{V_A}{I_{CQ}} = \infty \qquad (\because V_A = \infty)$$

$$\boxed{r_\pi = 1.53\,k\Omega,\ g_m = 0.065\ \text{milli-mho},\ r_o = \infty}$$

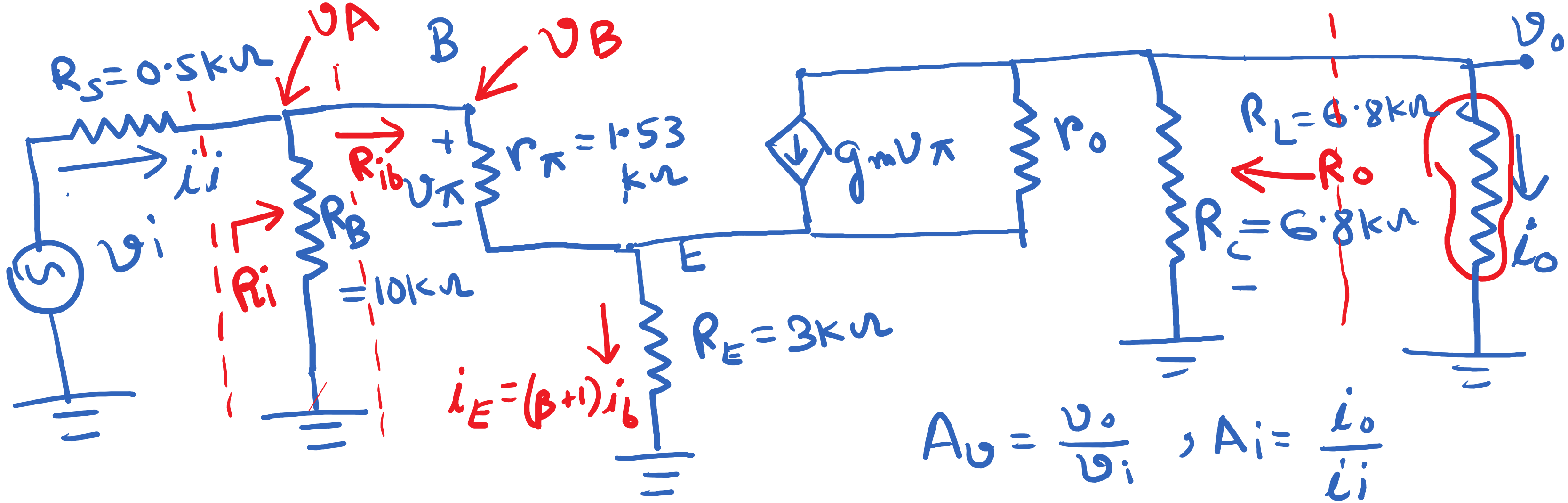
$$A_i = \frac{i_o}{i_I} \qquad A_v = \frac{v_o}{v_i}$$



$V_+ = 16V$
$R_C = 6.8k\Omega$
v_o
C_o
$R_S = 0.5k\Omega$
C_i
i_i
v_i
$\beta = 100$
$V_A = \infty$
i_o
$R_L = 6.8K$
$R_B = 10k\Omega$
$R_E = 3k\Omega$
$-6V$



$R_S = 0.5k\Omega$
B
v_i
$R_B = 10k\Omega$
v_π
$r_\pi = 1.53 k\Omega$
$g_m v_\pi$
r_o
E
$R_E = 3k\Omega$
R_C
v_o
R_L



$$A_v = \frac{v_o}{v_i}, \quad A_i = \frac{i_o}{i_i}$$

The resistance seen between the base and the ground is known as the input Base resistance (R_{ib})

$$v_B = r_\pi i_b + i_E R_E = r_\pi i_b + (\beta+1) i_b R_E$$

$$\Rightarrow R_{ib} = \frac{v_B}{i_b} = r_\pi + (\beta+1) R_E$$

Since i_E is higher than i_B by a factor of $(\beta+1)$, therefore the resistance R_E is multiplied by $(\beta+1)$ when one looks into the Base terminal. This is known as the resistance reflection rule.

The total input resistance (Ri) of the amplifier is the total resistance which one sees when they look into the amplifier input port. The total input resistance excludes the input voltage source resistance (Rs)

$$R_i = R_B \| R_{ib}.$$

The total resistance which one sees when one looks into the collector terminal is known as the output resistance (R_o). R_o excludes the load resistance.

$$R_o \cong (R_C + R_E) \| r_o$$

R_{ib}, R_o and R_i are the characteristics of the amplifier circuit.

$$R_{ib} = r_\pi + (\beta+1)R_E$$
$$= 1.53\,k\Omega + 101 \times 3\,k\Omega$$
$$= 304.53\,k\Omega.$$

$$R_i = R_B \parallel R_{ib} = (10\,k\Omega \parallel 304.53\,k\Omega)$$
$$= 9.68\,k\Omega.$$

The voltage at the Base (v_A or v_B)

$$= \frac{v_s}{R_s + R_i} \times R_i$$

$$= v_s \times \frac{9.68\,k\Omega}{0.5\,k\Omega + 9.68\,k\Omega} = v_s \times \frac{9.68}{10.18}$$

$$v_\pi = v_A \times \frac{r_\pi}{R_{ib}}$$

$$= v_A \times \frac{1.53}{304.53}$$

$$= v_s \times \frac{9.68}{10.18} \times \frac{1.53}{304.53}$$

$$= 0.004779 v_s .$$

$$i_c = g_m V_\pi$$

$$= 0.065 \times 0.004779 v_s \,(\mathrm{mA})$$

$$= 0.00031 v_s \,(\mathrm{mA})$$

$$v_o = -i_c\,(R_c \| R_L)$$

$$= -0.000311 v_s \overset{(mA)}{} \times (6.8\,k\Omega \| 6.8\,k\Omega)$$

$$= -0.000311\, v_s (mA) \times 3.4\,k\Omega$$

$$= -1.06\, v_s$$

$$A_v = \frac{v_o}{v_s} = -1.06$$

$$|i_o| = \left|\frac{v_o}{R_L}\right| = \frac{|-1.06 v_s|}{R_L} = 1.06\,\frac{v_s}{R_L}$$

$$|i_i| = \frac{v_s}{R_s + R_i}$$

$$A_i = \left|\frac{i_o}{i_i}\right| = 1.062 \times \frac{R_i + R_s}{R_L}$$

$$= 1.062 \times \frac{0.5\,k\Omega + 9.68\,k\Omega}{6.8\,k\Omega}$$

$$= 1.59$$