Unit - I

BJT Amplifiers

Overview of DC Analysis of BJT Circuits & Models:

Introduction to BJT Circuits & Models.

* Transistor is a 3 terminal device with the 3 terminals namely:
* Emitter
* Base &
* Collector.

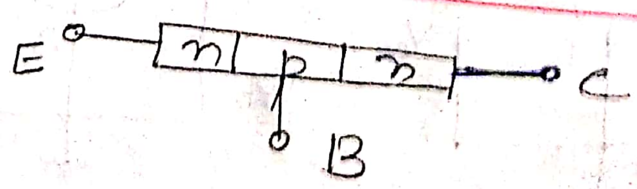
Two types of transistors:

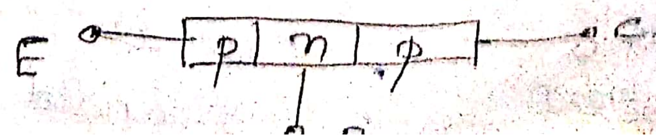
1) Unipolar: current conduction is due to o[ne] type of charge carriers.
2) Bipolar: current conduction is due to b[oth] type of charge carriers.

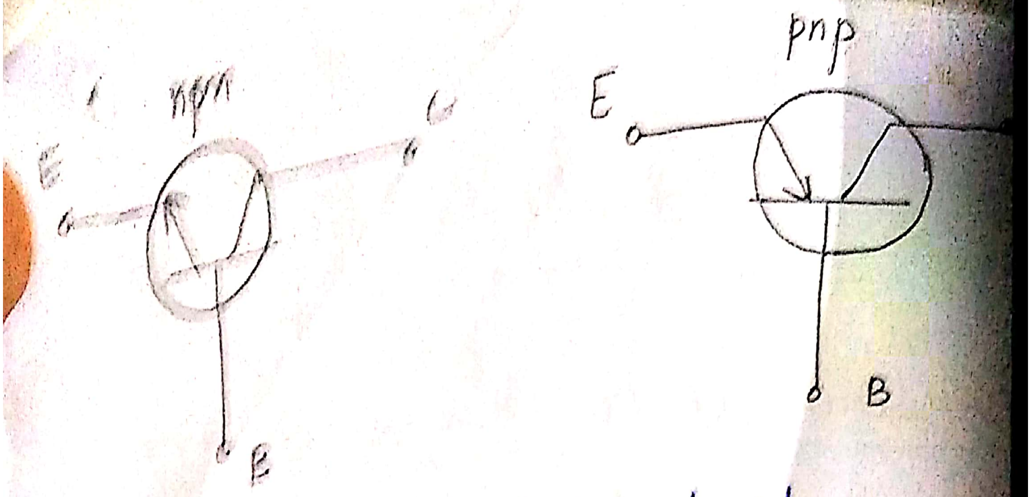
BJT: Current Controlled device, the o/p current is controlled by i/p cu[rrent]

Types of BJT based on construction:

1) n-p-n
2) p-n-p.







* Base is thin & lightly doped.
* Emitter is heavily doped.
* Collector is large and moderately doped.

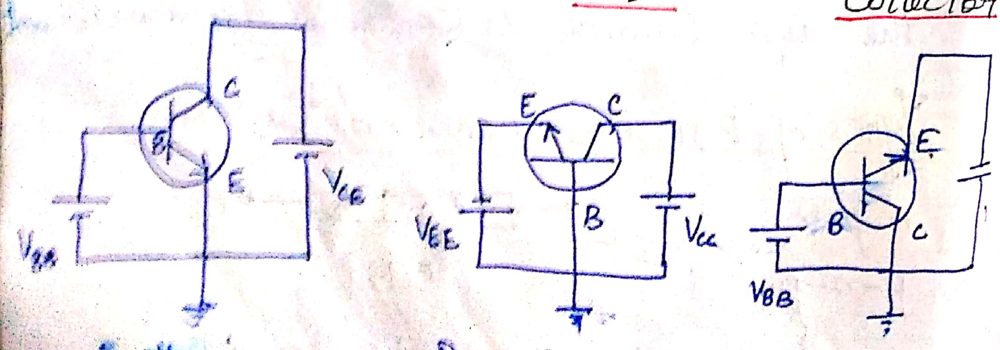
Arrowhead indicates the conventional cur[rent] direction which is opposite to the d[irection] of electron current in emitter.

$$\boxed{\begin{aligned} I_E &= (1+\beta) I_B \\ I_C &= \beta I_B \\ I_E &\simeq I_C \end{aligned}}$$

BJT Configurations

There are 3 configurations

① Common Emitter ② Common Base ③ Common Collector



Emitter is grounded

Base is grounded

Collector is

* CE is the most popular configuration because of its high voltage and current gain.

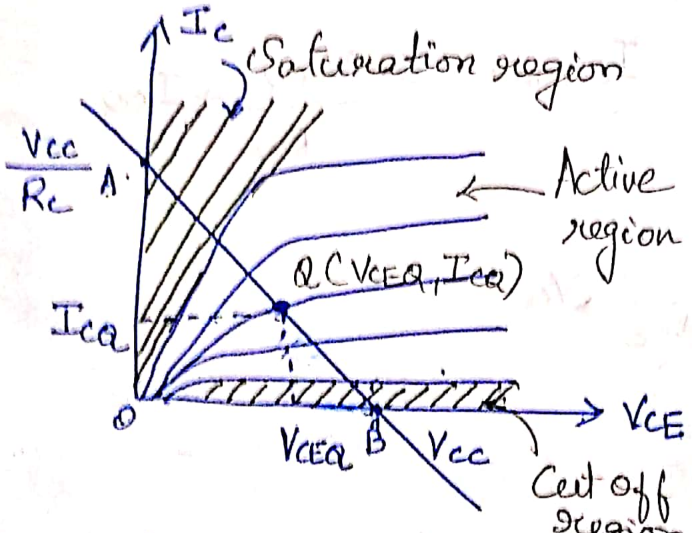
Need for Biasing:

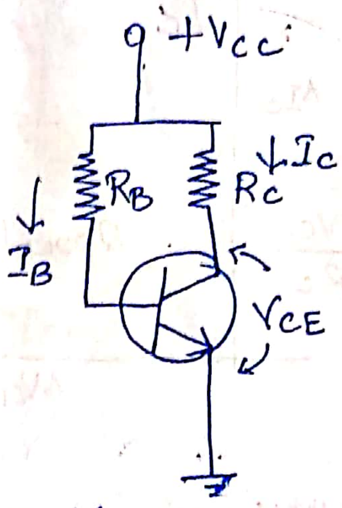
Application of dc voltages to establish a fixed level of current and voltages.

Operating / Quiescent point:

When we bias a transistor we establish a certain current and voltage conditions for the transistor. These conditions are called dc operating point.

DC Load line & Q-point





$V_{CC} - I_C R_C - V_{CE} = 0$

To find A & B : $V_{CC} - I_C R_C = V_{CE}$

(i) Let $V_{CE} = 0$ $\therefore V_{CC} = I_C R_C$ & $I_C = V_{CC}/R_C \rightarrow$ (A)

(ii) Let $I_C = 0$ $\therefore V_{CE} = V_{CC} \rightarrow$ (B)

Draw a line between A & B called the DC Load line.

Q point is at (V_{CEQ}, I_{CQ}).

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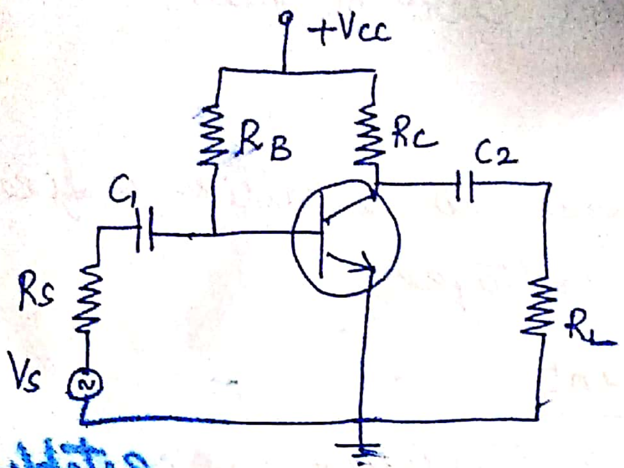
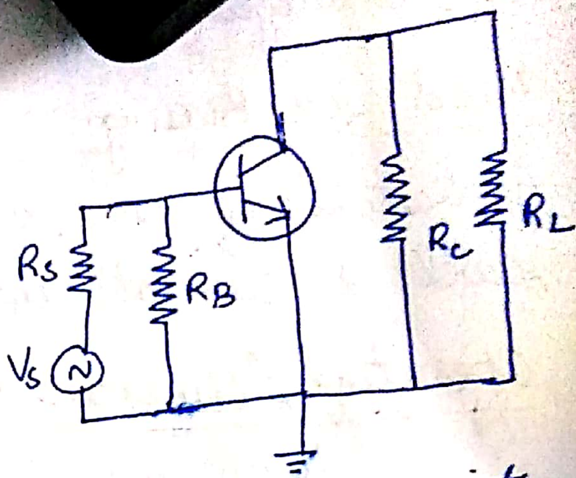
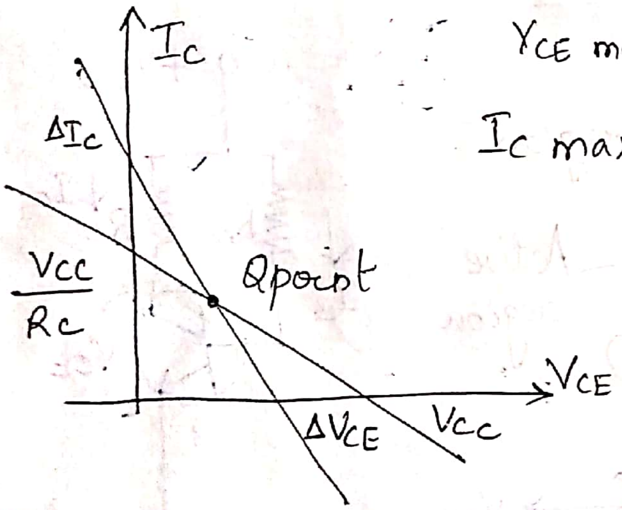
Ac Load line

$R_{ac} = R_C \| R_L$





* For ac analysis coupling & bypass capacitors act as short circuit.
* DC supply also replaced by short circuit.



$$V_{CE\,max} = V_{CEQ} + I_{CQ} R_{ac}$$

$$I_{C\,max} = \frac{V_{CEQ}}{R_{ac}} + I_{CQ}.$$

Types of Biasing

1) Self Bias / Voltage Divider Bias
2) Fixed Bias
3) Collector to base bias
4) Emitter stabilised bias.

Stability

measure of sensitivity of a network to variations in its parameters :

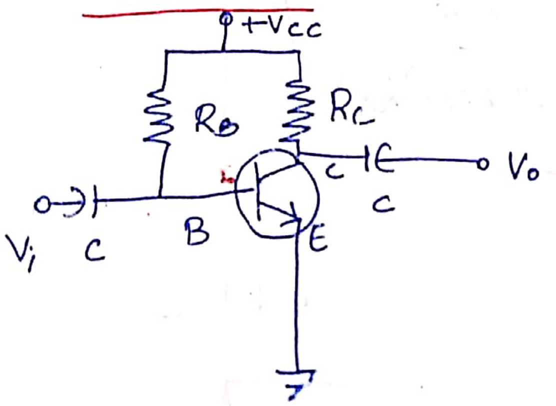
I_c is sensitive

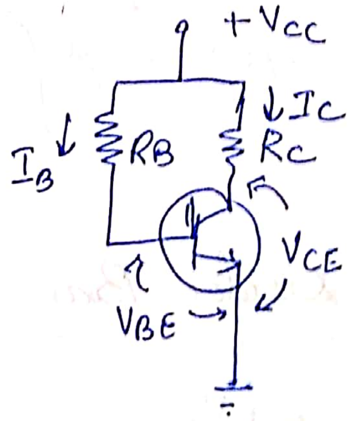
(i) β (ice) $S(\beta) = \dfrac{\Delta I_c}{\Delta \beta}$

(ii) V_{BE} $S(V_{BE}) = \dfrac{\Delta I_c}{\Delta V_{BE}}$

(iii) I_{co} $S(I_{co}) = \dfrac{\Delta I_c}{\Delta I_{co}}$.

Fixed Bias





To find Q-point:

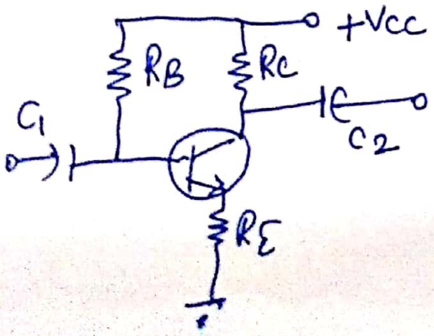
$V_{cc} - I_c R_c - V_{CE} = 0 \Rightarrow V_{CE} = V_{cc} - I_c R_c$

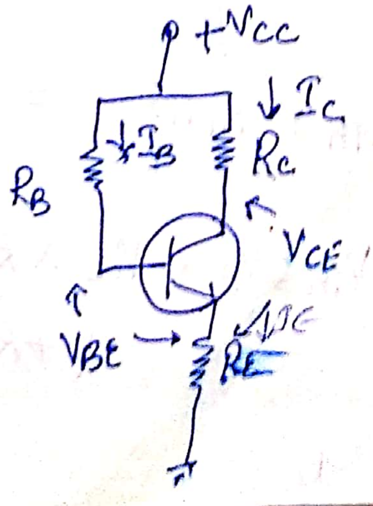
$V_{cc} - I_B R_B - V_{BE} = 0$

$I_B = \dfrac{V_{cc} - V_{BE}}{R_B} \Rightarrow I_c = \beta I_B \Rightarrow I_c = \beta\left[\dfrac{V_{cc} - V_{BE}}{R_B}\right]$

$S(I_{co}) = \beta + 1$

Emitter Bias Configuration





Q point

$[I_E = (1+\beta) I_B]$

$$V_{CC} - I_B R_B - V_{BE} - I_E R_E = 0$$

$$V_{CC} - I_B R_B - V_{BE} - (1+\beta) I_B \cdot R_E = 0$$

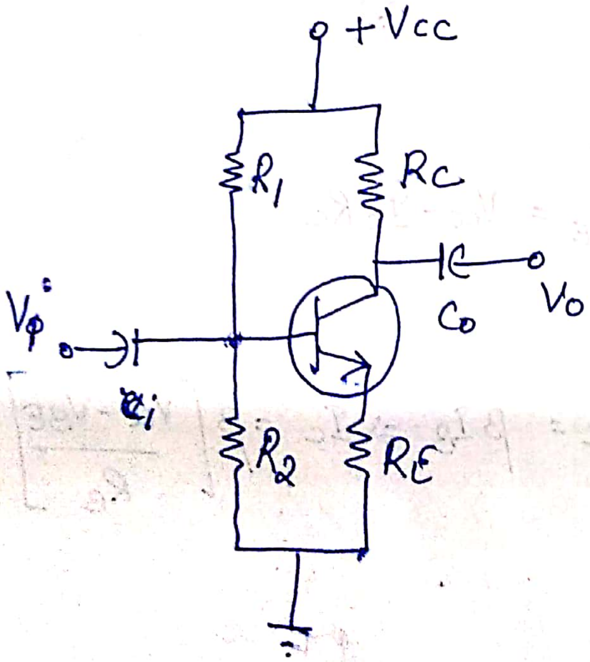
$$I_B R_B + (1+\beta) I_B R_E = V_{CC} - V_{BE}$$

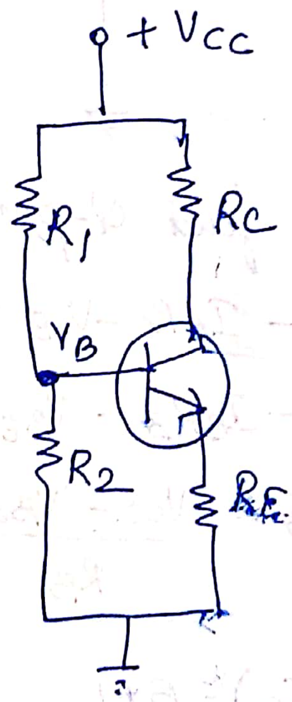
$$I_B [R_B + (1+\beta) R_E] = V_{CC} - V_{BE}$$

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (1+\beta) R_E}$$

$$\therefore \boxed{I_C = \beta I_B = \beta \left[\frac{V_{CC} - V_{BE}}{R_B + (1+\beta) R_E} \right]}$$

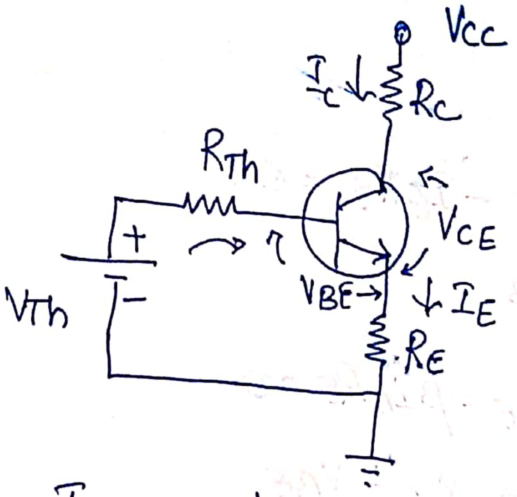
Voltage Divider Bias





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

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



To find Q point

$$V_{Th} - I_B R_{Th} - V_{BE} - I_E R_E = 0$$

$$V_{Th} - I_B R_{Th} - V_{BE} - (1+\beta) I_B R_E = 0$$

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

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

$$I_C = \beta I_B = \beta \left[\frac{V_{Th} - V_{BE}}{R_{Th} + (1+\beta) R_E} \right]$$

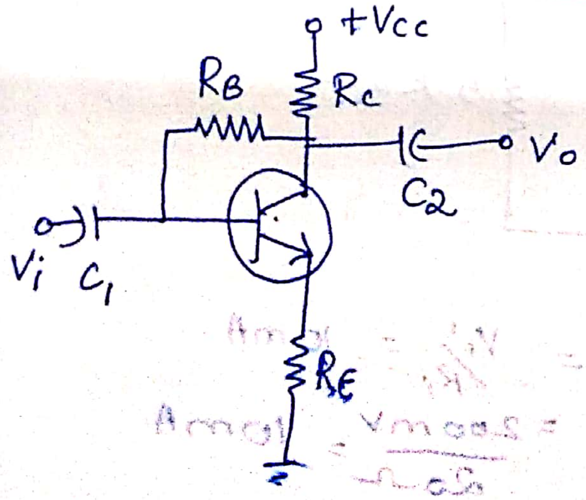
$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0.$$

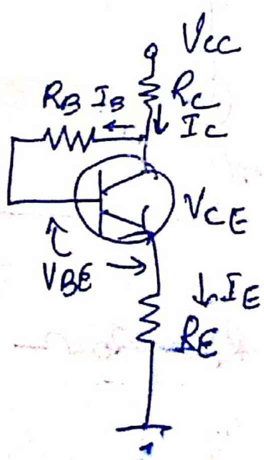
$$V_{CE} = V_{CC} - I_C R_C - I_E R_E \quad (I_E \simeq I_C)$$

$$\therefore V_{CE} = V_{CC} - I_C (R_C + R_E)$$

$$S = (\beta+1) \frac{1 + R_{Th}/R_E}{(1+\beta) + R_{Th}/R_E}.$$

Collector Feedback Bias





Q point

$$V_{CC} - I_C R_C - I_B R_B - V_{BE} - I_E R_E = 0.$$

$$I_E \simeq I_C \quad \& \quad I_C = \beta I_B$$

$$V_{CC} - \beta I_B R_C - I_B R_B - V_{BE} - \beta I_B R_E = 0$$

$$R_B I_B + I_B(1+\beta)(R_C+R_E) = V_{CC} - V_{BE}$$

$$I_B \left[R_B + (1+\beta)(R_C+R_E) \right] = V_{CC} - V_{BE}$$

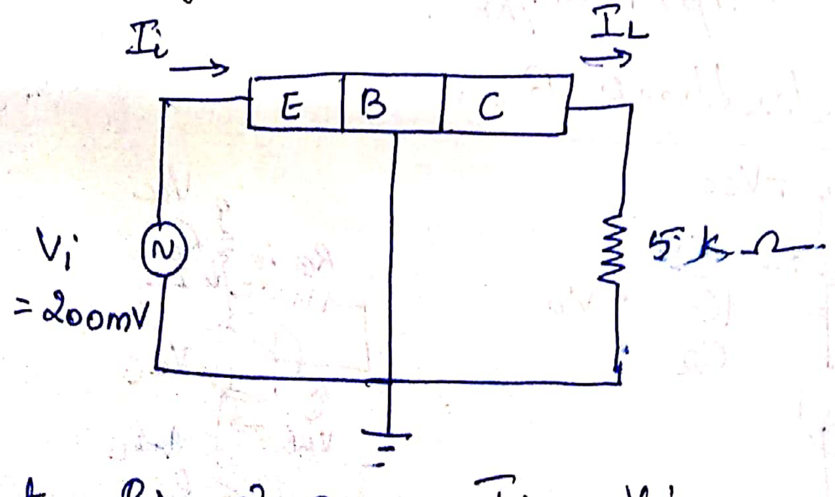
$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (1+\beta)(R_C+R_E)}.$$

$$\therefore I_C = \beta I_B = \beta \left[\frac{V_{CC} - V_{BE}}{R_B + (1+\beta)(R_C+R_E)} \right].$$

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

$$V_{CE} = V_{CC} - I_C(R_C+R_E).$$

AC Analysis



Let $R_i = 20\Omega$ $\quad I_i = V_i / R_i = 10 mA.$

$$= \frac{200 mV}{20\Omega} = 10 mA.$$

$I_L = 10 mA.$

$V_o = R_L \times I_L = 10mA \times 5K\Omega$

$V_o = 50V$

$$\text{Gain} = \frac{V_o}{V_i} = \frac{50V}{200mA} = 250$$

An ac signal changes the i/p current (i.e.) of I_b, & I_c changes ∴ If I_c changes Q point shifts. Therefore ac analysis is necessary.

Ac analysis of a transistor network depends on the magnitude of the i/p signal:

1) Small signal analysis
2) large signal analysis

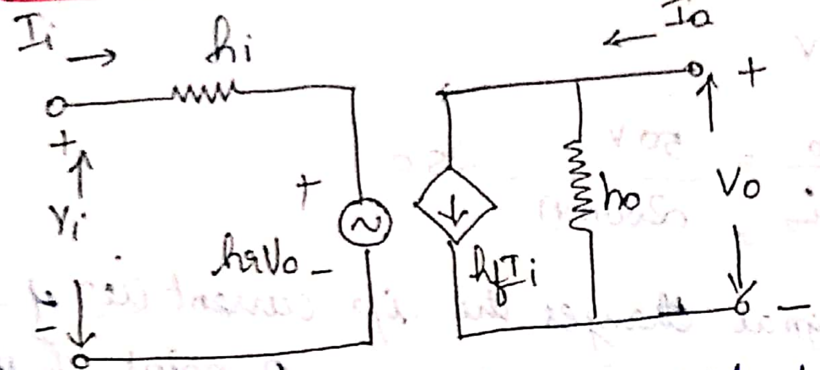
There are 3 models in small signal analysis:

1) re model
2) hybrid equivalent model (h-parameters)
3) hybrid π model.

<u>Model</u> :-

A model is a combination of circuit elements that best approximates the actual behaviour of a semiconductor device under specific operating conditions.

hybrid - parameters (h-model)



The hybrid model is suitable for small signals at mid band & describes the action of transistor

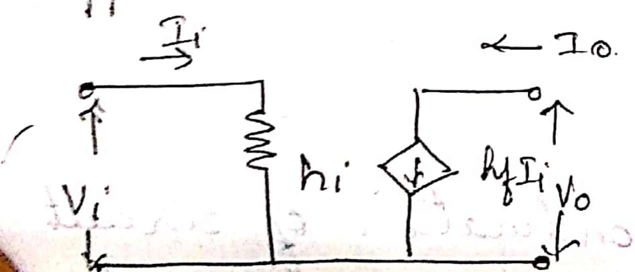
h_i = input resistance $V_i / I_i \,\big|_{V_o=0}$ Ω

$h_r = \dfrac{V_i}{V_o}\Big|_{I_i=0}$ reverse transfer voltage ratio

$h_f = I_o / I_i \,\Big|_{V_o=0}$ forward transfer current ratio.

$h_o = I_o / V_o \,\Big|_{I_i=0}$ o/p conductance.

Approximate Model - hybrid



h_r to be very small & h_o to be large.

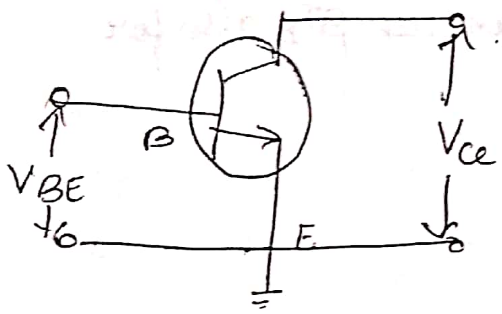
AC analysis of basic BJT Amplifier configuration using classical discrete circuit bias arrangement

Small signal AC Model

Linear DC models are used for determining the Q point, however an ac model is used for determining the voltage or power gain when the transistor is operated as an amplifier in the active region.

Hybrid π model

* Popular circuit model used for analysing small signal behaviour of BJT & FET.
* These are quite accurate



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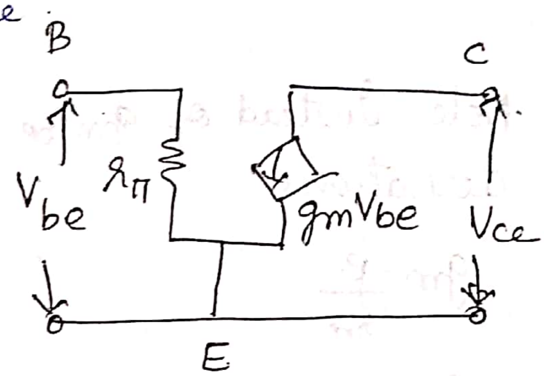


The hybrid π is a linearized 2 port network approximation to BJT using small signal base emitter voltage, Vce as independent variables & ib, ic as dependent variables.

The various parameters are:

$$g_m = \left.\frac{i_c}{V_{be}}\right|_{V_{ce}=0} = \frac{I_c}{V_T} = \text{transconductance}$$

$I_c = I_{CQ}$ = Quiescent collector current.

$V_T = \frac{kT}{q}$ = thermal voltage.

K → Boltzmann's constant

q → charge of electron

T → temperature in kelvins.

$V_T = 26\,mV$ at room temperature

base emitter resistor

diffusion resistance $r_\pi = \left.\frac{V_{be}}{I_b}\right|_{V_{ce}=0} = \frac{V_T}{I_B} = \frac{\beta}{g_m}$

$\boxed{\beta = g_m r_\pi}$ → h_{fe}

I_b = DC bias base current

$\beta_0 = \frac{I_c}{I_B}$ is current gain.

$r_o = \left.\frac{v_{ce}}{i_c}\right|_{v_{be}=0} \simeq \frac{V_A}{I_c}$ is the O/P resistance due to Early Effect.

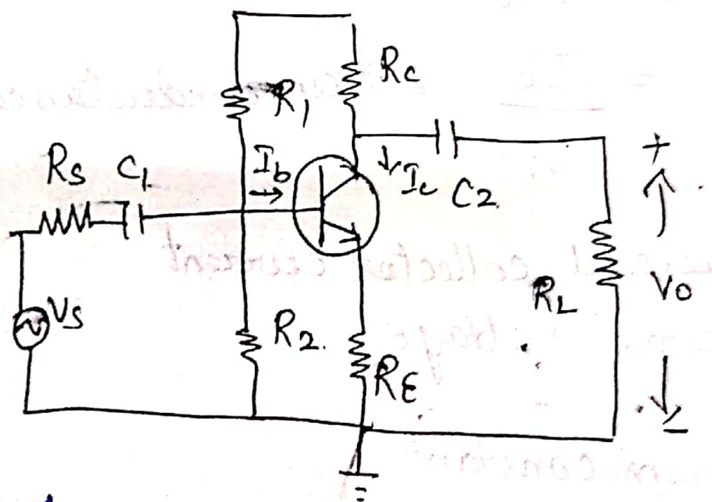
Note: Instead of $g_m v_{be}$ we can use βI_b also for derivations.

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

$v_{be} = r_\pi \times I_b$

$\therefore g_m v_{be} = \frac{\beta}{\cancel{r_\pi}} \times \cancel{r_\pi} I_b = \beta I_b$.

Common Emitter Amplifier (AC Analysis).



* Figure shows CE circuit with voltage divider bias. Emitter is at ground potential.
* The signal from source is coupled to the base of the transistor through

the coupling capacitor → provides dc isolation between amplifier & signal source.

* R_1 & R_2 → establish dc transistor biasing & is not disturbed when the source is capacitively coupled to the amplifier.

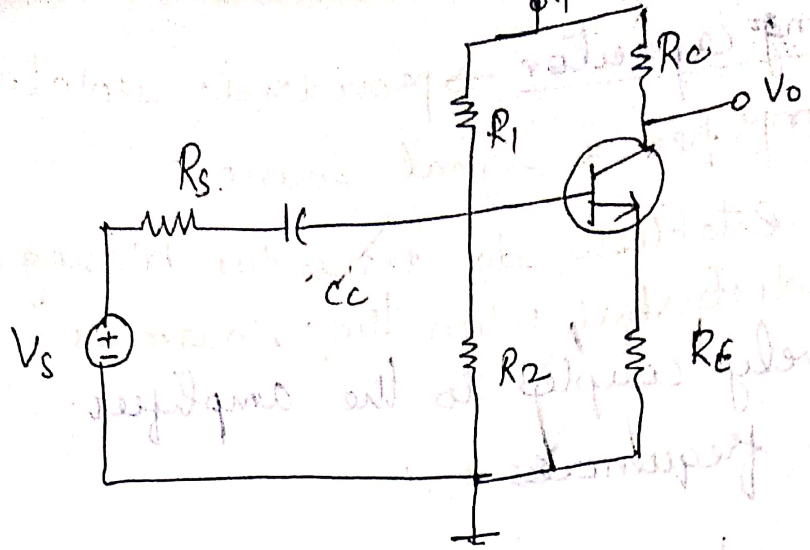
* At high frequencies

$$|Z_C| = \frac{1}{2\pi f C_C}$$ which is very less. Hence capacitor is considered as short circuit.

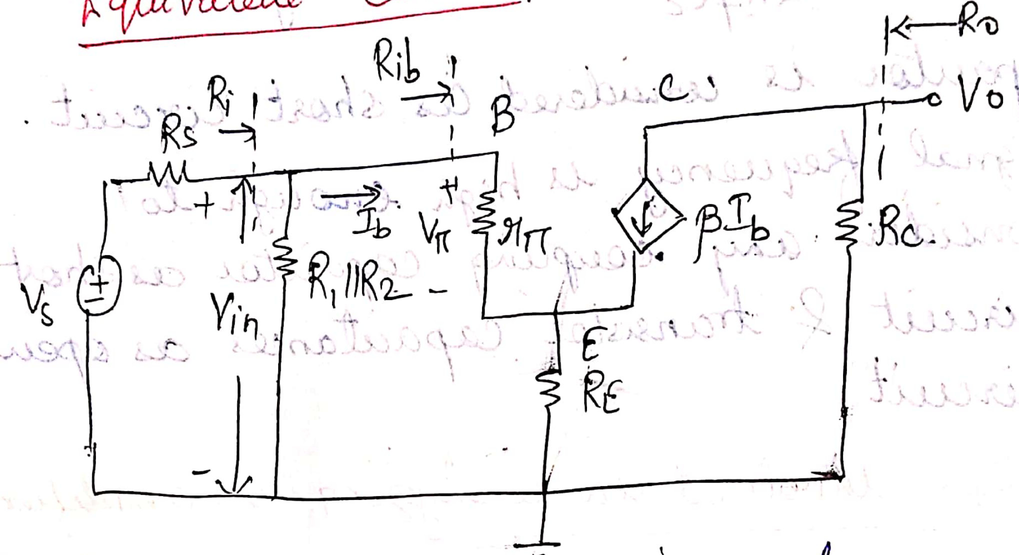
* Signal frequency is high enough to consider any coupling capacitor as short circuit & transistor capacitances as open circuit.

Steps involved in analyzing an amplifier circuit:

1) Conduct a dc biasing analysis of the transistor circuit.
2) Determine the signal parameters g_m, r_π & r_o.
3) Determine the ac equivalent circuit of
4) Perform a small signal analysis to find R_i, A_{vo} & R_o.



Equivalent Circuit



Current gain parameter β is used
r_o is neglected since early effect voltage is ∞.

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

1) ## Input Resistance R_i

$$R_i = R_1 \| R_2 \| R_{ib}$$

$R_{ib} = \frac{V_{in}}{I_b}$ = input resistance looking into the base of transistor

Appling loop equations :-

$$V_{in} = I_b r_\pi + (I_b + \beta I_b) R_E$$

$$\frac{V_{in}}{I_b} = R_{ib} = r_\pi + (1+\beta) R_E$$

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This is called as resistance reflection rule. (8)

Input resistance to the amplifier is

$$\boxed{R_i = R_1 \| R_2 \| r_\pi + (1+\beta)R_E}$$

2) O/p resistance R_o

The o/p resistance is

$$\boxed{R_o = R_C}$$

3) Voltage Gain A_v

A_{vo} : Open Loop voltage gain (without R_s).

$$A_{vo} = \frac{V_o}{V_{in}}$$

$$V_o = -\beta I_b R_C$$

$$V_{in} = I_b r_\pi + (I_b + \beta I_b)R_E$$

$$V_{in} = I_b[r_\pi + (1+\beta)R_E]$$

$$\therefore \frac{V_o}{V_{in}} = A_{vo} = \frac{-\beta \cancel{I_b} R_C}{\cancel{I_b}[r_\pi + (1+\beta)R_E]}$$

$$\boxed{A_{vo} = \frac{-\beta R_C}{r_\pi + (1+\beta)R_E}}$$

If $r_\pi << (1+\beta)R_E$ then

$$A_{vo} = \frac{-\beta R_C}{1+\beta R_E} \simeq \frac{-R_C}{R_E}.$$

Voltage gain including source resistance & V_s

$$A_{vs} = \frac{V_o}{V_s} = \frac{V_o}{V_{in}} \times \frac{V_{in}}{V_s}.$$

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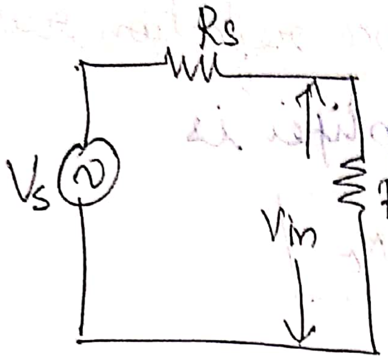


Using voltage divider rule

$$V_{in} = \frac{V_s \times R_i}{R_s + R_i}$$

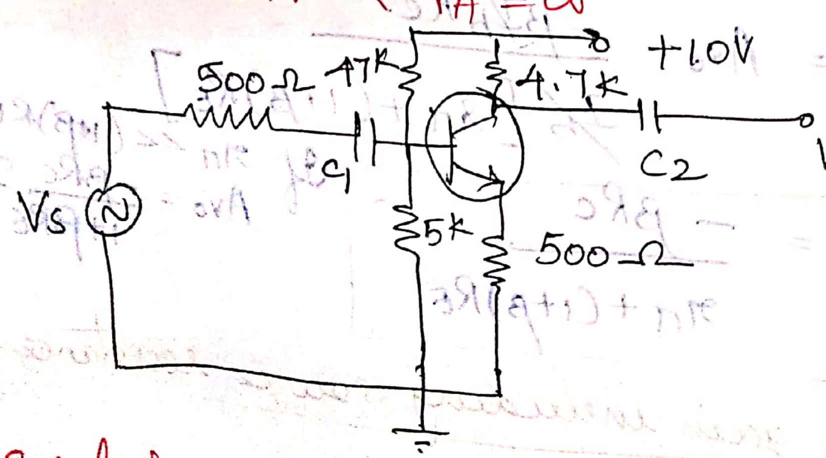
$$\frac{V_{in}}{V_s} = \frac{R_i}{R_s + R_i}$$

$$\boxed{A_{vs} = \frac{-\beta R_c}{r_\pi + (1+\beta)R_E} \cdot \left(\frac{R_i}{R_s + R_i}\right)}$$

A_{vo} can be made high by
* Choosing large value of β_f
* Choosing large value of R_c
* Choosing low value of R_E (or) $R_E \simeq 0$

$$A_{vo} = \frac{-\beta_f R_c}{r_\pi} = \frac{-g_m r_\pi R_c}{r_\pi} = -g_m R_c$$

Eg ① For the circuit shown, determine the value of R_i, R_o & A_{vo} for $\beta = 100$, $V_{BE} = 0.7V$ & $V_A = \infty$



Solution :-

Find hybrid π parameters :-

$$r_\pi = \frac{V_T}{I_B} = \frac{V_T}{I_{CQ}} \times \beta$$

$$g_m = \frac{I_{CQ}}{V_T} \quad \&$$

$$r_o = \frac{V_A}{I_{CQ}}$$

find I_{CQ}

To find I_{CQ}, do dc analysis

$$I_{CQ} = \beta \left[\frac{V_{Th} - V_{BE}}{R_{Th} + (1+\beta)R_E} \right]$$

$$V_{Th} = \frac{V_{cc} \times R_2}{R_1 + R_2} = \frac{10V \times 5K}{5K + 47K} = 0.96V$$

$$R_{Th} = R_1 \| R_2 = 47K \| 5K = \frac{47K \times 5K}{47K + 5K} = 4.52K\Omega$$

$$\therefore I_B = \frac{V_{Th} - V_{BE}}{R_{Th} + (1+\beta)R_E} = \frac{0.96 - 0.7}{4.52 + (1+100)0.5}$$

$$I_B = 4.73\,\mu A$$

$$I_{CQ} = \beta I_B = 100 \times 4.73\,\mu A = 0.473\,mA$$

To find R_i, R_o & A_{Vo}.

find r_π & g_m

1) $$r_\pi = \frac{V_T \beta}{I_{CQ}} = \frac{0.026 \times 100}{0.473} = 5.497\,K\Omega$$

0) $g_m = \frac{I_{CQ}}{V_T} = \frac{0.473}{0.026} = 18.19\, mA/V$

1) $R_i = \underbrace{R_1 \| R_2}_{4.52k} \| \underbrace{r_\pi + (1+\beta)R_E}_{R_{ib}}$

$R_{ib} = r_\pi + (1+\beta)R_E$

$= 5.497 + (1+100)0.5$

$R_{ib} = 56k\Omega$

$R_i = 4.52k \| 56k = 4.18k\Omega$

$\boxed{R_i = 4.18k\Omega}$

2) $\boxed{R_o = R_C = 4.7k\Omega}$

3) $A_{vo} = \frac{-\beta R_C}{r_\pi + (1+\beta)R_E}$

$A_{vo} = \frac{-100 \times 4.7}{5.497 + (1+100) \times 0.5}$

$A_{vo} = \frac{-100 \times 4.7}{56}$

$\boxed{A_{vo} = 8.39}$

② Determine the small signal voltage gain of a CE circuit with emitter resistor. The transistor parameters are $\beta = 100$, $V_{BE(ON)} = 0.7V$ & $V_A = \infty$

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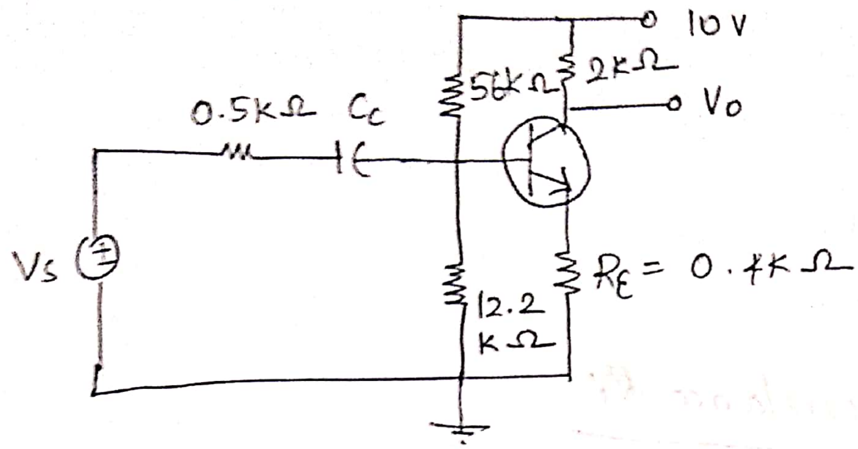
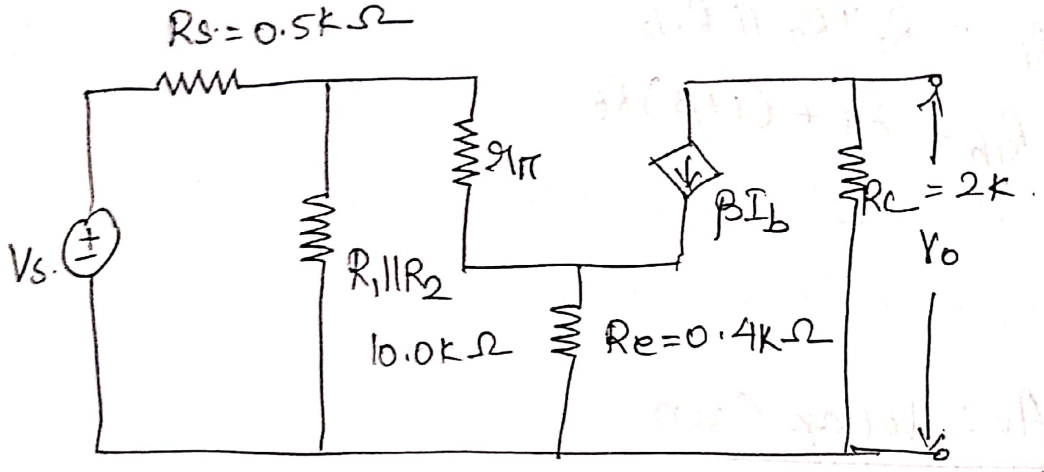




Solution :-

Dc Analysis to find ICQ :-

$$V_{Th} = \frac{V_{CC} \times R_2}{R_1 + R_2} = \frac{12 \times 12.2}{56 + 12.2}$$

$$R_{Th} = \frac{R_1 R_2}{R_1 + R_2} = \frac{56 \times 12.2}{56 + 12.2}.$$

$$I_{CQ} = \frac{\beta\left[V_{Th} - V_{BE}\right]}{R_{Th} + (1+\beta)R_E} = 2.16\,mA.$$

Determine small signal hybrid π parameters:

$$r_\pi = \frac{V_T \beta}{I_{CQ}} = \frac{(0.026)(100)}{2.16} = 1.20k\Omega$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{2.16}{0.026} = 83.1\, mA/V.$$

$$r_o = \frac{V_A}{I_{CQ}} = \infty$$

i) Input resistance R_i

$$R_i = R_1 \| R_2 \| R_{ib}$$

$$R_{ib} = r_\pi + (1+\beta) R_E$$

$$R_{ib} = 1.20 + (101)(0.4) = 41.6\, K\Omega$$

$$R_i = 10 \| 41.6 = 8.06\, K\Omega$$

ii) A_V: Voltage Gain

$$A_V = \frac{-R_C(\beta)}{r_\pi + (1+\beta)R_E} \left[\frac{R_i}{R_s + R_i}\right]$$

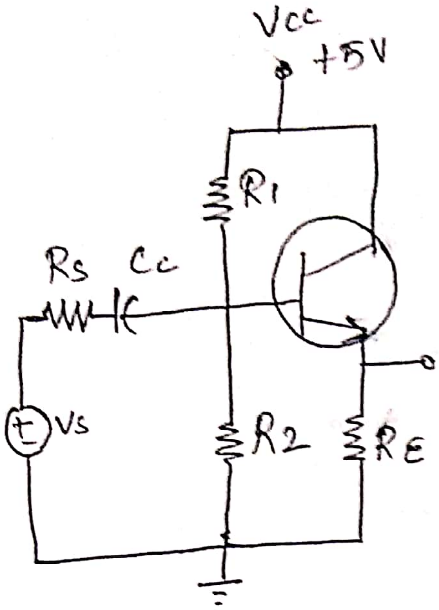
$$= \frac{-2(100)}{1.20 + (101)(0.4)} \left[\frac{8.06}{8.06 + 0.5}\right] = -4.53$$

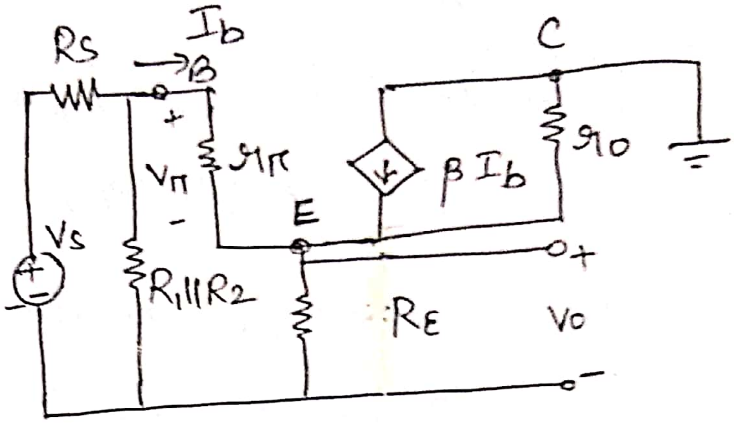
Using approximate analysis

$$A_V = \frac{-R_C}{R_E} = \frac{-2}{0.4} = -5.0.$$

Conclusion :- By including R_E the gain is nearly independant of β.

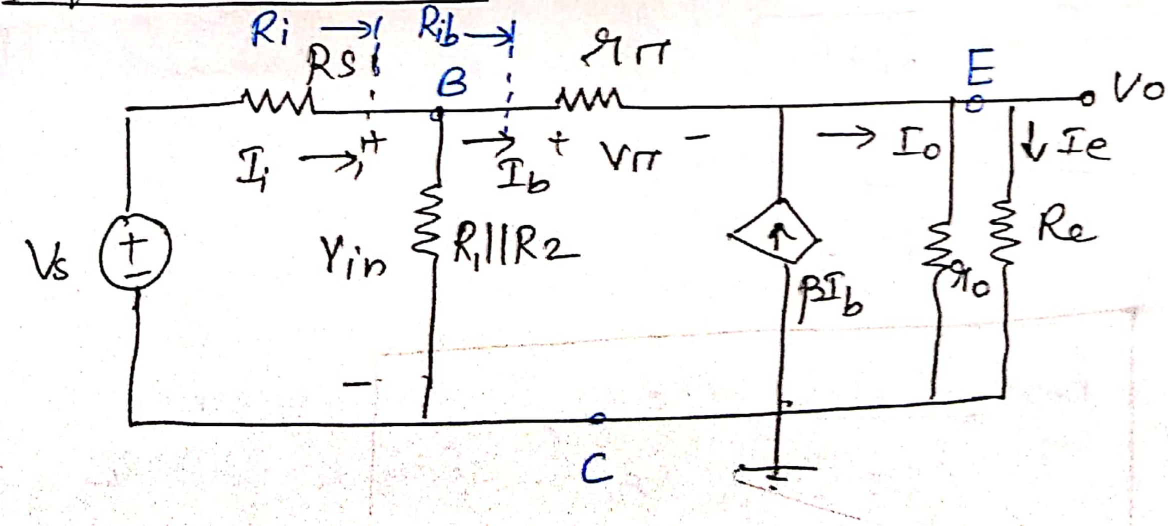
Common Collector Amplifier / Emitter follower :-





* The O/P is taken off the emitter with respect to ground & collector is connected to Vcc.
* Since Vcc is at signal ground in ac equivalent circuit, we have the name common collector.
* It is known as emitter follower because the emitter voltage follows the voltage at the base terminal.
* low O/P resistance & high i/p resistance.
* Used as buffer b/w source & load.

Equivalent Circuit



① Voltage Gain A_V (open Loop)

$$A_V = \frac{V_o}{V_{in}}$$

$$V_o = I_o (r_o \parallel R_E) = (I_b + \beta I_b)(r_o \parallel R_E)$$

$$= I_b (1+\beta)(r_o \parallel R_E)$$

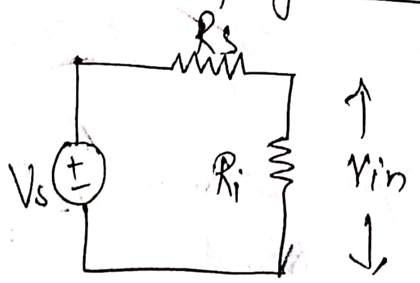
$$V_{in} = I_b r_\pi + I_o (r_o \parallel R_E)$$

$$V_{in} = I_b r_\pi + I_b (1+\beta)(r_o \parallel R_E)$$

$$A_V = \frac{V_o}{V_{in}} = \frac{\cancel{I_b}(1+\beta)(r_o \parallel R_E)}{\cancel{I_b}[r_\pi + (1+\beta)(r_o \parallel R_E)]}$$

$$\boxed{A_V = \frac{V_o}{V_{in}} = \frac{(1+\beta)(r_o \parallel R_E)}{r_\pi + (1+\beta)(r_o \parallel R_E)}}$$

Closed Loop gain A_{VS}



$$A_{VS} = \frac{V_o}{V_s} = \frac{V_o}{V_{in}} \times \frac{V_{in}}{V_s}$$

$$V_{in} = \frac{V_s \times R_i}{R_i + R_s}$$

$$\therefore \frac{V_{in}}{V_s} = \frac{R_i}{R_i + R_s}$$

$$\therefore A_{VS} = \frac{V_o}{V_{in}} \left(\frac{R_i}{R_i + R_s} \right)$$

$$\boxed{A_{VS} = \frac{(1+\beta)(r_o \parallel R_E)}{r_\pi + (1+\beta)(r_o \parallel R_E)} \left(\frac{R_i}{R_i + R_s} \right)}$$

where $R_i = R_1 \parallel R_2 \parallel R_{ib}$

Voltage gain is +ve, ∴ o/p voltage at emitter is in phase with i/p voltage. o/p follows i/p.

(15)

2) Input Impedance

$R_i = R_1 || R_2 || R_{ib}$

$$R_{ib} = \frac{V_{in}}{I_b}$$

$$V_{in} = I_b r_\pi + I_o (r_o || R_E)$$

$$= I_b r_\pi + (I_b + \beta I_b)\, r_o || R_E$$

$$V_{in} = I_b [r_\pi + (1+\beta) r_o || R_E]$$

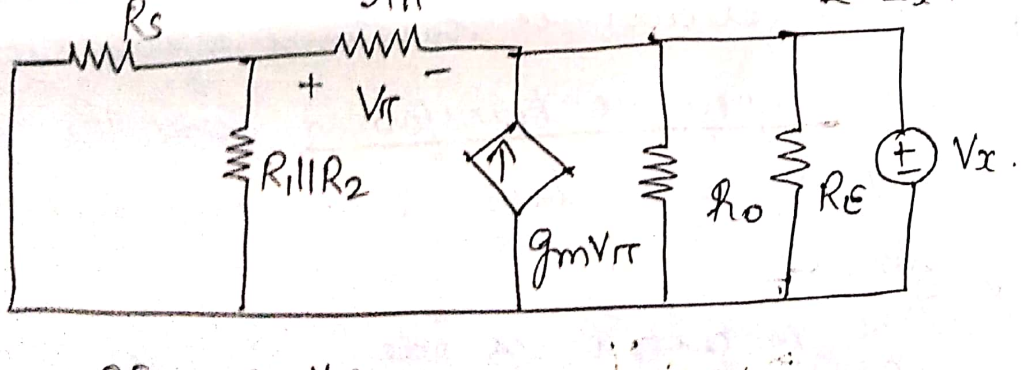
$$\frac{V_{in}}{I_b} = r_\pi + (1+\beta)(r_o || R_E) = R_{ib}$$

$$\boxed{\therefore R_i = R_1 || R_2 || r_\pi + (1+\beta)(r_o || R_E)}$$

This is called reflection rule. Impedance in the emitter is multiplied $(1+\beta)$.

3) Output Impedance R_o.

The independant voltage source is set to zero ($V_s = 0$). A test voltage V_x is applied to the o/p terminals & the resulting test current is I_x.



$\beta I_b = g_m V_\pi$

$\beta I_b = \dots$

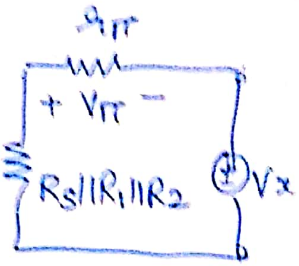
$g_m r_\pi \times V_\pi / r_\pi$

$$R_o = \frac{V_x}{I_x}$$

Applying KCL at o/p:

$$I_x + g_m V_\pi = \frac{V_x}{R_E} + \frac{V_x}{r_o} + \frac{V_x}{r_\pi + (R_s \| R_1 \| R_2)} \longrightarrow (1)$$

$$V_\pi = \frac{-V_x \times r_\pi}{r_\pi + (R_s \| R_1 \| R_2)}$$



Substitute in (1)

$$I_x = \frac{V_x\, g_m r_\pi}{r_\pi + (R_s \| R_1 \| R_2)} + \frac{V_x}{R_E} + \frac{V_x}{r_o} + \frac{V_x}{r_\pi + (R_s \| R_1 \| R_2)}$$

$$I_x = V_x \left[\frac{1}{R_E} + \frac{1}{r_o} + \frac{(1 + g_m r_\pi)}{r_\pi + (R_s \| R_1 \| R_2)} \right]$$

$$I_x = V_x \left[\frac{1}{R_E} + \frac{1}{r_o} + \frac{1+\beta}{r_\pi + (R_s \| R_1 \| R_2)} \right]$$

$$\therefore \boxed{R_o = \frac{V_x}{I_x} = R_E \,\|\, r_o \,\|\, \frac{r_\pi + (R_s \| R_1 \| R_2)}{1+\beta}}$$

* Emitter follower is sometimes referred to as an impedance transformer, since the i/p impedance is large & o/p impedance is small.
* This makes it an ideal voltage source, so the o/p is not loaded when used to drive another load.
* This is used as o/p stage in multistage amplifier.

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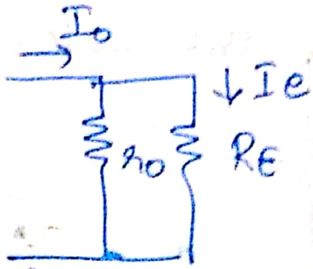
(4) Small signal Current gain A_i

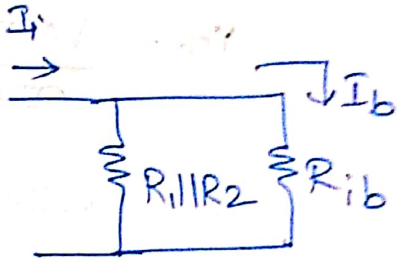
$$A_i = \frac{I_e}{I_i}$$



$$I_e = \frac{I_o\, r_o}{r_o + R_E}$$

$$I_o = I_b + \beta I_b = (1+\beta) I_b$$

$$I_e = (1+\beta) I_b \left(\frac{r_o}{r_o + R_E}\right)$$



$$I_b = I_i \times \frac{R_1 \| R_2}{R_{ib} + (R_1 \| R_2)}$$

$$I_e = (1+\beta) I_i \frac{R_1 \| R_2}{R_{ib} + (R_1 \| R_2)} \left(\frac{r_o}{r_o + R_E}\right).$$

$$\frac{I_e}{I_i} = (1+\beta) \frac{(R_1 \| R_2)}{R_{ib} + (R_1 \| R_2)} \left(\frac{r_o}{r_o + R_E}\right).$$

$$\boxed{A_i = \frac{I_e}{I_i} = (1+\beta) \frac{R_1 \| R_2}{R_{ib} + R_1 \| R_2} \left(\frac{r_o}{r_o + R_E}\right)}$$

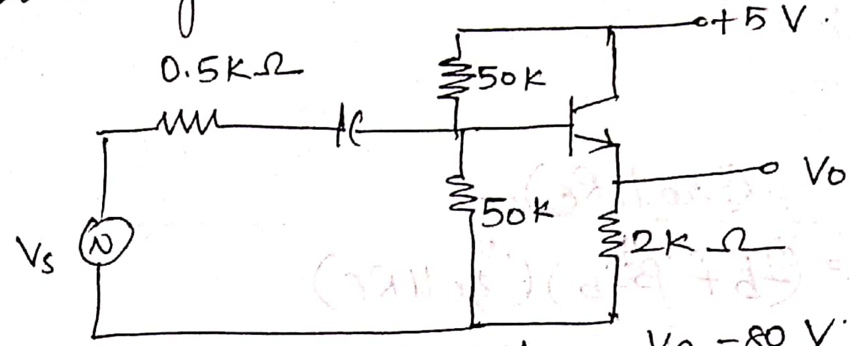
$R_1 \| R_2 >> R_{ib}$ $\qquad r_o >> R_E$

$$\therefore \boxed{A_i \simeq (1+\beta)}$$

The small signal current gain is greater than 1. ∴ the circuit produces a small signal power gain.

Example:-

① For the given circuit calculate the Av, Ai, Ro & Ri



$\beta = 100$ $V_{BE} = 0.7$ $V_A = 80\ V$.

⊗ Find I_{CQ}

$$V_{Th} = \frac{V_{CC} \times 50}{50+50} = \frac{5 \times 50}{50+50} = \frac{250}{100} = 2.5V$$

$$R_{Th} = R_1 \| R_2 = 25\ k\Omega$$

$$I_{CQ} = \frac{V_{Th} - V_{BE}}{R_{Th} + (1+\beta) R_E} = \frac{2.5 - 0.7}{25 + (101)2} = \frac{1.8}{227}$$

$$\boxed{I_{CQ} = 0.793\ mA.}$$

TO Calculate r_π, g_m & r_o:-

$$r_\pi = \frac{V_T \beta}{I_{CQ}} = \frac{(0.026)(100)}{0.793} = 3.28\ k\Omega$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{0.793}{0.026} = 30.5\ mA/V$$

$$r_o = \frac{V_A}{I_{CQ}} = \frac{80}{0.793} \simeq 100\ k\Omega.$$

TO find R_i, R_o, A_v & A_o.

R_i

$$R_i = R_1 \| R_2 \| R_{ib}$$

$$R_{ib} = r_\pi + (1+\beta)(r_o \| R_E)$$

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$R_{ib} = 3.28 + (101)(100 \| 2) = 201\,k\Omega$

$R_i = R_{ib} \| R_1 \| R_2 = 201 \| 50 \| 50 = 22.2\,k\Omega$

(2) $\underline{A_v}$

$$A_v = \frac{(1+\beta)(r_o \| R_E)}{r_\pi + (1+\beta)(r_o \| R_E)} \left(\frac{R_i}{R_i + R_s}\right)$$

$$= \frac{(101)(100\|2)}{3.28 + (1+100)(100\|2)} = \frac{22.2}{22.2 + 0.5}$$

$$\boxed{A_v = 0.962}$$

(3) $\underline{R_o}$

$$R_o = \left[\frac{r_\pi + R_1 \| R_2 \| R_s}{1+\beta}\right] \| R_E \| r_o.$$

$$= \left[\frac{3.28 + 50 \| 50 \| 0.5}{101}\right] \| 2 \| 100$$

$$= 0.0373 \| 2 \| 100 = 0.0366\,k\Omega$$

$$\boxed{R_o = 36.6\,\Omega}$$

(4) $\underline{A_i}$

$$A_i = (1+\beta)\left(\frac{R_1 \| R_2}{R_1 \| R_2 + R_{ib}}\right)\left(\frac{r_o}{r_o + R_E}\right)$$

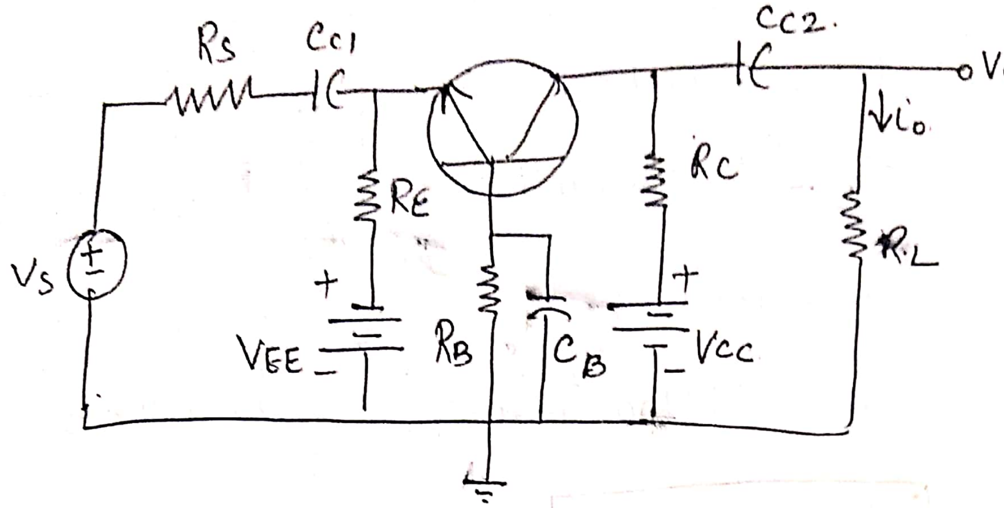
$$= (101)\left(\frac{25}{25 + 22.2}\right)\left(\frac{100}{102}\right) = 52.4$$

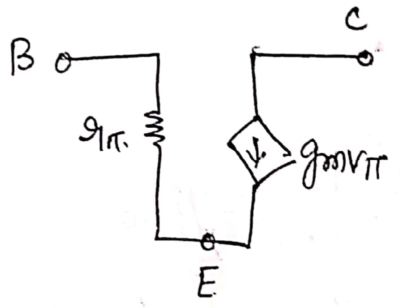
$$\boxed{A_i = 52.4}$$

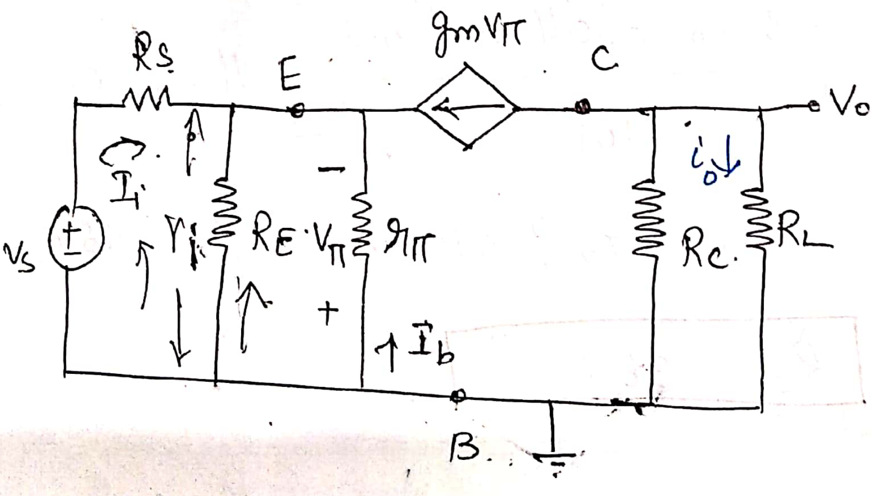
Common-Base Amplifier

1 * Base is at signal ground & i/p is applied to emitter.

* r_o is assumed to be infinite.







④ Small signal voltage gain Av :- $A_v = \frac{V_o}{V_s}$

$V_o = -g_m V_\pi (R_c \| R_L) \rightarrow ①$

KCL at the emitter node :-

$$g_m V_\pi + \frac{V_\pi}{r_\pi} + \frac{V_\pi}{R_E} + \frac{V_s + V_\pi}{R_s} = 0.$$

$$V_\pi \left[g_m + \frac{1}{r_\pi} + \frac{1}{R_E} + \frac{1}{R_s} \right] = -\frac{V_s}{R_s}$$

$$V_\pi \left[\frac{g_m r_\pi + 1}{r_\pi} + \frac{1}{R_e} + \frac{1}{R_s} \right] = -\frac{V_s}{R_s}$$

$$V_\pi \left[\frac{1+\beta}{r_\pi} + \frac{1}{R_e} + \frac{1}{R_s} \right] = -\frac{V_s}{R_s}.$$

$$V_\pi = \frac{-V_s}{R_s} \left[R_s \,||\, R_E \,||\, \frac{r_\pi}{1+\beta} \right] \rightarrow (2)$$

Substituting (2) in (1).

$$V_o = -g_m \left(\frac{-V_s}{R_s} \left(R_s || R_E || \frac{r_\pi}{1+\beta} \right) \right)$$

$$\boxed{A_v = \frac{V_o}{V_s} = \frac{g_m}{R_s} \left(R_s || R_E || \frac{r_\pi}{1+\beta} \right) (R_c || R_L).}$$

If $R_s = 0$

$$A_v \simeq g_m (R_c || R_L).$$

(2) Small signal current gain A_i

$$A_i = \frac{I_o}{I_i} \qquad I_o = -g_m V_\pi \frac{R_c}{R_c + R_L} \rightarrow (3)$$

KCL at the i/p:

$$I_i + \frac{V_\pi}{R_E} + \frac{V_\pi}{r_\pi} + g_m V_\pi = 0.$$

$$V_\pi \left[\frac{1}{R_E} + \frac{1}{r_\pi} + g_m \right] = -I_i$$

$$V_\pi \left[\frac{1}{R_E} + \frac{(1+\beta)}{r_\pi}\right] = -I_i$$

$$V_\pi = -I_i \left[R_E \parallel \frac{r_\pi}{1+\beta}\right] \longrightarrow (4)$$

Sub V_π from (4) in (3)

$$I_o = +g_m I_i \left[R_E \parallel \frac{r_\pi}{1+\beta}\right]\left(\frac{R_C}{R_C+R_L}\right).$$

$$\boxed{\frac{I_o}{I_i} = A_i = g_m\left(R_E \parallel \frac{r_\pi}{1+\beta}\right)\left(\frac{R_C}{R_C+R_L}\right)}$$

R_E approaches ∞ if $R_L = 0$.

$$\therefore A_{io} = \frac{g_m r_\pi}{1+\beta} = \frac{\beta}{1+\beta} = \alpha.$$

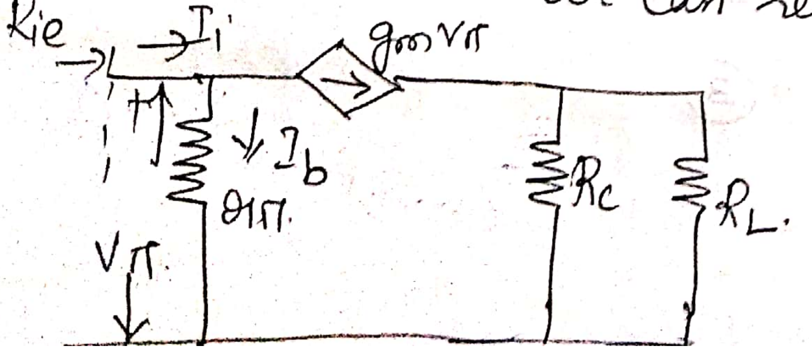
$\alpha \rightarrow$ common base current gain of amplifier.

$A_V > 1$ & $A_i < 1$.

we have small signal power gain.

R_i : Input Impedance

For convenience we can reverse the polarities



$$R_{ie} = \frac{V_\pi}{I_i}$$

$$I_i = I_b + g_m V_\pi$$

$$I_i = \frac{V_\pi}{r_\pi} + g_m V_\pi$$

$$I_i = V_\pi \left[\frac{1}{r_\pi} + g_m\right] = V_\pi \left[\frac{1+\beta}{r_\pi}\right].$$

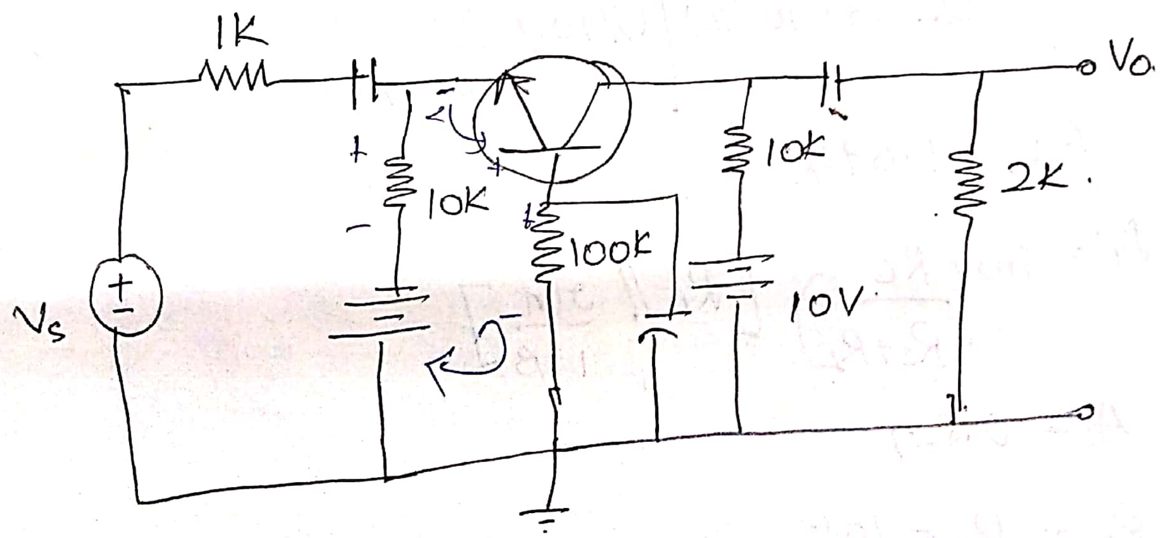
$$\boxed{\frac{V_\pi}{I_i} = \frac{r_\pi}{1+\beta}} \simeq r_\pi.$$

R_o: O/P Impedance

$R_o \simeq R_C$.

Eg.) For a common base circuit shown calculate R_i, A_V, A_i & R_o.

$\beta = 100$, $V_{BE} = 0.7V$, $V_A = \infty$.



① Find I_{CQ}:-

$$I_B = \frac{V_{EE} - V_{BE}}{R_B + (1+\beta)R_E} = \frac{10-0.7}{100+(1+100)10} = 8.378 \mu A.$$

$$\boxed{I_C = \beta I_B = 0.8378\, mA}$$

2) Determine r_π, g_m & r_0:

$$r_\pi = \frac{V_T \beta}{I_{CQ}} = \frac{(0.026)(100)}{0.8378} = 3.1k\Omega.$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{0.8378}{0.026} = 32.223\, mA/V$$

$$r_0 = \frac{V_A}{I_{CQ}} = \frac{\infty}{I_{CQ}} = \infty$$

③ Find R_i, A_v, A_i & R_o

1) $$R_i = \frac{r_\pi}{1+\beta} = \frac{3.1}{1+100} = 30.69\Omega$$

2) $$A_v = \frac{g_m (R_C \| R_L)}{R_s} \left[R_E \| R_s \| \frac{r_\pi}{1+\beta} \right]$$

$$= 32.223 (10 \| 2) \left[1 \| 10 \| \frac{3.1}{100+1} \right]$$

$$A_v = 1.594.$$

3) $$A_i = g_m \left(\frac{R_C}{R_C + R_L} \right) \left[R_E \| \frac{r_\pi}{1+\beta} \right].$$

$$A_i = 0.821$$

4) $$R_o = R_C = 10K$$

Multistage Amplifiers

Need for cascading :-

1) When amplification of single stage amplifier is not sufficient, or

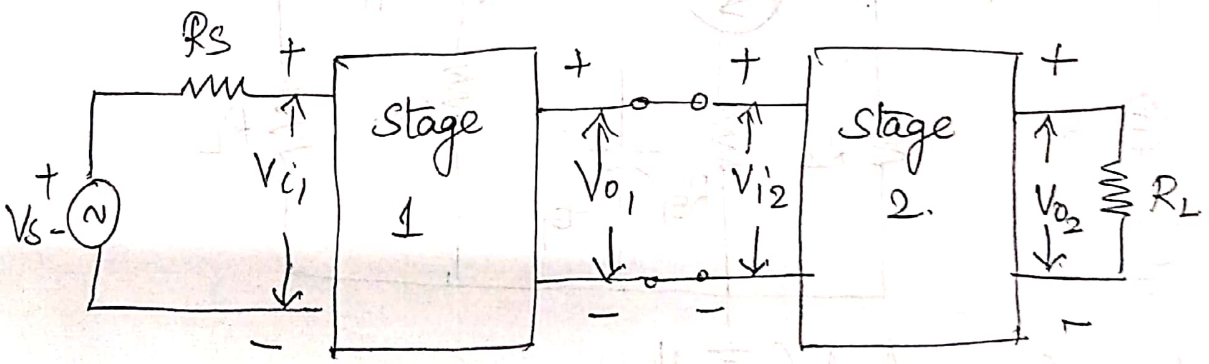
2). When the i/p or o/p impedance is not of correct magnitude for a particular application two or more stages are connected in cascade. Such an amplifier with two or more stages is known as multistage amplifier.

Limitations of multistage amplifiers

1) The bandwidth of multistage amplifier is always less than that of a single stage amplifier.

2) Non linear distortion is more in a multistage amplifier.

Two stage cascaded amplifier



O/p of first stage is connected to the i/p of 2nd stage.

$$A_v = \frac{V_{o2}}{V_{i1}} = \frac{V_{o2}}{V_{i2}} \times \frac{V_{i2}}{V_{i1}} \qquad [V_{o1} = V_{i2}]$$

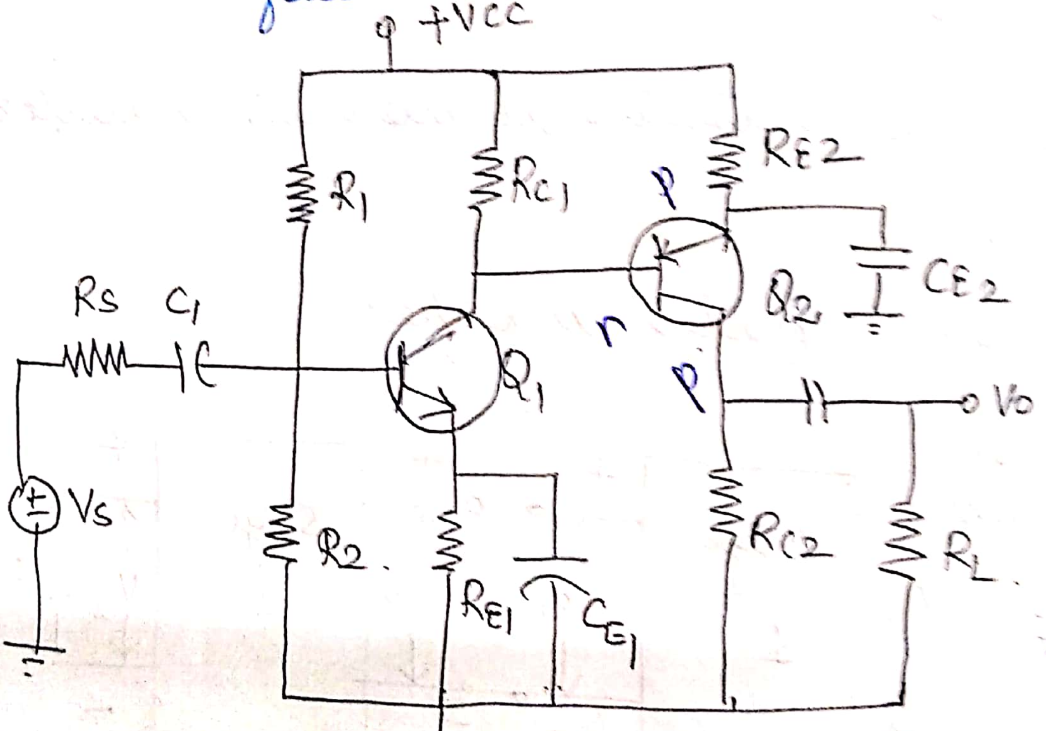
$$= \frac{V_{o2}}{V_{i2}} \times \frac{V_{o1}}{V_{i1}}$$

$$\boxed{A_v = A_{v2} \cdot A_{v1}}$$

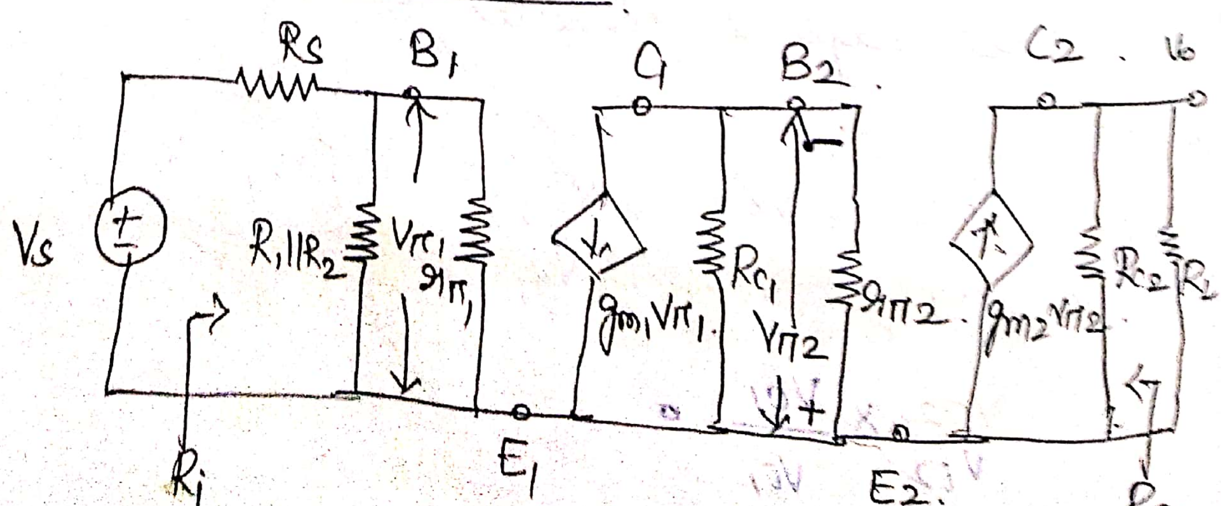
* Voltage gain of multistage amplifier is the product of voltage gains of the individual stages.

2 stage CE Amplifier

Figure shows the cascade configuration of 2 CE circuits.
For ac analysis all capacitors are shorted & each transistor o/p resistance r_o is infinite.



Ac Equivalent Circuit



o/p impedance of one stage is shunted by the i/p impedance of the next stage. (18)

Stage 2:-

1) Input impedance R_{i2}

$R_{i2} = r_{\pi 2}$

2) Voltage gain A_{v2}

$A_{v2} = \frac{V_o}{V_{\pi 2}}$; $V_o = g_{m2} V_{\pi 2} (R_{C2} \| R_L)$

$\therefore A_{v2} = \frac{V_o}{V_{\pi 2}} = g_{m2} (R_{C2} \| R_L)$

Stage 1

1) Input impedance R_{i1}

$R_{i1} = R_1 \| R_2 \| r_{\pi 1}$

2) Voltage gain A_{v1}

$A_{v1} = \frac{V_{\pi 2}}{V_{\pi 1}}$

$V_{\pi 2} = g_{m1} V_{\pi 1} (R_{C1} \| r_{\pi 2})$

$A_{v1} = \frac{V_{\pi 2}}{V_{\pi 1}} = g_{m1} (R_{C1} \| r_{\pi 2})$

Total voltage gain (Open Loop) A_{v_o}

$A_{v_o} = \frac{V_o}{V_{\pi 1}} = \frac{V_o}{V_{\pi 2}} \times \frac{V_{\pi 2}}{V_{\pi 1}} = A_{v1} \times A_{v2}$

$$\boxed{A_{VD} = g_{m1}(R_{C1} \parallel r_{\pi 2})\, g_{m2}(R_{C2} \parallel R_L)}$$

$$A_{VS} = \frac{V_o}{V_s} = \frac{V_o}{V_{\pi 2}} \times \frac{V_{\pi 2}}{V_{\pi 1}} \times \frac{V_{\pi 1}}{V_s}$$

$$A_{VS} = A_{V2} \times A_{V1} \times \frac{R_i}{R_i + R_S}$$

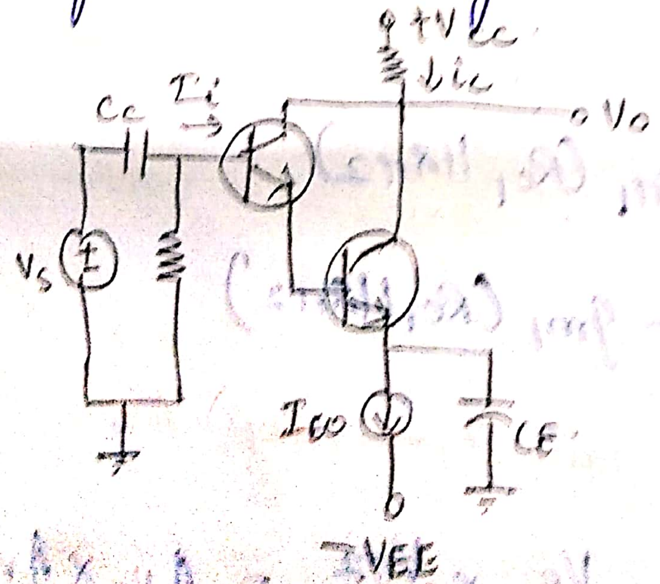
$$\boxed{A_{VS} = g_{m1} g_{m2} (R_{C1} \parallel r_{\pi 2})(R_{C2} \parallel R_L) \frac{R_i}{R_i + R_S}}$$

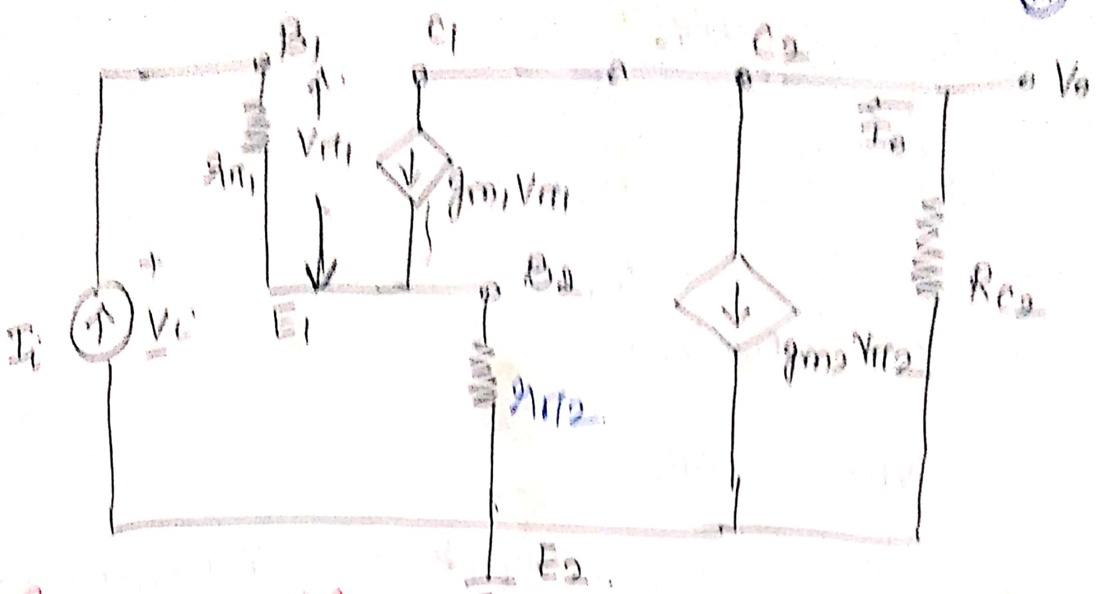
O/P resistance R_o

$R_o \simeq R_{C2}$.

Darlington Transistors

* High input resistance
* Improves current gain.





Small signal current gain A_i

$$A_i = \frac{I_o}{I_i}$$

$$I_o = g_{m2} V_{\pi 2} + g_{m1} V_{\pi 1}$$

$$V_{\pi 1} = I_i r_{\pi 1}$$

$$V_{\pi 2} = (I_i + g_{m1} V_{\pi 1}) r_{\pi 2}$$

$$= (I_i + I_i g_{m1} r_{\pi 1}) r_{\pi 2}$$

$$= (I_i + I_i \beta_1) r_{\pi 2}.$$

$$V_{\pi 2} = I_i r_{\pi 2} + I_i \beta_1 r_{\pi 2}.$$

Sub $V_{\pi 1}$ & $V_{\pi 2}$ in I_o

$$\therefore I_o = g_{m2}(I_i r_{\pi 2} + I_i \beta_1 r_{\pi 2}) + g_{m1} I_i r_{\pi 1}$$

$$= I_i g_{m2} r_{\pi 2} + I_i \beta_1 g_{m2} r_{\pi 2} + I_i r_{\pi 1} g_{m1}$$

$$= I_i [\beta_2 + \beta_1 \beta_2 + \beta_1]$$

$$\boxed{A_i = \frac{I_o}{I_i} = \beta_1 + \beta_2 + \beta_1 \beta_2.}$$

$$\boxed{A_i \simeq \beta_1 \beta_2.}$$

The overall current gain of a Darlington pair is the product of individual current gains.

Input Resistance R_i

$$R_i = \frac{V_i}{I_i}$$

$$V_i = V\pi_1 + V\pi_2$$

$$V\pi_1 = I_i r\pi_1$$

$$V\pi_2 = (I_i + g_{m1} V\pi_1) r\pi_2 = (I_i + g_{m1} I_i r\pi_1) r\pi_2$$

$$V\pi_2 = I_i (1+\beta_1) r\pi_2$$

$$V\pi_2 = I_i (1+\beta_1) r\pi_2$$

Sub $V\pi_1$ & $V\pi_2$ in V_i

$$\therefore V_i = I_i r\pi_1 + I_i (1+\beta_1) r\pi_2$$

$$V_i = I_i [r\pi_1 + (1+\beta_1) r\pi_2]$$

$$\therefore \boxed{R_i = \frac{V_i}{I_i} = [r\pi_1 + (1+\beta_1) r\pi_2]}$$

$$r\pi_1 = \frac{\beta_1}{g_{m1}} = \frac{\beta_1 V_T}{I_{CQ1}}$$ Let $I_{CQ1} \simeq \frac{I_{CQ2}}{\beta_2}$.

$$\therefore r\pi_1 = \frac{\beta_1 V_T \beta_2}{I_{CQ2}}$$

$$r\pi_1 = \beta_1 r\pi_2$$

$$\therefore R_i = \beta_1 r\pi_2 + (1+\beta_1) r\pi_2$$

$$\boxed{R_i \simeq 2\beta_1 r\pi_2}$$

The input resistance of Darlington pair is large because of β multiplication. (50)

Cascode Amplifier

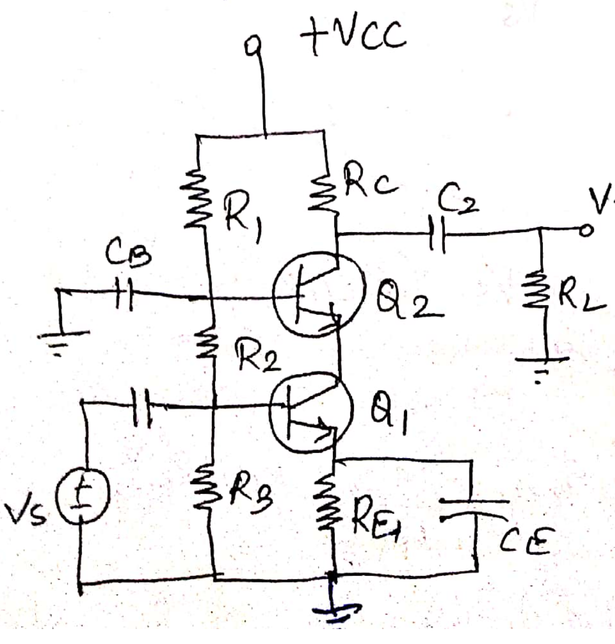
* It has a common emitter stage in series with a common base amplifier.
* $Q_1 \rightarrow CE$
  $Q_2 \rightarrow CB$.

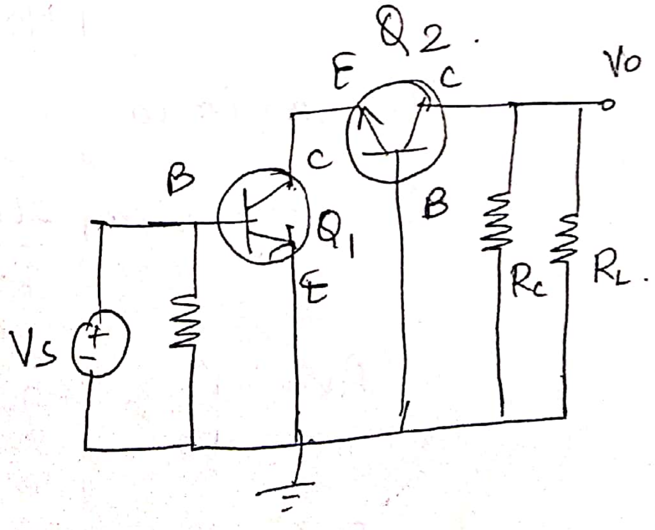
Features :-

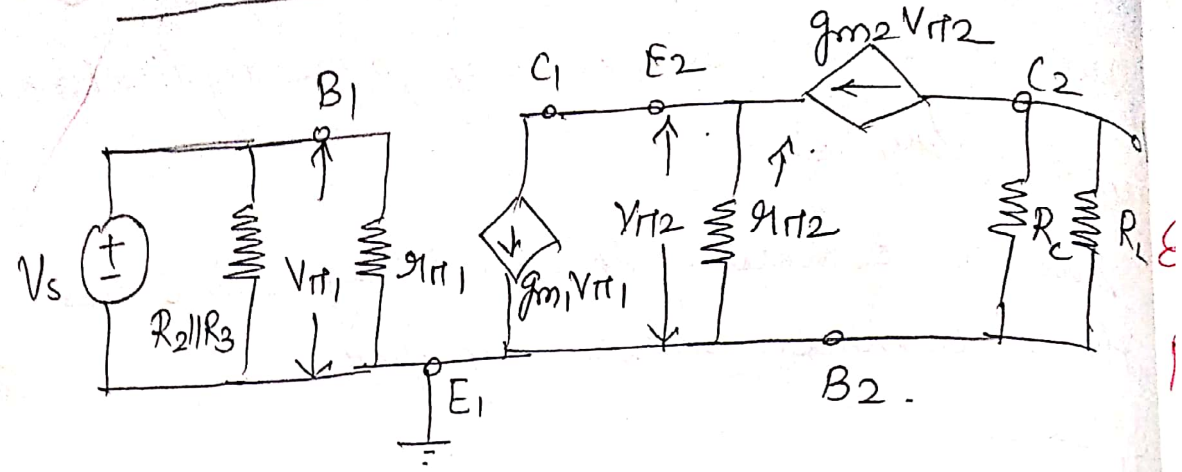
1) It provides high input impedance.
2) High voltage gain
3) Improved i/p o/p isolation as there is no direct coupling from o/p to i/p. This eliminates Miller effect & thus provides much BW.
4) High o/p resistance.
5) High slew rate & stability

Disadvantages:

1) high supply voltage is required &
2) need for 2 transistors.







To find voltage gain A_v.

$$A_v = \frac{V_o}{V_s} \qquad V_o = -g_{m2}V_{\pi 2}(R_c \| R_L)$$

$$V_s = V_{\pi 1}.$$

Apply KCL to E_2.

$$g_{m2}V_{\pi 2} + \frac{V_{\pi 2}}{r_{\pi 2}} = g_{m1}V_{\pi 1} = g_{m1}V_s.$$

$$\therefore V_{\pi 2} \cdot \left[\frac{1+\beta_2}{r_{\pi 2}}\right] = g_{m1}V_s.$$

$$V_{\pi 2} = g_{m1}\frac{r_{\pi 2}}{1+\beta_2}V_s.$$

Sub $V_{\pi 2}$ in V_o

$$V_o = -g_{m2}g_{m1}\frac{r_{\pi 2}}{1+\beta_2}V_s \cdot (R_c \| R_L)$$

$$\therefore A_v = \frac{V_o}{V_s} = -g_{m1}g_{m2}\frac{r_{\pi 2}}{1+\beta_2}(R_c \| R_L).$$

$$\boxed{A_v = \frac{V_o}{V_s} = -g_{m1}\frac{\beta_2}{1+\beta_2}(R_c \| R_L)}$$

$A_V \simeq -g_{m1}(R_C \| R_L)$ $\{\because \frac{\beta_2}{1+\beta_2} \simeq 1\}$ 21

Eg. 1 For a cascode amplifier, $I_{CQ} = 0.5mA$, $\beta = 100$, $V_{BE} = 0.7$, $V_A = \infty$ $R_C = 7.5K$, $R_L = 2K$. Find A_V. (for both transistors)

Determine r_π & g_m :-

$$r_{\pi 1} = r_{\pi 2} = \frac{\beta V_T}{I_{CQ}} = \frac{(100)(0.026)}{0.5} = 5.2K\Omega$$

$$g_{m1} = g_{m2} = \frac{I_{CQ}}{V_T} = \frac{0.5}{0.026} = 19.23\ mA/V.$$

$$r_o = r_{o1} = r_{o2} = \infty.$$

Calculate A_V:

$$A_V = \frac{V_o}{V_s} = -g_{m1} g_{m2} \left(\frac{r_{\pi 2}}{1+\beta_2}\right)(R_C \| R_L)$$

$$= -(19.23)(19.23)\left(\frac{5.2}{1+100}\right)(7.5 \| 2)$$

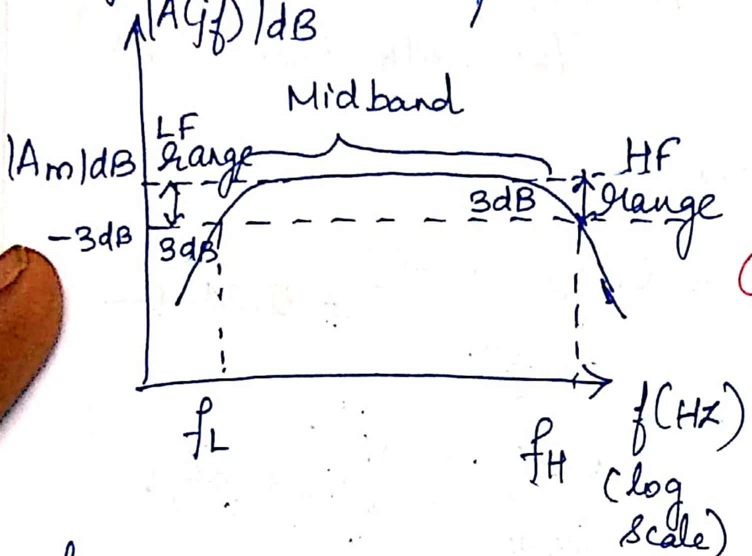
$$\boxed{A_V = -30.06.}$$

Frequency Response Analysis of Basic BJT CE Amplifier

Amplifier Frequency response

* All amplifier gain factors are functions of signal frequency
* we have ...

high enough that coupling & bypass capacitors can be treated as short circuit and at the same time signal frequency is low enough such that transistor capacitors & stray capacitances are open circuit.



Three ranges of frequency

① Low frequency range :- $f < f_L$, the gain decreases as frequency decreases because of coupling & bypass capacitors effects.

② High frequency range $f > f_H$: stray capacitance & transistor capacitance effects cause gain to decrease as the frequency increases.

③ Midband range : Coupling & bypass capacitors act as short circuit & stray & transistor 'C' act as open circuit, Gain is constant.

* gain at f_H & f_L is 3dB less than the max. midband gain.

$$BW = f_H - f_L.$$

Equivalent Circuits : Each capacitor is important to only one end of frequency spectrum. We can develop equivalent circuits that apply to

1) LF range 2) HF range & 3) Midband range.

1) LF range → bypass & coupling C → taken into consideration; stray & transistor C → open circuit.

2) HF range → bypass & coupling → short; stray & transistor → considered.

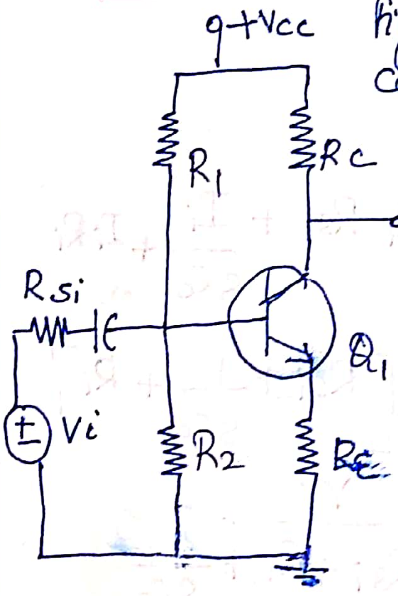
3) Midband range → bypass & coupling → short; stray & transistor → open

Frequency response: Transistor amplifier with Capacitor circuit

* Coupling } At low frequencies
* Bypass }
* Load capacitor. → At high frequencies.

I/P Coupling capacitor for CE Circuit

Fig shows CE amplifier with coupling capacitor. $r_o \simeq \infty$.



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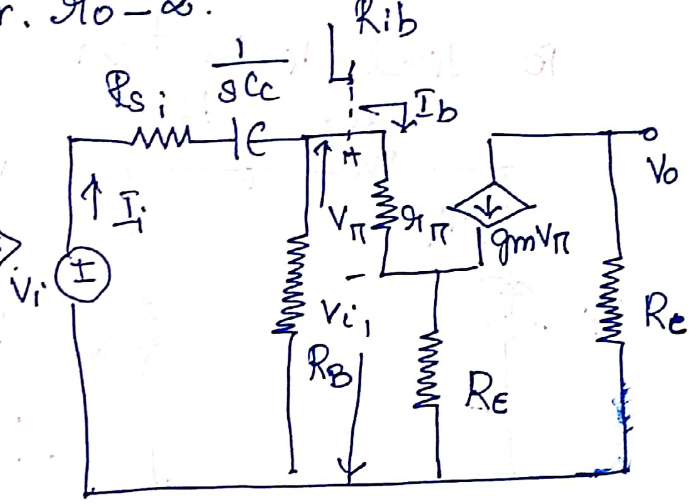


$R_B = R_1 || R_2$.

To determine the transfer function.

highpass network

To find Av(S)

$$A_v(s) = \frac{V_o(s)}{V_i(s)}.$$

(ie) At high frequencies, Cc acts as short ckt & i/p to coupled through Q_1 to o/p. As f is low o/p ≃ 0.

$$V_o(s) = -g_m V_\pi R_c$$

we know that $V_\pi = I_b r_\pi$.

From the i/p circuit

$$R_i = R_1 || R_2 || R_{ib}$$

$$R_{ib} = \frac{V_{i_1}}{I_b} \Rightarrow V_{i_1} = V_\pi + (I_b + g_m V_\pi) R_E$$

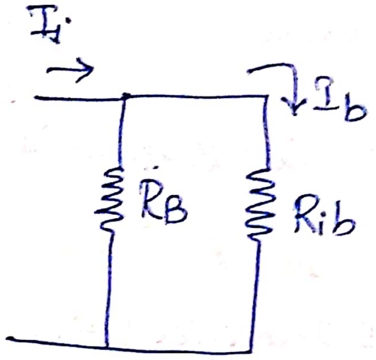
$$= I_b r_\pi + (I_b + g_m I_b r_\pi) R_E$$

$$= I_b [r_\pi + (1+\beta) R_E].$$

$$\therefore R_{ib} = \frac{V_{i_1}}{I_b} = r_\pi + (1+\beta) R_E$$

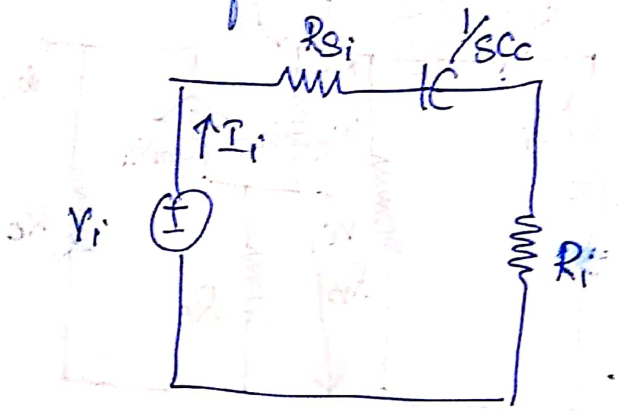
$\therefore R_i = R_1 \| R_2 \| r_\pi + (1+\beta) R_E$

To find I_b in terms of I_i



$$I_b = I_i \times \frac{R_B}{R_B + R_{ib}}.$$

To find I_i in terms of V_i



$$V_i = I_i R_{si} + \frac{I_i}{sC_c} + I_i$$

$$V_i = I_i \left[R_{si} + \frac{1}{sC_c} + R_i \right.$$

$$\therefore I_i = \frac{V_i}{R_{si} + R_i + \frac{1}{sC_c}}.$$

Sub. V_π in V_o:

$$\therefore V_o = -g_m R_C I_b r_\pi$$

Sub I_b in V_o

$$\therefore V_o = -g_m R_C I_i \frac{R_B}{R_B + R_{iB}} \cdot r_\pi$$

Sub. I_i in V_o.

$$\therefore V_o = -g_m R_C \frac{V_i}{R_{si} + R_i + \frac{1}{sC_c}} \cdot \frac{R_B}{R_B + R_{iB}} \cdot r_\pi$$

$$= -g_m r_\pi R_C \frac{V_i (sC_c)}{1 + sC_c(R_{si} + R_i)} \cdot \frac{R_B}{R_B + R_{iB}}.$$

$$A_v = \frac{V_o}{V_i} = -g_m r_\pi R_c \frac{sC_c}{1+sC_c(R_{si}+R_i)} \frac{R_B}{R_B+R_i}$$

Let $\tau_s = C_c(R_i + R_{si})$.

$$\therefore A_v = \frac{V_o}{V_i} = -g_m r_\pi R_c \frac{sC_c}{1+\tau s} \frac{R_B}{R_B+R_i}$$

$\times$ & divide by τ_s

$$\therefore A_v = \frac{V_o}{V_i} = \frac{-g_m r_\pi R_c}{\cancel{C_c}(R_i+R_{si})} \times \frac{s\cancel{C_c}\tau_s}{1+\tau s} \frac{R_B}{R_B+R_i}$$

$$\therefore \boxed{A_v(s) = \frac{-g_m r_\pi R_c}{R_i+R_{si}}\left(\frac{\tau_s}{1+\tau_s}\right)\left(\frac{R_B}{R_B+R_i}\right)}$$

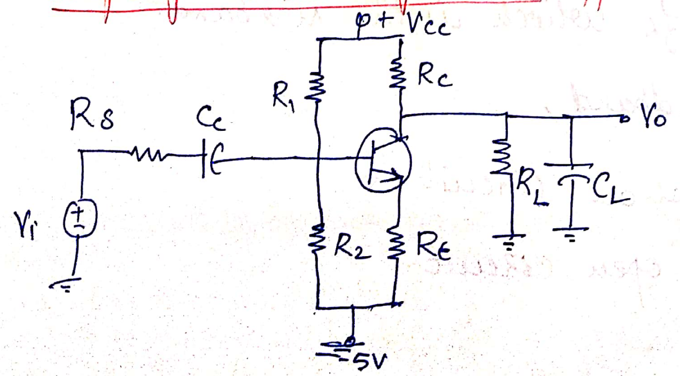
$\tau_s \rightarrow$ determines the corner frequency

Lower cut off frequency

$$f_L = \frac{1}{2\pi\tau_s} = \frac{1}{2\pi(R_i+R_{si})C_c}$$

$$|A_{v\max}|_{dB} = 20\log\left(\frac{g_m r_\pi R_c}{R_{si}+R_i}\right)\left(\frac{R_B}{R_B+R_i}\right)$$

Coupling & Load Capacitors Effect :-



The values of coupling & load capacitances differ by orders of magnitude, the corner frequencies are far apart and can be treated seperately.

Lower corner frequency

$$f_L = \frac{1}{2\pi \tau_s}$$ ← lower corner frequency

τ_s ← time constant assosiated with coupling capacitor

$$\tau_s = (R_s + R_1 || R_2 || R_i)\, C_c$$

Upper Corner frequency

$$f_H = \frac{1}{2\pi \tau_p}$$

$f_H \rightarrow$ upper corner frequency

$\tau_p \rightarrow$ time constant assossiated with load capacitor

$$\tau_p = (R_c || R_L)\, C_L.$$

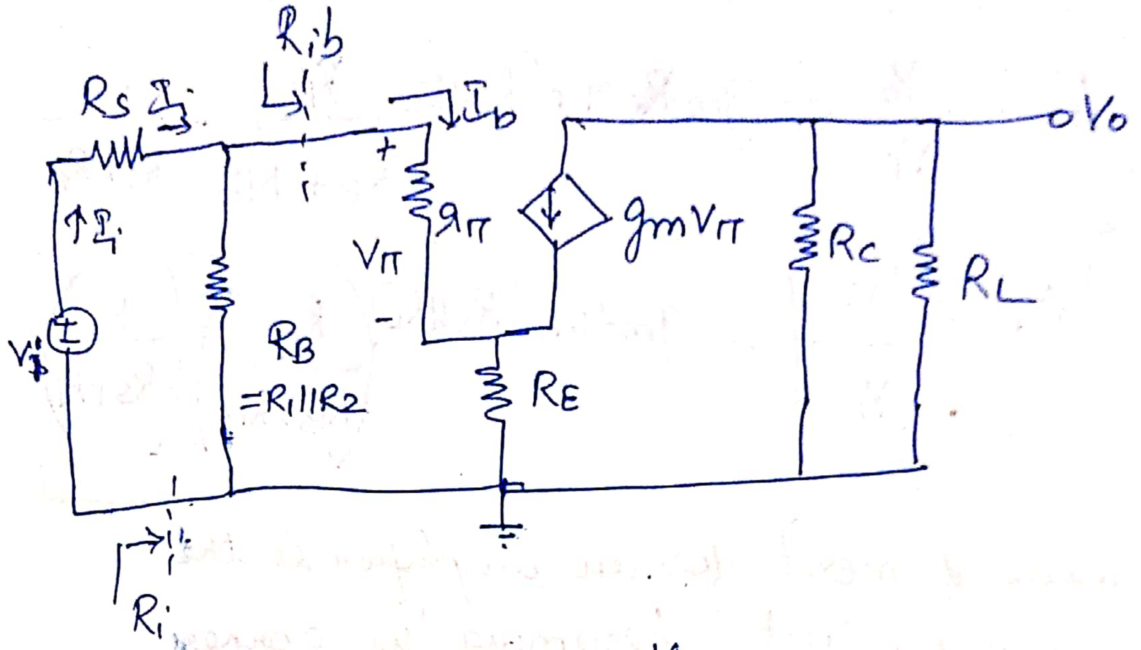
Calculation of mid band gain

The gain will reach maximum between f_H & f_L. which is the mid band.

At midband,

$C_c \rightarrow$ short circuit &

C_L is open circuit.



Midband gain $A_V = \frac{V_o}{V_i}$

$$V_o = -g_m V_\pi (R_c \| R_L) = -g_m I_b r_\pi (R_c \| R_L)$$

$$V_\pi = I_b r_\pi.$$

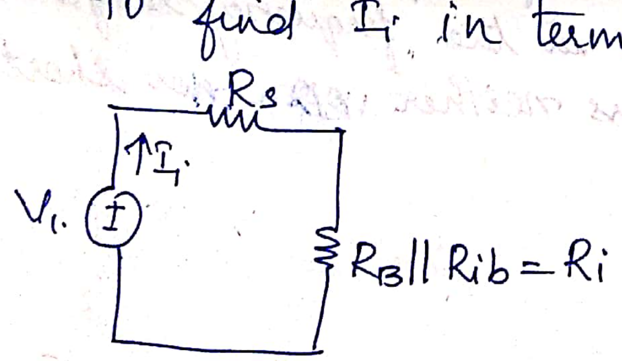
$$I_b = I_i \times \frac{R_B}{R_B + R_{ib}}$$

where $R_{ib} = r_\pi + (1+\beta) R_E$

Sub I_b in V_o.

$$V_o = -g_m r_\pi (R_c \| R_L) I_i \frac{R_B}{R_B + R_{ib}}$$

To find I_i in terms of V_i



$$\therefore V_i = I_i (R_s + R_i)$$

$$I_i = \frac{V_i}{R_s + R_i}$$

Sub in $V_o = -g_m r_\pi (R_c \| R_L) \frac{V_i}{R_s + R_i} \frac{R_B}{R_B + R_{ib}}$

$$A_V = \frac{V_o}{V_i} = -g_m \cancel{R_c}\, r_\pi (R_C \| R_L) \frac{R_B}{R_B + R_{ib}} \cdot \frac{1}{R_{S+}}$$

$$\boxed{|A_V| = \left|\frac{V_o}{V_i}\right| = g_m r_\pi (R_C \| R_L)\left(\frac{R_B}{R_B+R_{ib}}\right)\left(\frac{1}{R_{S+}}\right.}$$

A figure of merit for an amplifier is the gain-BW product. Assuming the corner frequencies are far apart, BW is

$$f_{BW} = f_H - f_L \simeq f_H.$$

$$GB = |A_V|_{max} \cdot f_H.$$

Bypass Capacitor Effects

* By pass capacitors are included to stabilize t Q point without sacrificing the small signal gain.

* To choose a bypass capacitor we must determ the circuit response in the frequency range where these capacitors neither open nor short circuit.

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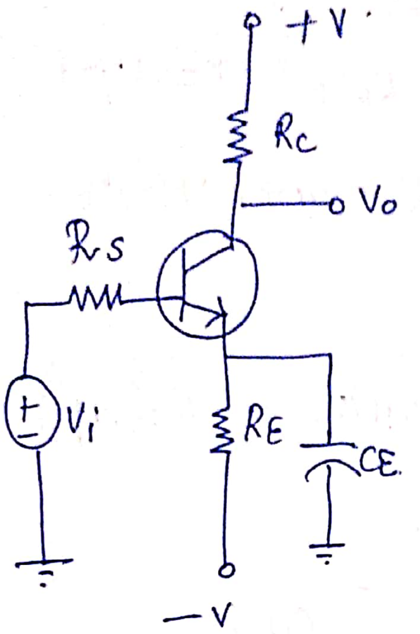
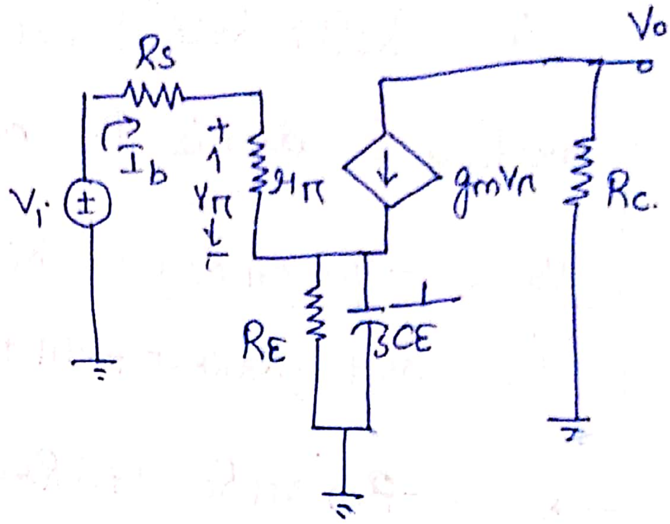




the transfer function

$$A_V = \frac{V_o(s)}{V_i(s)}$$

$$V_o = -g_m V_\pi (R_C) = -g_m I_b r_\pi R_C$$

$$V_\pi = I_b r_\pi$$

$$V_i = I_b \left[R_S + r_\pi + \left(R_E \| \frac{1}{sC_E}\right)(1+\beta) \right]$$

$$\Rightarrow I_b = \frac{V_i}{R_S + r_\pi + \left(R_E \| \frac{1}{sC_E}\right)(1+\beta)}$$

Sub in

$$V_o = -g_m r_\pi R_C \frac{V_i}{R_S + r_\pi + \left(R_E \| \frac{1}{sC_E}\right)(1+\beta)}.$$

$$\frac{V_o}{V_i} = -g_m r_\pi R_C \frac{1}{R_S + r_\pi + \frac{R_E \times \frac{1}{sC_E}}{R_E + \frac{1}{sC_E}} (1+\beta)}$$

$$= -g_m r_\pi R_C \frac{1}{R_S + r_\pi + (1+\beta) \frac{R_E / sC_E}{R_E C_E + 1/sC_E}}$$

$$\frac{V_o}{V_i} = \frac{-g_m r_\pi R_C (1+sR_EC_E)}{R_s(1+sR_EC_E)+r_\pi(1+sR_EC_E)+R_E(1+\beta)}$$

multiply & divide the by $R_s+r_\pi+(1+\beta)R_E$.

$$\frac{V_o}{V_i} = \frac{-g_m r_\pi R_C (1+sR_EC_E)}{R_s+sR_sR_EC_E+r_\pi+sr_\pi R_EC_E+R_E(1+\beta)}$$

$$= \frac{-g_m r_\pi R_C (1+sR_EC_E)}{R_s+r_\pi+(1+\beta)R_E+sR_EC_E(R_s+r_\pi)}$$

Take $R_s+r_\pi+(1+\beta)R_E$ in Dr outside.

$$\frac{V_o}{V_i} = \frac{-g_m r_\pi R_C (1+sR_EC_E)}{R_s+r_\pi+(1+\beta)R_E\left[1+\frac{sR_EC_E(R_s+r_\pi)}{R_s+r_\pi+(1+\beta)R_E}\right]}$$

$$\therefore A_v = \frac{-g_m r_\pi R_C}{R_s+r_\pi+(1+\beta)R_E}\frac{(1+s\tau_A)}{(1+s\tau_B)}.$$

where $\tau_A = R_EC_E$

$$\tau_B = \frac{R_EC_E(R_s+r_\pi)}{R_s+r_\pi+(1+\beta)R_E}.$$

At $\omega \to 0$, C_E becomes open circuit.

$$\therefore |A_v|_{\omega\to 0} = \frac{g_m r_\pi R_C}{R_s+r_\pi+(1+\beta)R_E}$$

At $\omega \to \infty$ C_E is short circuit

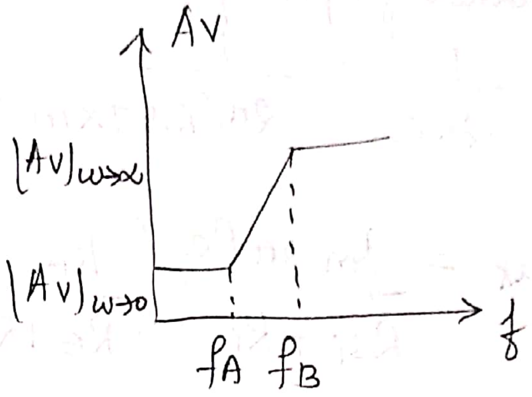
$$|A_v|_{\omega \to \infty} = \frac{g_m r_\pi R_C}{R_S + r_\pi}.$$

R_E is shorted by C_E.

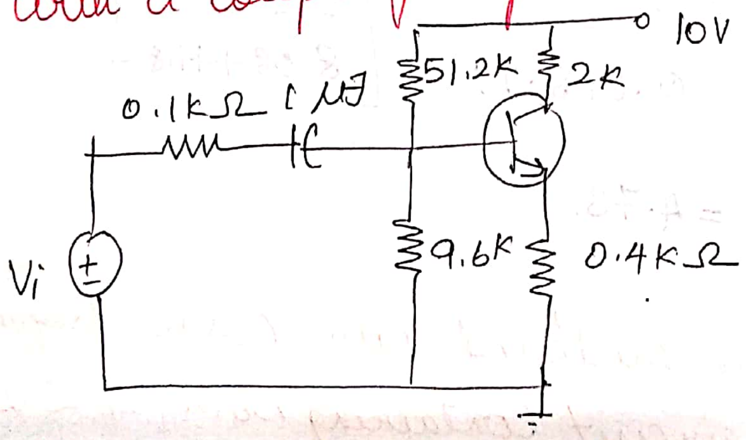
Corner frequencies

$$f_B = \frac{1}{2\pi \tau_B}$$

$$f_A = \frac{1}{2\pi \tau_A}.$$



① Calculate the corner frequency & maximum gain of a bipolar common emitter circuit with a coupling capacitor.



$V_{BE}(on) = 0.7V$

$\beta = 100$

$V_A = \infty$.

Solution :- $I_{CQ} = 1.81 mA$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{1.81}{0.026} = 69.6 \text{ mA/V}$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(100)(0.026)}{1.81} = 1.44 \text{ k}\Omega.$$

$$R_i = R_1 \| R_2 \| r_\pi + (1+\beta) R_E$$
$$= 51.2 \| 9.6 \| [1.44 + (101)(0.4)] = 6.77 \text{k}\Omega.$$

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$$\tau_S = (R_{Si} + R_i) C_C = (0.1 \times 10^3 + 6.77 \times 10^3)(1 \times 10^{-6})$$

$$\tau_S = 6.87 \times 10^{-3}\ s$$

$$\tau_S = 6.87\ ms.$$

The corner frequency:

$$f_L = \frac{1}{2\pi \tau_S} = \frac{1}{2\pi(6.87 \times 10^{-3})} = 23.2\ Hz.$$

$$|A_v|_{max} = \frac{g_m r_\pi R_C}{R_{Si} + R_i}\left(\frac{R_B}{R_B + R_{ib}}\right)$$

$$R_{ib} = r_\pi + (1+\beta) R_E = 1.44 + (101)(0.4)$$

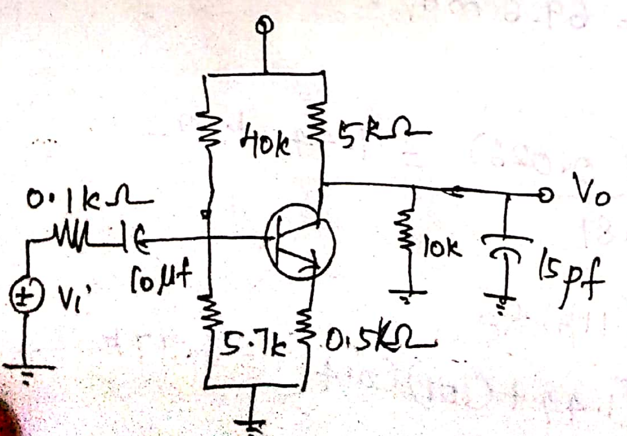
$$R_{ib} = 41.8\ k\Omega$$

$$|A_v|_{max} = \frac{(69.6)(1.44)(2)}{0.1 + 6.77}\left[\frac{8.08}{8.08 + 41.8}\right]$$

$$|A_v|_{max} = 4.73.$$

(2) Determine the midband gain, corner frequen[cy] & BW of a circuit containing both C_C & C_L.

$V_{BE(ON)} = 0.7V$ $\quad \beta = 100$ $\quad V_A = \infty$



Solution

$$I_{CQ} = 0.99\ mA$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{0.99}{0.026}$$

$$g_m = 38.1\ mA/V$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(100)(0.026)}{0.99} = 2.63\,k\Omega$$

$$R_i' = r_\pi + (1+\beta) R_E = 2.63 + (101)(0.5) = 53.1\,k\Omega$$

$$|A_v|_{max} = \left|\frac{V_o}{V_i}\right|_{max} = g_m r_\pi (R_C \| R_L) \left[\frac{R_1 \| R_2}{R_1 \| R_2 + R_i}\right] \left[\frac{1}{R_S + (R_1 \| R_2 \| R_i)}\right]$$

$$= (38.1)(2.63)(5 \| 10) \left[\frac{40 \| 5.7}{40 \| 5.7 + 53.1}\right] \left[\frac{1}{0.1 + (40 \| 5.7 \| 53.1)}\right]$$

(or)

$$|A_v|_{max} = 6.16$$

The time constant τ_S is

$$\tau_S = (R_S + R_1 \| R_2 \| R_i) C_C$$

$$= (0.1 \times 10^3 + (5.7 \times 10^3) \| (40 \times 10^3) \| 53.1 \times 10^3)(10 \times 10^{-6}) = 4.66 \times 10^{-2}\ \text{sec}.$$

$$\boxed{\tau_S = 46.6\,ms.}$$

The time constant τ_P is

$$\tau_P = (R_C \| R_L) C_L = (5 \times 10^3 \| 10 \times 10^3)\, 15 \times 10^{-12}$$

$$\tau_P = 5 \times 10^{-8}\ \text{sec}.$$

$$\Rightarrow \boxed{\tau_P = 50\,ns}$$

The lower corner freq

$$f_L = \frac{1}{2\pi \tau_S} = \frac{1}{2\pi(46.6 \times 10^{-3})} = 3.42\ Hz$$

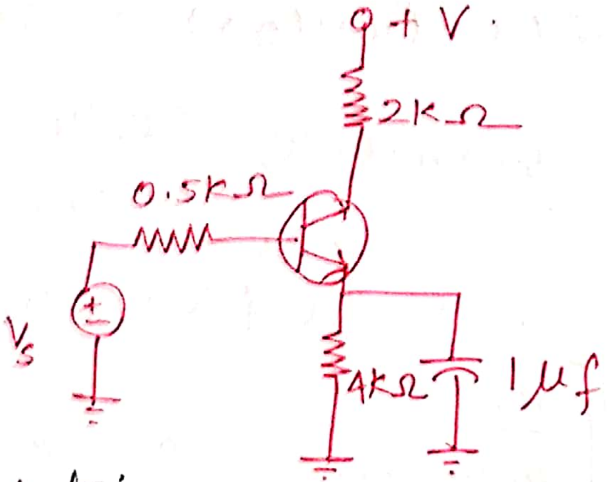
The upper corner freq.

$$f_H = \frac{1}{2\pi \tau_P} = \frac{1}{2\pi(50 \times 10^{-9})}$$

$$f_H = 3.18\ MHz$$

$$BW = f_H - f_L = 3.18\,MHz - 3.4\,Hz \simeq 3.18\,MHz$$

③ Determine the corner frequencies & limiting horizontal asymptotes of CE amplifier with R_E



$I_{CQ} = 1.06mA$

$V_{BE} = 0.7V$

$\beta = 100$

$r_0 = \infty$.

Solution :-

$$g_m = \frac{I_{CQ}}{V_T} = \frac{1.06}{0.026} = 40.8mA/V.$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(100)(0.026)}{1.06} = 2.45K\Omega$$

$$\tau_A = R_E C_E = (4\times10^3)(1\times10^{-6}) = 4\times10^{-3} sec.$$

$$\tau_B = \frac{R_E(R_s + r_\pi) C_E}{R_s + r_\pi + (1+\beta)R_E} = \frac{(4\times10^3)(0.5\times10^3 + 2.45\times10^{3}\ldots}{[0.5\times10^3 + 2.45\times10^3 + (101)\ldots}$$

$$\tau_B = 2.90\times10^{-5} sec.$$

$$f_A = \frac{1}{2\pi\tau_A} = \frac{1}{2\pi(4\times10^{-3})} = 39.8 Hz$$

$$f_B = \frac{1}{2\pi\tau_B} = \frac{1}{2\pi(2.9\times10^{-5})} = 5.49 KHz$$

Limiting low frequency horizontal asymtote is:

$$|A_v|_{\omega\to0} = \frac{g_m r_\pi R_c}{R_s + r_\pi + (1+\beta)R_E} = \frac{(40.8)(2.45)(2)}{0.5 + 2.45 + (101)(\ldots}$$

(or)

$$|A_v|_{\omega\to0} = 0.49$$

Limiting high frequency hor... asymtote

$$|A_v|_{\omega\to\infty} = \frac{g_m r_\pi R_c}{R_s + r_\pi} = \frac{(40.8)(2.45)(2)}{0.5 . 2.45} = 67.8$$