6/12/19

R, C, L, Diode, Transistor — BJT, MOSFET

BASICS OF ELECTRONICS

* Basic Properties of Resistor (R)

1. It opposes current flow. Protect the element

5V —1kΩ— 0V

5V —— 0V

$\frac{5-0}{0} = \infty$ resistance

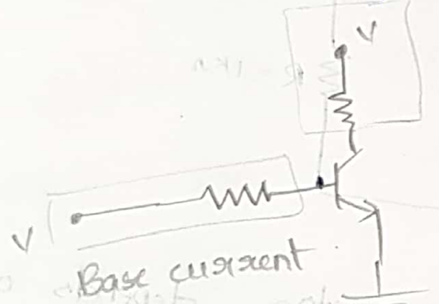
$\frac{5-0}{1k} = 5$ mA

→ Current flow depends on voltage source or resistor value.

2.) Voltage source in series with a resistor acts as current source.

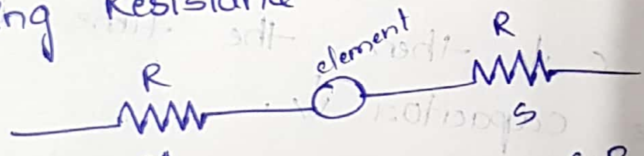
Resistor + voltage source ⟶ current source

$= 1/i \propto R \mid V = i \propto V/R$



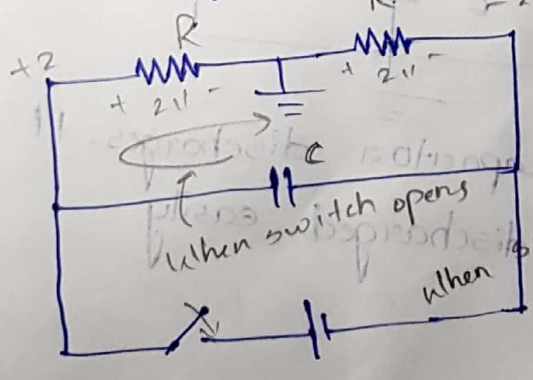
current source (get collector current)

3. Scaling Resistance networks



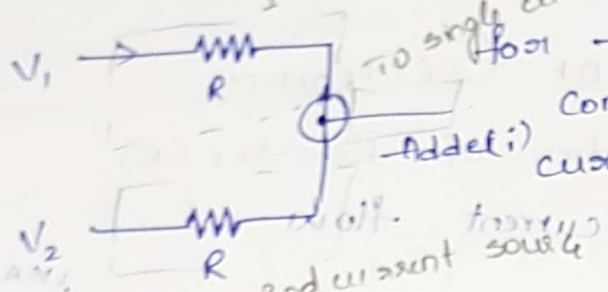
Scaling factor = Gain = $\frac{S \cdot R}{M \cdot R}$ $\frac{\text{scaling resistance}}{\text{Main resistance}}$

4. Phase splitting



when switch is closed capacitor charges and it discharges when it is opened.

5 R as adder (i)



To single current source
For adding 2 voltages connect them to single current source.

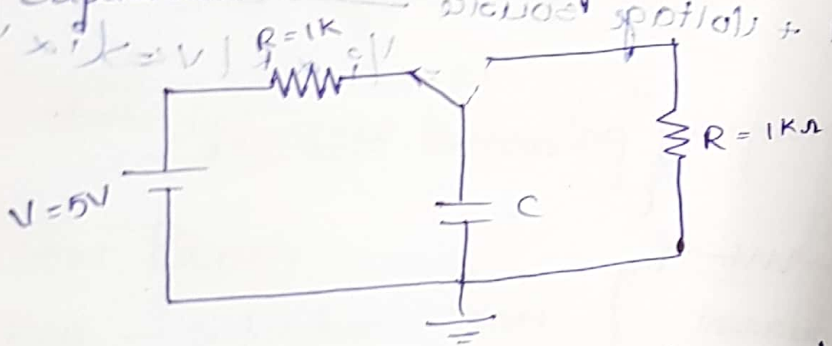
* NOTE

→ Voltage to current converter is resistor that is we use resistor in series with voltage source to get current source.

→ Resistor is also current to voltage converter.

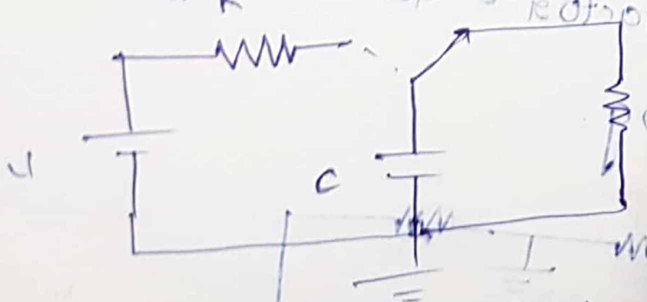
* Basic Properties of Capacitor (C)

Capacitor as a voltage source (Battery)



charging of the capacitor depends on R & C values the time taken to

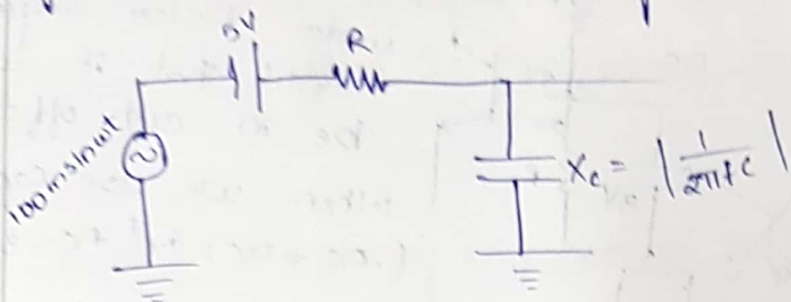
If R and C ↓ then charge the capacitor ↓.



Here the capacitor discharges. If R_2 ↓ then capacitor is discharged easily.

2. Capacitor as a filter.

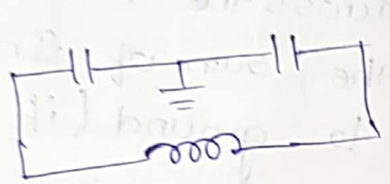
If C value is more then capacitor can ground the low frequency ripples also



$i = C\frac{dv}{dt}$ At sudden change $dt = 0 \Rightarrow i = \infty$

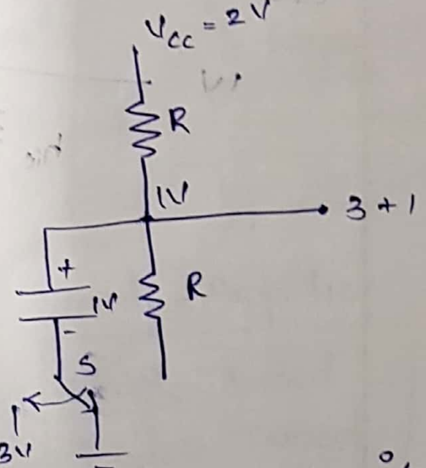
So capacitor is short circuit.

3. Capacitor as a phase splitter.



4. Capacitor as a Adder

when S is connected to ground, 1V is given to capacitor so it charges

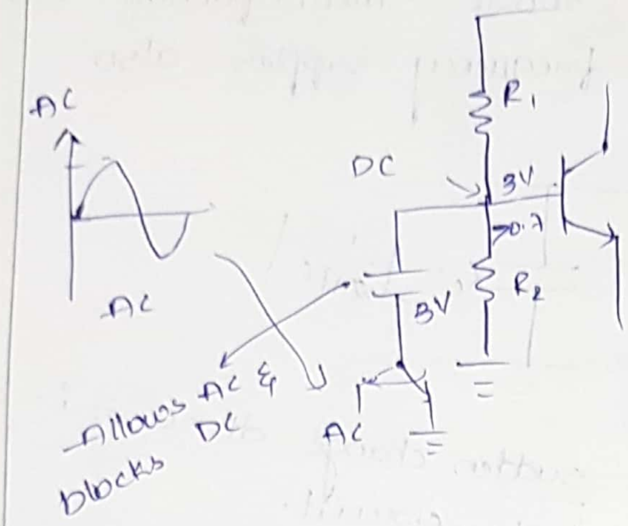


When S is moved to 3V Then 3V is given to capacitor so total of (3+1) V we get at o/p so capacitor acts as Adder.

Before t = 1 sec capacitor charged to 1 V

After t = 1 sec it charges to 3V

→ In Amplifier circuit capacitor acts as both Adder and filter.

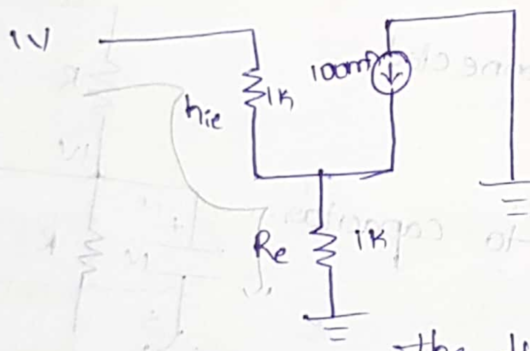


> 0.4V only The transistor com under Active region until that it will be in cut off region when we use capacitor (AC + DC) i.e (AC + 3)

5. Basic Resistor properties

* Calculation of i/p resistance for Any circuit

Total resistance across the branch from 1 node to ground is the sum of Individual resistors from that node to ground (if that resistances are in series)



When we want to find resistance b/w 1V & ground hie & Re must be series so changing Re to 100K results in the flow of 1mA current same as in hie

∴ Total resistance = 1K + 100K = 101K

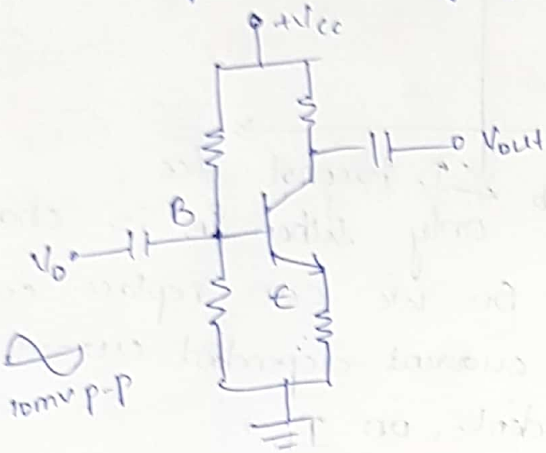
MAX100K
100K×100 1K×100m
Before seeing
45 m × 1K = 45V
1mA × x = 45
x = 45K Re

11/12/19

UNIT-1: Frequency Response of BJT Amplifier

1. Hybrid π-model.

for any small signal Amplifier when we give some voltage then V_{BE} slightly increases for Positive peak & slightly ↓ for -ve peak.

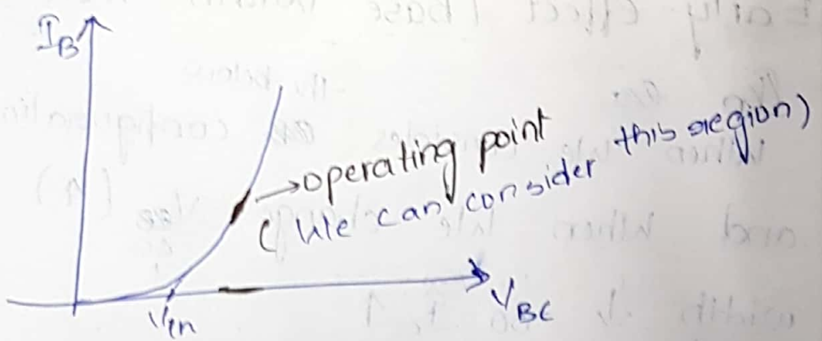


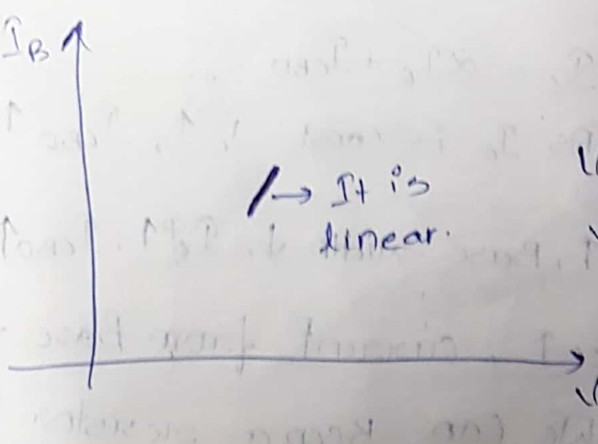
V_{BE} ↑ for +ve peak

V_{BE} ↓ for -ve peak.

1. Input characteristics:

for doing Analysis, we must have a linear element but the transistor is non linear so to make it linear we replace it with different linear models like π, h & r_e.





$V_{BE} \propto I_B$

$V_{BE} = r_{BE} I_B$

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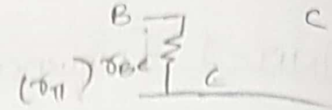
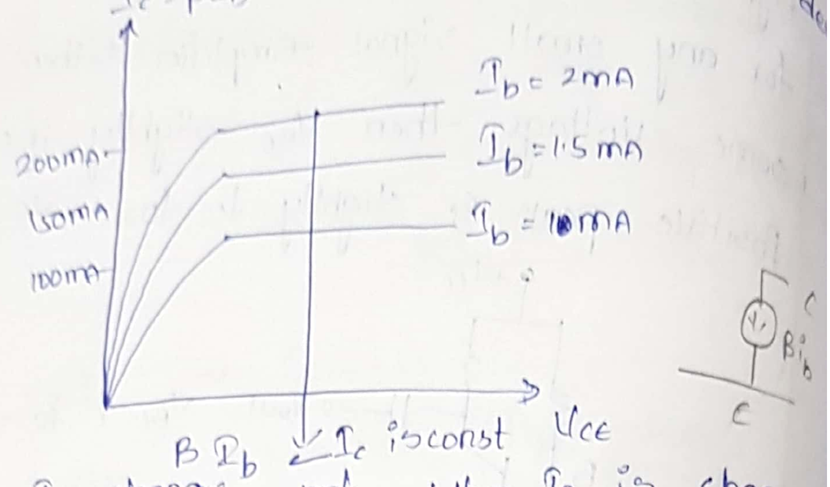
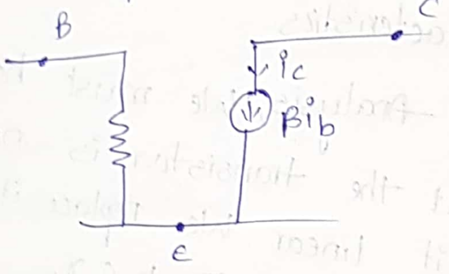
Here we replace a resistor r_{BE} across Base emitter or at i/p



2. O/p characteristics (current controlled current de...



Here, I_c changes only when I_B is changed independent of V_{CE}. So we can replace collector to emitter with a current dependent current source where it is dependent on I_b.



3. Early Effect / Base Width modulation

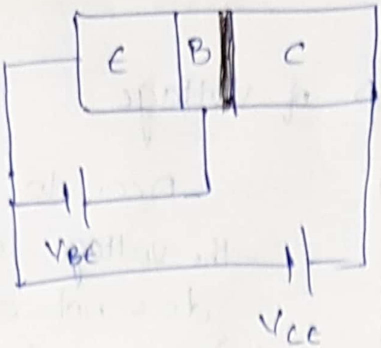
When we consider the below configuration, V_{BE} is const and when we change V_{CE} (↑) then Base width ↓ so I_c ↑

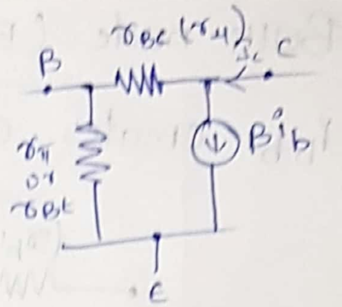
WKT, $I_c = \alpha I_E + I_{CBO}$

As I_E is const I_c ↑, I_{CBO} ↑

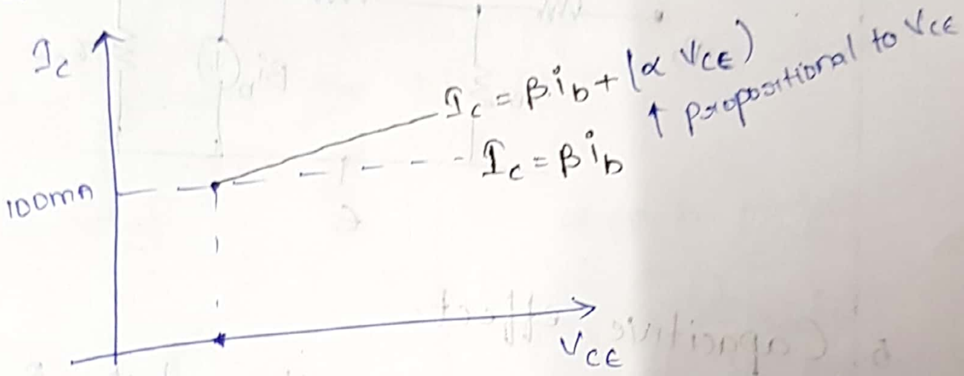
∴ V_{CE} ↑, Base width ↓, I_c ↑, I_{CBO} ↑

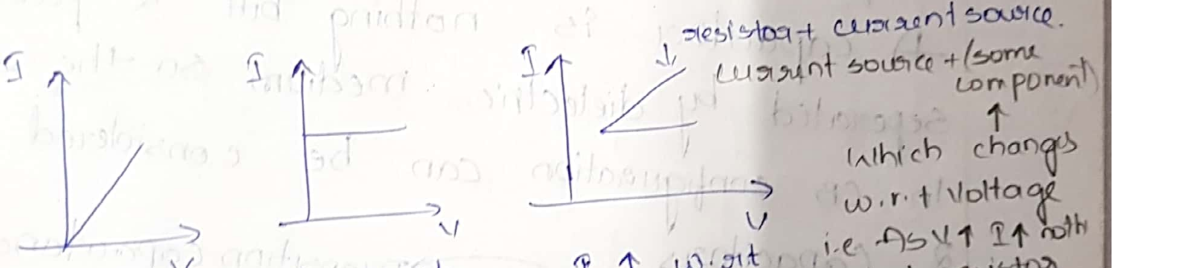
∴ As V_{CE} ↑, current from Base to current (I_{CBO}) ↑ so we can keep a resistor in b/w C & B





Generally acc. to o/p characteristics I_c is const. Though V_{CE} ↑, But Acc. to early effect I_c ↑ when V_{CE} is ↑ so the o/p characteristics should be modified

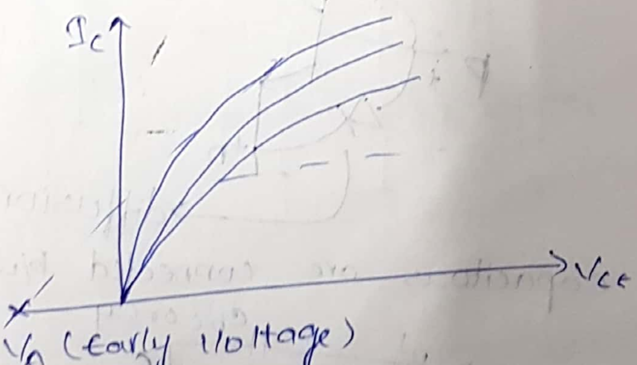


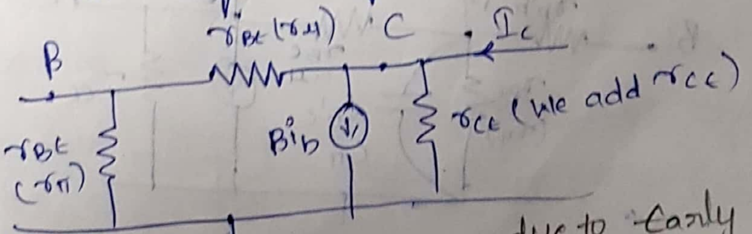


resistor

I = const
Can replace with current source

I ↑ w.r.t to voltage

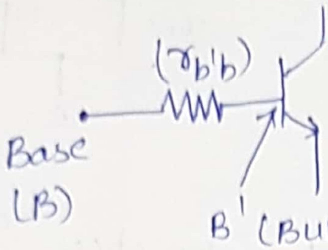




We add r_{BE} & r_{ce} due to Early effect

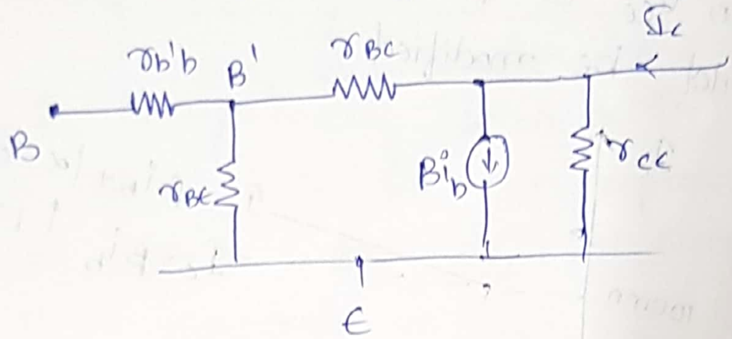
4. Bulk node. (B')

$r_{b'b}$ creates a drop of voltage



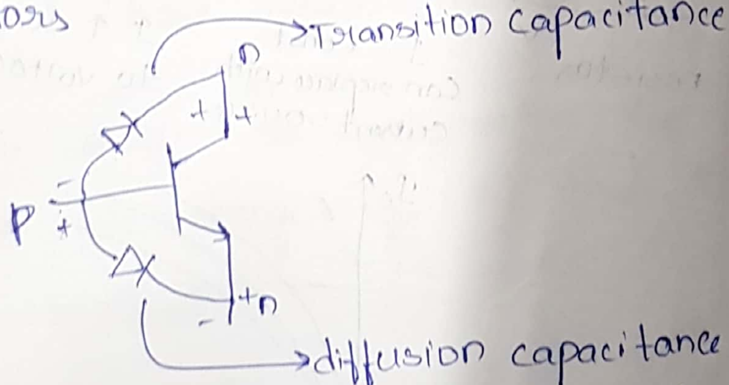
Acc. to losses w.r.t. the voltage applied at base does not reaches to B' (Bulk node) that drop is done $r_{b'b}$

$r_{b'b}$ - Base spreading resistor.

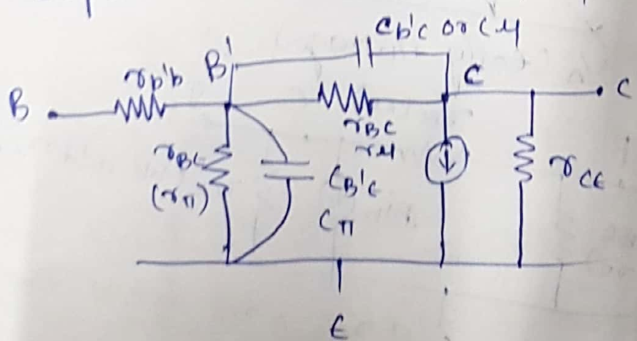


5. Capacitive effect.

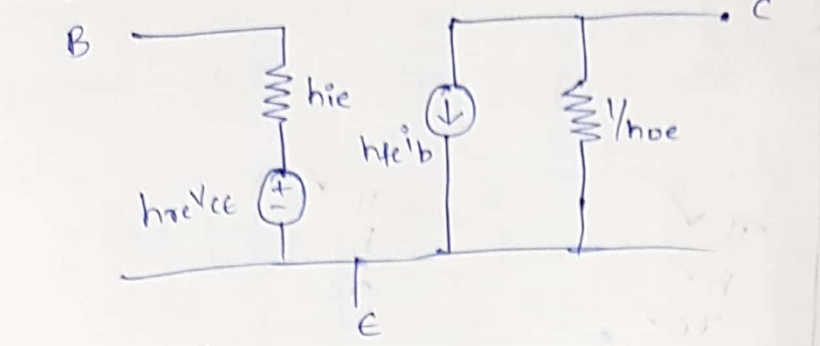
A capacitor is nothing but 2 parallel plates seperated by dielectric medium so the 2 junctions In CB configuration can be considered as 2 Capacitors



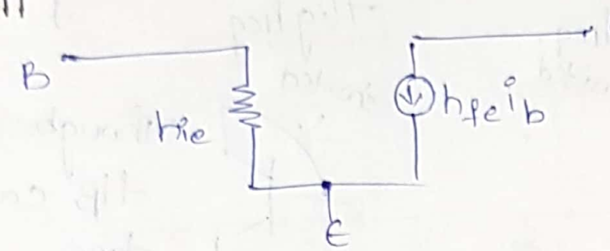
So capacitors are connected b/w B' & C, B' & E



B. h-parameter model

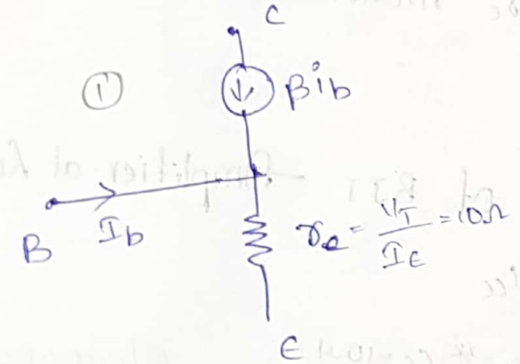


Approximation:

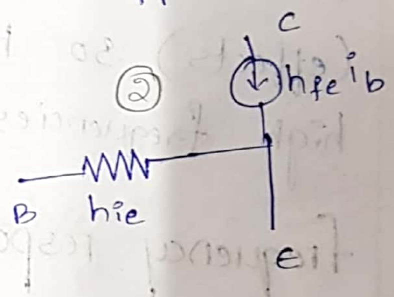


Here capacitive effect is neglected so it fails in many cases, so we consider π-model.

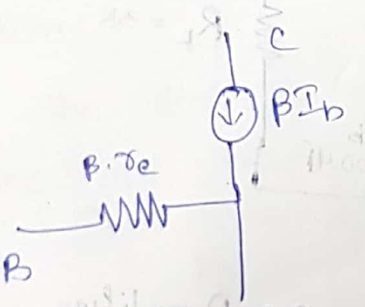
C. r_e model



App. h-model



⇅ on scaling



$h_{ie} = \beta \cdot r_e$

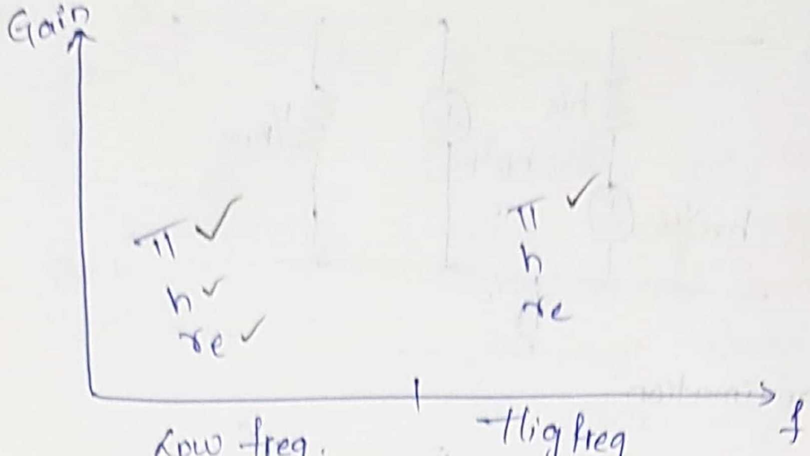
$h_{ie} = (100)(10)$ (Assumed)

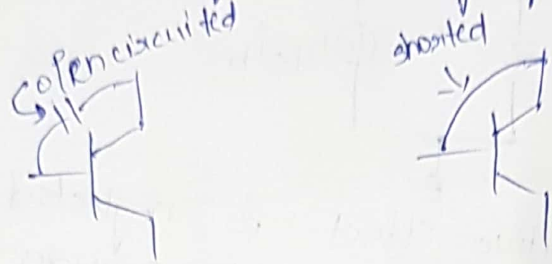
$h_{ie} = 1K\Omega$

① Here base current & current collector current is limited at emitter by r_e

② Here current from base is limited by hie so collector current also ↓ then it enters to emitter.

* Note:





Though shorted f/p can be done

So π is better at both low & High freq.
but h & re are neglected by some parameters (effects) so h & re models are not suited for high frequencies

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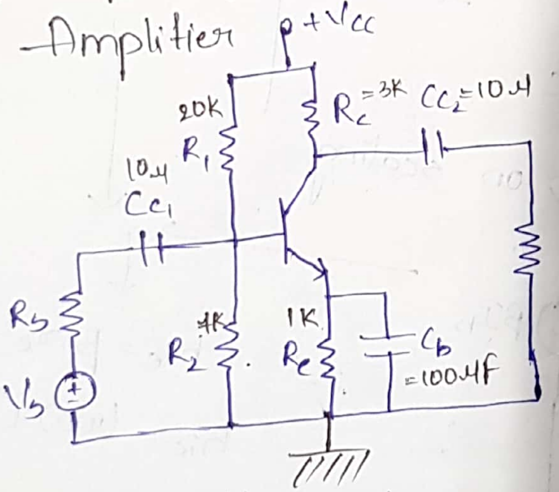
* frequency response of BJT Amplifier at low frequency

CE Amplifier

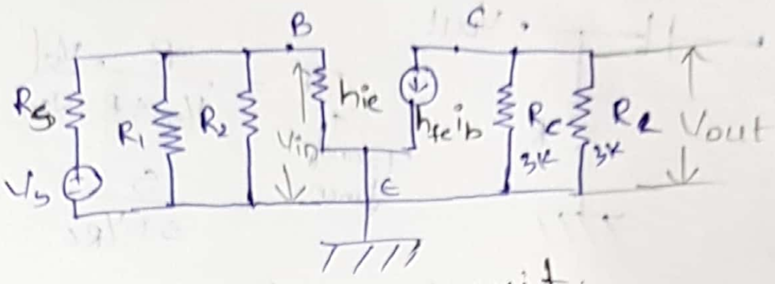


Observing at low frequencies so h-parameter model.

for Gain - 150 Design CE Amplifier, Calculate R_1, R_2, R_e, R_c

* AC Analysis
using linear mode (h-parameter model)

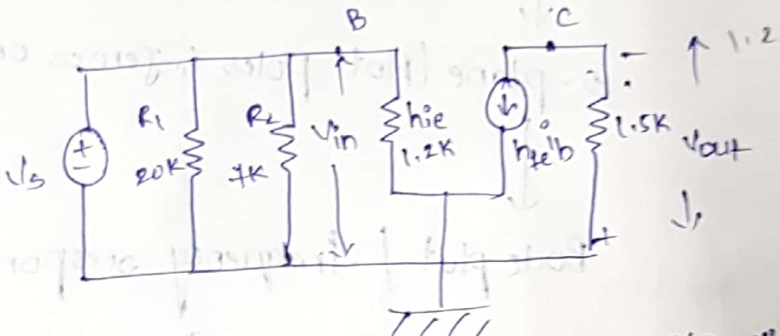
1. Ground the DC sources
2. short circuit all capacitors
3. Replace BJT with h-parameter model



AC equivalent circuit.

when $R_s = 0$ V_s will appear at hie (∵ all are Parallel)

↑200Ω
↑1.2K - base spread
+1K



$$\text{Gain} = \frac{V_{out}}{V_{in}} = \frac{-(h_{fe}\, i_b) \times 1.5}{hie \times i_b}$$

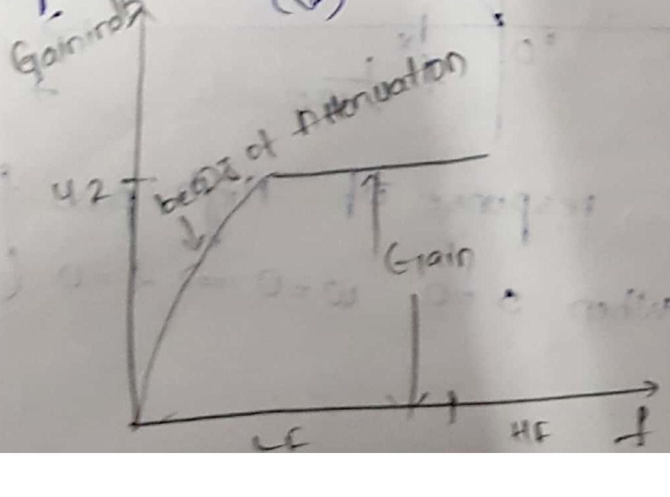
$$= \frac{-h_{fe} \times 1.5}{1.2} = \frac{-(\beta)\times 1.5}{1.2}$$

$$= \frac{-100 \times 1.5}{1.2} = -125$$

Gain dB $= 20 \log(+125)$

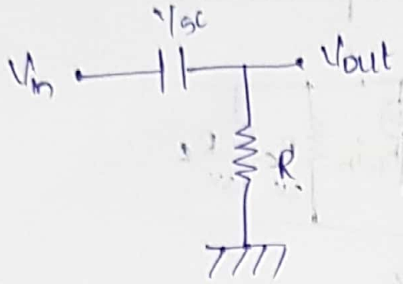
$= 42$

As the Gain is 42 but at low freq. Gain is rolling off becoz of Attenuation (due to capacitors) so Capacitors attenuate at low frequencies (↓)



* SYSTEM: deviation around zero +20dB/decade
pole. −20dB

Consider High pass filter.



$$TF = \frac{R}{1/sC + R} = \frac{V_o}{V_{in}} \left(R_1 / R_1 + R_2 \right)$$

↑ Transfer funcn

$$= \frac{s}{s + 1/RC}$$

Transfer funcn / Gain

↓

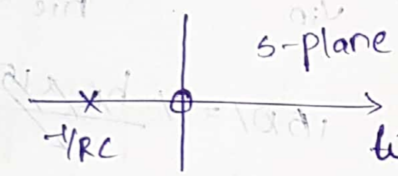
s-plane (Plot poles & zeroes on)

↓

Bode plot / frequency response plot

* $s = 0$ is zero & $s = -1/RC$ is pole.

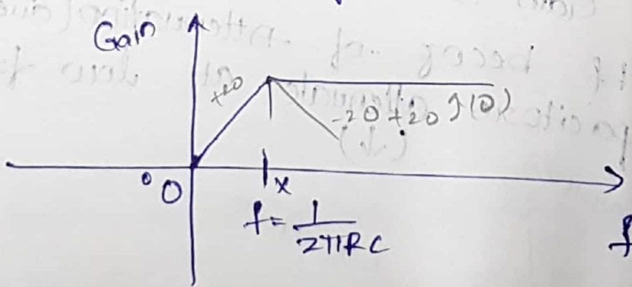
*



$\omega = +1/RC \Rightarrow$

$f = \frac{1}{2\pi RC}$

* When, we get a pole the curve deviates around by −20dB/decade & when it is a zero it deviates by +20dB/decade.

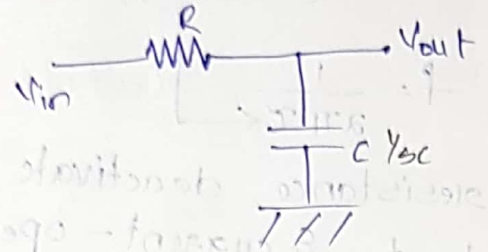


freq. response of High pass filter.

when $s = 0$ $\omega = 0 \Rightarrow f = 0$ (so strtd from origin)

* Low pass filter

for each RC network it has Time const. which generates pole (R & C) which affects the gain.



$$\text{Gain} = \frac{V_{out}}{V_{in}} = \frac{1/sC}{1/sC + R}$$

$$= \left(\frac{1}{s + 1/RC}\right)\left(\frac{1}{RC}\right)$$

Transfer funcn / Gain

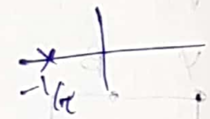
$s = -1/\tau$

$\Downarrow$

$\omega = 1/\tau$

$f = \frac{1}{2\pi RC} = \frac{1}{2\pi\tau}$

s - plane

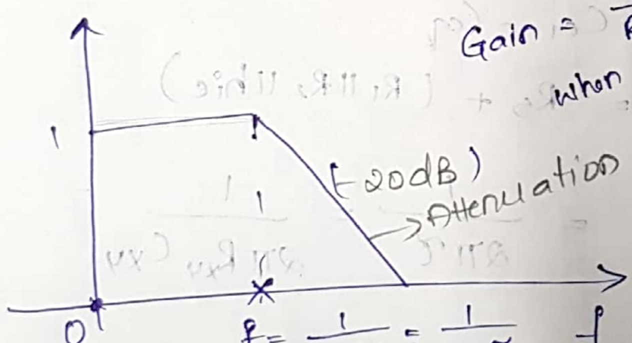


τ - time const.

Bode plot / freq. response plot

$$\text{Gain} = \frac{1}{RC}\left(\frac{1}{s + 1/RC}\right)$$

when $f = 0 \Rightarrow s = 0$ so Gain = 1 is done



$f = \frac{1}{2\pi RC} = \frac{1}{2\pi\tau}$

τ decides cut off freq where deviation occurs.

→ When we calculate 3 ex. Time const. τ_{cc1}, τ_{cc2}, τ_{cb} so that we can obtain cut off frequencies from where we can observe the deviations.

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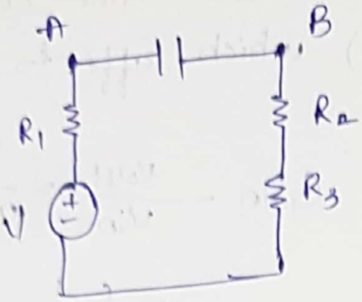
* How to calculate 'τ'



$$\tau = (R_{eq} \cdot C_{eq})$$

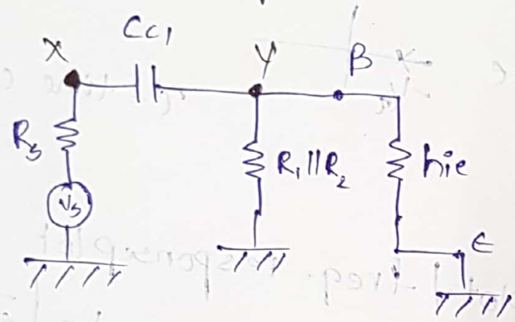
$$\tau = (R_1 + R_2 + R_3)(C)$$

$$f = \frac{1}{2\pi\tau}$$ (cut off freq)

To find effective resistance deactivate the sources (voltage - short & current - open)

* Effect of Coupling capacitors & bypass capacitor on frequency response

1. Effect of coupling capacitor C_{C1} on freq. response



$C_{XY} = C_{C1} = C_{eq}$

$R_{XY} = R_s + (R_1 \| R_2 \| hie)$

$$f_{C_{C1}} = \frac{1}{2\pi\tau} = \frac{1}{2\pi R_{XY} C_{XY}}$$

$$f_{C_{C1}} = \frac{1}{2\pi C_{C1}(R_s + R_1 \| R_2 \| hie)}$$

When, $R_s = 0$

$$f_{C_{C1}} = \frac{1}{2\pi C_{C1}(20K \| 7K \| 1.2K)}$$

$$= \frac{1}{(2\pi)(10\times10^{-6})(974.65)}$$

$f_{C_{C1}} = 16.329$ Hz

When $R_s = 1K\Omega$

$$f_{C_{C1}} = \frac{1}{2\pi C_{C1}(1.974K)}$$

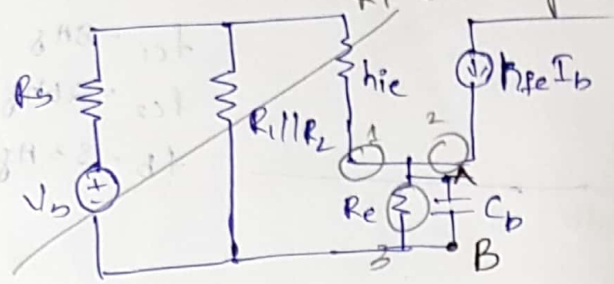
$$= \frac{10^5}{2\pi(1.974\times10^3)}$$

$= 8.06$ Hz

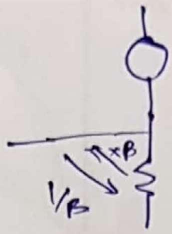
$\simeq 8$ Hz

2. Effect of bypass capacitor C_b on freq. response.

R_T (To bring all resistors to that branch)

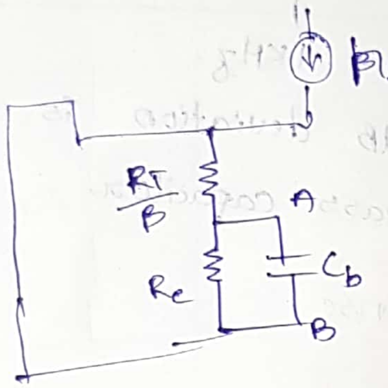


$$R_T = (R_o || R_1 || R_2) + h_{ie}$$



$$R_T = (1.2K || 20K || 7K) + 1.2K$$

$$= 2K$$



current won't disturb our circuit

(∵ short circuited)

$$R_{eq} = R_{AB} = \left(R_e || \frac{R_T}{\beta}\right) = \left(1K || \frac{2K}{100}\right)$$

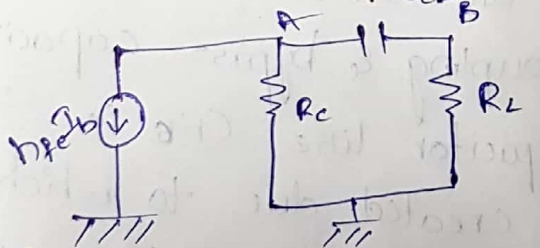
$$= 19.6\Omega$$

$$C_{eq} = C_b$$

$$f_{C_b} = \frac{1}{2\pi C_b R_{AB}} = \frac{1}{2\pi \times 100\times10^{-6} \times 19.6}$$

$$= 83\ Hz$$

3. Effect of coupling capacitor C_{C_2} on freq. response



$$C_{AB} = C_{C_2} = 10\mu f$$

$$R_{AB} = R_C + R_L = 3K + 3K$$

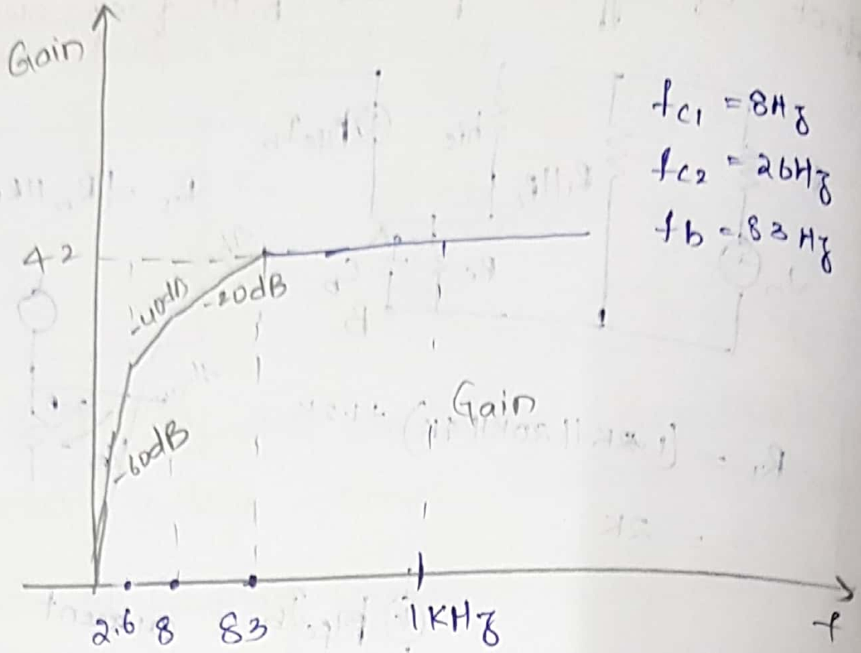
$$= 6K.$$

i/p source = 0
so $I_b = 0$
Here only o/p
$I_b = 0$ ∴ so that branch open circuited

$$f_{CC_2} = \frac{1}{2\pi\tau} = \frac{1}{2\pi C_{C_2} \times R_{AB}} = \frac{1}{2\pi (6K)(10\mu F)}$$

$$f_{CC_2} = 2.6\ Hz$$

* Coupling & bypass capacitors effect freq. response at low frequencies.



Here −40dB & −60dB deviation is becoz of coup. Capacitors than bypass capacitor.

* frequency response

w.r.t A_V — w.r.t A_I

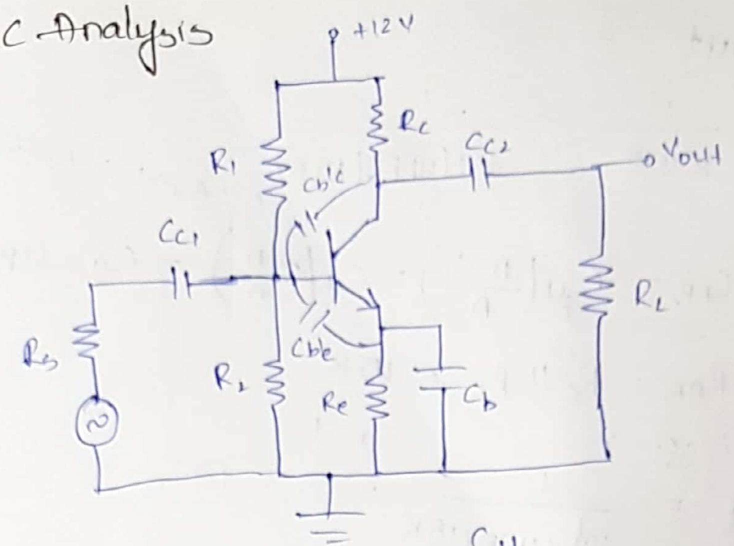
* frequency response of BJT Amplifier at High frequency

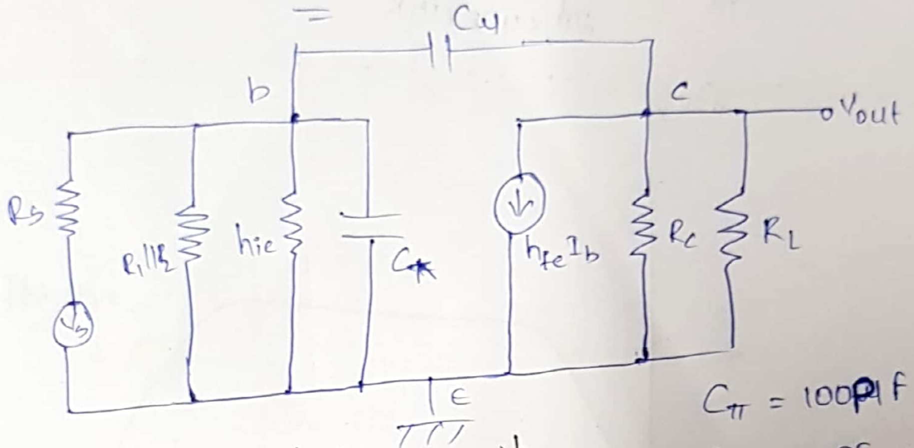
→ Effect of Parasitic Capacitances on frequency response

Generally we have 2 capacitances extra diffusion & transition capacitances (Parasitic Capacitances) for high frequencies all capacitors including Parasitic capacitors are short circuited. So there is no effect due to coupling & bypass capacitors but when parasitic capacitor like $C_{b'e}$ is shorted a feedback is created due to which Gain ↓. So there is a roll off at high frequencies also so as Gain ↓ the Gain & frequency graph is drawn.

→ Here we replace BJT/Transistor with π-model (or (General we place 2 capacitors in h-parameter, so that it can resemble to π-model)

AC Analysis



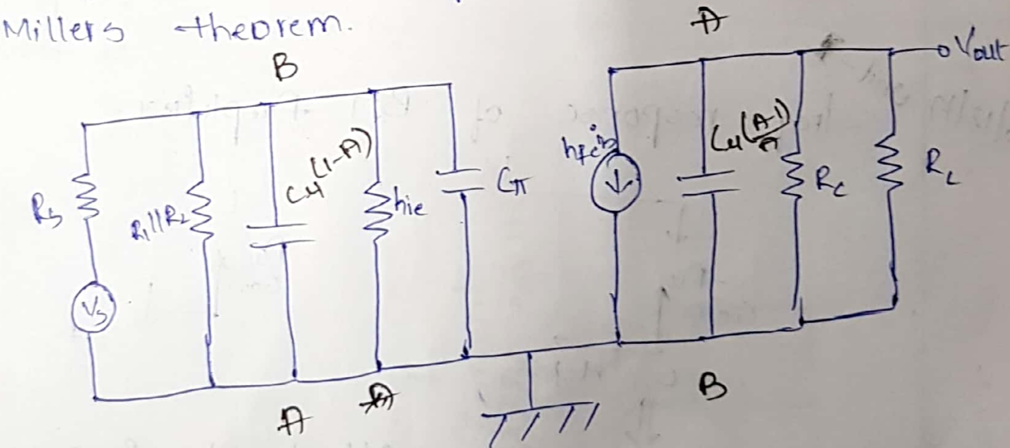


$C_\pi = 100\,pF$

$C_\mu = 4\,pF$

AC equivalent circuit

Here, Analysis of about circuit becomes complex as C_μ is connected across i/p & o/p so to make it simple to we modify the circuit According to Millers theorem.



We analyse i/p side & o/p side.

At i/p

$$f_{in} = \frac{1}{2\pi\tau} = \frac{1}{2\pi R_{eq} C_{eq}}$$

$$C_{eq} = C_{AB} = C_\mu(1-A) + C_\pi$$

$$R_{eq} = R_{AB} = R_s \| R_1 \| R_2 \| hie.$$

$$f_{in} = \frac{1}{2\pi(R_s \| R_1 \| R_2 \| hie)(C_\mu(1-A) + C_\pi)}$$

At output

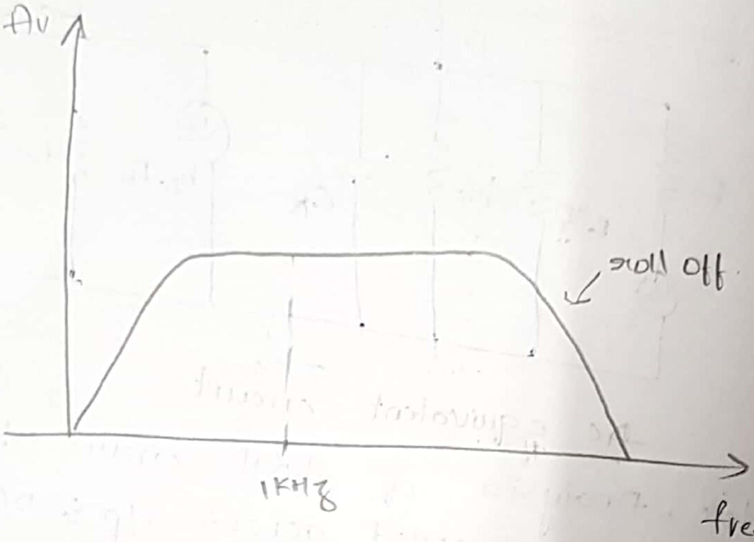
$$f_{out} = \frac{1}{2\pi\tau} = \frac{1}{2\pi(4pF)(15K)}$$

$(\because A_V \gg 1 \therefore A_{-1} \approx A_V)$

$$C_{eq} = C_{AB} = C_\mu\left(\frac{A-1}{A}\right) = C_\mu\left(\approx\frac{A}{A}\right) = C_\mu = 4pf$$

$$R_{eq} = R_{AB} = R_c \parallel R_L = 15K$$

$$f_{out} = \frac{1}{2\pi \times 4pF \times 15K} =$$



r_μ - Mega
C_μ - pico
C_π - pico

16/12/19 unit-

Freq. response of BJT Amplifier.

$\Downarrow$

Low freq. response → 1. Effect of Bypass/coupling capacitor on freq. response

High freq. response → 2. Effect of parasitic capacitor on freq. response

π model	h par	r_e model
$r_{b'b} = h_{ie} + r_\pi$	$= \frac{h_{fe}}{g_m}$	α/r_e
		h_{fe}/r_π

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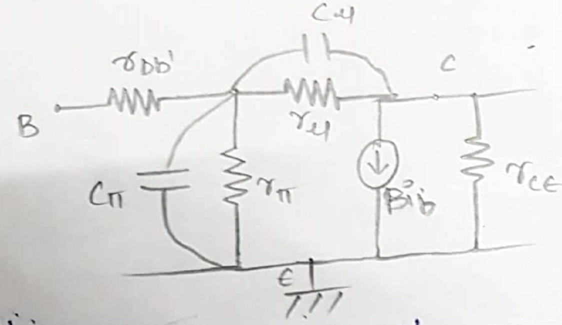
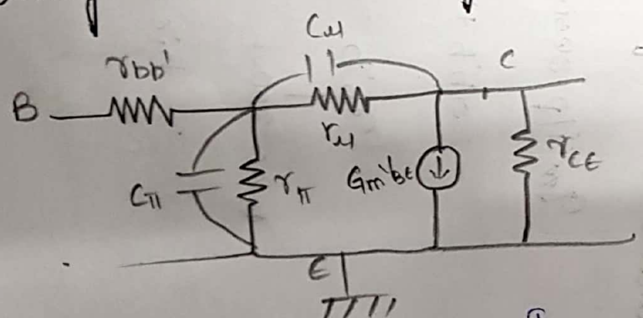
Hybrid π-model :

Current control - current source



How o/p current changes w.r.t i_b is decided by factor β

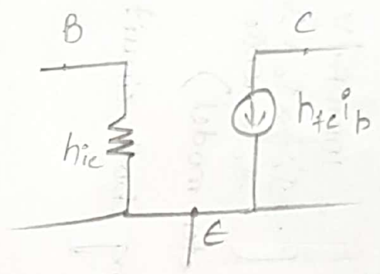
Voltage control - ~~voltage~~ current source



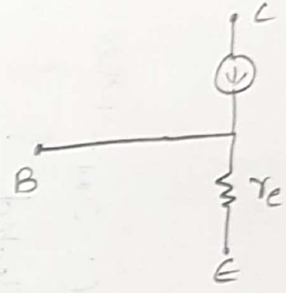
Gm - Trans conductance $= \frac{I_c}{V_{BE}}$

How o/p current changes w.r.t V_{BE} is decided by factor Gm

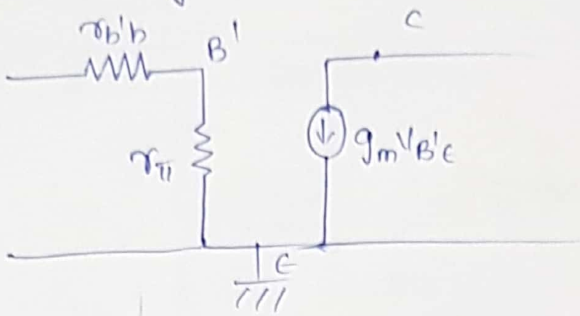
h-parameter (approx)



r_e model



We use Voltage controlled current source



We neglect r_μ, C_μ, C_π ($\because r_\mu$ - MΩ open)

C_μ & C_π - PF range (neglected.)

Calculation of g_m (r_e)

$r_e = \frac{V_{B'E}}{I_E}$
↑
dynamic

$$g_m = \frac{\partial I_c}{\partial V_{BE}} = \alpha \frac{\partial I_E}{\partial V_{B'E}} = \frac{\alpha}{r_e} = \frac{<1}{10} = <0.1$$

$= 100$ mA/V.

$$g_m = \frac{I_c}{V_{BE}} \quad \beta = \frac{I_c}{I_B}$$

$\left(\because I_c = \alpha I_E + I_{CBO} \right.$
$\left. \partial I_c = \alpha \partial I_E \right)$

Calculation of g_m (h-parameter model)

$g_m V_{BE} = h_{fe} i_b$ (comparing both circuits)

$$g_m = \frac{h_{fe} i_b}{V_{B'E}}$$

$$g_m = \frac{(h_{fe})}{r_\pi} = 100 \text{ mA/V.}$$

Calculation of ~~g_m (K)~~ $r_{b'b}$ (h)

g_m i/p resistance of π = i/p of h

$$r_{b'b} + r_\pi = h_{ie}$$

$$r_{b'b} = h_{ie} - r_\pi$$

$r_{b'b}$ ↑ take 200Ω; h_{ie} ↓ ?; r_π ↓ 1K

$\therefore h_{ie} = 1.2K$

Calculation of r_π

WKT, $g_m = \frac{h_{fe}}{r_\pi}$

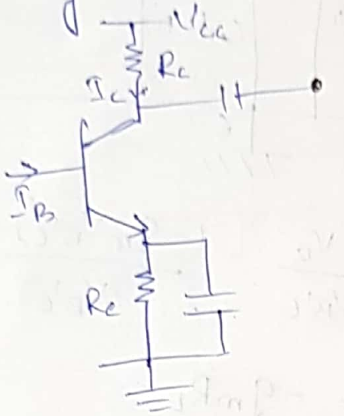
$\therefore r_\pi = \frac{h_{fe}}{g_m} = \frac{100}{100\,mA/V} \rightarrow r_\pi = 1\,K\Omega$

16/12/19

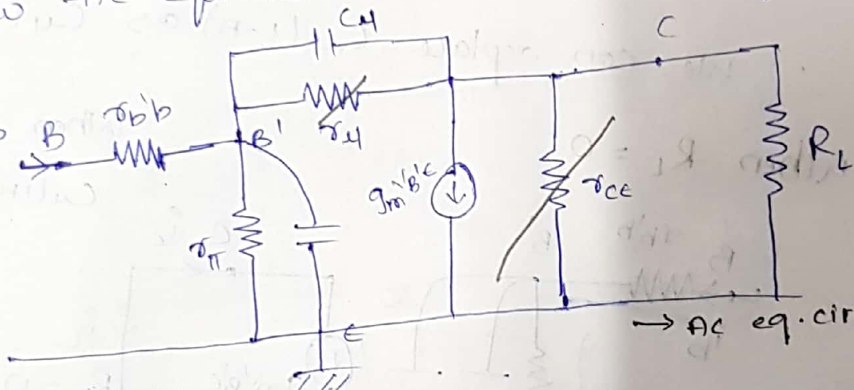
* Current Gain (i) $(R_L = 0)$ / (ii) $(R_L \neq 0)$

Case (i) : $R_L = 0$ (short circuit current Gain)

Consider only transistor circuit



→ Draw Ac equivalent circuit for analysis.



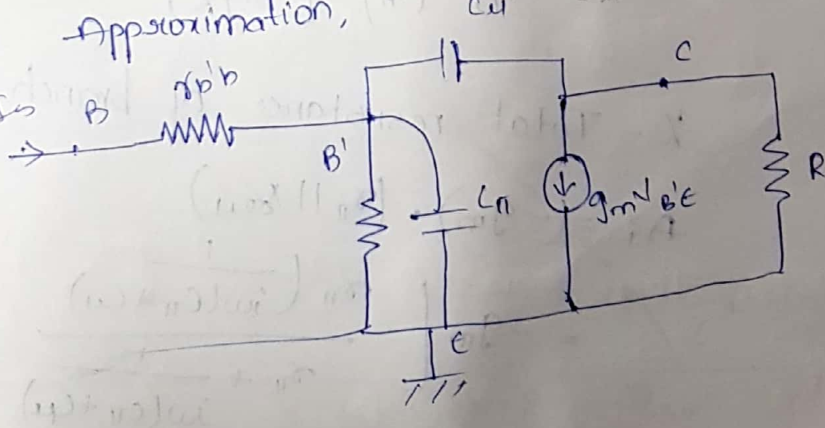
→ Ac eq. circuit

Approximations

r_{CE} & r_μ are neglected as their values are very - very large

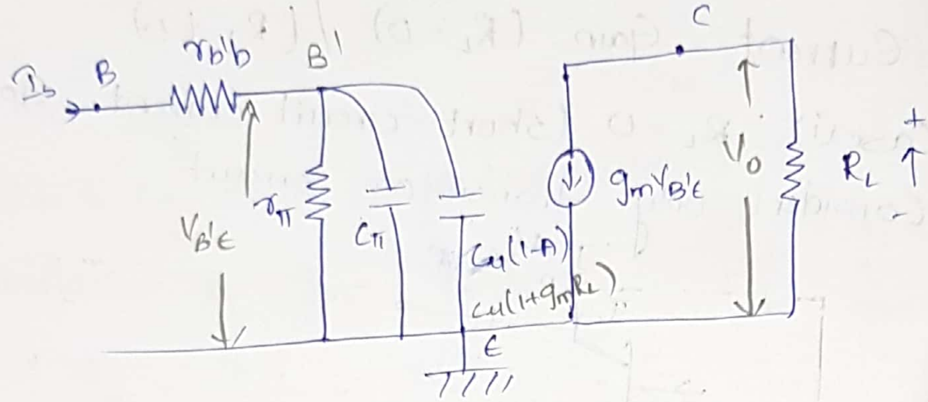
We have to find short circuit current since $R_L = 0$

After Approximation,



We have branch capacitor (C_μ) so for easy Analysis We can connect them on i/p. side & o/p side by using miller's theorem as $C_\mu(1-A)$; $\left[C_\mu\left(\frac{A-1}{A}\right) \simeq C_\mu\right]$ ($\because A$ is voltage gain $>>1$)

C_μ is neglected ($\because$ very small)



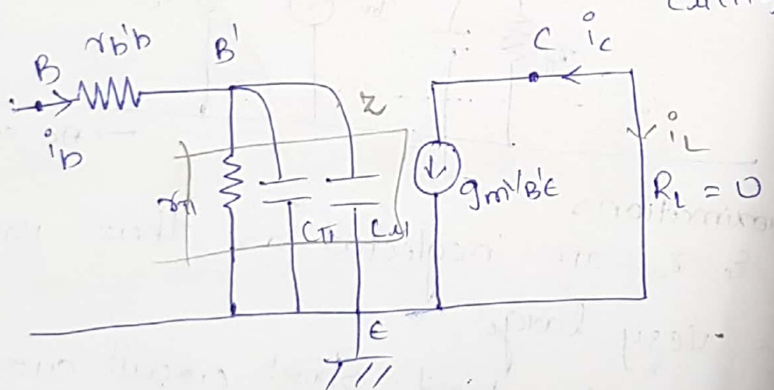
$$A = A_V = \frac{V_o}{V_{B'E}} = \frac{(-g_mV_{B'E})R_L}{V_{B'E}}$$

$$\therefore A = -g_mR_L$$

$\therefore$ We can replace $C_\mu(1-A)$ as $C_\mu(1+g_mR_L)$

When $R_L = 0$

When $R_L = 0$
$C_\mu(1+g_mR_L) = C_\mu$



$$A_i = \frac{i_L}{i_b} = \left(\frac{-i_c}{i_b}\right) = \frac{-g_mV_{B'E}}{(V_{B'E}/Z)} = (-g_mZ)$$

Z - Total resistance of branch

$$A_i = (-g_m)\cdot(r_\pi \,||\, X_{C\pi\mu})$$

$$= -g_m\left(\frac{r_\pi\left(\frac{1}{j\omega(C_\pi+C_\mu)}\right)}{r_\pi + \frac{1}{j\omega(C_\pi+C_\mu)}}\right)$$

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$$A_i = \left[\frac{-g_m r_\pi}{1 + j\omega r_\pi (C_\pi + C_\mu)} \right]$$

$$= \left| \frac{g_m r_\pi}{1 + j 2\pi f r_\pi (C_\mu + C_\pi)} \right|$$

→ τ for the circuit,

$$\tau = R_{eq} \times C_{eq} = r_\pi (C_\pi + C_\mu)$$

$$\boxed{f_c = \frac{1}{2\pi \tau} = \frac{1}{2\pi r_\pi (C_\pi + C_\mu)} = f_\beta}$$

Consider for notation

cut off freq.

We can neglect C_μ as it is small but for comparision we are not neglecting in circuit

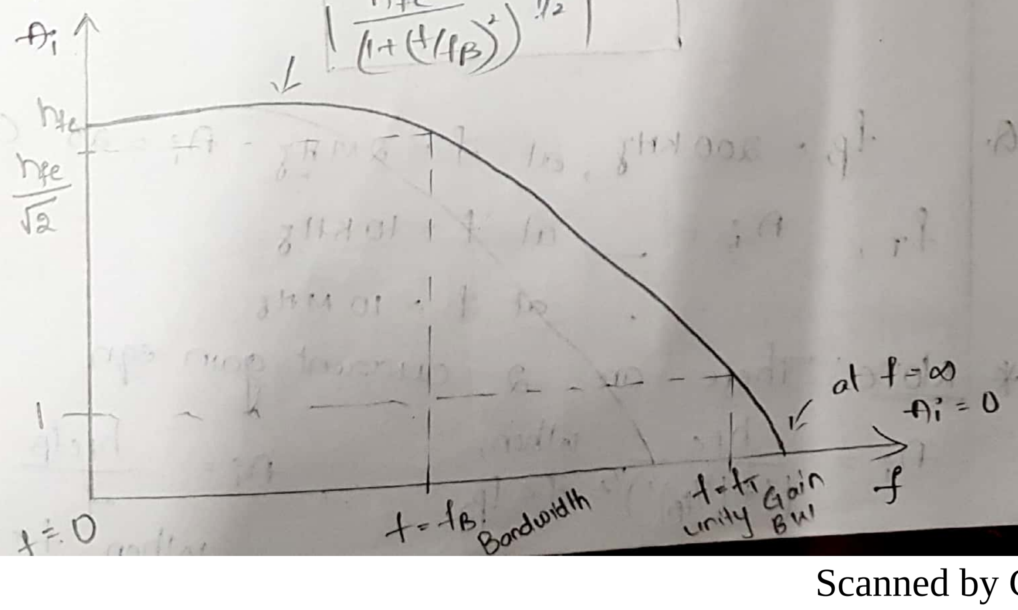
$$A_i = \frac{h_{fe}}{1 + j(f/f_\beta)}$$

$$\therefore \boxed{A_i = \left| \frac{h_{fe}}{1 + j(f/f_\beta)} \right|}$$

$$= \frac{h_{fe}}{\left(1 + (f/f_\beta)^2\right)^{1/2}}$$

freq. response plot (A_i)

$$\left| \frac{h_{fe}}{\left(1 + (f/f_\beta)^2\right)^{1/2}} \right|$$



We have,

$$A_i = \left| \frac{h_{fe}}{\left(1+\left(f_\beta/f_\beta\right)^2\right)^{1/2}} \right|$$

(i) $|A_i|_{f=0} = h_{fe}$

(ii) $(A_i)_{f=f_\beta} = \dfrac{h_{fe}}{\left(1+\left(f_\beta/f_\beta\right)^2\right)^{1/2}} = \dfrac{h_{fe}}{\sqrt{2}}$ f_β - cut off freq. where gain roll off by $1/\sqrt{2}$ of max. value

(iii) $(A_i)_{f=f_T} = \dfrac{h_{fe}}{\left(1+\left(f_T/f_\beta\right)^2\right)^{1/2}}$

But from graph,

f_β is $1/\sqrt{2}$ cut off freq. & $f_T >> f_\beta$

$\therefore \dfrac{f_T}{f_\beta} >> 1$

$\therefore (A_i)_{f=f_T} = \dfrac{h_{fe}}{\left(\left(f_T/f_\beta\right)^2\right)^{1/2}} = \dfrac{h_{fe} f_\beta}{f_T}$

But at $f = f_T$,

$A_i = 1$

$\therefore \dfrac{h_{fe} f_\beta}{f_T} = 1$

$\therefore \boxed{f_T = h_{fe} f_\beta}$

Q. $f_\beta = 200\ \text{KHz}$, at $f = 2\ \text{MHz}$ $A_i = 25$. Calculate f_T, $A_i =$ __ at $f = 10\ \text{KHz}$

__ at $f = 10\ \text{MHz}$

* NOTE: There are 2 current gain eqn

$A_i = \dfrac{h_{fe}}{\left(1+\left(f/f_\beta\right)^2\right)^{1/2}}$ when, $f < f_\beta$ $A_i = \dfrac{h_{fe} f_\beta}{f}$ when $f > f_\beta$

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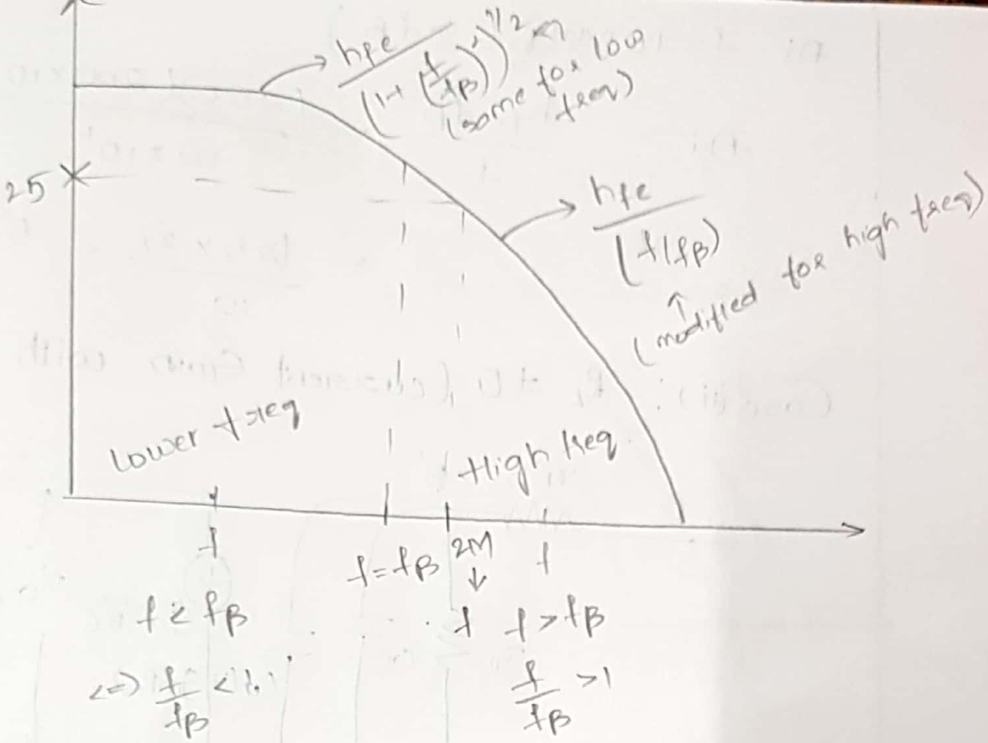


Given, at $f = 2MHz$ $A_i = 25$

But f is high freq $(f > f_\beta)$

$$\therefore A_i = \frac{h_{fe}}{f/f_\beta}$$

$$\Rightarrow \frac{25 \times 2 \times 10^{6}}{200 \times 10^{3}} = h_{fe}$$

$$h_{fe} = 250$$

When, $f = f_T$ $A_i = 1$

As $f_T > f_\beta$ we have, $A_i = \frac{h_{fe} f_\beta}{f_T}$

$$1 = \frac{(250)(200 \times 10^3)}{f_T}$$

$$f_T = 50 \text{ MHz}$$

At $f = 10$ KHz $(< f_\beta (200 \text{KHz}))$

$$A_i = \frac{h_{fe}}{(1+(f/f_\beta)^2)^{1/2}} = \frac{250}{\left(1+\left(\frac{10\times10^3}{200\times10^3}\right)^2\right)^{1/2}}$$

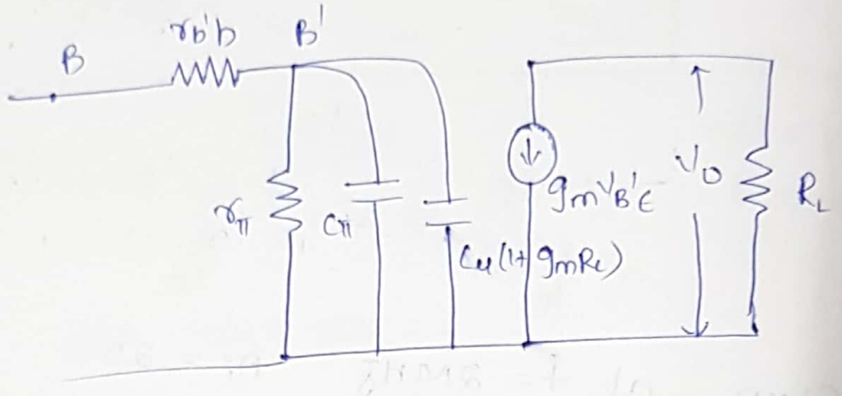
$$= 249.68$$

At $f = 10\,MHz$ ($> f_\beta$)

$$A_i = \frac{h_{fe} f_\beta}{f} = \frac{(250)(200\times10^3)}{10\times10^6}$$

$$= \frac{(25\times2)}{10} = 5$$

Case (ii): $R_L \neq 0$ (current Gain with load)



$$A_i = \left|\frac{I_o}{I_{in}}\right| = \frac{-g_m V_{B'E}}{V_{B'E}/Z} = -g_m Z$$

$$= \left|\frac{-g_m \cdot r_\pi}{1 + j2\pi f(r_\pi)(C_\pi + C_\mu(1+g_m R_L))}\right|$$

$Z \rightarrow r_\pi \parallel C_\pi + C_\mu(1+g_m R_L)$

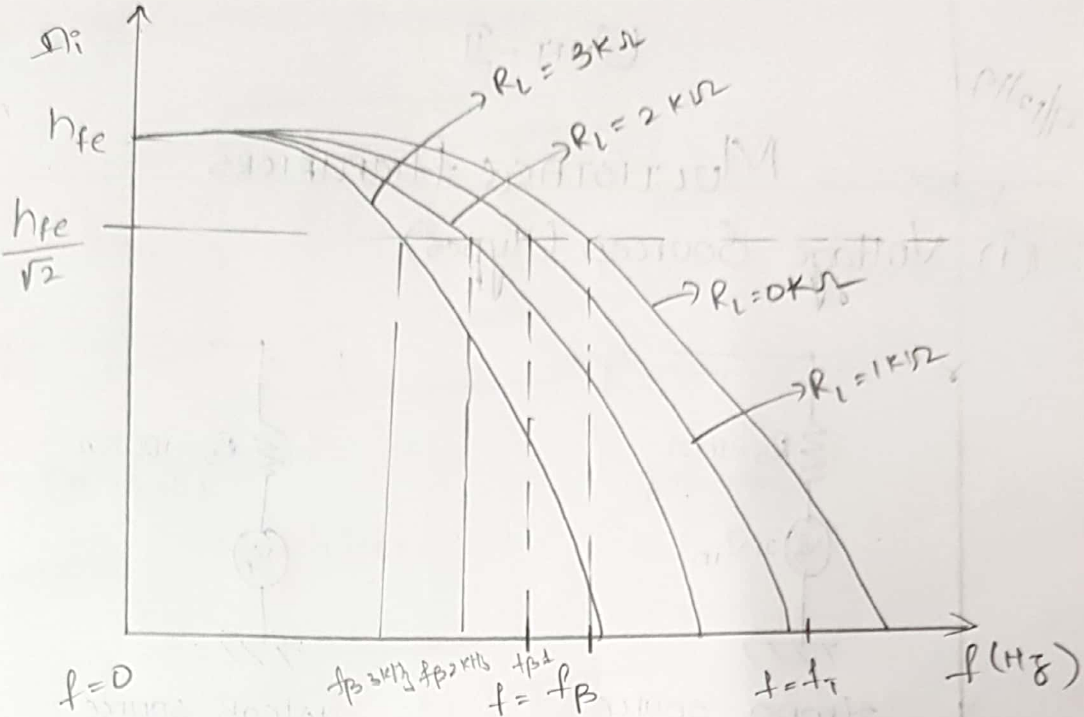
for cut off frequency,

$$\tau = R_{eq} C_{eq} = r_\pi(C_\pi + C_\mu(1+g_m R_L))$$

$$f_c = \frac{1}{2\pi(r_\pi(C_\pi + C_\mu(1+g_m R_L))} = f_\beta$$

$$\therefore A_i = \left|\frac{h_{fe}}{1 + j(f/f_\beta)}\right|$$

$$A_i = \left|\frac{h_{fe}}{(1+(f/f_\beta)^2)^{1/2}}\right|$$



WKT,

$$f_\beta = \frac{1}{2\pi(r_\pi)(C_\pi + C_\mu(1+g_m R_L))}$$

$$f_\beta \propto \frac{1}{(1+g_m R_L)}$$ ∴ Roll off depends of f_β freq

As $R_L \uparrow$ $f_\beta \downarrow$ upper cut off freq ↓ lower cut off freq ↑

When $f_\beta \downarrow$, Bandwidth $(f_\beta - 0 = f_\beta)$ also decreases

Effect of bypass & coupling & problm

Av - high freq. response | low freq. response

$R_L \neq 0$

$A_i - R_L = 0$