BJT as an Amplifier

Amplifier is an electronic circuit designed by using an active design (like BJT, FET or vacuum tube) that usually ↑ the amplitude of i/p signal usually voltage or current.

For ex:-

- In public while addressing an amplifier is used to magnify the electrical s/g produced by microphone to operate loudspeaker to make human voice louder.
- The relation btw i/p & o/p s/g of amplifier is expressed as function of i/p frequency known as transfer function of amplifier

→ Based on value of s/g variation, amplifier ⟨ small s/g amplifier / large s/g amplifier

→ Small Signal Amplifier :-

- An amplifier in which s/g variation is much smaller than the DC value is known as small signal amplifier.
- In small s/g amplifier BJT exhibits piece-wise linearity or it behaves as a linear element.
- BJT behaves as a linear element so in small s/g amplifiers o/p s/g will be distortionless.
- Small s/g amplifiers are used as voltage amplifiers.

→ Large Signal Amplifier :-

- An amplifier in which s/g variation is large or s/g variation is comparable to dc value is known as large s/g amplifier.
- In large s/g amplifiers, transistor behaves as non-linear element due to which equal changes in base current do not produce proportionally equally changes in collector current and o/p s/g gets distorted.

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• A large s/g amplifier has large AC o/p current and voltage, and also it can supply greater AC o/p power to the load hence it is useful as power amplifier.

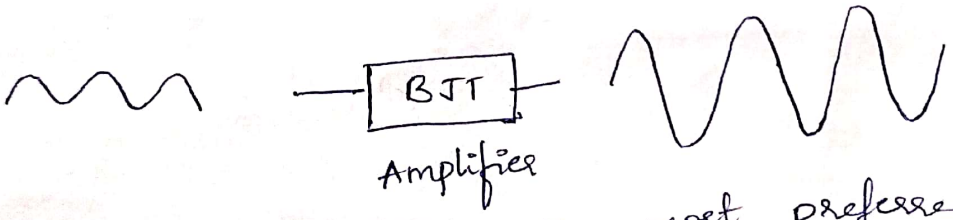
BJT Large Signal Model :-

* The most common application of BJT is to use it as an amplifier.

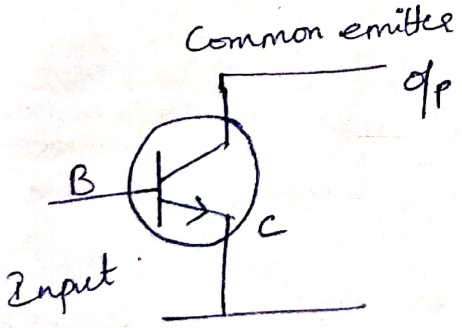
↳ could be either current/voltage/power amplifier.

but I'm referring to voltage amplifier

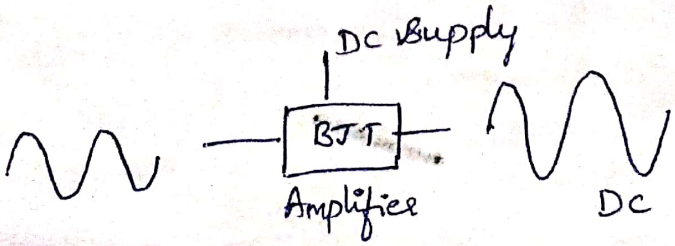
• When small voltage s/g is applied at i/p of BJT then its possible to amplify the s/g



• In BJT CE is the most preferred configuration for voltage amplification.



• To use BJT as an amplifier we need to apply DC voltage to BJT & that's called Biasing of BJT.



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• Without biasing the BJT won't be able to amplify the i/p s/g.

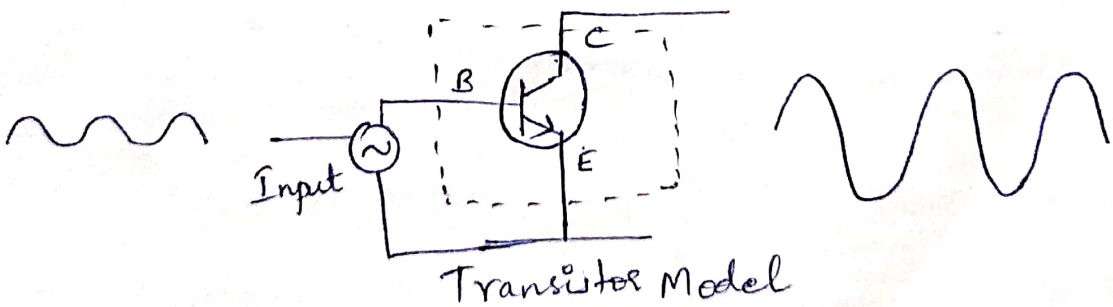
Ex:- If we connect microphone btw base & emitter terminal then it won't be able to amplify the s/g.

* When you want to use BJT as amplifier we need to do 2 types of analysis — DC analysis
— AC analysis

• DC analysis — we can identify operating point of circuit & we can identify in which region its operating. (BJT should be ~~used~~ operated in active region to use it as an amplifier).

• AC analysis - we can know the gain of the amplifier & we can find the i/p & o/p impedance of the amplifier.

• So we need to model the BJT transistor model which closely represents the transistor characteristics & it consists of familiar ckt elements so that the analysis of the ckt becomes easier.



Transistor Model

• Based on the magnitude of i/p signals there are 2 transistor models
1) Large s/g model
2) Small s/g model.

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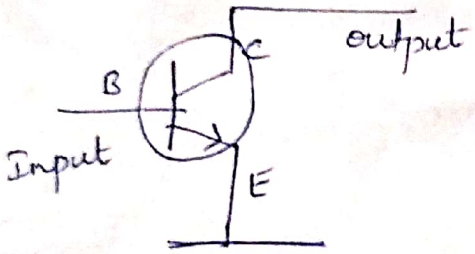
* When transistor used as an amplifier it consists of 2 components — DC component (used for biasing transistor)
— time varying s/g (which we want to amplify)

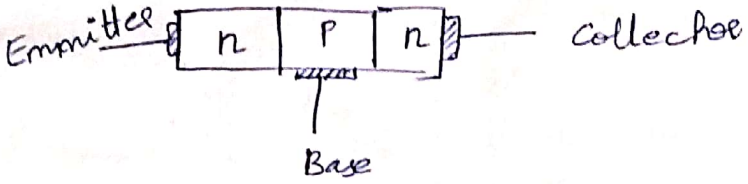
• DC s/g often referred as large s/g

time varying s/g referred as small s/g.

* We know BJT is a non-linear device so when the i/p s/g is large the behaviour of device is also non-linear.

• This is valid only when BJT is operating in forward active region only.





• when base emitter — forward biased
collector base — reverse biased
} forward active region.

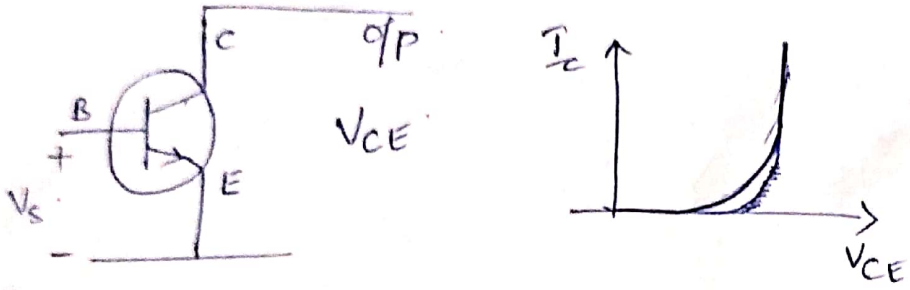
* ~~When we know the~~

* Let us draw the large s/g model.

We know BJT has 2 PN junctions & it looks like 2 diodes are connected back to back.

• Now in CE config. let's say Voltage V_{CE} is constant & we are varying the voltage b/w this

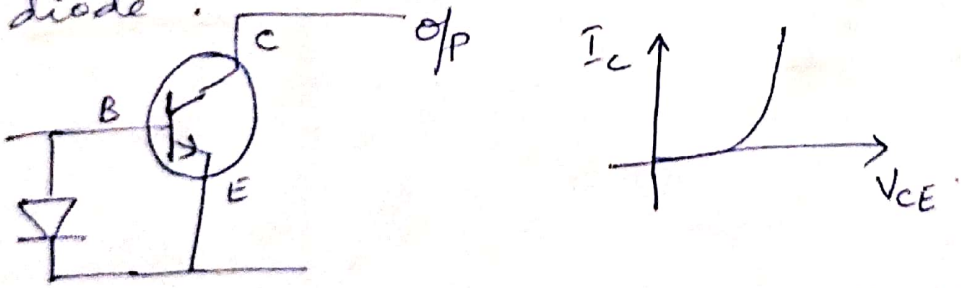
base & emitter terminal & now by varying the voltage if we measure the collector current & if we draw VI characteristics then it will look similar to diode characteristics & relationship btw current & base emitter voltage can be given by $\boxed{I_c = I_s \exp\left(\frac{V_D}{V_T}\right)}$



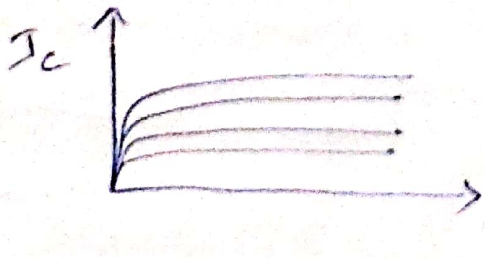
Where $I_s \rightarrow$ Reverse saturation current

$V_T \rightarrow$ Thermal voltage.

- The above expression is similar to shockley's diode equation so from the eq/. & curve we can say the base emitter terminal can be represented by the diode.



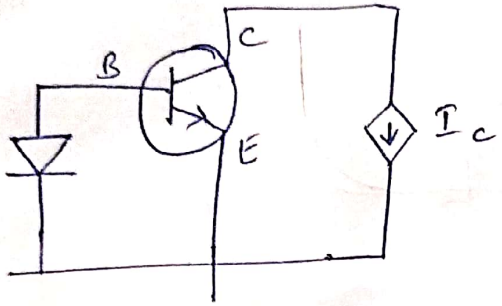
* We have seen I_c Vs V_{CE} curves for CE config/.



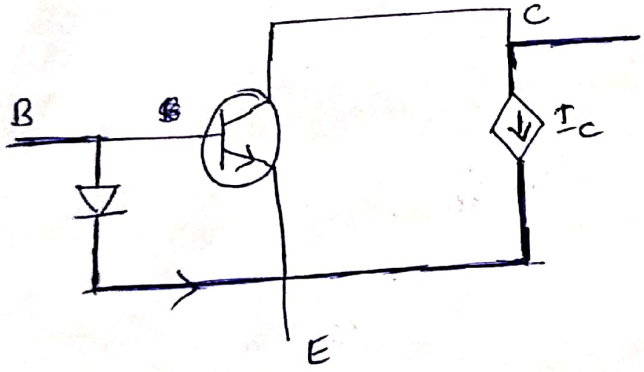
For fixed value of V_{BE} or fixed value of current I_B

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If we change the voltage DC then in this active region the collector current I_C almost remains constant that means current flowing from collector to emitter terminal can be assumed to be a constant for the given value of V_{BE} so we can represent it as a voltage controlled current source.



BJT large s/g model.



This is large s/g model of BJT in forward active region

collector current $I_C = I_S \, e^{\left(\frac{V_{BE}}{V_T}\right)}$

$\boxed{I_C = \beta I_B}$ we know this

Base current $I_B = \frac{I_S}{\beta} \, e^{\left(\frac{V_{BE}}{V_T}\right)}$

& emitter current is summation of collector current & base current that means emmitter current

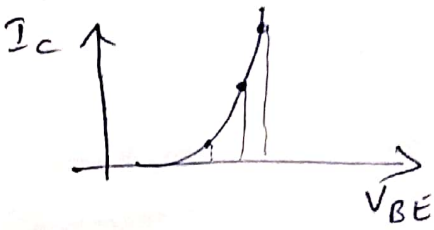
$$I_E = (\beta + 1) I_B$$

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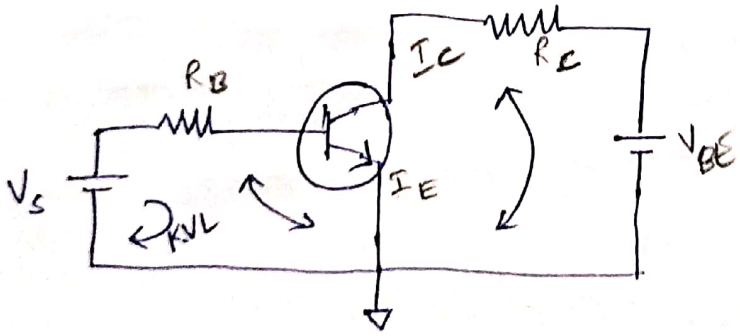
$$= (\beta+1)\frac{I_s}{\beta}\exp\left(\frac{V_{BE}}{V_T}\right)$$

- The collector current depends on the value of voltage V_{BE}.

* As relationship is non-linear so even if voltage V_{BE} changes by small amount then there will be a significant change in collector current, so if we do DC analysis using this large s/g model then we need to deal with this non-linear equations. & the analysis would also be complicated



* In the I_c Vs V_{BE} if there is a very small change in V_{BE} there is a significant change in collector current so for DC analysis we can app/.. value of $V_{BE} = 0.7$ Vol



For the gvn ckt if you apply DC analysis then Apply KVL

By Applying KVL on i/p side we can get value of base current & then

$\boxed{I_c = \beta I_B}$ using this we can calculate the value of collector current I_c as well as voltage V_{CE}.

This method gives app/.. values of operating point & if we want exact values we need to do itegations & its complicated.

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Small signal model

till

When using pen & paper. we need to do iterations $V_{BE}(n+1)$ is same as $V_{BE}(n)$. But if you follow certain criteria its easier to get operating point which is close to actual value.

$V_{BB} > V_{BE}$ ↑ R_B ↑ base current insensitive

For ex:-

In fixed bias config.

If the voltage V_{BB} is much greater than V_{BE} & base resistor R_B is very high then the base current and effectively the collector current is almost insensitive to value of V_{BE}. So this way by following certain criteria & appx. we can get rid of the non-linear equations.

* The fixed bias config. is very sensitive to the value of β so the voltage divider or collector feedback bias config. provides better stability.

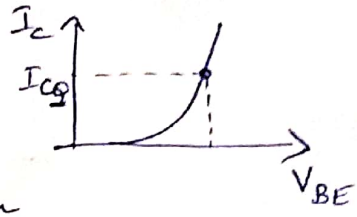
So this the Large sig model of BJT which can be used in the forward active region.

Small s/g Model

* Based on magnitude of i/p s/g we can model BJT as either large s/g or small s/g model.

* During large s/g model I_C vs V_{BE} curve for BJT.

* So lets say for some large s/g voltage V_{BE} we are getting some collector current & Q defines the biasing or operating voltages.



* So when we apply some voltage V_{BE}, Collector current I_C can be given by $\boxed{I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right)}$ where

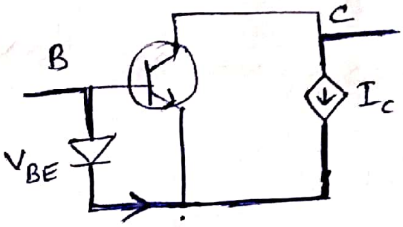
$I_S \rightarrow$ Saturation current

$V_T \rightarrow$ Thermal voltage.

* Now assume on the large DC s/g a small AC s/g is also applied.

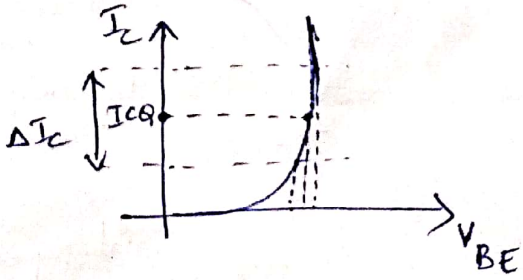
& lets says that voltage = ΔV_{BE}

So because of this AC s/g there will be a change in collector current as well.



So, change in collector current to change in Voltage V_{BE} can be given as

$$\boxed{\text{Transconductance} = \frac{\Delta I_C}{\Delta V_{BE}}}$$



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* It shows how change in voltage V_{BE} gets translated into the change in the collector current.

* Unit of transconductance is Ampere/Volt or Siemens.

* Now lets assume the small AC s/g that we applied is sinusoidal in nature.

$$\Delta V_{BE} = V_m \sin(\omega t)$$ (omega)

*So because of this small AC s/g lets say the total collector current is equal to I_C'.

$$I_C' = I_S \exp\left(\frac{V_{BE} + \Delta V_{BE}}{V_T}\right)$$

$$= I_S \exp\left(\frac{V_{BE}}{V_T}\right) * \exp\left(\frac{\Delta V_{BE}}{V_T}\right)$$

where $\Delta V_{BE} = V_m \sin(\omega t)$

Here the collector current involves the exponential term & it is difficult to find change in current ~~because of that~~ because of change in voltage V_{BE}.

* But if we use approximation then we can find the change in collector current.

* If we look at

$$I_C' = I_S \exp\left(\frac{V_{BE}}{V_T}\right) \times \exp\left(\frac{\Delta V_{BE}}{V_T}\right).$$

↓

The first term is collector current.

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That means we can say

$$I_C' = I_C \exp\left(\frac{\Delta V_{BE}}{V_T}\right)$$

Now, let say ΔV_{BE} is very small & $\frac{\Delta V_{BE}}{V_T}$ is much less than 1.

* When ΔV_{BE} is very small we can say that we are operating in linear region of exponential curve which means if change in voltage V_{BE} is sinusoidal then change in collector current will also be sinusoidal.

* Mathematically, we can say collector current

$$I_C' = I_C\left(1 + \frac{\Delta V_{BE}}{V_T}\right)$$

$\exp\left(\frac{\Delta V_{BE}}{V_T}\right) = 1 + \frac{\Delta V_{BE}}{V_T}$. where exponential can be given as e^x

$$e^x = 1 + x + \frac{x^2}{2!} + \cdots\cdots$$

So when x is small we can neglect high order terms approximate e^x as $1 + x$.

* Similarly when $\frac{\Delta V_{BE}}{V_T}$ is very small then we can approximate this $\exp\left(\frac{\Delta V_{BE}}{V_T}\right)$ as $\left(1 + \frac{\Delta V_{BE}}{V_T}\right)$

$$I_C' = I_C\left(1 + \frac{\Delta V_{BE}}{V_T}\right)$$

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Or we can say

$$I_c' = I_c + I_c\left(\frac{\Delta V_{BE}}{V_T}\right)$$

↳ This term shows the change in collector current because of change in voltage V_{BE}.

If $I_c\left(\frac{\Delta V_{BE}}{V_T}\right) = \Delta I_c$.

$$\Delta I_c = I_c\left(\frac{\Delta V_{BE}}{V_T}\right)$$

$$\frac{\Delta I_c}{\Delta V_{BE}} = \text{transconductance } (g_m).$$

So $g_m = \frac{I_c}{V_T}$.

when $\frac{\Delta I_c}{\Delta V_{BE}}$ is very small, we can represent it as $\frac{dI_c}{dV_{BE}}$. So, in this case by differentiating the eq/.

$I_c = I_s \exp\left(\frac{V_{BE}}{V_T}\right)$ we can get value of transconductance

For ex:-

If we differentiate collector current w.r.t Voltage V_{BE} then we get

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$$\frac{dI_c}{dV_{BE}} = I_S \exp\left(\frac{V_{BE}}{V_T}\right) \times \frac{1}{V_T}$$

↳ This is collector current

$\frac{dI_c}{dV_{BE}}$ that is transconductance $g_m = \frac{I_c}{V_T}$.

* Transconductance depends on operating point
* As value of collector current ↑ the g_m will also ↑.
* If collector current ↑ then for the same change in base - emitter voltage there will be ↑ more change in collector current.
* Once again

$$I_C' = I_C + I_C\left(\frac{\Delta V_{BE}}{V_T}\right).$$

$$= I_C + g_m * \Delta V_{BE} \quad \text{(As discussed earlier)}$$

$$I_C' = \underbrace{I_S \exp\left(\frac{\Delta V_{BE}}{V_T}\right)}_{\text{represents collector current due to DC biasing voltage } V_{BE}} + \underbrace{g_m * \Delta V_{BE}}_{\text{represents the change in collector current due to small s/g}}$$

So in first term the collector current can be found using this large s/g model while we can find the change in collector current by multiplying the change in the s/g with transconductance

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* Now we can treat the 1st term large s/g & 2nd term small s/g seperately.

(OR)

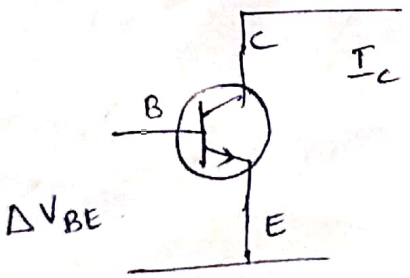
By using this small s/g approximation we can apply the principle of super-position.

* That means during the DC analysis we can consider all AC sources as zero & find operating point

Similarly, for small s/g analysis we can consider all DC sources as zero & find AC response.

& Total response will be summation of individual response.

→ Lets draw the small s/g model of BJT which can be used for small-s/g analysis.

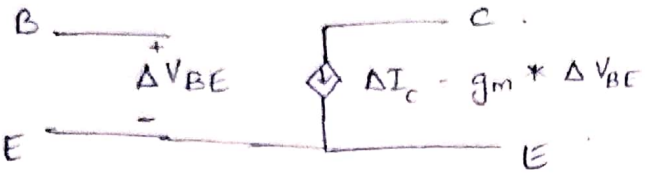


• When we apply a small perturbation or small A/c s/g ΔV_{BE} btw base & emitter terminal then change in Collector current $I_c = g_m * \Delta V_{BE}$.

which means change in collector current I_c is linearly proportional to change in voltage V_{BE}.

* So in a small s/g model, we can represent it as a voltage controlled current source.

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btw emitter & collector terminal.

* When there is a change in collector current then there is also change in base current.

$I_C = \beta I_B$. which means when there is change in collector current, then the change in base current $\Delta I_B = \frac{\Delta I_C}{\beta}$.

And as base current exists, there has to be some element btw this base & emitter terminal. So Lets find out that.

We know that $\Delta I_C = g_m * \Delta V_{BE}$.

↓

Change in collector current

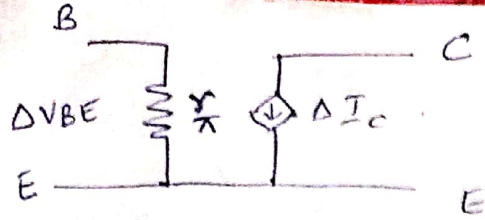
$$\Delta I_B = \frac{\Delta I_C}{\beta}$$

$$\boxed{\Delta I_B = g_m * \frac{\Delta V_{BE}}{\beta}}$$

* This expression shows when there is a change in base emmitter voltage then how base current changes. & the relationship btw the two is linear.

* That means in the small s/g model, resistor exists btw the base & emitter terminal & lets call this resistor as R_π.

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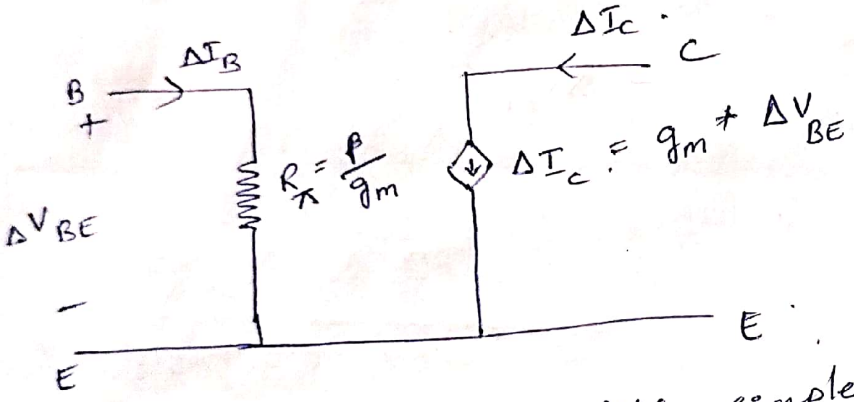
The value of resistor r_π can be found by taking ratio of voltage ΔV_{BE} to ΔI_B.

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

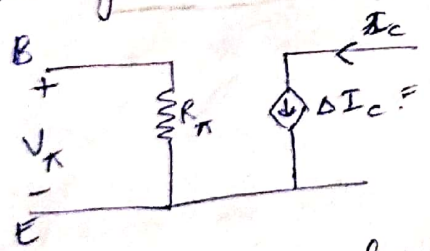
$$\Delta I_B = \frac{\Delta I_C}{\beta} = \frac{g_m * \Delta V_{BE}}{\beta}$$

From the above expression we can say

$$\frac{\Delta V_{BE}}{\Delta I_B} = \frac{\beta}{g_m} = R_\pi$$



* Now to make it little simpler, lets represent change in base emitter voltage as V_π.



That means change in collector current $= g_m * V_\pi$.

& let change in collector current ΔI_c as i_c.

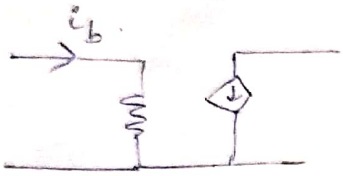
* In general, when we refer to DC signals they are referred by upper case letters & when we refer to AC s/g they are referred by lower case letters.

I_C → represents DC current.

i_c → represents change in collector current.
or it is AC collector current.

∴ Now, $I_c = g_m * V_\pi$.

while base current is equal to i_b.

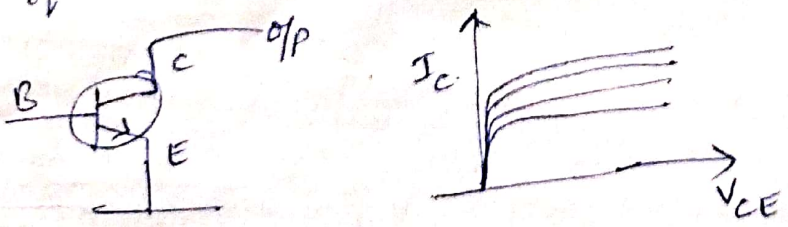


So the total emitter current is the summation of this base current and the collector current.

* This is the small s/g model of BJT which can be used for small s/g analysis.

$$i_e = i_b + i_c$$

* Till now while drawing this large & small s/g model we have assumed that even if there is change in collector to emitter voltage, then there is no change in the collector current which means I_c is constant. But actually collector current does change with the change in voltage V_{CE}. This effect is known as early effect.

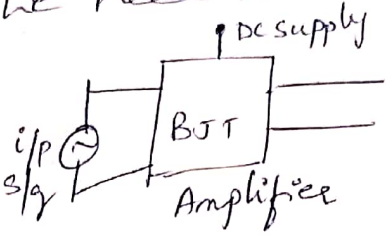


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*

We are assuming that i/p to the amplifier is very small typically in the range of micro volt millivolt & when BJT is used as an amplifier we know i/p is from microphone / antenna. For BJT to work as an amplifier we need to bias it.

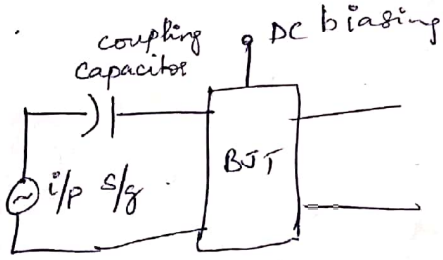
When we apply i/p s/g to BJT it should not affect the biasing condition of the BJT



similarly biasing voltage should not affect the i/p s/g so to isolate the i/p s/g & biasing voltage this coupling capacitor is used.

(OR)

The i/p s/g is applied to BJT via this coupling capacitor.



* Capacitor blocks DC s/g because for DC s/g it will act as open ckt.

*The reactance (X_C) of the capacitor can be given as

$$X_C = \frac{1}{2\pi f C}$$

C → capacitance.
F → Frequency

for DC voltage freq. F is equal to 0

$$F = 0$$

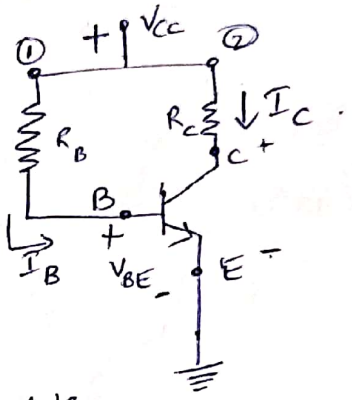
that means reactance of capacitor will be infinite

$$X_C = \infty$$

& hence acts as open ckt & at same time will allow AC signal to pass through it. For A/c s/g this capacitor acts as short ckt. Similarly at o/p to block DC s/g we use coupling capacitor

→ Fixed Bias configuration of a transistor

* The first type of biasing ckt is fixed biasing ckt.
* Fixed bias ckt is the simplest DC bias configuration
* Fixed bias conf/. is also known as base bias config..
* In this V_{cc} is biasing potential & V_{cc} is not represented here as potential diff instead it represented as potential at point.

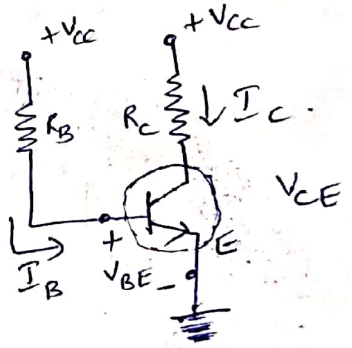


R_B - Resistance connected in series with base

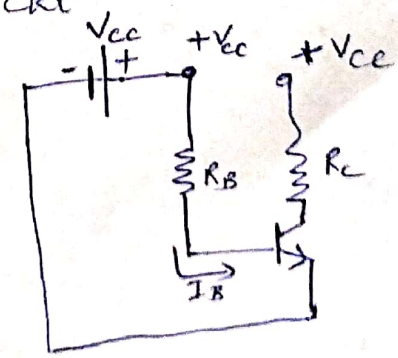
R_c - Resistance connected in series with collector.

Since the potential at pt ① & ② is $+V_{cc}$ we can redraw this ckt ~~which potential at pt~~

* Now we can easily analyze this ckt & obtain the o/p current I_c & o/p voltage V_{CE}.

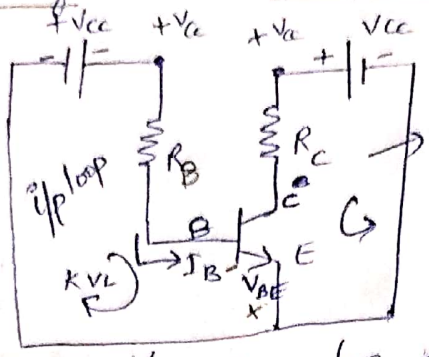


* Now since V_{cc} is +ve we give to +ve plate & Emitter is ground having zero potential so it will act as negative teaminal & with this the i/p ckt is completed.



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* In the same way even complete the o/p side as well.



KVL → Sum of entering currents = sum of leaving currents

So from this I_C & V_{CE} can be easily obtained.

* Now apply KVL in i/p loop

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

With this eq. we can calculate base current I_B.

I_B = i/p current.

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} \rightarrow (2)$$

I_C = collector current.

& we know $I_C = \beta I_B \rightarrow (3)$

Substitute (3) in (2).

$$I_C = \frac{\beta (V_{CC} - V_{BE})}{R_B}$$

We know V_{BE} = 0.7V for Silicon.
= 0.3V for Germanium

V_{BE} is the voltage across the forward bias diode & when we replace the diode with its equivalent model & we are considering the constant voltage drop model then V_{BE} = 0.7V (Silicon)
= 0.3V (Germanium)

So if we know β value the biasing potential

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& Resistance R_B we can easily calculate I_C. Now, Calculate V_{CE} (o/p voltage)

For this apply KVL in o/p loop.

$$+V_{CC} - I_C R_C - V_{CE} = 0 \rightarrow (4)$$

From above equation $\boxed{V_{CE} = V_{CC} - I_C R_C} \rightarrow (5)$

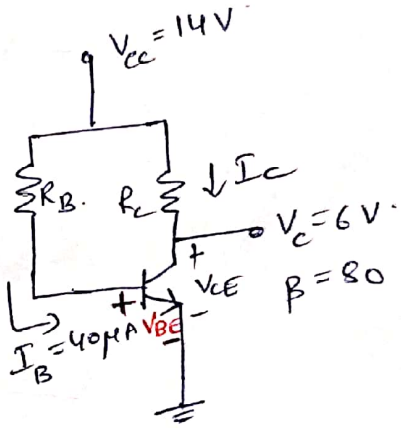
Substitute I_C value in eq (5)

& V_{BE} value is known & R_C value is given & now its easy to calculate o/p voltage V_{CE}.

Ex:-

Calculate

1) I_C
2) R_C
3) R_B
4) V_{CE}.



for fixed bias configuration.

Sol:-

$V_{CC} = 14V$

$I_B = 40\mu A$

$\beta = 80$

$V_C = 6V$

$I_C = \beta I_B$

$= 80 \times 40$

$I_C = 3.2\ mA$

$R_C =$

Apply KVL to outer loop.

start from V_{CC} till 6V.

$$+14V - I_C R_C = 6V$$

$$R_C = \frac{14-6}{I_C}$$

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$$R_C = \frac{8V}{I_C}$$

$$= \frac{8V}{3.2mA}$$

$$R_c = 2.5k\Omega.$$

R_B

Apply KVL in i/p loop.

$$14V - I_B R_B - V_{BE} = 0$$

$$R_B = \frac{14V - V_{BE}}{I_B}.$$

$$V_{BE} = 0.7V.$$

$$= \frac{13.3V}{40\mu A}.$$

$$= 332.5\ k\Omega.$$

V_{CE}

$$V_{CE} = V_C - V_E$$

$= (V_C \rightarrow$ potential at pt C.

$V_E \rightarrow$ potential at point E)

$= 6V - 0V$ Since pt E is grounded.

$$V_{CE} = 6V$$

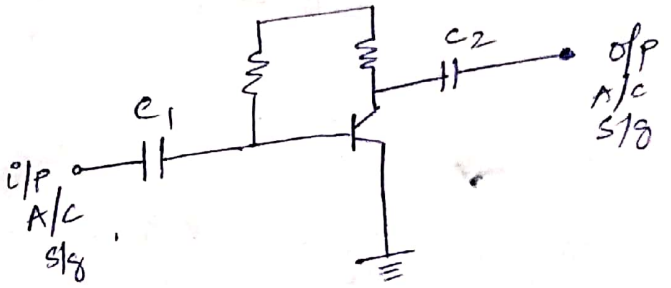
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* In case of fixed bias configuration the

EB junction → forward biased by V_{cc}.

CB " → Reverse biased by V_{cc}.

* We even have coupling capacitors C_1 where we apply the i/p AC s/g & second coupling capacitor C_2 is connected at collector.



* We do not consider capacitors C_1 & C_2 in DC analysis because

reactance $X_C = \frac{1}{2\pi f C}$

where F = Freq.

C = capacitance.

& in case of DC; Freq = 0.

$\therefore X_C = \infty$

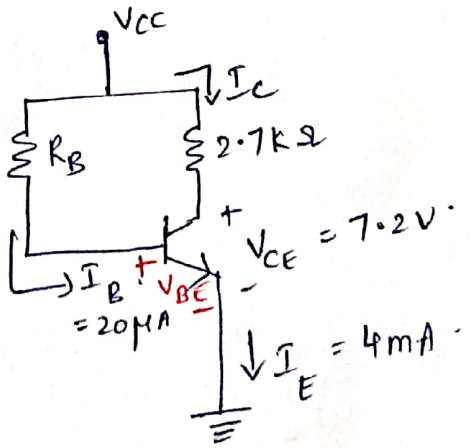
& C_1 & C_2 will be represented as open ckt.

Homework :-

* For fixed bias configuration.

Calculate

I_C, V_{cc}, β, R_B.



Sol :-

$R_C = 2.7k\Omega$.

$I_B = 20\mu A$

$I_E = 4mA$.

$V_{CE} = 7.2V$

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a) $I_E = I_C + I_B$

$I_C = I_E - I_B$ ← (from above eq)

$= 4mA - 20\mu A$

$= 4mA - 0.02\,mA$

$I_C = 3.98\,mA$

I_C is nearly equal to Emitter current I_E.

$I_C \approx I_E$

b) V_{CC}

Apply KVL in o/p loop

$V_{CC} - I_C(2.7k\Omega) - 7.2V = 0$

$V_{CC} = (3.98mA)\,2.7k\Omega) + 7.2V$

$= 10.746\,V + 7.2V$

$V_{CC} = 17.946\,V$

c) β

$\beta = \frac{I_C}{I_B} = \frac{3.98mA}{20\mu A} = \frac{3.98mA}{0.02mA} = 199$

$\therefore \beta = 199$

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d) R_B

Apply KVL in o/p loop

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

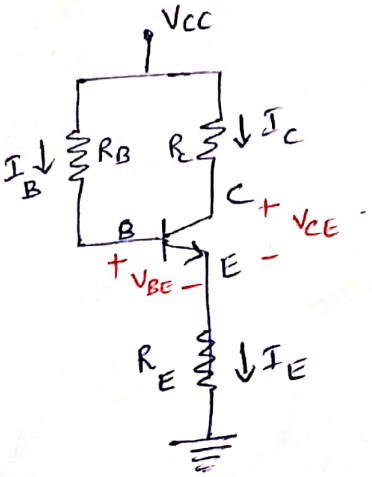
$(V_{BE} = 0.7V)$

$$17.946V - (20\mu A) R_B - 0.7V = 0$$

$$R_B = \frac{17.946V - 0.7V}{20\mu A}$$

$$= 862.3 k\Omega$$

→ Emitter - Bias configuration



* The only difference btw fixed bias & emitter bias config/ is we introduce R_E (Emitter resistance) to improve stability of operating point.

* To find the co-ordinates of operating pt.

$Q_{point} = (I_{CQ}, V_{CEQ})$

Q → operating point

* To calculate I_{CQ} or I_C we have to apply KVL in i/p loop

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

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$I_E = I_C + I_B$ } We already know)

$I_C = \beta I_B$.

$\therefore I_E = \beta I_B + I_B$

$= (\beta+1) I_B$.

Substitute these values in above equation.

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

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

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

$$I_C = \beta I_B.$$

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

To calculate V_{CE}

Apply KVL in o/p loop.

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

$I_E \approx I_C$ (we know this).

$$V_{CC} - I_C (R_C + R_E) - V_{CE} = 0.$$

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

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We know the derivation for I_c using that we can calculate I_c value & using that we can calculate V_{CE}.

* Advantage of using emitter resistance R_E :-

• We don't want to change the operating point once its fixed & if I_c changes then Q point also changes as its one of the co-ordinates.

• I_c changes because of 1) Temperature.

If Temp ↑ I_c will also ↑.

$$I_c = \beta I_B + (\beta+1) I_{CBO}$$

as I_{CBO} is leakage current or reverse saturation current & it only depends on minority charge carriers, when Temp ↑ no/.. of minority charge carriers will ↑ & also I_{CBO}. when I_{CBO} ↑ then even I_c also ↑ from above equation.

So, lets see how R_E introduction will help the above situation.

When I_c ↑, the drop $I_E R_E$ will also ↑ & when this drop ↑ base current ↓

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

When $I_E R_E$ ↑ then I_B ↓.

∴ As I_B ↓ I_c also ↓.

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because $I_c = \beta I_B$

Hence as $I_c \uparrow$ because of $\uparrow$ in temp is equally compensated by $I_B \downarrow$.

* Because of R_E introduced, temperature will no longer have effect on I_c & R_E plays its role in the drop.

2) β

When β value changes the I_c will also change because $I_c = \beta I_B$.

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

Since β is large value $\beta+1$ is nearly equal to β.

$$I_c = \frac{\beta(V_{cc} - V_{BE})}{R_B + \beta R_E}$$

Lets says βR_E is $>> R_B$

Then

$$I_c = \frac{\beta(V_{cc} - V_{BE})}{\beta R_E}$$

$$I_c = \frac{(V_{cc} - V_{BE})}{R_E}$$

∴ We see that I_c is independent of β.

So no effect on I_c if transistor is changed because collector current is independent of current amplification

factor.

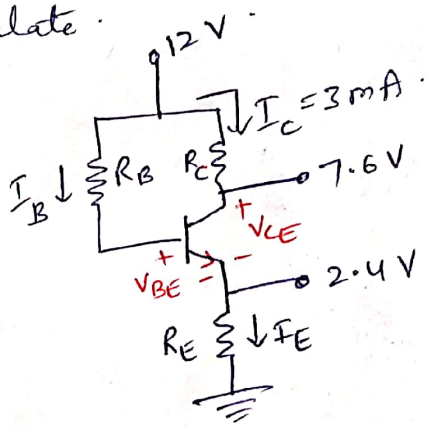
disadv of this ckt in order to have collector current independent of β. We must follow the condition $\boxed{\beta R_E >> R_B}$ & at many times β is unknown to us. So to achieve this condition we must make R_E high & R_B very low.

$R_C \uparrow\uparrow$ → (For this condition we need to put $V_{CC} \uparrow\uparrow$ & cost ↑)
$R_B \downarrow\downarrow$

If R_B is $\downarrow\downarrow$ the reverse bias of CB junction will reduce & this is the disadv. of this config/..

Ex:-

For emitter bias ckt. Calculate.



a) R_C
b) R_E
c) R_B
d) V_{CE}
e) V_B

Sol:-

I_C = 3 mA

β = 80.

We are using npn transistor.

V_C = 7.6 V (potential at collector)

V_E = 2.4 V (" " Emitter).

V_{CC} = 12 V.

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V_B (potential at base)

$V_{BE} = 0.7V$

$V_B - V_E = 0.7V$

$V_B = 0.7V + V_E$

$= 2.4 + 0.7$

$V_B = 3.1V$

V_{CE}

$V_{CE} = V_C - V_E$

$= 7.6 - 2.4V$

$V_{CE} = 5.2V$

R_B

Apply KVL in i/p loop.

$+12V - I_B R_B = V_B$

$V_B = 3.1V$

$I_B = \frac{I_C}{\beta}$

$= \frac{3mA}{80} = 37.5\mu A$

$\therefore R_B = \frac{12V - 3.1V}{37.5\mu A} = 237.4k\Omega$

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R_E

Apply KVL in R_E.

$$2.4V - I_E R_E = 0V$$

$$I_E \approx I_C$$

$$R_E = \frac{2.4V}{3mA} = 0.8\ K\Omega$$

R_C

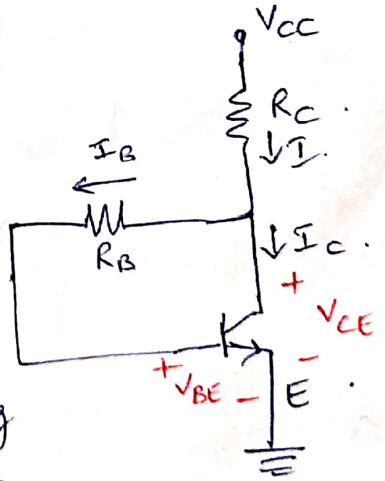
Apply KVL in R_C.

$$12V - I_C R_C = 7.6V$$

$$R_C = \frac{12V - 7.6V}{3mA}$$

$$= 1.47\ K\Omega$$

→ Collector Feedback biasing :-



* In case of emitter biasing we introduce R_E & because of that the stability of operating point ↑. The stability of operating point can also be improved by introducing feedback from collector to base & this is what we are doing in this biasing. We are introducing feedback from collector to base. First we calculate I_C & V_{CE}. They are

the coordinates of operating point.

I_B is current in $\xleftarrow{I_B}$

I_c is current in this branch.



If I wanted to calculate current across R_c.

Apply KVL

↓

~~Sum of entering currents = Sum of leaving currents~~

I_B, I_c → Leaving current

I → entering current.

$$I = I_c + I_B$$

Apply KVL at B/P loop

$$V_{CC} - (I_c + I_B) R_c - I_B R_B - V_{BE} = 0$$

Using the above equation calculate I_B.

$$I_c = \beta I_B \quad \text{(We know this)}$$

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

$$V_{CC} - [(\beta+1) R_c + R_B] I_B - V_{BE} = 0$$

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

$$I_c = \beta I_B$$

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

For V_{CE}:

Apply KVL in o/p loop

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

$$I = I_C + I_B$$

$$V_{CC} - (I_C + I_B) R_C - V_{CE} = 0$$

$$V_{CE} = V_{CC} - (I_C + I_B) R_C \rightarrow$$

In the above equation substitute I_C value & once we get I_C. we can substitute in V_{CE}

Adv

1) stabilises the operating point against the variation of temperature.

2) stabilises operating point against the variation of biasing voltage V_{CC}.

3) " "

β value:

I_C is independant of β.

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

If $\beta+1$ nearly equal to β.

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If $\beta R_C >> R_B$

then R_B gets neglected

$$\therefore I_C = \frac{\beta (V_{CC} - V_{BE})}{R_B \times \beta}$$

$\therefore$ Independent of β value.

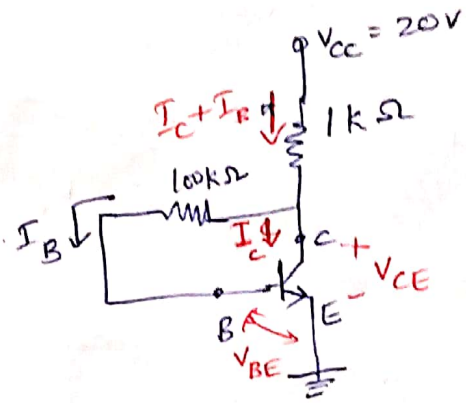
Disadv

1) Same as emitter bias config. disadv.

Ex:-

1) Figure shows a silicon transistor biased by collector feedback method. Determine operating point.

$\beta = 100$



Sol:-

$V_{CC} = 20V$

$R_C = 1k\Omega$

$R_B = 100k\Omega$

Q-point $= (I_C, V_{CE})$

$\beta = 100$

Calculate I_C

We need to calculate I_B.

Apply KVL to i/p loop

$$V_{CC} - (I_C + I_B) \times 1K\Omega - I_B(100k\Omega) - V_{BE} = 0$$

$$V_{CC} - (I_C + I_B)\,1k\Omega - I_B(100k\Omega) - 0.7V = 0$$

$$I_C = \beta I_B$$

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$$V_{CC} - (\beta I_B + I_B)(1k\Omega) - I_B(100k\Omega) - 0.7V = 0$$

$$I_B = \frac{V_{CC} - 0.7V}{(\beta+1)(1k\Omega) + 100k\Omega} = \frac{19.3V}{201k\Omega} = 0.0960mA = 96\mu A$$

$\therefore \beta = 100$

$R_C = 1k\Omega$

$R_B = 100k\Omega$

$V_{CC} = 20V$

$$I_C = \beta I_B$$

$$= 100 \times 96\mu A = 9.6mA$$ (milli)

V_{CE}

Apply KVL in o/p loop.

start from V_{CC} & end at 0V.

$$20V - (I_C + I_B)1k\Omega - V_{CE} = 0$$

$$V_{CE} = 10.304V$$

Q point = (9.6mA, 10.304V)

H-W

Find the Q. point for the same figure but $\beta = 150$.

All other parameters are same.

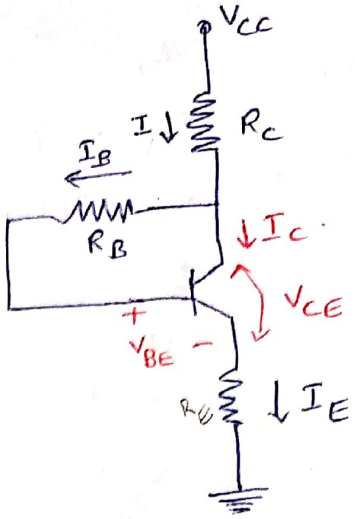
→ Collector feedback biasing with Emitter Resistance

This is a mix of collector feedback + emitter feedback biasing & we need to find the operating point.

Apply KVL in the i/p loop.

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



$$I = I_C + I_B$$

$$V_{CC} - (I_C + I_B) R_C - I_B R_B - V_{BE} - I_E R_E = 0$$

$$I_E = I_C + I_B.$$

$$I_C = \beta I_B.$$

$$= \beta I_B + I_B.$$

$$I_E = (\beta+1) I_B.$$

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

$$V_{CC} - I_B \left[(\beta+1)(R_C + R_E) + R_B \right] - V_{BE} = 0.$$

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

$$I_C = \beta I_B.$$

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

If $R_B << (\beta+1)(R_C + R_E)$

then $\frac{I_C}{\beta}$ is independent of β value.

V. V. Imp condition

V_{CE}

Apply KVL in o/p loop.

$$V_{CC} - (I_C + I_B) R_C - V_{CE} - I_E R_E = 0$$

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

$$V_{CC} - I_E (R_C + R_E) - V_{CE} = 0$$

$$I_E \approx I_C .$$

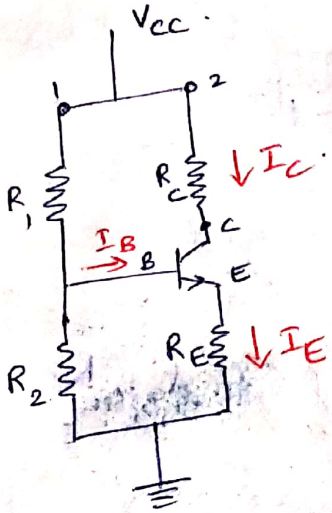
$$V_{CC} - I_C (R_C + R_E) - V_{CE} = 0$$

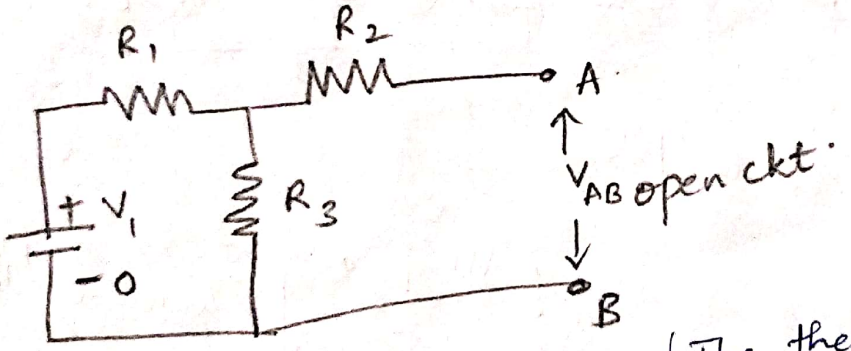
$$\boxed{V_{CE} = V_{CC} - I_C (R_C + R_E)}$$

Substitute I_C value & calculate V_{CE}

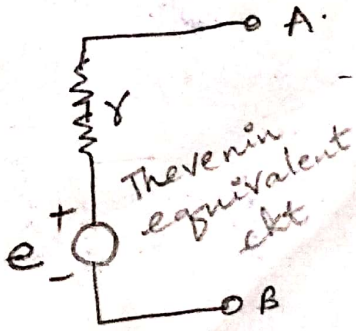
Voltage Divider Bias Configuration :- (We prefer this the most than others)

* We have R_C & R_E but no R_B in place of that we have 2 resistances R_1 & R_2 & because of this we need to use Thevenins theorem.





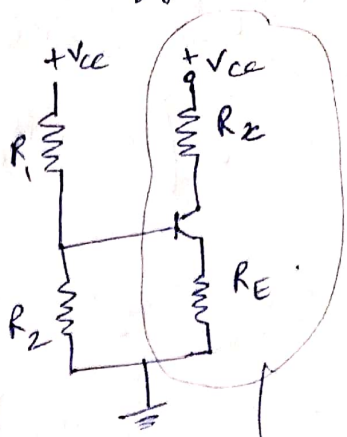
Thevenin voltage e is the open ckt voltage at terminals A & B.



The thevenin resistance r is the resistance seen at AB with all voltage sources replaced by short ckt & all current sources replaced by open ckts.

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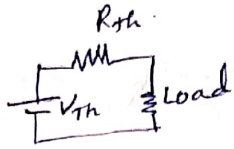
potential at pt 1 & 2 is V_{cc} so we can modify the ckt as shown below. We need to find the operating point.



To find operating point we need to draw the equivalent ckt by using thevenin's theorem. In this

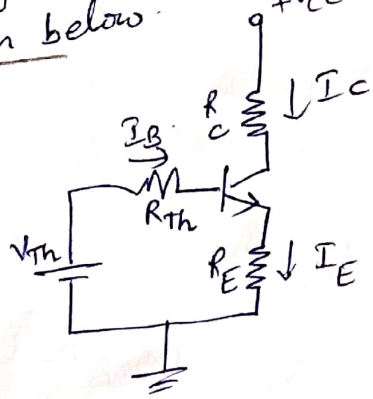
Thevenins resistance = R_{th} &

" Voltage = V_{th} and Load.



In case of voltage divider configuration the load is thevenin side

So the equivalent ckt is shown below.



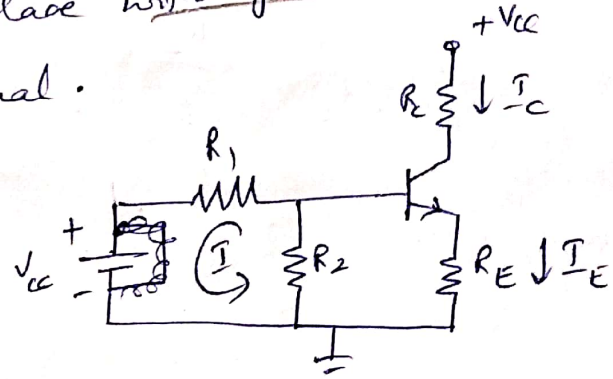
→ ckt (2)

Once we know the V_{th} & R_{th} we calculate I_C & V_{CE}

To find R_{th}

Redraw the ckt as

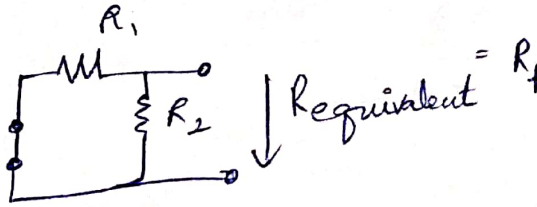
Potential of ground is 0 so replace with ground with -ve terminal & V_{cc} with +ve terminal.



Now, to find R_{th}

1) Short all voltage sources
2) open ckt the load.

So this ckt becomes.



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

R_1 is parallel to R_2.

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Now to calculate V_{BE}.

Apply KVL in i/p meaning near V_{cc}.

$$I = \frac{V_{cc}}{R_1 + R_2}$$

Now to calculate drop across R_2 ~~across~~ of V_{th}.

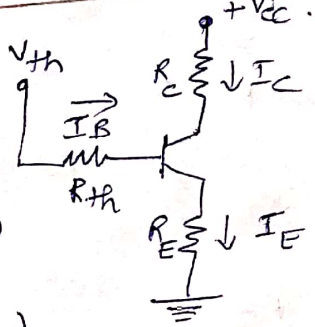
Multiply current with R_2.

$$V_{th} = IR_2 = \frac{R_2 V_{cc}}{R_1 + R_2}$$

∴ We can calculate I_C & V_{CE} value.

* If you look closely to the ckt ② it looks similar as emitter bias ckt. The only diff here is V_{th} & R_{th} same in emitter bias we had R_B in R_{th} & V_{cc} in V_{th}.

∴ It looks like this ckt.



Apply KVL in i/p loop.

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

$$I_E = (\beta+1) I_B \quad \text{(We know this)}$$

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

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

only diff is V_{th} in place of V_{cc} & R_{th} in place of R_B.

$$I_C = \beta I_B$$

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

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To make I_C independent of β. The condition R_{th} is smaller than $(\beta+1)R_E$.

$$R_{th} << (\beta+1)R_E$$

Then β gets cancelled & we won't have β.

For V_{CE}

Apply KVL in o/p loop

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

$$I_E \approx I_C$$

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

Adv :-

1) Because of R_{th} combination which consists of R_1 & R_2 & to make I_C independent of β we have to follow.

$$R_{th} << (\beta+1)R_E$$

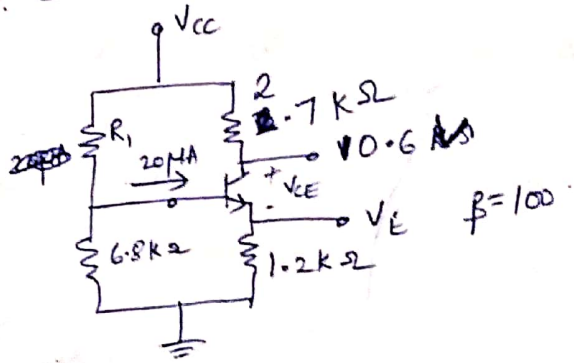
R_{th} is combination of $R_1 \parallel R_2$

whereas R_B is just a single resistor & this is very small & beyond a certain value we cannot reduce the R_B value whereas we don't have such pblm with R_{th}

Ex:-

For voltage divider bias config.. calculate

1) I_C
2) V_E
3) V_{CC}
4) V_{CE}
5) V_B
6) R_1



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Sol:

$I_B = 20\mu A$

$R_C = 2.7k\Omega$

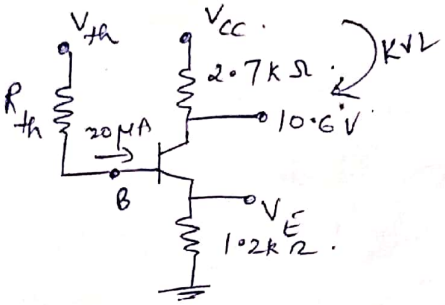
$V_C = 10.6V$

$\beta = 100$

$R_2 = 6.8k\Omega$

$R_E = 1.2k\Omega$

First draw the thevenins equivalent ckt



$$V_{th} = \frac{V_{CC} R_2}{R_1 + R_2}$$

$$R_{th} = \frac{R_1 R_2}{R_1 + R_2}$$

I_C :-

$I_C = \beta I_B$

$= 100 \times 20\mu A$

$= 100 \times 20 \times 10^{-6} A$

$I_C = 2mA$

V_{CC} :-

Apply KVL

$V_{CC} - I_C R_C = 10.6V$

$V_{CC} = (2mA)(2.7k\Omega) + 10.6V$

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$V_{cc} = 16V$.

V_E :-

$I_E = I_c + I_B = 2mA + 20\mu A$.

$= 2.02\,mA$.

$I_E \approx I_c$.

$\rightarrow I_E = 2mA$.

In both diff $= 0.02\,mA$.

Apply KVL in V_E loop.

$V_E - I_E R_E = 0$.

$V_E = I_E R_E$.

$= (2.02\,mA)(1.2k\Omega)$

$V_E = 2.424\,V$. (If you think $I_E = 2.02$)

$V_E = 2.4V$ (when $I_E = 2mA$).

V_{CE}

$V_{CE} = V_C - V_E$

$= 10.6V - 2.42V$

$= 8.176V$.

V_B. ~~Apply~~ Apply KVL (or)

$V_{BE} = V_B - V_E$.

$0.7V = V_B - 2.42V$

$V_B = 3.12V$.

R_1

Use thevenins eq. ckt.

$V_{th} \approx V_B$. because drop is very small across resistance R_{th}.

~~V_{th}~~.

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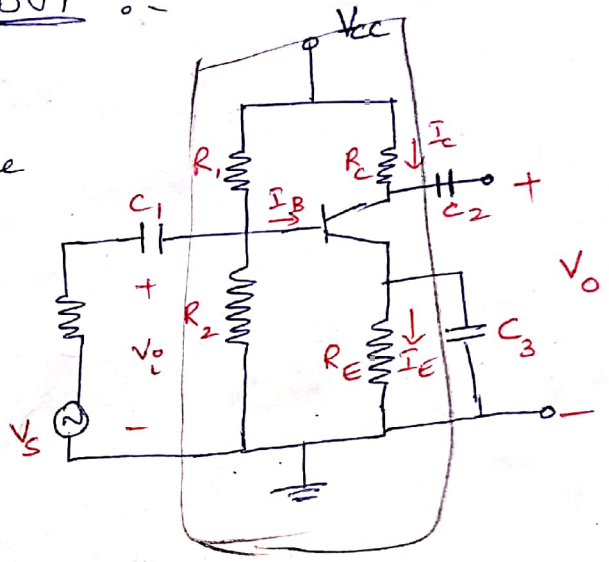
$$V_{th} = \frac{V_{cc} R_2}{R_1 + R_2}$$

$$V_{th} = \frac{16 \times 6.8k\Omega}{R_1 + 6.8k\Omega}$$

$$3.12V = \frac{16 \times 6.8k\Omega}{R_1 + 6.8k\Omega}$$

$$R_1 = 28k\Omega$$

Small signal Analysis of BJT :-



* The rectangular box is the ckt for DC analysis as the capacitors act as open ckt & while Ac analysis we consider the whole ckt.

while C_1 & C_2 → coupling capacitors.

C_3 → By pass capacitors.

$C_1 C_2 C_3$ have high capacitance & so they behave as Ac signals.

$$X_C = \frac{1}{2\pi f C}$$

where f = freq
C = capacitance

If we consider DC s/g · freq = 0.

∴ $X_C = \infty$ in case of Ac s/g

So all 3 capacitors will act as open ckt.

In case of AC S/g

$f \neq 0$

capacitances are ↑

$\therefore X_C = \frac{1}{\text{Large value}}$

$X_C \approx 0$

C_1 & C_2 → coupling capacitors because C_1 is coupling the previous stage & C_2 is coupling next stage.

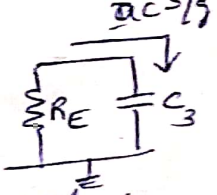
∴ we don't want C_1 C_2 to interfer with V_{cc} (DC biasing voltage) which will change the operating point.

C_3 → Bypass capacitor because it bypasses the AC S/g

The AC S/g has 2 parts 1) has R_E resistance.

2) has C_3 capacitor.

∴ The AC S/g will flow thaough this path & C_3 offers $X_C = 0$ & some resistance in R_E. Hence R_E is short ckted because the gain ↓ because of R_E & if short ckt the R_E gain ↓.



To find AC response

1) To find Ac equivalent ckt

2) Replace transistor with its equivalent model/ckt.

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AC equivalent ckt of BJT Amplifier :-

To find AC response we need AC equivalent ckt of BJT Amplifier. & once we have the equivalent ckt we replace the transistor with its equivalent model so we need equivalent model.

AC equivalent ckt

When we analyze the BJT amplifier ckt for the DC s/g the whole ckt does not comes & when we analyze it for AC s/g the same thing happens so we need to simply the ckt for AC analysis.

We have 3 steps.

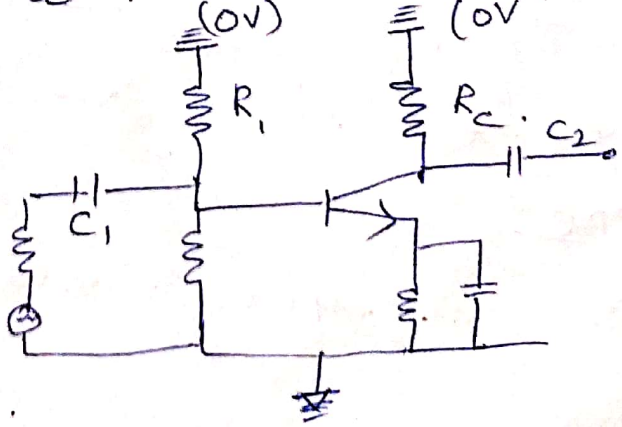
Step ① - Short ckt all the dc sources.

Step ② - Short all capacitors.

Step ③ - Redraw the network removing all the elements which are short circuited in step ① & ②.

Step ①

We have only one source V_{cc} & we need to short ckt so V_{cc} is shorted.



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Step ②

Short ckt all capacitors

C_1, C_2, C_3

∴ Since capacitances are very large

$$X_C = \frac{1}{2\pi fc}$$

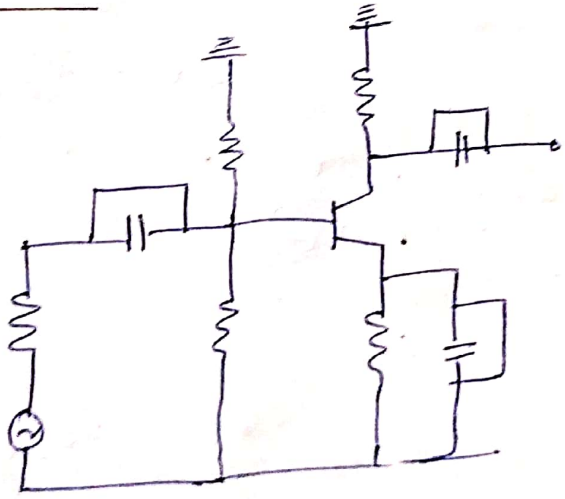
In case of AC i/p. $F \neq 0$.

∴ Capacitance is large.

$$\therefore X_C = \frac{1}{\text{Large value}}$$

$$\therefore \boxed{X_C \approx 0.}$$

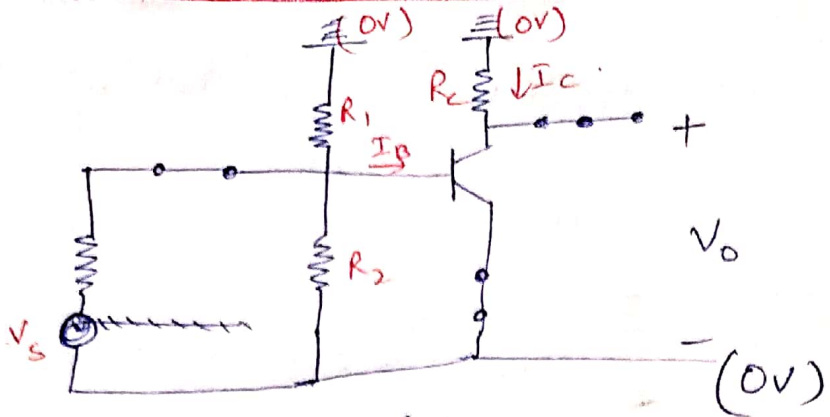
∴ Reactance offered is 0 Ω so we need to replace with short ckt.



We have short circuited the capacitors.

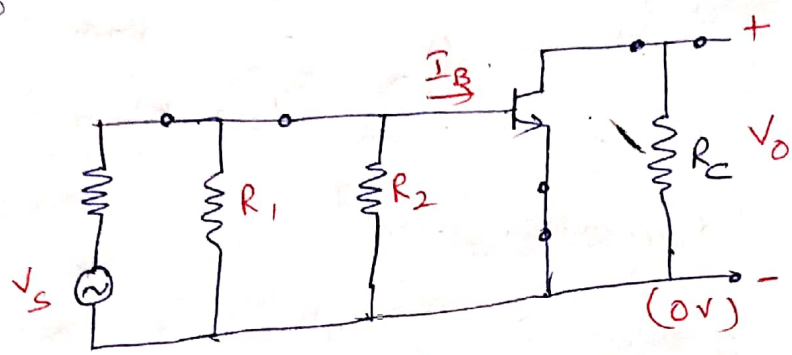
Step ③

Redraw after short ckt's.

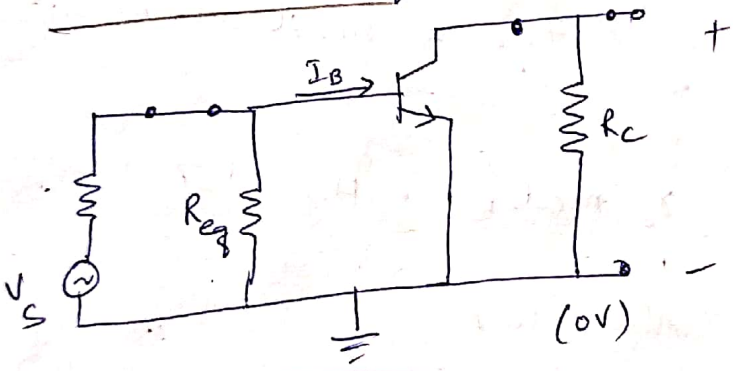


Further to simplify.

Since we have three (0V) lets connect it & redraw:



R_1 & R_2 are parallel. so we can have equivalent resistance (R_{eq})



→ This is the final equivalent ckt of BJT amplifier.

$$R_{eq} = \frac{R_1 \parallel R_2}{R_1 + R_2}$$

We need to find the equivalent model of transistor.

What is equivalent model?

Combination of circuit elements (like resistors, capacitors, etc) properly chosen to best represent the actual behaviour of device under specific operating point.

* We cannot apply network theorems directly on the practical device. So we need equivalent models to use theorems to find diff. network parameters like for Ex: PN junction diode.

- Piece wise linear model
- Constant voltage drop model
- Ideal Model.

* In case of transistors the equivalent models are

- Hybrid
- r_e model
  - Also called dynamic emitter resistance model
- Hybrid π model.

* In case of transistors we generally use r_e model.

* All the 3 models are for small signals.

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Hybrid Model

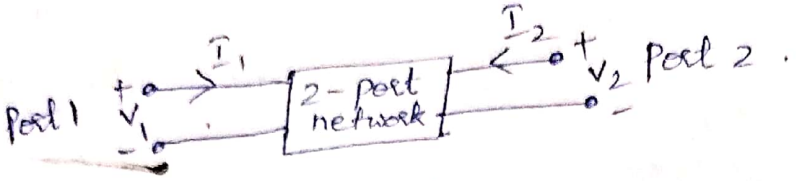
* equivalent model of transistor used for small s/g analysis
* Widely used before popularity of re model.
* parameters are defined in general terms for any operating conditions.
* Parameters are defined by the actual operating conditions.
* Also called h-parameter model.
* Using 'h' parameters we draw the equivalent ckt.
* Calculation of h-parameters :-

why 'h' → because of hybrid. It's called hybrid parameters because they have mixed dimensions.

* Before transistors were invented we used vaccum tubes for designing. only one out of impedance or admittance parameters was required to determine all the parameters. We have 4 important parameters in small s/g amplifiers. We can get these using only impedance (Z-parameters) or admidance (Y-parameters). for vaccum tubes. So for transistors we come across new set of parameters i.e h-parameters.

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Basic 2 port network :-



Port 1 current is I_1

Port 2 current is I_2.

Potential difference between these 2 terminals is equal to V_1 for port 1 & V_2 for port 2.

* Transistor ckt is also a 2-port network.

Lets' say

V_1 & I_2 → dependent Quantities

V_2 & I_1 → Independent "

V_1 is function of V_2 & I_1.

V_2 is " " I_1 & V_2.

$$V_1 = f_1(I_1, V_2)$$

$$V_2 = f_2(I_1, V_2)$$

changes in V_1 & I_2 is

$$dV_1 = \frac{\partial V_1}{\partial I_1} \cdot dI_1 + \frac{\partial V_1}{\partial V_2} \cdot dV_2 \rightarrow (1)$$

$\frac{\partial V_1}{\partial V_2}$ → (h_{12})

parameter units of having impedance say here

Small change in current I_2.

$$dI_2 = \frac{\partial I_2}{\partial I_1} \cdot dI_1 + \frac{\partial I_2}{\partial V_2} \cdot dV_2 \rightarrow (2)$$

$\frac{\partial I_2}{\partial I_1}$ → h_{21}

$\frac{\partial I_2}{\partial V_2}$ → Admittance (h_{22})

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We say h_{11} → cos Voltage & current are from port 1 so 11 & since its hybrid (h).

∴ We got the 4 parameters

∴ AC current represented as i

" Voltage " " v.

Rewrite eq ① & ②

$$v_1 = h_{11} i_1 + h_{12} v_2 \rightarrow ③$$

$$i_2 = h_{21} i_1 + h_{22} v_2 \rightarrow ④$$

equation ③ & ④ are applicable to all 3 transistor configurations. (CE, CC, CB)

If we make $v_2 = 0$ in eq ③ & ④ we get

h_{11} & h_{21}.

From eq ③

$$h_{11} = \left.\frac{v_1}{i_1}\right|_{v_2=0}$$

h_{11} → i/p impedance when o/p is short ckted ($v_2=0$)

Since h_{11} is i/p impedance change it to h_i.

$$h_i = \left.\frac{v_1}{i_1}\right|_{v_2=0}$$

From eq ④.

$$h_{21} = \left.\frac{i_2}{i_1}\right|_{v_2=0}$$

h_{21} → forward current gain when o/p is short ckted.

h_{21} → represented as h_f where f is forward current gain.

$$h_f = \left.\frac{i_2}{i_1}\right|_{v_2=0}$$

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Let's make $i_1 = 0$ in eq (3) & (4)

From eq (3)

$$h_{12} = \left.\frac{v_1}{v_2}\right|_{i_1 = 0}$$

h_{12} → reverse voltage gain when i/p is open ckt'd.

h_{12} → represented by h_r where

r → reverse voltage gain.

$$h_r = \left.\frac{v_1}{v_2}\right|_{i_1 = 0}$$

From eq (4)

$$h_{22} = \left.\frac{i_2}{v_2}\right|_{i_1 = 0}$$

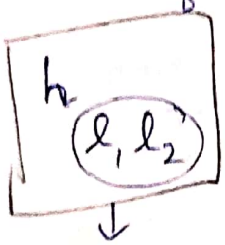
h_{22} → o/p admittance with i/p open ckt'd.

h_{22} → represented as h_o where

o → o/p admittance.

$$h_o = \left.\frac{i_2}{v_2}\right|_{i_1 = 0}$$

Nomenclature of h-parameters :-



↓

double script notation.

l_1 → denotes nature of parameter whether its i/p impedance, forward current gain, reverse voltage gain or o/p admittance.

l_2 → denotes transistor configuration whether it is CE/CB/CC.

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Ex:-

1) i/p impedance of CE

h_{ie} — i → i/p impedance. e → CE config

2) reverse voltage gain of CB.

h_{rb} — r → reverse voltage gain. b → CB conf.

HW.

3) h_{oc} → ? o/p admittance of cc.

4) h_{fb} → forward current gain of CB.

Equivalent ckt using h-parameters :-

$$v_1 = h_{11} i_1 + h_{12} v_2 \rightarrow (1)$$

$$i_2 = h_{21} i_1 + h_{22} v_2 \rightarrow (2)$$

Rewrite these as

$$v_1 = h_i i_1 + h_r v_2 \rightarrow (3)$$

$$i_2 = h_f i_1 + h_o v_2 \rightarrow (4)$$

For eq (3) & (4) lets draw equivalent ckt seperately

For equivalent ckt of eq/. (3)

Apply KVL.

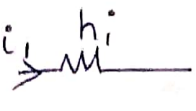
$$v_1 - h_i i_1 - h_r v_2 = 0$$

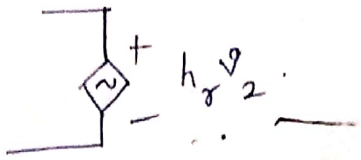
i_1 → direction is clockwise.

$v_1 \Rightarrow$ +v_1− (terminals)

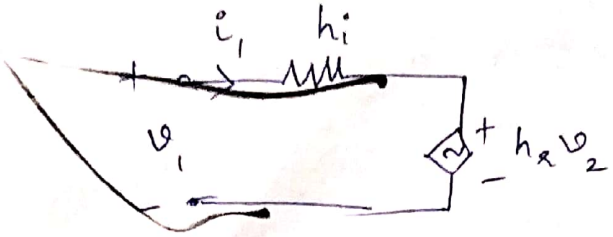
Since the units of equation (3) is volts we apply KVL.

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$h_i i_1 \rightarrow$ 

$h_r v_2 \rightarrow$ 

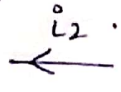
$\therefore$ equivalent ckt



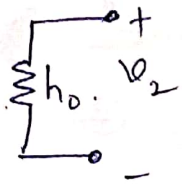
From equation (4)

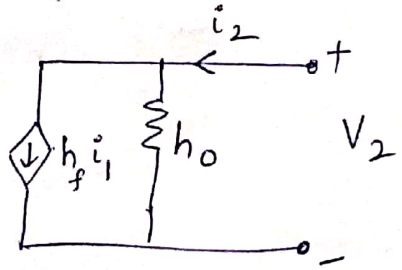
Since equation (4) has ampere (units). So we have units of current. So to obtain the equivalent ckt we need to apply KCL.

$i_2 \rightarrow$ entering current.

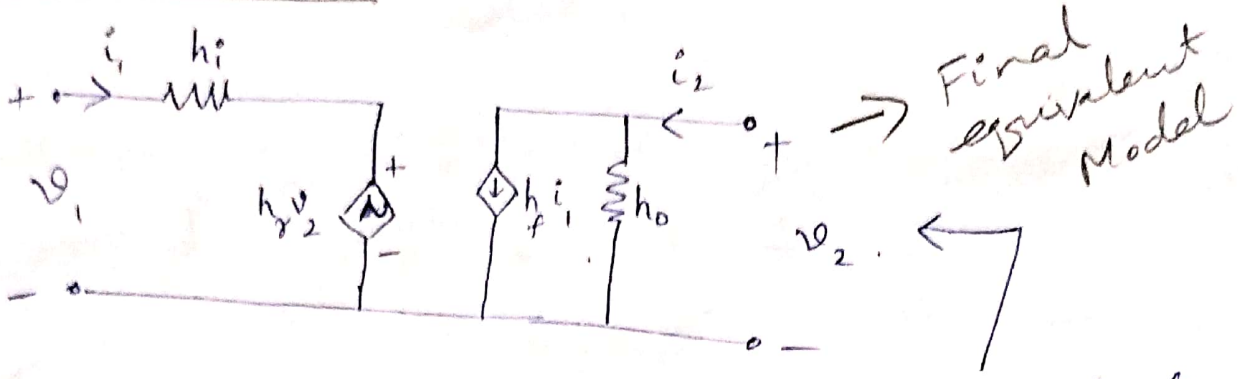
$i_2 \rightarrow$ 

$h_f i_1 \rightarrow$ 

$h_o v_2 \rightarrow$ 

$\therefore$ 

So by combining both the ckts the final equivalent ckt is $v_1 \rightarrow$



∴ Now replace transistor with this equivalent model which is general model.

* If we want about any transistor configuration

CE

$h_i \rightarrow h_{ie}$.

$h_f \rightarrow h_{fe}$

$h_o \rightarrow h_{oe}$

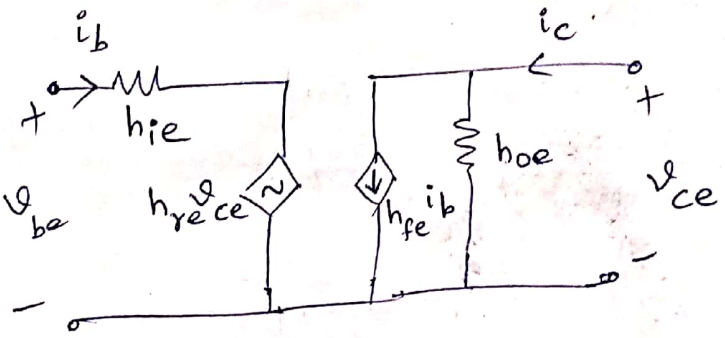
$h_r \rightarrow h_{re}$

i/p current $- i_1 \rightarrow i_b$.

$v_1 \rightarrow v_{be}$.

$i_2 \rightarrow i_c$.

$v_2 \rightarrow v_{ce}$.



for CB.

$h_i \rightarrow h_{ib}$.

for CC

$h_i \rightarrow h_{ic}$.

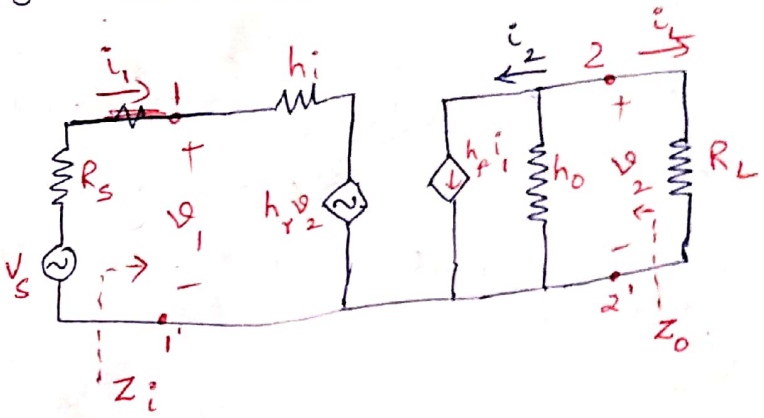
Analysis of transistor Amplifier using h-parameters :-

We need to find expressions for current gain, voltage gain & power gain.

The i/p side im gonna & introduce source voltage V_s and resistance R_s & the o/p side Load resistance R_L & current is i_L through load R_L:

$Z_o \rightarrow$ o/p impedance

$Z_i \rightarrow$ i/p "



* Lets find current gain (A_i)

Current gain = $\frac{\text{output current}}{\text{i/p current}}$

$$A_i = \frac{i_L}{i_1}$$

~~i_L~~ i_2 is opposite to i_L.

$$A_i = -\frac{i_2}{i_1}$$

Voltage drop across R_L is v_2.

$$v_2 = i_L R_L$$

$$= -i_2 R_L$$

Using equation (4) from h-parameters

$$i_2 = h_f i_2 + h_o(-i_2 R_L)$$ (substitute v_2 in $h_o v_2$)

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Add $h_o i_2 R_L$ on both sides.

$$i_2 + h_o i_2 R_L = h_f i_1$$

$$i_2(1 + h_o R_L) = h_f i_1$$

Divide by $1 + h_o R_L$ on both sides

$$i_2 = \frac{h_f i_1}{1 + h_o R_L}$$

Current gain $= \frac{-i_2}{i_1}$

Multiply $\frac{-1}{i_1}$ on both sides.

$$\frac{-i_2}{i_1} = \frac{-h_f}{1 + h_o R_L}$$

$$\boxed{A_i = \frac{-h_f}{1 + h_o R_L}}$$ → True for all 3 configurations.

(ii) Voltage gain (A_v)

$$A_v = \frac{\text{o/p voltage}}{\text{i/p voltage}} =$$

$$= \frac{v_2}{v_1} = \frac{-i_2 R_L}{v_1}$$

A_i (current gain) $= \frac{-i_2}{i_1}$

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$-i_2 = i_1 A_i$

Substitute $-i_2$ value

$$A_v = \frac{i_2 A_i R_L}{v_1}$$

$$= \frac{A_i R_L}{Z_i}$$

$$Z_i = \frac{v_1}{i_1}$$

$$Z_i = h_i - \frac{h_r h_f}{\frac{1}{R_L} + h_o}$$

$$A_i = \frac{-h_f}{1 + h_o R_L}$$

Replace A_i & Z_i

$$A_v = \frac{-h_f R_L}{h_i + (h_i h_o - h_r h_f) R_L}$$

$h_i h_o - h_r h_f = \Delta h$.

$$\boxed{A_v = \frac{-h_f R_L}{h_i + \Delta h R_L}}$$

True for all 3 configurations.

(iii) Power gain (A_p)

A_p = product of voltage gain * current gain.

$$= A_v \times A_i$$

$$= \left(\frac{-h_f R_L}{h_i + \Delta h R_L}\right) \times \left(\frac{-h_f}{1 + h_o R_L}\right)$$

$$\boxed{A_p = \frac{h_f^2 R_L}{(h_i + \Delta h R_L)(1 + h_o R_L)}}$$

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(iv) i/p impedance (Z_i)

& Z_i = impedance seen from terminals 1 & 1'

From ohm's law the i/p voltage $v_i = i_1(Z_i)$

$$Z_i = \frac{v_i}{i_1}$$

Using h - parameter equation (3)

$$v_1 = h_i i_1 + h_r v_2$$

$$= h_i i_1 + h_r(-i_2 R_L)$$

Divide by i_1 on both sides.

$$\frac{v_1}{i_1} = h_i - h_r \frac{i_2}{i_1} R_L$$

$$\left(A_i = -\frac{i_2}{i_1}\right)$$

$$\frac{v_1}{i_1} = h_i + h_r A_i R_L$$

A_i expression.

$$Z_i = h_i + h_r\left(\frac{-h_f}{1+h_o R_L}\right) R_L$$

$$\boxed{Z_i = h_i - \frac{h_r h_f}{\frac{1}{R_L} + h_o}}$$

True for all 3 config.

Sec-C 10|11 →

(v) o/p impedance (Z_o)

Z_o = impedance seen from terminals 2 & 2'.

To calculate Z_o we need to short circuit i/p source i.e V_s & o/p terminal as open ckt.

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Conditions to find Z_o

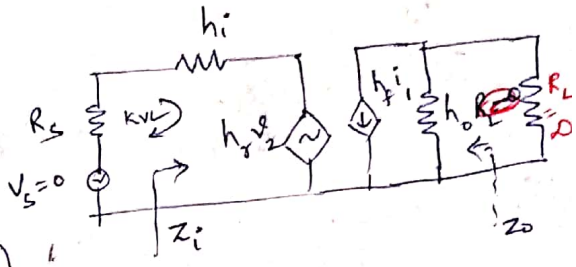
1) $V_s = 0$

2) $R_L = \infty$

Redraw the ckt.

From ohms law $\rightarrow$ o/p impedance $= \frac{v_2}{i_1}$ ($\frac{\text{o/p voltage}}{\text{i/p current}}$)

$$Z_o = \frac{v_2}{i_1}$$



$$i_2 = h_f i_2 + h_o v_2$$

$$Z_o = \frac{v_2}{h_f i_2 + h_o v_2} \rightarrow (1)$$

To find equation (2).

Apply KVL in i/p loop

$$-i_1 R_s - i_1 h_i - h_r v_2 = 0$$

$$i_1 (R_s + h_i) + h_r v_2 = 0$$

$$i_1 = \frac{-h_r v_2}{R_s + h_i} \rightarrow (2)$$

Substitute i_1 value in eq (1).

$$Z_o = \frac{v_2}{h_f \left(\frac{-h_r v_2}{R_s + h_i}\right) + h_o v_2}$$

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$$= \frac{R_s + h_i}{(h_o h_i - h_f h_r) + h_o R_s}$$

$h_o h_i - h_f h_r = \Delta h$

$$\boxed{Z_o = \frac{R_s + h_i}{\Delta h + h_o R_s}}$$

(6) Overall voltage gain (A_{vs})

$$A_{vs} = \frac{\text{o/p voltage}}{\text{Source voltage}}$$

$$A_{vs} = \frac{v_2}{v_s}$$

Multiply by v_1.

$$= \frac{v_2 \cdot v_1}{v_s \cdot v_1}$$

$$= \frac{v_2}{v_1} \cdot \frac{v_1}{v_s}$$

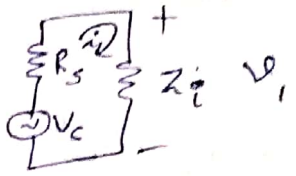
$A_v = \frac{v_2}{v_1}$

$$\boxed{A_{vs} = A_v \cdot \frac{v_1}{v_s}}$$

$Z_i \rightarrow$ i/p impedance

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Redraw the ckt



V_s → Source voltage.

By applying KVL

$$v_s - iR_s - iz_i = 0$$

$$i = \frac{v_s}{R_s + z_i}$$

$$v_1 = i z_i$$

$$= \left(\frac{v_s}{R_s + z_i}\right) z_i$$

$$= \frac{v_s z_i}{R_s + z_i}$$

$$v_1 = \frac{z_i v_s}{R_s + z_i}$$

$$\frac{v_1}{v_s} = \frac{z_i}{R_s + z_i}$$

Substitute $\frac{v_1}{v_s}$ in A_{vs}.

$$A_{vs} = A_v \cdot \frac{v_1}{v_2}$$

$$\boxed{A_{vs} = A_v\left(\frac{z_i}{R_s + z_i}\right)}$$

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When in ideal case voltage source.

V_s - ideal

$R_s = 0$.

Then $\boxed{A_{vs} = A_v}$

(7) Overall current gain (A_{is}).

$$A_{is} = \frac{\text{o/p current}}{\text{current delivered by source}}$$

$$= \frac{i_L}{i_s}$$

Multiply numerator & denominator by i_1.

$$= \frac{i_L}{i_s} \times \frac{i_1}{i_1}$$

$$= \frac{i_2}{i_1} \times \frac{i_1}{i_s}$$

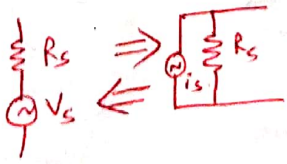
$i_L = -i_2$.

$$= \frac{-i_2}{i_1} \times \frac{i_1}{i_s}$$

$\frac{-i_2}{i_1}$ = current gain.

$$\boxed{A_{is} = A_i \times \frac{i_1}{i_s}}$$

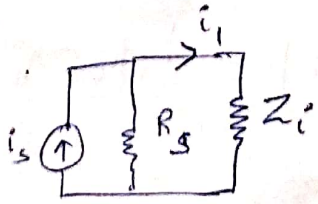
* Convert voltage source to current source



Redraw the ckt

where i_s = source current

R_s is || to i_s



sec-D 10/11

clear one girls doubt

Av

Using current divider rule.

$$i_1 = \frac{i_s R_s}{R_s + Z_i}$$

$$\frac{i_1}{i_s} = \frac{R_s}{R_s + Z_i}$$

Substitute in A_{is}

$$\boxed{A_{is} = A_i \left(\frac{R_s}{R_s + Z_i} \right)}$$

In case of ideal current source.

$$R_s = \infty$$

$$\boxed{A_{is} = A_i}$$

* $\Delta h = h_i h_o - h_f h_r$ (Let's derive this).

From eq ③ & ④ of h-parameters.

$$v_1 = h_i i_1 + h_r v_2 \rightarrow ③.$$

$$\& \; i_2 = h_f i_1 + h_o v_2 \rightarrow ④$$

$$\begin{bmatrix} v_1 \\ i_2 \end{bmatrix}_{2\times1} = \begin{bmatrix} h_i & h_r \\ h_f & h_o \end{bmatrix}_{2\times2} \times \begin{bmatrix} v_2 \\ i_1 \end{bmatrix}_{2\times1}$$

Represent ↑ as D → as h → as I.

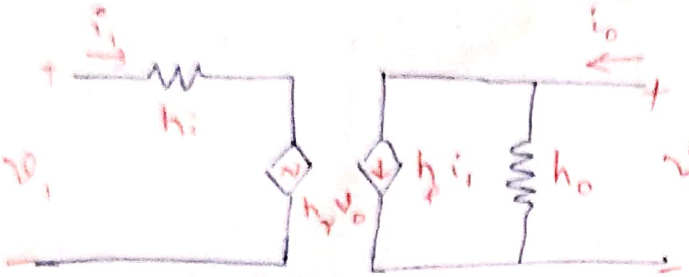
$$\Delta h = |h| = h_i h_o - h_f h_r.$$

Hence proved.

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Simplified hybrid equivalent model or Approximate hybrid equivalent Model

The hybrid Model



→ Let's say this is hybrid equivalent model of CE transistor.

where v_i → i/p voltage

v_o → o/p "

i_i → i/p current

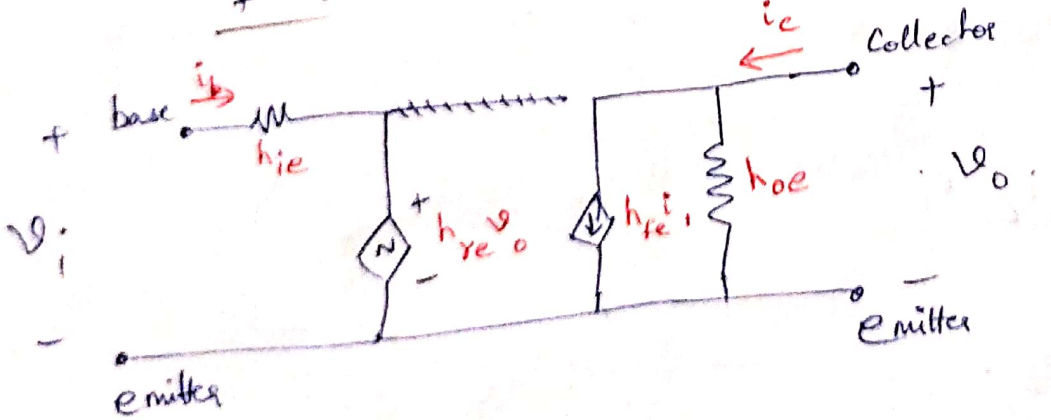
i_o → o/p "

hybrid parameters

- h_i → i/p impedance.
- h_o → o/p admittance.
- h_r → reverse voltage gain.
- h_f → forward current gain.

$h_r v_o$ → voltage dependent voltage source

$h_f i_i$ → current dependent current source



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For CE & CB config. for

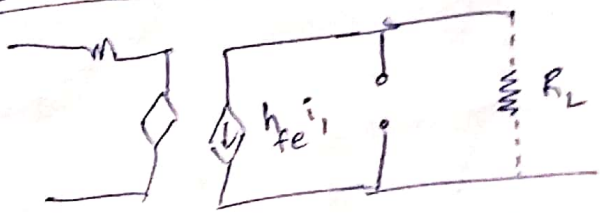
Magnitude of h_r & h_o like the parameters current gain, voltage gain, i/p impedance, o/p impedance are slightly affected if h_r & h_o are not included in ckt.

If we remove h_{re} & h_{oe} from the ckt then the parameters like current & voltage gain & i/p & o/p impedances will not change.

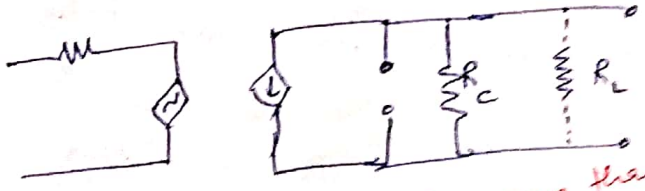
$1/h_o \rightarrow$ o/p impedance & its very large so we neglect it

$1/h_o$ to R_L is again large so we neglect it

$\boxed{\frac{1}{h_o} >> R_L}$ so neglect & represent as open ckt



If transistor connected in fixed bias configuration then is one more resistance || to R_L i.e R_c.



$\frac{1}{h_o} >> R_C \| R_L \rightarrow$ current passes through $R_C \| R_L$ & no current through $\frac{1}{h_o}$

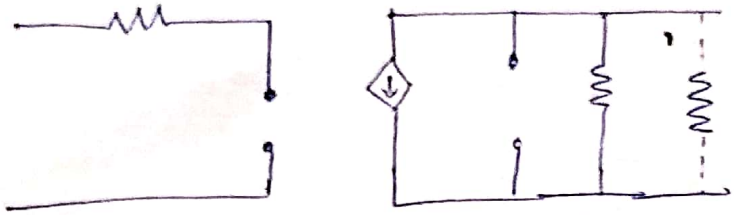
when 2 resistors are parallel then

$R_{eq} <$ Smallest of (R_C, R_L).

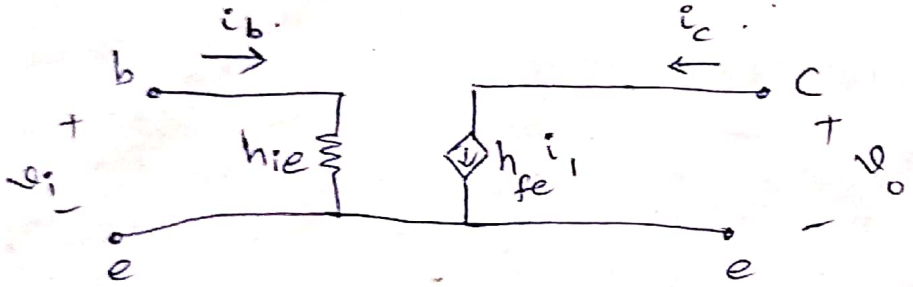
$\therefore$ $h_r = \frac{v_i}{v_o}$ → Small / large

Hence $h_r = \frac{v_i}{v_o} \approx 0$.

& hence $h_{re} v_o = 0$ (for CE)



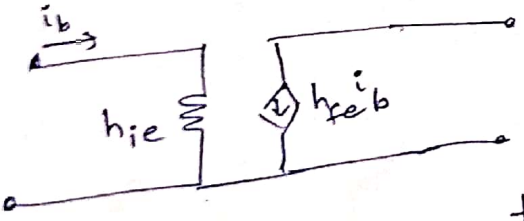
Further rearranging the ckt.



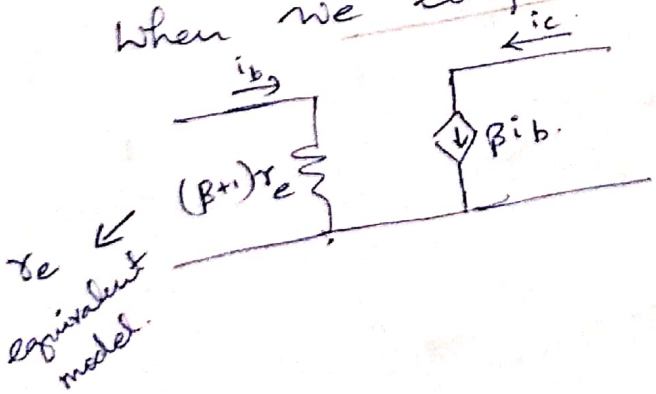
→ This is the Approximate hybrid equivalent Model.

This does not contain $h_{re} v_o$ & h_{oe}

$i_1 = i_b$ (i_1 → i/p current)



When we compare the above ckt with r_e equivalent model.



$h_{ie} = (\beta+1) r_e$.

$= \beta r_e$ ($\because (\beta+1) = \beta$)

$h_{fe} = \beta$

$h_{ie} = \beta r_e$

when we compare hybrid equivalent with r_e equivalent Model.

Conversion of h-parameters

h-parameters for CE

h_{ie}
h_{re}
h_{fe}
h_{oe}

Using this h-parameters for CE we need to find h-parameters for CB → h_{ib}, h_{rb}, h_{fb}, h_{ob}.

* Why we need conversion?

CE is widely used for & manfacturer gives CE value & with the formula we convert to which config. we want to. The formula are impl.. derivation is not required.

CE → CB

$$h_{ib} = \frac{h_{ie}}{1+h_{fe}}$$

$$h_{rb} = \frac{h_{ie}h_{oe}}{1+h_{fe}} - h_{re}$$

$$h_{fb} = \frac{-h_{fe}}{1+h_{fe}}$$

$$h_{ob} = \frac{h_{oe}}{1+h_{fe}}$$

CE → CC

$$h_{ic} = h_{ie}$$

$$h_{rc} = 1 - h_{re}$$

$$h_{fc} = -(1+h_{fe})$$

$$h_{oc} = h_{oe}$$

CB → CC

$$h_{ie} = \frac{h_{ib}}{1+h_{fb}} \qquad h_{oe} = \frac{h_{ob}}{1+h_{fb}}$$

$$h_{re} = \frac{h_{ib}h_{ob}}{1+h_{fb}} - h_{rb}$$

$$h_{fb} = \frac{-h_{fb}}{1+h_{fb}}$$

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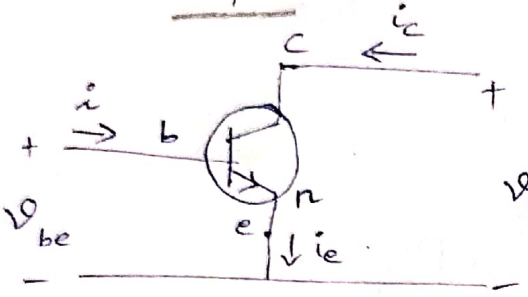
r_e Transistor Model.

→ For low freq. → we have h-parameter & re-model.

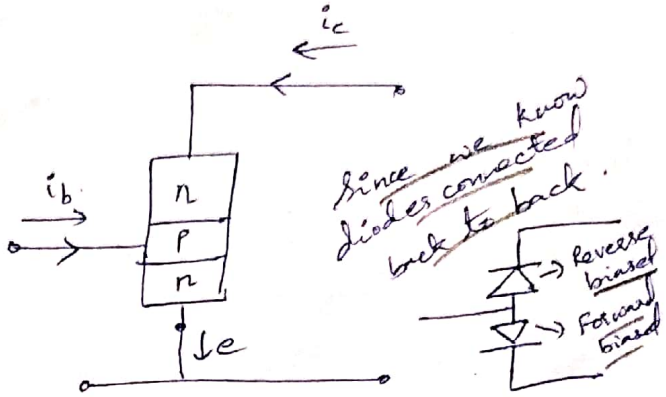
• high " → " " hybrid-π & Y-parameter model.

r_e model for CE

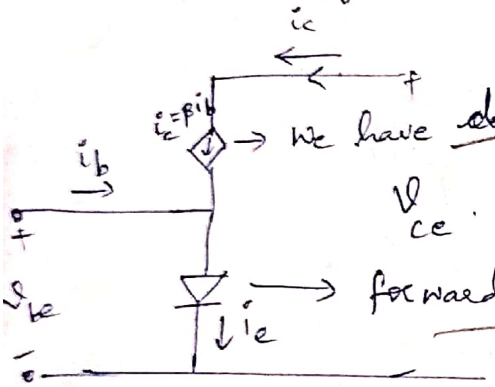
* Emitter is common for i/p & o/p.
* Consider npn.



⇒



As we modify the ckt.



→ We have dependent collector source in collector branch.

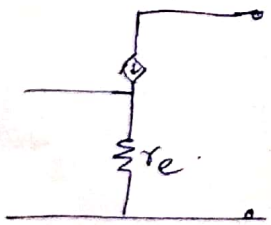
→ forward biased diode in emitter branch.

$$i_c = \beta i_b + I_{CBO}$$

↳ Reverse saturation current.

We neglect this.

Diode replaced with r_e.



$$I_D = I_S \left(e^{\frac{V_D}{\eta V_T}} - 1 \right)$$

We know this

$$\frac{dI_D}{dV_D} = I_S \frac{d}{dV_D}\left(e^{\frac{V_D}{\eta V_T}} - 1 \right)$$

when $\eta = 1$ (ETa)

$$\frac{1}{r_d} = \frac{I_S}{V_T} e^{\frac{V_D}{V_T}}$$

$$\frac{1}{r_d} = \frac{I_D + I_S}{V_T} \Rightarrow \frac{1}{r_d} = \frac{I_D}{V_T}$$

Since I_s → small → Reverse saturation

$$r_d = \frac{V_T}{I_D}$$

At room temp $V_T = 26mV$

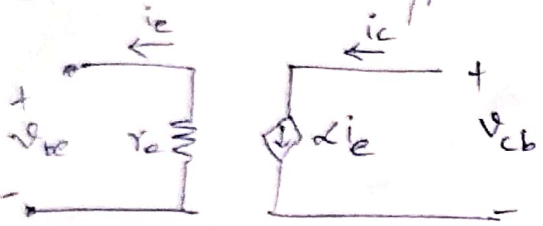
$$r_d = \frac{26mV}{I_D}$$ (Diode current)

$$r_E = \frac{26mV}{I_E}$$ → To calculate I_E → draw DC equivalent ckt

This model is also called T-model.

r_e model for CB

Base common to i/p & o/p



* When we see o/p characteristics

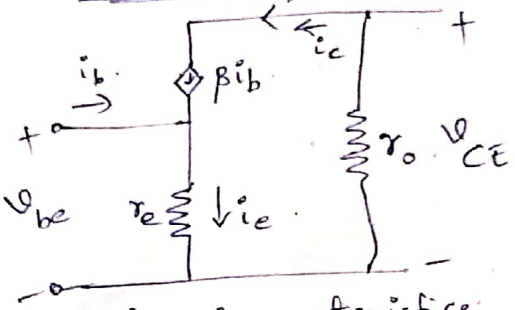
Slope ≈ 0

r_o → o/p resistance.

$$r_o = \frac{1}{\text{slope}} = \frac{1}{0} = \infty$$

So r_o → neglected as no current flows & its open ckt

r_e model for CE



o/p characteristics

Slope ≠ 0.

$I_B \uparrow \Rightarrow \uparrow V_{CE}$

& β is large

$r_o \neq \infty$

but very large.

If in qblm given to neglect neglect else r_o is also the r_e in r_e model for CE.

→ Modification of CE r_e model

$$i_e = i_b + i_c$$

$$i_c = \beta i_b$$

$$i_e = i_b + \beta i_b$$

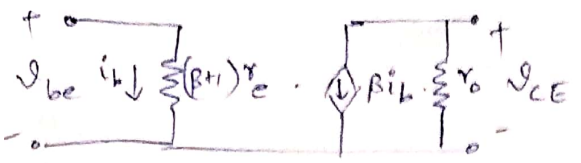
$$= (\beta+1) i_b$$

Drop across $r_e = r_e \cdot i_e$

$$= r_e \cdot (\beta+1) i_b$$

To seperate i/p & o/p → we need resistance $(\beta+1) r_e$ & current is i_b

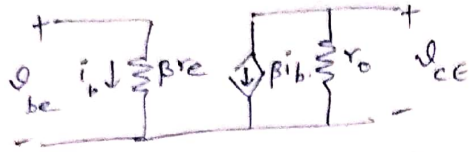
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→ This is r_e model for CE.

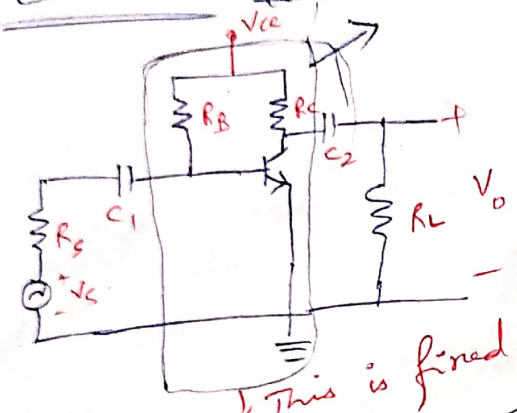
$(\beta+1) \approx \beta$

$(\beta+1) r_e \approx \beta r_e$



→ This is r_e final model for CE

r_e model – (Fixed Bias Config)



We need to find.

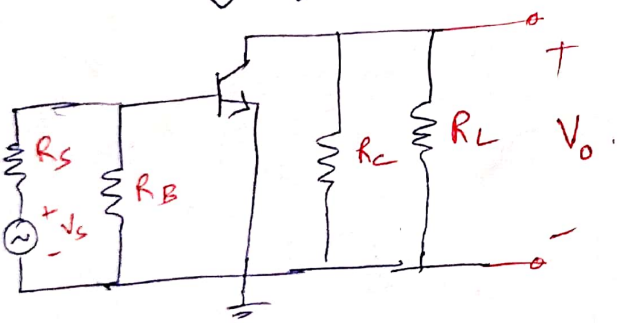
a) ac equivalent ckt.

b) Replace transistor with r_e model.

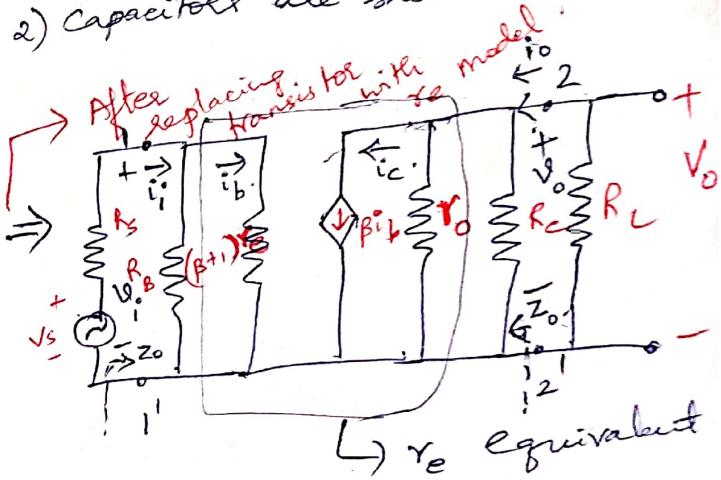
Ac equivalent model

1) DC sources → short ckt

2) Capacitors are short ckt



After this



↳ r_e equivalent model of transistor

Calculate i/p & o/p impedances

i/p voltage from 1 & 1' = V_i

o/p " " 2 & 2' = V_o.

$$Z_i = \frac{V_i}{i_i} = R_B \parallel (\beta+1) r_e$$

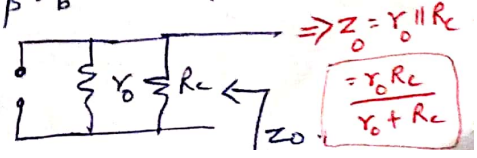
$$\boxed{Z_i = \frac{R_B (\beta+1) r_e}{R_B + (\beta+1) r_e}}$$

$$Z_o = \frac{V_o}{i_o}$$ (short ckt V_s & R_L = open ckt).

$V_s = 0 \Rightarrow V_i = 0V \Rightarrow i_b = 0A \Rightarrow i_c = 0$

$R_L = \infty$.

So βi_b is open ckt.



$\Rightarrow Z_o = r_o \parallel R_C$

$= \frac{r_o R_C}{r_o + R_C}$

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If $(\beta+1) \approx \beta$.

$(\beta+1) r_e \approx \beta r_e$.

If $R_B \geq 10(\beta+1) r_e$

$$Z_i = \frac{R_B \cdot (\beta+1) r_e}{R_B}$$

$\boxed{Z_i = (\beta+1) r_e}$ when $R_B \geq 10(\beta+1) r_e$.

In case of CE.

$r_o > 10 R_C$.

$$Z_o = \frac{r_o \cdot R_C}{r_o}$$

$\boxed{Z_o = R_C}$ when $r_o \geq 10 R_C$.

Current gain (A_i) =

$$A_i = \frac{i_o}{i_i}$$

Use current divider rule.

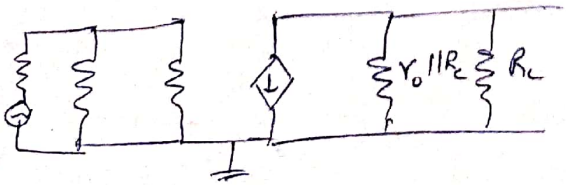
current divided when resistance are ||el.



$$I_2 = \frac{I R_1}{R_1 + R_2}$$

$$I_1 = \frac{I R_2}{R_1 + R_2}$$

In place of r_o & R_C we will have 1 resistance $r_o \| R_C$.



$$i_o = \frac{i_c (r_o \| R_C)}{r_o \| R_C + R_L}$$

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$i_c = \beta i_b$

$$A_i = \frac{\beta i_b (r_o \| R_c)}{r_o \| R_c + R_L} \cdot \frac{1}{i_i}$$

$$i_b = \frac{i_i R_B}{(R_B + \beta + 1) r_e}$$ (current divider rule on i/p side

$$A_i = \frac{\beta \left(\frac{i_i R_B}{R_B + (\beta+1) r_e}\right)\left(\frac{r_o \| R_c}{r_o \| R_c + R_L}\right)}{i_i}$$

$$\boxed{A_i = \beta \left(\frac{R_B}{R_B + (\beta+1) r_e}\right)\left(\frac{r_o \| R_c}{r_o \| R_c + R_L}\right)}$$

Case ①

$r_o \geq 10 R_C$

$r_o \| R_c = R_c$

$$A_i = \beta \left(\frac{R_B}{R_B + (\beta+1) r_e}\right)\left(\frac{R_c}{R_c + R_L}\right)$$

Case ②

R_B & $R_c = \infty$

No R_B & R_c means no fixed bias config/-

$r_o < R_c$

$r_o \| R_c = r_o$

$$A_i = \beta \left(\frac{R_B}{R_B}\right)\left(\frac{r_o}{r_o + R_L}\right) \Rightarrow A_i = \beta \left(\frac{r_o}{r_o + R_L}\right)$$

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Overall current gain (A_{is}):

$$A_{is} = \frac{i_o}{i_s} = A_i \left(\frac{R_s}{R_s + Z_i} \right)$$

↳ from h-parameters.

Voltage gain (A_v).

$$A_v = \frac{v_o}{v_i}$$

$$v_o = -i_o R_L .$$

Apply KVL in this loop (R_L, i_o, v_o). Apply KVL.

$$-i_o R_L - v_o = 0$$

$$v_o = -i_o R_L .$$

$$i_o = \frac{i_c (r_o \| R_L)}{r_o \| R_c + R_L} \quad \text{(from current divider rule)}$$

$$i_c = \beta i_b .$$

$$v_o = -\beta i_b \left(\frac{r_o \| R_c}{r_o \| R_c + R_L} \right) R_L$$

$$v_i = i_b (\beta + 1) r_e .$$

$$A_v = \frac{-\beta i_b \left(\frac{r_o \| R_c}{r_o \| R_c + R_L} \right) R_L}{i_b (\beta + 1) r_e}$$

$$\boxed{A_v = \frac{-\beta (r_o \| R_c \| R_L)}{(\beta + 1) r_e}}$$

$\frac{R_1 R_2}{R_1 + R_2} = R_1 \| R_2$ ↓ ↘ R_L

$\therefore r_o \| R_c$.

Case (1):

Neglect β as $\beta + 1 \approx \beta$:

$$A_v = \frac{-\beta (r_o \| R_c \| R_L)}{\beta r_e} = \boxed{\frac{-(r_o \| R_c \| R_L)}{r_e} = A_v}$$

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Case 2

$r_o \geq 10 R_c$

$$A_v = -\frac{R_c \| R_L}{r_e}$$

Case ③

$R_L = \infty \quad \therefore >> R_c$

$$A_v = -\frac{R_c}{r_e}$$

Overall voltage Gain (A_{vs})

$$A_{vs} = \frac{V_o}{V_s}$$

$$A_{vs} = A_v \left(\frac{Z_i}{Z_i + R_s} \right)$$

-ve sign in voltage gain.

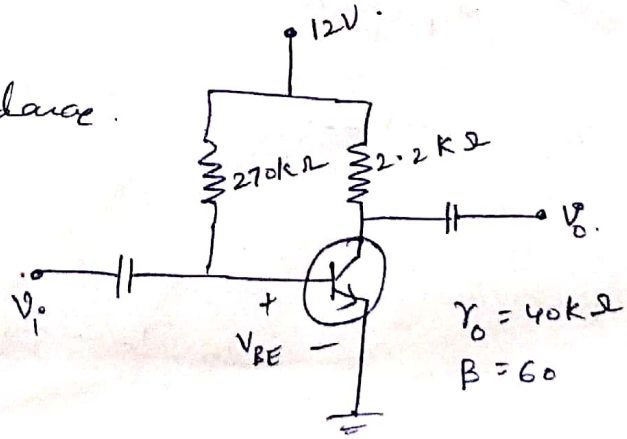
$$A_v = -\frac{\beta (r_o \| R_c \| R_L)}{(\beta+1) r_e}$$

-ve sign represents 180° phase shift btw o/p & i/p voltage

Ex:-

For the network shown:

1) Determine i/p & o/p impedance.
2) " voltage gain
3) " current gain



Sol:- $R_B = 270k\Omega$

$R_C = 2.2k\Omega$

$\beta = 60 \quad r_o = 40k\Omega$

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$$r_e = \frac{26mV}{I_E}$$

Apply KVL in i/p loop

$$12V - I_B R_B - V_{BE} = 0V$$

$$I_B = \frac{12V - V_{BE}}{270K\Omega}$$

$$= \frac{12V - 0.7V}{270K\Omega} = 0.04185\,mA$$

$$= 41.85\,\mu A$$

$$I_E = I_C + I_B$$

$$= \beta I_B + I_B$$

$$= (\beta+1) I_B$$

$$= (60+1)\, 41.85\,\mu A$$

$$= 2552.85\,\mu A$$

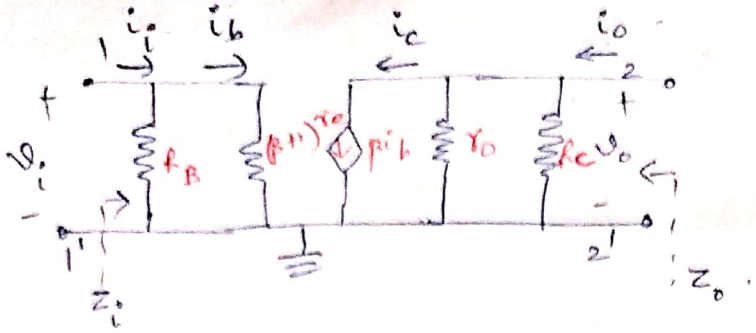
$$= 2.553\,mA$$

$$r_e = \frac{26mV}{2.553mA}$$

$$r_e = 10.18\,\Omega$$

(i) To find AC equivalent ckt replace transistor with r_e equivalent model.

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$$Z_i = R_B \parallel (\beta+1) r_e$$

$$= \frac{R_B(\beta+1)r_e}{R_B + (\beta+1)r_e}$$

$$= \frac{(270k\Omega)(0.621k\Omega)}{270k\Omega + 0.621k\Omega}$$

$$= 0.6195\ k\Omega$$

$$= 619.5\ \Omega$$

$(\beta+1)r_e$
$= 61 \times 10.18\ \Omega$
$= 0.621\ k\Omega$

If $R_B \geq 10(\beta+1)r_e$

Then we can neglect R_B & Z_i is

$$Z_i = (\beta+1) r_e$$

$$Z_i = 0.621\ k\Omega$$

$$= 621\ \Omega$$

∴ Both are nearly same.

Z_o

$$Z_o = r_o \parallel R_C$$

$$= 40\ k\Omega \parallel 2.2\ k\Omega$$

$$Z_o = 2.085\ k\Omega$$

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$10 R_C = 2.2\,k\Omega < r_o$. then neglect r_o.

$$Z_o = R_C = 2.2\,k\Omega.$$

Both are nearly same.

(ii)

$$A_v = \frac{v_o}{v_i}$$

$$= -\frac{\beta i_b R_C}{i_b(\beta+1) r_e}$$

If $(\beta+1) \approx \beta$

$$A_v = -\frac{R_C}{r_e}$$

$$= -216.1$$

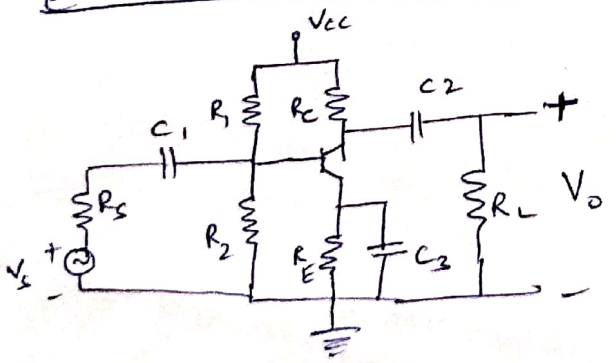
This is ccs of 180° phase shift.

(iii) $A_i = \frac{i_o}{i_i}$

H.W

$$=$$

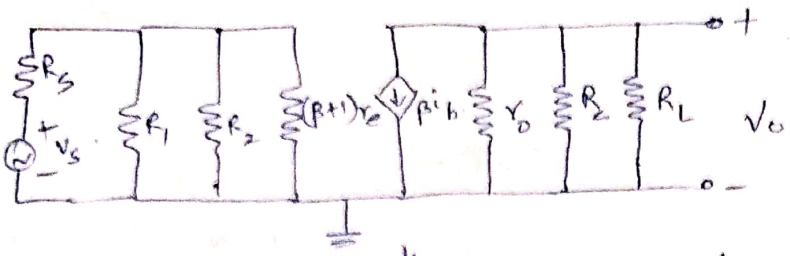
r_e Model with Voltage - Divider Bias :-

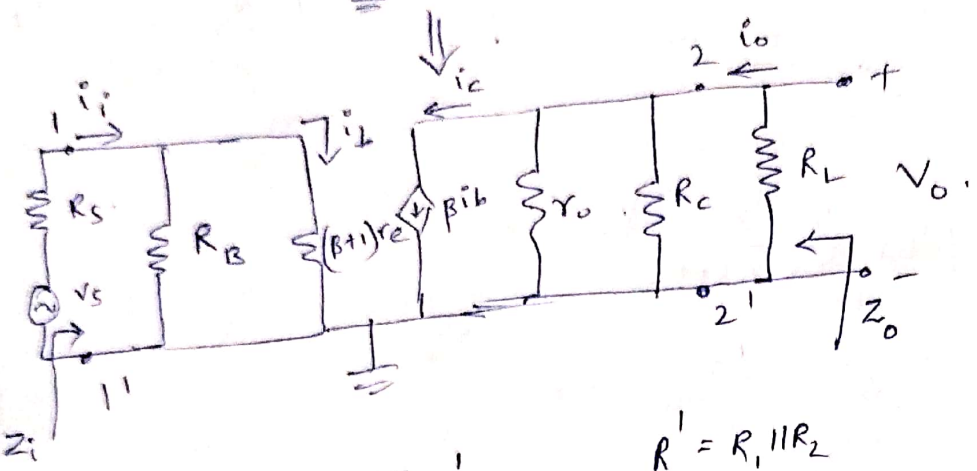


* To calculate the parameters we need to

1) find Ac equivalent model ckt
2) transistor replaced with r_e model.

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$$Z_i = (\beta+1) r_e \,//\, R'$$

$$R' = R_1 // R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

If β is large

$(\beta+1) \approx \beta$

$$\boxed{Z_i = \beta r_e // R'}$$

Z_o $\pm$ $-$

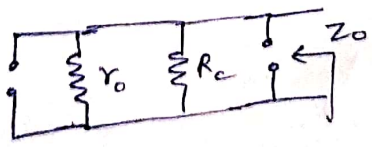
open ckt R_L

$R_L = \infty$

$V_S = 0 \Rightarrow i_b = 0$.

When $i_b = 0 \Rightarrow i_c = \beta i_b = 0$.

By Modifying the above conditions.



$$Z_o = r_o // R_c$$

$$= \frac{r_o R_c}{r_o + R_c}$$

If $r_o \geq 10 R_c$ we neglect r_o

$$\boxed{Z_o = R_c}$$

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Voltage gain (A_v)

$$A_v = \frac{v_o}{v_i}$$

$$v_o = -i_o R_L$$

By using current divider rule. $\left(i_o = -i_c \left(\frac{r_o \| R_c}{r_o \| R_c + R_L}\right) R_L\right.$.

$$= -\beta i_b \left(\frac{r_o \| R_c}{r_o \| R_c + R_L}\right) R_L$$

$r_o \geq 10 R_c$ we neglect R_c.

$$= -\beta i_b \left(\frac{R_c}{R_c + R_L}\right) R_L.$$

If $R_L >> R_C$ we neglect R_c from denominator)

$$= -\beta i_b \left(\frac{R_c}{R_L}\right) R_L$$

$$v_o = -\beta i_b R_c.$$

$$v_i = i_b (\beta + 1) r_e$$

$$A_v = \frac{-\beta i_b R_c}{i_b (\beta + 1) r_e}$$

$$= \frac{-\beta R_c}{(\beta + 1) r_e}$$

we know $(\beta + 1) \approx \beta$.

$$\boxed{A_v = \frac{-R_c}{r_e}}$$

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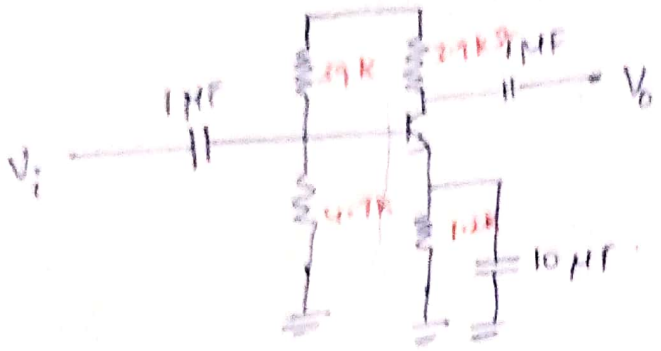
Ex:- r_e model

i) Determine r_e

b) Z_i, Z_o

c) A_v

d) A_i



Sol:-

$r_o = 50k$

$C_3 = 10\mu F$

$R_E = 1.2k$

$R_2 = 4.7k$

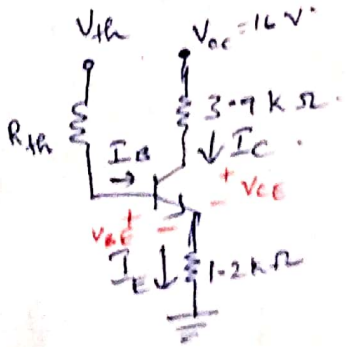
$\beta = 100$

a) $r_e = \frac{26mV}{I_E}$.

In case of DC analysis

$X_C = \infty$ Hence $C_1, C_2, C_3 \rightarrow$ open ckt).

Now find thevenins eq^t. ckt because we have voltage divider bias.



$V_{th} = \frac{R_2 V_{cc}}{R_1 + R_2} = 1.72\,V$

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

$= 4.194\,k\Omega$

Apply KVL in i/p loop

$V_{th} - I_B R_{th} - V_{BE} - I_E (1.2k) = 0$

$I_E = I_C + I_B$

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$I_c = \beta i_b$.

$I_E = (\beta+1) I_B$.

$V_{th} - I_B R_{th} - V_{BE} - (\beta+1) I_B (1.2k) = 0$.

$$I_B = \frac{V_{th} - V_{BE}}{R_{th} + (\beta+1)(1.2k)}$$

$= 8.134\ \mu A$ (micro Amps)

$I_c = \beta i_b$.

$= 100 \times 8.134$.

$= 813.4\ \mu A$.

$I_E = I_c + I_B$

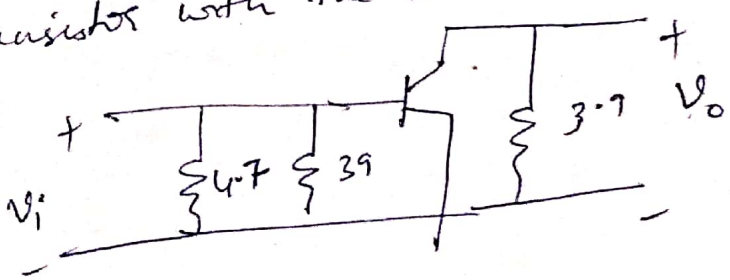
$= 0.821\ mA$.

$$r_e = \frac{26mv}{0.821\ mA}$$

$= \underline{31.6\ \Omega}$

(ii) To find Z_i & Z_o

We need to find AC equivalent ckt & replace transistor with the model.

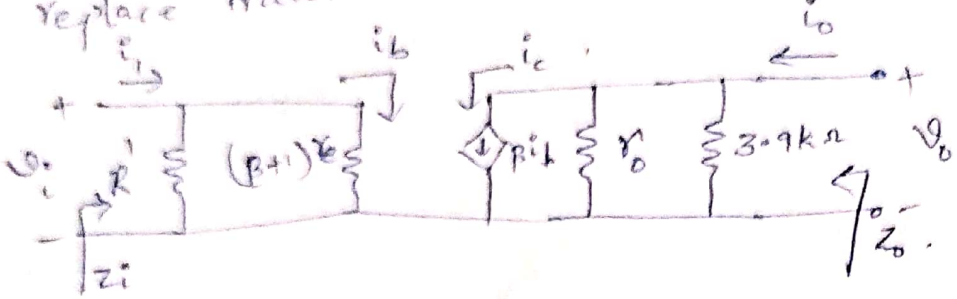


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$R' = 4.7 \parallel 39$

$= 4.19\,k\Omega = R_{Th}$

replace transistor with r_e model



$Z_i = R' \parallel (\beta+1) r_e$

$(\beta+1) r_e \approx 3.19\,k\Omega$

$R' = 4.19\,k\Omega$

$R' \geq 10(\beta+1) r_e$

$$Z_i = \frac{R'(\beta+1) r_e}{R' + (\beta+1) r_e} = 1.811\,k\Omega$$

Z_o

$Z_o = r_o \parallel 3.9\,k\Omega$

$r_o = 50\,k\Omega$ (given in pblm)

$r_o \geq 10 R_c$ we neglect R_c

$r_o \geq 3.9\,k$

$\therefore Z_o = 3.9\,k\Omega$

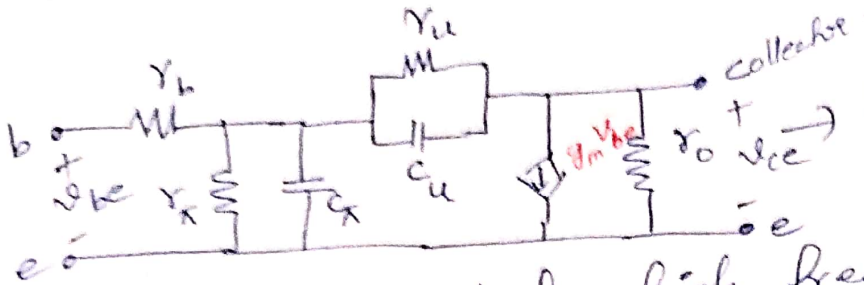
H.W

c) A_{vo} =

d) A_i =

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Hybrid - π



→ Full hybrid π - model.

* It can be used for high freq small s/g & doing some modifications we can also use for small freq small s/g.

* We include parameters which are not seen in hybrid or r_e model so it can be used for high freq.. as well.

* This ckt was given by L.J. Jacques Alito in 1969.

* Also called Jackal Alitho model.

* C_μ → introduced to represent early effect and it is usualy gust ca few pico farad to a few tenths of picofarad

C_π → diffussion capacitance that represents the minority carrier storage in base region & less than 1 pico farad to few pico farad.

r_b → includes resistance due to base connection r_b is very small & can be replaced by short ckt it is

r_π → i/p resistance & the resistance btw base & emitter terminal

$r_\pi = \beta r_e$.

When we compare it with r_e model.

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$= (\beta+1) r_e$

$(\beta+1) \propto \beta$

$r_\pi = \beta r_e$.

$r_\mu \rightarrow$ resistance btw base & collector terminal, because of this fact we call this terminal resistance btw base & collector terminal.

$r_\mu \rightarrow$ large so we can replace with open ckt

$r_o \rightarrow$ o/p resistance.

We have voltage dependent current source ($g_m v_{be}$)

If we have such type then its called as VCCS

Voltage controlled current source.

& If we have βi_b in place of $g_m v_{be}$ then its

CCCS $\rightarrow$ current controlled current source.

$$g_m \text{ (transconductance)} = \left.\frac{i_{out}}{v_{in}}\right|_{v_{out}=0}$$

In case of CE

o/p current $= i_c$.

$$g_m = \left.\frac{i_c}{v_{be}}\right|_{v_{ce}=0}$$

when we simply $\Rightarrow \frac{I_C}{V_T}$ $\rightarrow$ DC collector current

$V_T \rightarrow 26mV$

$$\therefore g_m = \frac{I_C}{V_T} = \frac{I_C}{26mV}$$

In r_e model of transistor.

$$r_e = \frac{26mV}{I_E}$$

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$I_E \approx I_C$.

$r_e = \frac{26mV}{I_C}$.

$\therefore \boxed{g_m = \frac{1}{r_e}}$ → Relation b/w transconductance & emitter dynamic resistance.

$r_\pi = \beta r_e$.

$r_\pi = \frac{\beta}{g_m}$ $\Rightarrow \boxed{g_m r_\pi = \beta}$.

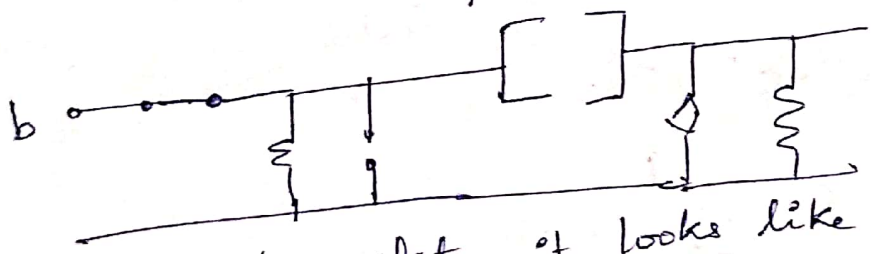
$\boxed{r_o = \frac{1}{h_{oe}}}$ where h_{oe} → o/p admittance of CE.

for using it for small freq s/g.

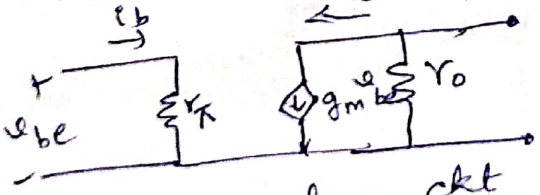
Since r_b is very small replace with short ckt.

r_u → very large replace with open ckt.

C_π & C_u → have high reactances replace with open ckt

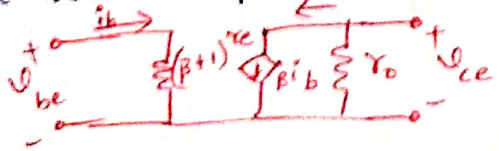


If we redraw the ckt it looks like.



→ Simplified hybrid π low freq model. (used for problems)

When we compare above ckt with re transistor model.



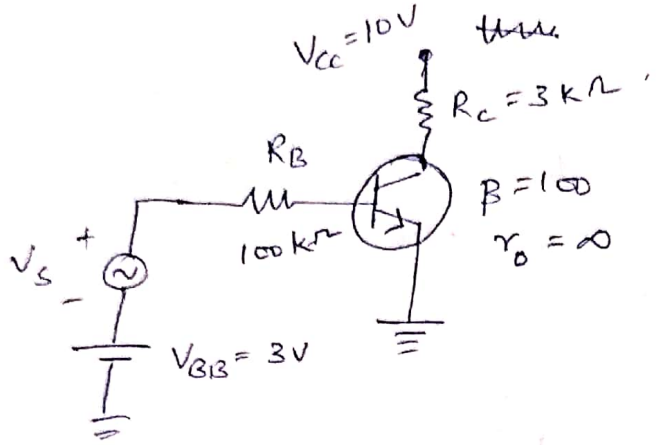
$(\beta+1)r_e \rightarrow r_\pi$.

$\beta i_b \rightarrow g_m v_{be}$.

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Ex:-

Determine voltage gain of amplifier



Sol:-

$A_v = ?$

$R_s = 0\ \Omega$.

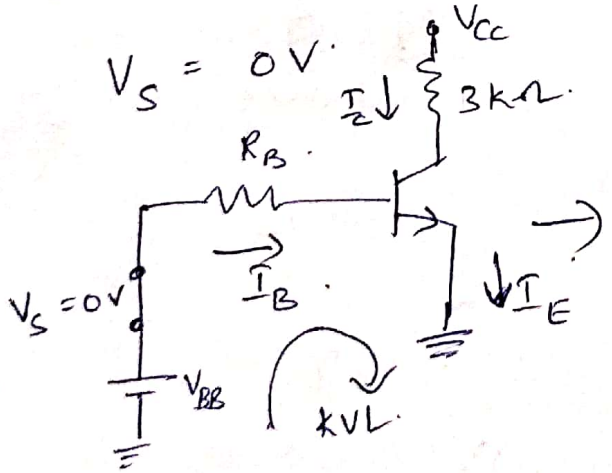
Using hybrid-π model as transistor equivalent model

For that we need (DC collector current I_C)

because $g_m = \frac{I_C}{V_T}$ & $r_\pi = \frac{\beta}{g_m}$.

DC analysis to get I_C.

1) short AC voltages.
2) open ckt all capacitors.



→ DC equivalent ckt.

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KVL in i/p loop

$$0V + 3V - 100k(I_B) - V_{BE} = 0$$

$$I_B = \frac{3V - 0.7V}{100k}$$

$$= 0.023\,mA \text{ or } 23\mu A$$

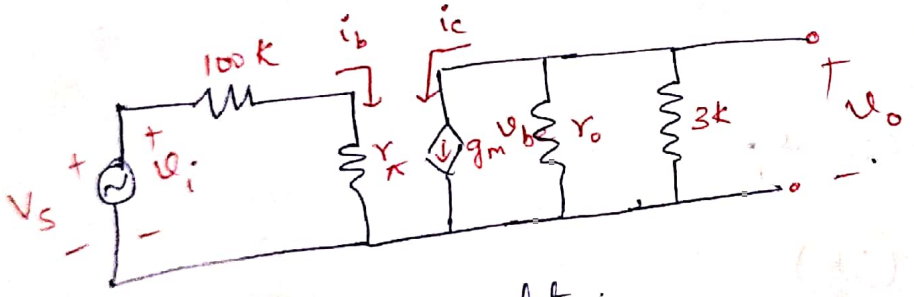
$$I_C = \beta i_b$$

$$= 100 \times 23\mu A$$

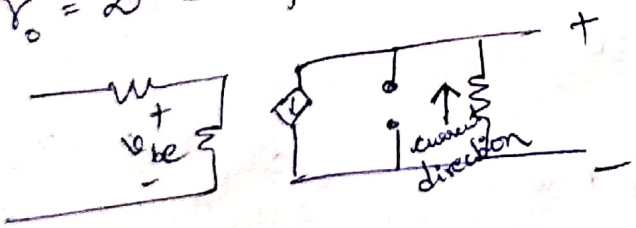
$$= 2.3\,mA$$

Now for AC analysis → we need to do AC equivalent model

1) Short ckt all DC sources (V_{CC}, V_{BE})
2) Short ckt all capacitors.
3) Replace transistor with hybrid model.



$r_o = \infty$ So open ckt.



$$g_m = \frac{2.3mA}{26mV} \quad \left(\frac{I_C}{V_T} = g_m\right)$$

$$= 88.4\,mA/volt$$

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

$$= \frac{100}{88.4\ mA/volt}$$

$$= 1.131\ k\Omega.$$

$$A_v = \frac{v_o}{v_i}$$

$$v_{be} = \frac{v_i\, r_\pi}{100k + r_\pi}$$ (using voltage divider rule)

$v_s = v_i$.

$r_\pi = 1.31\ k\Omega$

$$= \frac{v_i (1.131\ k\Omega)}{100\ k\Omega + 1.131\ k\Omega}.$$

$$= 0.0112\, v_i$$

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

$$= -g_m v_{be} \times 3k\Omega$$

$$= -(88.4\ mA/volt)(0.0112 v_i) \times 3k\Omega$$

$$= -2.970 v_i$$

Divide by v_i on b.s.

$$\frac{v_o}{v_i} = \frac{-2.970\, v_i}{v_i}$$

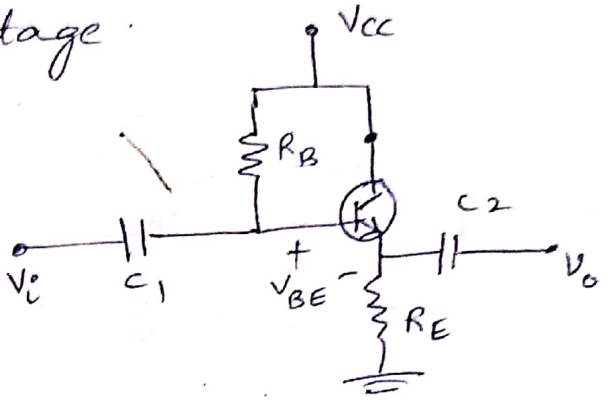
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$$\frac{V_o}{V_i} = -2.970$$

$$A_v = -2.970$$

Emitter Follower Configuration

In this instead of taking o/p from collector terminal we are taking from emitter terminal. We are using CE transistor & we need to find o/p voltage V_o & V_i → i/p voltage.



To obtain o/p V_o

Apply KVL

$$V_i - V_{BE} = V_o$$

$$V_o \approx V_i \quad \left(\text{Because } V_{BE} = 0.7V \text{ or } 0.3V \text{ which is very small}\right).$$

$$A_v = \frac{V_o}{V_i}$$

$$\boxed{A_v \approx 1} \quad (\because \text{Voltage gain} = 1)$$

Why this named as emitter follower

1) i/p & o/p has 180° phase shift. (when o/p at collector terminal)
2) but V_o & V_i have same phase shift & not 180° phase shift. when o/p is taken at emitter.

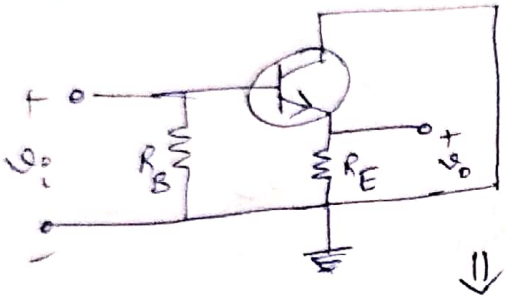
Hence we call emitter follower config.

* We use this ckt for impedance matchings
* High impedance at i/p ($Z_i \uparrow$)
  Low " " o/p ($Z_o \downarrow$)

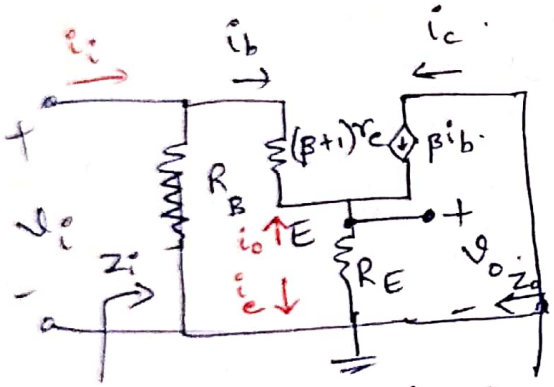
To obtain AC equivalent ckt of CE

1) Short DC source
2) Short capacitors

* We don't have any bypass capacitor, if we have then R_E is short ckt & $V_o = 0$. So we don't have bypass capacitor.



→ Replace transistor with re equivalent model.



→ AC equivalent ckt of CE

We know $(\beta+1)r_e \approx \beta r_e$

$$Z_i = R_B \parallel (\beta r_e + R_E)$$

↳ But this is not right.

Cos current in βr_e is i_b & R_E is i_e.

So these 2 resistors are not connected in series since currents are diff.

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* If we want the 2 resistors in series we need to do certain modifications.

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

$$= i_e R_E$$

$$= i_b (\beta+1) R_E$$

So instead of R_E we can have $(\beta+1) R_E$ so that current i_b only flows through R_E & βr_e.

$$Z_i = R_B \,||\, (\beta r_e + (\beta+1) R_E)$$

Since $\beta \rightarrow$ large

$$\beta+1 \approx \beta$$

$$Z_i = R_B \,||\, (\beta r_e + \beta R_E)$$

$$= R_B \,||\, \beta (r_e + R_E)$$

$R_E >> r_e$. So we neglect r_e.

$$Z_i = R_B \,||\, \beta R_E$$

$$= \frac{\beta R_E R_B}{R_B + \beta R_E}$$

<u>Z0</u> Apply KVL to find i_b.

$$i_b = \frac{V_i}{\beta r_e + \beta R_E} \qquad i_e = (\beta+1) i_b$$

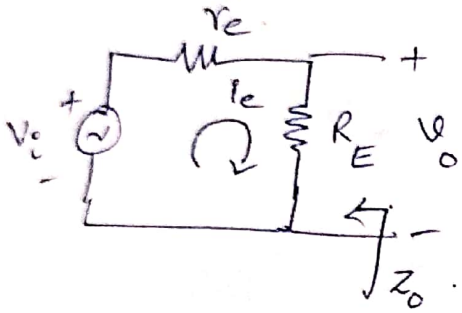
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$$i_e = \frac{(\beta+1)v_i}{\beta r_e + \beta R_E} \qquad (\because \beta+1 \approx \beta)$$

$$= \frac{\beta(v_i}{\beta(r_e + R_E)}$$

$$i_e = \frac{v_i}{r_e + R_E}$$

using this equation we can draw a network.



To calculate Z_o, make $V_i = 0$.

$$Z_o = r_e \,||\, R_E$$

$$= \frac{r_e R_E}{r_e + R_E}$$

$R_E >> r_e$ neglect r_e in denominator.

$$Z_o = \frac{r_e R_E}{R_E}$$

$$\boxed{Z_o \simeq r_e}$$

Using the above ckt we can find voltage gain.

$$A_v = \frac{v_o}{v_i}$$

$$v_o = i_e R_E$$

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$$i_e = \frac{v_i}{r_e + R_E} \quad \text{(We know this).}$$

$$v_o = \frac{v_i}{R_E + r_e} \times (R_E).$$

Divide $\frac{}{v_i}$ on b.s.

$$\frac{v_o}{v_i} = \frac{R_E}{R_E + r_e}.$$

$$A_v = \frac{R_E}{r_e + R_E}$$

$R_E \rightarrow$ emitter resistance.

$r_e \rightarrow$ dynamic emitter resistor

$$R_E >> r_e.$$

$$A_v = \frac{R_E}{R_E}.$$

$$\boxed{A_v \simeq 1}$$

Two port systems Approach :-

For BJT we obtained Z_i, Z_o, A_v & A_i. till now: But if you don't know the circuitry how will you find the parameters ??. In general you will have packaged product when you're an engineer.

↳ you will have amplifier + voltage gain + i/p & o/p impedances.

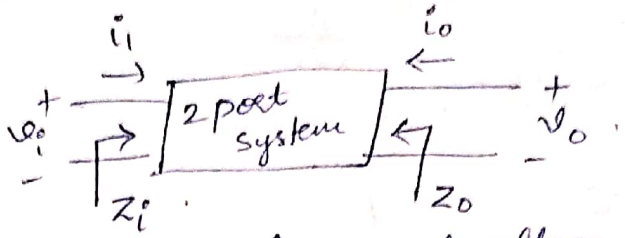
* The voltage gain, i/p & o/p impedances are calculated at no load so its $A_{v_{NL}}$.

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By this approach we don't need to know the ckt & what elements are used in the amplifier ckt.

Adv:

1) No worry about ckt elements
2) A_L & R_S can be obtained.



$$A_{v_{NL}} = \frac{\text{o/p voltage}}{\text{i/p voltage}}$$

$$v_o = A_{V_{NL}} \times v_i$$

We need to use thevenins ckt & we get

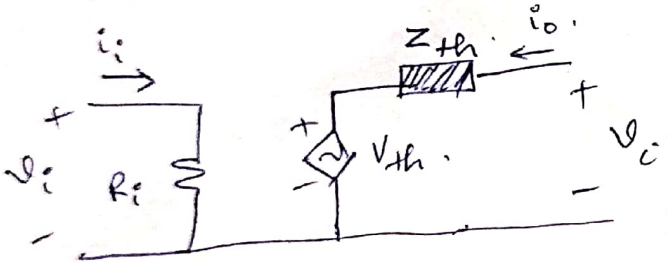
$$Z_{th} = Z_o$$

$$V_{th} = v_o$$

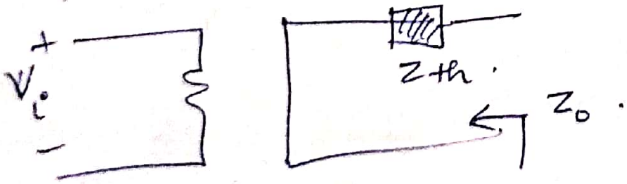
$$v_{th} = A_{V_{NL}} \times v_i$$

Now we can draw thevenins equivalent ckt.

v_{th} → Voltage dependent voltage source.



$v_i = 0V \Rightarrow V_{th} = 0V$



$$Z_o = Z_{th} = R_o$$