$$R_i = h_{ie} - \frac{h_{fe} h_{re} r_L}{1 + h_{oe} r_L} = 995.45$$

$A_v = -45.65$

$R_o = 10.2K\Omega$

$R_{os} = R_o \| r_L = 911\Omega$

$$\frac{A_i \, r_L}{R_i + R_s}$$

$$A_{vs} = \frac{A_i \cdot r_L}{R_i + R_s} = -22.63$$

$$A_{is} = \frac{A_i \times R_s}{R_s + R_i}$$

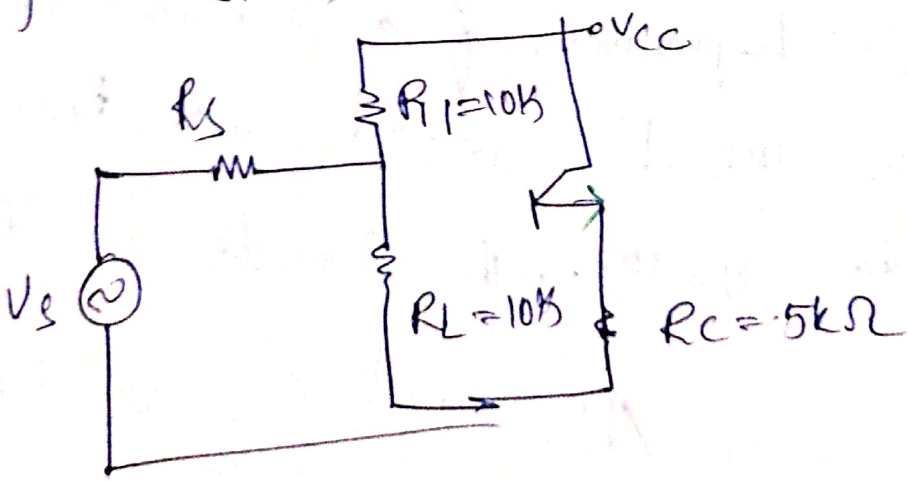
$\boxed{R_{os} = R_o \| r_L}$

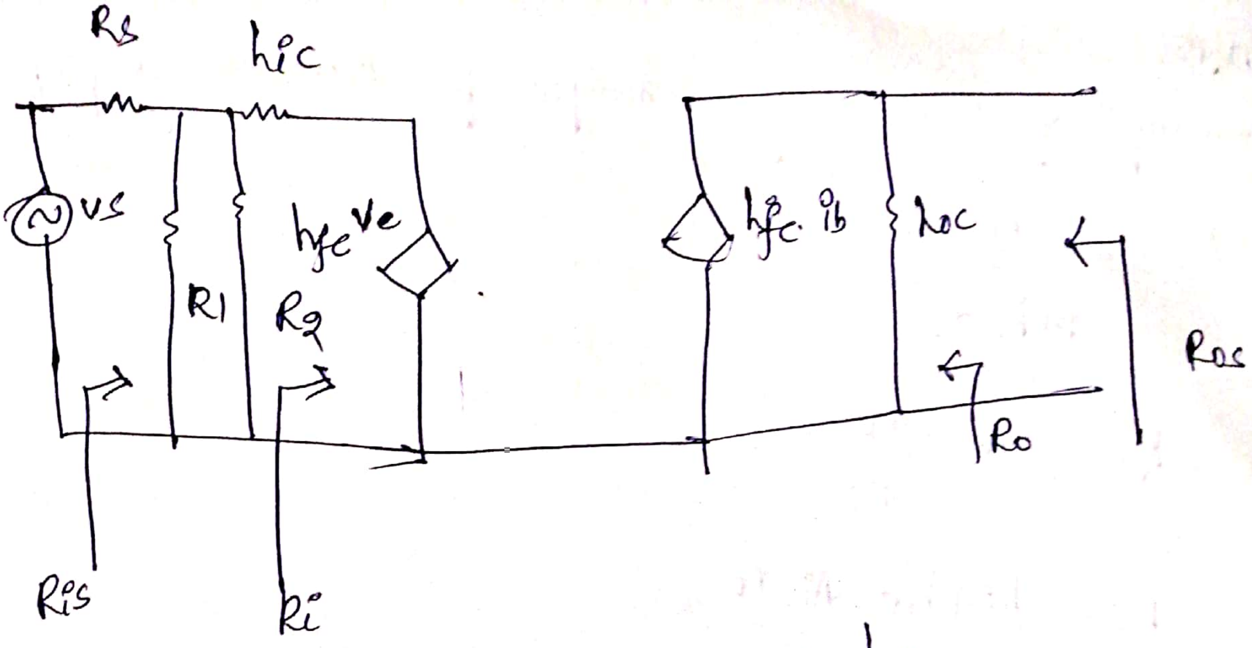
$R_{is} = R_i + R_s$

3) A transistor used in a C.C circuit as shown below has the following set of h-parameters.

$h_{ic} = 2K\Omega$, $h_{fc} = -51$, $h_{rc} = 1$, $h_{oc} = 25 \times 10^{-6}$ mhos.

Find the values of I/p & o/p resistances current & voltage gain of amplifier stage. use the exact hybrid formula's.





$r_e = r_L = 5k\Omega$

$$A_i = \frac{-h_{fc}}{1+h_{oc} r_L} = 45.33$$

$$R_i = h_{ic} - \frac{h_{fc} h_{rc} r_L}{1+h_{oc} r_L} = 228.7k\Omega$$

$$A_v = \frac{A_i r_L}{R_i} = 0.994$$

$$R_{is} = R_i \| R_1 \| R_2 = R_i \| 5k\Omega = 4.892k\Omega$$

$\Delta h = 51.1$

$$R_o = \frac{R_s + h_i}{R_s h_o + \Delta h} = 58.67$$

$A_{is} = 7.644$

$$A_{vs} = \frac{A_v \cdot R_s}{R_{is} + R_s} = 0.833$$

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Summary of small signal analysis of transistor amplifiers

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

$$A_v = A_I \cdot \frac{r_L}{R_i}$$

$$R_i = h_i + h_r \cdot A_i \cdot r_L$$

$$R_i = h_i - \frac{h_r h_f}{h_o + 1/r_L} \quad \text{or} \quad h_i - \frac{h_r h_f r_L}{1+h_o r_L}$$

$$R_o = \frac{R_s + h_i}{R_s h_o + \Delta h} \qquad \Delta h = h_i h_o - h_r h_o$$

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

$$A_p = A_v \cdot A_i = A_i^2 \cdot \frac{r_L}{R_i}$$

$$A_{vs} = \frac{A_v \cdot R_i}{R_s + R_i} = \frac{A_i \cdot r_L}{R_s + R_i} = \frac{A_{Is} \cdot r_L}{R_s}$$

$$A_{Is} = \frac{A_i \cdot R_s}{R_s + R_i} = A_{vs} \cdot \frac{R_s}{r_L}$$

NOTE: The above formulae are applicable for all transistor configurations, only we have to add the appropriate subscript to h-parameters ie; 'e' for CE 'b' for CB & 'c' for CC results such as hie, hfe, hoe, hre, etc.

Typical h-parameter values for a transistors

Parameter	CE	CC	CB
$h_{11} = h_i$	1100 Ω	1100 Ω	≃ 22 Ω
$h_{12} = h_r$	2.5×10^{-4}	≃ 1	3×10^{-4}
$h_{21} = h_f$	50	−51	−0.98
$h_{22} = h_o$	25 μA/V	25 μA/V	0.49 μA/V

standardized values at room temparature.

Comparision of 3-transistor configurations :

The quantities A_i, A_v, R_i, R_o & A_p are calculated for a typical transistor whose h-parameters are shown in previous table.

The values of R_L & r_s taken as 3KΩ.

Quantity	CB	CC	CE
A_i	0.98 (L)	47.5 (H)	−46.5 (H)
A_v	131 (H)	0.989 (L)	−131 (H)
A_p	128.38	46.98	6091.5
R_i	22.6 Ω (L)	144 KΩ (H)	1065 Ω (L)
R_o	1.72 MΩ (H)	80.5 Ω (L)	45.5 KΩ (H)

OBSERVATIONS

CE configuration: This configuration gives high current gain and high voltage gain also medium input resistance and high ~~input~~ output resistance is a good compromise value.

Due to this features, the CE configuration is most versatile and widely used.

CC configuration: the most important feature of this configuration is high input resistance and low output resistance.

The high input resistance makes suitable for used high impedance loads.

the low output resistance allows to be used with low impedance loads.

Thus this configuration is widely used buffer stage.

CB Configuration:

The low input resistance and high output resistance of the ckt makes of a choice for use with low impedance source and a high impedance load.

This configuration is not widely used.

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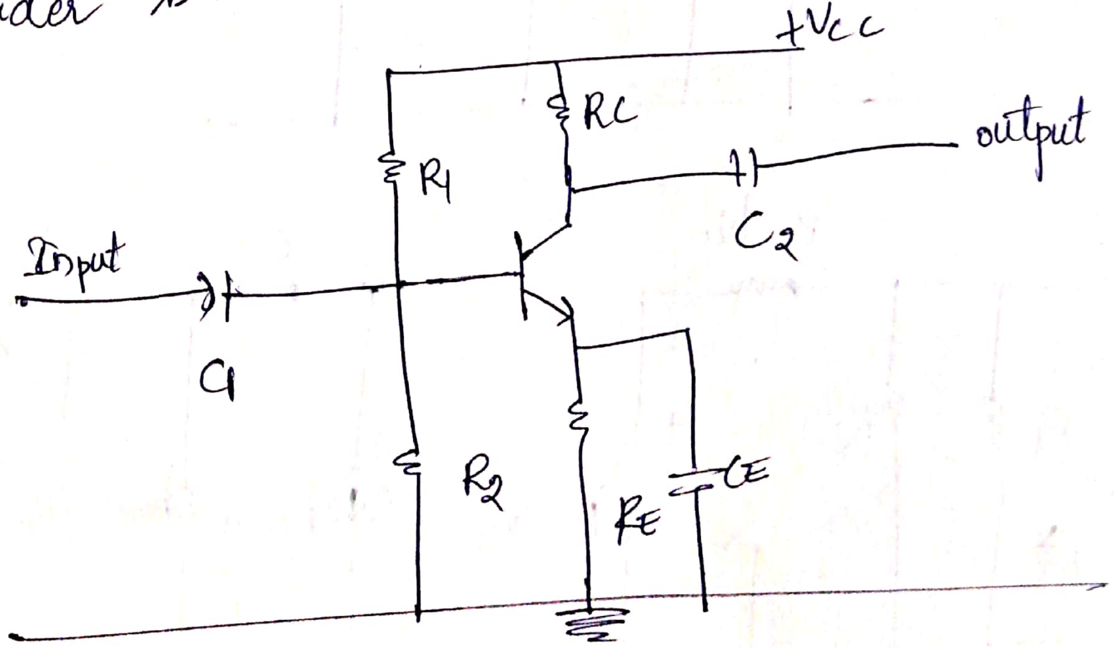
Guidelines for analysis of a transistor circuit (or) small signal equivalent circuits

1) Draw the actual circuit diagram.
2) Replace coupling capacitors and emitter by pass capacitors by short circuit.
3) Replace DC source by a short circuit. in other words short Vcc and ground lines.
4) Make the points B, C & E on the circuit diagram
5) Replace the transistor by its h-parameter model

The following example explains us how to use guidelines for analysis of a transistor circuit:-

Consider CE amplifier with voltage divider bias circuit.



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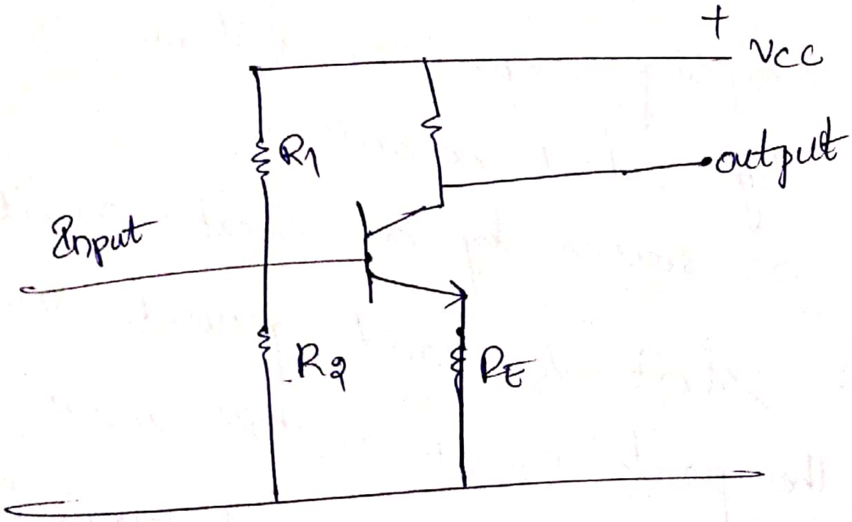
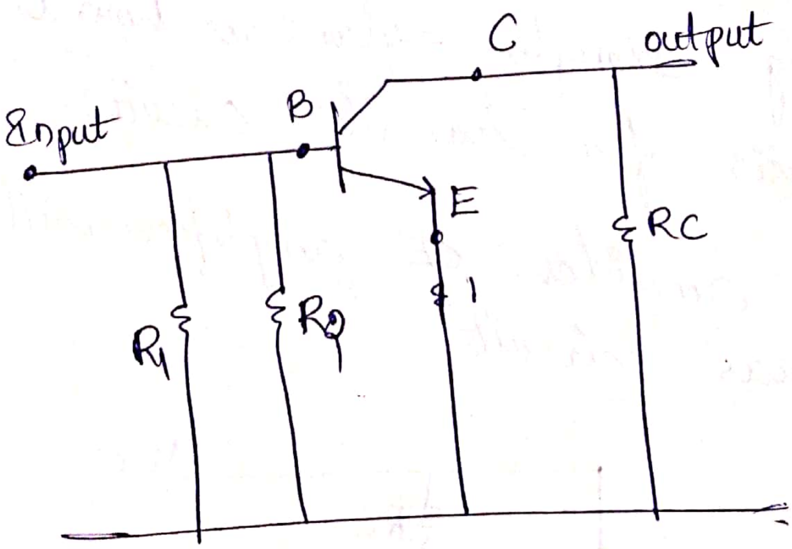
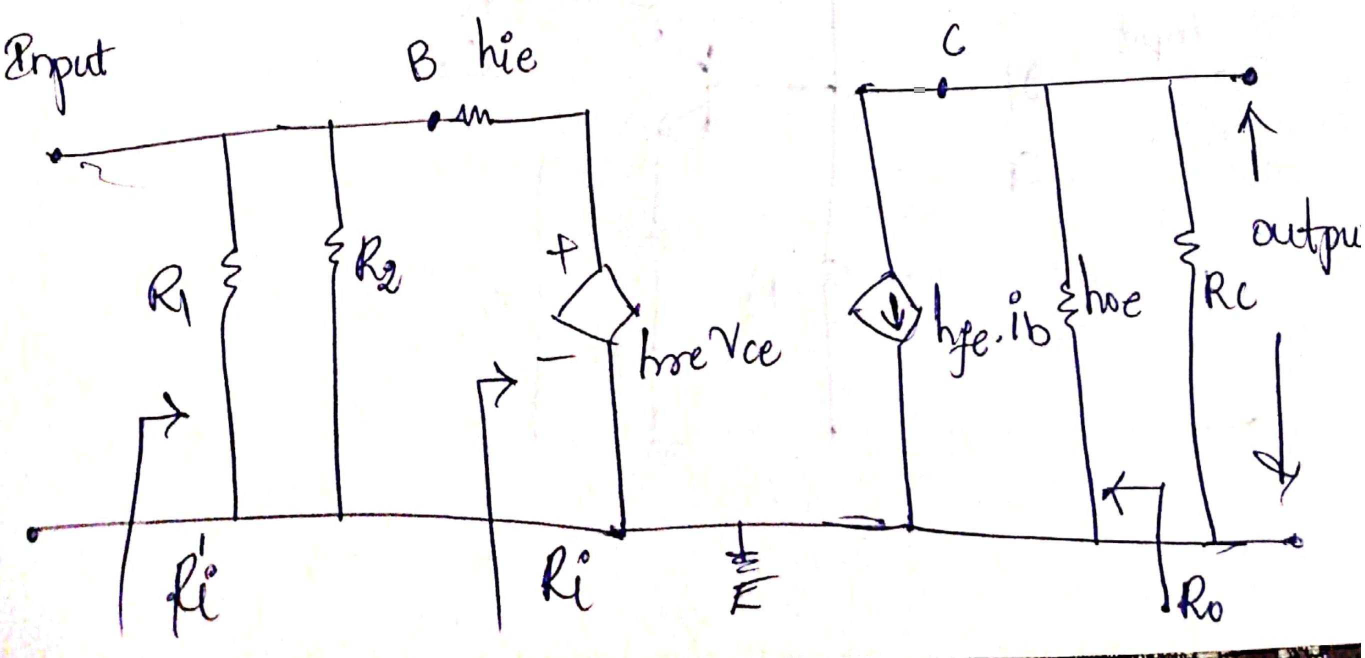
C_1 & C_2 are coupling capacitors & C_E emitter bypass capacitor.







)

$R_i' = R_i \| R_1 \| R_2$ & $R_o' = R_o \| R_C$

Consider a single stage CE amplifier with $R_s = 1K\Omega$ & $R_1 = 50K\Omega$, $R_2 = 2K\Omega$, $R_C = 1K\Omega$, $R_L = 1.2K\Omega$, $h_{fe} = 50$, $h_{ie} = 1.1K\Omega$, $h_{oe} = 25\,\mu A/V$ & $h_{re} = 2.5 \times 10^{-4}$ as shown below.

Sol) $R_i' = R_1 \| R_2 \| R_i = (1.92K\Omega) \| 1.1K\Omega$

$= 0.700 K\Omega$

$R_o' = R_o \| R_C = 1\Omega$

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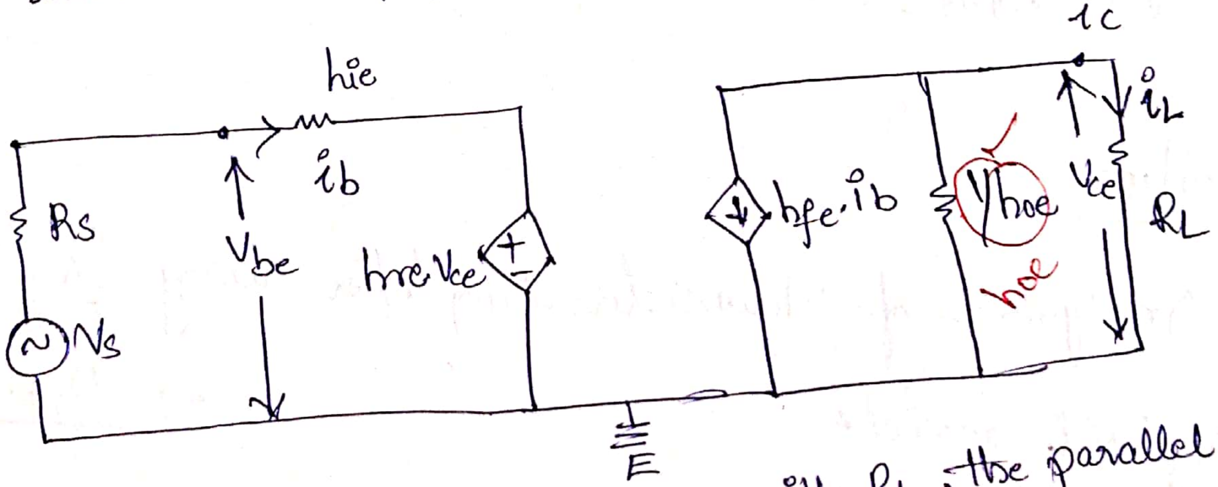
Analysis of Transistor Amplifier using Simplified (or) Approximate Hybrid models

So far we have seen that exact calculations of current gain, voltage gain, input resistance, output resistance of transistor amplifier circuits. In most practical cases, it is appropriate to obtain the approximate values. (simplified values) of A_i, A_v, A_p, R_i, R_o rather than to carry out more lengthy exact calculations.

The condition for approximate analysis is $\boxed{h_{oe} \cdot R_L \nless 0.1}$, otherwise solve with exact analysis

Analysis of common emitter transistor amplifier using simplified hybrid model:

Consider the hybrid equivalent circuit of CE transistor amplifier:



Since $1/h_{oe}$ is in parallel with R_L, the parallel combination of two unequal impedances ie; $1/h_{oe}$ & R_L is approximately equal to lower value ie; R_L

Hence $1/h_{oe}$ is very much greater than R_L

ie;

$$\frac{1}{h_{oe}} >> R_L$$

$$\Rightarrow h_{oe} \cdot R_L << 1$$

$h_{oe} = 25\,\mu A/V$

$\frac{1}{h_{oe}} = \frac{1}{25} \times 10^{6}$

$\frac{1}{25} \times 10^6\, A/V$

Then the term hoe may be neglected. If we neglect hoe, the collector current $i_c = h_{fe} \cdot i_b$

The magnitude of voltage of the generator in emitter circuit is $h_{re} \cdot V_{ce}$ i.e;

$h_{re} = 2.5\times10^{-4}$
$h_{fe} = 50$

$$h_{re} \cdot V_{ce} = -h_{re} \cdot i_c \cdot r_L$$

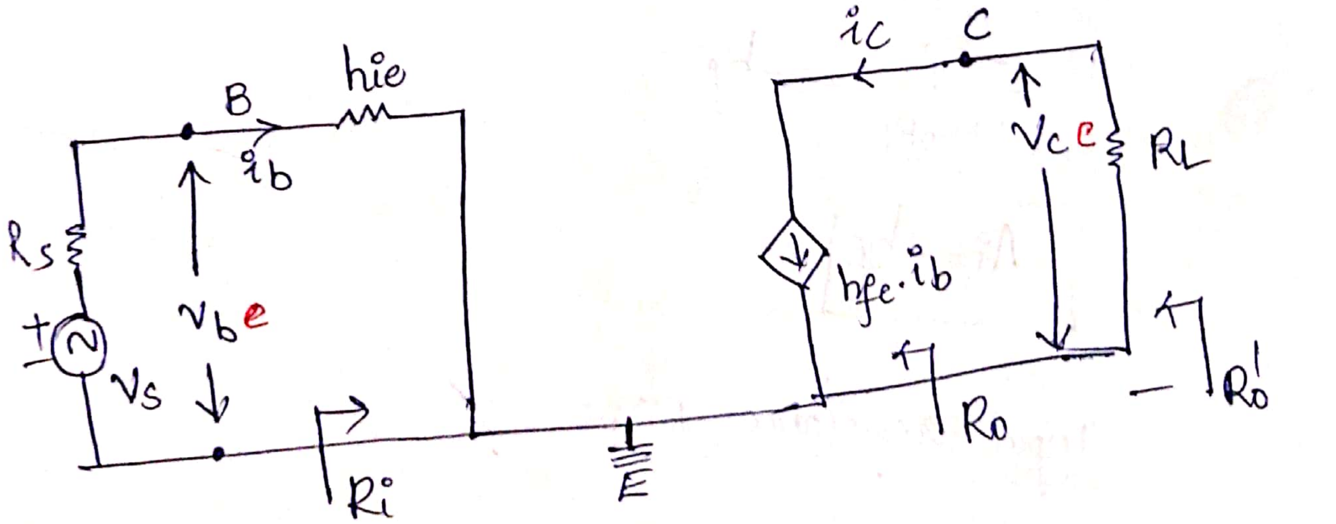
$$h_{re} \cdot V_{ce} = -h_{re} \cdot h_{fe} \cdot i_b \cdot r_L$$

$2.5\times10^{-4}\times50$ 0.0125

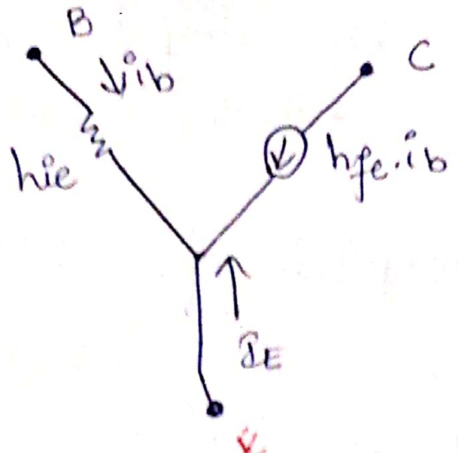
12.5×10^{-4}
0.00125

Since $h_{re} \cdot h_{fe} \simeq 0.01$. This voltage may be neglected in comparision with voltage drop across hie i.e; $h_{ie} \cdot i_b$

To conclude if the load resistance R_L is too small, it is possible to neglect the parameters, h_{re}, h_{oe} and obtain the hybrid equivalent circuit as shown below



Generalised approximate models



the above figure is valid for any configuration by simply grounding the appropriate terminal.

The input is applied between input and ground and the load is connected between output an ground.

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hre & hoe may be neglected

Current gain (Ai)

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

$$\boxed{-A_i = -h_f}$$

$A_i = -h_{fe}$

Input resistance R_i :

$$R_i = h_{ie} + h_{re} A_i R_L$$

$$\boxed{R_i = h_i}$$

$R_i = h_{ie}$

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③ Voltage gain (A_v):

$$A_v = A_i \frac{R_L}{R_i}$$

$$A_v = A_i \cdot \frac{R_L}{h_i} = \boxed{\frac{-h_f R_L}{h_i} = A_v}$$

④ Output resistance R_o:

$$R_o = \frac{V_{ce}}{i_c} = \frac{V_{ce}}{i_L} \qquad i_c = i_L = 0$$

while obtaining the output resistance, the condition is $R_L = \infty$

$\Rightarrow \; i_L = 0$

$$\boxed{R_o = \infty}$$

(or) $$Y_o = h_{oe} - \frac{h_f h_{re}}{h_{ie} + R_s}$$

$$Y_o = 0$$

$$R_o = 1/Y_o = \infty$$

① CE is amplifier is drawn by a voltage source of $R_s = 80$, $h_{oe} = 25\times10^{-6}\,\mu A$, $R_L = 1000\,\Omega$, $h_{ie} = 1K\Omega$, $h_{re} = 2\times10^{-4}$, $h_{fe} = 50$.

Compute A_i, A_v & R_i.

Approximate

$A_i = -50$

$R_i = h_i = 1K\Omega$

$A_v = -50$

$R_o = \infty$

Exact

$A_i = -48.78$

$A_v = -49.26$

$R_i = 990.24\Omega$

$R_o = 51.28K\Omega$

$\frac{-50\times1000}{1K}$

$= -50$

$h_{oe} \cdot R_L < 0.1$

4.884 Approximate

$25\times10^{-6}\times10$

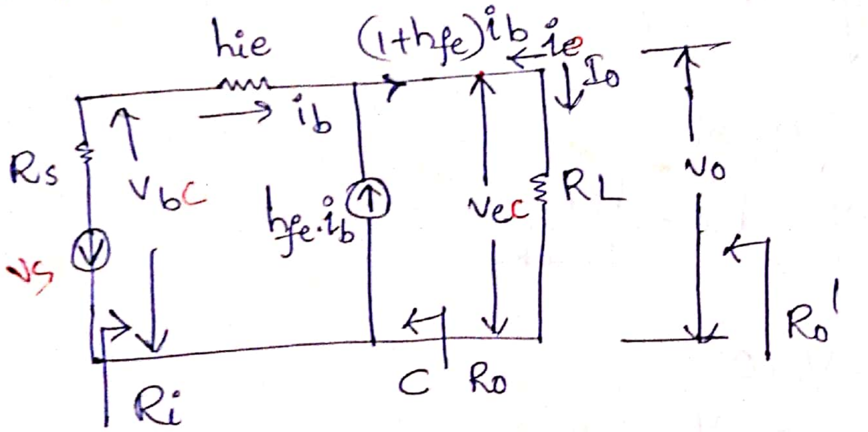
$= 25\times10^{-3}$

0.025

② CE amplifier is driven by voltage Source of $R_s = 600\Omega$, $R_L = 1200\Omega$, $h_{ie} = 1100\Omega$, $h_{re} = 2.4\times10^{-4}$, $h_{fe} = 52$, $h_{oe} = 20\times10^{-6}$ μ mhos.

Sol:
$A_i = -50.7815$
$R_i = 1085.375\Omega$
$A_v = -56.14$
$R_o = 78.996\,K\Omega$
$R_L \| R_o = R_{oT} = 1182.04\Omega$

Simplified Model of Common Collector Circuit:



$i_b + h_{fe}\cdot i_b$
$i_b(1+h_{fe})$

the $h_{fe}\cdot i_b$ current direction is now exactly opposite that of CE model. Since the current $h_{fe} i_b$ is always pointing towards emitter. In this, C is grounded. Input is applied between base & collector, load is connected between emitter & collector.

Simplified hybrid model of CC amplifier is shown in the figure:

$$A_V = \frac{V_o}{V_b} = \frac{R_L I_o}{V_b} = \frac{R_L(1+h_{fe})i_b}{V_b}$$

$$A_V = \frac{R_L(1+h_{fe})i_b}{h_{ie} i_b + (1+h_{fe})i_b \cdot R_L} = \frac{(1+h_{fe})R_L}{h_{ie}+(1+h_{fe})R_L} = \frac{h_{ie}+(1+h_{fe})R_L - h_{ie}}{h_{ie}+(1+h_{fe})R_L}$$

$$= 1 - \frac{h_{ie}}{R_i}$$

Current gain - A_i :

$$-A_i = \frac{I_o}{I_b} = \frac{-i_e}{i_b} = \frac{(1+h_{fe})\cancel{I_b}}{\cancel{I_b}} = 1+h_{fe}$$

$$\boxed{-A_i = 1+h_{fe}}$$

Input resistance R_i :

$$R_i = \frac{V_b}{I_b} = \frac{h_{ie}I_b + (1+h_{fe})i_bR_L}{I_b}$$

$$\boxed{R_i = h_{ie} + (1+h_{fe})R_L}$$

$$\boxed{R_i = h_{ie} + A_iR_L}$$

$I_o = (1+h_{fe})i_b$

Voltage gain - A_V

$$-A_V = \frac{V_o}{V_b} = \frac{R_L I_o}{V_b} = \frac{R_L(1+h_{fe})I_b}{V_b}$$

$R_i = \frac{V_b}{i_b}$

$$= \frac{R_L}{R_i}(1+h_{fe})$$

(or)

$$\boxed{-A_V = 1 - \frac{h_{ie}}{R_i}}$$

$$\boxed{1 - \frac{h_{ie}}{R_i}}$$

$A_V = \frac{R_L}{h_{ie} + A_iR_L}(1+h_{fe})$

$A_V = \frac{R_L(1+h_{fe})}{h_{ie} + (1+h_{fe})R_L}$

Output Resistance (R_o)

$$R_o = \frac{V_o}{i_e}$$

$$R_o = \cancel{\frac{V_o}{I_o}} = \frac{V_o}{-i_e}$$

Apply KVL

$$V_s - i_bR_s - i_bh_{ie} - V_o = 0$$

To obtain R_o, we have to make $V_s = 0$

$V_s = 0$

$$V_o = -i_b R_s - i_b h_{ie}$$

$$V_o = -i_b (R_s + h_{ie})$$

$$i_e = -(1+h_{fe})\, i_b$$

$$\frac{i_b}{I_O} = \frac{-i_b(R_s+h_{ie})}{i_b(1+h_{fe})}$$

$$\cancel{R_O = \frac{V_O}{-i_e} = \frac{-i_b(R_s+h_{ie})}{(1+h_{fe})i_b}}$$

$$\boxed{R_o = \frac{R_s + h_{ie}}{1+h_{fe}}}$$

$$R_o' = R_{OT} = R_o \parallel^{el} R_L$$

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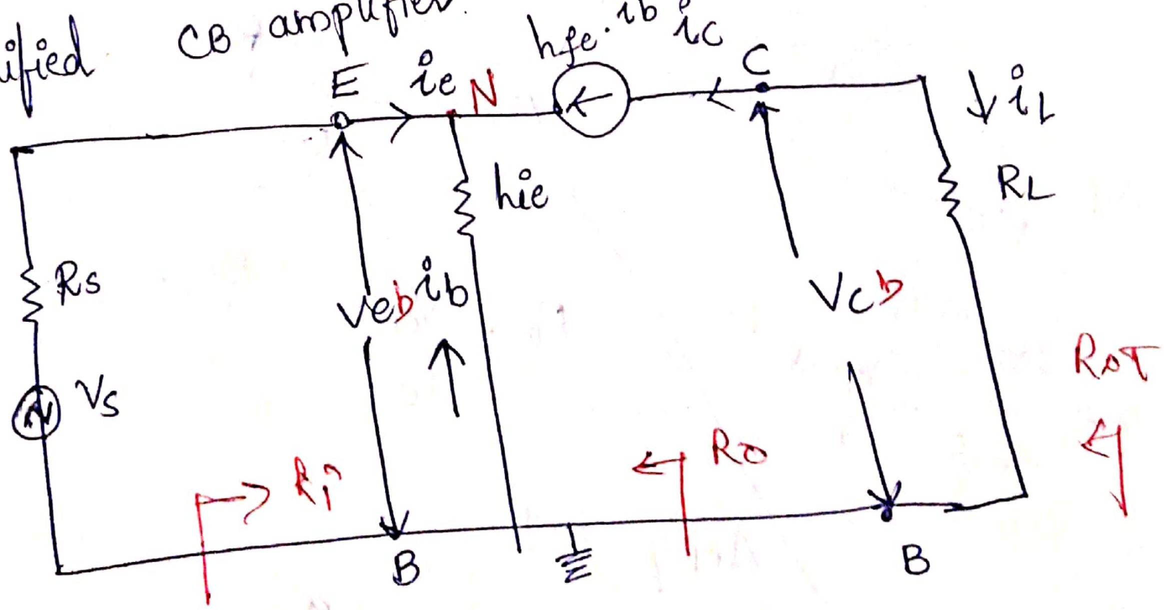
Analysis of CB amplifier using the approximate models

In the case of CB, the input is applied between emitter and base and load is connected between collector and base. The figure shown below is a Simplified CB amplifier.



Current gain:- $A_i = \frac{i_L}{i_e} = \frac{-i_c}{i_e} = \frac{-h_{fe} \cdot i_b}{i_e}$

- Apply KCL at point 'N';

$i_e + i_b + h_{fe} \cdot i_b = 0$

$i_e + i_b + h_{fe} i_b = 0$

$i_e = -(1+h_{fe}) i_b$

$\Rightarrow i_e = -(1+h_{fe}) i_b$

$\therefore A_i = \frac{-h_{fe} \cdot i_b}{-(1+h_{fe}) i_b}$

$\therefore \boxed{A_i = \frac{h_{fe}}{1+h_{fe}}}$

Input Resistance:- $R_i = \frac{\cancel{V_e}\, V_e}{i_e}$

$V_e = -i_b \cdot h_{ie}$

$\therefore i_e = -(1+h_{fe}) i_b$

$\boxed{R_i = \frac{h_{ie}}{1+h_{fe}}}$

Voltage Gain:- $A_V = \frac{V_c}{V_e}$

$V_c = i_L \cdot R_L = -i_c \times r_L = -h_{fe} \cdot i_b \cdot r_L$

$V_e = -i_b \cdot h_{ie}$

$$\boxed{A_v = \frac{h_{fe} R_L}{h_{ie}}}$$

To obtain the value of R_o, the output must be open circuited.

$\therefore i_c = 0 \qquad R_o = \frac{V_c}{i_c} = \frac{V_c}{0} = \infty$

R_{ot} (terminal resistance) $= R_o \| R_L = \infty \| R_L = R_L$

Conversion of h-parameters of different configurations :-

Conversion		Formulae
From	To	
CE	CB	$h_{ib} = \frac{h_{ie}}{1+h_{fe}}$, $h_{fb} = \frac{-h_{fe}}{1+h_{fe}}$ $h_{rb} = \frac{h_{ie} \cdot h_{oe}}{1+h_{fe}} - h_{re}$, $h_{ob} = \frac{h_{oe}}{1+h_{fe}}$
CE	CC	$h_{ic} = h_{ie}$, $h_{fc} = -(1+h_{fe})$ $h_{rc} = 1$, $h_{oc} = h_{oe}$
CB	CE	$h_{ie} = \frac{h_{ib}}{1+h_{fb}}$, $h_{fe} = \frac{-h_{fb}}{1+h_{fb}}$ $h_{re} = \frac{h_{ib}\, h_{ob}}{1+h_{fb}} - h_{rb}$, $h_{oe} = \frac{h_{ob}}{1+h_{fb}}$

→ A voltage source of internal resistance $r_s = 900\Omega$, drives a CC amplifier using load resistance $R_L = 2000\Omega$, the CE h-parameters are $h_{ie} = 1200\Omega$, $h_{re} = 2\times10^{-4}$, $h_{fe} = 60$ & $h_{oe} = 25\mu A/V$. compute the current gain A_i, A_v, R_i & R_o using approximate analysis and exact analysis.

Sol: the conversion formulae for CE → CC are

$h_{ic} = h_{ie} = 1200\Omega$

$h_{fc} = -(1+h_{fe}) = -61$

$h_{rc} = 1$

$h_{oc} = h_{oe} = 25\mu A/V$

Exact analysis:-

$A_i = \dfrac{-h_{fc}}{1+h_{oc}\cdot R_L} = 58.095$

$A_v = A_i \cdot \dfrac{r_L}{R_i} = 0.99897$

$R_o = \dfrac{1}{Y_o} = h_o - \dfrac{h_r h_f}{R_s + h_i} = \cancel{34.39\Omega}$ 0.0290Ω

$R_i = h_{ic} + h_{rc}\cdot A_i \cdot R_L$

$= 1200 + (1)(58.095)(2000)$

$= 117.39 K\Omega$

Approximate analysis:

$A_i = -h_f = 61$

~~$A_v = \dfrac{-h_f R_L}{h_i} = 101.67$~~

$R_i = \cancel{1200\Omega}$ $h_{ie} + (1+h_{fe})R_L$

$= 123.2 K\Omega$

$A_v = 1 - \dfrac{h_{ie}}{R_i} = 0.9903$

$R_o = \dfrac{R_s + h_{ie}}{1+h_{fe}} = 34.43\Omega$

Consider the h-parameter values of ce configuration. $h_{ie} = 1K\Omega$, $h_{fe} = 100$, $h_{re} = 10^{-4}$, $h_{oe} = 50\times10^{-6}\mho$ correct (a) these parameters for cc configuration (b) Derive the expressions for A_v, A_i, R_o, R_i for cc configuration and by using the above parameters if $R_L = 5K\Omega$

$R_s = 100K\Omega$

sol

$h_{ic} = h_{ie} = 1K\Omega$

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

$h_{oc} = h_{oe} = 50\times10^{-6}\mho$

$h_{fc} = -(1+h_{fe}) = -101$

Exacth

Approximateh

A_i = 80.8

$A_i = 101$

$A_v = 0.997$

$A_v = 0.998$

$R_i = h_{ic} + h_{rc} \cdot A_i \cdot R_L$

$= 405000$

$R_i = 506\ K\Omega$

$R_o = 1000\Omega$

$R_o = 952.38\Omega$

Draw the circuit diagram of CC ~~and~~ amplifier Draw the equivalent circuit using approximate model & derive the expressions for A_v, A_i, R_i, R_o. It is given that, the source resistance $R_s = 600\Omega$ & the load resistance $R_L = 2K\Omega$. The CE h parameters are $h_{ie} = 1100\Omega$, $h_{re} = 2.6\times10^{-4}$, $h_{fe} = 54$

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& hoe = 26 μ℧ compute A_i, A_v, R_i, R_o & R_{ot} using the approximate analysis.

Soln

CE analy

- $A_i = 55$
- $A_v = 0.9901$ &
- $R_i = 111.1K\Omega$
- $R_o = 29.9$
- $R_{ot} = 2K\Omega$

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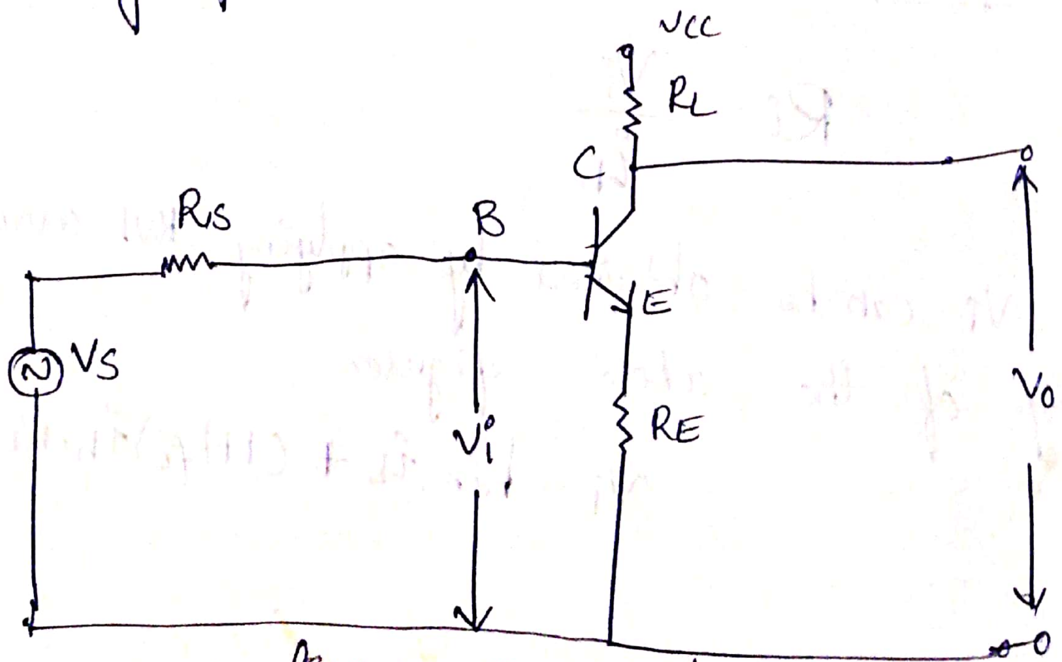
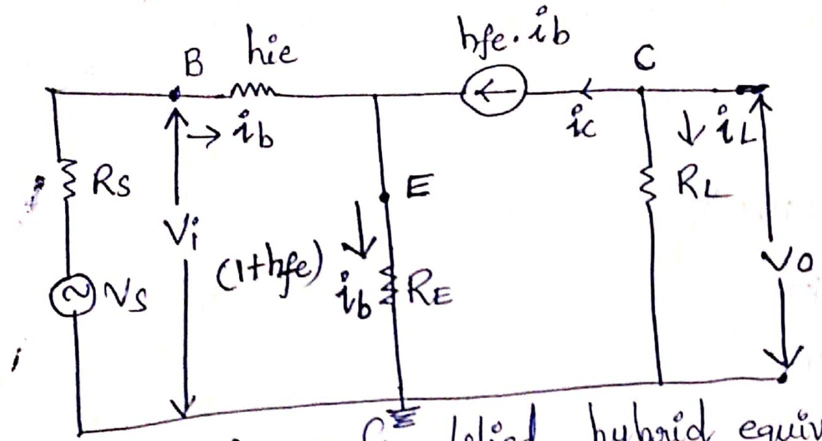
Analysis of CE amplifier using Emitter Resistor (R_E):

An effective way of provide voltage gain stabilization in a CE amplifier is to add an Emitter resistor R_E in the circuit as shown below. By using this resistor, (R_E) the circuit stability can be improved however the use of R_E results substantial reduction of voltage gain.



fig(a) CE amplifier with RE



fig(b): Simplified hybrid equivalent circuit of fig(a).

ⓐ **Current Gain (A_I):**

$$A_i = \frac{i_L}{i_b} = \frac{-i_c}{i_b} = \frac{-h_{fe} \cdot \cancel{i_b}}{\cancel{i_b}}$$

$$\boxed{A_i = -h_{fe}}$$

NOTE: The current gain remains unchanged inspite of putting a resistor in emitter circuit.

ⓑ **Input Resistance (R_i):**

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

V_i can be obtained by applying KVL around LHS loop of the above figure.

$$V_i = h_{ie} \cdot i_b + (1+h_{fe}) i_b \cdot R_E$$

$$\boxed{R_i = h_{ie} + (1+h_{fe})R_E}$$

NOTE: The input resistance of CE amplifier is only hie, thus input resistance is greatly increased due to the use of R_E.

ⓒ Voltage Gain (A_v):

we know that $A_v = \dfrac{-A_i \cdot R_L}{R_i}$

Substitute for A_i & R_i

$$\boxed{A_v = \frac{-h_{fe} \cdot R_L}{h_{ie} + (1+h_{fe})R_E}}$$

The A_v for a CE amplifier is $\dfrac{-h_{fe} \cdot R_L}{h_{ie} \cancel{+(1+}}$ only.

∴ It indicates that A_v is drastically reduced since R_i is increased greatly.

If $(1+h_{fe})R_E \gg h_{ie}$, then $A_v = \dfrac{-h_{fe} \cdot R_L}{(1+h_{fe})R_E}$

∵ $h_{fe} \gg 1$; ∴ $A_v = \dfrac{-\cancel{h_{fe}} \cdot R_L}{\cancel{h_{fe}} \cdot R_E} = \dfrac{-R_L}{R_E}$

thus A_v is independent of all transistor parameters and so on etc.

and is governed by R_L and R_E, if the above conditions met.

ⓓ Output Resistance (R_o):

$$R_o = \infty$$

Analysis of CE amplifier with R_E bypassed by a Capacitor C_E:

We know that the use of resistor ~~and~~ in the emitter has major disadvantage ie; drastic reduction in voltage gain. However, if we connect a capacitor C_E in parallel to the resistor R_E as shown in the figure, the voltage gain doesnot get reduced.

The CE amplifier with unbypassed R_E is shown below:

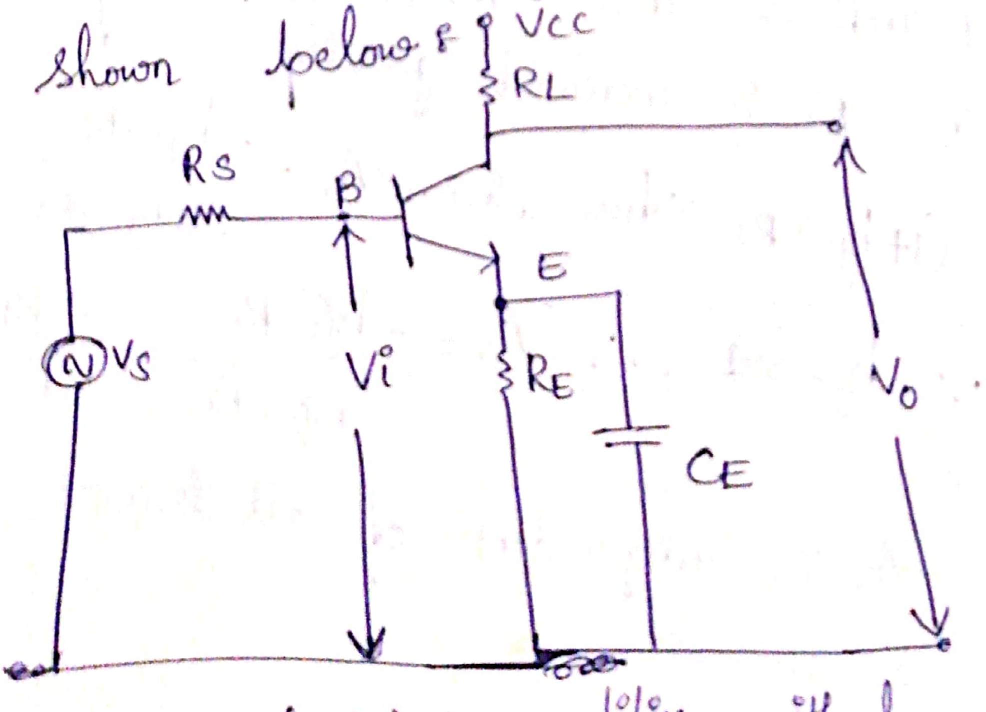
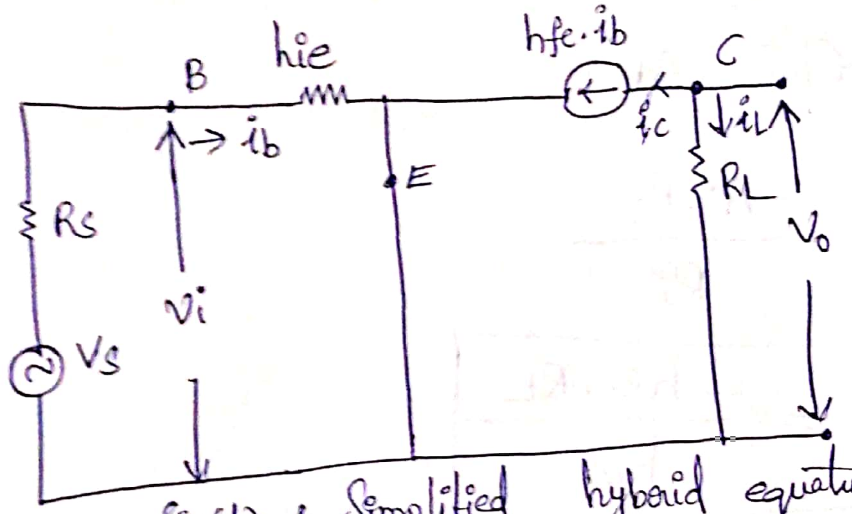


fig (a) CE amplifier with bypass R_E



fig(b) : Simplified hyboid equation ckt of fig (a).

(a) Current Gain A_i :

$$A_i = \frac{i_L}{i_b} = \frac{-i_c}{i_b} = \frac{-h_{fe} \cdot \cancel{i_b}}{\cancel{i_b}}$$

$$\boxed{A_i = -h_{fe}}$$

(b) Input Resistance (R_i) :

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

$$v_i = h_{ie} \cdot i_b$$

$$R_i = \frac{h_{ie} \cdot \cancel{i_b}}{\cancel{i_b}}$$

$$\boxed{R_i = h_{ie}}$$

(c) Voltage Gain A_V :

$$A_V = \frac{-A_i \cdot R_L}{R_i}$$

$$\boxed{A_V = \frac{-h_{fe} \cdot R_L}{h_{ie}}}$$

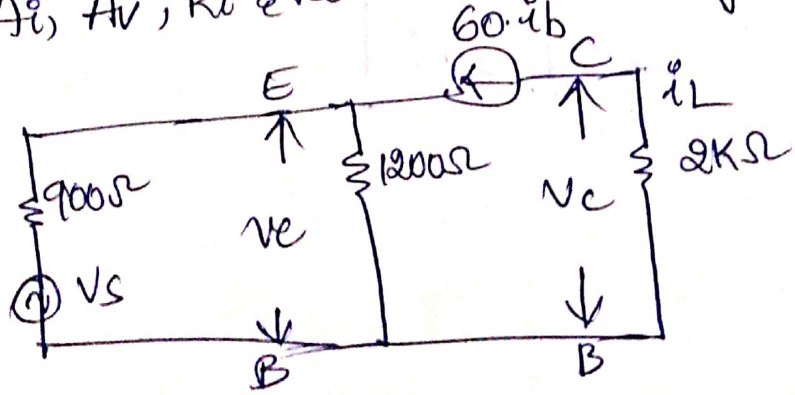
(d) Output Resistance R_o :

$$\boxed{R_o = \infty}$$

NOTE :- All the four characteristics are same as that of an ordinary CE amplifier.

(*) Draw the ckt diagram of CB amplifier, draw its equivalent circuit using approximate h-model. Derive the expressions for A_i, A_v, R_i, & R_o. It is given that $R_s = 900\Omega$, $R_L = 2K\Omega$. CE h parameters are $h_{ie} = 1200\Omega$, $h_{re} = 2\times10^{-4}$, $h_{fe} = 60$, $h_{oe} = 10\mu℧$. Compute A_i, A_v, R_i & R_o and R_{ot} using approximate model.

Sol



$A_i =$

$A_i = \frac{60}{61} = 0.983$

$\cancel{A_v =} R_i = \frac{1200}{61} = 19.67$

$A_v = \frac{60 \times 2K}{1200} = 100$

$R_o = \infty$

$R_{ot} = 2K\Omega$

A CE amplifier uses load resistor $R_L = 2K\Omega$ in the collector ckt and is given by Voltage sourse ~~Vs=~~ $R_s = 1K\Omega$, $h_{ie} = 1300\Omega$, $h_{re} = 2\times10^{-4}$, $h_{fe} = 55$ & $h_{oe} = 22.1\mu$ Compute A_i, A_v, R_i, R_o & R_{ot} for the following values of R_E (1) 200Ω (2) 400Ω (3) 1000Ω by approximate analysis.

Sol: (i) 200Ω

$A_i = -55$

$R_i = 11.5K\Omega$ or $12.5K\Omega$

$A_v = -9.56$ -8.8

$R_o = \infty$

(ii) 400Ω

$A_i = -55$

$R_i = 23.7K\Omega$

$A_v = -4.64$

$R_o = \infty$

(iii) 1000Ω

$A_i = -55$

$R_i = 57.3K\Omega$

$A_v = -1.919$ -1.92

$R_o = \infty$

NOTE: $h_{oe}(R_E + R_C) < 0.1$, approximate model is permissable

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Miller's Theorem

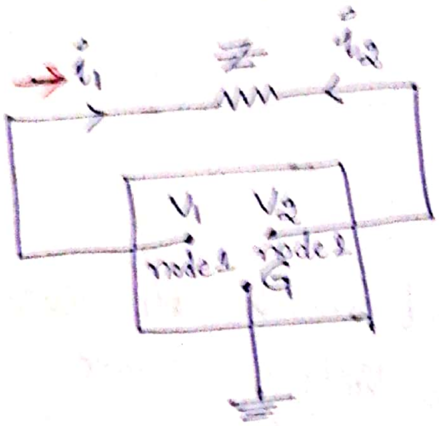

fig (a)

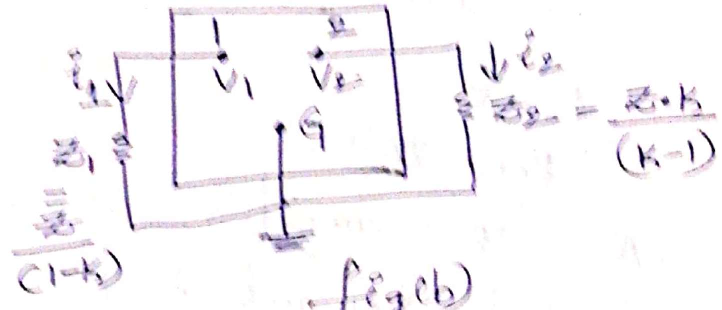

fig (b)

miller's theorem is useful in converting any circuit having configuration in figure (a) to another configuration shows in fig (b). The impedance Z is connected between two node namely node 1 and node 2 can be replaced by two separate impedances.

$Z_1 = \frac{Z}{1-K}$ and $Z_2 = \frac{ZK}{(K-1)}$ where Z_1 is connected between node 1 and ground and Z_2 is connected between node 2 and ground as shown in fig (b).

proof: Let the voltages of nodes 1 and 2 be V_1 & V_2 respectively. The node G is grounded.

NOTE: The remaining part of the circuit is represented by a box which remains unchanged, even after the application of miller's theorem on the impedance Z.

Let $\frac{V_2}{V_1} = K$

From fig (a), $i_1 = \frac{V_1 - V_2}{Z}$,

$$K = \frac{V_2}{V_1}$$

$$V_2 = KV_1$$

$$i_1 = \frac{V_1 - KV_1}{Z} = \frac{V_1(1-K)}{Z}$$

$$i_1 = \frac{V_1}{Z/(1-K)} \quad \text{--- (1)}$$

From fig (b) current through Z_1

$$i_1 = \frac{V_1}{Z_1} \quad \text{--- (2)}$$

Equating equations (1) & (2)

$$Z_1 = \frac{Z}{1-K}$$

From fig (a)

$$i_2 = \frac{V_2 - V_1}{Z}$$

$$i_2 = \frac{V_2 - V_2/K}{Z} = \frac{V_2(1 - 1/K)}{Z}$$

$$i_2 = \frac{V_2}{Z/\frac{(K-1)}{K}} \quad \text{--- (1)}$$

From fig (b)

$$i_2 = \frac{V_2}{Z_2} \quad \text{--- (2)}$$

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$$\frac{\cancel{V_2}}{Z_2} = \frac{\cancel{V_2}}{Z \Big/ \frac{(K-1)}{K}}$$

$$\boxed{Z_2 = \frac{Z.K}{(K-1)}}$$

It must be emphasized that this theorem is useful in making calculations only if it is possible to find the value of 'K' by ~~sum~~ some independent means.

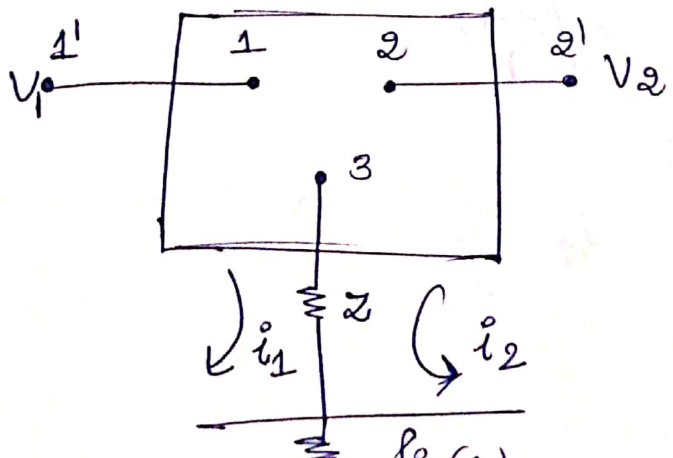
Dual of Miller's theorem :

The dual of miller's theorem helps us to transform any impedance 'Z' which is common to both input and output loop into two separate impedances Z_1 & Z_2.

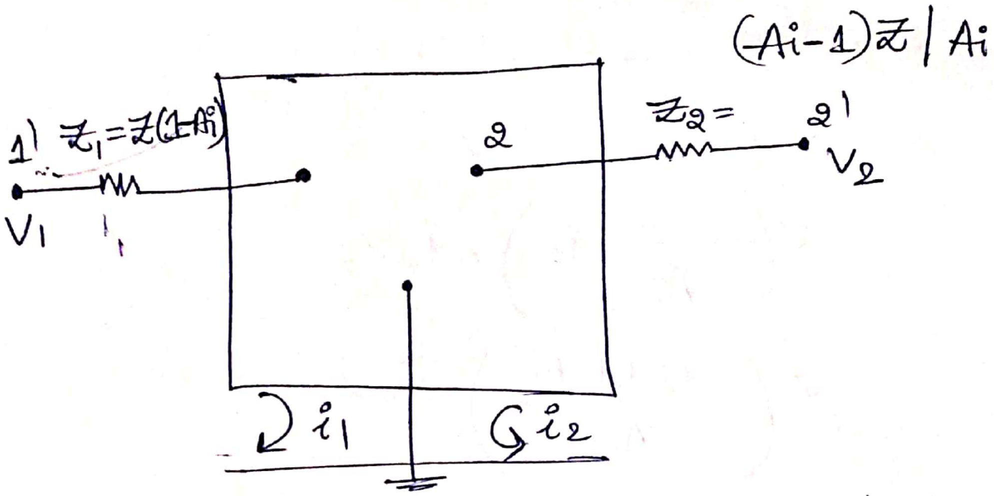
$$Z_1 = Z\,(1-A_i)$$

$$Z_2 = \frac{(A_i-1)}{-A_i}\,Z$$

Figure (a) shows the impedance Z) through which the input current i_1 and output current i_2 flows.



fig(a)



After transformation by the dual of miller's theorem, this 'Z' is removed and replaced by two separate impedances. Z_1 in the input side loop and Z_2 in the output side loop. The currents i_1 & i_2 remains unchanged as shown in the figure below.

From fig(a) $A_i = \dfrac{-i_2}{i_1}$,

from fig(b) $V_1 = i_1 Z_1$ $\quad$ — ①

from fig(a) $V_1 = Z(i_1 + i_2)$ $\quad$ — ②

Equating ① & ②

$$i_1 Z_1 = Z(i_1 + i_2)$$

$$= Z(i_1 - A_i i_1)$$

$$\cancel{i_1} Z_1 = \cancel{i_1} Z(1 - A_i)$$

$$Z_1 = Z(1 - A_i)$$

<u>Similarly</u> for <u>mesh 2 &</u>

From fig(a) $V_2 = Z(i_1 + i_2)$ $\quad$ — ③

From fig(b) $V_2 = i_2 Z_2$ $\quad$ — ④

Equating equations ① & ② ③,④,⑪

$$z(i_1+i_2) = i_2 z_2$$

$$z\left(\frac{-i_2}{-A_i}+i_2\right) = i_2 z_2$$

$$z\left(\frac{-i_2+i_2 A_i}{-A_i}\right) = i_2 z_2$$

$$z_2 = \frac{z\cancel{i_2}(A_i-1)}{\cancel{i_2}\,A_i}$$

$$\boxed{z_2 = \frac{z(A_i-1)}{A_i}}$$

NOTE:- The theorem is used for analysis of circuits such as CE configuration with unbypassed R_E where, R_E is common for both input and output loops.

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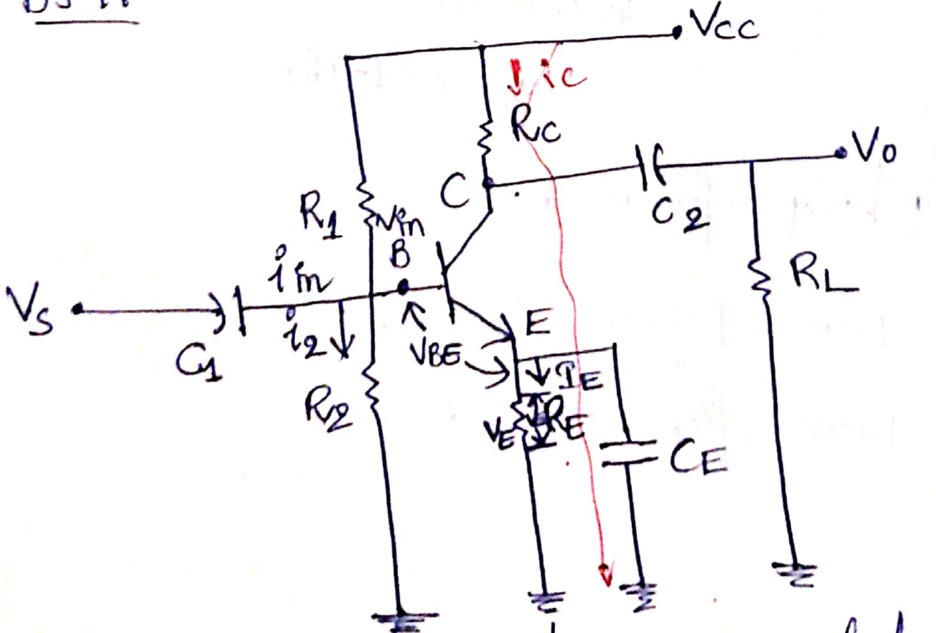
Design of Single stage RC coupled Amplifier using BJT:-



fig(a) Single stage RC coupled BJT amplifier

The circuit diagram of single stage RC coupled amplifier is shown in figure. The design of resistor values involves application of ohm's law after selecting suitable voltage and current values throughout the circuit. The design of capacitor values are based on the lower cut off frequency of the circuit (f_L).

The biasing is provided by the resistors R_1 & R_2. $R_1 R_2$ acts as a potential divider giving a fixed voltage.

Designing of R_C & R_E :

The voltage gain of the CE amplifier is given by

$$-A_v = \frac{-h_{fe} \cdot R_L}{h_{ie}} = \frac{-h_{fe} \cdot (R_C \| R_L)}{h_{ie}}$$

$-A_v$ is directly proportional to $R_C \| R_L$; the design of large $-A_v$ requires selection of the largest possible collector resistance. The R_C can be obtained by applying KVL around the collector to emitter circuit.

$$\boxed{V_{CC} = i_C R_C + V_{CE} + V_E}$$

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$$\Rightarrow \boxed{R_C = \frac{V_{CC} - V_{CE} - V_E}{i_C}}$$ where

$V_E = I_E R_E$

To get the large value of R_C, let us assume $V_{CE} = \frac{V_{CC}}{2}$ & $V_E = \frac{V_{CC}}{10}$

For good bias stability, $V_E >> V_{BE}$

$(V_E = V_B - V_{BE})$

Hence i_E & i_C remains stable at

$$\boxed{I_E = I_C = \frac{V_E}{R_E}}$$

Analysis of voltage divider bias circuit

By applying ohm's law, the input resistance

$$R_{in}(base) = \frac{V_{in}}{i_{in}}$$

$V_{in} = V_{BE} + V_E$

$V_{in} = V_{BE} + I_E R_E$

$\because V_{BE}$ is very much less than V_E or $I_E R_E$

$V_{in} = I_E R_E$

$(I_E = I_C)$

$V_{in} = \beta I_B R_E$

$(I_C = \beta I_B)$

$i_{in} = I_B$

$$\therefore R_{in(base)} = \frac{\beta \cancel{I_B} R_E}{\cancel{I_B}} = \beta R_E$$

the total resistance from base to ground is

$R_2 \parallel \beta R_E$

The voltage divider is formed by

R_1 and Resistance from base to ground

ie; $R_2 \parallel \beta R_E$

$$\boxed{V_B = V_{cc} \times \frac{(R_2 \parallel \beta R_E)}{R_1 + (R_2 \parallel \beta R_E)}}$$

for good bias stability;

$\beta R_E \gg R_2$ (atleast 10 times)

Neglect βR_E

$$\boxed{\therefore V_B = V_{cc} \times \frac{R_2}{R_1 + R_2}}$$

Design of Bias Resistors :-

The voltage divider current i_2 is selected as $\frac{i_c}{10}$ (for good bias stability).

Hence, the bias resistors are

Calculated as,

$$\boxed{R_2 = \frac{V_B}{I_2} \quad \& \quad R_1 = \frac{V_{CC} - V_B}{I_2}}$$

where $V_B = V_E + V_{BE}$ (or) $V_B = \frac{V_{CC} \times R_2}{R_1 + R_2}$

<u>Design of bypass and coupling capacitors</u>:

The reactance offered by bypass capacitor C_E is $X_{CE} = \frac{1}{2\pi f C_E}$ f_{CE}

$$\boxed{\therefore C_E = \frac{1}{2\pi f X_{CE}}}$$

f_{CE}

The voltage gain for CE circuit with unbypassed R_E resistance is given by

$$A_V = \frac{-h_{fe} \cdot R_L}{h_{ie} + R_E(1 + h_{fe})}$$

But $R_L = R_C \parallel R_L$

and including the bypass capacitor reactance (in parallel with R_E)

$$A_v = \frac{-h_{fe}\,(R_C \| R_L)}{h_{ie} + R_E\,(1+h_{fe})\,(R_E \| X_{CE})}$$

X_{CE} should be fixed .is one-tenth of R_E

$R_E \gg X_{CE}$ ($\because R_E$ neglecting)

Hence $$|A_v| = \frac{-h_{fe}\cdot(R_C \| R_L)}{\sqrt{h_{ie}^2 + [(1+h_{fe})\times X_{CE}]^2}}$$

$$|A_v| = \frac{\sqrt{(h_{fe})^2}}{\sqrt{a^2+b^2}}$$

Let $h_{ie} = (1+h_{fe})\,X_{CE}$

$$|A_v| = \frac{-h_{fe}\,(R_C \| R_L)}{h_{ie}\sqrt{1^2+1^2}}$$

$$\boxed{A_v = \frac{-h_{fe}\,(R_C \| R_L)}{h_{ie}\sqrt{2}} = \frac{A_{vm}}{\sqrt{2}}}$$

where $$A_{vm} = \frac{-h_{fe}\,(R_C \| R_L)}{h_{ie}}$$

A_{vm} is the mid frequency gain,

$h_{ie} = (1+h_{fe})\,X_{CE}$

hence $$X_{CE} = \frac{h_{ie}}{1+h_{fe}} = h_{ib}$$ (Conversion formula

$$\therefore C_E = \frac{1}{2\pi f_L X_{CE}}$$

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$$\boxed{\therefore C_E = \frac{1}{2\pi f_L \cdot h_{ib}}}$$

The Coupling Capacitors C_1 & C_2 are obtained by following equations:

$$C_1 = \frac{1}{2\pi f_L X_{C_1}} \quad \&$$

$$X_{C_1} = \frac{R_i}{10}$$ [~~the~~ good stability of bias]

[the reactance of each coupling capacitor is selected to be approximately equal to $\frac{1}{10}$ of the impedance]

$$\boxed{R_i = R_1 \| R_2 \| h_{ie}}$$

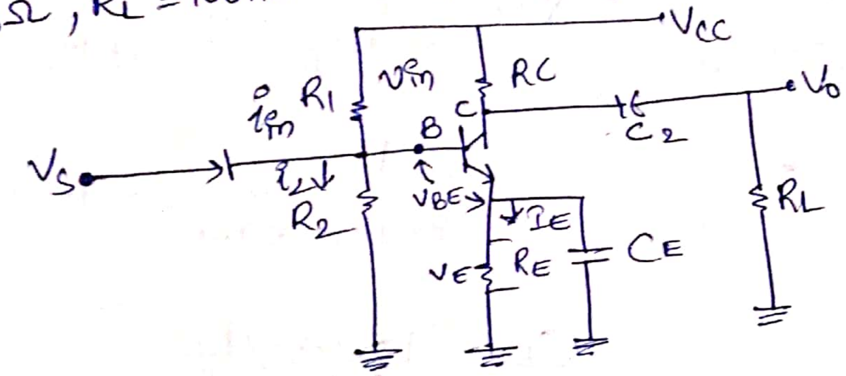
$$C_2 = \frac{1}{2\pi f_L X_{C_2}}$$

$$X_{C_2} = \frac{R_o}{10}$$

$$\boxed{R_o = R_C \| R_L}$$

01/02/15

Design a single stage RC coupled BJT amplifier circuit shown in figure below. Assume that $V_{CC} = 10V$, $I_C = 4mA$, $h_{fe} = 100$, $h_{ie} = 1K\Omega$, $R_L = 100K\Omega$ & $f_L = 100 Hz$, $\beta = 100$



$$R_C = \frac{10 - 5 - 1}{4mA} = \frac{4V}{4mA} = 1K\Omega$$

$$R_E = \frac{V_E}{I_C} = \frac{1V}{4mA} = 0.25K\Omega = 250\Omega$$

$V_E = \frac{V_{CC}}{10} = \frac{10}{10} = 1$

$$V_B = 0.7 + 1 \; (V_{BE} + V_E) = 1.7V$$

$$V_B = V_{CC} \times \frac{R_2}{R_1 + R_2} \Rightarrow 10 \times \frac{R_2}{R_1 + R_2} = 1.7$$

$$\frac{R_2}{R_1 + R_2} = 0.17 \Rightarrow \boxed{R_1 = 4.12 R_2}$$

$R_2 = 0.17(R_1 + R_2)$

$5.88 R_2 = R_1 + R_2$

$R_1 = 4.88 R_2$

$\beta = 100$, $R_E = 250\Omega$, $\beta R_E = 25K\Omega$

In order to satisfy the condition $\beta R_E \gg 10$ times atleast

$$\beta R_E \gg R_2$$

So R_2 is selected as $2K\Omega$. when $R_2 \simeq 2K\Omega$

then $R_1 = 4.12 \times 2 = 8.24K\Omega$

$R_1 = 4.88 \times 2$

$= 9.76 K\Omega$

$\simeq 10K\Omega$

Calculation of $C_E = \frac{1}{2\pi f X_{CE}}$

$$X_{CE} = \frac{h_{ie}}{1+h_{fe}} = \frac{1K\Omega}{1+100} = 9.9\ \Omega$$

$$C_E = \frac{1}{2\times\pi\times 100\times 9.9} = 1.61\times 10^{-4} = 160.8\ \mu F$$

$R_i = R_1 \| R_2 \| h_{ie}$
$= 10\times10^3 \| 2\times10^3 \| 1\times10^3$

$$C_E = 160.8\ \mu f$$

$$C_1 = \frac{1}{2\pi f_L \times \frac{R_i}{10}} = \frac{1}{\frac{2\times\pi\times 100}{10}\times(24.6)} = \cancel{24.654}\ 246.154$$

$\frac{1001}{101}$

$$= 6.47\ \mu f$$

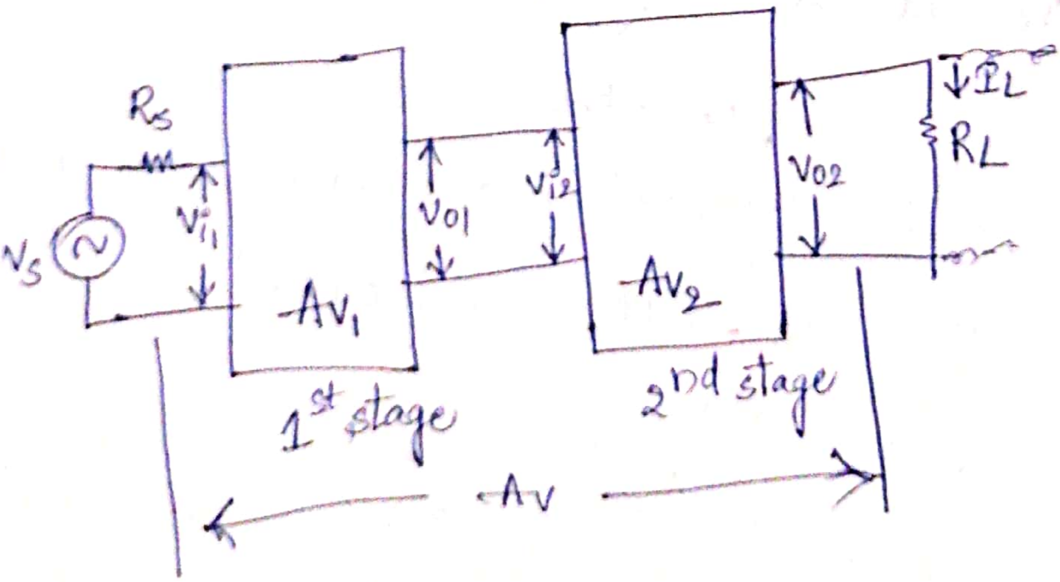
$$C_2 = \frac{1}{2\pi f_L \times \frac{R_o}{10}} = \frac{1}{2\times\pi\times 10\times 1.98} = 16.06\ \mu$$

99.001 $= 0.01608$

$R_o = R_C \| R_L$
$= 1K \| 100K$
$= 699$

Analysis of Cascaded RC coupled BJT amplifiers

~~Sect~~ Two stage cascaded amplifier

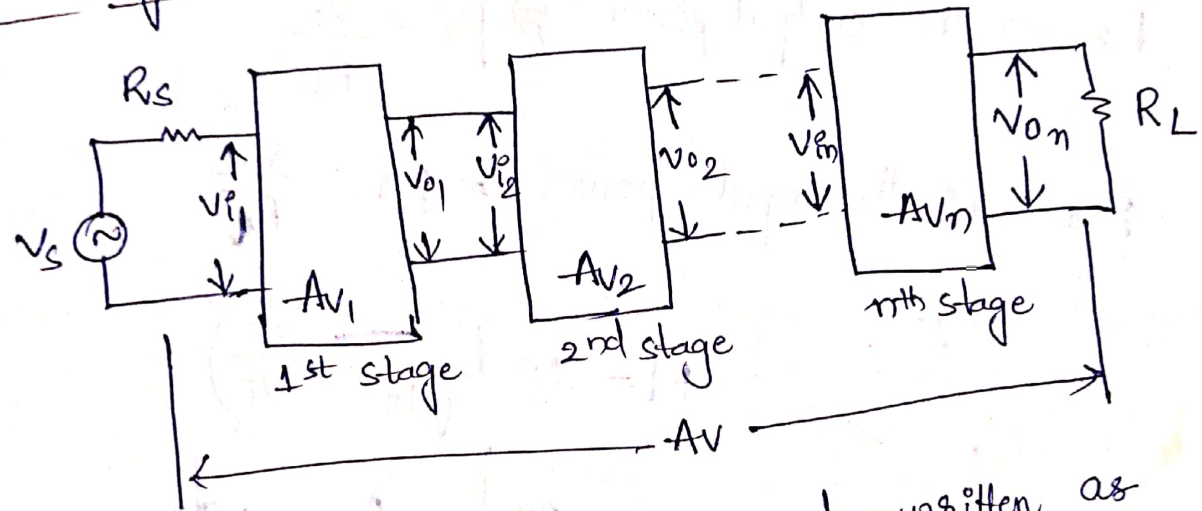


Overall voltage gain; $A_V \Rightarrow \dfrac{V_{o2}}{V_{i1}} = \dfrac{V_{o2}}{V_{i2}} \cdot \dfrac{V_{i2}}{V_{i1}}$

$$\boxed{A_V = A_{V2} \cdot A_{V1}}$$

∴ The overal voltage gain of the multistage amplifier is the product of the gains of individual stages.

<u>n-stage cascaded amplifier</u>:



Overall voltage gain A_V can be written as

$$A_V = A_{V1} \cdot A_{V2} \cdots A_{Vn}$$

$$\boxed{A_V = \cancel{\sum_{i=1}^{n}} A_{Vi}} \qquad \prod_{i=1}^{n} A_{Vi}$$

the voltage gain of the K^{th} stage $\Rightarrow$ $\boxed{A_{VK} = \dfrac{A_{iK} \cdot R_{LK}}{R_{iK}}}$

and R_{LK} is the effective load resistance of K^{th} stage.

Gain in decibels :-

It is most convinient to compare the two powers on a logarithmic scale rather than normal scale. The unit of logarithmic scale is 'dB'. The number of 'N' dB by which power P_2 exceeds the power P_1;

$$N = 10 \log_{10}\left(\frac{P_2}{P_1}\right)$$

P_2 is the output power $\Rightarrow P_2 = \frac{V_o^2}{R_o}$ $\qquad N = 10\log_{10}\left(\frac{V_o}{V_i}\right)^2$

P_1 is the input power $= P_1 = \frac{V_i^2}{R_i}$

$R_i = R_o$

$$N = 20 \log_{10}\left(\frac{V_o}{V_i}\right)$$

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

$$N = 20 \log_{10} A_v \rightarrow dB$$

10 — common
e — natural

02/02/15

$$N = G_v = 20\log_{10}(A_v)$$

We know that $A_v = A_{v_1} \cdot A_{v_2} \cdot A_{v_3} \cdots\cdots A_{v_n}$

$$G_v = 20\log_{10} A_v$$

$$G_v = 20\log_{10}(A_{v_1} \cdot A_{v_2} \cdot A_{v_3} \cdots A_{v_n})$$

$$G_v = 20\log_{10} A_{v_1} + 20\log_{10} A_{v_2} + 20\log_{10} A_{v_3} + \cdots 20\log_{10} A_{v_n}$$

$$G_V = G_{V1} + G_{V2} + \cdots + G_{Vn}$$

the overall voltage gain in dB of multistage amplifier is sum of decibel voltage gains of individual stages.

Advantages of Gain in dB:

(i) It allows to denote both very small as well as very large quantities of linear scale by considerably small figures.

(ii) It permits to add individual gains of this stages to calculate overall gain.

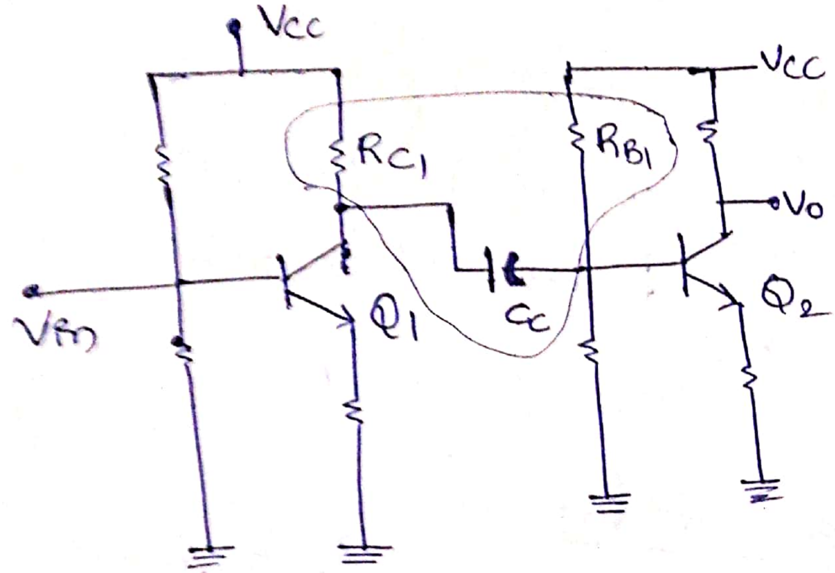
(logarithmic changes multiplication to addition)

Different Coupling Schemes used in Amplifiers:

Depending upon the type of coupling, the multistage amplifiers classified as

1. Resistance - Capacitance Coupling (R/C coupled amplifier)
2. Transformer coupled amplifier
3. Direct coupled amplifier

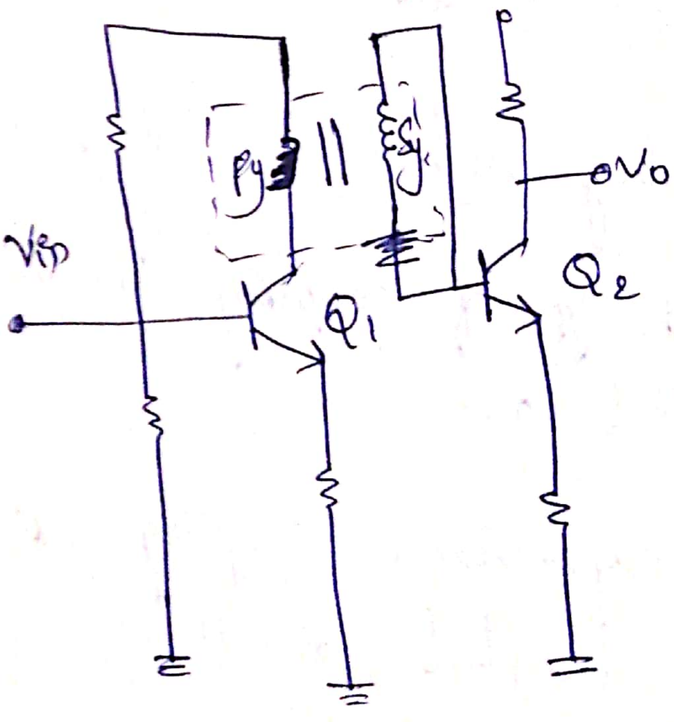
(1)



The signal developed across the collector resistor of each stage is coupled through capacitor into the base of the next stage.

The cascaded stages amplify the signals and the overall voltage gain is equal to the product of the individual stage gains.

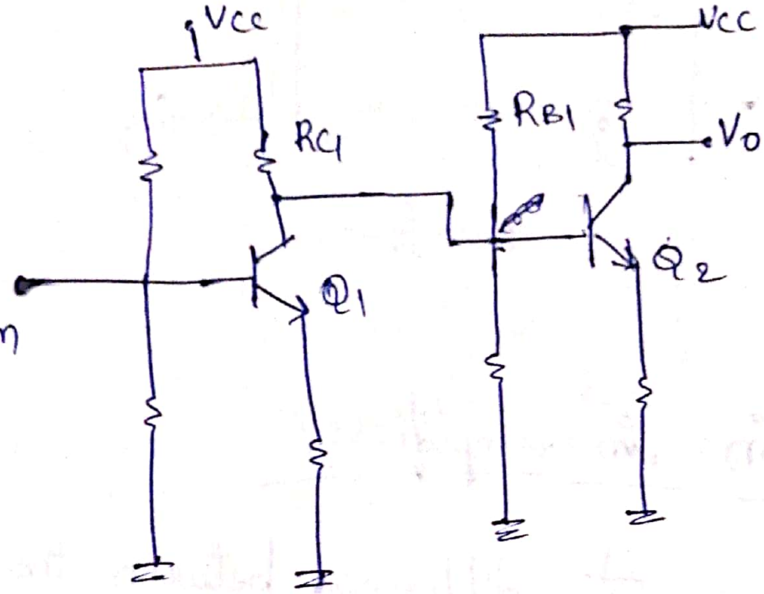
(2)



Transformer coupling

In this method primary winding of a transformer acts as a collector load and the collector load conveys the ac output signal directly to the base of the next stage.

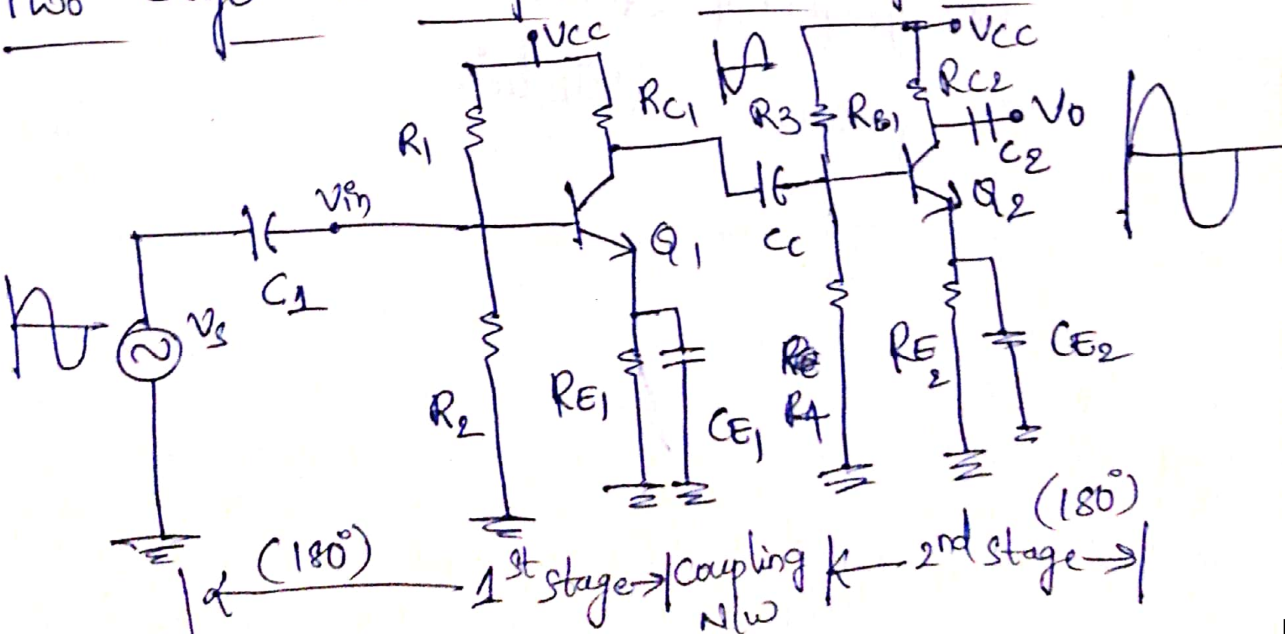
(3)

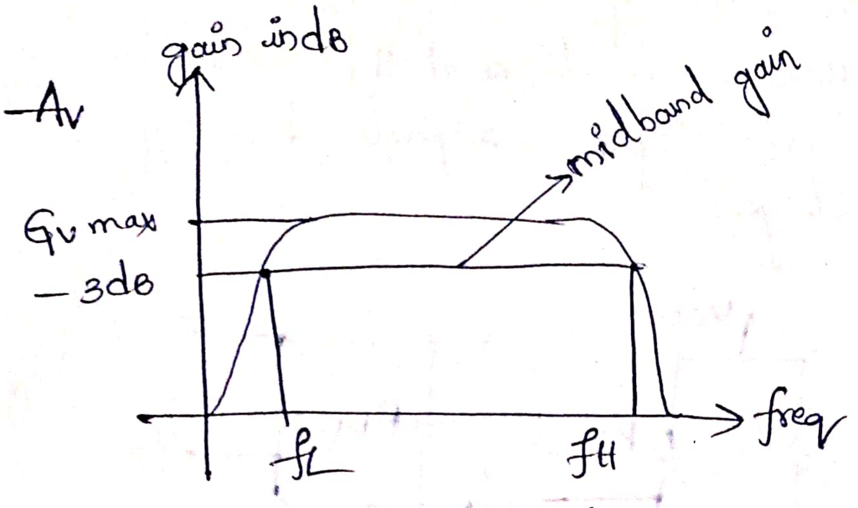


DC

In this method, the a.c output signal of stage one is fed directly to the base of the next stage. This type of coupling is used where low frequency signals are to be amplified.

Two stage RC coupled BJT amplifier





N_i = constant

Changing N_o

$\frac{N_o}{V_i}$

$BW = f_2 - f_1$

$BW = f_H - f_L$

Distortion in amplifiers:

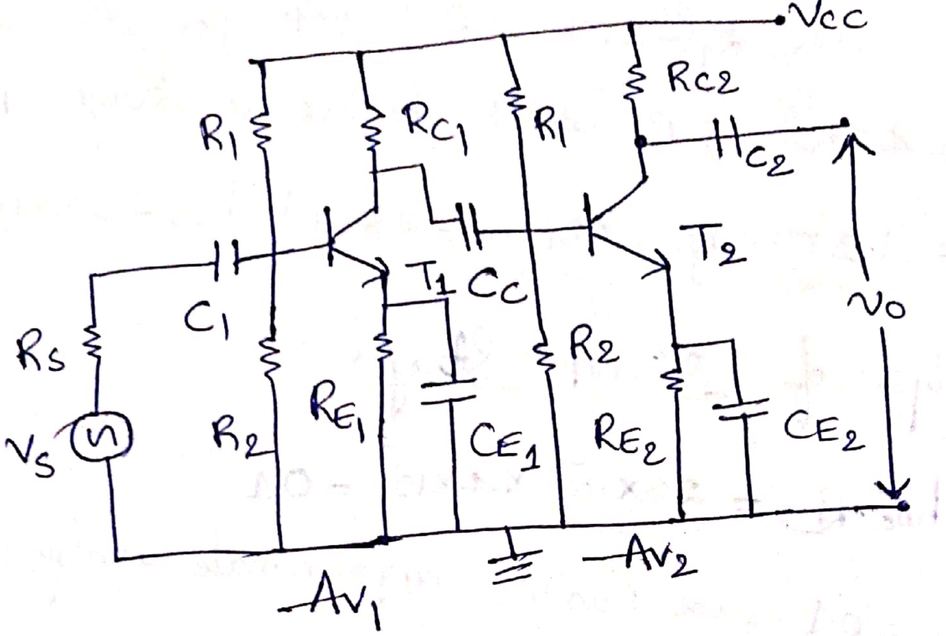
Distortion: The difference between the output signal to the input signal.

There are 3 types of distortions:

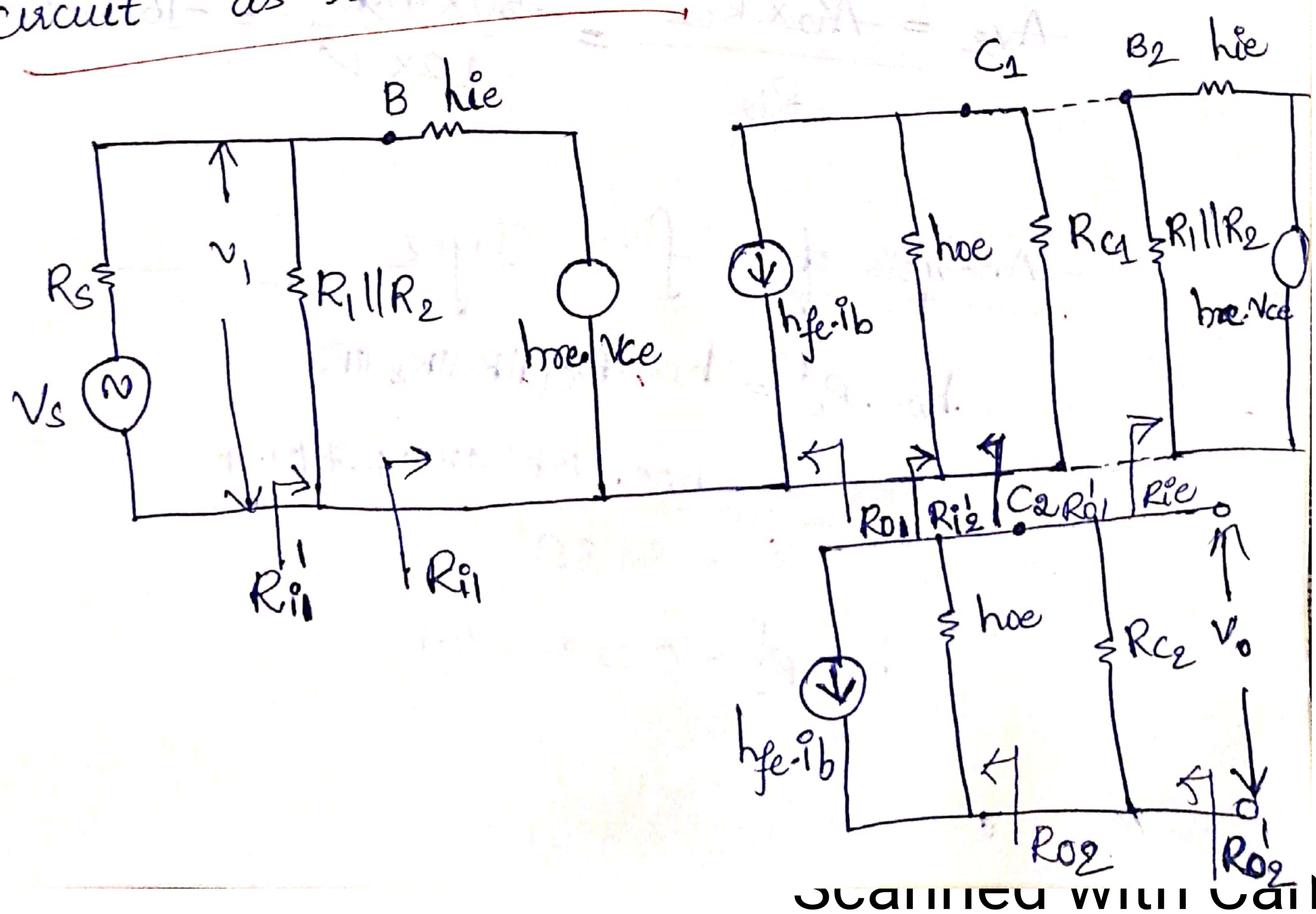
1. Amplitude distortion
2. Frequency distortion
3. phase distortion

03/02/15

Two stage RC coupled CE – CE Cascaded amplifiers



~~Assuming act~~ all capacitors acts a short circuit for ~~A.C~~ signal. we draw the h-parameter equivalent circuit as shown below.



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Let us calculate R_i, A_v, A_i, A_{vs} if circuit parameters are $R_S = 1K\Omega$, $R_{C_1} = 15K$, $R_{E_1} = 100\Omega$, $R_{C_2} = 4K\Omega$, $R_{E_2} = 330\Omega$, with $R_1 = 200K$ & $R_2 = 20K$ for first stage and $R_1 = 47K$ & $R_2 = 4.7K$ for Second stage. Assume that $h_{ie} = 1.2K\Omega$, $h_{fe} = 50$, $h_{re} = 2.5\times10^{-4}$, $h_{oe} = 25\times10^{-6}$ A/V.

Sol: Analysis of Second Stages

$$h_{oe}\cdot R_L = 25\times10^{-6}\times4\times10^{3} = 0.1$$

$h_{oe}\cdot R_L = 0.1$, we can use approximate analysis.

$$A_{i2} = -h_{fe} = -50$$

$$R_{i2} = h_{ie} = 1.2K\Omega$$

$$A_{v2} = \frac{A_{i2}\times R_{C2}}{R_{i2}} = \frac{-50\times4\times10^{3}}{1.2\times10^{3}} = -166.67$$

$-h_{fe}$

Analysis of first stages

$$h_{oe}\cdot R_L' = h_{oe}\cdot(R_{C1} \| R_1 \| R_2 \| R_{i2})$$

$$= h_{oe}\cdot 15K \| 47 \| 4.7 \| 1.2K$$

$$= 881.8\Omega$$

$$h_{oe}\cdot R_L' = 0.022 < 0.1$$

$A_{i1} = -h_{fe} = -50$

$R_{i1} = h_{ie} = 1.2K\Omega$

$$A_{v1} = \frac{-A_{i1} \times R_L'}{R_{i1}} = \frac{-50 \times 881.8}{1.2 \times 10^3} = -36.74$$

Overall voltage gain $A_v = A_{v1} \cdot A_{v2}$

$$= -166.67 \times -36.74$$

$$\boxed{A_v = 6123.45}$$

$$A_{vs} = \frac{A_v \cdot R_{i1}'}{R_{i1}' + R_s} \qquad R_{i1}' = R_1 || R_2 || R_{i1} = 7227.4$$

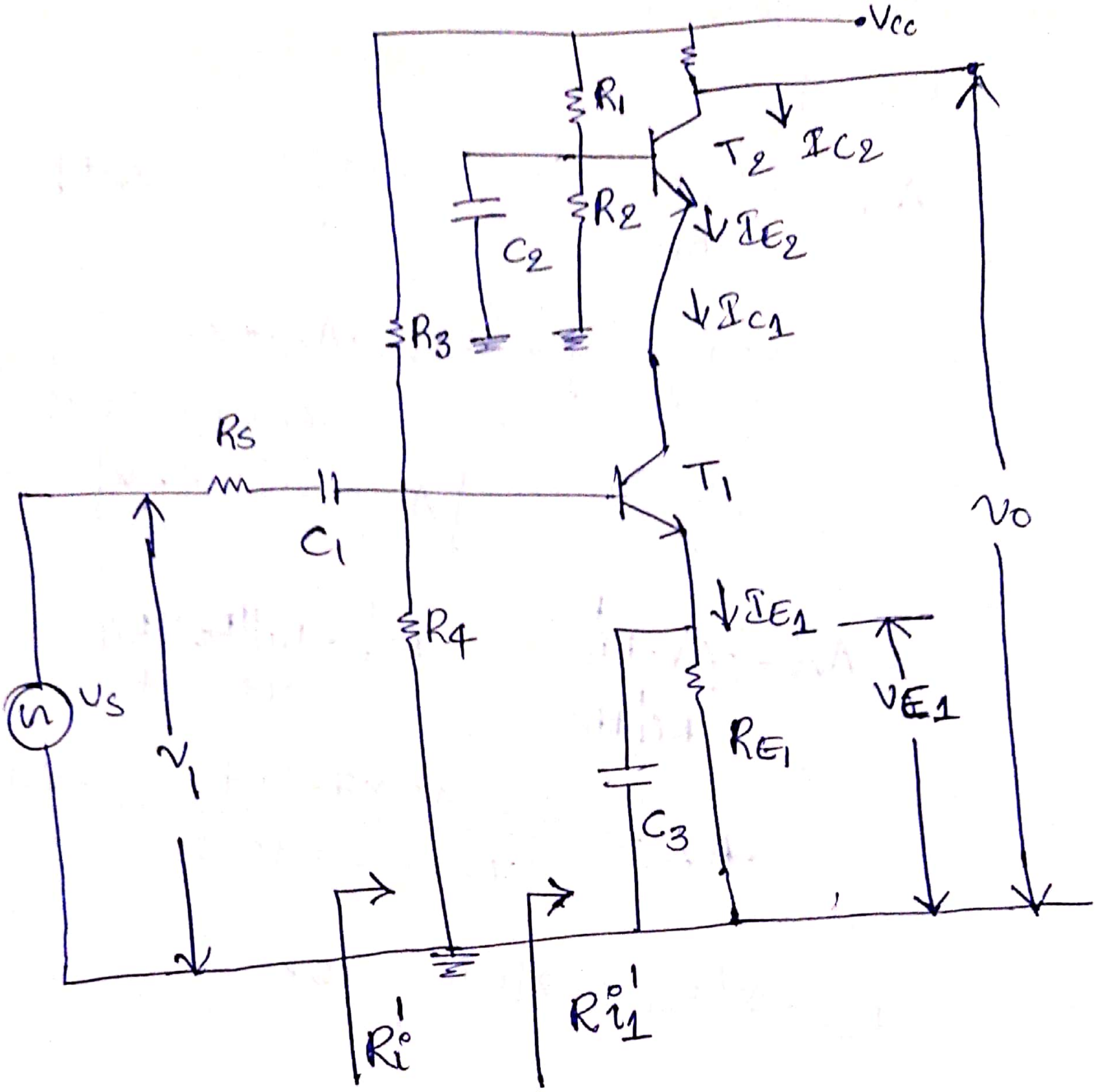
$$A_{vs} = \frac{6123.45 \times 7227.4}{(7227.4 + 1000)} = 3248.6$$

$$R_{o1}' = \infty / R_{c1} = \infty / 15K = 15K$$

Cascode amplifier :

The cascode amplifier consists of common Emitter amplifier stage in series with the common collector Source amplifier as 2nd Stage. It is used to solve the low impedance problem of circuit.

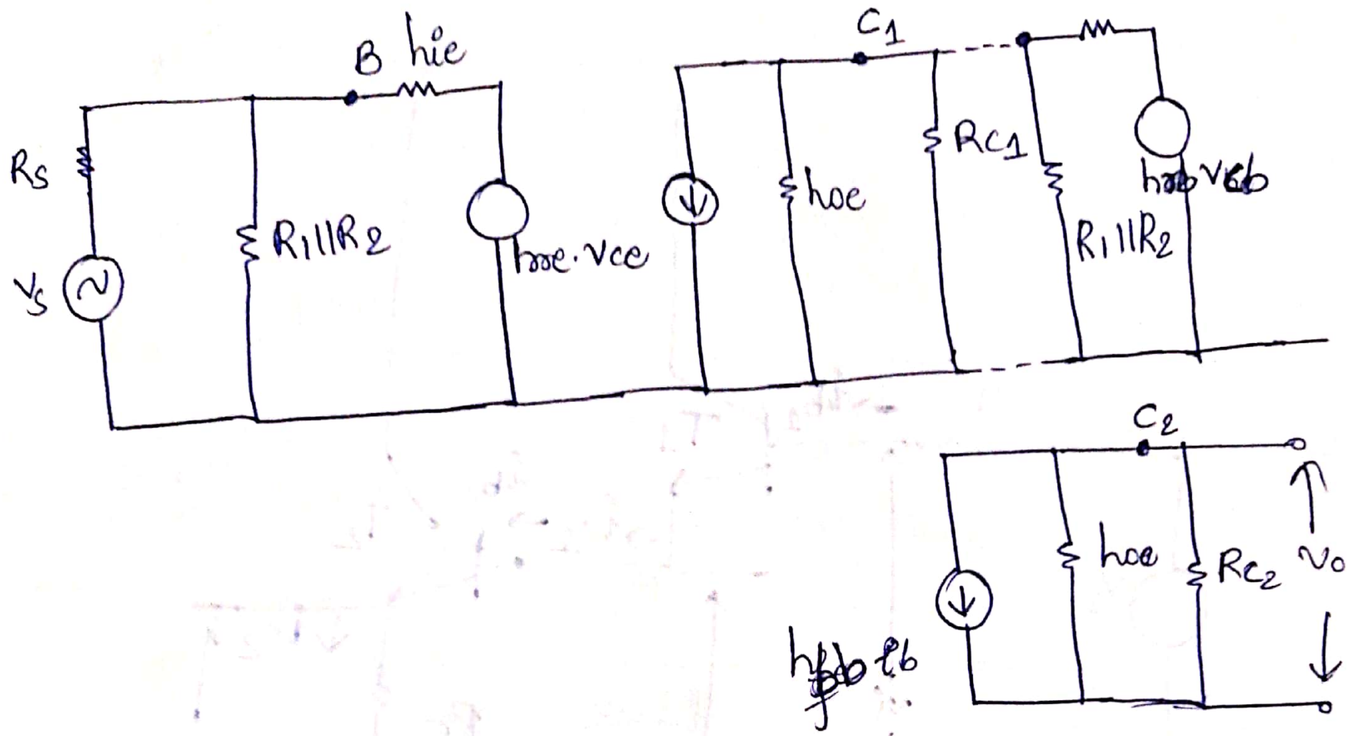
The cascoding amplifier gives the high input impedance and good voltage gain.



$R_S = 1K$, $R_3 = 200K$, $R_4 = 10K$, $R_L = 3K$, $h_{ie} = 1.1K$, $h_{fe} = 50$

The Simplified hybrid equivalent circuit for Cascode amplifier is drawn by replacing their transistors with their Simplified equivalent circuit.

Calculate Av, Ri, Ro & Ai.



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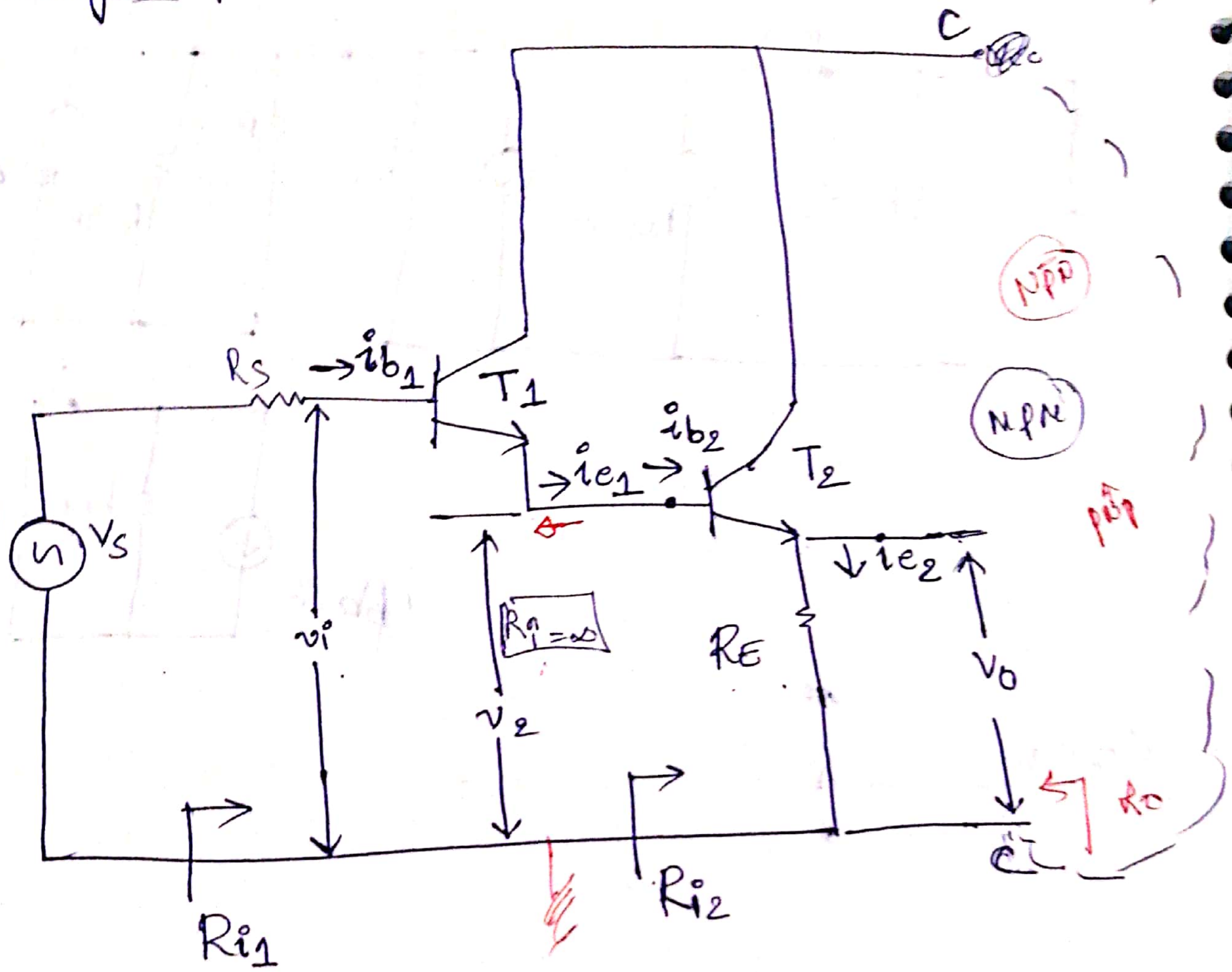
Darlington pairs



Darlington pair is used to improve the input impedance of the amplifier circuit. Direct coupling (≅ 500kΩ) of two emmitter followers (Emitter of stage 1 — Base of stage 2) results a darlington emitter follower amplifier. The above figure shows the Cascaded connected of two emitter followers called the darlington connection.

Analysis of 2nd stage:

Assume that R_E (or) R_L is small such that

$$h_{oe} \cdot R_L < 0.1$$

So we can use the approximate analysis for this stage (2 stage).

Current gain: $A_{i2} = (1+h_{fe})$ → ∵ CC configuration

Input Resistance: $R_{i2} = h_{ie} + (1+h_{fe})R_E$

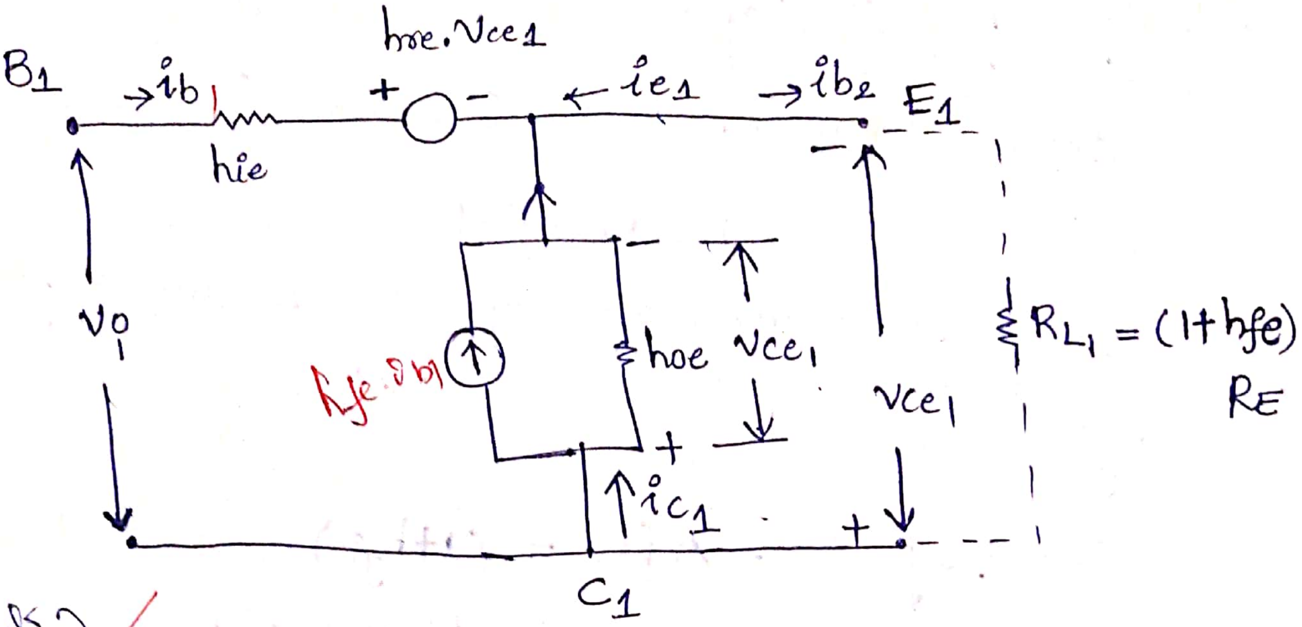
if $h_{ie} << (1+h_{fe})R_E$

$$R_{i2} = (1+h_{fe})R_E = R_{L1}$$

The load resistance of the first stage is the input resistance of the R_{i2}. As R_{i2} is very high, usually it doesnot meet the requirement $h_{oe} \cdot R_{L1} < 0.1$. Hence we have to use exact analysis for the first stage.

The hybrid equivalent circuit of CC-configuration for stage 1 is shown below.

$R_{i2} = R_{L1}$, very high



(Exact Analysis)

$$A_{i1} = \frac{i_{b2}}{i_{b1}} = \frac{-i_{e1}}{i_{b1}}$$

$i_{b2} = -i_{e1}$

$i_{b1} + i_{c1} + i_{e1} = 0$

$i_{e1} = -(i_{b1} + i_{c1})$

$V_{ce1} = -i_{b2} \times R_{L1}$

$$i_{e1} = -(i_{b1} + i_{c1})$$

$$i_{c1} = h_{fe} \cdot i_{b1} + h_{oe} \cdot V_{ce1}$$

$$= h_{fe} \cdot i_{b1} + h_{oe}(-i_{b2} \cdot R_{L1})$$

$$i_{c1} = h_{fe} \cdot i_{b1} + h_{oe} \cdot i_{e1} \cdot R_{L1}$$

Sub. i_{c1} in i_{e1}.

$$i_{e1} = -(i_{b1} + h_{fe} i_{b1} + h_{oe}(-i_{b2} \cdot R_{L1}))$$

$h_{oe}\, i_{e1} \cdot R_{L1}$

$$i_{e1} + h_{oe} R_{L1} i_{e1} = -i_{b1}(1+h_{fe})$$

$$-\frac{i_{e1}}{i_{b1}} = \frac{(1+h_{fe})}{1+h_{oe} \cdot R_{L1}}$$

we know that

$$R_{L1} = (1+h_{fe}) R_E \quad \text{sub. in above equation}$$

$$-A_{i_1} = \frac{-i_{e1}}{i_{b1}} = \frac{(1+h_{fe})}{1+h_{oe}(1+h_{fe})R_E}$$

$$\boxed{-A_{i_1} = \frac{1+h_{fe}}{1+h_{oe}\cdot h_{fe}\cdot R_E}}$$

if $1 << h_{fe}$

h_{oe} : in μmhos

$h_{oe} R_E << 1$

0.1

$1 + \cancel{h_{oe} R_E} + h_{oe} h_{fe}$

Input Resistance (R_{i_1}) :

$$R_{i_1} = \frac{V_i}{i_{b_1}}$$

Apply KVL to output loop, we get

$$V_i - i_{b_1} h_{ie} - h_{re} V_{ce1} + V_{ce1} = 0$$

$$V_i = i_{b_1} h_{ie} + h_{re} V_{ce1} - V_{ce1}$$

the term $h_{re} \cdot V_{ce1}$ is negligable. Since h_{re} in the order of 2.5×10^{-4}

$V_{ce1} = -i_{b2}$

$$V_i = i_{b_1} h_{ie} - (V_{ce1})$$

$$V_i = i_{b_1} h_{ie} - (-i_{b_2} R_{L1})$$

$$V_i = i_{b_1} h_{ie} + i_{b_2} R_{L1}$$

$\div$ by i_{b1}

$$R_{i1} = \frac{v_i}{i_{b_1}} = h_{ie} + \frac{i_{b_2}}{i_{b_1}} R_{L1}$$

$\frac{i_{b2}}{i_{b1}} = A_{i1}$

$R_{L1} = (1+h_{fe}) R_E$

$$= h_{ie} + A_{i1} \cdot R_{L1}$$

$$R_{i1} = h_{ie} + A_{i1}(1+h_{fe}) R_E$$

Sub. the value of A_{i1}.

$$R_{i1} = h_{ie} + \frac{(1+h_{fe})(1+h_{fe}) R_E}{1+h_{fe} h_{oe} R_E}$$

$$R_{i1} = h_{ie} + \frac{(1+h_{fe})^2 R_E}{1+h_{oe} h_{fe} R_E}$$

$$\because h_{ie} << \frac{(1+h_{fe})^2 R_E}{1+h_{oe} h_{fe} R_E}$$

$$\boxed{\therefore R_{i1} = \frac{(1+h_{fe})^2 R_E}{1+h_{oe} \cdot h_{fe} \cdot R_E}}$$

(Ai) overall current gain :

$$A_i = A_{i1} \cdot A_{i2} = \frac{(1+h_{fe})}{1+h_{oe}(1+h_{fe}) R_E} \times (1+h_{fe})$$

$$-A_i = \frac{(1+h_{fe})^2}{1+h_{oe}(1+h_{fe})R_E}$$

Parameter	Stage ~~1~~ (2)	Darlington
Input Resistance	$(1+h_{fe})R_E$	$\frac{(1+h_{fe})^2 R_E}{1+h_{oe}h_{fe}R_E}$
Current Gain	$-\cancel{A_i}(1+h_{fe})$	$\frac{(1+h_{fe})^2}{1+h_{oe}(1+h_{fe})R_E}$

Take $R_E = 3.3K$ and $h_{ie} = 1100\Omega$, $h_{re} = 2.5\times10^{-4}$

$h_{fe} = 50$, $h_{oe} = 25\ \mu A/V$

Stage (1)$_2$

$R_i = 168.3 K\Omega$

$-A_i = 51$

Darlington

$R_i = 1.67 M\Omega$

$-A_i = 499.47$

overall voltage gain (A_v)

$$A_v = A_i \cdot \frac{R_L}{R_i}$$

Substracting '1' on both sides

$$1 - A_v = 1 - \frac{A_i R_L}{R_i}$$

general $R_i = h_i + h_r \cdot A_i \cdot R_L$ (not simplified model)

$$1 - A_v = \frac{R_i - A_i R_L}{R_i}$$

$$1 - A_v = \frac{h_{ic} + h_{rc} A_i R_L - A_i R_L}{R_i}$$

$$1 - A_v = \frac{h_{ic} + h_{rc} \cdot A_i R_L - A_i R_L}{h_{ic} + h_{rc} \cdot A_i R_L} \quad = R_i$$

from conversion Table, we have

~~$h_{rc} = h_{ic}$~~ $h_{ic} = h_{ie}$ $h_{re} = 1$ $\rightarrow h_{rc} = 1$

$$1 - A_v = \frac{h_{ie} + \overset{=1=h_{rc}}{h_{ie}} \cdot A_i R_L - A_i R_L}{h_{ie} + h_{ie} \cdot A_i R_L} \quad = R_i$$

$$1 - A_v = \frac{h_{ie}}{R_i}$$

$$\boxed{A_v = 1 - \frac{h_{ie}}{R_i}}$$

$\therefore$ overall voltage gain is the product of individual voltage gains.

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

$$A_v = \left(1 - \frac{h_{ie1}}{R_{i1}}\right)\left(1 - \frac{h_{ie2}}{R_{i2}}\right)$$

$$A_v = 1 - \frac{h_{ie2}}{R_{i2}} - \frac{h_{ie1}}{R_{i1}} + \left(\frac{h_{ie1}\,h_{ie2}}{R_{i1}\,R_{i2}}\right)$$

we know that $R_{i1} >> R_{i2}$

$$A_v = 1 - \frac{h_{ie2}}{R_{i2}}$$

$$\therefore \boxed{A_v = 1 - \frac{h_{ie2}}{R_{i2}}}$$

$1 - \frac{h_{ie}}{R_{i2}}$

Output impedance: R_o

$$R_o = \frac{1}{Y_o}$$

(general model)

$$Y_{o1} = h_{oe} + \frac{(1+h_{fe})}{h_{ie}+R_s} \qquad \left(\because Y_{o1} = h_{oc} - \frac{h_{fc}\,h_{rc}}{h_{ic}+R_s}\right.$$

$h_{oc} \approx h_{oe}$

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

$$Y_{o1} = h_{oe} + \frac{(1+h_{fe})}{h_{ie}+R_s} \qquad \therefore \quad h_{rc} = 1, \quad h_{ic} = h_{ie}$$

$$Y_{o1} = \frac{1+h_{fe}}{h_{ie}+R_s}$$

$$h_{oe} \ll \frac{1+h_{fe}}{h_{ie}+R_s}$$

$Y_{o1} =$

$$R_{o1} = 1/Y_{o1}$$

$$R_{o1} = \frac{h_{ie1}+R_s}{1+h_{fe}}$$

$$(\because R_{s2} = R_{o1})$$

$$R_{o2} = \frac{R_{s2}+h_{ie2}}{1+h_{fe}} = \frac{\left(\frac{h_{ie1}+R_s}{1+h_{fe}}\right)+h_{ie2}}{1+h_{fe}}$$

Since current in T_2 is $(1+h_{fe})$ times the current in T_1, i.e. $h_{ie1} = (1+h_{fe})h_{ie2}$

$$R_{o2} = \frac{h_{ie1}+R_s}{(1+h_{fe})^2} + \frac{h_{ie2}}{1+h_{fe}}$$

$$R_{o2} = \frac{(1+h_{fe})h_{ie2}+R_s}{(1+h_{fe})^2} + \frac{h_{ie2}}{1+h_{fe}} \qquad \left(\because \text{current terms } h_{ie1} \approx (1+h_{fe})\, h_{ie2}\right)$$

By expanding, we get

$$R_{o2} = R_s/(1+h_{fe})^2 + 2h_{ie2}/(1+h_{fe})$$