RC coupled Amplifier

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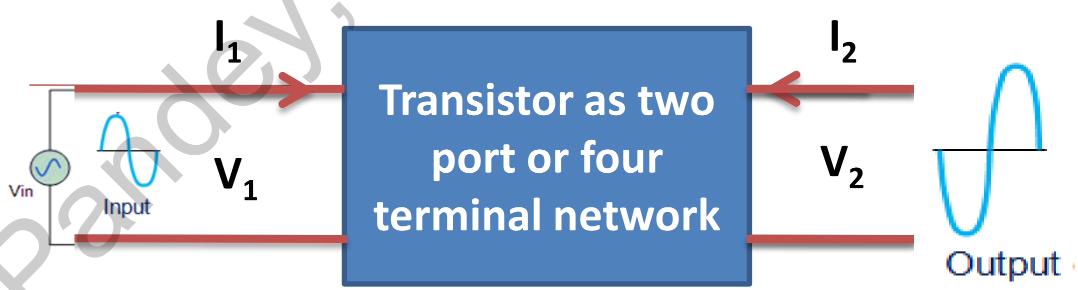
Amplifiers

1. *An amplifier, electronic amplifier is an electronic device that can increase the power of a signal. In other word, it is an electronic circuit that amplifies a low magnitude of input signal to a high magnitude of signal.*
2. *It is a two-port electronic circuit that uses electric power from a power supply to increase the amplitude of a signal applied to its input terminals, producing a proportionally greater amplitude signal at its output.*
3. *The amount of amplification provided by an amplifier is measured by its gain: the ratio of output voltage, current, or power to input.*
4. *An amplifier is a circuit that has a power gain greater than one.*



Terms for an Amplifiers

1. **Gain:** ***Ratio of output amplitude and input amplitudes of current or voltage or power.***

$$A_i = \frac{\text{Output current}}{\text{Input current}} = \frac{I_{out}}{I_{in}}$$

$$A_v = \frac{\text{Output voltage}}{\text{Input voltage}} = \frac{V_{out}}{V_{in}}$$

$$A_p = \frac{\text{Output Power}}{\text{Input Power}} = \frac{P_{out}}{P_{in}} = A_v.A_i$$

Unit less

Normally these gain quantities have not unit but in logarithmic scale Power and voltage gain can be represented in terms of bel and decibel (dB).

Common logarithmic (log base 10) of power gain is termed as bel.

$$A_p = \log_{10} \frac{P_{out}}{P_{in}} \text{ bel}$$

$$A_p = 10 \log_{10} \frac{P_{out}}{P_{in}} \text{ dB}$$

$$\because 1\,\text{bel} = 10\,\text{dB}$$

$$A_v = 20 \log_{10} \frac{V_{out}}{V_{in}} \text{ dB}$$

$$\because P = \frac{V^2}{R}$$

Terms for an Amplifiers

2. Frequency response: ***The curve between voltage gain and signal frequency of amplifier is called as Frequency response curve.***

Lower Cut-off frequency: ***The frequency in low frequency region at which gain reduces to 70.7% of maximum gain or falls by 3dB from maximum gain of amplifier is called as lower cut off frequency (F_L).***

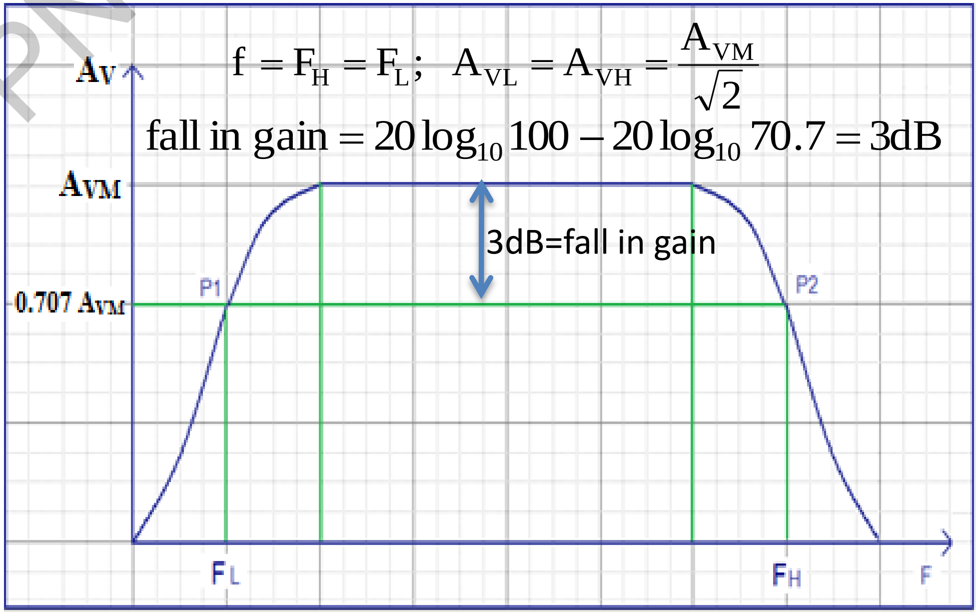
Upper Cut-off frequency: ***The frequency in high frequency region at which gain reduces to 70.7% of maximum gain or falls by 3dB from maximum gain of amplifier is called as Upper cut off frequency (F_H).***

F_L and F_H are also called as 3dB-frequency of half power frequency..

3. Bandwidth: ***The range of frequency over which the voltage gain is equal to or greater than the 70.7% of maximum gain is known as bandwidth.***

Mathematically, it is equal to difference of lower and higher/upper cut off frequency.

$$BW = F_H - F_L$$



Cascade or Multistage Amplifiers

For many applications, the performance obtained by a single-stage amplifier is often insufficient , hence several stages may be combined forming a **multistage amplifier**.

A transistor circuit containing more than one stage amplification is known as multistage transistor amplifier.

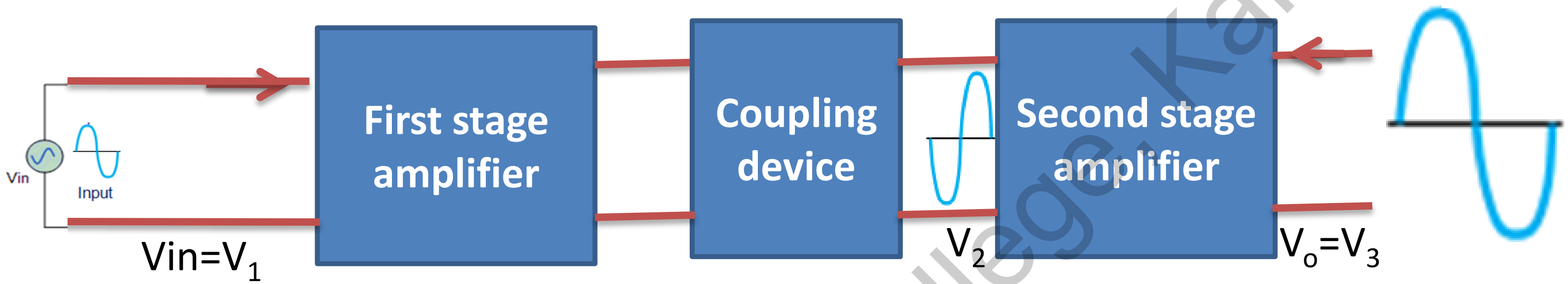
In multistage amplifier, a number of amplifiers are connected in series or cascade arrangement. Due to this, it is also called as Cascade amplifiers.

In such amplifiers, the output of first stage is connected to input of second stage through suitable coupling device and so on.

On the basis of coupling device, following types of cascade amplifier can be designed.

1. **R-C coupled amplifier**
2. **R-L coupled amplifier**
3. **L-C coupled amplifier**
4. **Transformer coupled amplifier**
5. **Direct coupled amplifier**
6. **Optical coupled amplifier**

Gain in Cascade Amplifiers



$$A_v = \frac{\text{Output voltage}}{\text{Input voltage}} = \frac{V_{out}}{V_{in}} = \frac{V_3}{V_1} = \frac{V_2}{V_1} \times \frac{V_3}{V_2} = A_1 \times A_2$$

If there are n stages having gains A_1, A_2, ..., A_n then total can be written as-

$$A_v = A_1 \times A_2 \times \ldots\ldots\ldots \times A_n$$

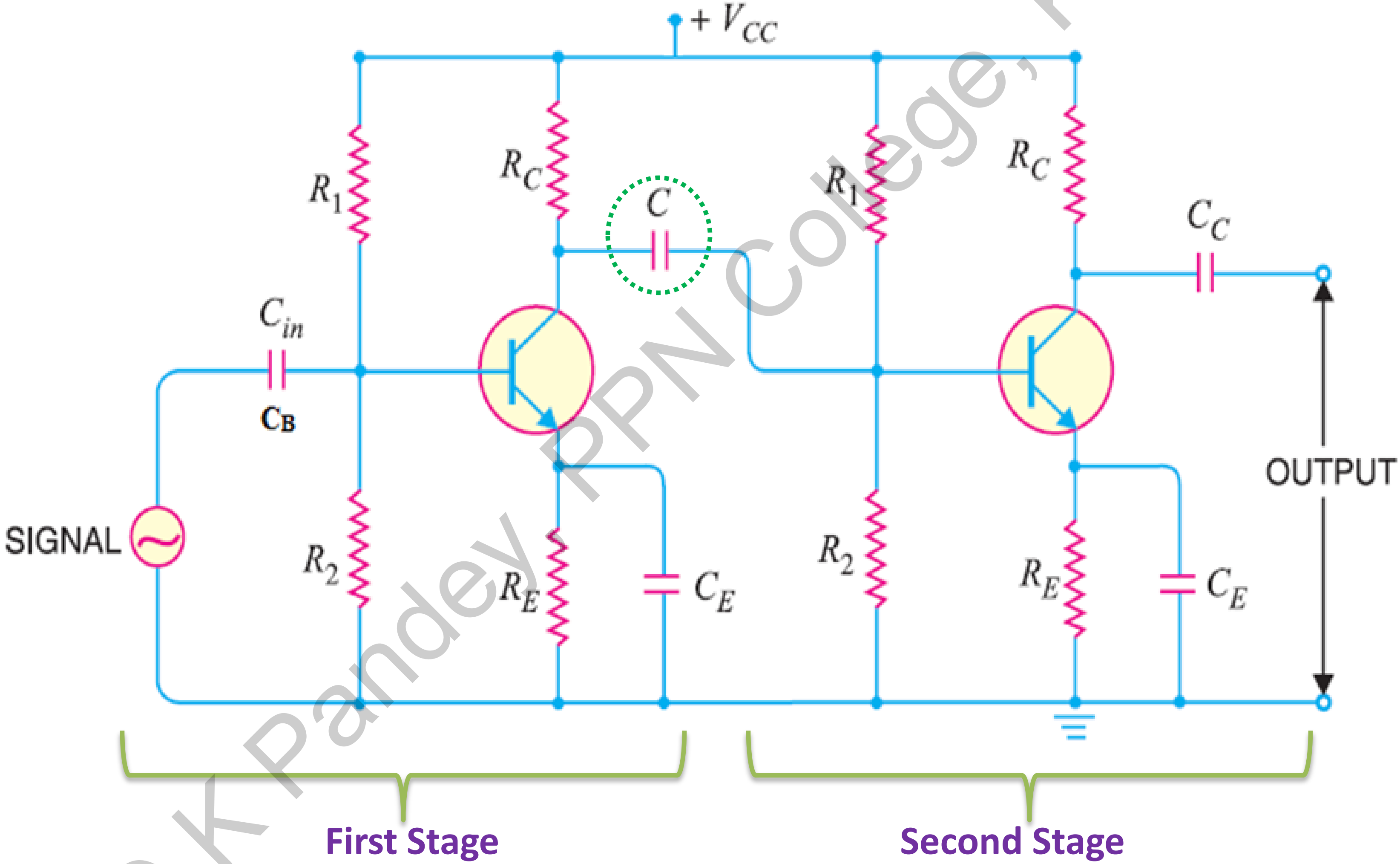
If gains are dB then net gain will be-

$$A_v \text{ in dB} = 20 \log_{10}\left(\frac{V_2}{V_1} \times \frac{V_3}{V_2}\right) = 20 \log_{10}\frac{V_2}{V_1} + 20 \log_{10}\frac{V_3}{V_2} = A_1 + A_2$$

For n stages $$A_v \text{ in dB} = A_1 + A_2 + \ldots\ldots\ldots + A_n$$

R C coupled Amplifiers

Two CE amplifiers are coupled with a coupling capacitor C.



R C coupled Amplifiers

R_1 and R_2: Biasing resistance which forms potential divider to provide source (V_2=V_{Th}=V_{BB}) to input circuit.

R_C : Biasing resistance to provide appropriate source to output circuit.

R_E : Stabilization resistance.

C_B : Base/input capacitor which forward only ac voltage of input signal for the amplification.

C_E : Bypass capacitor which bypasses ac voltage through it to reduce the potential drop through R_E.

C_C : Collector capacitor which forwards only amplified ac voltage in output.

C : Coupling capacitor ; **V_{CC} :** Power dc source

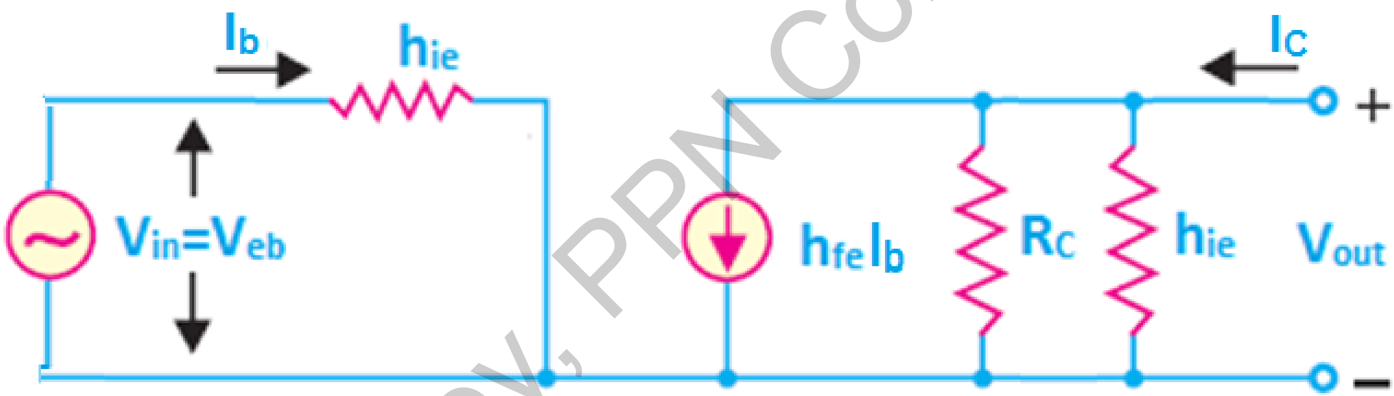
Operation : When an ac signal is applied to the base of first transistor, it appears in amplified form across collector load R_C. This amplified signal is given to base of second transistor through coupling capacitor C_C. The second stage does further amplification of the signal which is obtained at output terminals.

RC coupled amplifier : Analysis

The gain, frequency response curve and bandwidth of RC coupled amplifier can be analyzed in three different frequency regions using hybrid equivalent circuit.

1. Mid frequency region: (typically 50Hz to 20kHz)

Reactance of coupling capacitor is small, so its effect is neglected. No development of Shunt capacitance. Input impedance of second stage comes into effect. So, hybrid circuit takes the following form.



$$A_{vm} = \frac{V_{out}}{V_{in}} = \frac{I_C Z_L}{I_b h_{ie}} = \frac{-h_{fe} I_b \left(h_{ie} \| R_C\right)}{h_{ie} I_b} = -\frac{h_{fe}}{h_{ie}}\left(\frac{h_{ie} R_C}{h_{ie} + R_C}\right)$$

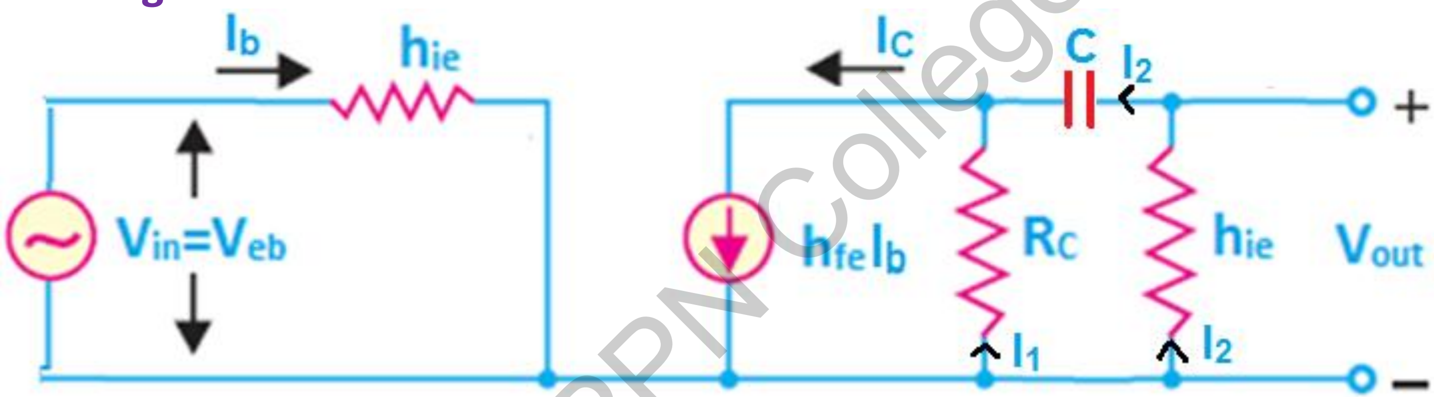
$$A_{vm} = -\frac{h_{fe} R_C}{h_{ie} + R_C}$$

The negative sign shows 180^0 phase change between input and output signals. In mid-frequency region, Gain is independent of frequency.

RC coupled amplifier : Analysis

2. Low frequency region: (typically <50Hz)

Reactance of coupling capacitor is high, so its effect is incorporated. Input impedance of second stage comes into effect. So, hybrid circuit takes the following form.



$$A_{VL} = \frac{V_{out}}{V_{in}} = \frac{-I_2 h_{ie}}{I_b h_{ie}} = -\frac{I_2}{I_b}$$

Potential difference across C and h_{ie} = P. d. across load impedance Z_L

$$I_2\left(h_{ie} - \frac{j}{\omega C}\right) = h_{fe} I_b Z_L \qquad Z_L = R_C \left\| \left(h_{ie} - \frac{j}{\omega C}\right)\right.$$

RC coupled amplifier : Analysis

$$\frac{I_2}{I_b} = \frac{h_{fe} Z_L}{\left(h_{ie} - \frac{j}{\omega C}\right)}$$

$$\frac{I_2}{I_b} = \frac{h_{fe}}{\left(h_{ie} - \frac{j}{\omega C}\right)} \times \frac{R_C\left(h_{ie} - \frac{j}{\omega C}\right)}{R_C + h_{ie} - \frac{j}{\omega C}} = \frac{h_{fe} R_C}{\left(h_{ie} + R_C - \frac{j}{\omega C}\right)}$$

$$A_{VL} = -\frac{h_{fe} R_C}{\left(h_{ie} + R_C - \frac{j}{\omega C}\right)} = \frac{\left(-\frac{h_{fe} R_C}{h_{ie} + R_C}\right)}{\left(1 - \frac{j}{\omega C(h_{ie} + R_C)}\right)}$$

$$A_{VL} = \frac{A_{vm}}{\left(1 - j\frac{f_L}{f}\right)}$$

Gain in Low frequency region

$$f_L = \frac{1}{2\pi C(h_{ie} + R_C)}$$

Lower cut-off frequency

$$\phi_L = 180 + \tan^{-1}\frac{f_1}{f}$$

Phase Change

RC coupled amplifier : Analysis

$$\because A_{VL} = \frac{A_{vm}}{\left(1 - j\frac{f_L}{f}\right)}$$

$$\Rightarrow \quad \left|A_{VL}\right| = \frac{\left|A_{vm}\right|}{\sqrt{1 + \left(\frac{f_L}{f}\right)^2}} < A_{vm}$$

When f = f_L, $$\left|A_{VL}\right| = \frac{\left|A_{vm}\right|}{\sqrt{2}} = 0.707\left|A_{vm}\right| = 70.7\%\ \left|A_{vm}\right|$$

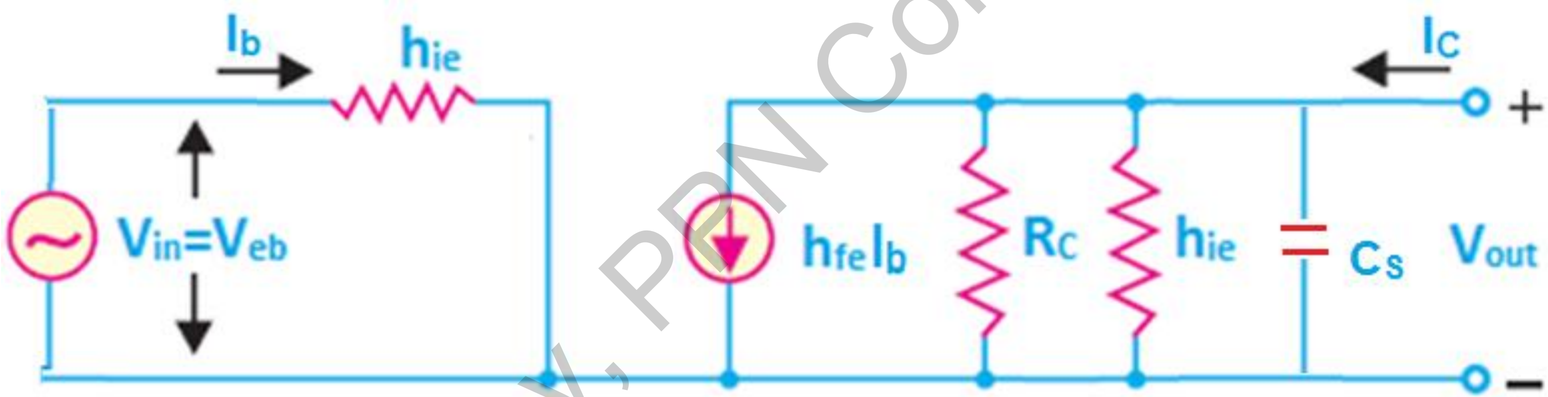
And phase change, $$\phi_L = 180 + 45 = 225^0$$

Lower Cut-off frequency:* *The frequency in low frequency region at which gain reduces to 70.7% of maximum gain or falls by 3dB from maximum gain of amplifier is called as lower cut off frequency (F_L).

RC coupled amplifier : Analysis

3. High frequency region: (typically >20kHz)

Reactance of coupling capacitor is low, so its effect (series reactance) is negligible. Input impedance of second stage comes into effect. As well as shunt capacitance comes into effect. The shunt capacitance C_S is the capacitance across output terminals that includes collector capacitance and stray wiring capacitance. So, hybrid circuit takes the following form.



$$A_{vm} = \frac{V_{out}}{V_{in}} = \frac{I_C Z_L}{I_b h_{ie}} = \frac{-h_{fe} I_b Z_L}{h_{ie} I_b} = -\frac{h_{fe} Z_L}{h_{ie}}$$

Where, $Z_L = R_C \| h_{ie} \| (1/j\omega C_S)$

RC coupled amplifier : Analysis

$$\because Z_L = R_C \| h_{ie} \| (1/j\omega C_S) \quad \Rightarrow \quad \frac{1}{Z_L} = \frac{1}{R_C} + \frac{1}{h_{ie}} + \frac{1}{(1/j\omega C_S)}$$

$$\Rightarrow Z_L = \frac{h_{ie} R_C}{h_{ie} + R_C + j\omega C_S h_{ie} R_C}$$

Thus, $$A_{vm} = -\frac{h_{fe} Z_L}{h_{ie}} = -\frac{h_{fe}}{h_{ie}} \times \frac{h_{ie} R_C}{h_{ie} + R_C + j\omega C_S h_{ie} R_C}$$

$$A_{vm} = -\frac{h_{fe} R_C}{h_{ie} + R_C + j\omega C_S h_{ie} R_C} = \frac{\left(-\frac{h_{fe} R_C}{h_{ie} + R_C}\right)}{1 + j\frac{\omega C_S h_{ie} R_C}{h_{ie} + R_C}}$$

$$A_{VH} = \frac{A_{vm}}{\left(1 + j\frac{f}{f_H}\right)}$$

Gain in High frequency region

$$f_H = \frac{h_{ie} + R_C}{2\pi C_S h_{ie} R_C}$$

Upper cut-off frequency

$$\phi_H = 180 - \tan^{-1}\frac{f}{f_H}$$

Phase Change

RC coupled amplifier : Analysis

$$\because A_{VH} = \frac{A_{vm}}{\left(1 + j\frac{f}{f_H}\right)}$$

$$\Rightarrow \quad |A_{VH}| = \frac{|A_{vm}|}{\sqrt{1 + \left(\frac{f}{f_H}\right)^2}} < A_{vm}$$

When f = f_H, $$|A_{VH}| = \frac{|A_{vm}|}{\sqrt{2}} = 0.707|A_{vm}| = 70.7\% \ |A_{vm}|$$

And phase change, $$\phi_H = 180 - 45 = 135^0$$

Upper Cut-off frequency:* *The frequency in high frequency region at which gain reduces to 70.7% of maximum gain or falls by 3dB from maximum gain of amplifier is called as Upper cut off frequency (F_H).

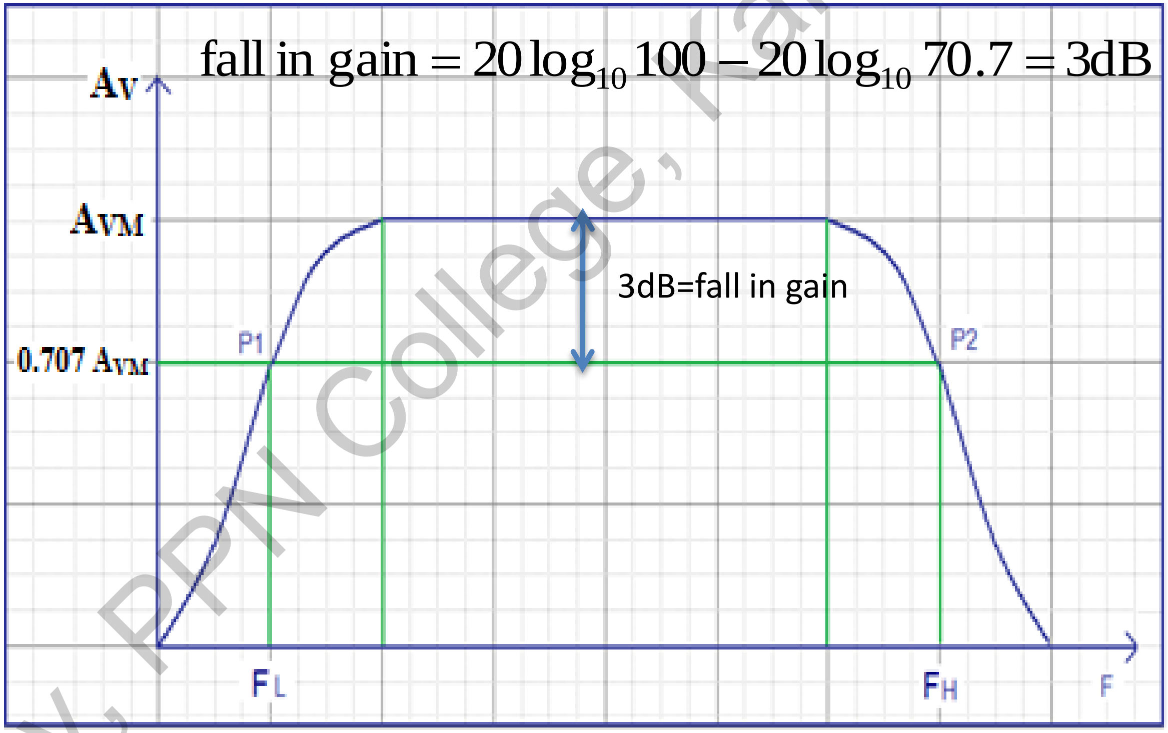
RC coupled amplifier : Frequency Response Curve

The curve between voltage gain and signal frequency of amplifier is called as Frequency response curve.

$$A_{vm} = -\frac{h_{fe}R_C}{h_{ie} + R_C}$$

$$A_{VL} = \frac{A_{vm}}{\left(1 - j\frac{f_L}{f}\right)}$$

$$A_{VH} = \frac{A_{vm}}{\left(1 + j\frac{f}{f_H}\right)}$$



$$|A_{VL}| = \frac{|A_{vm}|}{\sqrt{1 + \left(\frac{f_L}{f}\right)^2}} < A_{vm} \qquad |A_{VH}| = \frac{|A_{vm}|}{\sqrt{1 + \left(\frac{f}{f_H}\right)^2}} < A_{vm}$$

When $f = f_L = f_H$, $|A_{VL}| = |A_{VH}| = \frac{|A_{vm}|}{\sqrt{2}} = 0.707|A_{vm}| = 70.7\% \; |A_{vm}|$

RC coupled amplifier : Phase Change and Bandwidth

Phase change between input and out put can be understood as-

In mid frequency region; $\phi_m = 180$ *Opposite phase*

In low frequency region; $\phi_L = 180 + \tan^{-1}\frac{f_L}{f}$ *Phase change increases.*

In high frequency region; $\phi_H = 180 - \tan^{-1}\frac{f}{f_H}$ *Phase change reduces.*

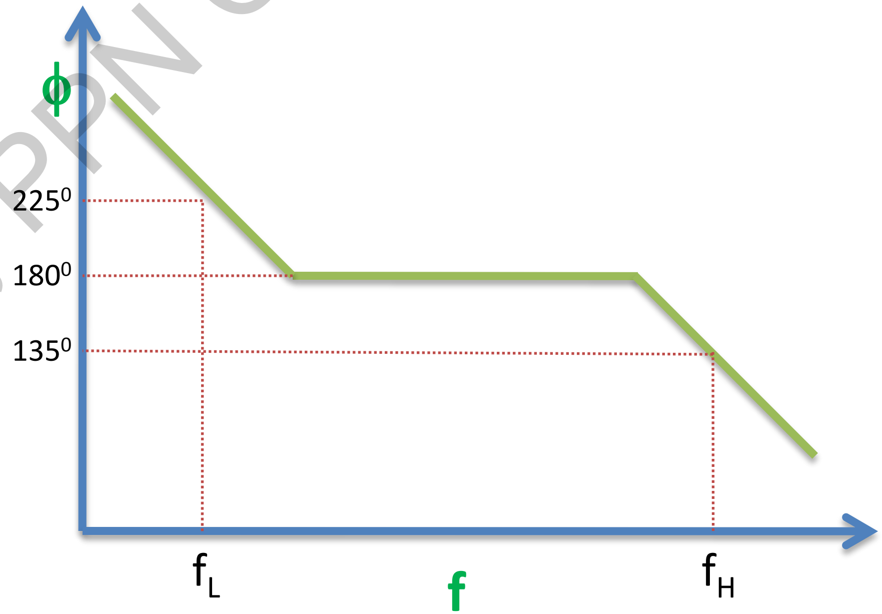
When f = f_L = f_H,

$$\phi_L = 180 + 45 = 225^0$$

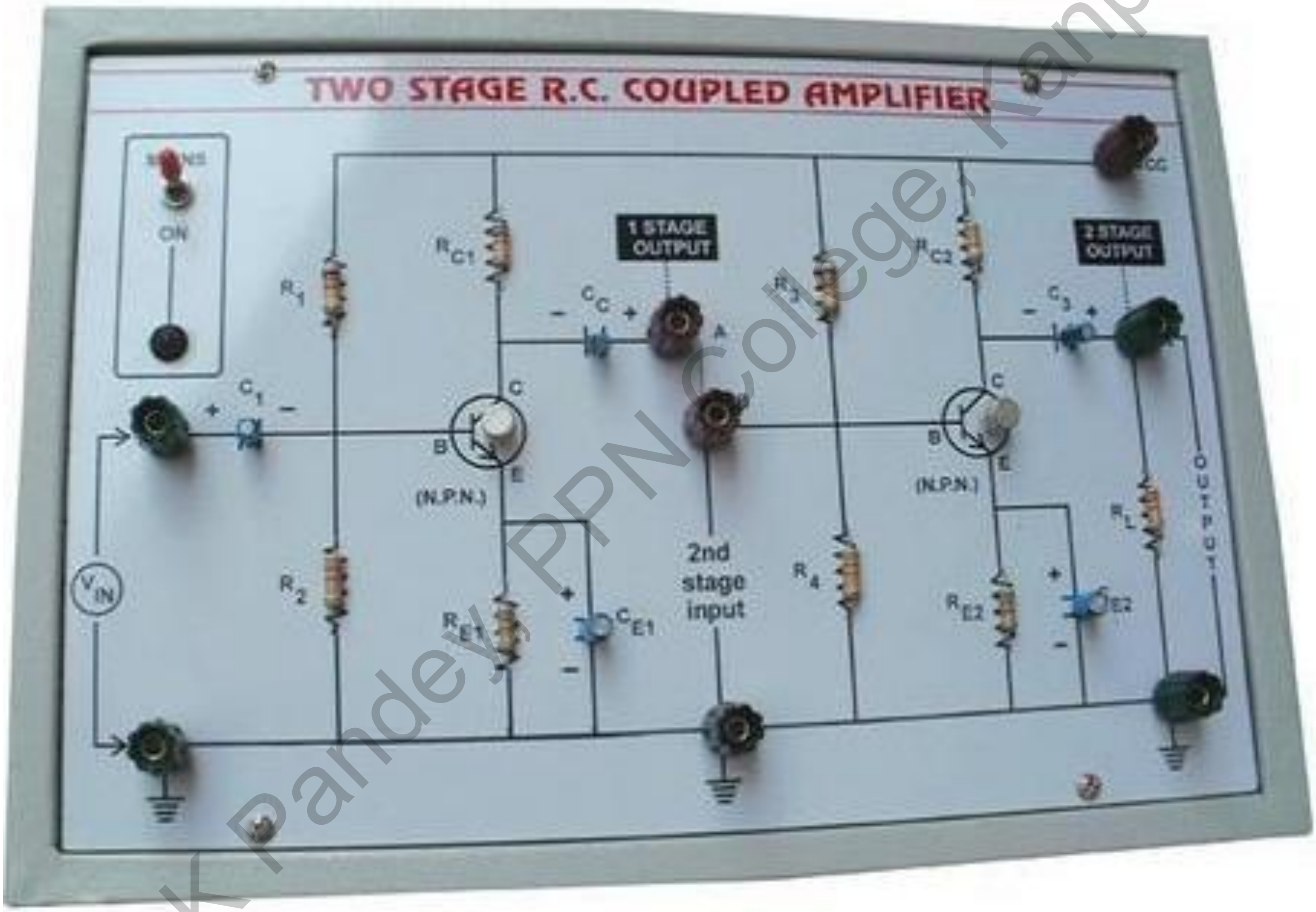
$$\phi_H = 180 - 45 = 135^0$$

Bandwidth,

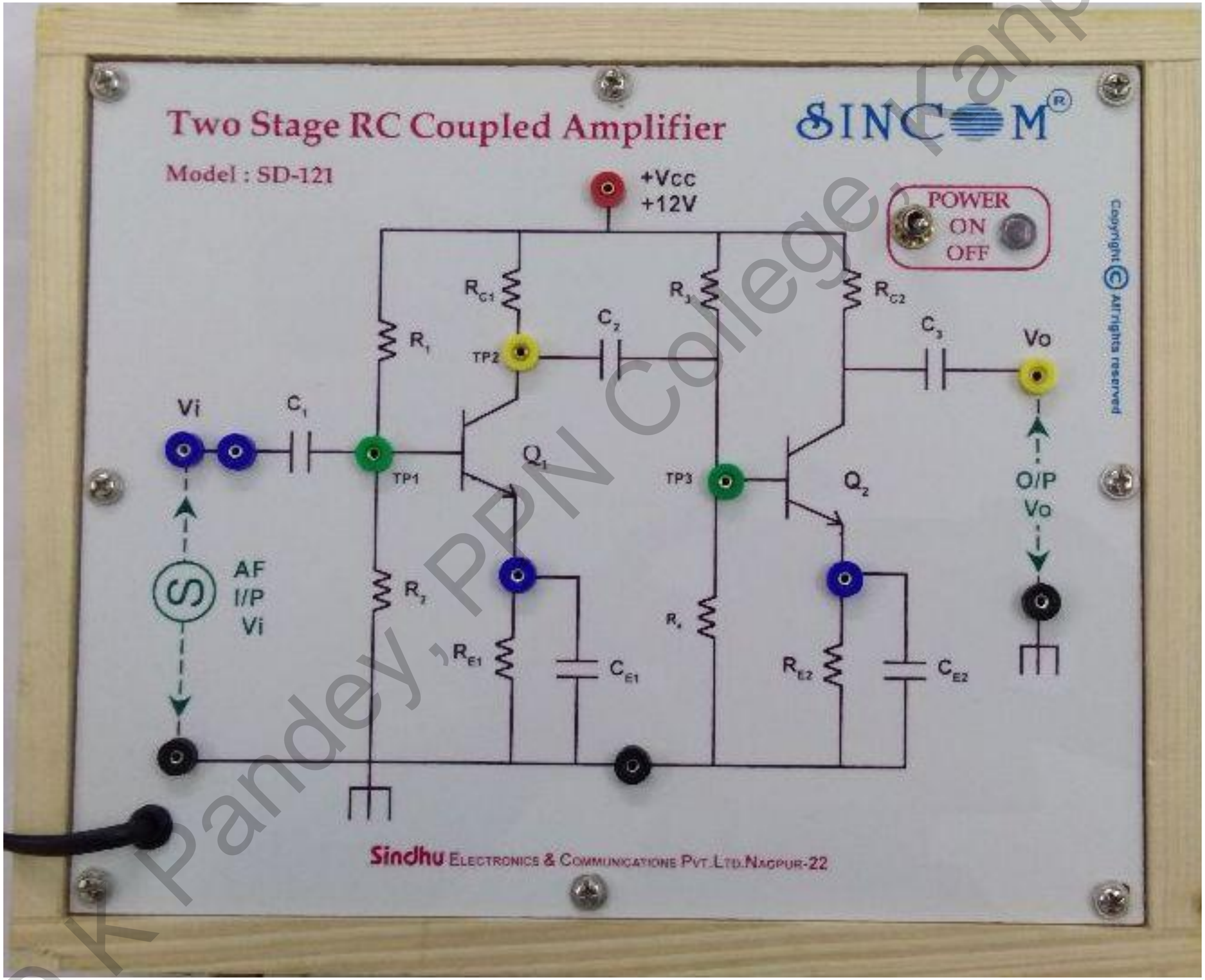
$$BW = F_H - F_L$$



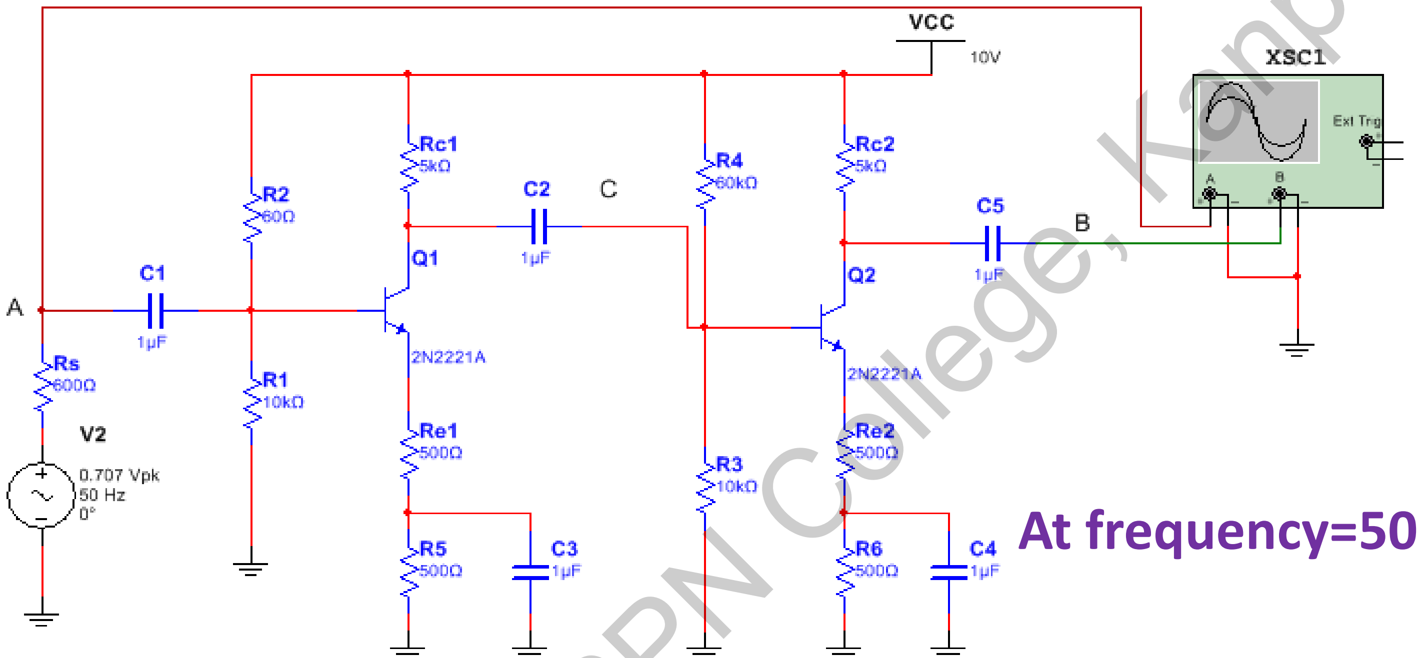
RC coupled amplifier : Practical Circuit



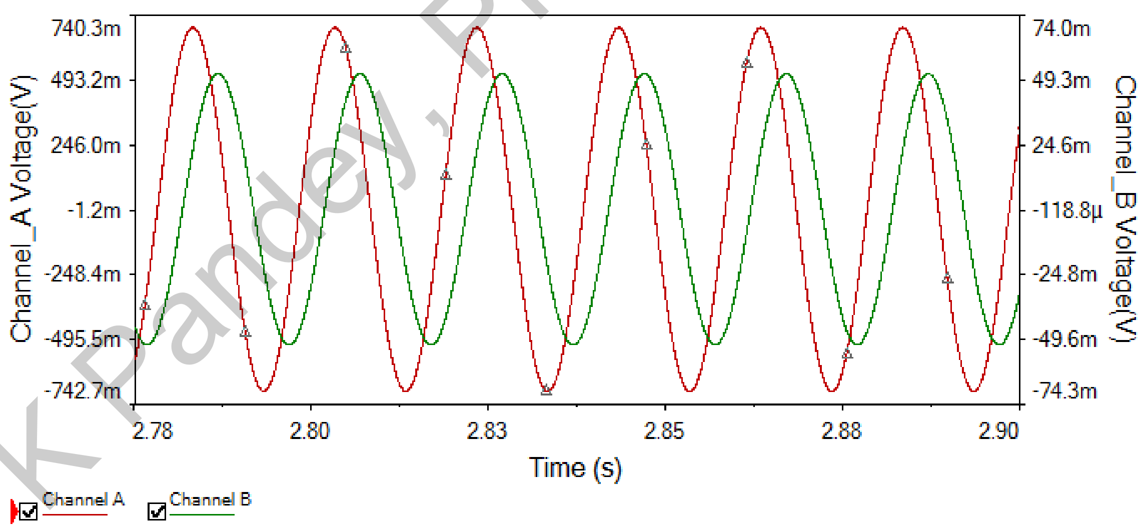
RC coupled amplifier : Practical Circuit



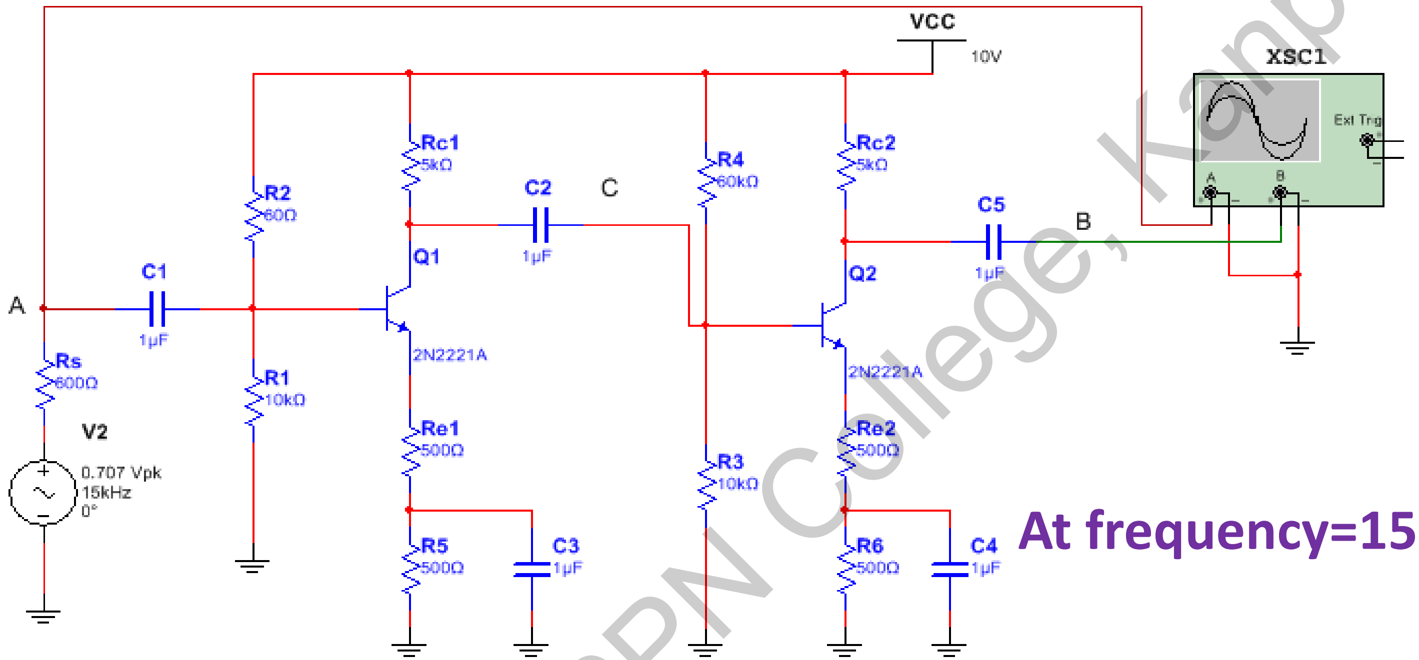
RC coupled amplifier : Simulation Circuit



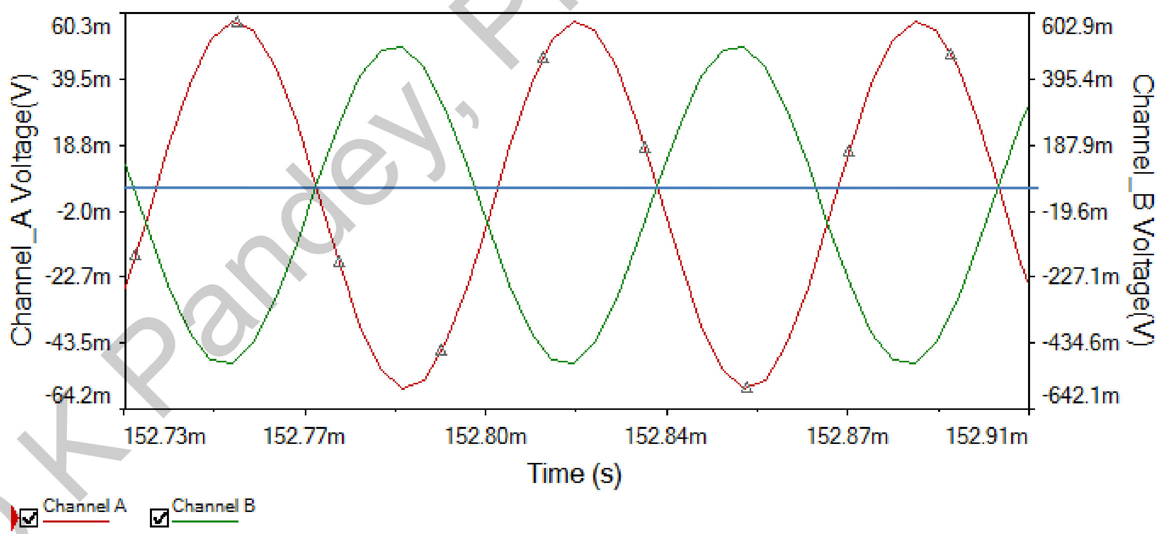
At frequency=50Hz



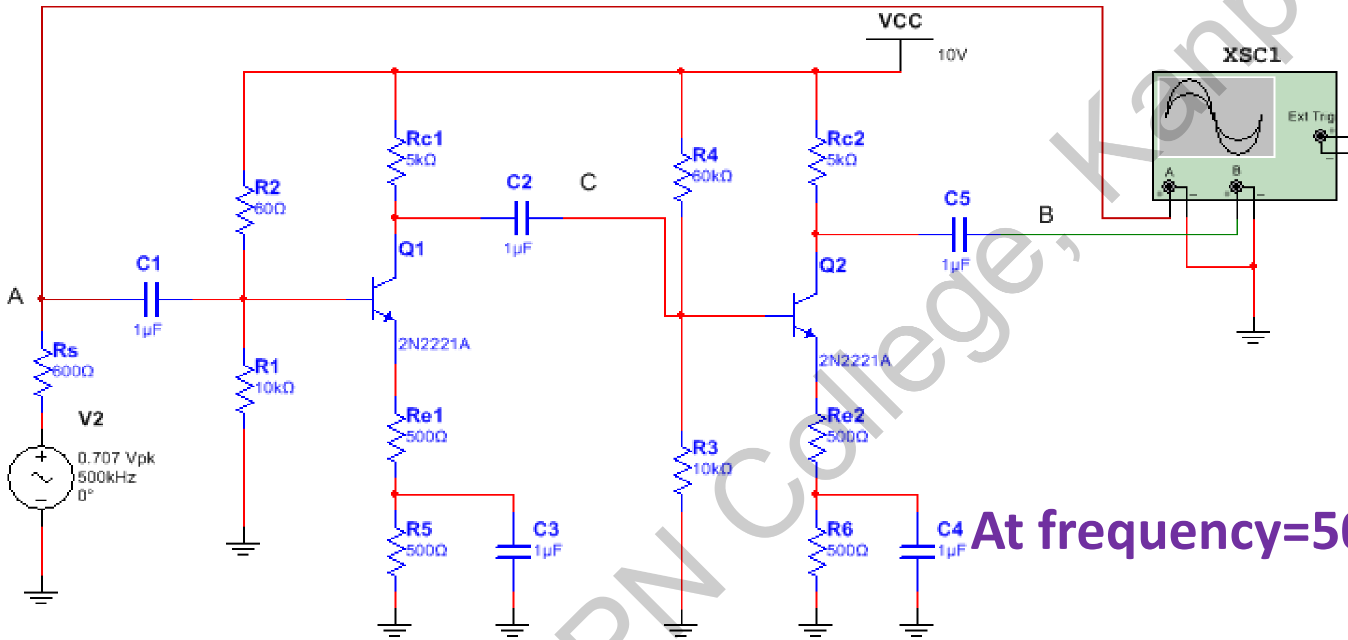
RC coupled amplifier : Simulation Circuit



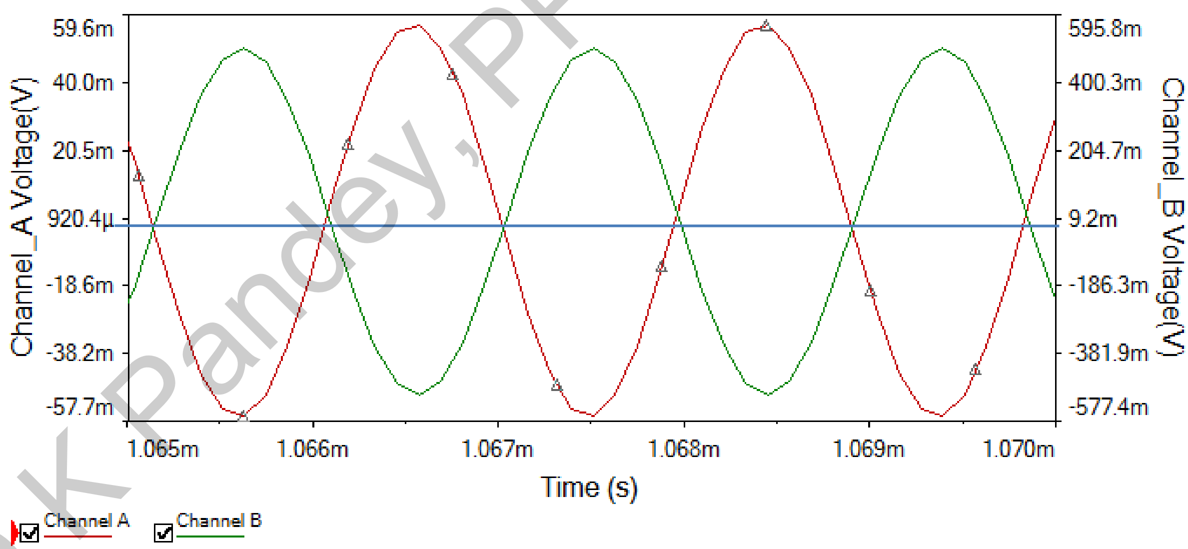
At frequency=15kHz



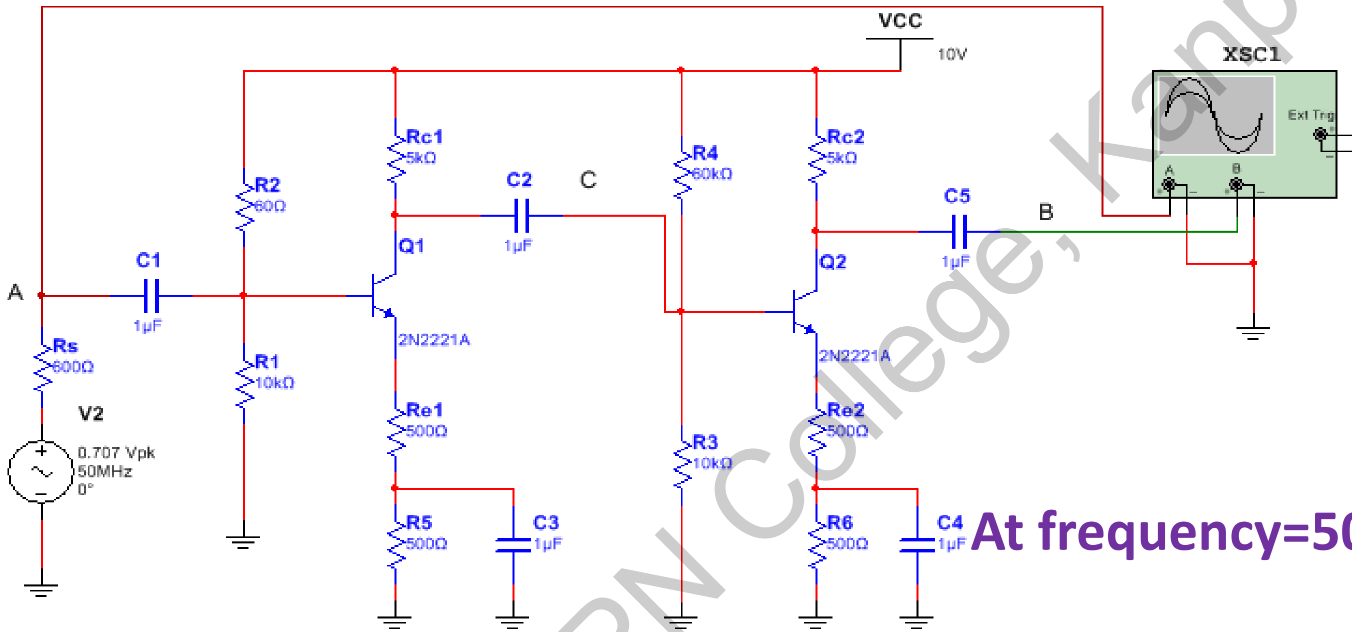
RC coupled amplifier : Simulation Circuit



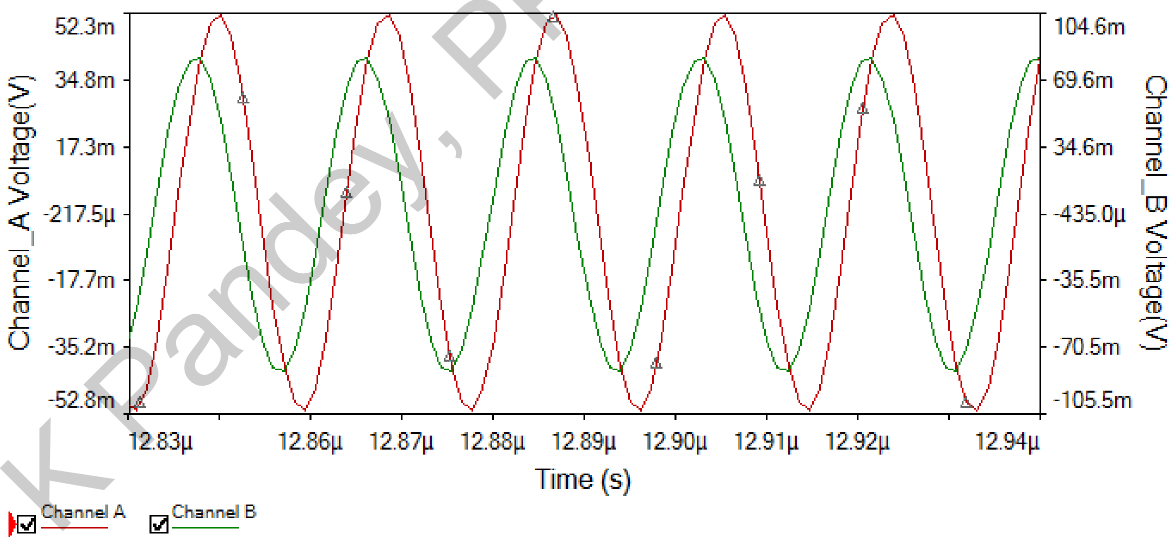
At frequency=500kHz



RC coupled amplifier : Simulation Circuit



At frequency=50MHz



Numerical

Example . *Find the gain in db in the following cases :*

(i) Voltage gain of 30 *(ii) Power gain of 100*

Solution.

(i) Voltage gain $= 20 \log_{10} 30\, db =$ **29.54 db**

(ii) Power gain $= 10 \log_{10} 100\, db =$ **20 db**

Example . *A three-stage amplifier has a first stage voltage gain of 100, second stage voltage gain of 200 and third stage voltage gain of 400. Find the total voltage gain in db .*

Solution.

First-stage voltage gain in $db = 20 \log_{10} 100 = 20 \times 2 = 40$

Second-stage voltage gain in $db = 20 \log_{10} 200 = 20 \times 2.3 = 46$

Third-stage voltage gain in $db = 20 \log_{10} 400 = 20 \times 2.6 = 52$

$\therefore$ Total voltage gain $= 40 + 46 + 52 =$ **138 db**

Numerical

Example . *A certain amplifier has voltage gain of 15 db. If the input signal voltage is 0.8V, what is the output voltage ?*

Solution.

$$db \text{ voltage gain} = 20 \log_{10} V_2/V_1$$

$$\text{or} \quad 15 = 20 \log_{10} V_2/V_1$$

$$\text{or} \quad 15/20 = \log_{10} V_2/V_1$$

$$\text{or} \quad 0.75 = \log_{10} V_2/0.8$$

Taking antilogs, we get,

$$\text{Antilog } 0.75 = \text{Antilog } (\log_{10} V_2/0.8)$$

$$\text{or} \quad 10^{0.75} = V_2/0.8$$

$$\therefore \quad V_2 = 10^{0.75} \times 0.8 = \mathbf{4.5\ V}$$

Example . *An amplifier feeding a resistive load of 1kΩ has a voltage gain of 40 db. If the input signal is 10 mV, find (i) output voltage (ii) load power.*

Solution.

$$(i) \quad \frac{V_{out}}{V_{in}} = (10)^{db\ gain/20} = (10)^{40/20} = 100$$

$$\therefore \quad V_{out} = 100 \times V_{in} = 100 \times 10 \text{ mV} = 1000 \text{ mV} = \mathbf{1\ V}$$

$$(ii) \quad \text{Load power} = \frac{V_{out}^2}{R_L} = \frac{(1)^2}{1000} = 10^{-3} \text{ W} = \mathbf{1\ mW}$$

Numerical

Example . *An amplifier rated at 40W output is connected to a 10Ω speaker.*

(i) *Calculate the input power required for full power output if the power gain is 25 db.*

(ii) *Calculate the input voltage for rated output if the amplifier voltage gain is 40 db.*

Solution.

(i) Power gain in $db = 10 \log_{10} \frac{P_2}{P_1}$ or $25 = 10 \log_{10} \frac{40\text{W}}{P_1}$

$$\therefore \quad P_1 = \frac{40\text{W}}{\text{antilog } 2.5} = \frac{40\text{W}}{3.16 \times 10^2} = \frac{40\text{W}}{316} = \mathbf{126.5\ mW}$$

(ii) Voltage gain in $db = 20 \log_{10} \frac{V_2}{V_1}$ or $40 = 20 \log_{10} \frac{V_2}{V_1}$

$$\therefore \quad \frac{V_2}{V_1} = \text{antilog } 2 = 100$$

Now $V_2 = \sqrt{P_2 R} = \sqrt{40\text{W} \times 10\ \Omega} = 20\text{ V}$

$$\therefore \quad V_1 = \frac{V_2}{100} = \frac{20\text{V}}{100} = \mathbf{200\ mV}$$

Numerical

Example . *A single stage amplifier has a voltage gain of 60. The collector load R_C = 500 Ω and the input impedance is 1kΩ. Calculate the overall gain when two such stages are cascaded through R-C coupling. Comment on the result.*

Solution. The gain of second stage remains 60 because it has no loading effect of any stage. However, the gain of first stage is less than 60 due to the loading effect of the input impedance of second stage.

$$\therefore \quad \text{Gain of second stage} = 60$$

$$\text{Effective load of first stage} = R_C \parallel R_{in} = \frac{500 \times 1000}{500 + 1000} = 333\ \Omega$$

$$\text{Gain of first stage} = 60 \times 333/500 = 39.96$$

$$\text{Total gain} = 60 \times 39.96 = \mathbf{2397}$$

Comments. The gain of individual stage is 60. But when two stages are coupled, the gain is *not* $60 \times 60 = 3600$ as might be expected rather it is less and is equal to 2397 in this case. It is because the first stage has a loading effect of the input impedance of second stage and consequently its gain is reduced. However, the second stage has no loading effect of any subsequent stage. Hence, the gain of second stage remains 60.

Example . *A single stage amplifier has collector load R_C = 10 kΩ; input resistance R_{in} = 1kΩ and β = 100. If load R_L = 100Ω, find the voltage gain.*

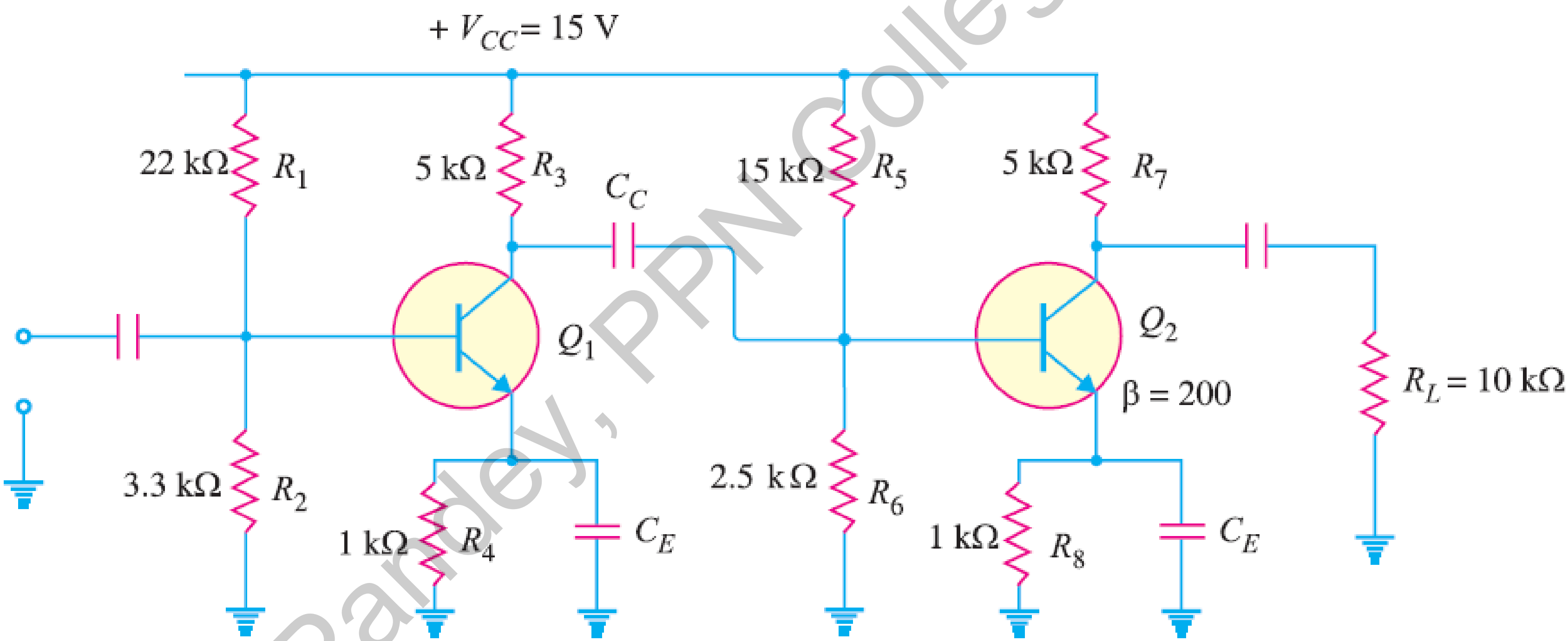
Solution. $$\text{Effective collector load, } R_{AC} = R_C \parallel R_L = 10\ \text{k}\Omega \parallel 100\ \Omega = {}^*100\ \Omega$$

$$\therefore \quad \text{Voltage gain} = \beta \times \frac{R_{AC}}{R_{in}} = 100 \times \frac{100}{1000} = \mathbf{10}$$

Numerical

Example . *Fig.* *shows a 2-stage RC coupled amplifier. Find the voltage gain of (i) first stage (ii) second stage and (iii) overall voltage gain.*

Solution. (*i*) Voltage gain of First stage. The input impedance of the second stage is the load for the first stage. In order to find input impedance of second stage, we shall first find r'_e (*ac* emitter resistance) for the second stage.



Numerical

$$\text{Voltage across } R_6 = \frac{V_{CC}}{R_5 + R_6} \times R_6 = \frac{15}{15 + 2.5} \times 2.5 = 2.14 \text{ V}$$

$$\text{Voltage across } R_8 = 2.14 - 0.7 = 1.44 \text{ V}$$

$$\text{Emitter current in } R_8,\ I_E = \frac{1.44 \text{ V}}{R_8} = \frac{1.44 \text{ V}}{1 \text{ k}\Omega} = 1.44 \text{ mA}$$

$$r_e' \text{ for second stage} = \frac{25 \text{ mV}}{I_E} = \frac{25 \text{ mV}}{1.44 \text{ mA}} = 17.4 \ \Omega$$

Similarly, it can be shown that r_e' for the first stage is $19.8 \ \Omega$.

$$Z_{in(base)} \text{ for second stage} = \beta \times r_e' \text{ for second stage} = 200 \times (17.4 \ \Omega) = 3.48 \text{ k}\Omega$$

$$\text{Input impedance of the second stage, } Z_{in} = R_5 \,||\, R_6 \,||\, Z_{in(base)}$$

$$= 15 \text{ k}\Omega \,||\, 2.5 \text{ k}\Omega \,||\, 3.48 \text{ k}\Omega = 1.33 \text{ k}\Omega$$

∴ Effective collector load for first stage is

$$R_{AC} = R_3 \,||\, Z_{in} = 5 \text{ k}\Omega \,||\, 1.33 \text{ k}\Omega = 1.05 \text{ k}\Omega$$

$$\text{Voltage gain of first stage} = \frac{R_{AC}}{r_e' \text{ for first stage}} = \frac{1.05 \text{ k}\Omega}{19.8 \ \Omega} = 53$$

(ii) **Voltage gain of second stage.** The load R_L (= 10 kΩ) is the load for the second stage.

∴ Effective collector load for second stage is

$$R_{AC} = R_7 \,||\, R_L = 5 \text{ k}\Omega \,||\, 10 \text{ k}\Omega = 3.33 \text{ k}\Omega$$

$$\therefore \quad \text{Voltage gain of second stage} = \frac{R_{AC}}{r_e' \text{ for second stage}} = \frac{3.33 \text{ k}\Omega}{17.4 \ \Omega} = 191.4$$

(iii) **Overall voltage gain.** Overall voltage gain = First stage gain × Second stage gain

$$= 53 \times 191.4 = 10144$$

A Lot of Thanks

for kind attention