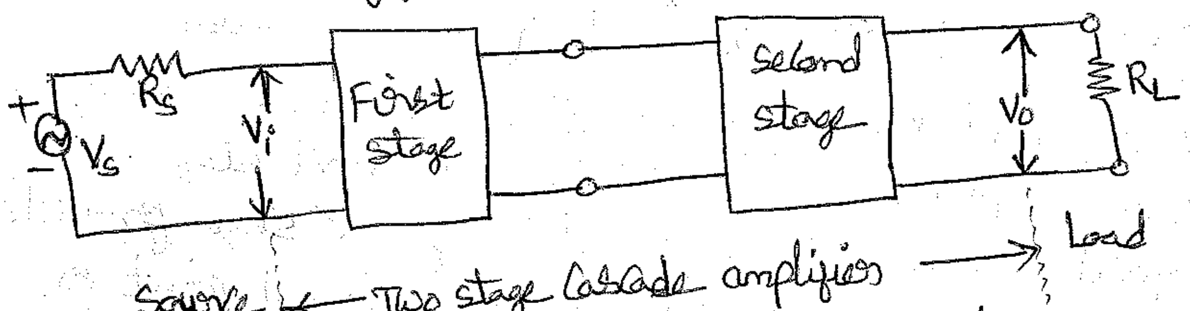
UNIT-II MULTISTAGE AMPLIFIERS.

Need for Cascading:

→ If the Voltage or power gain obtained from a single stage small signal amplifier is not sufficient for a practical application, one have to use more than one stage of amplification to achieve necessary Voltage and power gain. Such an amplifier is called a multistage amplifier.

→ In multistage amplifier, the output of one stage is fed as the input to the next as shown in figure:



Such a connection is commonly referred to as Cascading.

→ In amplifiers, Cascading is also done to achieve correct input and output impedances for specific applications.

→ Depending upon the type of amplifier used in individual stages, multistage amplifiers can be classified into several types.

→ A multistage amplifier using two or more single stage CE amplifier is called as Cascaded amplifiers.

→ A multistage amplifier with CE as the first stage and CB as the second stage is called as Cascode amplifier. Such Cascode and Cascade Connections are also possible in FET amplifiers.

Different Coupling Schemes used in amplifiers:

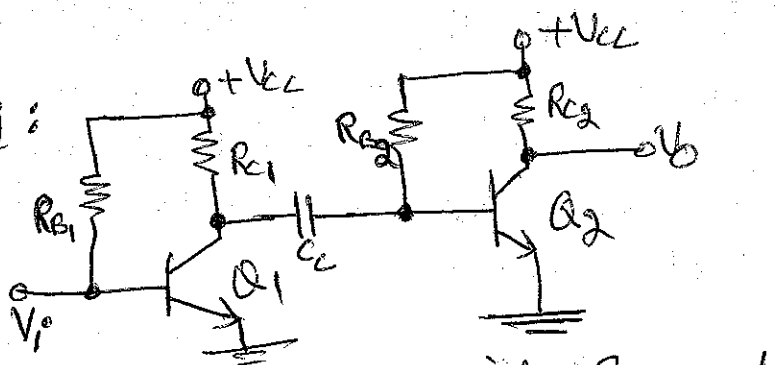
→ When amplifiers are cascaded, it is necessary to use a coupling network between the output of one amplifier and the input of the following amplifier. This type of coupling is called interstage coupling.

→ These coupling networks serve the following two purposes.

1) It transfers the ac output of one stage to the input of the next stage.
2) It isolates the dc conditions of one stage to the next.

→ The Coupling schemes commonly used in multistage amplifiers are,

1. RC Coupling
2. Transformer Coupling
3. Direct Coupling



Resistance Capacitance (RC) Coupling:

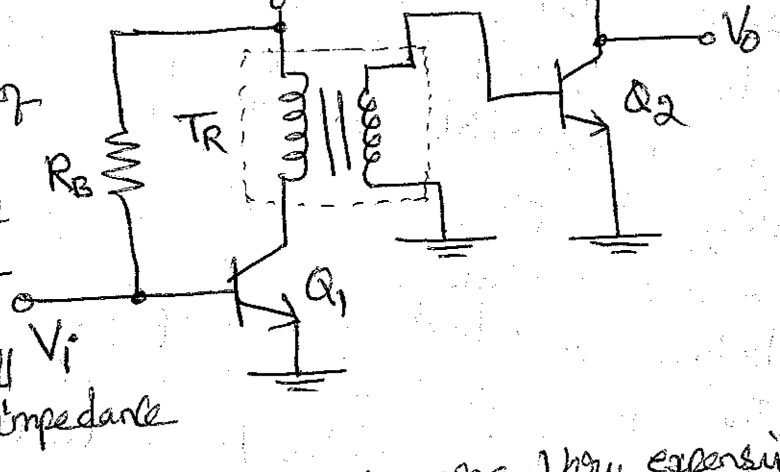
→ It is the most commonly used discrete device amplifiers as it is least expensive and has satisfactory frequency response.

→ In this method the signal developed across the collector resistor R_c of each stage is coupled through capacitor C_c into the base of the next stage.

→ The coupling capacitor C_c isolates dc conditions of one stage from the following stage, hence it does not affect the quiescent point of the following stage.

→ The RC network is broadband in nature. Therefore it gives a wideband frequency response without peak at any frequency and hence used to cover a complete AF amplifier bands.

→ However its frequency response drops off at very low frequencies due to coupling capacitors and also at high frequencies due to shunt capacitors such as stray capacitance.



Transformer Coupling:

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

→ Such a coupling increases the overall circuit gain and the level of interstage impedance matching.

→ However transformers with broad frequency response are very expensive and hence, this type of coupling is restricted mostly to power amplifiers where efficient impedance matching is a critical requirement for maximum power transfer and efficiency.

→ Frequency response of transformer coupled amplifier is poor in comparision with that of an RC coupled amplifier. Its leakage inductance and interwinding capacitances does not allow amplifier to amplify the signals of different frequencies equally well.

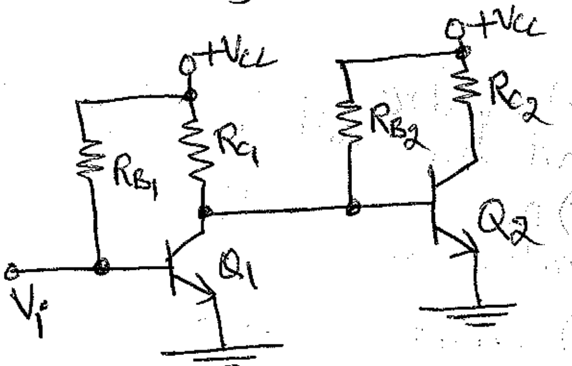
→ Interwinding capacitance of the transformer coupled may give rise resonance at certain frequency which makes amplifier to give very high gain at that frequency.

→ By putting shunting capacitors across each winding of the transformer, we can get resonance at any desired RF frequency. Such amplifiers are called tuned voltage amplifiers.

→ These provide high gain at the desired frequency i.e they amplify selective frequencies. For this reason, the transformer-coupled amplifiers are used in radio and TV receivers for amplifying RF signals.

→ As dc resistance of the transformer winding is very low, almost all dc voltage applied by V_{cc} is available at the collector. Due to the absence of collector resistance it also eliminates unnecessary power loss in the resistor.

Direct Coupling:



→ In this method the ac output signal is fed directly to the next stage as shown in figure.

→ No reactance is included in the coupling network. Special dc voltage level circuits are used to match the output dc levels.

→ It is used when amplification of low frequency signals is to be done. Further coupling devices such as capacitors, transformers cannot be used at low frequencies because their size becomes very large.

→ This direct coupling allows the quiescent dc collector current of first stage to pass through base of the next stage, affecting its baising conditions.

→ Due to absence of RC components its low frequency response is good but at higher frequencies shunting capacitors such as stray capacitances reduce the gain of the amplifier.

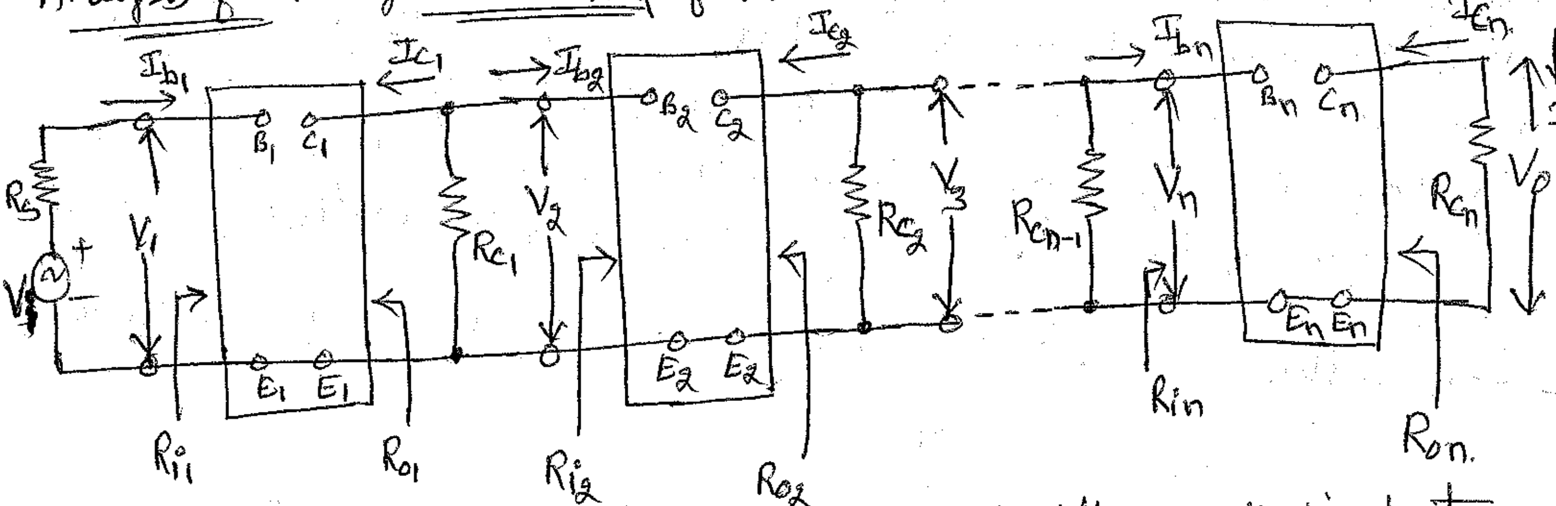
→ The transistor parameters such as V_{BE} and β change with temperature causing the collector current and voltage to change. Because of direct coupling these changes appear at the base of the next stage and hence in the output.

→ Such an unwanted change in the output is called drift and it is serious problem in the direct coupled amplifiers.

Comparision between various cascading methods:

Parameters	RC Coupled	Transformer Coupled	Direct Coupled.
1) Coupling Components	Resistor & Capacitor	Impedance matching transformer	—
2) Block DC	Yes	Yes	No
3) Frequency response	Flat at middle frequencies	Not uniform, high at resonant frequency and low at other frequencies	Flat at middle frequencies and improvement in the lo[w] frequency response.
4) Impedance matching	Not achieved	Achieved	Not achieved
5) DC amplification	No	No	Yes
6) Weight	Light	Bulky & heavy	—
7) Drift	Not present	Not present	present
8) Hum	Not present	present	Not present
9) Application	used in all audio small signal amplifiers used in record players, tape recorders, public address systems, radio receivers and television receivers	Used in amplifiers where impedance matching is an important criteria. used in output stage of the public address system to match the impedance of the loudspeaker. used in the RF amplifier stage of the receiver as a tuned voltage amplifier	used in amplification of slow varying parameters and where DC amplification is require[d]

Analysis of 'n' stage Cascade Amplifier:



Voltage gain: In a multistage amplifier the output voltage of the first stage acts as the input voltage of second stage and so on. The voltage gain of the complete cascade amplifier is equal to the product of the voltage gains of the individual stages.

Proof: The voltage gain of the first stage,

$$A_{V_1} = \frac{V_2}{V_1} = \frac{\text{output Voltage of first stage}}{\text{input Voltage of first stage}} = A_{V_1}\angle\theta_1$$

where A_{V_1} is the magnitude of voltage gain and θ_1 is phase angle of the output voltage relative to input voltage.

|||ly $$A_{V_2} = \frac{V_3}{V_2} = \frac{\text{output voltage of second stage}}{\text{input Voltage of second stage}} = A_{V_2}\angle\theta_2$$

The resultant Voltage gain, $$A_V = \frac{V_o}{V_1} = \frac{\text{output Voltage of } n^{th} \text{ stage}}{\text{input Voltage of first stage}}$$

$$A_V = A_V\angle\theta$$

But, $$\frac{V_o}{V_1} = \frac{V_2}{V_1}\cdot\frac{V_3}{V_2}\cdot\frac{V_4}{V_3}\cdot\;\cdots\frac{V_n}{V_{n-1}}\cdot\frac{V_o}{V_n}$$

$$A_V = A_{V_1}\cdot A_{V_2}\cdot A_{V_3}\cdot\cdots A_{V_n}\cdots\angle\theta_1+\angle\theta_2+\angle\theta_3+\cdots\angle\theta_n$$

$$= A_V\angle\theta$$

Hence $$A_V = A_{V_1}\cdot A_{V_2}\cdot A_{V_3}\cdots A_{V_n}$$

$$\theta = \theta_1+\theta_2+\theta_3+\cdots+\theta_n.$$

Hence for multistage cascade amplifier,

(i) the magnitude of the resultant voltage gain equals the product of the magnitudes of the voltage gains of the individual stages.

(ii) the phase shift of the resultant voltage gain equals the sum of the phase shifts of the individual stages comprising the multistage cascade amplifier.

→ The voltage of the K^{th} stage of the n stage cascaded amplifier is given by,

$$A_{VK} = \frac{A_{IK} \cdot R_{LK}}{R_{iK}}$$

where R_{LK} is the effective load impedance at the collector of the K^{th} stage and R_{iK} is the input impedance of the K^{th} stage.

→ The terms A_{IK}, R_{LK} and R_{iK} may be evaluated by starting from the last stage and proceeding backward to the first stage.

Current gain $A_{In} = \dfrac{-h_{fe}}{1+h_{oe} R_{Ln}}$

Input Resistance $R_{in} = h_{ie} + h_{re} A_{In} \cdot R_{Ln}$ and equals R_{in}.

where R_{Ln} is the effective load impedance for the last stage and equals R_{cn}.

→ The effective load impedance $R_{L(n-1)}$ of the $(n-1)^{th}$ stage is equal to,

$$R_{L(n-1)} = R_{c(n-1)} \| R_{i(n)} = \frac{R_{c(n-1)} \cdot R_{i(n)}}{R_{c(n-1)} + R_{i(n)}}$$

Having known $R_{L(n-1)}$, $A_{I(n-1)}$ can be found out from,

$$A_{I(n-1)} = \frac{-h_{fe}}{1+h_{oe} R_{L(n-1)}}$$

and $R_{i(n-1)} = h_{ie} + h_{re} A_{I(n-1)} \cdot R_{L(n-1)}$

→ By proceeding in this manner one can calculate the current gain and input impedance of each stage including the first.

Current gain: Inorder to find the resultant voltage gain, the voltage gain of the individual stages can be found out and the product of these gains give the resultant voltage gain.

→ Alternatively the resultant voltage gain can be found directly by the relation,

$$A_V = \frac{A_I R_{Ln}}{R_{i}}$$

where A_I is the current gain of the complete n-stage amplifier.

But
$$A_I = \frac{I_o}{I_{b1}} = \frac{-I_{cn}}{I_{b1}} = \frac{-I_{c1}}{I_{b1}} \cdot \frac{I_{c2}}{I_{c1}} \cdot \cdots \frac{I_{cn}}{I_{c(n-1)}}$$

$$A_I = A_{I_1} \cdot A'_{I_2} \cdot A'_{I_3} \cdot \cdots A'_{In}.$$

Here A_{I_1} is the base to collector gain of the first stage and equals $\frac{I_{c1}}{I_{b1}}$, while A'_{I_2}, A'_{I_3} are the collector to collector current gains of second and third stages.

For the K^{th} stage the collector to collector current gain is given by,

$$A'_{IK} = \frac{I_{cK}}{I_{c(K-1)}}$$

For the same K^{th} stage, the base to collector current gain is given by,

$$A_{IK} = \frac{-I_{cK}}{I_{bK}}$$

These two current gains can be related by the equation,

$$A'_{IK} = A_{IK} \cdot \frac{R_{c(K-1)}}{R_{c(K-1)} + R_{iK}}$$

The procedure for calculating the resultant current gain A_I is as follows

① Find the base to collector current gain A_{In} for the last stage i.e n^{th} stage

$$A_{In} = \frac{-h_{fe}}{1 + h_{oe} R_{Ln}}.$$

② Find input impedance of n^{th} stage,

$$R_{in} = h_{ie} + h_{re} A_{In} \cdot R_{Ln}.$$

③ Calculate the effect load resistance $R_{L(n-1)}$ for the last stage,

$$R_{L(n-1)} = R_{C(n-1)} \| R_{i(n)}$$

④ Calculate,

$$A_{I(n-1)} = \frac{-h_{fe}}{1 + h_{oe} R_{L(n-1)}}$$

Proceed in this manner to find A_{IK}.

⑤ Find the collector to collector current gain A'_{IK} for the K^{th} stage using

$$A'_{IK} = A_{IK} \cdot \frac{R_{C(K-1)}}{R_{C(K-1)} + R_{iK}}$$

⑥ Find the resultant current gain A_I of the n-stage cascaded amplifiers using

$$A_I = A_{I1} \cdot A''_{I2} \cdot A'_{I3} \cdot \text{---} A'_{In}.$$

<u>Power gain</u>: The power gain of n-stage amplifier is given by,

$$A_P = \frac{\text{output power of last stage}}{\text{Input power of first stage}}$$

$$A_P = \frac{V_0 \cdot I_0}{V_I \cdot I_{b1}} = \frac{-V_0 I_{cn}}{V_1 \cdot I_{b1}}$$

$$A_P = A_V \cdot A_I$$

Substituting, $A_V = A_I \cdot \frac{R_{cn}}{R_{i1}}$

$$A_P = A_I^2 \cdot \frac{R_{cn}}{R_{i1}}$$

<u>Input Impedance</u>: By starting from last stage and proceeding towards the first, the input impedance can be found out as follows,

① $A_{In} = \frac{-h_{fe}}{1 + h_{oe} R_{Ln}}$

② $R_{in} = h_{ie} + h_{re} \cdot A_{In} \cdot R_{Ln}$

③ $R_{L(n-1)} = R_{C(n-1)} \| R_{in}$

④ Calculate $A_{I(n-1)}$, $R_{i(n-1)}$ and $R_{L(n-2)}$ from above equations.

⑤ proceed in this manner to find the effective input impedance R_i of the first stage.

<u>output Impedance</u>: The output Impedance of each transistor amplifier stage and that of the complete multistage amplifiers may be calculated starting from the first stage.

The output admittance of first transistor is,

$$Y_{01} = h_{oe} - \frac{h_{fe}\, h_{re}}{h_{ie} + R_s}$$

$R_{01} = \frac{1}{Y_{01}}$ gives the output impedance of the first transistor.

parallel combination of R_{01} with R_{C1} forms the output impedance of the first stage.

$$R_{ot1} = \frac{R_{01} \cdot R_{C1}}{R_{01} + R_{C1}}$$

This R_{ot1} forms the source impedance of the second stage.

This R_{ot1} forms the R_s ... Again using above equations find Y_{02} with R_s replaced by R_{ot1}

Find $R_{ot2} = R_{02} \| R_{C2}$ where $R_{02} = \frac{1}{Y_{02}}$

Ily proceed to find output impedance of the last stage.

<u>Note</u>: The above methods can be used for CB and CC configurations also as well as for combination of these three configurations.

Selection of Configuration in Cascading Amplifiers:

characteristics	CB	CE	CC
1) R_i	Very low	Low	High.
2) R_o	Very high	High	Low
3) A_V	Medium	Medium	Low
4) A_i	less than unity	High.	High

→ From design point of view multistage amplifier is divided into three parts, Input stage, middle stages and output stage.

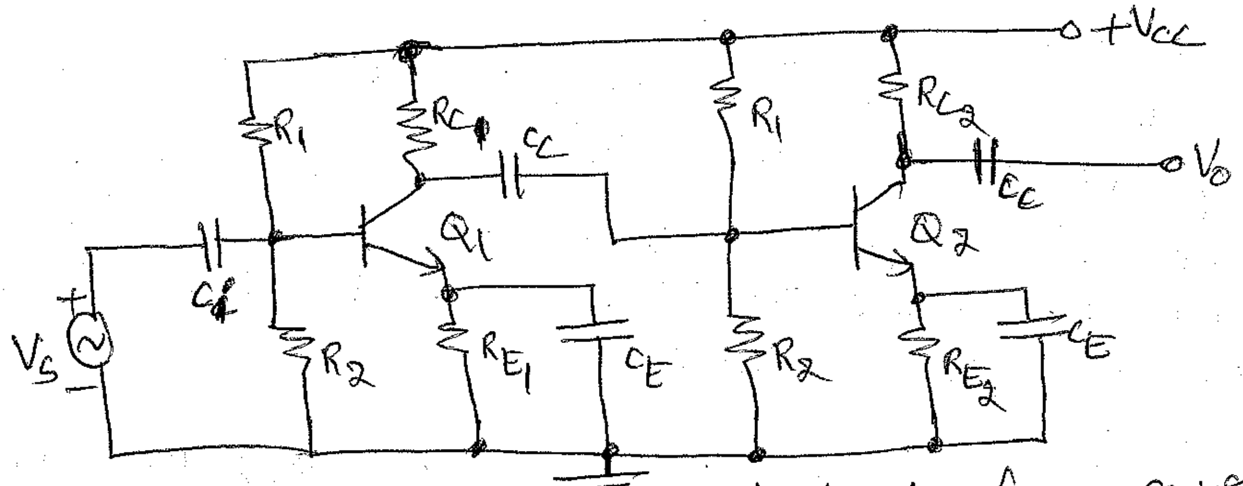
→ Input stage is designed such that its input impedance matches with the source impedance and the output stage is designed such that its output impedance matches with the load impedance. The remaining middle stages are designed to provide necessary power (Voltage as well as Current) gain.

→ CB configuration is selected for input stage because the input impedance of the CB configuration matches with a very low source impedance.

→ CE configuration provides Voltage as well as Current gain hence it is the best choice for the middle stages.

→ CC configuration is selected for output stage because the output impedance of CC configuration is low and matches with load impedance.

Two stage RC Coupled Amplifier:



→ The two transistors Q_1 and Q_2 are identical and a common power supply is used.
→ R_C is the collector (load) resistor, resistors R_1, R_2 and R_E provide the required bias.
→ The bypass capacitor C_E prevents loss of amplification due to negative feedback
→ The output of the first stage gets coupled to the input of the second stage via coupling capacitor C_c which also serves as the blocking capacitor to keep the dc component of the output of the first stage from reaching the input of the second stage and to pass ac component.

operation:
→ The ac input signal applied at the base is amplified by the transistor Q_1.
Its phase is reversed and the amplified output appears across its collector load R_C.
→ The output of the first stage across R_C is given to the base of second stage transistor Q_2 through the coupling capacitor C_c.
→ This signal at the base of Q_2 is further amplified and its phase is again reversed.
Hence the output signal is the twice amplified replica of the input signal.
The output signal is in phase with the input signal because it has been reversed twice.
→ In the mid frequency range, the gain is constant because the coupling and bypass capacitors are as good as short circuits. on both sides of the mid frequency range, the gain decreases.
→ At high frequencies, the value β of the transistor decreases. Hence the reactance of the capacitor C_c increases with the reduction in frequency of the signal; the voltage gain of the amplifier reduces.

→ At very low and very high frequencies, the gain of the amplifier reduces to almost zero.

Advantages of RC Coupling:

1) It requires cheap components like resistors and capacitors and not expensive or bulky components. Hence it is small, light and inexpensive.

2) It gives uniform voltage amplification over a wide frequency range from a few Hz to a few MHz because resistor values are independent of frequency changes. Hence RC coupled amplifier can be used to great advantage in speech, music etc.

3) Since it does not use any coil or transformer which may pick up unwanted signals, it has minimum possible non-linear distortion. Hence there is no magnetic field to interface with the signal.

4) Its overall amplification is higher than that of the other couplings.

Disadvantages of RC Coupling:

1) Due to large drop across collector load resistors, the collectors work at relatively small voltages unless higher supply voltage is used to overcome this voltage drop.

2) It is noisy in humid weather.

3) The impedance matching is poor as the output impedance of the RC coupled amplifier is several hundred ohms while that of a speaker is only a few ohms. Hence, the amount of power transferred to the speaker is reduced.

Differences in performance of an RC Coupled Amplifier over Single stage:

1) Its overall amplification is higher.

2) Its non-linear distortion is less.

3) It has better fidelity over a wide frequency range.

4) Its frequency response is much better over the audio frequency range.

Applications:

→ Since audio fidelity is excellent over a wide range of frequencies, the RC Coupled amplifier is extensively employed as a Voltage amplifier eg. in the initial stages of a public address System. However as the impedance matching is poor, reduced power is transfered to the Speaker.

A.C Analysis:

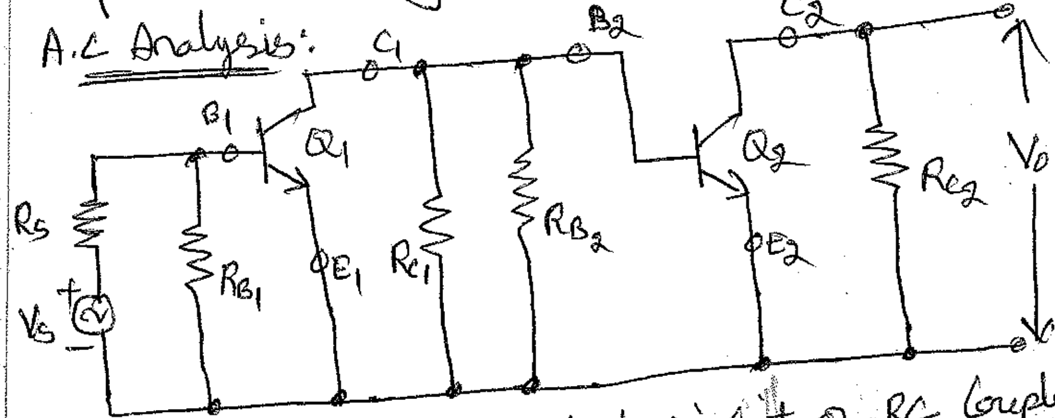


Fig (b) AC equivalent circuit of RC Coupled Amplifiers

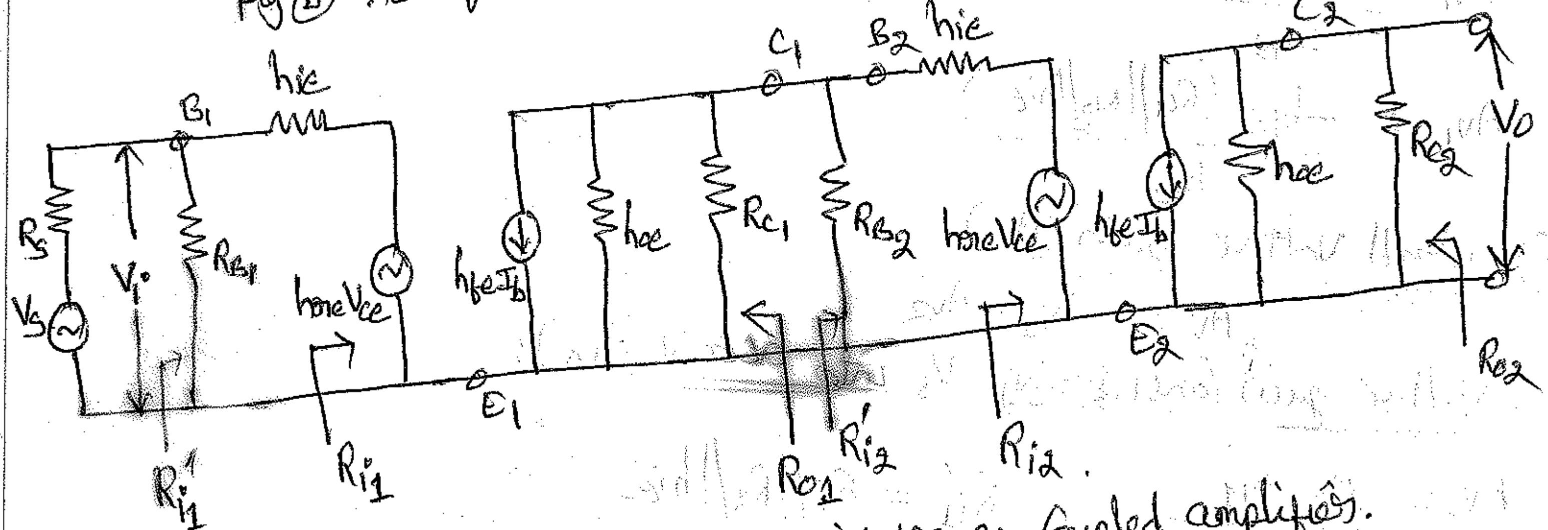


Fig (c) h-parameter equivalent Circuit for RC Coupled amplifier.

Second stage analysis:

① Current gain (A_{i2}):

$$A_{i2} = \frac{-h_{fe}}{1+h_{oe}R_L} = \frac{-h_{fe}}{1+h_{oe}R_{c2}}$$ $\{\because R_L = R_{c2}\}$

$$A_{i2} = -h_{fe}$$ $\{\because$ neglecting $h_{oe}R_{c2}\}$

② Input impedance (Z_{i2}):

$Z_{i2} = h_{ie} \parallel R_{B2}$ where $R_{B2} = R_1 \parallel R_2$

$Z_{i2} = h_{ie}$ since $R_{B2} \gg h_{ie}$ hence neglecting R_{B2}.

③ Voltage gain (A_{V2}):

$$A_{V2} = \frac{A_{i2} R_L}{Z_{i2}} = \frac{A_{i2} R_{C2}}{Z_{i2}} = \frac{-h_{fe} R_{C2}}{h_{ie}}$$

First stage analysis:

④ Current gain (A_{i1}):

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

⑤ Input Resistance (R_{i1}):

$$R_{i1} = Z_{i1} = h_{ie}$$

⑥ Voltage gain (A_{V1}):

$$A_{V1} = \frac{A_{i1} \cdot R_L}{Z_{i1}} \qquad R_L = R_{C1} \| R_{B2} \| h_{ie}$$

$$A_{V1} = \frac{-h_{fe} (R_{C1} \| R_{B2} \| h_{ie})}{h_{ie}}$$

⑦ overall Voltage gain (A_V):

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

⑧ Voltage gain Considering V_s into account (A_{Vs}):

$$A_{Vs} = \frac{A_V \cdot R_{i1}'}{R_s + R_{i1}'} \qquad R_{i1}' = R_1 \| R_2 \| h_{ie}$$

$$A_{Vs} = \frac{A_V \cdot (R_1 \| R_2 \| h_{ie})}{R_s + (R_1 \| R_2 \| h_{ie})}$$

⑨ output Impedance (Z_o'):

$$Z_{o1} = R_{C1} \| h_{oe1}$$

$$Z_{o2} = R_{C2} \| h_{oe2}$$

Prob①: For a CE-CE cascade amplifier find R_i, A_i, A_v, R_i', R_o' and A_{vs} if circuit parameters are, $R_s = 1K$, $R_{C1} = 15K$, $R_{E1} = 100\Omega$, $R_{C2} = 4K$, $R_{E2} = 330$ with $R_1 = 200K$ & $R_2 = 20K$ for first stage and $R_1 = 47K$ & $R_2 = 4.7K$ for second stage. Assume that $h_{ie} = 1.2K\Omega$, $h_{fe} = 50$, $h_{re} = 2.5 \times 10^{-4}$ and $h_{oe} = 25\,\mu A/V$.

Sol^n:

Second stage analysis: $h_{oe} \cdot R_L = h_{oe} \cdot R_{C2} = 25 \times 10^{-6} \times 4 \times 10^{3} = 0.1$ we can use approximate analysis.

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

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

$$A_{V2} = \frac{A_{i2} R_L}{R_{i2}} = \frac{A_{i2} \cdot R_{C2}}{R_{i2}} = \frac{-50 \times 4 \times 10^3}{1.2 \times 10^3} = -166.67$$

Analysis of first stage: $h_{oe} \cdot R_L' = h_{oe} \cdot (R_{C1} || R_1 || R_2 || R_{i2})$

$h_o \cdot R_L' = 25 \times 10^{-6} (881.8) = 0.022 < 0.1$

So we can use approximate analysis.

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

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

$$A_{V1} = \frac{A_{i1} \cdot R_L'}{R_{i1}} = \frac{-50 \times 881.8}{1.2 \times 10^3} = -36.74$$

$\therefore$ overall gain $A_V = A_{V1} \cdot A_{V2} = (-166.67) \times (-36.74) = 6123.45$

overall voltage gain $A_{VS} = \dfrac{A_V \cdot R_{i1}'}{R_S + R_{i1}'}$

$R_{i1}' = R_1 || R_2 || R_{i1} = 200K || 20K || 1.2K = 1.13K\Omega$

$$\therefore A_{VS} = \frac{6123.45 \times 1.13 \times 10^3}{1 \times 10^3 + 1.13 \times 10^3} = 3248.6$$

R_o :

$R_{o1}' = R_{o1} || R_{C1} = \infty || 15K = 15K$

$R_{o2}' = R_{o2} || R_{C2} = \infty || 4K = 4K$

Cascode Amplifier :

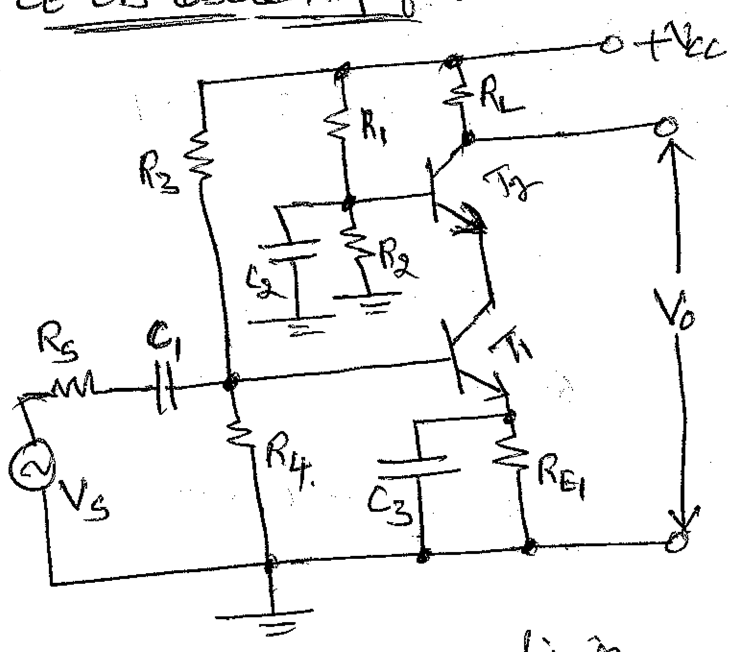
→ Cascode amplifier is a Composite amplifier pair with a large bandwidth used for RF applications and as a Video amplifier.

→ It Consists of a CE stage followed by a CB Stage directly Coupled to each other and Combines some of the features of both the amplifiers.

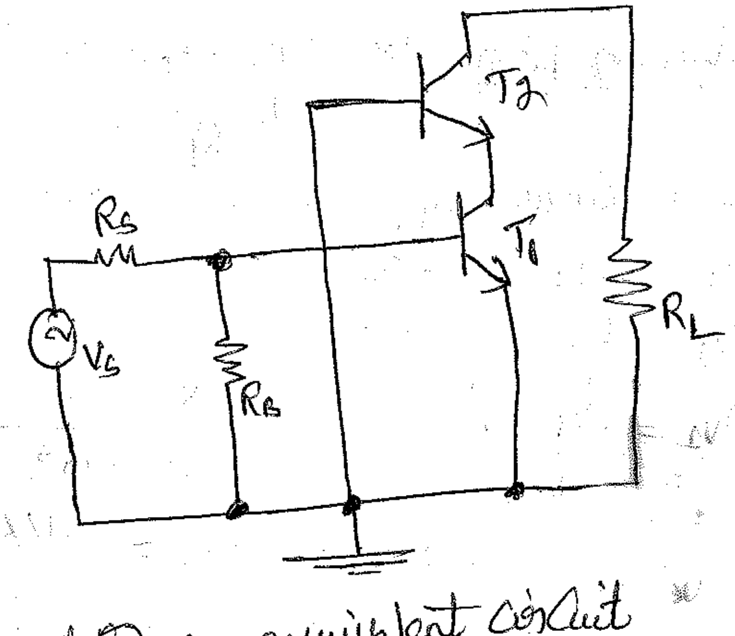
→ For high frequency applications, CB Configuration has the most desirable characteristics. However it Suffers from low input impedance ($Z_i \approx h_{ib}$).

→ The Cascode Configuration is designed to have the input impedance essentially that of CE amplifier, the Current gain that of CE amplifier, the Voltage gain that of CB amplifier and good isolation between input and output.

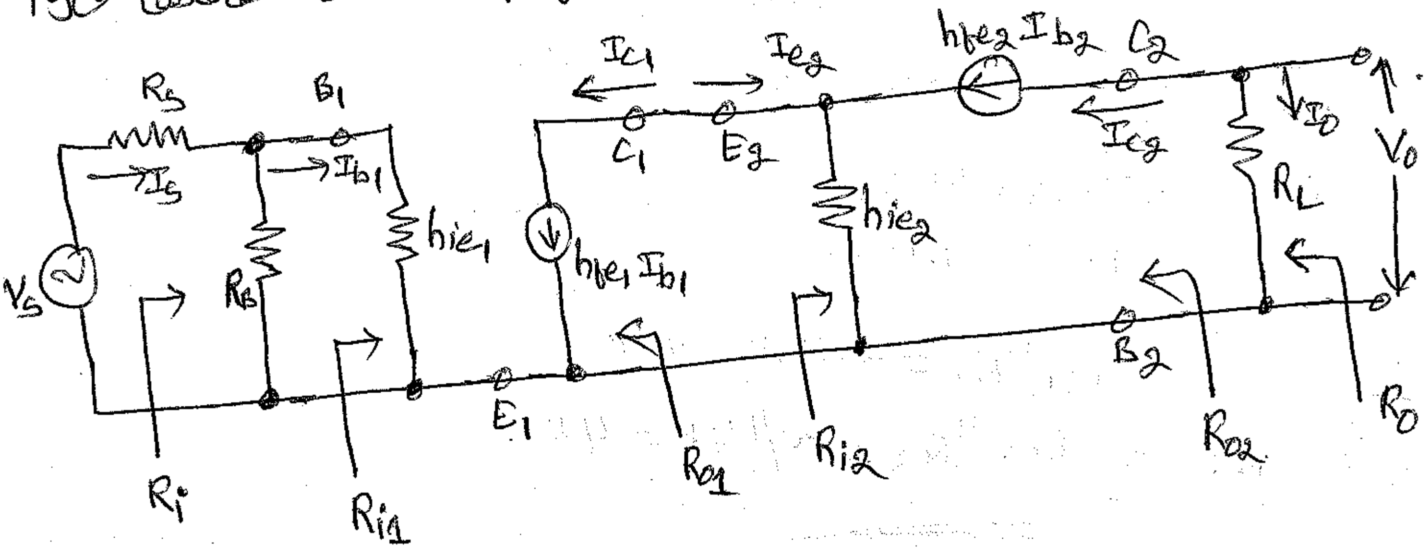
CE-CB Cascode Amplifier :



Fig(a) Cascode CE-CB amplifier



Fig(b) AC equivalent circuit



Let $R_s = 1K$, $R_3 = 200K$, $R_4 = 10K$, $R_L = 3K$ and $h_{ie} = 1.1K$, $h_{fe} = 50$.
Find A_i, R_i', A_v, A_{is}, A_{vs}, R_o.

Second stage (CB amplifier) analysis:

① Current gain $A_{i2} = \frac{h_{fe}}{1+h_{fe}} = \frac{50}{1+50} = 0.98$

② Input resistance $R_{i2} = \frac{h_{ie}}{1+h_{fe}} = \frac{1.1\times10^3}{1+50} = 21.56\,\Omega$

③ Voltage gain $A_{v2} = \frac{A_{i2} \cdot R_{L2}}{R_{i2}} = \frac{0.98 \times 3\times10^3}{21.56} = 136.36$

(or) $A_{v2} = \frac{h_{fe} R_{L2}}{h_{ie}} = \frac{50 \times 3\times10^3}{1.1\times10^3} = 136.36$

First state analysis (CE amplifier)

④ Current gain $A_{i1} = -h_{fe} = -50$

⑤ Input resistance $R_{i1} = h_{ie} = 1.1K\Omega$

⑥ Voltage gain $A_{v1} = \frac{A_{i1} \cdot R_{L1}}{R_{i1}}$ where $R_{L1} = R_{i2} = 21.56\,\Omega$

$$A_{v1} = \frac{-50 \times 21.56}{1.1\times10^3} = -0.98$$

⑦ overall voltage gain $A_v = A_{v1} \cdot A_{v2} = -0.98 \times 136.36 = -133.63$

⑧ overall input resistance $R_i' = R_{i1} \| R_B = R_{i1} \| R_3 \| R_4 = 1.1K \| 200K \| 10K = 986.1$

⑨ Voltage gain taking R_s into account,

$$A_{vs} = \frac{V_o}{V_s} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_s} = A_v \cdot \frac{R_i'}{R_i' + R_s} = -133.63 \times \frac{986.1}{986.1 + 1000} = -66.3$$

⑩ Current gain $A_{is} = \frac{I_o}{I_s} = \frac{I_o}{I_{c2}} \cdot \frac{I_{c2}}{I_{e2}} \cdot \frac{I_{e2}}{I_{c1}} \cdot \frac{I_{c1}}{I_{b1}} \cdot \frac{I_{b1}}{I_s}$

$I_o = -I_{c2} \Rightarrow \frac{I_o}{I_{c2}} = -1$, $\frac{I_{c2}}{I_{e2}} = -A_{i2}$, $I_{e2} = -I_{c1} \Rightarrow \frac{I_{e2}}{I_{c1}} = -1$

$\frac{I_{c1}}{I_b} = -A_{i1}$, $\frac{I_{b1}}{I_s} = \frac{R_B}{R_B + R_{i1}} = \frac{(200K \| 10K)}{(200K \| 10K) + 1.1K} = \frac{9.524K}{9.524K + 1.1K}$

$= 0.896$

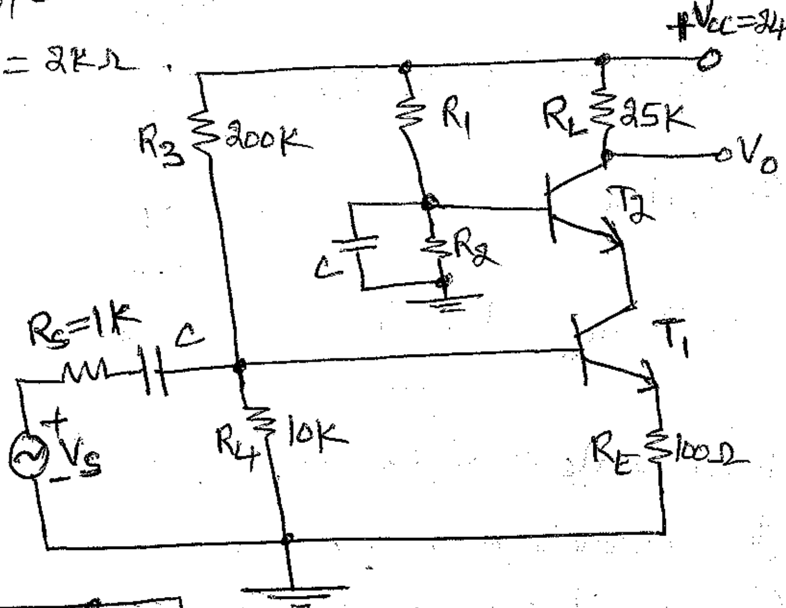
$\therefore A_{is} = -1 \times -(0.98) \times -1 \times [-(-50)] \times 0.896 = -43.9$.

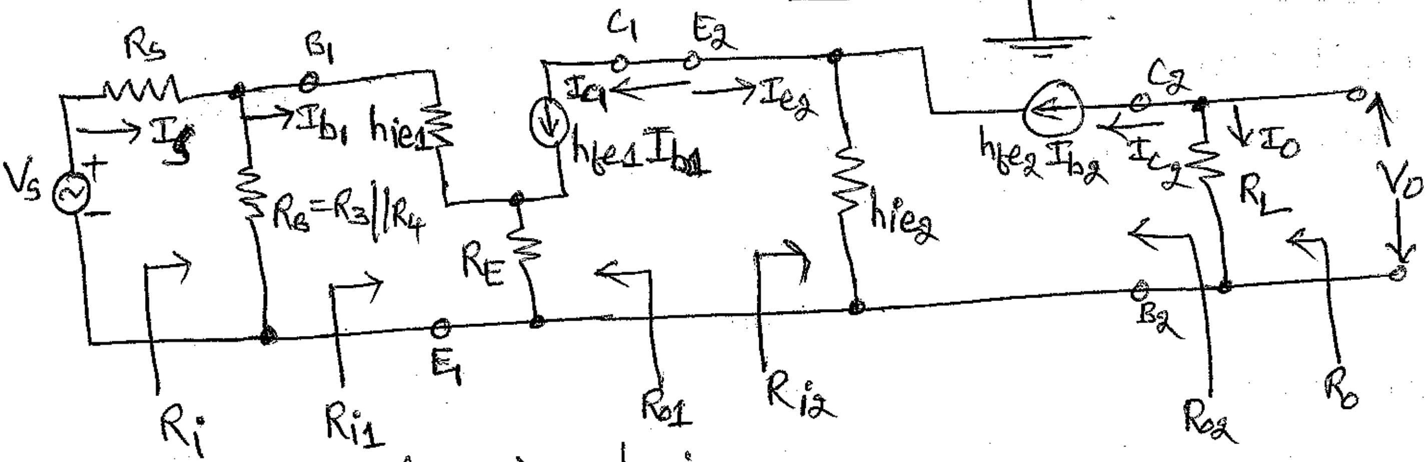
(11) Output Resistance (R_o):

$R_{o1} = \infty$, $R_{o2} = \infty$, $R_o = R_{o2} || R_L = \infty || 3K = 3K$.

Prob(2): Calculate A_i, R_i, A_V, A_{Vs} & R_o for cascode circuit shown in figure. Assume $h_{fe} = 100$ & $h_{ie} = 2K\Omega$.

Sol:





Second stage (CB amplifier) analysis:

(1) Current gain $A_{i2} = \dfrac{h_{fe}}{1+h_{fe}} = \dfrac{100}{1+100} = 0.99$

(2) Input resistance $R_{i2} = \dfrac{h_{ie}}{1+h_{fe}} = \dfrac{2K}{1+100} = 19.8\,\Omega$

(3) Voltage gain $A_{V2} = \dfrac{A_{i2} \cdot R_{L2}}{R_{i2}} = \dfrac{0.99 \times 25 \times 10^3}{19.8} = 1250$

First stage analysis (CE amplifier with unbypassed R_E):

(4) Current gain $A_{i1} = -h_{fe} = -100$

(5) Input resistance $R_{i1} = h_{ie} + (1+h_{fe})R_E = 2K + (1+100) \times 100 = 12.1K$

(6) Voltage gain $A_{V1} = \frac{A_{i1} \times R_{L1}}{R_{i1}} = \frac{-100 \times 19.8}{12.1K} = -0.1636$ $\{\because R_{L1} = R_{i2}\}$

(7) overall voltage gain $A_V = A_{V1} \cdot A_{V2} = -0.1636 \times 1250 = -204.5$

(8) overall input resistance $R_i = R_{i1} \| R_B = 12.1K \| 9.523K = 5.328K\Omega$

$R_B = R_3 \| R_4 = 200K \| 10K$

$R_B = 9.523K\Omega$

(9) Voltage gain $A_{Vs} = A_V \cdot \frac{R_i}{R_i + R_s} = \frac{V_o}{V_s} = -204.5 \times \frac{5.328K}{5.328K + 1K}$

$A_{Vs} = -172.18$

(10) Current gain $A_i = \frac{I_o}{I_s} = \frac{I_o}{I_{c2}} \times \frac{I_{c2}}{I_{e2}} \times \frac{I_{e2}}{I_{c1}} \times \frac{I_{c1}}{I_{b1}} \times \frac{I_{b1}}{I_s}$

$\frac{I_o}{I_{c2}} = -1$, $\frac{I_{c2}}{I_{e2}} = -A_{i2}$, $\frac{I_{e2}}{I_{c1}} = -1$, $\frac{I_{c1}}{I_{b1}} = -A_{i1}$, $\frac{I_{b1}}{I_s} = \frac{R_B}{R_B + R_{i1}}$

$\therefore A_i = -1 \times -A_{i2} \times -1 \times -A_{i1} \times \frac{R_B}{R_B + R_{i1}}$

$= -1 \times (-0.99) \times -1 \times -(-100) \times \frac{9.523K}{9.523K + 12.1K} = -43.6$

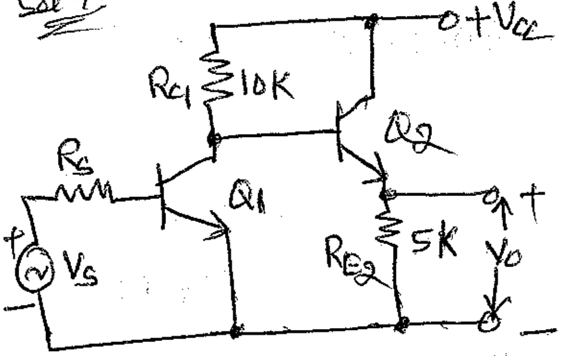
(11) output resistance (R_o):

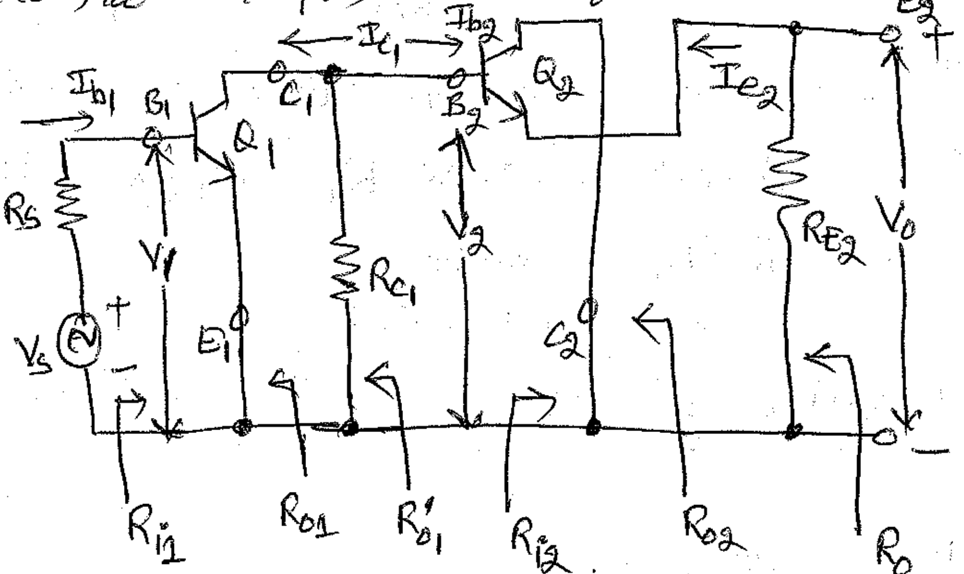
$R_{o1} = \infty$, $R_{o2} = \infty$, $R_o = R_{o2} \| R_L = \infty \| 25K = 25K\Omega$

CE-CC Amplifier:

Prob①: A two stage CE-CC amplifier is shown in figure. Calculate $A_V, A_I, R_i, R_o, A_{is}$ & A_{vs} if $h_{ie} = 2K$, $h_{fe} = 50$, $h_{re} = 6\times10^{-4}$, $h_{oe} = 25\mu A/V$, $h_{ic} = 2K$, $h_{fc} = -51$, $h_{rc} = 1$ and $h_{oc} = 25\mu A/V$.

Sol n:





Second stage analysis (CC amplifier):

$h_{oc} \cdot R_{L2} = h_{oc} \cdot R_{E2} = 25\times10^{-6} \times 5\times10^{3} = 0.125 > 0.1$ so use exact analysis

① Current gain $A_{i2} = \dfrac{-I_{e2}}{I_{b2}} = \dfrac{-h_{fc}}{1+h_{oc} \cdot R_{E2}} = \dfrac{-(-51)}{1+25\times10^{-6}\times5\times10^{3}} = 45.3$

② Input resistance $R_{i2} = h_{ic} + h_{rc} A_{i2} R_{E2} = 2\times10^{3} + 1\times 45.3 \times 5\times10^{3}$

$R_{i2} = 228.5K\Omega$

③ Voltage gain $A_{V2} = \dfrac{V_o}{V_2} = \dfrac{A_{i2}\times R_{E2}}{R_{i2}} = \dfrac{45.3\times5\times10^{3}}{228.5\times10^{3}} = 0.991$

First stage analysis (CE amplifier):

$R_{L1} = R_{C1} \| R_{i2} = 10K \| 228.5K = 9.58K\Omega$

$h_{oe} \cdot R_{L1} = 25\times10^{-6} \times 9.58\times10^{3} = 0.239 > 0.1$ So use exact analysis.

④ Current gain $A_{i1} = \dfrac{-I_{c1}}{I_{b1}} = \dfrac{-h_{fe}}{1+h_{oe} \cdot R_{L1}} = \dfrac{-50}{1+25\times10^{-6}\times9.58\times10^{3}}$

$A_{i1} = -40.34$

⑤ Input resistance $(R_{i1}) = h_{ie} + h_{re} A_{i1} \cdot R_{L1}$

$= 2\times10^{3} - 6\times10^{-4} \times 40.34 \times 9.58\times10^{3}$

$R_{i1} = 1.768K\Omega$

(6) Voltage gain $A_{V1} = \frac{V_2}{V_1} = \frac{A_{i1} R_{L1}}{R_{i1}} = \frac{-40.34 \times 9.52 \times 10^3}{1.768 \times 10^3} = -218.$

(7) output resistance (R_o):

$$Y_{o1} = h_{oe} - \frac{h_{fe} \cdot h_{re}}{h_{ie} + R_s} = 25 \times 10^{-6} - \frac{50 \times 6 \times 10^{-4}}{2 \times 10^3 + 1 \times 10^3} = 1.5 \times 10^{-5} A/V.$$

$$\therefore R_{o1} = \frac{1}{Y_{o1}} = 66.7 K\Omega$$

$$R_{o1}' = R_{C1} || R_{o1} = 10K || 66.7K = 8.69 K\Omega$$

$$Y_{o2} = h_{oc} - \frac{h_{fc} \cdot h_{rc}}{h_{ic} + R_{S2}} \quad \text{where } R_{S2} = R_{o1}'$$

$$Y_{o2} = 25 \times 10^{-6} - \frac{-51 \times 1}{2 \times 10^3 + 8.69 \times 10^3} = 4.79 \, mA/V.$$

$$\therefore R_{o2} = \frac{1}{Y_{o2}} = 208 \, \Omega$$

$$\therefore R_o = R_{o2} || R_{E2} = 208 || 5K = 199.69 \, \Omega$$

(8) overall Voltage gain $A_V = \frac{V_o}{V_1} = \frac{V_o}{V_2} \cdot \frac{V_2}{V_1} = A_{V2} \cdot A_{V1} = 0.991 \times (-218.5$

$$A_V = -216.5$$

(9) Voltage gain $A_{Vs} = \frac{V_o}{V_s} = A_V \cdot \frac{R_{i1}}{R_{i1} + R_s} = -216.5 \times \frac{1.768K}{1.768K + 1K}$

$$A_V = -138.28$$

(10) overall Current gain (A_i)

$$A_i = \frac{-I_{e2}}{I_{b1}} = \frac{-I_{e2}}{I_{b2}} \times \frac{I_{b2}}{I_{c1}} \times \frac{I_{c1}}{I_{b1}}$$

$$\frac{-I_{e2}}{I_{b2}} = A_{i2} \; ; \; \frac{+I_{c1}}{I_{b1}} = -A_{i1} \; , \; \frac{I_{b2}}{I_{c1}} = \frac{-R_{C1}}{R_{i2} + R_{C1}} = \frac{-10K}{228.5K + 10K}$$

$$= -0.0419.$$

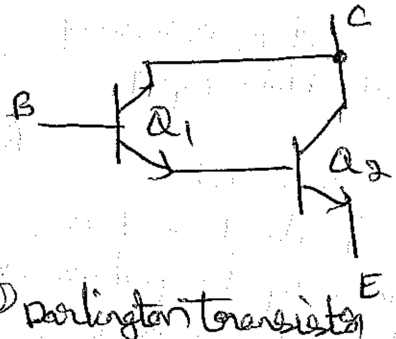
$$\therefore A_i = +45.3 \times (-0.0419) \times (+40.34)$$

$$A_i = -76.56$$

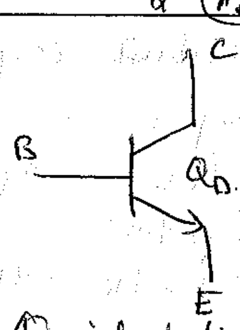
Darlington Amplifier:

→ A very popular connection of two BJT's for operation as one superbeta transistor is the darlington connection.

→ The main feature of the darlington connection is that the composite transistor act as a single unit with a current gain that is product of the current gains of the individual transistors.



(a) Darlington transistor connection.



(b) Single darling[ton] transistor

→ If the connection is made using two seperate transistors having current gain[s] of β_1 and β_2, the darlington connection provides a current gain of $\beta_D = \beta_1 \cdot \beta_2$

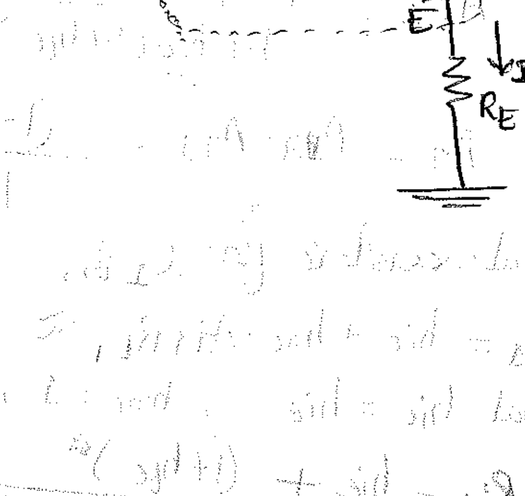
→ If the two transistors are matched such that $\beta_1 = \beta_2 = \beta$, the darlington connection provides a current gain of , $\beta_D = \beta^2$.

→ when two transistors having high current gain are connected as a darlington pair, the overall gain of the pair becomes very high.

→ Darlington pairs are generally available in IC packages. The package has only three terminals namely, base, emitter and collector, it can be considered as a single darlington transistor having very high current gain as compared to other typical single transistor.

→ Darlington transistor is commonly used in emitter follower circuit. This gi[ves] an equivalent circuit of two emitter followers in cascade, thereby increasin[g] the input impedance.

Biasing the darlington circuit:



$$I_B = \frac{V_{cc} - V_{BE}}{R_B + \beta_D R_E}$$

as $I_E = (\beta_D + 1) I_B$

$I_E \approx \beta_D I_B$

$$V_E = I_E R_E$$

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

Darlington Composite Emitter Follower:

→ For some applications, it is necessary to have an amplifier with high input impedance.

→ Emitter follower may be used to have input resistances of about 500 kΩ. For achieving still higher input impedances, the Darlington connection shown in figure is used.

→ Darlington connection has two transistors forming a composite pair. The input resistance of the second transistor constitutes the emitter load for the first.

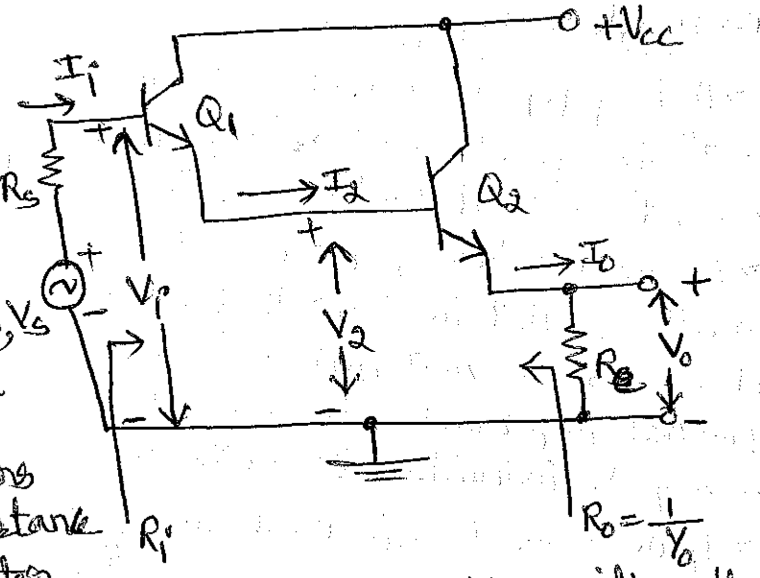


Fig: Darlington Composite Emitter follower

→ The Darlington circuit consists of two cascaded emitter followers with infinite emitter resistance in the first stage.

→ Assume $h_{oe}R_e \le 0.1$ and $h_{fe}R_e \gg h_{ie}$, so use approximate analysis for second stage.

$R_{i2} = h_{ie} + (1+h_{fe})R_{L2} \approx (1+h_{fe})R_e \quad \{\because R_{L2} = R_e\}$

$$A_I = \frac{I_o}{I_b} = \frac{I_o}{I_2}\cdot\frac{I_2}{I_b} = A_{I2}\cdot A_{I1}$$

$$A_{I2} = \frac{I_o}{I_2} = (1+h_{fe}) \quad \{\because \text{Approximate analysis of CC second stage}\}$$

$$A_{I1} = \frac{I_2}{I_b} = \frac{-h_{fc}}{1+h_{oc}R_{L1}} \quad \{\because \text{Exact analysis of CC first stage as load of } Q_1 \text{ is } R_{i2}. \text{ So } h_{oe}R_{i2} \not< 0.1\}$$

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

$h_{oc} = h_{oe}$ and $R_{L1} = R_{i2} \approx (1+h_{fe})R_e$.

$$\therefore A_{I1} = \frac{1+h_{fe}}{1+h_{oe}(1+h_{fe})R_e} \approx \frac{1+h_{fe}}{1+h_{oe}h_{fe}R_e}$$

$$\therefore A_I = A_{I2}\cdot A_{I1} = \frac{(1+h_{fe})^2}{1+h_{oe}h_{fe}R_e}$$

Input resistance for Q_1 is,

$$R_{i1} = h_{ic} + h_{rc}\cdot A_{I1}R_{L1} \approx A_{I1}\cdot R_{L1}$$

But $h_{ic} = h_{ie}$, $h_{rc} = 1$, $R_{L1} = R_{i2}$

$$\therefore R_{i1} = h_{ie} + \frac{(1+h_{fe})}{1+h_{oe}h_{fe}R_e} \times (1+h_{fe})R_e \approx \frac{(1+h_{fe})^2 R_e}{1+h_{oe}h_{fe}R_e}$$

$$A_{V2} = 1 - \frac{h_{ie}}{R_{i2}}$$

$$A_{V1} = 1 - \frac{h_{ie}}{R_{i1}}$$ But $R_{i1} = h_{ie} + A_{I1} R_{i2} \approx A_{I1} R_{i2}$

$$A_{V1} = 1 - \frac{h_{ie}}{A_{I1} \cdot R_{i2}}$$

$$\therefore \; A_V = A_{V1} \cdot A_{V2} = \left(1 - \frac{h_{ie}}{A_{I1} \cdot R_{i2}}\right)\left(1 - \frac{h_{ie}}{R_{i2}}\right)$$

$$A_V = 1 - \frac{h_{ie}}{R_{i2}} - \frac{h_{ie}}{A_{I1} \cdot R_{i2}} + \frac{h_{ie}^2}{A_{I1} \cdot R_{i2}^2}$$

As $A_{I1} \gg 1$ so neglecting the 3rd & 4th terms we get,

$$A_V \approx 1 - \frac{h_{ie}}{R_{i2}}.$$

The output resistance R_{o1} of Q_1 is,

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

$$Y_{o1} = h_{oc} - \frac{h_{fc} \cdot h_{rc}}{h_{ic} + R_s}$$ But $h_{oc} = h_{oe}$, $h_{ic} = h_{ie}$, $h_{rc} = 1$, $h_{fc} = -(1+h_{fe})$

$$\therefore Y_{o1} = h_{oe} + \frac{(1+h_{fe})}{h_{ie} + R_s}$$

$$Y_{o1} \approx \frac{(1+h_{fe})}{h_{ie} + R_s}$$

Now R_{o1} acts as source resistance for second stage, so output resistance of second stage is,

$$R_{o2} = \frac{R_{o1} + h_{ie}}{1 + h_{fe}}$$

$$R_{o2} = \frac{\frac{R_s + h_{ie}}{1 + h_{fe}} + h_{ie}}{1 + h_{fe}}$$

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

→ Hence the Darlington emitter follower has higher current gain, a higher input resistance, a voltage gain less close to unity and a lower output resistance than a single-stage emitter follower.

→ The drawback of Darlington transistor pair is that the leakage current of the transistor Q_1 is amplified by the transistor Q_2 and hence the overall leakage current may be high. So Darlington connection of three or more transistors is not used.

Analysis of RC Coupled Amplifier :

→ Assume C_E is large enough to provide short circuit for the entire audio frequency range.

→ Fig (a) shows h-parameter equivalent circuit for output section of first stage and the input section of second stage.

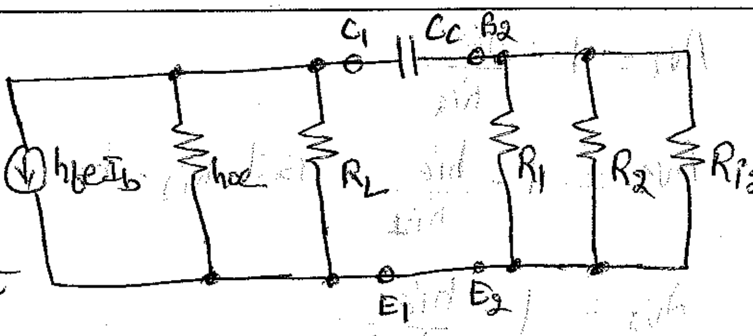


Fig (a)

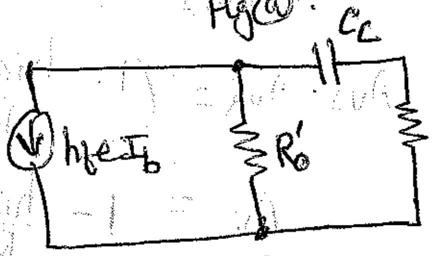


Fig (b)

$$R_o' = \frac{1}{h_{oe}} \| R_L \quad \text{and} \quad R_i' = R_1 \| R_2 \| R_{i2}$$

(1) Mid frequency response :

→ At mid frequencies the impedance offered by coupling capacitance C_c is so small such that it acts as an effective short circuit.

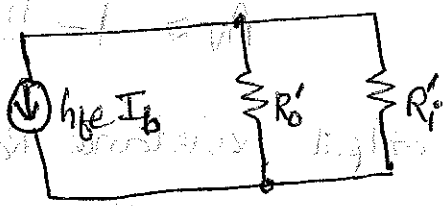


Fig (c)

$$V_o = \frac{-h_{fe} I_b R_o' R_i'}{R_o' + R_i'}$$

$$\frac{V_o}{V_i} = A_{V(mid)} = \frac{-h_{fe} I_b R_o' R_i'}{(R_o' + R_i') V_i}$$

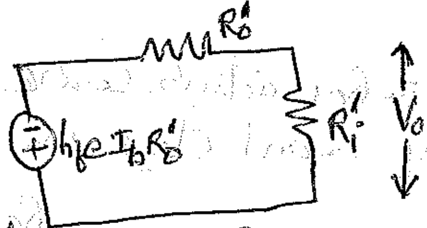
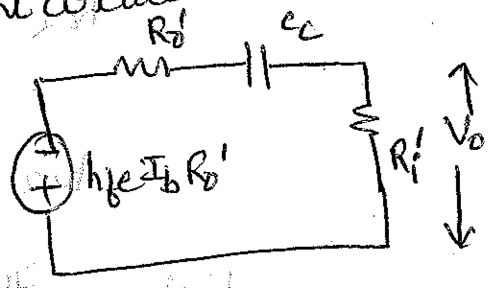


Fig (d)

(2) Low frequency response :

→ In this frequency range the impedance offered by coupling capacitor is comparable to the load resistance so that coupling capacitor largely affects the amplification. Therefore we include the capacitor in this equivalent circuit.



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

$$V_o = \frac{-h_{fe} I_b R_o' R_i'}{R_o' + R_i' + \frac{1}{j\omega C_c}}$$

$$\therefore A_{V(low)} = \frac{V_o}{V_i} = \frac{-h_{fe} I_b R_o' R_i'}{\left(R_o' + R_i' + \frac{1}{j\omega C_c}\right) V_i}$$

$$A_V(low) = \frac{\frac{-h_{fe} R_0' R_i' I_b}{R_0'+R_i'}}{1+\frac{1}{j\omega C_c(R_0'+R_i')}} \times \frac{1}{V_i}$$

$$A_V(low) = \frac{A_V(mid)}{1-\frac{j}{\omega C_c(R_0'+R_i')}}$$

$$\therefore \frac{A_V(low)}{A_V(mid)} = \frac{1}{1-\frac{j}{\omega C_c(R_0'+R_i')}}$$

Let $f_L = \frac{1}{2\pi C_c(R_0'+R_i')}$

$$\therefore \frac{A_V(low)}{A_V(mid)} = \frac{1}{1-j(f_L/f)}$$

$$\Rightarrow \left|\frac{A_V(low)}{A_V(mid)}\right| = \frac{1}{\sqrt{1+\left(\frac{f_L}{f}\right)^2}}$$

At $f=f_L$ $\quad \frac{A_V(low)}{A_V(mid)} = \frac{1}{\sqrt{2}} = 0.707$

Hence the output power at low frequency will be half of the signal power at mid frequency range.

(3) High frequency response:

→ In high frequency range the reactance offered by C_c is very small and hence can be considered as short circuited, but the shunting capacitors provide low reactance which is in parallel with output reducing the gain.

By similar Analysis we get,

$$\frac{A_V(high)}{A_V(mid)} = \frac{1}{\sqrt{1+\left(\frac{f}{f_H}\right)^2}}$$ and at $f=f_H$ $\quad \frac{A_V(high)}{A_V(mid)} = \frac{1}{\sqrt{2}} = 0.70$

prob①: A coupling capacitor is used between two stages of an amplifier which uses BJT connected in CE configuration where $h_{fe} = 100$, $h_{ie} = 2K\Omega$, $R_L = 3K$, $R_1 = 47K\Omega$, $R_2 = 4.7K\Omega$ and $C_c = 5\mu F$. Calculate lower 3dB frequency 'f_L' and calculate the frequency at which voltage gain is down by 12dB from its mid frequency value. use approximate analysis.

Soln: $R_o' = \frac{1}{h_{oe}} || R_L \approx R_L$ as $\frac{1}{h_{oe}} \gg R_L$

$R_o' = 3K\Omega$

$R_i' = R_1 || R_2 || R_{i2} = R_1 || R_2 || h_{ie}$ $\{\because R_{i2} = h_{ie}\}$

$R_i' = 47K || 4.7K || 2K = 1.36K\Omega$

$$\therefore f_L = \frac{1}{2\pi C_c (R_o' + R_i')} = \frac{1}{2\pi \times 5\times10^{-6}(3\times10^3 + 1.36\times10^3)} = 7.3Hz$$

It is given that,

$$20\log\left|\frac{A_V(low)}{A_V(mid)}\right| = -12$$

$$\therefore \left|\frac{A_V(low)}{A_V(mid)}\right| = \frac{1}{\sqrt{1+\left(\frac{f_L}{f}\right)^2}} = 0.251$$

$$\Rightarrow \left(\frac{1}{0.251}\right)^2 = 1 + \left(\frac{f_L}{f}\right)^2$$

$$\Rightarrow 15.87 = 1 + \left(\frac{f_L}{f}\right)^2$$

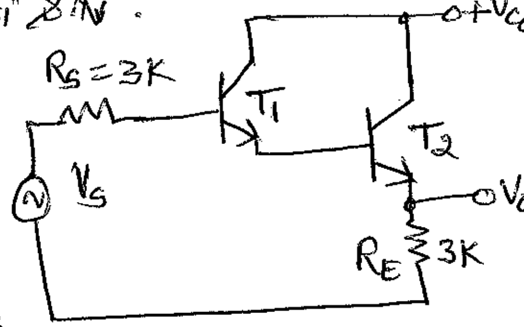
$$\Rightarrow f = f_L / \sqrt{14.87} = 1.893 Hz.$$

Therefore voltage gain is down by 12dB from its mid frequency value at frequency 1.893Hz.

(problem on darlington pair)

prob ①: For circuit shown in figure calculate R_i, R_o, A_i & A_v.

$h_{ie} = 1.1K\Omega$, $h_{fe} = 50$, $h_{re} = 2.5\times10^{-4}$ & $h_{oe} = 25\mu A/V$.



Soln: $h_{oe} \cdot R_{L2} = 25\times10^{-6} \times 3\times10^{3}$ $\{\because R_{L2} = R_{E}\}$

< 0.1 so use approximate analysis

$A_{i2} = 1 + h_{fe} = 1 + 50 = 51$

$R_{i2} = h_{ie} + (1+h_{fe}) R_{L2} = 1.1\times10^{3} + (1+50)\times 3\times10^{3} = 154.1K\Omega$

$A_{v2} = 1 - \frac{h_{ie}}{R_{i2}} = 1 - \frac{1.1\times10^{3}}{154.1K\Omega} = 0.9928$

$h_{oe} \cdot R_{L1} = h_{oe} \cdot R_{i2} = 25\times10^{-6} \times 154.1\times10^{3} = 3.85 > 0.1$ so use exact analysis

$A_{i1} = \frac{1+h_{fe}}{1+h_{oe}(1+h_{fe})R_{E}} = \frac{1+50}{1+25\times10^{-6}(1+50)\times 3\times10^{3}} = 10.56$

$R_{i1} = h_{ie} + A_{i1} R_{L1} = 1.1\times10^{3} + 10.56 \times 154.1\times10^{3} = 1.628M\Omega$

$A_{v1} = 1 - \frac{h_{ie}}{R_{i1}} = 1 - \frac{1.1\times10^{3}}{1.628\times10^{6}} = 0.999$

$A_V = A_{v1} \cdot A_{v2} = 0.9918$ (or) $A_V \approx 1 - \frac{h_{ie}}{R_{i2}} = 0.9928$

$A_I = A_{I1} \cdot A_{I2} = 10.56 \times 51 = 538.56$

(or)

$A_I = \frac{(1+h_{fe})^2}{1+h_{oe}(1+h_{fe})R_E} = \frac{(1+50)^2}{1+25\times10^{-6}(1+50)\times 3\times10^{3}} = 539.06$

$R_{o1} = \frac{h_{ie}+R_S}{1+h_{fe}} = \frac{1.1\times10^{3}+3\times10^{3}}{1+50} = 80.39\Omega$

$R_{o2} = \frac{h_{ie}+R_{S2}}{1+h_{fe}} = \frac{h_{ie}+R_{o1}}{1+h_{fe}} = \frac{1.1\times10^{3}+80.39}{1+50} = 23.145\Omega$

$R_o = R_{o2} \| R_E = 23.145 \| 3\times10^{3} = 22.97\Omega$

Direct Coupled (DC) Amplifiers:

→ In the field of instrumentation and power supplies there are many signals that change very slowly with time.

→ To process these signals, circuits must be employed whose frequency response is stretched flat down to DC.

→ This prevents the use of interstage coupling elements such as capacitors and transformers as these components attenuate very low frequencies & completely block DC signals.

→ There are two basic techniques for amplifying such low frequency signals that change very slowly with time.

→ one is to use direct coupled (DC) amplifiers and the second one requires chopping the dc signals so as to change it to an ac signal which is then amplified using conventional AC amplifiers and reconstructed at the output as dc.

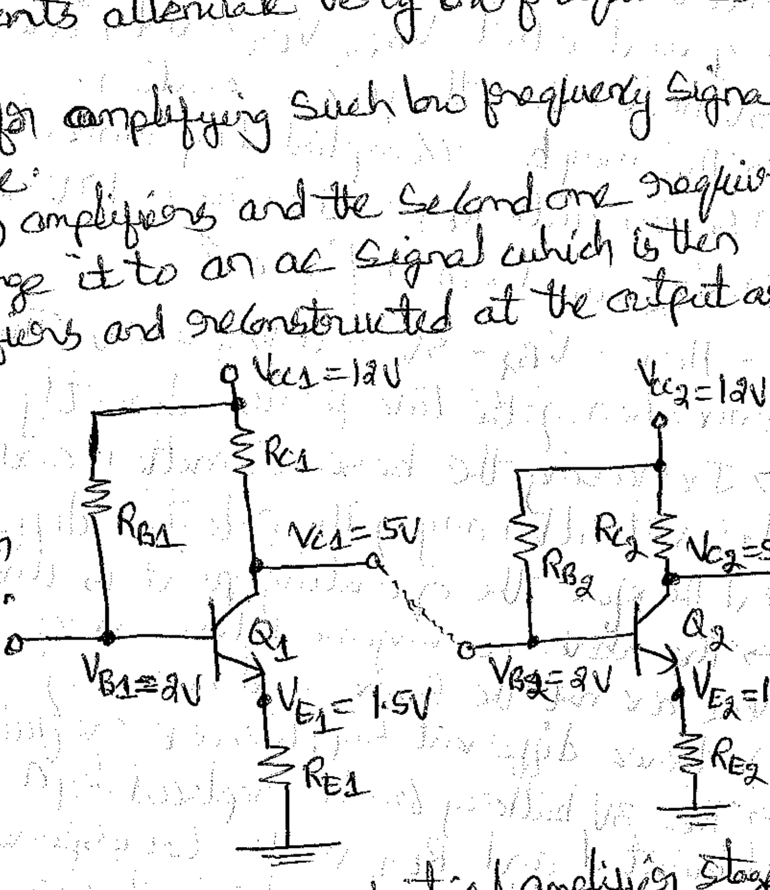


Fig (a): Two Identical amplifier stages

→ In the design of DC amplifiers one should ensure that dc levels of each stage are compatible with those of other circuits to which the stage is connected.

→ As an example, consider the identical amplifier stages in figure (a).
$V_{CC1} = V_{CC2} = 12V$, $V_{B1} = V_{B2} = 2V$,
$V_{E1} = V_{E2} = 1.5V$ and $V_{C1} = V_{C2} = 5V$.
Each stage is biased at $V_{BE} = 0.5V$ and $V_{CE} = 3V$ and also there is a potential difference of 3V between the collector of Q_1 and the base of Q_2.

→ For ac operation, a capacitor is connected between the collector of Q_1 and the base of Q_2 as in figure (b).

→ By this method, the ac signal is coupled from Q_1 to Q_2 but the capacitor charges to 3V dc so that V_{C1} is still at 5V and V_{B2} is still at 2V. The dc levels of both the stages remain independent of the other.

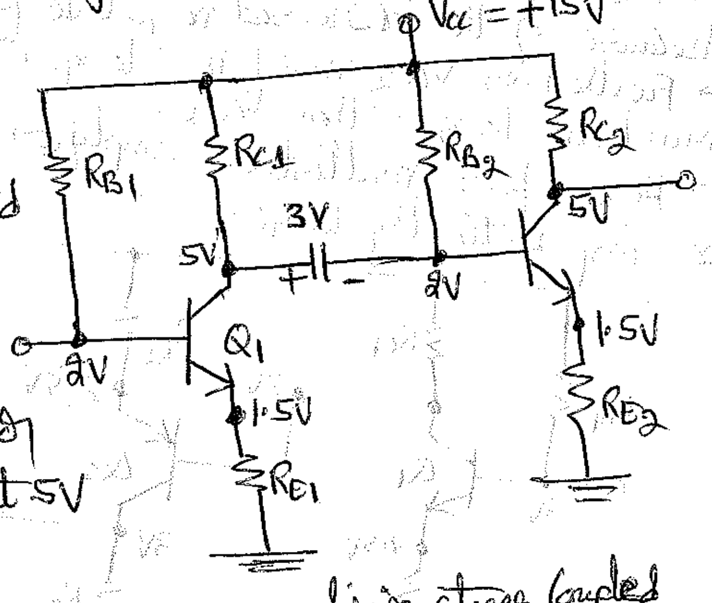
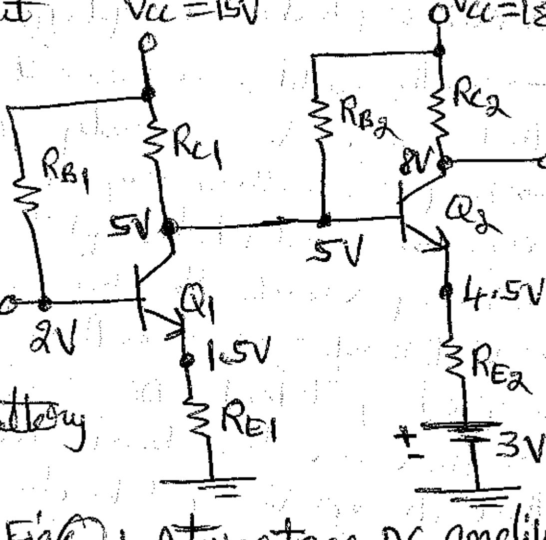


Fig (b): Two amplifier stages coupled by a capacitor.

→ For dc operation, the capacitor is to be omitted but the collector of Q_1 cannot be directly connected to the base of Q_2 unless the voltages at these points are the same.

→ one possible solution is to leave the first stage as it is but lift the second stage by 3V relative to ground so that V_{B2}, V_{E2} and V_{C2} are all 3V higher than they were earlier.

→ This may be accomplished by connecting a 3V battery in series with R_{E2} and using a 18V supply for V_{CC2} as shown in figure ©.



Fig©: A twostage DC amplif

→ Here $V_{B2} = 5V$ and $V_{C2} = 8V$. This causes V_{C1} to be equal to V_{B2} enabli connection of the two points directly to each other.

→ Increasing the base, emitter and collector voltages by the same amou does not alter any of the potential differences i.e $V_{BE2} = 0.5V$ and $V_{CB2} = 3V$ and therefore the operating point is unchanged.

→ The above arrangement has a no. of obvious disadvantages. As V_{CC1} and V_{CC2} are not the same and because of 3V battery in series with R_{E2} a total of three different supplies are required.

→ The 3V battery can be replaced by a 3V zener diode or it could be simply eliminated and R_{E2} made correspondingly larger.

→ This would increase the input resistance of Q_2 and lower the gain because of the increased negative feedback.

→ Further as V_{CC2} must be larger than V_{CC1} if a third stage is added V_{CC3} must be larger than V_{CC2}.

→ Hence for a multistage amplifier the required dc voltage supplies might be impractically large.

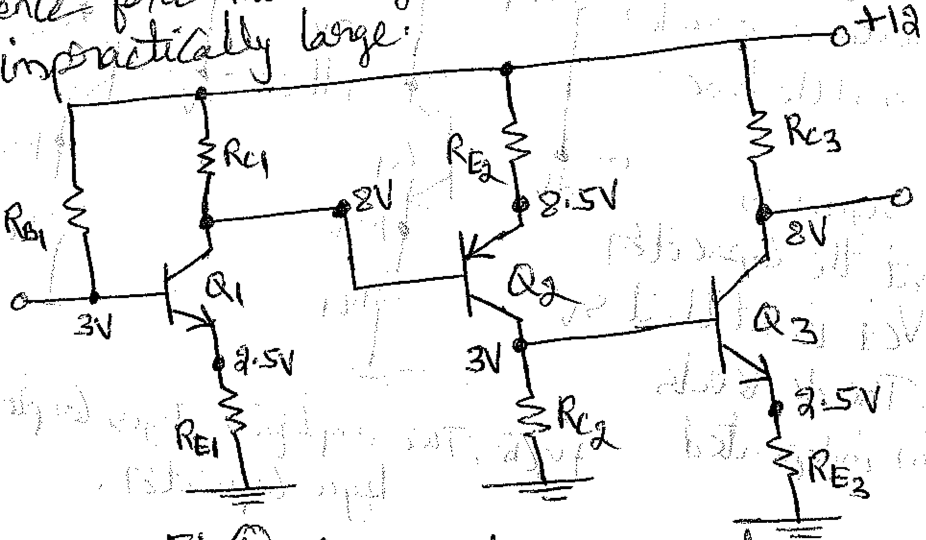


Fig ⓓ : A three stage DC amplifier

→ A Circuit arrangement that solves the above problem is shown in fig①
Here alternate polarity transistors are cascaded and the dc Voltages are so adjusted that each of that three transistors is operating at exactly the same point.

→ In this circuit there is a 0.5V forward bias across each base-emitter junction and 5V reverse bias across each Collector-base junction. Further it is to be noted that only one external supply is needed.

→ An additional problem peculiar to DC amplifiers is that small changes in the operating point due to temperature or power supply fluctuations as well as aging of circuit components are also amplified as there is nothing to block dc and these changes appear in the amplified form across the output.

→ The dc input Voltage required to bring the output Voltage back to its original level (no signal level) is a measure of performance of DC amplifiers and is called Voltage offset V_{os}.

→ similarly a dc input current known as offset current I_{os} might be required to bring the output current back to its original level.

→ Both the offset Voltage and current tend to vary with time and temperature

→ DC amplifiers generally require a potentiometer adjustment for cancelling such offsets.

→ The manufacturers also usually specify the values of E_{os} and I_{os} and the expected drift with time and temperature.

→ Stabilising techniques can also be applied here.